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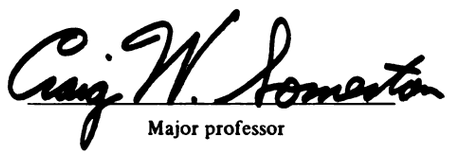
RANKINE 3.0: A STEAM POWER PLANT COMPUTER SIMULATION

presented by

Wayne Andrew Thelen

has been accepted towards fulfillment
of the requirements for

MS degree in Mechanical Engineering



Major professor

Date 12/6/95

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RANKINE 3.0: A STEAM POWER PLANT COMPUTER SIMULATION

By

Wayne Andrew Thelen

A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

Masters of Science

Department of Mechanical Engineering

1995

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friendly, PC compati
cycle based system an
power system. RAN
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preliminary design
modular structure, a

ABSTRACT

RANKINE 3.0: A STEAM POWER PLANT COMPUTER SIMULATION

By

Wayne Andrew Thelen

A computer program has been developed which models the thermal performance of any Rankine cycle based power system. The focus of the development was to create a user friendly, PC compatible program capable of modeling a complex, user specified Rankine cycle based system and provide a basis for optimizing the design and operation of a steam power system. RANKINE 3.0 is a modular program capable of performing a first and second law steady state analysis on any user specified combination of thermal devices commonly found in steam power systems. As a result of the software's flexibility, user friendliness, and internal checks, RANKINE 3.0 is ideal as an educational tool and for preliminary design calculations. The computer program's theoretical basis, objectives, modular structure, and bench marking are discussed.

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1995

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Chapter 1 The Ra

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1.0.1 The Simple Ran

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working fluid is water.
cycle is shown below in

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Chapter 1 The Rankine Cycle and Procedure for System Analysis

1.0.0 The Rankine Cycle

The operation of most major electrical generating stations are based upon a theoretical thermodynamic cycle called the Rankine cycle. The Rankine cycle consists of a series of thermodynamic processes intended to convert energy in a heat form to energy in a work form. Since the Rankine cycle is the foundation for most vapor powered electrical generating systems, its analysis is vital to the design and operation of both electric and co-generation systems.

1.0.1 The Simple Rankine Cycle

The ideal thermodynamic cycle for a vapor powered system is refereed to as the simple Rankine cycle. In the simple Rankine cycle, the working fluid undergoes a series of thermodynamic processes and finally returns to its initial state. Since water is the most common working fluid used in vapor powered systems, it is assumed that the cycle working fluid is water. A schematic of a power plant operating on the simple Rankine cycle is shown below in Figure 1-1.

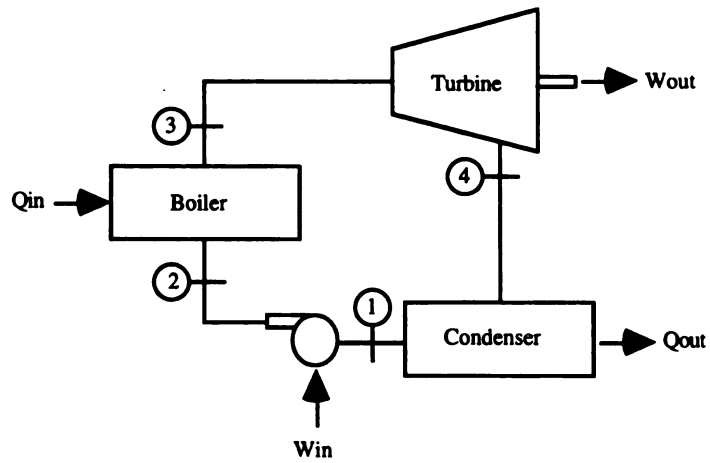


Figure 1-1. Schematic of a simple Rankine cycle

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By definition, the simple Rankine cycle does not involve any internal irreversibilities and consists of the following four processes:

1-2 Isentropic compression in a pump

2-3 Constant pressure heat addition in a boiler

3-4 Isentropic expansion in a turbine

4-1 Constant pressure heat rejection in a condenser

A temperature-entropy diagram (T-s diagram) graphically illustrates the thermodynamic processes which occurs within a cycle. The T-s diagram for the simple Rankine cycle is shown in Figure 1-2.

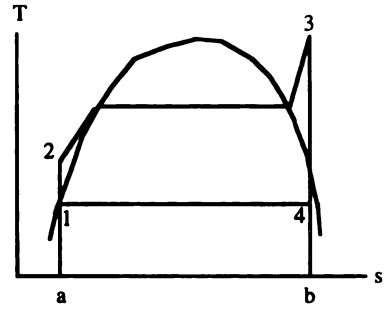


Figure 1-2. T-s diagram for a simple Rankine cycle

In the simple Rankine cycle, water enters the pump at state 1 as a saturated liquid and is compressed isentropically to the operating pressure of the boiler. During this isentropic compression, the water temperature increases due to a slight increase in the water's density.

Water enters the boiler as a compressed liquid at state 2 and leaves as a superheated vapor at state 3. The water absorbs heat originating from combustion gases, a nuclear reactor or other sources and the working fluid pressure remains constant during the heat transfer.

The superheated water vapor at state 3 enters the turbine where it expands isentropically and produces work by rotating a shaft connected to an electric generator. The water vapor pressure and temperature decrease during this process and the working fluid exits the turbine as a liquid-vapor mixture.

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The low pressure liquid-vapor mixture at state 4 enters the condenser where the 2-phase mixture is condensed at a constant pressure by rejecting heat to a cooling medium such as a lake, a river or the atmosphere. Steam exits the condenser as a saturated liquid and enters the pump, completing the cycle.

A key feature of the Rankine cycle is that the working fluid compression is confined only to the liquid phase. The advantages of this arrangement are that the high compression work and mechanical problems associated with 2-phase compression are avoided.

The simple Rankine cycle may be operated as either an open or closed cycle. A cycle is termed "open" (also refereed to as a non-condensing cycle) if the working fluid is drawn from ambient, executes the cycle once and is then discharged to ambient never to repeat the cycle again. A cycle is termed "closed" (also refereed to as a condensing cycle) if the same fluid repeatedly executes the various processes within the cycle. The simple Rankine cycle, as shown in figure 1-1, represents a closed cycle. Figure 1-1 could be modified to represent an open cycle by replacing the text "condenser" with the text "ambient". In general, a closed Rankine cycle is usually utilized since it possesses a higher cycle efficiency and permits better control of working fluid chemistry. For the remainder of this chapter, all cycles are considered to be closed.

1.0.2 Evaluating the Thermodynamic Performance of the Rankine Cycle

The overall thermodynamic performance of the Rankine cycle is quantified with the 1st law thermal efficiency. For the Rankine cycle, the 1st law thermal efficiency is defined as the ratio of the net work produced to the total heat supplied. Mathematically, the 1st law thermal efficiency is defined as

$$\eta_{th} = \frac{W_{net}}{Q_{in}} = \frac{W_{trb} - W_{pmp}}{Q_{in}} = 1 - \frac{Q_{out}}{Q_{in}} \qquad 1\text{-}1$$

where the work and heat terms are specified in Figure 1-1.

If changes in the kinetic and potential energies are neglected, the heat transferred during a reversible process may be represented by the various areas on a T-s diagram. For the

simple Rankine cycle. th
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simple Rankine cycle, the heat transferred to the working fluid in the boiler is represented by area a-1-2-3-4-b, and the heat rejected by the working fluid in the condenser is represented by area a-1-4-b. Therefore, for the simple Rankine cycle, the thermal efficiency can be defined as

$$\eta_{th} = 1 - \frac{\text{area a-1-4-b}}{\text{area a-1-2-3-4-b}} \qquad 1\text{-}2$$

From equation 1-2, it can be seen that any cycle modification that increases the average temperature at which heat is supplied to the system or decreases the average temperature at which heat is rejected from the system will increase the thermal efficiency of the cycle.

The thermodynamically maximum obtainable 1st law thermal efficiency for any cycle (open or closed) operating between two constant temperature reservoirs is defined by the Carnot cycle. The Carnot Cycle is composed of four reversible processes - two isothermal and two adiabatic and may be applied to any vapor or two phase substance undergoing a cycle operating between two constant temperature reservoirs. The maximum obtainable 1st law thermal efficiency is commonly refereed to as the Carnot cycle efficiency and is defined as

$$\eta_{th,carnot} = 1 - \frac{T_L}{T_H} \qquad 1\text{-}3$$

Where T_L = absolute temperature of low temperature reservoir

T_H = absolute temperature of high temperature reservoir.

Even though the Carnot cycle is very difficult to operate in reality, it is of great value since it represents a standard against which any cycle operating between two constant temperature reservoirs may be evaluated.

It should be noted that equation 1-3 indicates that an improved Carnot cycle efficiency may only be obtained by reducing the temperature at which heat is rejected by the system or by increasing the temperature at which heat is added to the system.

Since a simple Rankine cycle 1st law thermal efficiency definition makes no reference to the best possible performance for a cycle operating between two temperature reservoirs

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$$\eta_{II} = \frac{\text{(Availability P}}{\text{(Availability Co}}$$

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Where: $T_{dead\ state}$ = A
$T_{heat\ reservoir}$

1.8.3 Improving the

Since the Rankine cycl
even small increases in

(i.e., Carnot cycle efficiency), the magnitude of the 1st law thermal efficiency may be misleading. In order to quantify the performance of a cycle relative to its performance under reversible conditions while operating between the same temperature reservoirs, a 2nd law effectiveness is defined as

$$\eta_{effectiveness} = \frac{\eta_{th}}{\eta_{th,carnot}} \qquad 1\text{-}4$$

where η_{th} and $\eta_{th,carnot}$ are define as equations 1-1 and 1-3 respectively.

Since some Rankine cycles applications are intended to have useful outputs or inputs that are not in the form of heat or work (co-generation power plants for example), some measure of cycle efficiency is required which provides "credit" for energy provided to or extracted from a cycle in forms other than heat or work. The 2nd Law efficiency was established to address this problem and is defined by the author as

$$\varepsilon_{II} = \frac{\text{Availability Produced by Cycle}}{\text{Availability Consumed by Cycle}} \qquad 1\text{-}5$$

$$e_{II} = \frac{\text{(Availability Produced)} + \text{(Work Produced)} + \text{(Adjusted Heat Produced)}}{\text{(Availability Consumed)} + \text{(Work Consumed)} + \text{(Adjusted Heat Consumed)}} \qquad 1\text{-}6$$

Where adjusted heat is defined as

$$\text{Adjusted heat} = \left(1 - \frac{T_{\text{dead state}}}{T_{\text{heat reservoir}}}\right) \cdot Q \qquad 1\text{-}7$$

Where: $T_{\text{dead state}}$ = Absolute dead state temperature

$T_{\text{heat reservoir}}$ = Absolute temperature of reservoir at which heat is coming from or is going to.

1.0.3 Improving the Efficiency of the Simple Rankine Cycle

Since the Rankine cycle is responsible for a majority of the electric power in the world, even small increases in the thermal efficiency can justify modifications to the simple

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Rankine cycle. The fundamental idea behind all modifications intended to increase the thermal efficiency of a power cycle is to increase the average temperature at which heat is supplied to the working fluid or to decrease the average temperature at which heat is rejected from the working fluid. Three common methods used to increase the thermal efficiency are discussed below.

1) Decrease the condenser pressure - Since the working fluid exists as a saturated mixture within the condenser, the lowering of the condenser operating pressure automatically lowers the temperature of the working fluid and, thus, the temperature at which heat is rejected.

2) Increase the boiler exit temperature - Since the thermal efficiency is related to the average temperature at which heat is supplied, increasing the boilers superheat will increase the average temperature at which heat is supplied and, hence, increase the thermal efficiency. It should be noted that, for a fixed boiler operating pressure, increasing the boiler exit temperature shifts the cycle to the right on a T-s diagram and, hence, decreases the moisture content of the steam at the turbine exit. The decreasing the moisture content at the turbine exit is a desired result.

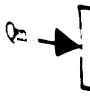
3) Increase the boiler pressure - Since the working fluid undergoes a phase change within the boiler, increasing the boiler operating pressure will automatically increase the temperature at which the phase change occurs and, thus, the average temperature at which heat is supplied. It should be noted that, for a fixed boiler exit temperature, increasing the boiler pressure shifts the cycle to the left on a T-s diagram and, hence, increases the moisture content of the steam at the turbine exit. The increasing moisture content at the turbine exit is not a desired result.

Each of these methods do, however, have some limitations as to there applicability. Improving the thermal efficiency by decreasing the condenser pressure is limited such that the working fluid temperature in the condenser must be greater than the temperature of the low temperature reservoir. Since the working fluid exists as a 2-phase mixture within the condenser, the condenser operating pressure must have a corresponding saturation temperature which is greater than the temperature of the low temperature reservoir. Improving the thermal efficiency by increasing the boiler exit temperature is limited by the maximum meterlogically safe temperature of the components in the cycle. Improving the cycle efficiency by increasing the boiler exit pressure is limited with

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1.0.4 The Simple

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respect to the fact that the higher boiler operating pressures result in increased moisture content at the turbine exit. Excessive working fluid moisture within the turbine decreases the turbine efficiency and may increase turbine blade wear. Modifications to the simple Rankine cycle can address some of these concerns and may result in a cycle with a significantly increased thermal efficiency.

1.0.4 The Simple Reheat Rankine Cycle

One of the limitations associated with increasing the boiler pressure to improve the thermal efficiency is the resulting increase in moisture content at the turbine exit. Since excessive moisture within the turbine decreases the turbine efficiency and may result in increased turbine blade wear, minimizing the moisture content within the turbine is a design priority. One solution to the excessive turbine moisture problem is to modify the simple Rankine cycle by expanding the steam through two turbines and reheating the steam in-between. A schematic of a power plant operating on the simple reheat Rankine cycle is shown in Figure 1-3.

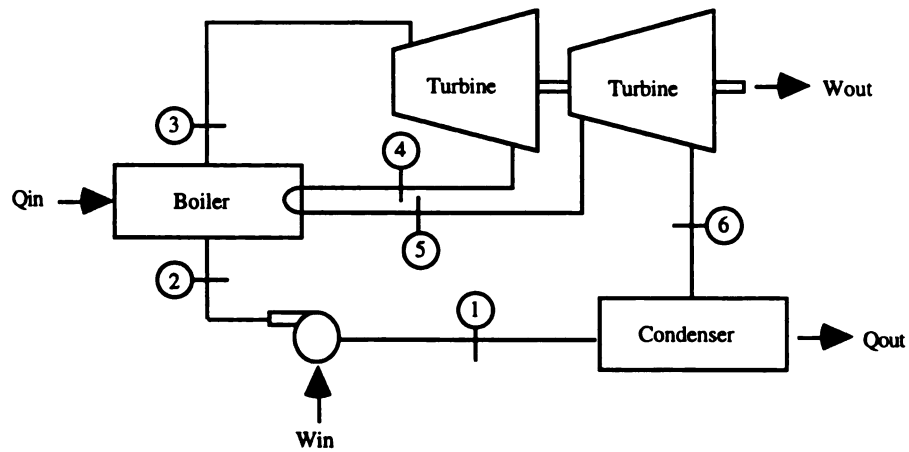


Figure 1-3. Schematic of the simple reheat Rankine Cycle

The simple reheat Rankine cycle differs from the simple Rankine cycle in that the isentropic expansion takes place in two stages. The reheating process removes any moisture which may exist and superheats the working fluid. In addition to addressing the excessive moisture problem, the reheating process also improves the cycle efficiency by increasing the average temperature at which heat is added to the working fluid. This

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Figure

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1.0.5 The Simple Reg

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increase can be seen on the simple reheat Rankine cycle T-s diagram shown in Figure 1-4.

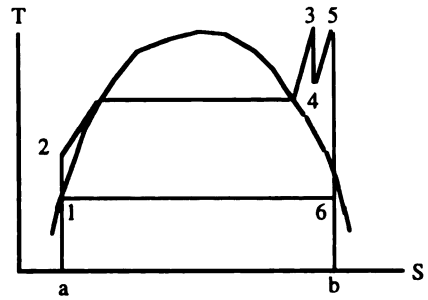


Figure 1-4. T-s diagram for a simple reheat Rankine cycle

The average temperature at which heat is added to the working fluid may be increased even more with the addition of a second or third reheat leg but, usually, the added cost and complexity do not justify such a modification.

Previous work performed by Reynolds and Harris and White indicate that reheating results in an increase in the 1st law thermal efficiency of approximately 5 percent. About 40 percent of this improvement comes from adding heat at a higher than average temperature and the remaining 60 percent comes from improvements in the turbine stage group efficiencies due to reduced moisture and increased reheat factors. As compared with no reheating, a system with a single reheat leg reheating to the initial boiler temperature reduces the throttled and condenser steam flow rates by approximately 17 and 13 percent for a given turbine power output. Reynolds and Harris and White recommend that the reheat pressure should be between 15 to 30 percent of the pressure exiting the boiler.

1.0.5 The Simple Regenerative Rankine Cycle

Another commonly used method for increasing the thermal efficiency of a steam power plant consists of regenerative feed water heating. Since a system's thermal efficiency can be increased by increasing the average temperature at which heat is supplied, reheating (or regenerating) the working fluid with extracted turbine steam before the working fluid enters the boiler increases the average temperature at which heat is supplied and, hence, increase the system's thermal efficiency. A schematic of a power plant operating on the

simple regenerative R

Figure 1-5.

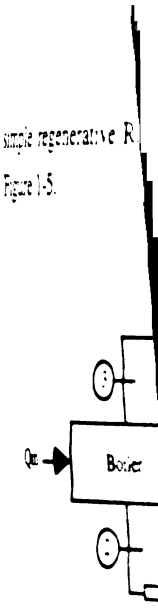


Figure 1

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Figure 1-6. T

simple regenerative Rankine cycle with a single open feed water heater is shown in Figure 1-5.

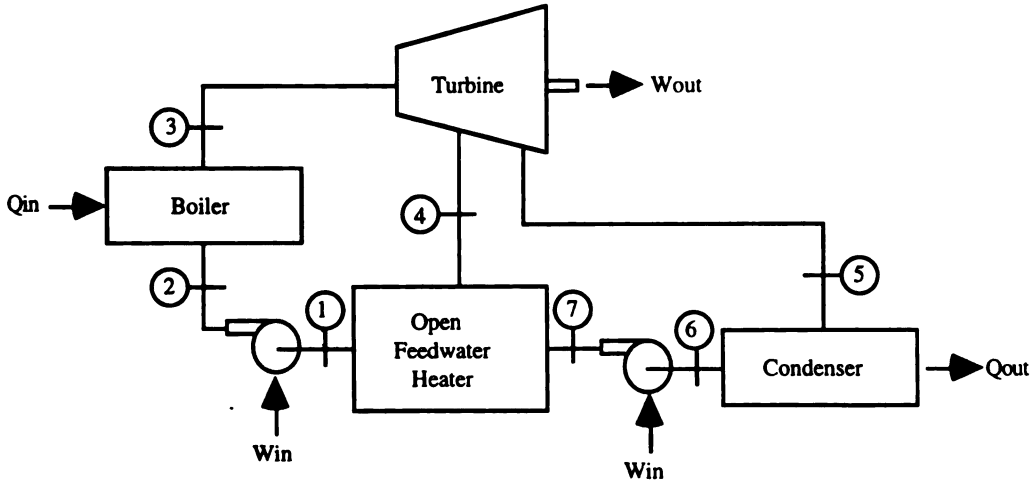


Figure 1-5. Schematic of simple regenerative Rankine cycle

The simple regenerative Rankine cycle differs from the simple Rankine cycle in that a fraction of the mass flow through the turbine is extracted to preheat the feed water traveling between the condenser and the boiler. Since the simple regenerative Rankine cycle consists of open feed water heaters which permit direct contact between the extraction steam and the feed water, two pumps are required. The preheating of the feed water improves the system thermal efficiency since the average temperature of heat supplied to the system is increased. The advantage of reheating the working fluid before it enters the boiler can be seen on the simple regenerative Rankine cycle T-s diagram shown in Figure 1-6.

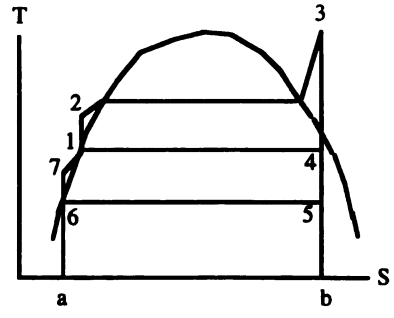


Figure 1-6. T-s diagram for simple regenerative Rankine cycle

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By definition, all processes within the simple regenerative Rankine cycle are reversible and, hence, the heat transfer during the cycle may be represented by the various areas on the T-s diagram. The enclosed area on the T-s diagram represents the net work produced by the cycle. It should be noted that the addition of the open feed water heaters in the simple regenerative Rankine cycle reduces the enclosed area (and, hence, the work output), but also reduces the heat supplied in the boiler.

In addition to the improved cycle thermal efficiency, the simple regenerative Rankine cycle possesses two additional positive features. By preheating the feed water before it enters the boiler, thermal shock resulting from pumping 'cold' feed water into a 'hot' boiler is avoided. In addition, turbine blades can be designed to drain a majority of the liquid condensate that exists in the turbine, and hence, turbine stage group efficiency can be maximized and turbine blade wear can be minimized.

1.0.6 Additional Rankine Cycle Systems Designs

The two fundamental techniques used to increase the Rankine cycle's 1st law thermal efficiency are reheating and regenerating. In modern Rankine cycle based designs, components other than reheat legs and open feed water heaters may be utilized to apply these two fundamental techniques and achieve improved 1st law thermal efficiency

In the simple reheat Rankine cycle, a reheat leg was used to reheat the working fluid between the high and low pressure turbines. In some modern Rankine cycle based designs, Moisture Separator Reheaters (MSR) are used to accomplish the identical thermodynamic result. Physically, a MSR accomplishes two functions: (1) extracts all entrained moisture from the working fluid traveling between the high and low pressure turbines, and (2) reheats the saturated vapor component of the working fluid to a superheated vapor. The two phase working fluid exiting the high pressure turbine is separated into a saturated liquid and saturated vapor by the moisture separator component of the MSR. The saturated liquid removed by the MSR is drained to the feed water heaters and the remaining saturated vapor is reheated in the reheating component of the MSR by steam that is extracted from the high pressure turbine or the single steam line exiting the boiler. The working fluid extracted by the MSR and the condensed reheat steam exiting the MSR are both drained to the feed water heaters. The advantages of this setup are that the low energy component of the working fluid (saturated liquid) is first

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1.0 Deviations of A

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1.1.0 Procedure For

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drained before reheating and only one exit from the boiler is required (Reheat legs are a costly feature of a boiler).

In the simple regenerative Rankine cycle, an open feed water heat was used to reheat the working fluid between the condenser and the boiler. In some modern Rankine cycle based designs, closed feed water heaters are used to accomplish the identical thermodynamic result. Physically, a closed feed water heater is usually a shell and tube heat exchanger with "hot" extracted steam within the shell and the "cold" feed water within the tubes. The advantage of utilizing closed feed water heater rather than open feed water heaters is the fact that closed feed water heaters do not permit mixing of the working fluids and, hence, the pressure of the extracted steam and the feed water do not need to be identical. As a result, multiple closed feed water heat exchangers do not require a pump between each heat exchanger as required by multiple open feed water heaters. In addition, closed feed water heaters offer a greater potential to optimize since turbine extraction pressures and feed water heater pressures may be decoupled.

1.0.7 Deviations of Actual Power Cycles From Ideal Power Cycles

Actual vapor power cycles differ from the reversible Rankine cycles discussed in sections 1.0.1, 1.0.4 and 1.0.5 due to irreversibilities within the individual components which are part of the cycle. Physical factors such as fluid friction, undesired heat loss, unrestrained expansion and heat transfer at a finite temperature contribute to a reduction in the cycle's 1st and 2nd law efficiency. The existence of non-ideal components coupled with complicated system designs make the modeling of modern Rankine cycle based designs very difficult and very time consuming.

1.1.0 Procedure For System Analysis

The sequence of steps utilized to evaluate the thermal performance of any system is independent of the system layout or the working fluid. This sequence of steps is collectively refereed to as the Procedure for System Analysis and summarizes the process used to evaluate the thermal performance of any well posed system. The Procedure for System Analysis is stated below.

1) The system layo
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2) The nodes betwe
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3) A table is constr
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1) The system layout is sketched. The devices representing the various processes are placed and connected according to the system description.
2) The nodes between the devices are numbered. These nodes represent locations within the system where the state of the working fluid is of interest.
3) A table is constructed with the following headings (Assuming a simple compressible substance): Node, Temperature, Pressure, Fluid Phase, Enthalpy, Entropy, Mass Flow Rate, and Availability.
4) With the given operating conditions and system description, all known thermodynamic information is entered on the table.
5) Using the state postulate and the working fluid property tables, all obtainable thermodynamic information is added to the table.
6) The system is traversed, device by device, analyzing the fluid as it passes through each device. This analysis provides additional fluid properties, which when used in conjunction with step #5 systematically completes the table.
7) With the completed table, system information (such as thermal efficiency and work produced) is calculated.

By employing the Procedure for System Analysis, any well posed system may be systematically analyzed. In essence, the Procedure for System Analysis uses the working fluid property tables, the physical characteristics of each device type, and the 1st and 2nd law of thermodynamics to systematically calculate all unknown thermodynamic information within a well posed system. The repetitive nature of these calculations is ideally suited for a computer application.

1.2.0 Previous Work and RANKINE 3.0 Objectives

Previous software packages dealing with steam power systems fall into one of three groups. The first group consists of simple program developed for use on hand held calculators. These are normally restricted to considering only the simplest steam power systems and, hence, do not provide a realistic analysis of a steam power system. The second group involves software packages that are designed for classroom use only. Preston et al. and Cengel and Boles have written programs that analyze the operation of the Rankine cycle for a limited number of the simplest steam power system. Since the primary use of these programs are for classroom instruction, they are not flexible enough to model modern steam power plant designs. Finally, there are some massive industry

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computer programs available for the analysis of actual steam power system; but these are usually very difficult to use, expensive to maintain, and impractical as an educational tool. The RANKINE 3.0 software package was developed as a continuation of the RANKINE family of computer software.

The development of RANKINE 3.0 was intended to remove many of the limitations possessed by earlier versions of RANKINE. The earlier versions of RANKINE contained sets of hardwired code logic which performed a thermal analysis for a finite set of specific system layouts. Although RANKINE 2.4 contained a total of 28 unique system layouts, it provided no method to quantify the effect of slightly modifying the system layout. In essence, RANKINE 2.4 only provided a method to study (and, hence, optimize) the relationship between the operating conditions, device performance parameters, and the system performance for a finite set of system layouts. In addition, RANKINE 2.4 did not provide any mechanism to study system layouts with closed feed water heaters, moisture separators, or reheaters. RANKINE 3.0 was developed to permit the user to specify the system layout, operating conditions, and device performance parameters in an input file and, hence, provide the user with a method to study the relationship between the system layout, operating conditions, device performance parameters, and system performance. In addition, RANKINE 3.0 increased the number of thermal devices from eight to eleven, which permits additional system layouts to be studied.

In addition to greater flexibility, RANKINE 3.0 was developed to improve user friendliness and internal checks. In order to use RANKINE 3.0 as an educational tool, the program was developed with an input processor that recognizes a key phrase library. As a result, all RANKINE 3.0 input files are composed of English phrases as opposed to a series of numbers separated by commas. Furthermore, RANKINE 3.0 was developed to include a series of internal input file checks to determine if any inconsistencies exist. If an inconsistency is identified, a diagnostic messages informs the user of the inconsistency. The output generated by RANKINE 3.0 also undergoes a series of internal checks, which includes the results of a mass and energy balance on the various control volumes within the system. These internal checks ensure that code results are based upon valid input information and are correct.

13.0 Sample In

A sample input file. E

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The RANKINE 3.0 in

shown below.

```
TITLE LINE
 SAMPLE PROBLEM
END TITLE

NUMBER OF NODES IS 4
HIGH TEMPERATURE R
LOW TEMPERATURE RE
DEAD STATE TEMPER A
DEAD STATE PRESSURE
GENERATOR MECHANI
GENERATOR ELECTRIC

DEVICE #1  SIMPLE TU
 INLET NODE NUMBER
 EXTRACTION #1 NOD
 STAGE GROUP #1 EFF
 EXTRACTION #1 PRES
END DEVICE
```

1.3.0 Sample Input File, ECHO.DAT File and Output File

A sample input file, ECHO.DAT file, and output file is included within this section in order to provide the reader with a feel for the input and output format of RANKINE 3.0. The system layout for this sample problem is shown below.

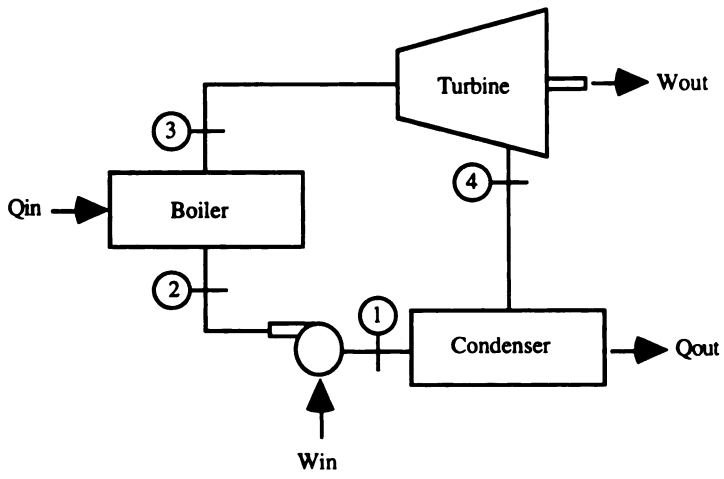


Figure 1-7. Schematic of sample problem

The RANKINE 3.0 input file which describes the system layout as shown in Figure 1-7 is shown below.

```
TITLE LINE
  SAMPLE PROBLEM
  END TITLE

NUMBER OF NODES IS 4
HIGH TEMPERATURE RESERVOIR: 600.0 DEG C
LOW TEMPERATURE RESERVOIR: 25.0 DEG C
DEAD STATE TEMPERATURE: 25.0 DEG C
DEAD STATE PRESSURE: 101 KPA
GENERATOR MECHANICAL LOSS IS 0.0 MW
GENERATOR ELECTRICAL LOSS IS 0.0 MW

DEVICE #1:  SIMPLE TURBINE
  INLET NODE NUMBER IS 3
  EXTRACTION #1 NODE NUMBER IS 4
  STAGE GROUP #1 EFFICIENCY IS 75 PERCENT
  EXTRACTION #1 PRESSURE IS 0.1 MPA
  END DEVICE

DEVICE #2: SIMPLE CONDENSER
  EXIT NODE NUMBER IS 1
  INLET #1 NODE NUMBER IS 4
  END DEVICE

DEVICE #3:  SIMPLE PUMP
  SUCTION NODE NUMBER IS 1
  DISCHARGE NODE NUMBER IS 2
  PUMP EFFICIENCY IS 75 PERCENT
  END DEVICE

DEVICE #4: SIMPLE BOILER
  BOILER INLET NODE NUMBER IS 2
  BOILER EXIT NODE NUMBER IS 3
  BOILER EXIT PRESSURE IS 20.0 MPA
  BOILER EXIT TEMPERATURE IS 600 DEG C
  BOILER EXIT MASS FLOW RATE IS 50 KG/SEC
  BOILER PRESSURE LOSS IS 0.0 MPA
  END DEVICE
```

The ECHO.DAT file

TITLE

SAMPLE PROBLEM

NUMBER OF NODES 4
NUMBER OF DEVICES 4

DEAD STATE PRESSURE
DEAD STATE TEMPERATURE

HIGH TEMPERATURE R
LOW TEMPERATURE R

GENERATOR MECHAN
GENERATOR ELECTR

DEVICE NUMBER 1 IS

TURBINE INLET NODE
TURBINE INLET TEMP
TURBINE INLET PRESS
TURBINE INLET MASS
TURBINE EXTRACTION
TURBINE EXTRACTION
STAGE GROUP # 1 EFFI

DEVICE NUMBER 2 IS

CONDENSER EXIT NOD
CONDENSER INLET #
CONDENSER INLET #

PUMP DEVICE NUMBE

PUMP SUCTION NODE
PUMP DISCHARGE NO
PUMP EFFICIENCY IS

DEVICE NUMBER 4

BOILER INLET NODE
BOILER EXIT NODE
BOILER EXIT TEMP
BOILER EXIT PRESS
BOILER EXIT MASS
BOILER PRESSURE

The output file p

PLANT

SAMPLE PROBLEM

The ECHO.DAT file produced by RANKINE 3.0 is shown below.

```
TITLE
****************************************
  SAMPLE PROBLEM

NUMBER OF NODES:  4
NUMBER OF DEVICES:  4

DEAD STATE PRESSURE IS  .1010 MPA
DEAD STATE TEMPERATURE IS  25.00 DEG C

HIGH TEMPERATURE RESERVOIR TEMPERATURE IS  600.00 DEG C
LOW TEMPERATURE RESERVOIR TEMPERATURE IS  25.00 DEG C

GENERATOR MECHANICAL LOSSES:    .000 MW
GENERATOR ELECTRICAL LOSSES:    .000 MW

DEVICE NUMBER  1 IS A SIMPLE TURBINE
****************************************
TURBINE INLET NODE NUMBER IS  3
TURBINE INLET TEMPERATURE IS  600.00 DEG C
TURBINE INLET PRESSURE IS 20.0000 MPA
TURBINE INLET MASS FLOW IS  50.00 KG/SEC
TURBINE EXTRACTION # 1 NODE NUMBER IS  4
TURBINE EXTRACTION # 1 PRESSURE IS  .1000 MPA
STAGE GROUP # 1 EFFICIENCY IS .75

DEVICE NUMBER  2 IS A SIMPLE CONDENSER
****************************************
CONDENSER EXIT NODE NUMBER IS  1
CONDENSER INLET # 1 NODE NUMBER IS  4
CONDENSER INLET # 1 PRESSURE IS  .1000 MPA

PUMP DEVICE NUMBER  3 IS A SIMPLE PUMP
****************************************
PUMP SUCTION NODE NUMBER IS  1
PUMP DISCHARGE NODE NUMBER IS  2
PUMP EFFICIENCY IS .75

DEVICE NUMBER  4 IS A SIMPLE BOILER
****************************************
BOILER INLET NODE NUMBER IS  2
BOILER EXIT NODE NUMBER IS  3
BOILER EXIT TEMPERATURE IS  600.00 DEG C
BOILER EXIT PRESSURE IS 20.0000 MPA
BOILER EXIT MASS FLOW IS  50.00 KG/SEC
BOILER PRESSURE LOSS  .0000 MPA
```

The output file produced by RANKINE 3.0 is shown below.

```
            RANKINE 3.0: A steam power plant computer simulation

                                Copyright 1994
                            W.A. Thelen, C.W. Somerton

************************************ TITLE ************************************

  SAMPLE PROBLEM

********************************** NODE DATA **********************************
```



NODE	T(C)	P(MPa)	L	Q	S(KJ/KG/K)	H(KJ/KG)	V(M^3/KG)	M(KG/S)	A(KJ/KG)
1	99.63	.1000	4	*****	1.3020	417.31	.00104	50.0000	33.47
2	103.52	20.0000	1	*****	1.3228	448.50	.00105	50.0000	58.45
3	600.00	20.0000	3	*****	6.5052	3536.61	.01808	50.0000	1601.44
4	99.63	.1000	2	.990	7.2962	2651.90	1.67621	50.0000	480.88

********** DEVICE DATA (DEVICE BEFORE NODE) **********

NODE	REV. WRK (KW)	ACT. WRK (KW)	IRREV (KW)	HEAT X-FER (KW)	MASS ERROR (KG/S)	ENERGY ERROR (KW)
1	22370.37	.00	22370.37	-111729.90	.000	-.008
2	-1249.04	-1559.60	310.56	.00	.000	.000
3	71843.58	.00	71843.58	154405.60	.000	.000
4	56028.13	44235.28	11792.86	.00	.000	.000

********** SYSTEM DATA **********

TOTAL MASS FLOW RATE EXITING SYSTEM:	.0000	KG/SEC
TOTAL MASS FLOW RATE ENTERING SYSTEM:	.0000	KG/SEC
TOTAL ENTHALPY FLOW RATE EXITING SYSTEM:	.0000	KW
TOTAL ENTHALPY FLOW RATE ENTERING SYSTEM:	.0000	KW
TOTAL HEAT AND WORK ENTERING SYSTEM:	-.0039	KW
BOILER HEAT (DEVICE # 4):	154405.6000	KW
TOTAL BOILER HEAT:	154405.6000	KW
TOTAL HEAT LOAD HEAT:	.0000	KW
CONDENSER HEAT (DEVICE # 2):	-111729.9000	KW
TOTAL PIPE ENERGY LOSSES:	.0000	KW
TURBINE WORK (DEVICE # 1):	44235.2800	KW
NET WORK TO GENERATORS:	44235.2800	KW
PUMP WORK (DEVICE # 3):	-1559.6010	KW
TOTAL PUMP WORK:	-1559.6010	KW
GENERATOR MECHANICAL LOSSES:	.0000	KW
GENERATOR ELECTRICAL LOSSES:	.0000	KW
NET ELECTRICAL POWER:	42675.6800	KW
SYSTEM HEAT RATE:	12345.0200	BTU/KW*HR
CARNOT CYCLE EFFICIENCY:	65.8535	PERCENT
1ST LAW EFFICIENCY:	27.6387	PERCENT
2ND LAW EFFICIENCY:	42.8466	PERCENT
2ND LAW EFFECTIVENESS:	41.9699	PERCENT

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Chapter 2 Code Structure

2.0.0 Code Overview

The basic structure of RANKINE 3.0 is directly analog to the Procedure for System Analysis and can be visualized as consisting of four independent sections; input file processing, input file checking, thermodynamic analysis and output processing. Figure 2-1 illustrates the relationship among the four independent sections of RANKINE 3.0.

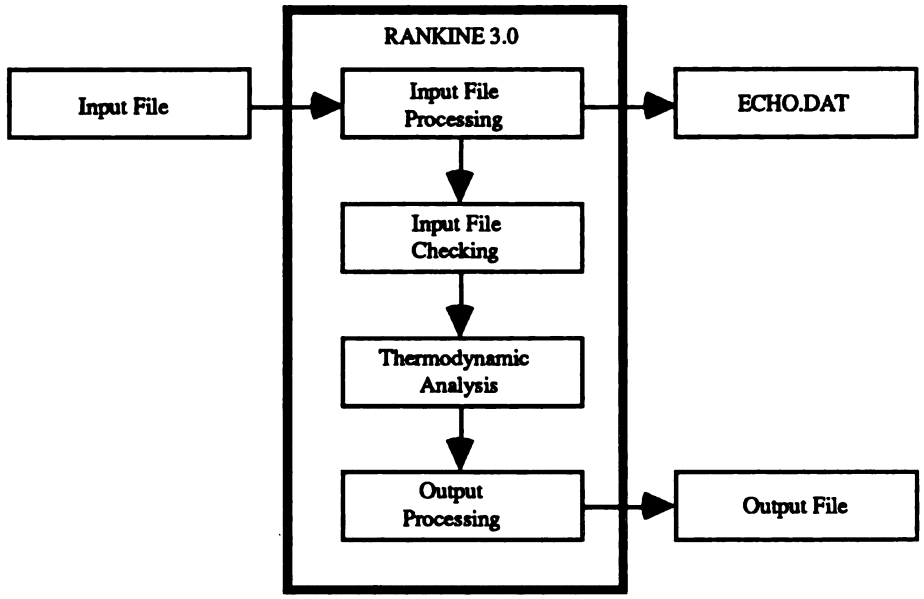


Figure 2-1. Overview of RANKINE 3.0 code structure

The input file is a user written ASCII file that contains a description of the system layout, all known thermodynamic information, and all device performance parameters. In order to increase the user friendliness of RANKINE 3.0, the input file is created using a key phrases library. Using this key phrase library, the system layout, operating conditions and device performance parameters are communicated to RANKINE 3.0 for the analysis.

The input file processor prompts the user for an input file and scans the input file, line by line, for key phrases. When a key phrase is identified, the information contained within the line is interpreted and organized. After the entire input file has been scanned and interpreted, RANKINE 3.0 writes all input file information to an external file named ECHO.DAT. Inspection of the ECHO.DAT file clarifies any questions associated with the interpretation of an input file.

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2.0.1 Subroutin

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Abbreviation	
AI	
BAL	
CAL	

The input file checking section verifies that the information obtained from the input file is complete and consistent. A message is provided to the user in the event that either the input file did not provide sufficient information for an analysis or an inconsistency is identified.

The thermodynamic analysis section systematically traverses the system layout, device by device, and calculates all unknown thermodynamic device information based on the input file information. Calculation of unknown thermodynamic device information is based upon computerized steam tables and hardwired code logic that applies the 1st and 2nd law of thermodynamics for a control volume (neglecting kinetic and potential energy terms) to each device within the system. After all possible node and device information is calculated, overall system performance parameters, such as the 1st and 2nd law efficiencies, are calculated based upon the results of the thermodynamic analysis.

The output processing section performs a mass and energy balance on each of the various control volumes throughout the system, prompts the user for an output file name, and writes the results of the analysis to the specified file. The user specified output file summarizes the results of the thermodynamic analysis and all important system parameters.

The only communication between the four independent sections of RANKINE 3.0 is through two common blocks; IO and DEAD. Due to the modular structure of the code, additional thermal models may be written and easily integrated into the existing code structure.

2.0.1 Subroutine Nomenclature

Due to the large number of subroutines within RANKINE 3.0, a set of subroutine nomenclature was developed to simplify the code. A summary of the subroutine nomenclature is shown in Table 2-1.

Table 2-1. Subroutine nomenclature

Abbreviation	Representation	Abbreviation	Representation
AI	Artificial intelligence	DIAG	Diagnostic
BAL	Balance	EC	Echo
CAL	Calculation	FIXSTA	Fix state

Table 2-1. Cont'd

Abbreviation	Representation	Abbreviation	Representation
FND	Find	SCND	Simple condenser model
IC	Input checking	SHLD	Simple heat load model
IN	Input processing	SJCT	Simple junction model
INF	Information	SOFW	Simple open feed water heater model
M	Model	SPIP	Simple pipe model
ME	Mass and energy	SPMP	Simple pump model
NOD	Node	SREH	Simple reheater model
NUM	Number	SSEP	Simple moisture separator model
O	Output	STR	String
RANK	Rankine	STRB	Simple turbine model
SBOL	Simple boiler model	SYS	System
SCFW	Simple closed feed water heater model	WARN	Warning

For example, the subroutine INSTRB may be interpreted as the input processing subroutine for the simple turbine model. All subroutines employing other combinations of this nomenclature may be interpreted by strict analogy to this example. As a result of this nomenclature, insight into the exact function of each subroutine may be readily obtained by inspection of the subroutine name. It should be noted that the steam table subroutines do not utilize this nomenclature and, therefore, the function of each steam table subroutine must be interpreted independently.

2.0.2 RANKINE 3.0 Pseudo Flow Chart

The ideal method for examining the relationship among the subroutines within RANKINE 3.0 is through a pseudo flow chart. Figure 2-2 shows the pseudo flow chart for RANKINE 3.0.

The interpretation of the pseudo flow chart requires the employment of a set of rules. These rules are summarized below:

1) Capitalized text indicates a subroutine with access to common blocks. Lower case text indicates a subroutine without access to common blocks.

2) A single line indicates a subroutine call. A double line indicates a loop.

3) Begin at the top. The subroutine order of execution is down, left, right and up.


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RANKAI
MIRAI.

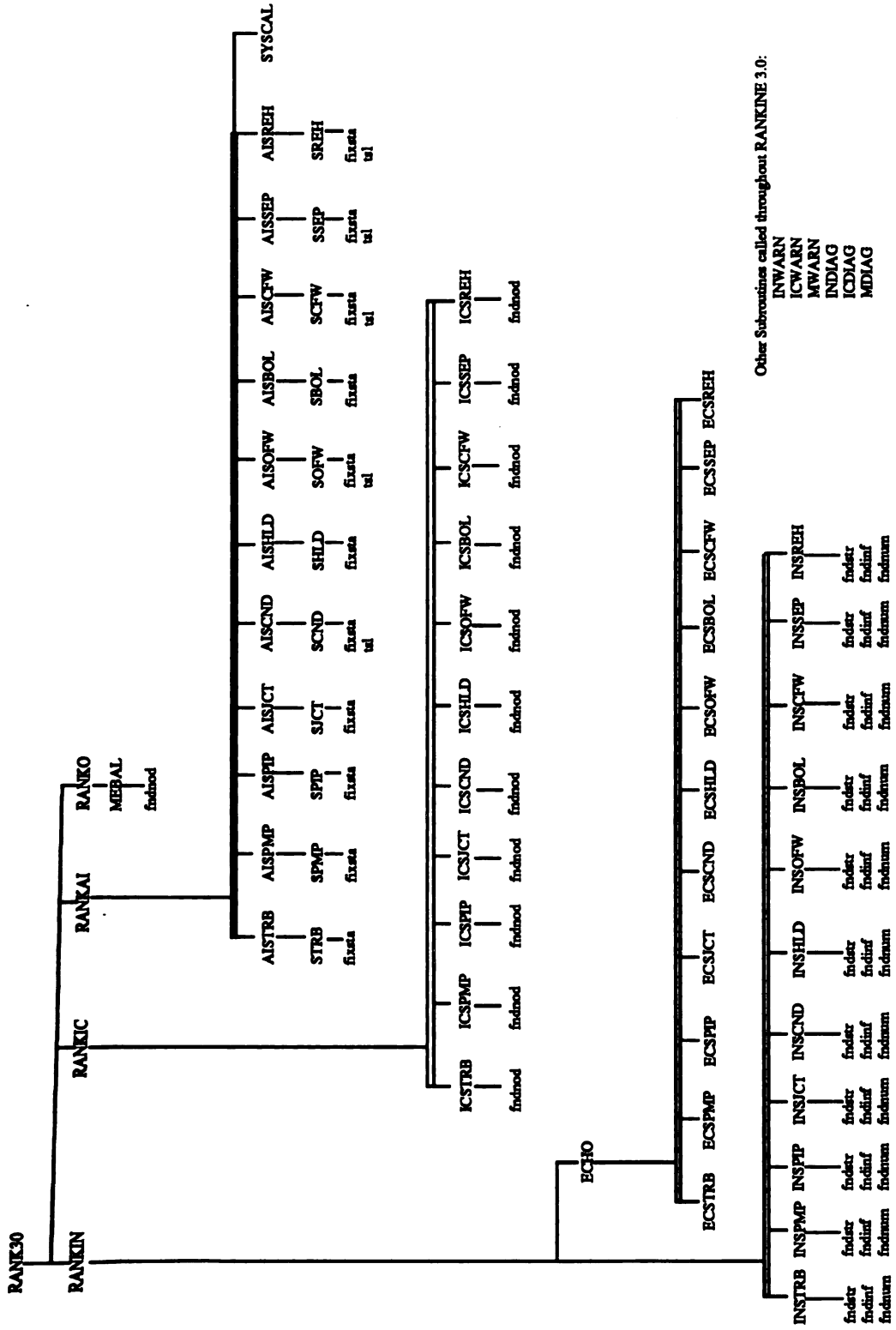


Figure 2-2. RANKINE 3.0 pseudo flow chart

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2.1.0 Input Process

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Inspection of Fig. 2-2 clearly illustrates the basic code structure. At the top of Fig. 2-2, the FORTRAN program name RANK30 and the 4 subroutines RANKIN, RANKIC, RANKAI and RANKO can be identified. The program name RANK30 represents the highest level subroutine within the program and is responsible for setting variables to a default value of -1.0 (representing an unknown value) and calling the four independent sections of RANKINE 3.0. Each one of the four subroutines represent one of the four independent sections of the program: input file processing (RANKIN), input file checking (RANKIC), thermodynamic analysis (RANKAI), and output file processing (RANKO). Each of these four subroutines contain a set of lower level subroutines which perform the tasks required. The use of the pseudo flow chart facilitates navigation through the program structure and provides a visual method from which the internal flow of the program may be identified.

2.1.0 Input Processing

The primary purpose of the input processing section is to identify the important information within the user provided input file and organize the information such that the other sections of the code can utilize the information. Since RANKINE 3.0 input files are written using English phrases, the search for information within the input file is based upon a line by line comparison of the input file with a key phrase library. When a key phrase is identified within a line, hardwired code logic elects to either searches for information or to call another subroutine to search for information. After the information is obtained from the input file, the information is stored within a set of arrays. When RANKINE 3.0 has completed the scan of the input file, the input file is closed and the only information that is accessible to the other sections of RANKINE 3.0 are the arrays.

2.1.1 Scanning for Information Within the Input File

The identification of information within the input file is based upon a line by line comparison of the input file to a key phrase library. The highest level input processing subroutine is RANKIN and is primarily responsible for obtaining information that affects the execution of RANKINE 3.0 and information revenant to the system but not directly applicable to a single device. The subroutines INSTRB, INSPMP, INSPIP, INSJCT, INSCND, INSHLD, INSOFW, INSBOL, INSCFW, INSSEP and INSREH are called from subroutine RANKIN and are responsible for identifying and organizing information pertaining to a specific device type (i.e., simple turbine, simple pump, ect.).

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The search for a key phrase or number within an input file line is accomplished by three utility subroutines; GETLIN, FNDSTR, and FNDNUM. Subroutine GETLIN is called by all input processing subroutines to open or close the input file as needed and read the next input file line as a 80A1 format. Subroutine FNDSTR is called by all input processing subroutines to search the 80A1 character string, character by character, for a specific sequence of characters. If a character sequence is located, an integer flag is set to the location within the string that the sequence is identified. If the sequence of characters is not located, the integer flag is set to -1. The utility subroutine FNDNUM is responsible for searching the 80A1 character string, character by character, for a number. After a sequence of numbers is located within the 80A1 string, the equivalent numerical representation of the sequence of numbers is determined. Figure 2-3 illustrates the basic structure for all input processing subroutines.

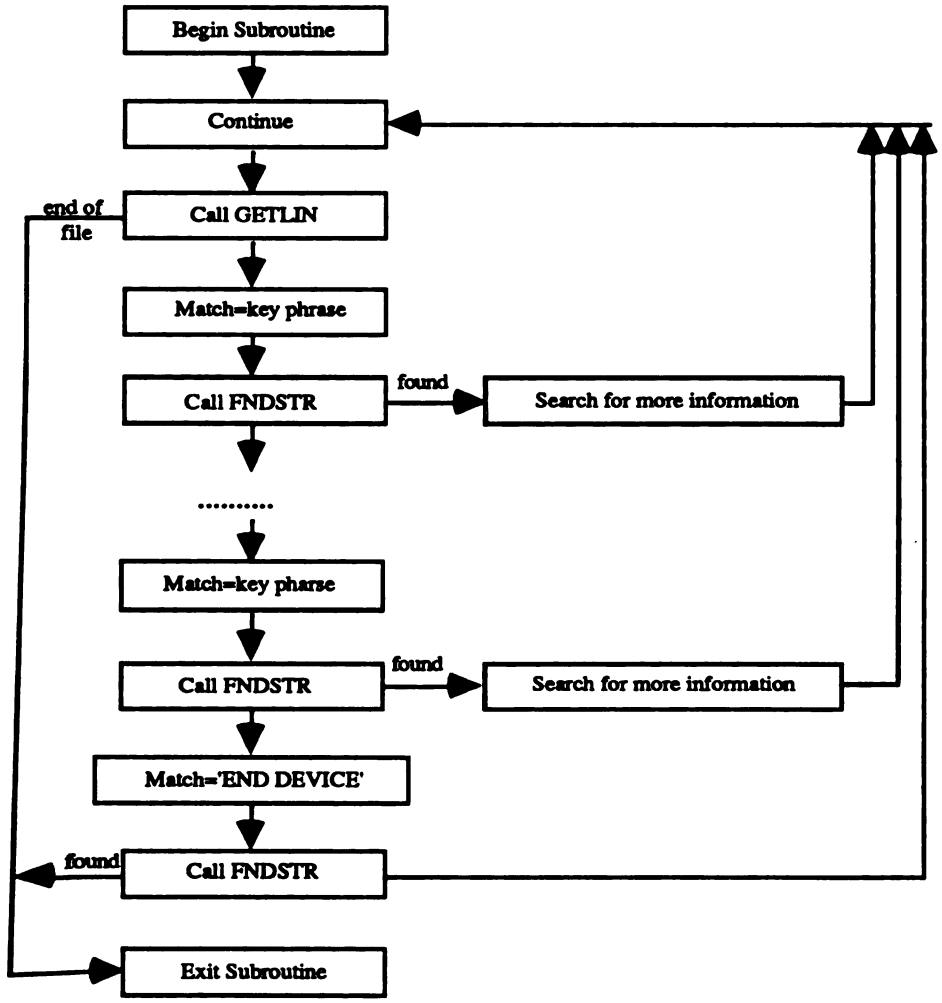


Figure 2-3. Basic structure of input processing subroutine

Usually, the first key phrase within a line is sufficient only to describe a position on a specific device. For example, a 1st key phrase such as FEED WATER INLET specifies a position on a device (in this case, an open feed water heater) but no thermodynamic information at this position. In many instances, a 2nd key phrase is required to specify information pertaining to a particular position. For example, the phrase THE FEED WATER INLET TEMPERATURE IS 197.2 DEG F specifies a position on an device and a piece of thermodynamic information at the position (in this case, a temperature). Frequently, the identification of a 2nd key phrase, a number, and units is accomplished within the utility subroutine FNDINF.

The utility subroutine FNDINF is called throughout the input processing subroutines after a 1st key phrase has been identified and a 2nd key phrase is expected. The purpose of subroutine FNDINF is to identify a 2nd key phrase, a number (if expected, based on the 2nd key phrase), and the units of the number. The identification of the 2nd key phrase and a number within the 80A1 character string is accomplished by the utility subroutines FNDSTR and FNDNUM respectively. In addition, subroutine FNDINF applies the appropriate conversion factors to all numbers such that S.I. units are calculated and stored internally. Table 2-2 contains a list of the acceptable 2nd key phrase and recognized units. In the event that units are not provided within the character string, the number is assumed to be in S.I. units.

Table 2-2. Summary of 2nd key phrases

2nd Key Phrase	Number	Acceptable Units
NODE	Yes	**** NONE EXPECTED ****
PRESSURE	Yes	MPA, KPA, PA, PSIA, PSIG, PSID, INCHES HG GAUGE, INCHES HG ABSOLUTE, INCHES H20 GAUGE, INCHES H2O ABSOLUTE
TEMPERATURE	Yes	DEG C, DEG K, KELVIN, DEG F, DEG R
TEMPERATURE DIFFERENCE	Yes	DEG C, DEG K, KELVIN, DEG F, DEG R
ENTHALPY	Yes	KJ/KG, J/KG, BTU/LBM
ENTROPY	Yes	KJ/KG/K, J/KG/K, BTU/LBM/R
MASS FLOW	Yes	KG/SEC, KG/HR, LBM/SEC, LBM/HR
SATURATED LIQUID	No	**** NONE EXPECTED ****
SATURATED VAPOR	No	**** NONE EXPECTED ****
SUPERHEATED	Yes	DEG C, DEG K, KELVIN, DEG F, DEG R
SUBCOOLED	Yes	DEG C, DEG K, KELVIN, DEG F, DEG R
FLUID PHASE	No	SUBCOOLED LIQUID, SATURATED LIQUID, 2 PHASE MIXTURE, SATURATED VAPOR, SUPERHEATED VAPOR
QUALITY	Yes	PERCENT, %
JUNCTION DEVICE	Yes	**** NONE EXPECTED ****
FLOW FRACTION	Yes	PERCENT, %

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2.1.2 1st Phras

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GENER ELECTRIC
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SIMPLE
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It should be noted that if a 2nd key phrase is expected and is not contained within the 80A1 character string, a diagnostic message is provided to the user and program execution is stopped.

2.1.2 1st Phrase Key Phrase Library

The highest level input processing subroutine within RANKINE 3.0 is subroutine RANKIN. Subroutine RANKIN is responsible for interpreting 1st key phrases that affect the execution of RANKINE 3.0 and information relevant to the system, but not directly related to a specific device. Table 2-3 contains a list of all 1st key phrases identified within subroutine RANKIN and their impact on the code logic.

Table 2-3. Summary of subroutine RANKIN key phrases.

1st Key Phrase	Interpretation
COMMENT	Stops RANKINE 3.0 from scanning the current line.
ECHO OFF	Indicates that input file information should not be written to the external data file ECHO.DAT.
INPUT CHECK OFF	Indicates that input file checking will be bypassed. It is recommended that this feature not be used.
ITERATION OFF	Indicates that RANKINE 3.0 should not iterate to converge on a solution to the system.
TITLE	Indicates the beginning of title information. If a title is include within the input deck, the title information will be written to the output file. The title may be up to 10 lines long.
END TITLE	Indicates the end of the title information.
NUMBER OF NODES	Indicates the number of nodes in the system. This key phrase is followed by a number corresponding to the number of nodes (up to 100) in the system.
HIGH TEMPERATURE RESERVOIR	Indicates the temperature of the hot reservoir with which the system is interacting. Acceptable units are 'DEG C', 'DEG F', 'DEG R', 'DEG K'.
LOW TEMPERATURE RESERVOIR	Indicates the temperature of the cold reservoir with which the system is interacting. Acceptable units are 'DEG C', 'DEG F', 'DEG R', 'DEG K'.
DEAD STATE	Indicates a property of the dead state will be specified (such as a temperature or pressure). A second key phrase is expected.
GENERATOR MECHANICAL LOSSES	Indicates that the Generator Mechanical Losses are known and should be considered. Acceptable units are KW, MW, BTU/HR, HP.
GENERATOR ELECTRICAL LOSSES	Indicates that the Generator Electrical Losses are known and should be considered. Acceptable units are KW, MW, BTU/HP, HP.
SIMPLE TURBINE	Indicates that information pertaining to a simple turbine device will be specified.
SIMPLE PUMP	Indicates that information pertaining to a simple pump device will be specified.
SIMPLE PIPE	Indicates that information pertaining to a simple pipe device will be specified.
SIMPLE JUNCTION	Indicates that information pertaining to a simple junction device will be specified.
SIMPLE CONDENSER	Indicates that information pertaining to a simple condenser device will be specified.
SIMPLE HEAT LOAD	Indicates that information pertaining to a simple heat load device will be specified.

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SIMPLE BOILER
SIMPLE STEAM TRA
SIMPLE MOISTURE SEPARATOR
SIMPLE REHEATER

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Device Name
SIMPLE TURBINE
SIMPLE PUMP

Table 2-3. (cont'd)

1st Key Phrase	Interpretation
SIMPLE OFW HEATER	Indicates that information pertaining to a simple open feed water heater device will be specified.
SIMPLE BOILER	Indicates that information pertaining to a simple boiler device will be specified.
SIMPLE STEAM TRAP CFW	Indicates that information pertaining to a simple steam trap closed feed water heater device will be specified.
SIMPLE MOISTURE SEPARATOR	Indicates that information pertaining to a simple moisture separator device will be specified.
SIMPLE REHEATER	Indicates that information pertaining to a simple reheater device will be specified.

The subroutines INSTRB, INSPMP, INSPIP, INSJCT, INSCND, INSHLD, INSOFW, INSBOL, INSCFW, INSSEP, and INSREH are responsible for identifying information within an input file related to a specific device type and for organizing the information such that the other sections of the program can utilize the information. Each of these model specific subroutines are called from subroutine RANKIN whenever a 1st key phrase is identified that indicates device specific information. The basic structure of each model specific input processing subroutine is similar to that of subroutine RANKIN and may be visually represented by Fig. 2. The primary difference between subroutine RANKIN and each model specific input processing subroutines is that the model specific input processing subroutines focus on information related to a specific device, not information related to the system. Utilizing this type of organization facilitates the introduction of new thermodynamic models into the existing code structure. Table 2-4 contain a summary of the 1st key phrase library for each model specific input processing subroutines.

Table 2-4. Thermodynamic models 1st key phrase library

Device Name	1st Key Phrase	2nd Key Phrase	Units
SIMPLE TURBINE	INLET	Yes	Per 2nd key phrase
	EXTRACTION #_	Yes	Per 2nd key phrase
	STAGE GROUP #_ EFFICIENCY	No	%, PERCENT
	END DEVICE	No	None expected
SIMPLE PUMP	SUCTION	Yes	Per 2nd key phrase
	DISCHARGE	Yes	Per 2nd key phrase
	EFFICIENCY	No	%, PERCENT
	END DEVICE	No	None expected

Device Name

SIMPLE PIPE

SIMPLE JUNCTION

SIMPLE CONDENSE

SIMPLE OFW HEATE

SIMPLE BOILER

Table 2-4. (Cont'd)

Device Name	1st Key Phrase	2nd Key Phrase	Units
SIMPLE PIPE	INLET	Yes	Per 2nd key phrase
	EXIT	Yes	Per 2nd key phrase
	PIPE PRESSURE LOSS	No	Per 2nd key phrase PRESSURE
	PIPE PERCENTAGE PRESSURE LOSS	No	%, PERCENT
	PIPE ENTHALPY LOSS	No	Per 2nd key phrase ENTHALPY
	PIPE PERCENTAGE ENTHALPY LOSS	No	%, PERCENT
	END DEVICE	No	None expected
SIMPLE JUNCTION	INLET #_	Yes	Per 2nd key phrase
	EXIT #_	Yes	Per 2nd key phrase
	END DEVICE	No	None expected
SIMPLE CONDENSER	EXIT	Yes	Per 2nd key phrase
	INLET #_	Yes	Per 2nd key phrase
	END DEVICE	No	None expected
SIMPLE OFW HEATER	FEED WATER EXIT	Yes	Per 2nd key phrase
	FEED WATER EXIT IS NOT SATURATED	No	None expected
	FEED WATER INLET	Yes	Per 2nd key phrase
	EXTRACTION INLET	Yes	Per 2nd key phrase
	END DEVICE	No	None expected
SIMPLE BOILER	BOILER INLET	Yes	Per 2nd key phrase
	BOILER EXIT	Yes	Per 2nd key phrase
	BOILER PRESSURE LOSS	No	Per 2nd key phrase PRESSURE
	BOILER PERCENTAGE PRESSURE LOSS	No	%, PERCENT
	REHEAT LEG #_ INLET	Yes	Per 2nd key phrase
	REHEAT LEG #_ EXIT	Yes	Per 2nd key phrase
	REHEAT LEG #_ PERCENTAGE PRESSURE LOSS	No	%, PERCENT
	REHEAT LEG #_ PRESSURE LOSS	No	Per 2nd key phrase PRESSURE
	END DEVICE	No	None expected

Table 2-4. (Cont'd)

Device Name	1st Key Phrase	2nd Key Phrase	Units
SIMPLE HEAT LOAD	INLET	Yes	Per 2nd key phrase
	EXIT	Yes	Per 2nd key phrase
	END DEVICE	No	None expected
SIMPLE STEAM TRAP CFW	FEED WATER INLET	Yes	Per 2nd key phrase
	FEED WATER EXIT	Yes	Per 2nd key phrase
	EXTRACTION INLET	Yes	Per 2nd key phrase
	DRAIN INLET #_	Yes	Per 2nd key phrase
	DRAIN EXIT	Yes	Per 2nd key phrase
	FEED WATER PRESSURE LOSS	No	Per 2nd key phrase PRESSURE
	FEED WATER PERCENTAGE PRESSURE	No	%, PERCENTAGE
	EXTRACTION PRESSURE LOSS	No	Per 2nd key phrase PRESSURE
	EXTRACTION PERCENTAGE PRESSURE	No	%, PERCENTAGE
	TERMINAL TEMPERATURE DIFFERENCE	No	Per 2nd key phrase TEMPERATURE
	APPROACH TEMPERATURE DIFFERENCE	No	Per 2nd key phrase TEMPERATURE
	END DEVICE	No	None expected
SIMPLE MOISTURE SEPARATOR	SEPARATOR INLET	Yes	Per 2nd key phrase
	SEPARATOR VAPOR EXIT	Yes	Per 2nd key phrase
	SEPARATOR CONDENSATE EXIT	Yes	Per 2nd key phrase
	SEPARATOR PRESSURE LOSS	No	Per 2nd key phrase PRESSURE
	SEPARATOR PERCENTAGE PRESSURE LOSS	No	%, PERCENTAGE
	END DEVICE	No	None expected

Table 2-4. (Cont'd)

Device Name	1st Key Phrase	2nd Key Phrase	Units
SIMPLE REHEATER	CYCLE STEAM INLET	Yes	Per 2nd key phrase
	CYCLE STEAM EXIT	Yes	Per 2nd key phrase
	REHEAT STEAM INLET	Yes	Per 2nd key phrase
	REHEAT STEAM EXIT	Yes	Per 2nd key phrase
	REHEAT STEAM EXIT IS NOT A SATURATED LIQUID	No	None expected
	FLOW FRACTION CONTROLLED BY	No	Per 2nd key phrase JUNCTION DEVICE
	TERMINAL TEMPERATURE DIFFERENCE	No	Per 2nd key phrase TEMPERATURE
	CYCLE STEAM PRESSURE LOSS	No	Per 2nd key phrase PRESSURE
	CYCLE STEAM PERCENTAGE PRESSURE	No	%, PERCENTAGE
	REHEAT STEAM PRESSURE LOSS	No	Per 2nd key phrase PRESSURE
	REHEAT STEAM PERCENTAGE PRESSURE	No	%, PERCENTAGE
	END DEVICE	No	None expected

2.1.3 Information Organization

After RANKINE 3.0 has obtained the information from the input file, the information is stored within a set of arrays for future reference. The storage of information may be separated into three classes: 1) information related to the entire system, 2) information related to a device, and 3) information related to a node.

2.1.4 Organization of Information Related to the System

An example of information related to the entire system would be an input file statements such as BYPASS INPUT CHECK FOR THIS ANALYSIS or THE DEAD STATE TEMPERATURE IS 25.5 DEG C. Both statements relate directly to the execution of RANKINE 3.0 and not to a specific device or node. The storage of this class of information is accomplished with a set of common block variables. Table 2-5 contains a summary of the variables used to store this class of information.

Table 2-5. System related variables

Variable	Variable type	Common block	Variable Definition	Units
NDVC	Integer	IO	Number of devices within the system	-
NNODE	Integer	IO	Number of nodes within the system	-
GENML	Real	IO	Generator mechanical losses	MW
GENEL	Real	IO	Generator electrical losses	MW
ITITLE	Integer	IO	Number of lines in title	-
TITLE(10)	Character*80	IO	Title lines 1 through 10	-
INFILE	Character*10	IO	Input file name	-
TDEAD	Real	DEAD	Temperature of dead state	Deg C
PDEAD	Real	DEAD	Pressure of dead state	MPA
VDEAD	Real	DEAD	Specific volume of dead state	m^3/kg
HDEAD	Real	DEAD	Enthalpy of dead state	KJ/kg
SDEAD	Real	DEAD	Entropy of dead state	KJ/kg/k
QDEAD	Real	DEAD	Quality of dead state	-
LDEAD	Integer	DEAD	Fluid phase index of dead state	-
THRES	Real	DEAD	Temperature of high temperature reservoir	Deg C
TLRES	Real	DEAD	Temperature of low temperature reservoir	Deg C
CHK	Logical	IO	Flag to bypass input file check Default=.TRUE.	-
ECH	Logical	IO	Flag to bypass echo of input file Default=.TRUE.	-
ITEROF	Logical	IO	Flag to bypass iteration Default=.False.	-

2.1.5 Organization of Information Related to a Specific Device

An example of information related to a specific device is an input file line such as THE FEED WATER INLET NODE NUMBER IS 7 or THE PUMP EFFICIENCY IS 78 PERCENT. Both statements relate directly to the structure or performance of a specific device with the system. Organization of this class of information is accomplished within two arrays; DVCDAT(100,30) and ADDDAT(100,30).

When RANKINE 3.0 is executed, the elements of the arrays DVCDAT(100,30) and ADDDAT(100,30) are set to values of -1 and -1.0 respective (representing an unknown value). As information is obtained from the input file, the array is modified to reflect the synthesis of the input file.

The integer array DVCDAT(100,30) is an abbreviation for device data and is responsible for organizing node numbers on each device within the system. The first index of

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DVCDAT(100,30) represents a device number and the second index is used to organize information related to the specified device number.

The first element of the second index (i.e., DVCDAT(#,1)) indicates the device type (i.e., simple turbine, simple pump, ect.). Table 2-6 summarizes the interpretation of the numerical value contained within DVCDAT(#,1).

Table 2-6. Interpretation of the DVCDAT(#,1) element

DVCDAT(#,1)	Device type
1	SIMPLE TURBINE
2	SIMPLE PUMP
3	SIMPLE PIPE
4	SIMPLE JUNCTION
5	SIMPLE CONDENSER
6	SIMPLE HEAT LOAD
7	SIMPLE OFW HEATER
8	SIMPLE BOILER
9	SIMPLE STEAM TRAP CFW
10	SIMPLE MOISTURE SEPARATOR
11	SIMPLE REHEATER

For example, if DVCDAT(17,1) is equal to six, then the 17th device within the system is a simple heat load.

The second element of the second index (i.e., DVCDAT(#,2)) indicates the last ICALL completed for the device. (The ICALL concept is discussed within Section 2.3.2) Since this element is used only for internal bookkeeping, the user does not directly affect the value of this element.

The organization of the remaining 28 second index DVCDAT(100,30) elements depends on the device type (i.e., simple turbine, simple pump, ect.). Table 2-7 contains a summary of the remaining 28 second index elements as defined for each thermodynamic model.

Table 2-7. Organization of the DVCDAT(100,30) array

Model	Variable	Definition
SIMPLE TURBINE	DVCDAT(#,3)	Inlet node number
	DVCDAT(#,I+3) for I=1,10	Extraction #I node number
SIMPLE PUMP	DVCDAT(#,3)	Suction (inlet) node number
	DVCDAT(#,4)	Discharge (exit) node number
SIMPLE PIPE	DVCDAT(#,3)	Inlet node number
	DVCDAT(#,4)	Exit node number
SIMPLE JUNCTION	DVCDAT(#,I+2) for I=1,10	Inlet #I node number
	DVCDAT(#,I+12) for I=1,10	Exit #I node number
SIMPLE CONDENSER	DVCDAT(#,3)	Exit node number
	DVCDAT(#,I+3) for I=1,27	Inlet #I node number
SIMPLE HEAT LOAD	DVCDAT(#,3)	Inlet node number
	DVCDAT(#,4)	Exit node number
SIMPLE OFW HEATER	DVCDAT(#,3)	Feed water exit node number
	DVCDAT(#,4)	Extraction inlet node number
	DVCDAT(#,5)	Feed water inlet node number
SIMPLE BOILER	DVCDAT(#,3)	Boiler inlet node number
	DVCDAT(#,4)	Boiler exit node number
	DVCDAT(#,2*I+3) for I=1,10	Reheat leg #I inlet node number
	DVCDAT(#,2*I+4) for I=1,10	Reheat leg #I exit node number
SIMPLE STEAM TRAP CFW	DVCDAT(#,3)	Feed water inlet
	DVCDAT(#,4)	Feed water exit
	DVCDAT(#,5)	Extraction inlet node number
	DVCDAT(#,I+5) for I=1,10	Drain inlet #I node number
	DVCDAT(#,16)	Drain outlet node number
SIMPLE MOISTURE SEPARATOR	DVCDAT(#,3)	Inlet node number
	DVCDAT(#,4)	Vapor exit node number
	DVCDAT(#,5)	Condensate exit node number

Table 2-7. (Cont'd)

Model	Variable	Definition
SIMPLE REHEATER	DVCDAT(#,3)	Cycle steam inlet node number
	DVCDAT(#,4)	Cycle steam exit node number
	DVCDAT(#,5)	Reheat steam inlet node number
	DVCDAT(#,6)	Reheat steam exit node number
	DVCDAT(#,7)	Junction device number which controls the flow fraction

The DVCDAT(100,30) array is located within the common block IO and, hence, is accessible to each of the four independent sections of RANKINE 3.0.

The real number array ADDDAT(100,30) is an abbreviation for additional data and is responsible for information related to the performance characteristics of a particular device. For example, a pipe pressure loss or pump efficiency would be stored within ADDDAT(100,30). The first index of ADDDAT(100,30) represents the device number and the second index is for the storage of up to 30 pieces of information related to the specified device number. The organization of the 30 second index elements depends on the device type (i.e., simple turbine, simple pump, ect.) and can be seen in Table 2-8.

Table 2-8. Organization of the ADDDAT(100,30) array

Model	Variable	Definition	Units
SIMPLE TURBINE	ADDDAT(#,I) for I=1,10	Stage #I isentropic efficiency	0.0->1.0
SIMPLE PUMP	ADDDAT(#,1)	Pump isentropic efficiency	0.0->1.0
SIMPLE PIPE	ADDDAT(#,1)	Pipe pressure loss	MPA
	ADDDAT(#,2)	Pipe enthalpy loss	KJ/kg/K
	ADDDAT(#,3)	Pipe percentage pressure loss	0.0->1.0
	ADDDAT(#,4)	Pipe percentage enthalpy loss	0.0->1.0
SIMPLE JUNCTION	ADDDAT(#,I) for I=1,10	Inlet #I flow fraction	0.0->1.0
	ADDDAT(#,I+10) for I=1,10	Exit #I flow fraction	0.0->1.0
SIMPLE CONDENSER	-	-	-

Table 2-8. (Cont'd)

Model	Variable	Definition	Units
SIMPLE HEAT LOAD	-	-	-
SIMPLE OFW HEATER	ADDDAT(#,1)	A +1 indicates that the feed water exit state is not saturated liquid.	-
SIMPLE BOILER	ADDDAT(#,1)	Boiler pressure loss	MPA
	ADDDAT(#,I+1) for I=1,10	Reheat leg #I pressure loss	MPA
	ADDDAT(#,12)	Boiler percentage pressure loss	0.0->1.0
	ADDDAT(#,I+12) for I=1,10	Reheat leg #I percentage pressure loss	0.0->1.0
SIMPLE STEAM TRAP CFW	ADDDAT(#,1)	Feed water pressure loss	MPA
	ADDDAT(#,2)	Feed water percentage pressure loss	0.0->1.0
	ADDDAT(#,3)	Extraction pressure loss	MPA
	ADDDAT(#,4)	Extraction percentage pressure loss	0.0->1.0
	ADDDAT(#,5)	Terminal temperature difference	Deg C
	ADDDAT(#,6)	Approach temperature difference	Deg C
SIMPLE MOISTURE SEPARATOR	ADDDAT(#,1)	Separator pressure loss	MPA
	ADDDAT(#,2)	Separator percentage pressure loss	0.0->1.0
SIMPLE REHEATER	ADDDAT(#,1)	User specified terminal temperature difference	Deg C
	ADDDAT(#,2)	Actual terminal temperature difference	Deg C
	ADDDAT(#,3)	Cycle steam pressure loss	MPA
	ADDDAT(#,4)	Cycle steam percentage pressure loss	0.0->1.0
	ADDDAT(#,5)	Reheat steam pressure loss	MPA
	ADDDAT(#,6)	Reheat steam percentage pressure loss	0.0->1.0
	ADDDAT(#,7)	A '+1' indicates that the reheat steam is not a saturated liquid	-1,+1

The ADDDAT(100,30) array is located within the common block IO and, hence, is accessible to each of the four independent sections of RANKINE 3.0.

2.1.6 Organization of Information Related to a Specific Node

An example of information related to a specific node is an input file line such as THE FEED WATER INLET TEMPERATURE IS 175.4 DEG C. The information within this statements relates directly to a specific position on a device (or, more precisely, to a node

on a device).

fifteen arrays

number with

variable type.

Variable Name
TNODE(i)
PNODE(i)
VNODE(i)
HNODE(i)
SNODE(i)
QNODE(i)
LNODE(i)
MNODE(i)
ANODE(i)
WRNODE(i)
WRNODE(i)
IRNODE(i)
XNODE(i)
MBERR(i)
EBERR(i)

For example

14.3 kg/sec.

All fifteen ar

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DEG C befor

the program

has not yet

describe the

specified.

on a device). The organization of node specific information is accomplished with a set of fifteen arrays each dimensioned with 100 elements. The index refers to a specific node number within the system. Table 2-9 contains a summary of the fifteen arrays, their variable type, and definition.

Table 2-9. Storage of information related to nodes

Variable Name	Variable Type	Variable Definition	Units
TNODE(I)	Real	Temperature at node #I	Deg C
PNODE(I)	Real	Pressure at node #I	MPA
VNODE(I)	Real	Specific volume at node #I	m^3/kg
HNODE(I)	Real	Enthalpy at node #I	KJ/kg
SNODE(I)	Real	Entropy at node #I	KJ/kg/K
QNODE(I)	Real	Quality at node #I	-
LNODE(I)	Integer	Fluid phase index at node #I	-
MNODE(I)	Real	Mass flow rate at node #I	-
ANODE(I)	Real	Availability at node #I	KJ/kg
WKNODE(I)	Real	Actual work of device before node #I	KW
WRNODE(I)	Real	Reversible work of device before node #I	KW
IRNODE(I)	Real	Irreversibility of device before node #I	KW
XNODE(I)	Real	Heat transfer of device before node #I	KW
MBERR(I)	Real	Mass balance error of device before node #I	kg/sec
EBERR(I)	Real	Energy balance error of device before node #I	KW

For example, if an input file line indicated that the mass flow rate at node number 7 is 14.3 kg/sec, then MNODE(7) is internally set to 14.3.

All fifteen arrays summarized in Table 2-9 are located within the common block IO and, hence, are accessible to each of the four independent sections of RANKINE 3.0.

It should be noted that this organizational structure does inherently contain protocol. For example, if a input file stated THE FEED WATER INLET TEMPERATURE IS 175.4 DEG C before the input file stated THE FEED WATER INLET NODE NUMBER IS 7, the program will be unable to store the temperature information since the node number has not yet been specified. As a result of this protocol, the input files must always describe the node structure of each device before the conditions at each node are specified.

2.1.7 Subroutine

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2.2.6 Input File

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2.1.7 Subroutine ECHO

After the entire input file has been scanned for information, the input file is closed and subroutine ECHO is called. The purpose of subroutine ECHO is to create an external data file called ECHO.DAT which lists most of the information contained within the common blocks IO and DEAD. Since the common blocks IO and DEAD contain the only information which exits the input processing subroutines, inspection of the ECHO.DAT file clarifies any questions associated with the interpretation of an input file.

Subroutine ECHO is responsible for writing information to the ECHO.DAT file pertaining to the system and calling the model specific subroutines ECSTRB, ECSPMP, ECSPIP, ECSJCT, ECSCND, ECSHLD, ECSOFW, ECSBOL, ECSCFW, ECSSEP, and ECSREH. Each of these eleven subroutines are responsible for writing information to the ECHO.DAT file pertaining to a specific device type. Utilizing this type of organization facilitates the introduction of new thermodynamic models in the existing code structure.

2.2.0 Input File Checking

The primary purpose of the input file checking section is to verify that the information obtained from the input file is complete and consistent. Since RANKINE 3.0 requires the user to describe the system within the input file, the possibility of neglecting information or specifying a physically impossible system must be addressed. In order to address this concern, the program verifies that information obtained from the input file is complete and consistent. The input file checking can be separated into three classes; 1) required system information, 2) required device information, and 3) verification of consistent node connections.

2.2.1 Required System Information

The highest level subroutine within the input file checking section is RANKIC. This subroutine is responsible for verifying that all required system information is known and calling the device specific subroutines ICSTRB, ICSPMP, ICSPIP, ICSJCT, ICSCND, ICSHLD, ICSOFW, ICSBOL, ICSCFW, ICSSEP and ICSREH. Table 2-10 contains a summary of the system information checked within subroutine RANKIC.

Variable Requirements
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2.2.2 Required I

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Table 2-1

Model	
SIMPLE TURBINE	
SIMPLE PUMP	

Table 2-10. Required system information

Variable Requirements	Explanation	If not meet
TDEAD>0 and PDEAD>0 and HDEAD>0 and SDEAD>0 and	The Dead state must be fixed.	Diagnostic #161
NNODE>0	The number of nodes in the system must be specified.	Diagnostic #158
THRES>0	A high temperature reservoir must be specified.	Diagnostic #159
TLRES>0	A low temperature reservoir must be specified.	Diagnostic #160

2.2.2 Required Device Information

After RANKINE 3.0 has verified that all required system information is known, the program verifies that all required device information is known. For example, if a SIMPLE PIPE is specified, but the inlet pipe node number is unspecified, the program would identify the error and flag the user with a diagnostic message. The verification of the required device information is accomplished within the device specific subroutines ICSTRB, ICSPMP, ICSPIP, ICSJCT, ICSCND, ICSHLD, ICSOFW, ICSBOL, ICSCFW, ICSSEP and ICSREH. Table 2-11 contains a summary of the information each model specific input checking subroutines checks.

Table 2-11. Summary of device requirements checked by RANKINE 3.0

Model	Variable Requirement	Explanation	If not meet
SIMPLE TURBINE	DVCDAT(#,3)>0	A turbine must have inlet node number specified.	Diagnostic #100
	DVCDAT(#,4)>0	A turbine must have exit node number specified.	Diagnostic #101
	ADDDAT(#,I)>0 and ADDDAT(#,I)<1.0 or I=1..10	A turbine adiabatic efficiency must be between 0 and 1.0.	Diagnostic #106
SIMPLE PUMP	DVCDAT(#,3)>0	A pump must have a suction (inlet) node number specified.	Diagnostic #108
	DVCDAT(#,4)>0	A pump must have a discharge (exit) node number specified.	Diagnostic #109
	ADDDAT(#,1)>=0.0 and ADDDAT(#,1)=<1.0	A pump adiabatic efficiency must be between 0 and 1.0.	Diagnostic #110

Table 2-11. (Cont'd)

Model	Variable Requirement	Explanation	If not meet
SIMPLE PIPE	DVCDAT(#,3)>0	A pipe must have inlet node number specified.	Diagnostic #111
	DVCDAT(#,4)>0	A pipe must have exit node number specified.	Diagnostic #112
	ADDDAT(#,1)>=0 or ADDDAT(#,3)>=0	A pipe must have a specified pressure loss or specified percentage pressure loss.	Warning #130
	ADDDAT(#,3)=<1.0	A pipe percentage pressure loss must be less than 100%.	Diagnostic #115
	ADDDAT(#,2)>=0 or ADDDAT(#,4)>=0	A pipe must have a specified enthalpy loss or a specified percentage enthalpy loss.	Warning #131
	ADDDAT(#,4)=<1.0	A pipe percentage enthalpy loss must be less than 100%.	Diagnostic #116
SIMPLE JUNCTION	DVCDAT(#,3)>0	A junction must have at least one inlet node number specified.	Diagnostic #117
	DVCDAT(#,13)>0	A junction must have at least one exit node number specified.	Diagnostic #118
SIMPLE CONDENSER	DVCDAT(#,3)>0	A condenser must have an inlet node number specified.	Diagnostic #120
	DVCDAT(#,4)>0	A condenser must have at least one exit node number specified.	Diagnostic #119
SIMPLE HEAT LOAD	DVCDAT(#,3)>0	A heat load must have an inlet node number specified.	Diagnostic #121
	DVCDAT(#,4)>0	A heat load must have an exit node number specified.	Diagnostic #122
SIMPLE OFW HEATER	DVCDAT(#,3)>0	A open feed water heater must have a feed water exit node number specified.	Diagnostic #123
	DVCDAT(#,4)>0	A open feed water heater must have an extraction inlet node number specified.	Diagnostic #124
	DVCDAT(#,5)>0	A open feed water heater must have a feed water inlet node number specified.	Diagnostic #125
SIMPLE BOILER	DVCDAT(#,3)>0	A boiler must have an inlet node number specified.	Diagnostic #126
	DVCDAT(#,4)>0	A boiler must have an exit node number specified.	Diagnostic #127
	If DVCDAT(#,I)>0 then DVCDAT(#,I+1)>0 for I=5,23,2	Each boiler reheat leg must have an exit node number specified.	Diagnostic #128

Table 2-11. (Cont'd)

Model	Variable Requirement	Explanation	If not meet
SIMPLE BOILER (Cont'd)	If DVCDAT(#,I+1)>0 then DVCDAT(#,I)>0 for I=5,23,2	Each boiler reheat leg must have an inlet node number specified.	Diagnostic #129
	ADDDAT(#,1)>=0 or ADDDAT(#,12)>=0	A boiler pressure drop or percentage pressure drop must be specified.	Diagnostic #130
	ADDDAT(#,I)>=0 or ADDDAT(#,I+11)>=0 for I=6,24,2	Each boiler reheat leg must specify a pressure drop or a percentage pressure drop.	Diagnostic #131
SIMPLE STEAM TRAP CFW	DVCDAT(#,3)>0	A closed feed water heater must have a feed water inlet node number specified.	Diagnostic #132
	DVCDAT(#,4)>0	A closed feed water heater must have a feed water exit node number specified.	Diagnostic #133
	DVCDAT(#,5)>0	A closed feed water heater must have an extraction inlet node number specified.	Diagnostic #134
	DVCDAT(#,16)>0	A closed feed water heater must have a drain exit node number specified.	Diagnostic #135
	ADDDAT(#,1)>=0 or ADDDAT(#,2)>=0	A closed feed water heater must have a pressure drop or percentage pressure drop specified.	Diagnostic #162
	ADDDAT(#,3)>=0 and ADDDAT(#,4)>=0	A closed feed water heater must have an extraction pressure drop or percentage pressure drop specified.	Diagnostic #163
	ADDDAT(#,5)>=0	A closed feed water heater must have a terminal temperature difference specified.	Warning #132
	ADDDAT(#,6)>=0	A closed feed water heater must have an approach temperature difference specified.	Warning #133
SIMPLE MOISTURE SEPARATOR	DVCDAT(#,3)>0	A moisture separator inlet node number must be specified.	Diagnostic #146
	DVCDAT(#,4)>0	A moisture separator vapor exit node number must be specified.	Diagnostic #147
	DVCDAT(#,5)>0	A moisture separator condensate node number must be specified.	Diagnostic #148
	ADDDAT(#,1)>=0 or ADDDAT(#,2)>=0	A moisture separator pressure drop or percentage pressure drop must be specified.	Diagnostic #149
SIMPLE REHEATER	DVCDAT(#,3)>0	A reheater must have a cycle steam inlet node number specified.	Diagnostic #150
	DVCDAT(#,4)>0	A reheater must have a cycle steam exit node number specified.	Diagnostic #151
	DVCDAT(#,5)>0	A reheater must have a reheat steam inlet node number specified.	Diagnostic #152

Model
SIMPLE REHEATER (Cont'd)

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Table 2-11. (Cont'd)

Model	Variable Requirement	Explanation	If not meet
SIMPLE REHEATER (Cont'd)	DVCDAT(#,6)>0	A reheater must have a reheat steam exit node number specified.	Diagnostic #153
	DVCDAT(#,7)>0	A junction device number which controls the flow fraction through the reheater must be specified.	Diagnostic #154
	ADDDAT(#,1)>=0	A reheater terminal temperature difference must be specified.	Diagnostic #155
	ADDDAT(#,3)>=0 or ADDDAT(#,4)>=0	A reheater cycle steam pressure drop or percentage pressure drop must be specified.	Diagnostic #156
	ADDDAT(#,5)>=0 or ADDDAT(#,6)>=0	A reheater reheat steam pressure drop or percentage pressure drop must be specified.	Diagnostic #157

2.2.3 Verification of Consistent Node Connections

Since RANKINE 3.0 requires the user to describe the system layout within the input file, the possibility of specifying a physically impossible system must be addressed. For example, if an input file stated that a node number is an exit node on one device, it is physically impossible to specify the same node number to be an exit node on a second device. Since all RANKINE 3.0 mass flow rates are positive scalars, the thermodynamic analysis section of RANKINE 3.0 is unaware of whether the mass flow rates are entering or exiting a device, and hence, the possibility of connecting an exit node on one device to an exit node on a second device is significant. In order to avoid a physically impossible system, RANKINE 3.0 systematically searches the system for inconsistencies and flags the user if an inconsistency is identified.

Inconsistent node connections can be separated into three classes; 1) a node is not connected to any other device, 2) a node is connected to two or more device positions, and 3) a node is connected to another device position of the same type (inlet to inlet or exit to exit). RANKINE 3.0 systematically searches for each of these inconsistencies within the model specific subroutines ICSTRB, ICSPMP, ICSPIP, ICSJCT, ICSCND, ICSHLD, ICSOFW, ICSBOL, ICSCFW, ICSSEP, and ICSREH. Each of these device specific subroutines contain hardwired code logic that identifies inconsistencies related to one specific device type. The basic code logic for the systematic search for all three types of inconsistencies can be seen in Figure 2-4.

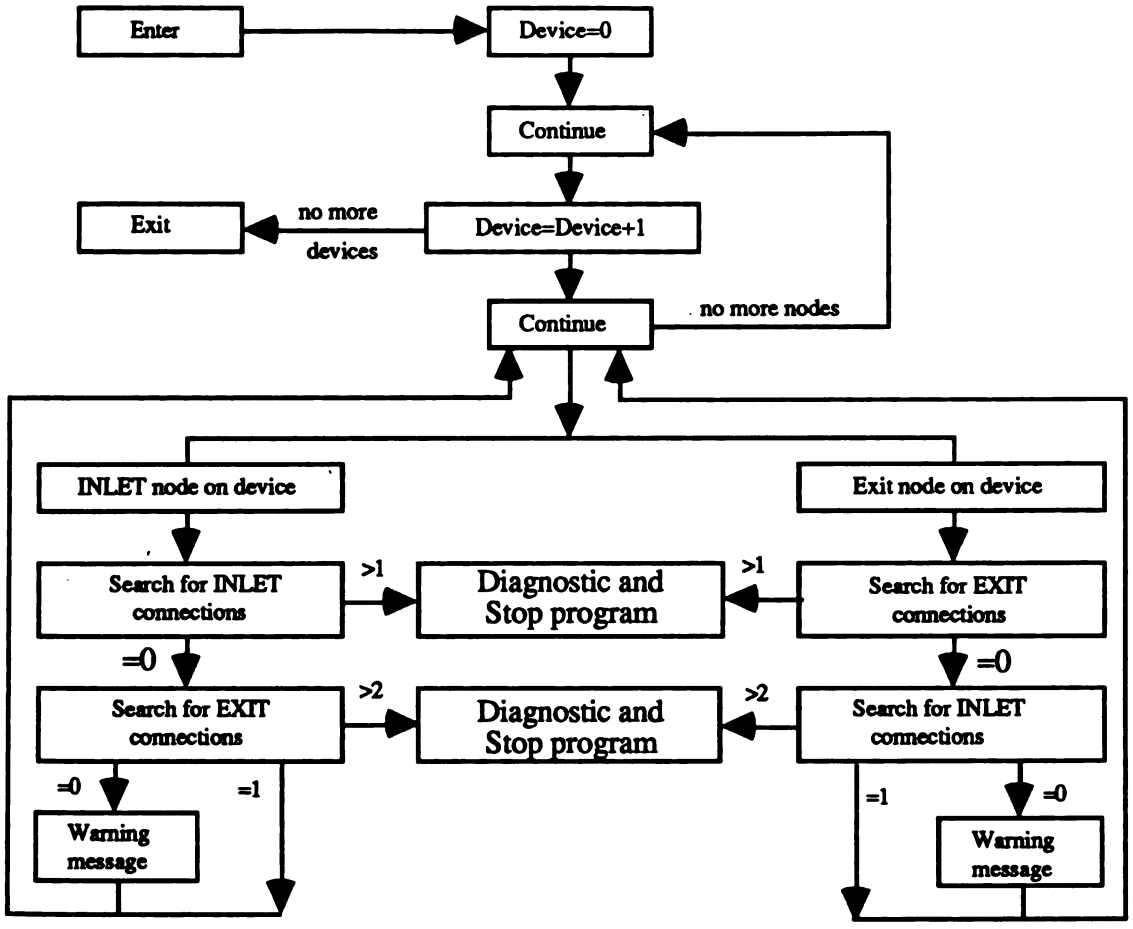


Figure 2-4. Basic structure of node checking logic

The search for inlet or exit nodes located on other devices is accomplished by the utility subroutine FNDNOD. Within the utility subroutine FNDNOD, sets of hardwired code logic systematically searches all inlet or exit node position on other devices for a specific node number. The output of subroutine FNDNOD is an integer which represents the number of times a specific node number was found as an inlet or exit on other devices. By calling subroutine FNDNOD when required, each input checking subroutine can systematically search for inconsistencies within the system.

It should be noted that an inconsistency does not always result in a diagnostic message (and, therefore, a program termination). In the event that a node is not connected to any other position within the system, the program only provides a warning message to the user. Since it is physically possible for a system to provide or receive fluid from an unmodeled location, RANKINE 3.0 will only notify the user of an unconnected node

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within the system. The existence of unconnected nodes within the system will, however, be reflected in the system mass and energy balance performed by the subroutine MEBAL in the output processing section.

2.3.0 Thermodynamic Analysis

The purpose of the thermodynamic analysis section is to calculate all unknown thermodynamic information within the system. The procedure employed to calculate the unknown thermodynamic information is very similar to the procedure for system analysis discussed in Section 1.1.0 Since all input file information has been organized within the input processing subroutines, RANKINE 3.0 systematically traverses the system, device by device, calculating all unknown thermodynamic information possible based on the physical characteristics of each device. For a well posed system, traversing the system a few times is sufficient to calculate all unknown thermodynamic device information. After all unknown thermodynamic device information has been calculated, the system performance parameters may be calculated utilizing the results of the device by device analysis.

In order for RANKINE 3.0 to successfully employ the procedure for cycle analysis, three sets of code logic were developed. First, code logic to traverse the cycle, and if necessary, iterate. Second, code logic to determine when a sufficient amount of information exists to calculate unknown information, and finally, code logic to perform internal checks based upon the thermodynamic and physical constraints associated with each device.

2.3.1 Traversing the System

Subroutine RANKAI represents the highest level subroutine within the thermodynamic analysis section and is responsible for traversing the system, and when necessary, iterating. When RANKAI traverses the system, the subroutines AISTRB, AISPMP, AISPIP, AISJCT, AISCND, AISHLD, AISBOL, AISOFW, AISCFW, AISSEP and AISREH are called to determine when sufficient information exists to calculate unknown thermodynamic information. Each of these device specific AI (artificial intelligence) subroutines contain sets of hardwired logic that reflects the conditions for which unknown thermodynamic information may be calculated. In the event that sufficient information exists for the calculation of some unknown thermodynamic information, the AI subroutine calls the appropriate device specific thermodynamic subroutine to calculate

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the unknown information. Figure 2-5 illustrates the basic code logic for the subroutine RANKAI.

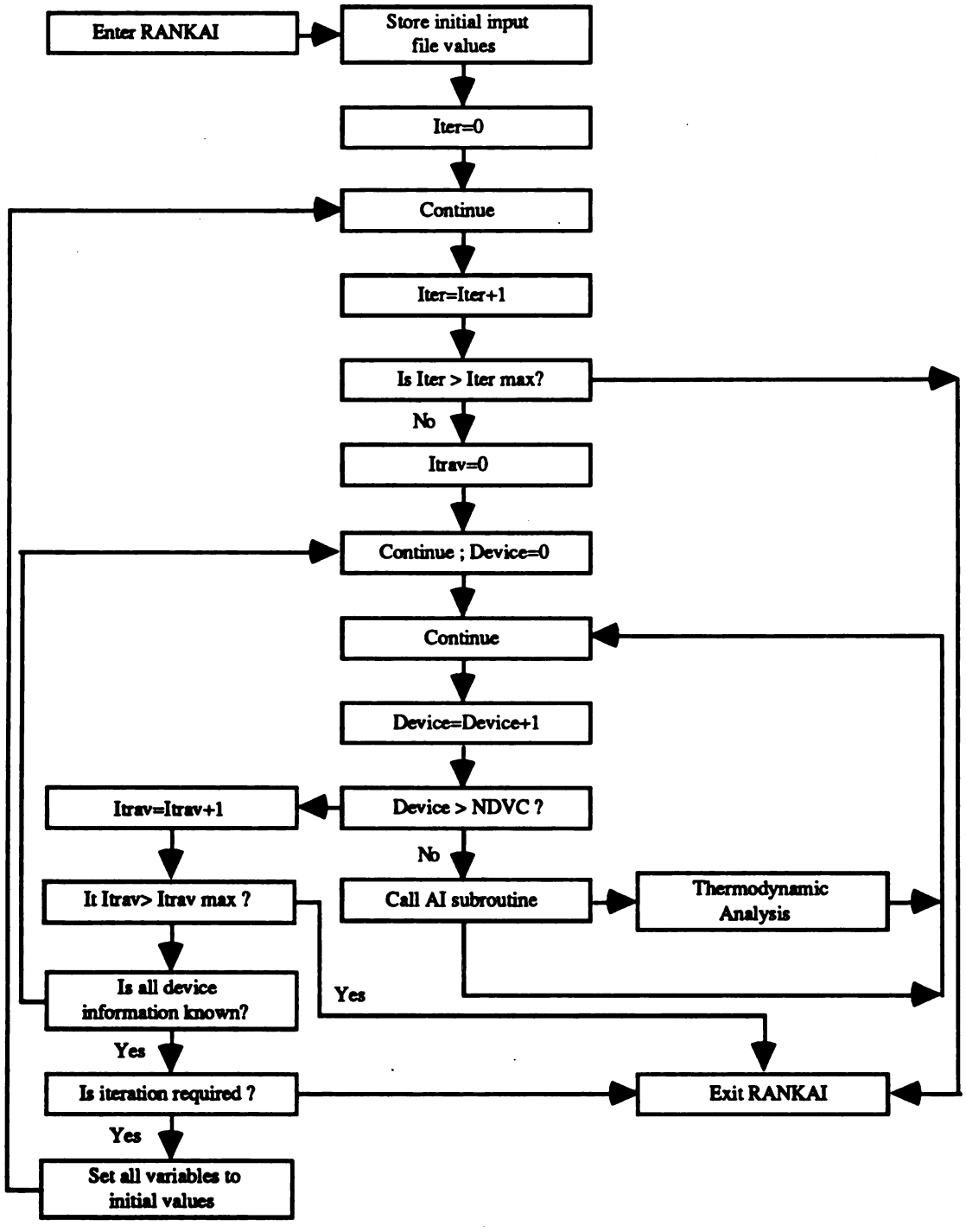


Figure 2-5. Basic structure of subroutine RANKAI

In addition to traversing the system, subroutine RANKAI is responsible for iteration. As a result of the thermodynamic modeling methods used, only systems which possess a simple reheater device will require iteration. Before RANKAI traverses the system for the first time, the input file information is stored within a set of initial value arrays. For any system which contains a simple reheater device, subroutine RANKAI compares the calculated terminal temperature difference to the input file specified terminal temperature difference after each iteration. If this comparison exceeds 0.1 degree Centigrade, RANKINE 3.0 sets all variables to their initial values, modifies the appropriate junction flow split fraction, and perform the device by device thermodynamic analysis again. RANKINE 3.0 will stop iterating when the prescribe tolerance is achieved or the code iterates 100 times.

2.3.2 AI Subroutines

The subroutines AISTRB, AISPMP, AISPIP, AISJCT, AISCND, AISBOL, AISHLD, AISOFW, AISCFW, AISSEP, and AISREH are called from subroutine RANKAI and are responsible for determining when sufficient information exists to calculate unknown thermodynamic information. In order to simplify the code, each model specific AI subroutine maps the global node variables into local variables. The advantage of mapping global node variables into local variables can be best illustrated with an example. In order to specify the mass flow rate for a turbine inlet using global node variables, the appropriate expression is MNODE(DVCDAT(#,3)). Using a mapped local variable, the identical expression would be MTRIN. Clearly, the mapped local variable enhances clarity and reduces possible confusion. Within all AI subroutines, a set of local variable nomenclature was employed to simplify the code. Table 2-12 contains a summary of the local variable nomenclature.

Table 2-12. Summary of local variable nomenclature

Abbreviation	Representation	Abbreviation	Representation
A	Availability	DR	Drain
APPRCH	Approach	EF	Efficiency
ACT	Actual	EX	Exit
BR,BOL	Boiler	EXT	Extraction
CD	Condenser	F	Flow fraction
CYL	Cycle steam	FW	Feed water

Table 2-12. (Cont'd)

Abbreviation	Representation	Abbreviation	Representation
OFW	Open feed water heater	PQL	Percentage enthalpy loss
P	Pressure	Q	Quality
PIP	Pipe	QL	Enthalpy loss
PL	Pressure loss	RH	Reheat
PMP	Pump	RHS	Reheater steam
PPL	Percentage pressure loss	S	Entropy
H	Enthalpy	S,SEP	Separator
HLD	Heat load	ST	Stage group
I,IN	Inlet	T	Temperature
IR	Irreversibility	TD	Terminal temperature difference
JCT	Junction	TR	Turbine
L	Fluid phase index	V	Specific volume
M	Mass flow rate	WK	Actual Work
N	Number	WR	Reversible Work
O	Output	X	Heat transfer

Communication between the model specific AI subroutine and the corresponding device specific thermodynamic subroutines is based upon the numerical value of two integers; ICALL and IFIND. The variable ICALL is an integer flag used to specify which of the four fundamental calculations should be performed; 1) calculate a thermodynamic states on a per-unit mass basis (ICALL=1), 2) calculate a mass flow rates (ICALL=2), 3) perform a 2nd law analysis (ICALL=3), and 4) verify model results (ICALL=4). The variable IFIND is an integer flag used to specify the exact calculation which should be performed. The definition of each IFIND is dependent on the type of device (i.e., simple turbine, simple pump, ect.). Table 2-13 contains a summary of the ICALL and IFIND options for each thermodynamic model.

Table 2-13. Summary of ICALLs and IFINDs

Model	ICALL	IFIND	Required information	Calculates
SIMPLE TURBINE	1	1	1) Inlet condition fixed or is fixable. 2) All extraction pressures known. 3) All stage group efficiencies known	1) Fix all states on turbine
	2	1	1) Completed ICALL=1 2) All but one mass flow rate is unknown	1) Unknown mass flow rate 2) Work and heat transfer
	3	1	1) Completed ICALL=2	1) Performs 2nd law analysis
	4	1	1) Completed ICALL=3	2) Verifies of model results

Model	iC
SIMPLE PUMP	
SIMPLE PIPE	

Table 2-13. Summary of ICALLs and IFINDs

Model	ICALL	IFIND	Required information	Calculates
SIMPLE PUMP	1	1	1) Suction (inlet) condition is fixed or is fixable 2) Discharge (exit) pressure is known 3) Efficiency is known	1) Discharge (exit) state
	1	2	1) Discharge (exit) condition is fixed or is fixable 2) Suction (inlet) pressure known 3) Efficiency is known	1) Suction (inlet) state
	2	1	1) One of two mass flow rates are known	1) The one unknown mass flow rate
	2	2	1) Completed ICALL=1 2) Both mass flow rates are known	1) Work and Heat transfer
	3	1	1) Completed ICALL=2	1) Perform 2nd law analysis
	4	1	1) Completed ICALL=3	2) Verification of model results
SIMPLE PIPE	1	1	1) Pipe inlet pressure is known. 2) Pipe exit pressure is unknown. 3) Pipe pressure drop or pipe percentage pressure drop is known.	1) Fix pipe exit pressure
	1	2	1) Pipe exit pressure is known. 2) Pipe inlet pressure is unknown. 3) Pipe pressure drop or pipe percentage pressure drop is known.	1) Fix pipe inlet pressure
	1	3	1) Pipe inlet enthalpy is known. 2) Pipe exit enthalpy is unknown. 3) Pipe enthalpy drop or pipe percentage enthalpy drop is known.	1) Fix pipe exit enthalpy
	1	4	1) Pipe exit enthalpy is known. 2) Pipe inlet enthalpy is unknown. 3) Pipe enthalpy drop or pipe percentage enthalpy drop is known.	1) Fix pipe inlet enthalpy
	1	5	1) Either inlet or exit state is unfixed.	1) Try to fix either unfixed state.
	2	1	1) One mass flow rate is known. 2) One mass flow rate is unknown.	1) The one unknown mass flow rate
	2	2	1) Completed ICALL=1 2) Both mass flow rates are known	1) Work and heat transfer
	3	1	1) Completed ICALL=2	1) Perform 2nd law analysis
	4	1	1) Completed ICALL=3	1) Verification of model results

Model | IC

SIMPLE JUNCTION

SIMPLE CONDENSER

SIMPLE HEAT LOAD

Table 2-13. (cont'd)

Model	ICALL	IFIND	Required information	Calculates
SIMPLE JUNCTION	1	1	1) At least one inlet or exit state known 2) At least one inlet or exit state unknown	1) All unknown states
	2	1	1) All but one mass flow rate unknown	1) The one unknown mass flow rate
	2	2	1) All but one inlet flow fraction is known	1) The one unknown inlet flow fraction
	2	3	1) All but one exit flow fraction is known	1) The one unknown exit flow fraction
	2	4	1) At least one inlet mass flow rate known 2) All inlet flow fractions are known	1) All inlet mass flow rates
	2	5	1) At least one exit mass flow rate known 2) All exit flow fractions are known	1) All exit mass flow rates
	2	6	1) All inlet mass flow rates are known 2) All exit flow fractions are known	1) All exit mass flow rates
	2	7	1) All exit mass flow rates are known 2) All inlet flow fractions are known	1) All inlet mass flow rates
	2	8	1) Completed ICALL=1 2) All mass flow rates known	1) Work and heat transfer
	3	1	1) Completed ICALL=2	1) Perform 2nd law analysis
	4	1	1) Completed ICALL=3	1) Verification of model results
SIMPLE CONDENSER	1	1	1) At least one condenser pressure known 2) At least one condenser pressure unknown	1) All unknown pressures
	1	2	1) At least one condenser state is unfixed	1) Try to fix all unknown states
	2	1	1) Only one condenser mass flow rate is unknown	1) The one unknown mass flow rate
	2	2	1) All condenser states are known 2) All condenser mass flow rates are known	1) Work and heat transfer
	3	1	1) Completed ICALL=2	1) Perform 2nd law analysis
	4	1	1) Completed ICALL=3	1) Verification of model results
SIMPLE HEAT LOAD	1	1	1) Both inlet state and exit state are fixed or are fixable	1) Fix either state
	2	1	1) One mass flow rate is known 2) One mass flow rate is unknown	1) The one unknown mass flow rate
	2	2	1) Inlet and exit state fixed 2) Both mass flow rates are known	1) Work and heat transfer

Model

SIMPLE
HEAT
LOAD
Cont

SIMPLE
OFW
HEATER

SIMPLE
BOILER

SIMPLE
STEAM
TRAP
OFW

Table 2-13. (cont'd)

Model	ICALL	IFIND	Required information	Calculates
SIMPLE HEAT LOAD (Cont'd)	3	1	1) Completed ICALL=2	1) Perform 2nd law analysis
	4	1	1) Completed ICALL=3	1) Verification of model results
SIMPLE OFW HEATER	1	1	1) At least one pressure is known 2) At least one pressure is unknown	1) All unknown pressures
	1	2	1) Feed water inlet and extraction inlet states are fixed or are fixable	1) Feed water inlet and/or extraction inlet state
	1	3	1) Feed water exit temperature or pressure is known 2) Feed water exit state is unknown 3) Feed water exit state is saturated	1) The unknown feed water exit saturation temperature or pressure
	1	4	1) Feed water exit state is fixable.	1) The feed water exit state
	2	1	1) All OFW enthalpies are known 2) One mass flow rate is known 3) Two mass flow rates are unknown	1) The two unknown mass flow rates
	2	2	1) Two mass flow rates are known 2) One mass flow rate is unknown	1) The one unknown mass flow rate
	2	3	1) Two enthalpies are known. One enthalpy is unknown. 2) All mass flow rates are known.	1) The one unknown enthalpy
	2	4	1) All states are fixed 2) All mass flow rates are known	1) Work and heat transfer
	3	1	1) Completed ICALL=2	1) Perform 2nd law analysis
	4	1	1) Completed ICALL=3	1) Verification of model results
SIMPLE BOILER	1	1	1) Any unknown inlet or exit pressure on boiler	1) Try to find all unknown pressures
	1	2	1) Any unfixed states on boiler	1) Try to fix all unfixed states
	2	1	1) Any unknown mass flow rates on boiler	1) Try to find all unknown mass flow rates
	2	2	1) All states fixed on boiler 2) All mass flow rates are known on boiler	1) Work and heat transfer
	3	1	1) Completed ICALL=2	1) Perform 2nd law analysis
	4	1	1) Completed ICALL=3	1) Verification of model results
SIMPLE STEAM TRAP CFW	1	1	1) Not completed ICALL=1	1) Try to fix all unfixed states
	1	2	1) One feed water pressure is known and one is unknown 2) Pressure drop or percentage pressure drop is known	1) The one unknown feed water pressure

Model	IC
SIMPLE STEAM TRAP CFW (Cont'd)	
SIMPLE SEPARATOR	

Table 2-13. (cont'd)

Model	ICALL	IFIND	Required information	Calculates
SIMPLE STEAM TRAP CFW (Cont'd)	1	3	1) One shell side pressure is known and one is unknown 2) Extraction pressure loss or extraction percentage pressure loss	1) All unknown shell side pressures
	1	4	1) Terminal temperature difference is known 2) Either extraction inlet pressure or feed water exit temperature is known	1) Either extraction inlet pressure or feed water exit temperature
	1	5	1) Approach temperature difference is known 2) Either feed water inlet temperature or drain exit temperature is known	1) Either feed water inlet temperature or drain exit temperature
	2	1	1) One Feed water mass flow rate is known 2) One Feed water mass flow rate is unknown	1) The one unknown feed water mass flow rate
	2	2	1) One unknown shell side mass flow rate	1) The one unknown shell side mass flow rate
	2	3	1) All feed water and shell side enthalpies 2) Both feed water mass flow rates 3) All but one inlet shell side inlet mass flow rates 4) Exit shell side mass flow rate is unknown	1) The one unknown shell side inlet mass flow rate
	2	4	1) All states fixed 2) All mass flow rates known	1) Work and heat transfer
	3	1	1) Completed ICALL=2	1) Perform 2nd law analysis
	4	1	1) Completed ICALL=3	1) Verification of model results
SIMPLE SEPARATOR	1	1	1) Separator inlet state is unknown	1) Try to fix inlet state
	1	2	1) Separator inlet state and mass flow rate are known 2) Pressure loss or percentage pressure loss is known	1) Separator vapor exit and condensate exit states and mass flow rates
	2	1	1) Completed ICALL=1	1) Work and heat transfer
	3	1	1) Completed ICALL=2	1) Perform 2nd law analysis
	4	1	1) Completed ICALL=3	1) Verification of model results

Model	
SIMPLE REHEATER	

2.3.3 Verific

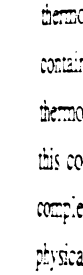
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Table 2-13. (cont'd)

Model	ICALL	IFIND	Required information	Calculates
SIMPLE REHEATER	1	1	1) Any reheater states unfixed	1) Try to fix all states
	1	2	1) Either cycle steam inlet or cycle steam exit pressure is known 2) Either cycle steam inlet or cycle steam exit pressure is unknown 3) Cycle steam pressure drop or cycle steam percentage pressure drop is known	1) The unknown cycle steam pressure
	1	3	1) Either reheat steam inlet or reheat steam exit pressure is known 2) Either reheat steam inlet or reheat steam exit pressure is unknown 3) Either the reheat steam pressure drop or reheat steam percentage pressure drop is known	1) The unknown reheat steam pressure
	1	4	1) All enthalpies except cycle steam exit are known 2) All mass flow rates known 3) Cycle steam exit mass flow rate is positive	1) Cycle steam exit enthalpy
	1	5	1) All enthalpies except reheat steam exit are known 2) All mass flow rates known 3) Reheat steam exit mass flow rate is positive	1) Reheat steam exit enthalpy
	2	1	1) Either cycle steam inlet or cycle steam exit mass flow rate is known 2) Either cycle steam inlet or cycle steam exit mass flow rate is unknown	1) The one unknown cycle steam mass flow rate
	2	2	1) Either reheat steam inlet or exit mass flow rate is known 2) Either reheat steam inlet or exit mass flow rate is unknown	1) The one unknown reheat steam mass flow rate
	2	3	1) All states fixed 2) All mass flow rates are known	1) Work and heat transfer 2) Actual terminal temperature difference.
	3	1	1) Completed ICALL=2	1) Perform 2nd law analysis
	4	1	1) Completed ICALL=3	1) Verification of model results

2.3.3 Verification of Model Results

In order to insure that all RANKINE 3.0 results are thermodynamically and physically possible, each model specific thermodynamic subroutine compares its results against a set of thermodynamic and physical constraints. For example, if an analysis of a turbine resulted in a large negative irreversibility, a warning message would flag the user of a



thermodynamically impossible result. Each model specific thermodynamic subroutine contains a set of hardwired code logic which compares the results of its analysis to the thermodynamic and physical constraints associated with the specific device type. Since this comparison is performed in ICALL=4, it is performed after all calculations are complete. Table 2-14 contains a summary of the model specific thermodynamic and physical constraints verified by the program.

Table 2-14. Model specific constraints checked by RANKINE 3.0.

Model	Variable Requirement	Explanation	If not meet
SIMPLE TURBINE	MTRIN >= 0.0	A turbine inlet must have a positive mass flow rate.	Diagnostic #202
	MTRST(I) >= 0.0 for I=1,NTRST	All turbine stages group must have a positive mass flow rates.	Diagnostic #204
	PTRIN >= PTREX(1)	A turbine must have monotonically decreasing extraction pressures.	Diagnostic #207
	HTRIN >= HTREX(1)	A turbine must have monotonically decreasing extraction enthalpies.	Diagnostic #205
	PTREX(I-1) >= PTREX(I) for I=2,NTRST	A turbine must have monotonically decreasing extraction enthalpies.	Diagnostic #208
	HTREX(I-1) >= HTREX(I) for I=2,NTRST	A turbine must have monotonically decreasing extraction enthalpies.	Diagnostic #206
	IRTREX(I) >= -0.01 for I=1,NTRST	A turbine stage group must have a positive irreversibility.	Warning #200
	STREX(1)-STRIN >= -0.01	A turbine must have equal or increasing extraction entropy.	Warning #201
	STREX(I)-STREX(I+1) >= -0.01 for I=2,NTRST	A turbine must have equal or increasing extraction entropy.	Warning #202
SIMPLE PUMP	MPMPO >= 0.0	A pump exit must have a positive mass flow rate.	Diagnostic #212
	MPMPI >= 0.0	A pump inlet must have a positive mass flow rate.	Diagnostic #213
	HPMPO >= HPMPI	A pump must maintain or increase the enthalpy of the fluid.	Diagnostic #210
	PPMPO >= PPMPI	A pump must maintain or increase the pressure of the fluid.	Diagnostic #211
	SPMPO-SPMPI >= -0.01	A pump must increase the entropy of the fluid.	Warning #203
	IRPMPO >= -0.01	A pump must have a positive irreversibility.	Warning #204

Model
SIMPLE PIPE
SIMPLE JUNCTION
SIMPLE CONDENSER

Table 2-14. (cont'd)

Model	Variable Requirement	Explanation	If not meet
SIMPLE PIPE	MPIPO >= 0.0	A pipe exit must have a positive mass flow rate.	Diagnostic #216
	MPIPI >= 0.0	A pipe inlet must have a positive mass flow rate.	Diagnostic #215
	ABS(PPIPI-PPIPO-PLPIP) =< 0.01 for PLPIP >= 0.0	A pipe pressure drop must be correctly applied.	Diagnostic #217
	ABS((1-PPLPIP)* PPIPI-PPIPO) =< 0.01 for PPLPIP >= 0.0	A pipe percentage pressure drop must be correctly applied.	Diagnostic #219
	ABS(HPIPI-HPIPO-QLPIP) =< 0.01 for QLPIP >= 0.0	A pipe enthalpy drop must be correctly applied.	Diagnostic #218
	ABS((1-PQLPIP)* HPIPI-HPIPO) =< 0.01 for PQLPIP >= 0.0	A pipe percentage enthalpy drop must be correctly applied.	Diagnostic #220
	ABS(SPIPI-SPIPO) =< 0.01 for (QLPIP=0.0 or PQLPIP=0.0) and (PLPIP=0.0 or PPLPIP=0.0)	A pipe with zero heat transfer and zero pressure loss must not have an entropy increase.	Warning #205
	IRPIPO >= -0.01	A pipe irreversibility must be positive.	Warning #206
SIMPLE JUNCTION	MJCTI(I) >= 0.0 for I=1,NJCTI	All junction inlets must have a positive mass flow rate.	Diagnostic #221
	MJCTO(I) >= 0.0 for I=1,NJCTO	All junction exits must have a positive mass flow rate.	Diagnostic #222
		All inlet state must be identical to all other inlet states.	Diagnostic #223
		All exit state must be identical to all other exit states.	Diagnostic #224
		All inlet state must be identical to all other exit states.	Diagnostic #225
SIMPLE CONDENSER	MCDO >= 0.0	A condenser exit must have a positive mass flow rate.	Diagnostic #228
	MCDI(I) >= 0.0 for I=1, NCDIN	All condenser inlets must have a positive mass flow rate.	Diagnostic #229
	ABS(PCDI(I)-PCDO) =< 0.01 for I=1,NCDIN	All condenser inlets must have the same pressure as the condenser exit.	Diagnostic #230
	XCDO =< 0.0	A condenser must reject heat.	Warning #207
	IRCDO >= -0.01	A condenser irreversibility must be positive.	Warning #208

Model

SIMPLE HEAT LOAD

SIMPLE OFW HEATER

SIMPLE BOILER

Table 2-14. (cont'd)

Model	Variable Requirement	Explanation	If not meet
SIMPLE HEAT LOAD	MHLDO >= 0.0	A heat load exit mass flow rate must be positive.	Diagnostic #233
	MHLDI >= 0.0	A heat load inlet mass flow rate must be positive.	Diagnostic #234
	IRHLDO >= -0.01	A heat load irreversibility must be positive.	Warning #209
SIMPLE OFW HEATER	MOFWF >= 0.0 MOFWI >= 0.0 MOFWO >= 0.0	The feed water inlet, extraction inlet, and feed water exit mass flow rates must be positive.	Diagnostic #236, #241 or #241
	HOFWF >= 0.0 HOFWI >= 0.0 HOFWO >= 0.0	The feed water inlet, extraction inlet, and feed water exit enthalpies must be positive.	Diagnostic #235
	ABS(POFWF-POFWI) =< 0.01	An OFW heater is a constant pressure device.	Diagnostic #244
	ABS(POFWP-POFWO) =< 0.01	An OFW heater is a constant pressure device.	Diagnostic #244
	IROFWO >= -0.01	An OFW heater irreversibility must be positive.	Warning #210
SIMPLE BOILER	MBRI >= 0.0	A boiler inlet must have a positive mass flow rate.	Diagnostic #245
	MBRO >= 0.0	A boiler exit must have a positive mass flow rate.	Diagnostic #246
	ABS(PBRO+PLBOL-PBRI) =< 0.01 for PLBOL >= 0.0	A boiler pressure drop must be correctly applied.	Diagnostic #247
	ABS(PBRO-(1-PPLBOL)*PBRI) =< 0.01 for PPLBOL >= 0.0	A boiler percentage pressure drop must be correctly applied.	Diagnostic #251
	MRHI(I) >= 0.0 for I=1,NBRRH	A boiler reheat leg inlet must have a positive mass flow rate.	Diagnostic #248
	MRHO(I) >= 0.0 for (=1,NBRRH	A boiler reheat leg exit must have a positive mass flow rate.	Diagnostic #249
	ABS(PRHI(I)-PLRH(I)-PRHO(I)) =< 0.01 for I=1,NBRRH for PLRH(I) >= 0.0	A boiler reheat leg pressure drop must be correctly applied.	Diagnostic #250
	ABS(PRHO-PRHI(I)*(1-PPLRH(I)) =< 0.01 for I=1,NBRRH for PPLRH(I) >=0.0	A boiler reheat leg percentage pressure drop must be correctly applied.	Diagnostic #252
	IRBRO >= -0.01	A boiler irreversibility must be positive	Warning #211
	IRRHO(I) >= -0.01 for I=1,NBRRH	A boiler reheat leg irreversibility must be positive.	Warning #212

Model

SIMPLE CFW HEATER

SIMPLE SEPARATOR

Table 2-14. (cont'd)

Model	Variable Requirement	Explanation	If not meet
SIMPLE CFW HEATER	MEXTI >= 0.0	A CFW heater extraction inlet mass flow rate must be positive.	Diagnostic #253
	MDRO >= 0.0	A CFW heater drain exit mass flow rate must be positive.	Diagnostic #254
	MFWI >= 0.0	A CFW heater feed water inlet mass flow rate must be positive.	Diagnostic #255
	MFWO >= 0.0	A CFW heater feed water exit mass flow rate must be positive.	Diagnostic #256
	MDRI(I) >= 0.0 FOR I=1,NDRI	All CFW heater drain inlet mass flow rates must be positive.	Diagnostic #257
	ABS(PFWI-PLFW-PFWO) =< 0.01 for PLFW >= 0.0	A CFW heater feed water pressure drop must be correctly applied.	Diagnostic #258
	ABS(PFWI* (1-PPLFW)-PFWO) =< 0.01 for PPLFW >= 0.0	A CFW heater feed water percentage pressure drop must be correctly applied.	Diagnostic #259
	ABS(PEXTI-PLEXT-PDRO) =< 0.01 for PLEXT >= 0.0	A CFW heater extraction pressure drop must be correctly applied.	Diagnostic #261
	ABS(PEXTI* (1-PPLEXT)-PDRO) =< 0.01 for PPLEXT >= 0.0	A CFW heater extraction percentage pressure drop must be correctly applied.	Diagnostic #169
	ABS(PDRI(I)-PEXTI) =< 0.01 for I=1,NDRI for PPLEXT >= 0.0	All CFW heater extraction inlets must have identical pressures.	Warning #213
	IRFWO >= -0.01	A CFW heater tube side irreversibility must be positive.	Warning #214
	IRDRO >= -0.01	A CFW heater shell side irreversibility must be positive.	Warning #215
SIMPLE SEPARATOR	TSEPO >= TSAT(@PSEPO)	A separator vapor exit temperature must be equal to or greater than the saturation temperature.	Diagnostic #262
	TSDRO =< TSAT(@PSDRO)	A separator condensate exit temperature must be equal to or less than the saturation temperature.	Diagnostic #263
	MSEPI >= 0.0 MSEPO >= 0.0 MSDRO >= 0.0	All separator mass flow rates must be positive.	Diagnostic #264
	ABS(PSEPI-PSEPO-PLSEP) =< 0.01 for PLSEP >= 0.0	A separator pressure loss must be correctly applied.	Diagnostic #265
	ABS(PSEPI* (1-PPLSEP)-PSEPO) =< 0.01 for PPLSEP >= 0.0	A separator percentage pressure loss must be correctly applied.	Diagnostic #265
	IRSEPO >= -0.01	A separator irreversibility must be positive.	Warning #221

Model
SIMPLE REHEATER

3.4 Subro

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Table 2-14. (cont'd)

Model	Variable Requirement	Explanation	If not meet
SIMPLE REHEATER	MCYLI >= 0.0 MCYLO >= 0.0 MRHSI >= 0.0 MRHSO >= 0.0	A reheater mass flow rates must be positive.	Diagnostic #266
	ABS(PCYLI-PCYLO-PLCYL) =< 0.01 for PLCYL >= 0.0	A cycle steam pressure drop must be correctly applied.	Diagnostic #267
	ABS((1-PPLCYL)* PCYLI-PCYLO) =< 0.01 for PPLCYL >= 0.0	A cycle steam percentage pressure drop must be correctly applied.	Diagnostic #267
	ABS(PRHSI-PRHSO-PLRHS) =< 0.01 for PLRHS >= 0.0	A reheat steam pressure drop must be correctly applied.	Diagnostic #268
	ABS((1-PPLRHS)* PRHSI-PCYLO) =< 0.01 for PPLRHS >= 0.0	A reheat steam percentage pressure drop must be correctly applied.	Diagnostic #268
	IRCYLO >= -0.01	A cycle steam irreversibility must be positive.	Warning #222
	IRRHSO >= -0.01	A reheat steam irreversibility must be positive.	Warning #223

2.3.4 Subroutine FIXSTA and the Computerized Steam Tables.

Subroutine FIXSTA is called throughout the thermodynamic analysis section and is responsible for interfacing between RANKINE 3.0 and the computerized steam tables. Subroutine FIXSTA may performs one of three functions; 1) determines if a state can be fixed (IFIND=1), 2) fixes a state by calling the appropriate steam table subroutine (IFIND=2), or 3) calculates a saturation temperature or pressure given a pressure or temperature (IFIND=3). Even though the state postulate requires two independent intensive thermodynamic properties to fix a state, the information required by RANKINE 3.0 to fix a thermodynamic state is based upon the requirements (or limitations) of the computerized steam tables. Table 2-15 contains a summary of the thermodynamic conditions for which a state is fixed and all unknown thermodynamic information may be calculated.



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Table 2-15. Requirements to fix a thermodynamic state

Known	Calculates
Temperature Pressure Subcooled liquid or Superheated vapor	Specific volume Enthalpy Entropy
Temperature Quality Two phase mixture	Saturation pressure Specific volume Enthalpy Entropy
Pressure Quality Two phase mixture	Saturation temperature Specific volume Enthalpy
Pressure Entropy	Temperature Specific volume Enthalpy Quality Fluid phase index
Pressure Enthalpy	Temperature Specific volume Entropy Quality Fluid phase index

The methods employed by the computerized steam tables to calculate the unknown thermodynamic information are based upon fundamental relation for the working fluid. The fundamental relation is represented by the steam tables. Since the computerized steam tables were not written by the author, the internal details of the computerized steam tables are beyond the scope of this discussion.

It should be noted that the numerical methods used to calculate the steam table properties introduce considerable error whenever the pressure is greater than the critical pressure. Therefore, the maximum allowable pressure is 22.09 MPa and the maximum allowable temperature is 1300 Deg C. In addition, the computerized steam tables incorporated by RANKINE 3.0 possess a very slight discontinuity between the 2-phase correlation and the compressed liquid and superheated steam correlation. As a result of this discontinuity, RANKINE 3.0 may calculate a working fluid entropy decrease across a device or a negative irreversibility for a device. Since both conditions are physically impossible, RANKINE 3.0 checks each device in the system to insure that neither condition exists and, if necessary, provides a warning message to the user during program execution. Usually, the discontinuity problem may be avoided by not modeling very small device pressure losses when the working fluid is close to the saturated liquid or saturated vapor line.

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The internal units utilized within RANKINE 3.0 are set by the operating units of the computerized steam tables. Table 2-16 summarizes the steam table units.

Table 2-16. Steam table units

Thermodynamic Property	Units
Temperature	Deg C
Pressure	MPa
Specific volume	m^3/kg
Enthalpy	KJ/kg
Entropy	KJ/kg/K
Fluid phase index	-
Quality	-

2.3.5 Calculation of System Related Performance Parameters

After all unknown thermodynamic device information is known, subroutine SYSCAL is called. Subroutine SYSCAL is responsible for calculating and/or organizing all important system parameters. The important system parameters can be separated into two classes; 1) information related to device total parameter, and 2) information related to system performance parameter.

An example of information related to a device total parameter is total turbine work or total pump work. Within the subroutine SYSCAL, the system is systematically traversed and information pertaining to the total device parameters are organized and stored within a set of common block variables. Table 2-17 contains a summary of these variables and their definition.

Table 2-17. Summary of device total variables

VARIABLE	DEFINITION	VARIABLE	DEFINITION
AJQBOL	Total Adjusted heat transfer by all boilers	NNODEO	Number of unconnected exit nodes in system
DVCBOL(I)	Device number of simple boiler #I	NODEI(I)	Node number of #I unconnected inlet node
DVCTRB(I)	Device number of simple turbine #I	NODEO(I)	Node number of #I unconnected exit node
DVCCND(I)	Device number of simple condenser #I	QBOL(I)	Heat transferred into system by boiler #I
DVCHLD(I)	Device number of simple heat load #I	QCND(I)	Heat transferred into system by condenser #I
DVCPMP(I)	Device number of simple pump #I	QHLD(I)	Heat transferred into system by heat load #I
NNODEI	Number of unconnected inlet nodes in system	WKPMP(I)	Actual work of pump #I

Table 2-17. (Cont'd)

VARIABLE	DEFINITION	VARIABLE	DEFINITION
WKPMPT	Total pump actual work in system	XHLDT	Total heat transfer into all simple heat loads
WKSYS	Total actual work output of system	XPIPT	Total heat transfer into all simple pipes
WKTRBT	Total actual work output by all turbines	XSYS	Total heat trasfer into system
WKTRB(I)	Actual work of simple turbine #I	XSYSI	Total heat transfer into all boilers

Each of the variable specified in Table 2-17 are located within the common block IO, and hence, are accessible to the other sections of RANKINE 3.0.

The second class of information subroutine SYSCAL calculates are system performance parameters. By applying the thermodynamic definitions for the system performance parameters, subroutine SYSCAL calculates five system parameters; the 1st and 2nd law efficiency, heat rate, CARNOT cycle efficiency, and 2nd law effectiveness. After SYSCAL calculates these system parameters, they are stored within a set of common block variables. Table 2-18 contains a summary of the five variables used to store the five system parameters and their definitions.

Table 2-18. Summary of system performance variables

Variable	Definition	Units
FLEFF	1st law efficiency	None
SLEFF	2nd law efficiency	None
HRSYS	Heat rate	BTU/KW/HR
CCEFF	CARNOT cycle efficiency	None
SLEWE	Second law effectiveness	None

Each of the variable specified in Table 2-18 are located within the common block IO, and hence, are accessible to the other independent sections of RANKINE 3.0.

2.4.0 Output Processing

The purpose of the output processing section is to perform a mass and energy balance on each of the various control volumes throughout the system and to write all results to a user specified file. Subroutine RANKO is the highest level subroutine in the output

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processing section and is responsible for calling subroutine MEBAL, prompting the user for an output file name, and writing the results to the user specified output file.

2.4.1 Mass and Energy Balance

Subroutine MEBAL is responsible for performing a mass and energy balance on each of the various control volumes throughout the system. Subroutine MEBAL performs a mass and energy balance with control volumes selected around each device within the system and around the entire system. Performing a mass and energy balance around each device independently verifies the conservation of mass and energy and increases the overall credibility of the program results. Performing a mass and energy balance with a control volume around the entire system determines if unaccounted mass and/or energy is entering or exiting the system. Within the subroutine MEBAL, the system is traversed and the mass and energy flows entering and exiting each control volume is accounted. The results of the mass and energy balances are stored within five common block variables. Table 2-19 contains a summary of these five variables, their definition, and units.

Table 2-19. System mass and energy balance variables

Variable	Variable definition	Units
MBERR(I)	Unaccounted mass flow rate entering the device before node #I	kg/sec
EBERR(I)	Unaccounted energy flow rate entering the device before node #I	KW
MSERRI	Unaccounted mass flow rate entering the system	kg/sec
MSERRO	Unaccounted mass flow rate exiting the system	kg/sec
ESERRI	Unaccounted energy flow rate entering the system	KW
ESERRO	Unaccounted energy flow rate exiting the system	KW

Each of the variable specified in Table 2-19 are located within the common block IO, and hence, are accessible to the other independent sections of RANKINE 3.0.

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It should be noted that the mass and energy balance performed on the various control volumes throughout the system are true balances. For example, when performing an energy balance on a condenser, the work term in the energy balance is not neglected (i.e., set to zero) even though it is known that a condenser does not do work on the surrounds. By performing a true mass and energy balance, additional model credibility is acquired.

2.4.2 Output File

Subroutine RANKO is responsible for prompting the user for an output file name and writing all results to the user specified output file. The output file name is read as a A12 format and, hence, the output file name is limited to a maximum of 12 characters (including the extension). In addition, an internal check within subroutine RANKO verifies that the output file name is not identical to the input file name. After the output file name has been specified, the results of the thermodynamic analysis are written the output file. The output file include three types of data; 1) Node data, 2) Device data, and 3) System data. Tables 2-20 and 2-21 contain the definitions of the abbreviations used within the output file.

Table 2-20: Node data abbreviations

Abbreviation	Definition	Units
T	Temperature	Deg C
P	Pressure	MPA
L	Fluid phase index 1-subcooled liquid 2-two phase mixture 3-superheated vapor 4-saturated liquid 5-saturated vapor	-
Q	Quality	-
S	Entropy	KJ/kg/k
H	Enthalpy	KJ/kg
V	Specific volume	m^3/kg
M	Mass flow rate	Kg/sec
A	Availability	KJ/kg

Table 2-21: Device data abbreviations

Abbreviation	Definition	Units
REV WRK	The reversible work associated with the device before the node.	KW
ACT WRK	The actual work associated with the device before the node.	KW
IRREV	The irreversibility associated with the device before the node.	KW
HEAT X-FER	The heat transferred into the device before the node.	KW
MASS ERR	The mass balance error associated with the device before the node.	Kg/sec
ENG ERR	The energy balance error associated with the device before the node	KW

2.5.0 Code Modifications Required for Addition Thermodynamic Models

The basic structure of RANKINE 3.0 has been designed to facilitates additional thermodynamic models within the existing framework. In order to add additional thermodynamic model, five subroutines must be written and seven existing subroutines must be modified. Table 2-22 contains a summary of the subroutines which must be written or modified to insert an additional thermodynamic model within the exiting framework.

Table 2-22. Subroutines required for new Thermodynamic model

Subroutine Name	Change Required	Purpose of Subroutine
IN_	Write subroutine	Input processing
EC_	Write subroutine	Echo
IC_	Write subroutine	Input processing
AI_	Write subroutine	Artificial intelligence
S_	Write subroutine	Thermodynamic analysis
RANKIN	Modify subroutine	-
ECHO	Modify subroutine	-
RANKIC	Modify subroutine	-
RANKAI	Modify subroutine	-
SYSCAL	Modify subroutine	-
MEBAL	Modify subroutine	-
FNDNOD	Modify subroutine	-

In order to maintain the structure of the program, it is recommended that the five new subroutines required for an additional thermodynamic model be written utilizing the same fundamental structure as the existing code. The creation of the input processing subroutine, echo subroutine and input checking subroutine can be almost entirely written

with a cut and paste approach with slight modifications. The creation of the artificial intelligence and thermodynamic subroutine requires the most original programming, however, they should still follow the fundamental frame work of the thermodynamic analysis section.

Due to the large size of the RANKINE 3.0 executable file (approximately 390K), it is possible to add additional thermodynamic models and exceed the maximum program executable size. In the event that this upper bound is approached, it is recommended that RANKINE 3.0 be divided into three individual executable files. As a result of the program structure, RANKINE 3.0 may be divided into an input processing executable, an input checking executable, and a thermodynamic analysis/output processing executable file. Since the only communication between each of these sections is through the common blocks IO and DEAD, the communication between each of the three executables could be achieved by writing the common blocks to an external data file. A DOS batch file could then be written to run all three executable files and to deleted the external data file after RANKINE 3.0 is run.

2.7.0 Program Limitations

Even though RANKINE 3.0 was developed to be as flexible as possible, the program does contain some limitations A summary of these limitations can be seen below.

1) The system must have less than 100 devices.
2) The system must have less than 100 nodes.
3) A SIMPLE TURBINE device may have a maximum of 10 extractions.
4) A SIMPLE CONDENSER device may have a maximum of 27 inlets.
5) A SIMPLE BOILER device may have a maximum of 10 reheat legs.
6) A SIMPLE JUNCTION device may have a maximum of 10 inlets and a maximum of 10 exits.
7) Transients can not be modeled by RANKINE 3.0.
8) Working fluid other than steam can not be modeled by RANKINE 3.0 (such as non condensable gasses).
9) RANKINE 3.0 does not provide insight into the physics within the thermodynamic control volumes.

10) The performance characteristics (such as pipe pressure loss or adiabatic stage group efficiency) of each device must be known before the system performance is analyzed.

11) Due to steam table limitations, the maximum allowable pressure is 22.09 MPa and the maximum allowable temperature is 1300 Deg C.

Chapter 3: Thermodynamic Modeling and Overall System Evaluation

3.0.0 Thermodynamic Devices

RANKINE 3.0 can model eleven different thermal devices commonly found in steam power systems. Each of these thermal devices are modeled by RANKINE 3.0 as steady state steady flow thermodynamic control volumes capable of performing as specified within the input file. The performance of each thermal device is calculated with hard wired code logic, which applies the 1st and 2nd law of thermodynamics for a control volume (neglecting kinetic and potential energy terms) and the appropriate performance parameters to calculate the performance of each device. In general, the control volume for the thermodynamic analysis is selected around the physical boundaries of each device, and hence, the only information acquired from the analysis is the state of the working fluid as it crosses the boundary of the control volume and the net work and/or heat transferred across the boundary of the control volume.

For each device, RANKINE 3.0 was developed to identify several different combinations of known information which represent a well posed device. As a result, RANKINE 3.0 is capable of solving for one set of unknown variables related to a specific device given a second set of known variables related to that same device. The conditions in which RANKINE 3.0 can identify a well posed device and perform calculations are based on the standard methods to model each device type. Table 2-13 summarizes the conditions in which RANKINE 3.0 may calculation an unknown piece of information.

The device performance parameters utilized in the thermodynamic analysis depends on the device type. The device performance parameter captures the physics of the device and may or may not be provided by the user for the analysis. For example, the physics of a 'pipe device' may be captured with a user specified pressure loss and a user specified enthalpy loss. These two parameters quantify the pressure loss encountered when a viscous fluid (in our case, steam) moves within a pipe and the heat loss (which appears in the form of a steam enthalpy decrease) when a 'hot' pipe interacts thermally with its environment.

Each of the eleven thermodynamic devices which can be modeled by RANKINE 3.0 is discussed in the following sections. For each device type, the device purpose, common

symbol, device performance parameters, 1st and 2nd law application, and mass and energy balance equations are discussed.

3.1.0 The Conservation Principles

Centuries of experimental data has resulted in the establishment of a set of fundamental principles which describe the behavior of nature. The three most common principles relate directly to the thermodynamic evaluation of the Rankine cycle and are commonly referred to as: 1) the mass conservation principle, 2) the energy conservation principle, and 3) the entropy generation principle. The conservation of mass principle, as it applies to the analysis, state that mass may be neither created or destroyed during any process. The general form of the conservation of mass principle does provide for mass conservation into an energy form, however, this conversion is not applicable to this analysis of the Rankine cycle. The conservation of energy principle is commonly refereed to as the 1st law of thermodynamics and is simply stated by Cengal & Boles as "During an interaction between a system and its surroundings, the amount of energy gained by the system must be exactly equal to the amount of energy lost by the surroundings." The entropy generation principle is commonly refereed to as the 2nd law of thermodynamics and is simply stated as: in order for a process to be physically possible without heat transfer, the entropy of the system must remain the same or increase. Since the thermodynamic analysis of the Rankine cycle requires the application of these three principles on a control volume, all three principles will be discussed in detail as they relate to a steady state steady flow control volume in the following sections.

3.1.1 Application of the Conservation of Mass Principle

The steady state, steady flow conservation of mass principle as it relates to any arbitrarily selected control volume with a single mass species crossing the control boundaries is stated as

$$\sum_i \dot{m}_{in,i} = \sum_i \dot{m}_{out,i} \qquad 3\text{-}1$$

Where $\dot{m}_{in,i}$ = the i^{th} mass flow rate entering the control volume, [kg/sec]

$m_{out,i}$ = the i^{th} mass flow rate exiting the control volume, [kg/sec].

It should be noted that equation 3-1 only accounts for mass flow rates that cross the boundaries of the control volume and mass flow within the control boundaries are not considered.

For the remainder of this discussion and within the RANKINE 3.0 code, mass flow rates are always positive and a mass flow rate leaving the control volume will be accounted via the sign notation within the equation.

The RANKINE 3.0 code possess a series of internal checks to verify that program results are accurate. One of the internal checks is a mass balance on each device after all device thermodynamic information has been determined for the entire system. The device mass balance error is defined as

$$\dot{m}_{error} = \sum_i \dot{m}_{in,i} - \sum_i \dot{m}_{out,i} \qquad 3\text{-}2$$

Where m_{error} = device mass balance error, [kg/sec]
$m_{in,i}$ = the i^{th} mass flow rate entering the control volume, [kg/sec]
$m_{out,i}$ = the i^{th} mass flow rate exiting the control volume, [kg/sec].

3.1.2 Application of the Conservation of Energy Principle

The steady state, steady flow conservation of energy principle neglecting kinetic and potential terms as it relates to any arbitrarily selected control volume with a single mass species crossing the control boundaries is stated as

$$Q_{in} - W_{out} = \sum_i (\dot{m}_{out} \cdot h_{out})_i - \sum_i (\dot{m}_{in} \cdot h_{in})_i \qquad 3\text{-}3$$

Where: Q_{in} = total net heat transfer entering the control volume, [kW]
W_{out} = total net work transferred exiting the control volume, [kW]
$m_{in,i}$ = the i^{th} mass flow rate entering the control volume, [kg/sec]
$h_{in,i}$ = the enthalpy of the i^{th} mass flow entering the control

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$m_{out,i}$ = the i^{th} mass flow rate exiting the control volume, [kg/sec]

$h_{out,i}$ = the enthalpy of the i^{th} mass flow exiting the control volume, [kJ/kg].

For the remainder of this discussion and within the RANKINE 3.0 code, the sign convention used for all heat and work terms shall be heat transferred into the control volume is positive and work transferred out the control volume is positive. In the event that heat transfer is exiting the control volume or work is entering the control volume, the sign of the scalar will be negative.

The RANKINE 3.0 code possess a series of internal checks to verify that program results are accurate. One of the internal checks is an energy balance on each device after all device thermodynamic information has been determined for the entire system. The device energy balance error is defined as

$$\dot{E}_{error} = \sum_i \dot{m}_{in,i} \cdot h_{in,i} - \sum_i \dot{m}_{out,i} \cdot h_{out,i} + \dot{Q}_{in} - \dot{W}_{out} \qquad 3\text{-}4$$

Where E_{error} = device energy balance error, [kW]

$m_{in,i}$ = the i^{th} mass flow rate entering the control volume, [kg/sec]

$h_{in,i}$ = the enthalpy of the i^{th} mass flow entering the control volume, [kJ/kg]

$m_{out,i}$ = the i^{th} mass flow rate exiting the control volume, [kg/sec].

$h_{out,i}$ = the enthalpy of the i^{th} mass flow exiting the control volume, [kJ/kg].

Q_{in} = total net heat transfer entering the control volume, [kW]

W_{out} = total net work transferred exiting the control volume, [kW]

3.1.3 Application of the Entropy Generation Principle

The 2nd law of thermodynamics represents the starting point for the derivation of several thermodynamic concepts which are applicable to the thermodynamic evaluation of the Rankine cycle. The applicable concepts are called availability, reversible work and irreversibility.

The property availability is a state variable and quantifies the thermodynamically maximum obtainable useful energy for a working fluid at a particular state. The availability at a particular state, neglecting kinetic and potential energy, is stated as

$$A = \left(h - h_{dead_state}\right) - T_o \cdot \left(s - s_{dead_state}\right) \qquad 3\text{-}5$$

Where: A = state availability, [kJ/kg]
h = state enthalpy, [kJ/kg]
h_{dead_state} = dead state enthalpy, [kJ/kg]
T_0 = dead state temperature, [K]
s = state entropy, [kJ/kg/K]
s_{dead_state} = dead state entropy, [kJ/kg].

It should be noted that the calculation of availability always uses the dead state temperature.

The definition of reversible work is similar to availability, except that reversible work quantifies the thermodynamically maximum obtainable useful energy for a process as opposed to a state. The reversible work for a steady state steady flow control volume analysis neglecting kinetic and potential energy changes is stated as

$$W_{rev} = \sum_i \left(m_i \cdot \left(\left(h_{in,i} - h_{out,i}\right) - T_{o,i} \cdot \left(s_{in,i} - s_{out,i}\right) \right) \right)_i \qquad 3\text{-}6$$

Where: W_{rev} = process reversible work [kW]
m_i = the i^{th} mass flow rate entering the control volume, [kg/sec]
$h_{in,i}$ = the enthalpy of the i^{th} flow entering the control volume, [kJ/kg]
$h_{out,i}$ = the enthalpy of the i^{th} flow exiting the control volume, [kJ/kg]
$T_{0,i}$ = temperature at which heat transfer occurs, [k]
$s_{in,i}$ = the entropy of the i^{th} flow entering the control volume [kJ/kg/K]
$s_{out,i}$ = the entropy of the i^{th} flow exiting the control volume [kJ/kg/K]

It should be noted that equation 3-4 applies for adiabatic as well as non-adiabatic processes. In the event that a process is adiabatic, the T_0 value is set to the temperature at which heat transfer would occur if it did occur, usually the dead state temperature.

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Irreversibility is defined as the difference between the maximum amount of work obtainable during a process and the actual work obtained during a process. Physically, irreversibility accounts for the lost potential to do work due to physical factors such as friction, unrestrained expansion, heat transfer due to non-incremental temperatures differences, mixing and turbulence. Mathematically, irreversibility is defined as

$$I = W_{rev} - W_{out} \qquad 3\text{-}7$$

Where: I = process irreversibility, [kW]
W_{rev} = process reversible work, [kW]
Wout = process actual work, [kW].

It should be noted that a negative irreversibility represents a thermodynamic performance better than the thermodynamically best performance and, hence, violates the 2nd law of thermodynamics.

3.2.0 The SIMPLE BOILER Device

A boiler is a device where heat originating from combustion gasses, a nuclear reactor, or other source is transferred to the working fluid traveling through the boiler. In an ideal boiler, the heat addition occurs as a constant pressure processes.

Frequently, a boiler will have one or more reheat legs. A boiler with a reheat leg permits the working fluid to reenter the boiler after the working fluid has traveled through a high pressure turbine. Since the overall system efficiency increases via reheating and the thermodynamic performance of a turbine decreases with increasing working fluid moisture, the reheat leg is a commonly used technique to increase the efficiency of a system.

The symbolic representation for a SIMPLE BOILER device with one reheat leg is shown in Figure 3-1. Even though RANKINE 3.0 is capable of modeling upto 10 reheat legs, only one reheat leg is shown in Fig. 3-1.

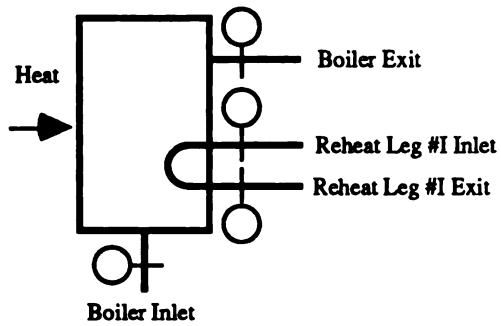


Figure 3-1. Symbolic representation for a SIMPLE BOILER device

Figure 3-2 shows the relevant state and device variables utilized within the RANKINE 3.0 source code. The conservation of mass, 1st law, and 2nd law application to the SIMPLE BOILER device will utilize the identical state and device variable nomenclature utilized with the RANKINE 3.0 source code. The variable nomenclature utilized by RANKINE 3.0 is defined in Table 2-12.

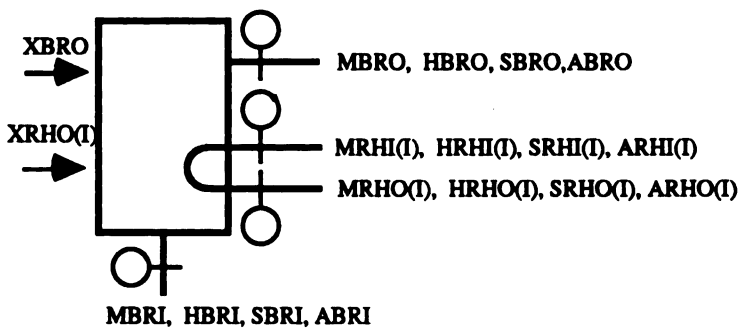


Figure 3-2. RANKINE 3.0 variables for the SIMPLE BOILER device

In order to provide the maximum amount of thermodynamic information to the user, the conservation of mass, the 1st law of thermodynamics, and the 2nd law of thermodynamics are applied to multiple control volumes within the SIMPLE BOILER device. The first control volume is selected around the inlet to exit fluid path and, if required, additional control volumes are selected around the fluid paths of each reheat leg.

3.2.1 The SIMPLE BOILER Device Performance Parameters

The working fluid pressure drop within the SIMPLE BOILER device is quantified with a user specified pressure drop or percentage pressure drop. If a user specified pressure drop is specified for the boiler inlet to exit path or for a reheat leg, than the relationships between inlet and exit pressure are defined below

$$PBRO = PBRI - PLBOL \qquad 3\text{-}8$$

$$PRHO(I) = PRHI(I) - PLRH(I) \qquad 3\text{-}9$$

Where:
PBRO = working fluid pressure at boiler exit, [MPa]
PBRI = working fluid pressure at boiler inlet, [MPa]
PLBOL = working fluid pressure loss between boiler inlet to exit, [MPa]
PRHO(I) = working fluid pressure at reheat leg #I exit, [MPa]
PRHI(I) = working fluid pressure at reheat leg #I inlet, [MPa]
PLRH(I) = working fluid pressure loss between reheat leg #I inlet and exit, [MPa]

If a user specified percentage pressure drop is specified for either the boiler or for a reheat leg, than the relationships between inlet and exit pressure are defined below

$$PBRO = PBRI \cdot [1 - PPLBOL] \qquad 3\text{-}10$$

$$PRHO(I) = PRHI(I) \cdot [1 - PPLRH(I)] \qquad 3\text{-}11$$

Where:
PBRO = working fluid pressure at boiler exit, [MPa]
PBRI = working fluid pressure at boiler inlet, [MPa]
PPLBOL = working fluid percentage pressure drop between boiler inlet to exit path, [-]
PRHO(I) = working fluid pressure at reheat leg #I exit, [MPa]
PRHI(I) = working fluid pressure at reheat leg #I inlet, [MPa]
PPLRH(I) = working fluid percentage pressure loss between reheat leg #I inlet and exit, [-]

It should be noted that percent pressure losses are based upon percent of inlet pressure, not percent of exit pressure.

3.2.2 Mass Conservation For The SIMPLE BOILER Device

With a control volume selected around the physical boundaries of the boiler inlet to boiler exit path, the steady state steady flow mass conservation principle yields

$$MBRI = MBRO \tag{3-12}$$

Where: MBRI = working fluid mass flow rate at the boiler inlet, [kg/sec]
MBRO = working fluid mass flow rate at the boiler exit, [kg/sec].

With a control volume selected around the physical boundaries of the I^{th} reheat leg, the steady state conservation of mass yields

$$MRHI(I) = MRHO(I) \tag{3-13}$$

Where: MRHI(I) = working fluid mass flow rate at the reheat leg #I inlet, [kg/sec]
MRHO(I) = working fluid mass flow rate at the reheat leg #I exit, [kg/sec].

3.2.3 1st Law Analysis For The SIMPLE BOILER Device

With a control volume selected around the physical boundaries of the boiler inlet to exit path, a steady state steady flow 1^{st} Law control volume analysis neglecting the kinetic and potential terms yields

$$XBRO = MBRO \cdot HBRO - MBRI \cdot HBRI \tag{3-14}$$

Where: XBRO = heat transferred from the surrounds during the boiler inlet to exit process, [kW]
MBRO = working fluid mass flow rate at boiler exit, [kg/sec]
HBRO = working fluid enthalpy at boiler exit, [kJ/kg]
HBRI = working fluid enthalpy at boiler inlet, [kJ/kg].

With a control volume selected around the physical boundaries of the I^{th} reheat leg, a steady state 1^{st} Law control volume analysis neglecting the kinetic and potential terms yields

$$XRHO(I) = MRHO(I) \cdot HRHO(I) - MRHI(I) \cdot HRHI(I)] \qquad 3\text{-}15$$

Where: XRHO(I) = heat transferred from the surrounds during the I^{th} reheat leg process, [kW]
MRHO(I) = working fluid mass flow rate at reheat leg #I exit, [kg/sec]
HRHO(I) = working fluid enthalpy at reheat leg #I exit, [kJ/kg]
HRHI(I) = working fluid enthalpy at reheat leg #I inlet, [kJ/kg].

Since the SIMPLE BOILER device does, by definition, no work on the surrounds, all SIMPLE BOILER device work terms are zero. These terms are stated below as

$$WKBRO = 0 \qquad 3\text{-}16$$

$$WKRHO(I) = 0 \qquad 3\text{-}17$$

Where: WKBRO = work done on the surrounds by the boiler inlet to exit process,.[kW].
WKRHO(I) = work done on the surrounds by the I^{th} reheat leg process, [kW].

3.2.4 2nd Law Analysis For The SIMPLE BOILER Device

The working fluid availability at each node denoted in Figure 3-1 is defined as

$$ABRI = HBRI - HDEAD - TDEAD \cdot [SBRI - SDEAD] \qquad 3\text{-}18$$

$$ABRO = HBRO - HDEAD - TDEAD \cdot [SBRO - SDEAD] \qquad 3\text{-}19$$

$$ARHI(I) = HRHI(I) - HDEAD - TDEAD \cdot [SRHI(I) - SDEAD] \qquad 3\text{-}20$$

$$ARHO(I) = HRHO(I) - HDEAD - TDEAD \cdot [SRHO(I) - SDEAD] \quad 3\text{-}21$$

Where:
ABRI = working fluid availability at boiler inlet, [kW]
HBRI = working fluid enthalpy at boiler inlet, [kJ/kg]
HDEAD = working fluid enthalpy at dead state conditions, [kJ/Kg]
TDEAD = Dead state temperature, [K]
SBRI = working fluid entropy at boiler inlet, [kJ/kg/K]
SDEAD = working fluid entropy at dead state conditions, [kJ/kg/K]
ABRO = working fluid availability at boiler exit, [kW]
HBRO = working fluid enthalpy at boiler exit [kJ/kg]
SBRO = working fluid entropy at boiler exit, [kJ/kg/K]
ARHI(I) = working fluid availability at reheat leg #I inlet, [kW]
HRHI(I) = working fluid enthalpy at reheat leg #I inlet, [kJ/kg]
SRHI(I) = working fluid entropy at reheat leg #I inlet, [kJ/kg/K]
ARHO(I) = working fluid availability at reheat leg #I exit, [kW]
HRHO(I) = working fluid enthalpy at reheat leg #I exit, [kJ/kg]
SRHO(I) = working fluid entropy at reheat leg #I exit,[kJ/kg/K]

With a control volume selected around the physical boundaries of the boiler inlet to exit path, a steady state steady flow 2nd Law control volume analysis neglecting the kinetic and potential terms yields

$$WRBRO = MBRI \cdot [HBRI - HBRO - THRES \cdot (SBRI - SBRO)] \quad 3\text{-}22$$

Where:
WRBRO = reversible work of boiler inlet to exit process, [kW]
MBRI = working fluid mass flow rate at boiler inlet, [kg/sec]
HBRI = working fluid enthalpy at boiler inlet, [kJ/kg]
HBRO = working fluid enthalpy at boiler exit, [kJ/kg]
THRES = high temperature reservoir temperature, [K]
SBRI = working fluid entropy at boiler inlet, [kJ/kg/K]
SBRO = working fluid entropy at boiler exit, [kJ/kg/K]

With a control volume selected around the physical boundaries of the reheat leg #I path, a steady state 2nd Law control volume analysis neglecting the kinetic and potential terms yields

$$WRRHO(I) = MRHI(I) \cdot [HRHI(I) - HRHO(I) - THRES \cdot (SRHI(I) - SRHO(I))] \quad 3\text{-}23$$

Where:
WRRHO = reversible work of working fluid in reheat leg #I, [kW]
MRHI(I) = working fluid mass flow rate at reheat leg #I inlet, [kg/sec]
HRHI(I) = working fluid enthalpy at reheat leg #I inlet, [kJ/kg]
HRHO(I) = working fluid enthalpy at reheat leg #I exit, [kJ/kg]
THRES = high temperature reservoir temperature, [K]
SRHI(I) = working fluid entropy at reheat leg #I inlet, [kJ/kg/K]
SRHO(I) = working fluid entropy at reheat leg #I exit, [kJ/kg/K]

It should be noted that RANKINE 3.0 assumes that the boiler inlet to exit path and all reheat legs exchange accept heat from the same high temperature reservoir.

For the working fluid traveling within the boiler inlet to exit path, the irreversibility is defined as

$$IRBRO = WRBRO - WKBRO \quad 3\text{-}24$$

Where:
IRBRO = irreversibility of inlet to exit process, [kW]
WRBRO = reversible work of inlet to exit path, [kW]
WKBRO = work done on the surrounds by the working fluid in the boiler inlet to exit process,.[kW]

For the working fluid traveling within the reheat #I path, the irreversibility is defined as

$$IRRHO(I) = WRRHO(I) - WKRHO(I) \quad 3\text{-}25$$

Where:
IRRHO(I) = irreversibility of reheat leg #I process, [kW]
WRRHO(I) = reversible work of reheat leg #I process, [kW]
WKRHO(I) = work done on the surrounds by the working fluid in the Ith reheat leg process, [kW].

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Section 3.2.5 The SIMPLE BOILER Device Mass and Energy Balance

For the working fluid traveling within the boiler inlet to exit path, the mass balance error is defined as

$$MBBOL = MBRI - MBRO \qquad 3\text{-}26$$

Where: MBBOL= mass balance error for boiler inlet to exit path, [kg/sec]
MBRI = working fluid mass flow rate at boiler inlet, [kg/sec]
MBRO = working fluid mass flow rate at boiler exit, [kg/sec].

For the working fluid traveling within the i^{th} reheat leg, the mass balance error is defined as

$$MB(I) = MRHI(I) - MRHO(I) \qquad 3\text{-}27$$

Where: MB(I) = mass balance flow rate error for the i^{th} reheat leg, [kg/sec]
MRHI(I) = working fluid mass flow rate at the i^{th} reheat leg inlet, [kg/sec]
MRHO(I) = working fluid mass flow rate at the i^{th} reheat leg exit,[kg/sec].

For the working fluid traveling within the boiler inlet to exit path, the energy balance error is defined as

$$EBBOL = MBRI * HBRI - MBRO * HBRO + XBRO - WKBRO \qquad 3\text{-}28$$

Where: EBBOL= energy balance error for boiler inlet to exit path, [kW]
MBRI = working fluid mass flow rate at boiler inlet, [kg/sec]
HBRI = working fluid enthalpy at boiler inlet, [kJ/kg]
MBRO = working fluid mass flow rate at boiler exit, [kg/sec]
HBRO = working fluid enthalpy at boiler exit, [kJ/kg]
XBRO = heat transferred from the surrounds to the working fluid in the boiler inlet to exit path, [kW]
WKBRO = work done on the surrounds by the boiler inlet to exit process,.[kW].

For the working fluid traveling within the i^{th} reheat leg, the energy balance error is defined as

$$EB(I) = MRHI(I) * HRHI(I) - MRHO(I) * HRHO(I) + XRHO(I) - WKRHO(I) \quad 3\text{-}29$$

Where: EB(I)= energy balance error for i^{th} reheat leg,[kW]
MRHI(I) = working fluid mass flow rate at reheat leg #I inlet, [kg/sec]
HRHI(I) = working fluid enthalpy at reheat leg #I inlet, [kJ/kg].
MRHO(I) = working fluid mass flow rate at reheat leg #I exit, [kg/sec]
HRHO(I) = working fluid enthalpy at reheat leg #I exit, [kJ/kg]
XRHO(I) = heat transferred from the surrounds during the I^{th} reheat leg process, [kW]
WKRHO(I) = work done on the surrounds by the I^{th} reheat leg process, [kW].

3.3.0 The SIMPLE TURBINE Device

A turbine is a device which converts energy contained within a working fluid into rotating mechanical energy. As the working fluid passes through the turbine, work is done against rotor blades which are attached to a shaft. When the rotating shaft is connected to an electrical generator, electricity is produced.

Frequently, a turbine is divided into stage groups. A stage group is defined as a set of stator and rotor blades in which the working fluid undergoes a continuous expansion. Usually, the end of a stage group is indicated by an extraction point.

The symbolic representation for a SIMPLE TURBINE device with two extractions are shown in Figure 3-3. Even though RANKINE 3.0 is capable of modeling upto 10 turbine extractions, only two extractions are shown in Fig. 3-3.

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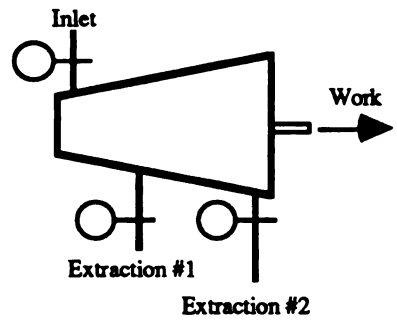


Figure 3-3. Symbol for a SIMPLE TURBINE device

Figure 3-4 shows the relevant state and device variables utilized within the RANKINE 3.0 source code. The conservation of mass, 1st law, and 2nd law application to the SIMPLE TURBINE device will utilize the identical state and device variable nomenclature utilized with the RANKINE 3.0 source code. The variable nomenclature utilized by RANKINE 3.0 is defined in Table 2-12.

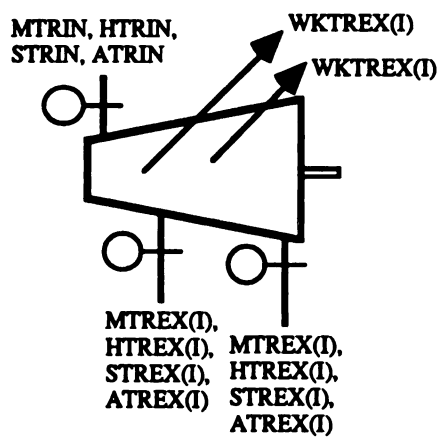


Figure 3-4. RANKINE 3.0 variables for the SIMPLE TURBINE

In order to provide the maximum amount of thermodynamic information to the user, the conservation of mass, the 1st law of thermodynamics, and the 2nd law of thermodynamics are applied to multiple control volumes within the SIMPLE TURBINE device. The control volumes for the analysis are selected around each stage group within the simple turbine device.

3.3.1 The SIMPLE TURBINE Device Performance Parameters

The thermodynamic performance of a SIMPLE TURBINE device is quantified with a user specified adiabatic stage group efficiency. The adiabatic stage group efficiency is defined as the ratio of actual working fluid enthalpy change divided by the ideal working fluid enthalpy change assuming an isentropic process. For the first stage group, the adiabatic stage group efficiency is defined as

$$\eta_{1st,turbine} = \frac{HTRIN - HTREX(1)}{HTRIN - HTREX(1)_{ideal}} \qquad 3\text{-}30$$

Where: HTRIN = working fluid enthalpy at turbine inlet, [kJ/kg]
HTREX(1) = working fluid enthalpy at turbine extraction #1, [kJ/kg]
$HTREX(1)_{ideal}$ = working fluid enthalpy at turbine extraction #1 assuming an isentropic process, [kJ/kg].

For the 2nd through 10th stage group, the adiabatic stage group efficiency is defined as

$$\eta_{2nd-10th,turbine} = \frac{HTREX(I) - HTREX(I+1)}{HTREX(I) - HTREX(I+1)_{ideal}} \qquad 3\text{-}31$$

Where: HTREX(I) = working fluid enthalpy at turbine extraction #I, [kJ/kg]
HTREX(I+1) = working fluid enthalpy at turbine extraction #(I+1), [kJ/kg]
$HTREX(I+1)_{ideal}$ = working fluid enthalpy at turbine extraction #(I+1) assuming an isentropic process, [kJ/kg]

In general, the adiabatic stage group efficiency is used to calculate the actual stage group exit enthalpy and, hence, equations 3-30 and 3-31 are algebraically manipulated to solve for HTREX(1) and HTREX(I+1).

3.3.2 Mass Conservation For The SIMPLE TURBINE Device

With a control volume selected around each turbine stage group, the steady state steady flow mass conservation principle provides a basis to determine the mass flow rate through each stage group.

For the 1st stage group, the working fluid mass flow rate through the stage group is given by

$$MTRST(1) = MTRIN \qquad 3\text{-}32$$

Where: MTRST(1) = working fluid mass flow rate through the 1st turbine stage group, [kg/sec]
MTRIN = working fluid mass flow rate at turbine inlet, [kg/sec]

For the Ith stage group, the working fluid mass flow rate through the stage group is given by

$$MTRST(I) = MTRST(I-1) - MTREX(I-1) \qquad 3\text{-}33$$

Where: MTRST(I) = working fluid mass flow rate through the Ith turbine stage group, [kg/sec]
MTRST(I-1) = working fluid mass flow rate through the (I-1)th turbine stage group, [kg/sec]
MTREX(I-1) = working fluid mass flow rate at (I-1)th turbine extraction, [kg/sec]

3.3.3 1st Law Analysis For The SIMPLE TURBINE Device

With a control volume selected around the first stage group, a steady state steady flow 1st Law control volume analysis neglecting the kinetic and potential terms yields

$$WKTREX(1) = MTRST(1) \cdot [HTRIN - HTREX(1)] \qquad 3\text{-}34$$

Where: WKTREX(1) = work done on the surrounds by the 1st turbine stage group process, [kW].
MTRST(1) = working fluid mass flow rate through the 1st turbine stage group, [kg/sec]

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Where

HTRIN = working fluid enthalpy at turbine inlet, [kJ/kg]
HTREX(1) = working fluid enthalpy at turbine extraction #1, [kJ/kg]

With a control volume selected around the 2nd through 10th stage group, a steady state steady flow 1st Law control volume analysis neglecting the kinetic and potential terms yields

$$WKTREX(I) = MTRST(I) \cdot [HTREX(I-1) - HTREX(I)] \qquad 3\text{-}35$$

Where: WKTREX(I) = work done on the surrounds by the stage group #I process,.[kW]
MTRST(I) = working fluid mass flow rate through the Ith turbine stage group, [kg/sec]
HTREX(I-1) = working fluid enthalpy at turbine extraction #(I-1), [kJ/kg]
HTREX(I) = working fluid enthalpy at turbine extraction #I, [kJ/kg]

Since the SIMPLE TURBINE device does not exchange heat with the surrounds, all SIMPLE TURBINE device heat transfer terms are zero. These terms are stated below as

$$XTREX(I) = 0 \qquad 3\text{-}36$$

Where: XTREX(I) = heat transferred from the surrounds during the Ith stage group process, [kW]

3.3.4 2nd Law Analysis For The SIMPLE TURBINE Device

The working fluid availability at each node denoted in Figure 3-4 is defined as

$$ATRIN = HTRIN - HDEAD - TDEAD \cdot [STRIN - SDEAD] \qquad 3\text{-}37$$

$$ATREX(I) = HTREX(I) - HDEAD - TDEAD \cdot [STREX(I) - SDEAD] \qquad 3\text{-}38$$

Where: ATRIN = working fluid availability at turbine inlet, [kW]
HTRIN = working fluid enthalpy at turbine inlet, [kJ/kg]
HDEAD = working fluid enthalpy at dead state conditions, [kJ/Kg]
TDEAD = Dead state temperature, [K]

STRIN = working fluid entropy at turbine inlet, [kJ/kg/K]
SDEAD = working fluid entropy at dead state conditions, [kJ/kg/K]
ATREX(I) = working fluid availability at turbine extraction #I, [kW]
HTREX(I) = working fluid enthalpy at turbine extraction #I,[kJ/kg]
STREX(I) = working fluid entropy at turbine extraction #I, [kJ/kg/K].

With a control volume selected around the 1st stage group, a steady state steady flow 2nd Law control volume analysis neglecting the kinetic and potential terms yields

$$WRTRST(1) = MTRST(1) \cdot [HTRIN - HTREX(1) - TDEAD \cdot (STRIN - STREX(1))] \quad 3\text{-}39$$

Where:
WRTRST(1) = reversible work of turbine stage group #1 process, [kW]
MTRST(1) = working fluid mass flow rate through turbine stage group #1, [kg/sec]
HTRIN = working fluid enthalpy at turbine inlet, [kJ/kg]
HTREX(1) = working fluid enthalpy at turbine extraction #1, [kJ/kg]
TDEAD = dead state temperature, [K]
STRIN = working fluid entropy at turbine inlet, [kJ/kg/K]
STREX(1) = working fluid entropy at turbine extraction #1, [kJ/kg/K].

With a control volume selected around the 2nd through 10th stage group, a steady state steady flow 2nd Law control volume analysis neglecting the kinetic and potential terms yields

$$WRTRST(I) = MTRST(I) \cdot [HTREX(I-1) - HTREX(I) - TDEAD \cdot (STREX(I-1) - STREX(I))] \quad 3\text{-}40$$

Where:
WRTRST(I) = reversible work of turbine stage group #I process, [kW]
MTRST(I) = working fluid mass flow rate through turbine stage group #I, [kg/sec]
HTREX(I-1) = working fluid enthalpy at turbine extraction #(I-1), [kJ/kg]
HTREX(I) = working fluid enthalpy at turbine extraction #I, [kJ/kg]
TDEAD = dead state temperature, [K]
STREX(I-1)= working fluid entropy at turbine extraction #(I-1), [kJ/kg/K]
STREX(I) = working fluid entropy at turbine extraction #I, [kJ/kg/K].

For the working fluid traveling within the I^{th} stage group, the irreversibility is defined as

$$IRTREX(I) = WRTREX(I) - WKTREX(I) \qquad 3\text{-}41$$

Where: IRTREX(I) = irreversibility of stage group #I process, [kW]
WRTREX(I) = reversible work of stage group #I process, [kW]
WKTREX(I) = work done on the surrounds by the stage group #I process,.[kW]

Section 3.3.5 The SIMPLE TURBINE Device Mass and Energy Balance

The mass balance error for the entire SIMPLE TURBINE device is defined as

$$MB(NTRST) = MTRIN - \sum_{I} MTREX(I) \qquad 3\text{-}42$$

Where: MB(NTRST)= mass balance error for entire turbine device, [kg/sec]
NTRST = number of turbine extractions, [-]
MTRIN = working fluid mass flow rate at turbine inlet, [kg/sec]
MTREX(I) = working fluid mass flow rate at I^{th} turbine extraction, [kg/sec]

The energy balance error for the entire SIMPLE TURBINE device is defined as

$$EB(NTRST) = MTRIN \cdot HTRIN - \sum_{i} (MTREX(I) \cdot HTREX(I) + XTREX(I) - WKTREX(I)) \qquad 3\text{-}43$$

Where: EBBOL= energy balance error for entire turbine device, [kW]
MTRIN = working fluid mass flow rate at turbine inlet, [kg/sec]
HTRIN = working fluid enthalpy at turbine inlet, [kJ/kg]
MTREX(I) = working fluid mass flow rate at I^{th} turbine extraction, [kg/sec]
HTREX(I) = working fluid enthalpy at turbine extraction #I, [kJ/kg]
XTREX(I) = heat transferred from the surrounds during the I^{th} stage group process, [kW]

WKTREX(I) = work done on the surrounds by the stage group #I process,.[kW]

3.4.0 The SIMPLE PUMP Device

A pump is a device used to increase the pressure of a working fluid. Work is supplied to this device from an external source through a rotating shaft.

The symbolic representation for a SIMPLE PUMP is shown in Figure 3-5.

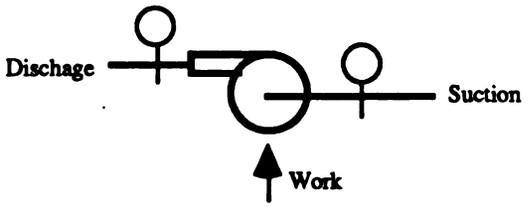


Figure 3-5. Symbol for a SIMPLE PUMP device

Figure 3-6 shows the relevant state and device variables utilized within the RANKINE 3.0 source code. The conservation of mass, 1st law, and 2nd law application to the SIMPLE PUMP device will utilize the identical state and device variable nomenclature utilized with the RANKINE 3.0 source code. The variable nomenclature utilized by RANKINE 3.0 is defined in Table 2-12.

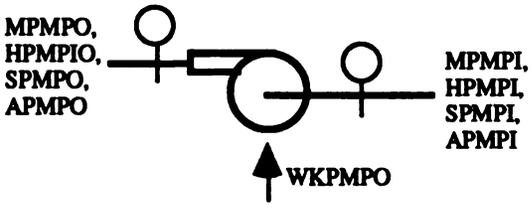


Figure 3-6. RANKINE 3.0 variables for the SIMPLE PUMP device

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For the SIMPLE PUMP device, the conservation of mass, the 1st law of thermodynamics, and the 2nd law of thermodynamics are applied with a single control volume selected around the physical boundary of the device.

3.4.1 The SIMPLE PUMP Device Performance Parameters

The thermodynamic performance of a SIMPLE PUMP device is quantified with a user specified adiabatic efficiency. The adiabatic efficiency is defined as the ratio of the ideal working fluid enthalpy change assuming an isentropic process divided by the actual working fluid enthalpy change. Mathematically, the adiabatic efficiency is defined as

$$\eta_{pump} = \frac{HPMPO_{ideal} - HPMPI}{HPMPO - HPMPI} \qquad 3\text{-}44$$

Where: $HPMPO_{ideal}$ = working fluid enthalpy at pump exit assuming an isentropic process, [kJ/kg].
HPMPI = working fluid enthalpy at pump inlet, [kJ/kg]
HPMPO = working fluid enthalpy at pump exit, [kJ/kg]
$HPMPO_{ideal}$ = working fluid enthalpy at pump exit assuming an isentropic process, [kJ/kg].

In general, the adiabatic efficiency is used to calculate the actual pump exit enthalpy and, hence, equation 3-44 is algebraically manipulated to solve for HPMPO.

3.4.2 Mass Conservation For The SIMPLE PUMP Device

With a control volume selected around the physical boundaries of the SIMPLE PUMP device, the steady state steady flow mass conservation principle yields

$$MPMPO = MPMPI \qquad 3\text{-}45$$

Where: MPMPO = working fluid mass flow rate at the pump exit, [kg/sec]
MPMPI = working fluid mass flow rate at the pump inlet, [kg/sec].

3.4.3 1st Law Analysis For The SIMPLE PUMP Device

With a control volume selected around the physical boundaries of the SIMPLE PUMP device, a steady state steady flow 1st Law control volume analysis neglecting the kinetic and potential terms yields

$$WKPMPO = MPMPI \cdot [HPMPI - HPMPO] \qquad 3\text{-}46$$

Where: WKPMPO = work done on the surrounds by the pump process, [kW].
MPMPI = working fluid mass flow rate at the pump inlet, [kg/sec].
HPMPI = working fluid enthalpy at pump inlet, [kJ/kg]
HPMPO = working fluid enthalpy at pump exit, [kJ/kg]

Since the SIMPLE PUMP device does not exchange heat with the surrounds, the SIMPLE PUMP device heat transfer term is zero. This term is stated below as

$$XPMPO = 0 \qquad 3\text{-}47$$

Where: XPMPO = heat transferred from the surrounds during the pump process, [kW]

3.4.4 2nd Law Analysis For The SIMPLE PUMP Device

The working fluid availability at each node denoted in Figure 3-6 is defined as

$$APMPI = HPMPI - HDEAD - TDEAD \cdot [SPMPI - SDEAD] \qquad 3\text{-}48$$

$$APMPO = HPMPO - HDEAD - TDEAD \cdot [SPMPO - SDEAD] \qquad 3\text{-}49$$

Where: APMPI = working fluid availability at pump inlet, [kW]
HPMPI = working fluid enthalpy at pump inlet, [kJ/kg]
HDEAD = working fluid enthalpy at dead state conditions, [kJ/Kg]
TDEAD = Dead state temperature, [K]
SPMPI = working fluid entropy at pump inlet, [kJ/kg/K]
SDEAD = working fluid entropy at dead state conditions, [kJ/kg/K]

APMPO = working fluid availability at pump exit, [kW]
HPMPO = working fluid enthalpy at pump exit [kJ/kg]
SPMPO = working fluid entropy at pump exit, [kJ/kg/K]

With a control volume selected around the physical boundaries of the SIMPLE PUMP device, a steady state steady flow 2nd Law control volume analysis neglecting the kinetic and potential terms yields

$$WRPMPO = MPMPI \cdot [HPMPI - HPMPO - TDEAD \cdot (SPMPI - SPMPO)] \qquad 3\text{-}50$$

Where: WRPMPO = reversible work of pump process, [kW]
MPMPI = working fluid mass flow rate at pump inlet, [kg/sec]
HPMPI = working fluid enthalpy at pump inlet, [kJ/kg]
HPMPO = working fluid enthalpy at pump exit, [kJ/kg]
TDEAD = dead state temperature, [K]
SPMPI = working fluid entropy at pump inlet, [kJ/kg/K]
SPMPO = working fluid entropy at pump exit, [kJ/kg/K].

For the SIMPLE PUMP device, the irreversibility is defined as

$$IRPMPO = WRPMPO - WKPMPO \qquad 3\text{-}51$$

Where: IRPMPO = irreversibility of pump process, [kW]
WRPMPO = reversible work of pump process, [kW]
WKBRO = actual work done on the surrounds by pump process,.[kW]

Section 3.4.5 The SIMPLE PUMP Device Mass and Energy Balance

For the SIMPLE PUMP device, the mass balance error is defined as

$$MB = MPMPI - MPMPO \qquad 3\text{-}52$$

Where: MB = mass balance error for pump device, [kg/sec]
MPMPI = working fluid mass flow rate at pump inlet, [kg/sec]
MPMPO = working fluid mass flow rate at pump exit, [kg/sec]

For the SIMPLE PUMP device, the energy balance error is defined as

$$EB = MPMPI * HPMPI - MPMPO * HPMPO + XPMPO - WKPMPO \quad 3\text{-}53$$

Where: EB = energy balance error for pump device, [kW]
MPMPI = working fluid mass flow rate at pump inlet, [kg/sec]
HPMPI = working fluid enthalpy at pump inlet, [kJ/kg]
MPMPO = working fluid mass flow rate at pump exit, [kg/sec]
HPMPO = working fluid enthalpy at pump exit, [kJ/kg]
XPMPO = heat transferred from the surrounds during the pump process, [kW]
WKPMPO = work done on the surrounds by the pump process, [kW].

3.5.0 The SIMPLE PIPE Device

A pipe is a device which directs a working fluid from one location to a second location. The thermodynamic behavior of a pipe device is a working fluid pressure drop and a working fluid enthalpy decreases. Physically, the pressure drop is a result of a flow restriction within the pipe (such as a valve) or the interaction of a viscous working fluid and the pipe walls. The working fluid enthalpy decrease is a result of a hot working fluid interacting thermally with the pipe surrounds.

The symbolic representation for a SIMPLE PIPE device is shown in Figure 3-7.



Figure 3-7. Symbol for a SIMPLE PIPE device

Figure 3-8 shows the relevant state and device variables utilized within the RANKINE 3.0 source code. The conservation of mass, 1st law, and 2nd law application to the SIMPLE PIPE device will utilize the identical state and device variable nomenclature utilized with the RANKINE 3.0 source code. The variable nomenclature utilized by RANKINE 3.0 is defined in Table 2-12.

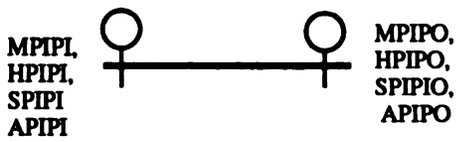


Figure 3-8. RANKINE 3.0 variables for the SIMPLE PIPE device

For the SIMPLE PIPE device, the conservation of mass, the 1st law of thermodynamics, and the 2nd law of thermodynamics are applied with a single control volume selected around the physical boundary of the device.

3.5.1 The SIMPLE PIPE Device Performance Parameters

The working fluid pressure drop within the SIMPLE PIPE device is quantified with a user specified pressure drop or percentage pressure drop. If a user specified pressure drop is specified, than the relationships between inlet and exit pressure is defined as

$$PPIPO = PPIPI - PLPIP \qquad 3\text{-}54$$

Where: PPIPO = working fluid pressure at pipe exit, [MPa]
PPIPI = working fluid pressure at pipe inlet, [MPa]
PLPIP = working fluid pressure loss between pipe inlet and exit, [MPa]

If a user specified percentage pressure loss is specified, than the relationships between inlet and exit pressure is defined as

$$PPIPO = PPIPI \cdot [1 - PPLPIP] \qquad 3\text{-}55$$

Where: PPIPO = working fluid pressure at pipe exit, [MPa]
PPIPI = working fluid pressure at pipe inlet, [MPa]
PPLPIP = working fluid percentage pressure loss between pipe inlet and exit, [-].

It should be noted that pipe percent pressure loss is based upon percent of inlet pressure, not percent of exit pressure.

The working fluid enthalpy drop within the SIMPLE PIPE device is quantified with a user specified enthalpy drop or percentage enthalpy drop. If a user specified enthalpy drop is specified, than the relationships between inlet and exit enthalpy is defined as

$$HPIPO = HPIPI - QLPIP \qquad 3\text{-}56$$

Where: HPIPO = working fluid enthalpy at pipe exit, [MPa]
HPIPI = working fluid enthalpy at pipe inlet, [MPa]
QLPIP = working fluid enthalpy loss between pipe inlet and exit, [MPa]

If a user specified percentage enthalpy loss is specified, than the relationships between inlet and exit enthalpy is defined as

$$HPIPO = HPIPI \cdot [1 - PQLPIP] \qquad 3\text{-}57$$

Where: HPIPO = working fluid enthalpy at pipe exit, [MPa]
HPIPI = working fluid enthalpy at pipe inlet, [MPa]
PQLPIP = working fluid percentage enthalpy loss between pipe inlet and exit, [-].

It should be noted that percent enthalpy loss is based upon percent of inlet enthalpy, not percent of exit enthalpy.

3.5.2 Mass Conservation For The SIMPLE PIPE Device

With a control volume selected around the physical boundaries of the SIMPLE PIPE device, the steady state steady flow mass conservation principle yields

$$MPIPO = MPIPI \qquad 3\text{-}58$$

Where: MPIPO = working fluid mass flow rate at the pipe exit, [kg/sec]
MPIPI = working fluid mass flow rate at the pipe inlet, [kg/sec].

3.5.3 1st Law Analysis For The SIMPLE PIPE Device

With a control volume selected around the physical boundaries of the SIMPLE PIPE device, a steady state steady flow 1st Law control volume analysis neglecting the kinetic and potential terms yields

$$XPIPO = MPIPO \cdot [HPIPO - HPIPI] \qquad 3\text{-}59$$

Where: XPIPO = heat transferred from the surrounds during the pipe process, [kW]
MPMPO = working fluid mass flow rate at the pipe exit, [kg/sec].
HPMPO = working fluid enthalpy at pipe exit, [kJ/kg]
HPMPI = working fluid enthalpy at pipe inlet, [kJ/kg]

Since the SIMPLE PUMP device does not do work on the surrounds, the SIMPLE PIPE device work term is zero. This term is stated below as

$$WKPIPO = 0 \qquad 3\text{-}60$$

Where: WKPMPO = work done on the surrounds during the pipe process, [kW].

3.5.4 2nd Law Analysis For The SIMPLE PIPE Device

The working fluid availability at each node denoted in Figure 3-8 is defined as

$$APIPI = HPIPI - HDEAD - TDEAD \cdot [SPIPI - SDEAD] \qquad 3\text{-}61$$

$$APIPO = HPIPO - HDEAD - TDEAD \cdot [SPIPO - SDEAD] \qquad 3\text{-}62$$

Where: APIPI = working fluid availability at pipe inlet, [kW]
HPIPI = working fluid enthalpy at pipe inlet, [kJ/kg]
HDEAD=working fluid enthalpy at dead state conditions, [kJ/Kg]
TDEAD = Dead state temperature, [K]

SPIPI = working fluid entropy at pipe inlet, [kJ/kg/K]
SDEAD = working fluid entropy at dead state conditions, [kJ/kg/K]
APIPO = working fluid availability at pipe exit, [kW]
HPIPO = working fluid enthalpy at pipe exit [kJ/kg]
SPIPO = working fluid entropy at pipe exit, [kJ/kg/K]

With a control volume selected around the physical boundaries of the pipe, a steady state steady flow 2nd Law control volume analysis neglecting the kinetic and potential terms yields

$$WRPIPO = MPIPI \cdot [HPIPI - HPIPO - TDEAD \cdot (SPIPI - SPIPO)] \qquad 3\text{-}63$$

Where: WRPIPO = reversible work of pipe process, [kW]
MPIPI = working fluid mass flow rate at pipe inlet, [kg/sec]
HPIPI = working fluid enthalpy at pipe inlet, [kJ/kg]
HPIPO = working fluid enthalpy at pipe exit, [kJ/kg]
TDEAD = dead state temperature, [K]
SPIPI = working fluid entropy at pipe inlet, [kJ/kg/K]
SPIPO = working fluid entropy at pipe exit, [kJ/kg/K].

For the SIMPLE PIPE DEVICE, the irreversibility is defined as

$$IRPIPO = WRPIPO - WKPIPO \qquad 3\text{-}64$$

Where: IRPIPO = irreversibility of pipe process, [kW]
WRPIPO = reversible work of pipe path, [kW]
WKPMPO = work done on the surrounds during the pipe process, [kW].

Section 3.5.5 The SIMPLE PIPE Device Mass and Energy Balance

For the SIMPLE PIPE DEVICE, the mass balance error is defined as

$$MB = MPIPI - MPIPO \qquad 3\text{-}65$$

Where: MB= mass balance error for pipe, [kg/sec]
MPIPI = working fluid mass flow rate at pipe inlet, [kg/sec]
MPIPO = working fluid mass flow rate at pipe exit, [kg/sec].

For the SIMPLE PIPE DEVICE, the energy balance error is defined as

$$EB = MPIPI * HPIPI - MPIPO * HPIPO + XPIPO - WKPIPO \qquad 3\text{-}66$$

Where: EB = energy balance error for pipe, [kW]
MPIPI = working fluid mass flow rate at pipe inlet, [kg/sec]
HPIPI = working fluid enthalpy at pipe inlet, [kJ/kg]
MPIPO = working fluid mass flow rate at pipe exit, [kg/sec]
HPIPO = working fluid enthalpy at pipe exit, [kJ/kg]
XPIPO = heat transferred from the surrounds during the pipe process, [kW]
WKPIPO = work done on the surrounds by the pipe process, [kW].

3.6.0 The SIMPLE JUNCTION Device

A junction is a device which is used to divide (or connect) a working fluid mass stream into multiple (or one) working fluid mass streams. The thermodynamic state of each mass steam is unaffected by the junction device.

The symbolic representation for a SIMPLE JUNCTION device with two inlets and two exits is shown in Figure 3-9. Even though only two inlets and two exits are shown in Fig. 3-9, RANKINE 3.0 is capable of modeling 10 inlets and 10 exits.

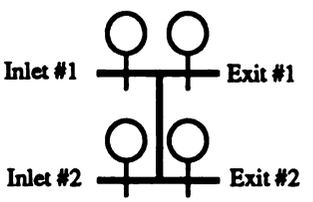


Figure 3-9. Symbol for a SIMPLE JUNCTION device

Figure 3-10 shows the relevant state and device variables utilized within the RANKINE 3.0 source code. The conservation of mass, 1st law, and 2nd law application to the

SIMPLE JUNCTION device will utilize the identical state and device variable nomenclature utilized with the RANKINE 3.0 source code. The variable nomenclature utilized by RANKINE 3.0 is defined in Table 2-12.

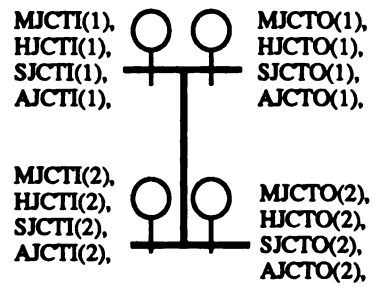


Figure 3-10. RANKINE 3.0 variables for the SIMPLE JUNCTION device

For the SIMPLE JUNCTION device, the conservation of mass, the 1st law of thermodynamics, and the 2nd law of thermodynamics are applied with a single control volume selected around the physical boundary of the device.

3.6.1 The SIMPLE JUNCTION Device Performance Parameters

The division of mass flow within the SIMPLE JUNCTION device may be stated with a user specified flow fraction. The flow fraction is defined as the ratio of a specific inlet (or exit) mass flow divided by the total device inlet (or exit) mass flow. For the junction inlet paths, this ratio is mathematically defined as

$$FJCTI(I) = \frac{MJCTI(I)}{\sum_{I} MJCTI(I)} \qquad 3\text{-}67$$

Where: FJCTI(I) = fraction of total inlet mass flow attributed to the Ith inlet,[-]
MJCTI(I) = working fluid mass flow rate at junction inlet #I, [kg/sec]

For the junction exit paths, this ratio is mathematically defined as

$$FJCTO(I) = \frac{MJCTO(I)}{\sum_{I} MJCTO(I)} \qquad 3\text{-}68$$

Where: FJCTO(I) = fraction of total inlet mass flow attributed to the Ith exit,[-]
MJCTO(I) = working fluid mass flow rate at junction exit #I, [kg/sec]

3.6.2 Mass Conservation For The SIMPLE JUNCTION Device

With a control volume selected around the physical boundaries of the boiler inlet to boiler exit path, the steady state steady flow mass conservation principle yields

$$\sum_{I} MJCTI(I) = \sum_{I} MJCTO(I) \qquad 3\text{-}69$$

Where: MJCTI(I) = working fluid mass flow rate at junction inlet #I, [kg/sec]
MJCTO(I) = working fluid mass flow rate at junction exit #I, [kg/sec].

3.6.3 1st Law Analysis For The SIMPLE JUNCTION Device

With a control volume selected around the physical boundaries of the SIMPLE JUNCTION device, a steady state steady flow 1st law control volume analysis neglecting the kinetic and potential terms yields

$$0 = \sum_{I} MJCTO(I) \cdot HJCTO(I) - \sum_{I} MJCTI(I) \cdot HJCTI(I) \qquad 3\text{-}70$$

Where: MJCTO(I) = working fluid mass flow rate at junction exit #I, [kg/sec]
HJCTO(I) = working fluid enthalpy at junction exit #I, [kJ/kg]
MJCTI(I) = working fluid mass flow rate at junction inlet #I, [kg/sec]
HJCTI(I) = working fluid enthalpy at junction inlet #I, [kJ/kg]

Since the SIMPLE JUNCTION device does no work on the surrounds and does not exchange heat with the surrounds, all SIMPLE JUNCTION device work terms and heat transfer terms are zero. These terms are stated below as

$$WKJCTO(I) = 0 \qquad 3\text{-}71$$

$$XJCTO(I) = 0 \qquad 3\text{-}72$$

Where: WKJCTO(I) = work done on the surrounds by the junction,.[kW]
XJCTO(I) = heat transferred from the surrounds during the junction process, [kW].

3.6.4 2nd Law Analysis For The SIMPLE JUNCTION Device

The working fluid availability at each node denoted in Figure 3-10 is defined as

$$AJCTI(I) = HJCTI(I) - HDEAD - TDEAD \cdot [SJCTI(I) - SDEAD] \qquad 3\text{-}73$$

$$AJCTO(I) = HJCTO(I) - HDEAD - TDEAD \cdot [SJCTO(I) - SDEAD] \qquad 3\text{-}74$$

Where: AJCTI(I) = working fluid availability at junction inlet #I, [kW]
HJCTI(I) = working fluid enthalpy at junction inlet #I, [kJ/kg]
HDEAD=working fluid enthalpy at dead state conditions, [kJ/Kg]
TDEAD = Dead state temperature, [K]
SJCTI(I) = working fluid entropy at junction inlet #I, [kJ/kg/K]
SDEAD = working fluid entropy at dead state conditions, [kJ/kg/K]
AJCTO(I) = working fluid availability at junction exit #I, [kW]
HJCTO(I) = working fluid enthalpy at junction exit #I, [kJ/kg]
SJCTO(I) = working fluid entropy at junction exit #I, [kJ/kg/K]

With a control volume selected around the physical boundaries of the SIMPLE JUNCTION device, a steady state steady flow 2nd law control volume analysis neglecting the kinetic and potential terms yields

$$WRJCTO = 0.0 \qquad 3\text{-}75$$

Where: WRBRO = reversible work of junction, [kW]

It should be noted that equation 3-75 is a direct result of the fact that the SIMPLE JUNCTION device does not change the state of the working fluid as it travels through the device (i.e., there is no thermodynamic process).

For the SIMPLE JUNCTION device, the irreversibility is defined as

$$IRJCTO(I) = 0.0 \qquad 3\text{-}76$$

Where: IRBRO = irreversibility of junction, [kW].

It should be noted that equation 3-75 is a direct result of the fact that the SIMPLE JUNCTION device does not change the state of the working fluid as it travels through the device (i.e., there is no thermodynamic process).

Section 3.6.5 The SIMPLE JUNCTION Device Mass and Energy Balance

For the SIMPLE JUNCTION device, the mass balance error is defined as

$$MB = \sum_{I} MJCTI(I) - \sum_{I} MJCTO(I) \qquad 3\text{-}77$$

Where: MB= mass balance error for junction, [kg/sec]
MJCTI(I) = working fluid mass flow rate at junction inlet #I, [kg/sec]
MJCTO(I) = working fluid mass flow rate at junction exit #I, [kg/sec].

For the SIMPLE JUNCTION device, the energy balance error is defined as

$$EB = \sum_{I} MJCTI(I) \cdot HJCTI(I) - \sum_{I} MJCTO(I) \cdot HJCTO(I) + \sum_{I} XJCTO(I) - \sum_{I} WKJCTO(I) \qquad 3\text{-}78$$

Where: EB= energy balance error for junction [kW]
MJCTI(I) = working fluid mass flow rate at junction inlet #I, [kg/sec]
HJCTI(I) = working fluid enthalpy at junction inlet #I, [kJ/kg].
MJCTO(I) = working fluid mass flow rate at junction exit #I, [kg/sec]
HJCTO(I) = working fluid enthalpy at junction exit #I, [kJ/kg]
XJCTO(I) = heat transferred from the surrounds during the junction process, [kW]
WKRHO(I) = work done on the surrounds by junction process, [kW].

3.7.0 The SIMPLE CONDENSER Device

A condenser is a device where working fluid energy is rejected to a cooling medium such as a lake, a river, or the atmosphere. In an ideal condenser, the working fluid experiences no pressure drop as it travels through the condenser and the fluid exits the condenser as a saturated liquid.

The symbolic representation for a SIMPLE CONDENSER device with two inlets is shown in Figure 3-11. Even though RANKINE 3.0 is capable of modeling upto 27 condenser inlets, only two are shown in Fig. 3-11.

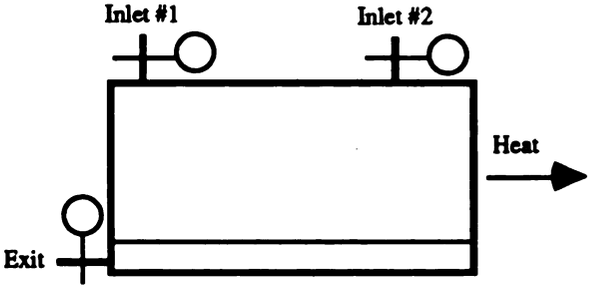


Figure 3-11. Symbol for a SIMPLE CONDENSER device

Figure 3-12 shows the relevant state and device variables utilized within the RANKINE 3.0 source code. The conservation of mass, 1st law, and 2nd law application to the SIMPLE CONDENSER device will utilize the identical state and device variable nomenclature utilized with the RANKINE 3.0 source code. The variable nomenclature utilized by RANKINE 3.0 is defined in Table 2-12.

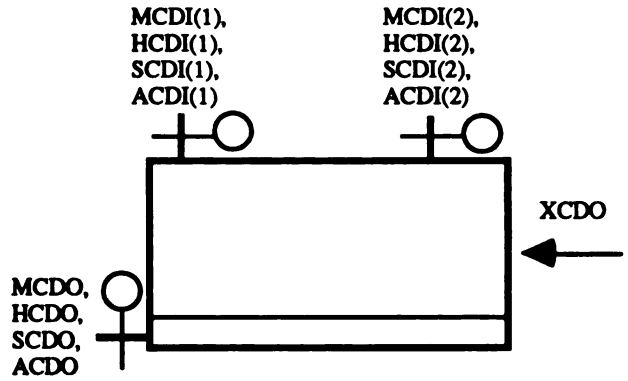


Figure 3-12. RANKINE 3.0 variables for the SIMPLE CONDENSER device

For the SIMPLE CONDENSER device, the conservation of mass, the 1st law of thermodynamics, and the 2nd law of thermodynamics are applied with a single control volume selected around the physical boundary of the device.

3.7.1 The SIMPLE CONDENSER Device Performance Parameters

The SIMPLE CONDENSER device does not have any device performance parameters.

3.7.2 Mass Conservation For The SIMPLE CONDENSER Device

With a control volume selected around the physical boundaries of the SIMPLE CONDENSER device, the steady state steady flow mass conservation principle yields

$$\sum_{I} MCDI(I) = MCDO \qquad 3\text{-}79$$

Where: MCDI(I) = working fluid mass flow rate at the condenser inlet #I, [kg/sec]
MCDO = working fluid mass flow rate at the condenser exit, [kg/sec].

3.7.3 1st Law Analysis For The SIMPLE CONDENSER Device

With a control volume selected around the SIMPLE CONDENSER device, a steady state steady flow 1st law control volume analysis neglecting the kinetic and potential terms yields

$$XCDO = MCDO \cdot HCDO - \sum_{I} MCDI(I) \cdot HCDI(I) \qquad 3\text{-}80$$

Where: XJCTO = heat transferred from the surrounds during the condensing process, [kW]
MCDO(I) = working fluid mass flow rate at condenser exit, [kg/sec]
HCDO(I) = working fluid enthalpy at condenser exit, [kJ/kg]
MCDI(I) = working fluid mass flow rate at condenser inlet #I, [kg/sec]
HCDI(I) = working fluid enthalpy at condenser inlet #I, [kJ/kg].

It should be noted that the SIMPLE CONDENSER model assumes that condenser exit state is a saturated liquid.

Since the SIMPLE CONDENSER device does no work on the surrounds, the SIMPLE CONDENSER device work term is zero. This term is stated below as

$$WKCDO = 0 \qquad 3\text{-}81$$

Where: WKCDO = work done on the surrounds by the condenser,.[kW]

3.7.4 2nd Law Analysis For The SIMPLE CONDENSER Device

The working fluid availability at each node denoted in Figure 3-12 is defined as

$$ACDI(I) = HCDI(I) - HDEAD - TDEAD \cdot [SCDI(I) - SDEAD] \qquad 3\text{-}82$$

$$ACDO = HCDO - HDEAD - TDEAD \cdot [SCDO - SDEAD] \qquad 3\text{-}83$$

Where: ACDI(I) = working fluid availability at condenser inlet #I, [kW]
HCDI(I) = working fluid enthalpy at condenser inlet #I, [kJ/kg]
HDEAD=working fluid enthalpy at dead state conditions, [kJ/Kg]

TDEAD = Dead state temperature, [K]
SCDI(I) = working fluid entropy at condenser inlet #I, [kJ/kg/K]
SDEAD = working fluid entropy at dead state conditions, [kJ/kg/K]
ACDO = working fluid availability at condenser exit, [kW]
HCDO = working fluid enthalpy at condenser exit [kJ/kg]
SCDO = working fluid entropy at condenser exit, [kJ/kg/K]

With a control volume selected around the physical boundaries of the SIMPLE CONDENSER device, a steady state steady flow 2nd Law control volume analysis neglecting the kinetic and potential terms yields

$$WRCDO = \sum_{I} (MCDI(I) \cdot [HCDI(I) - HCDO - TDEAD \cdot (SCDI(I) - SCDO)]) \qquad 3\text{-}84$$

Where: WRCDO = reversible work of condenser process, [kW]
MCDI(I) = working fluid mass flow rate at condenser inlet #I, [kg/sec]
HCDI(I) = working fluid enthalpy at condenser inlet #I, [kJ/kg]
HCDO = working fluid enthalpy at condenser exit [kJ/kg]
TDEAD = Dead state temperature, [K]
SCDI(I) = working fluid entropy at condenser inlet #I, [kJ/kg/K]
SCDO = working fluid entropy at condenser exit, [kJ/kg/K]

For the SIMPLE CONDENSER device, the irreversibility is defined as

$$IRCDO = WRCDO - WKCDO \qquad 3\text{-}85$$

Where: IRCDO = irreversibility of condenser process, [kW]
WRCDO = reversible work of condenser process, [kW]
WKCDO = work done on the surrounds by the condenser,.[kW]

Section 3.7.5 The SIMPLE CONDENSER Device Mass and Energy Balance

For the SIMPLE CONDENSER device, the mass balance error is defined as

$$MB = \sum_{I} MCDI(I) - MCDO \qquad 3\text{-}86$$

Where: MB= mass balance error for condenser, [kg/sec]
MCDI(I) = working fluid mass flow rate at condenser inlet #I, [kg/sec]
MCDO = working fluid mass flow rate at condenser exit, [kg/sec].

For the SIMPLE CONDENSER device, the energy balance error is defined as

$$EB = \sum_{I} MCDI(I) \cdot HCDI(I) - MCDO \cdot HCDO + XCDO - WKCDO \qquad 3\text{-}87$$

Where: EB= energy balance error for condenser, [kW]
MCDI(I) = working fluid mass flow rate at condenser inlet #I, [kg/sec]
HCDI(I) = working fluid enthalpy at condenser inlet #I, [kJ/kg]
MCDO = working fluid mass flow rate at condenser exit, [kg/sec].
HCDO = working fluid enthalpy at condenser exit [kJ/kg]
XCDO = heat transferred from the surrounds during the condensing process, [kW]
WKCDO = work done on the surrounds by the condenser,.[kW]

3.8.0 The SIMPLE HEAT LOAD Device

A heat load is a device which transfers heat between the working fluid and the surrounds. Usually, a heat load device is used in the modeling of co-generation power systems.

The symbolic representation for a SIMPLE HEAT LOAD device is shown in Figure 3-13.

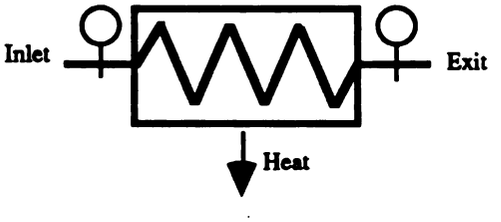


Figure 3-13. Symbol for a SIMPLE HEAT LOAD device

Figure 3-8 shows the relevant state and device variables utilized within the RANKINE 3.0 source code. The conservation of mass, 1st law, and 2nd law application to the SIMPLE HEAT LOAD device will utilize the identical state and device variable nomenclature utilized with the RANKINE 3.0 source code. The variable nomenclature utilized by RANKINE 3.0 is defined in Table 2-12.

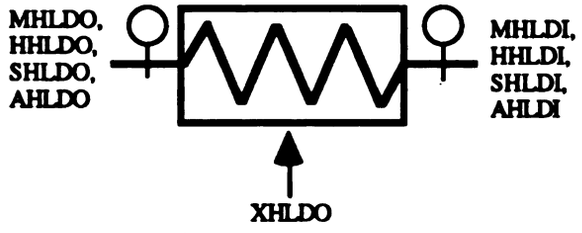


Figure 3-14. RANKINE 3.0 variables for the SIMPLE HEAT LOAD device

For the SIMPLE HEAT LOAD device, the conservation of mass, the 1st law of thermodynamics, and the 2nd law of thermodynamics are applied with a single control volume selected around the physical boundary of the device.

3.8.1 The SIMPLE HEAT LOAD Device Performance Parameters

The SIMPLE HEAT LOAD device does not have any device performance parameters.

3.8.2 Mass Conservation For The SIMPLE HEAT LOAD Device

With a control volume selected around the physical boundaries of the SIMPLE HEAT LOAD device, the steady state steady flow mass conservation principle yields

$$MHLDI = MHLDO \qquad 3\text{-}88$$

Where: MHLDI = working fluid mass flow rate at the heat load inlet, [kg/sec]
MHLDO = working fluid mass flow rate at the heat load exit, [kg/sec].

3.8.3 1st Law Analysis For The SIMPLE HEAT LOAD Device

With a control volume selected around the physical boundaries of the SIMPLE HEAT LOAD device, a steady state steady flow 1st Law control volume analysis neglecting the kinetic and potential terms yields

$$XHLDO = MHLDO \cdot HHLDO - MHLDI \cdot HHLDI \qquad 3\text{-}89$$

Where: XHLDO = heat transferred from the surrounds during the heat load process, [kW]
MHLDO = working fluid mass flow rate at heat load exit, [kg/sec]
HHLDO = working fluid enthalpy at heat load exit, [kJ/kg]
MHLDI = working fluid mass flow rate at heat load inlet, [kg/sec]
HHLDI = working fluid enthalpy at heat load inlet, [kJ/kg].

Since the SIMPLE HEAT LOAD device does no work on the surrounds, all SIMPLE HEAT LOAD device work terms are zero. These terms are stated below as

$$WKHLDO = 0 \qquad 3\text{-}90$$

Where: WKHLDO = work done on the surrounds by the heat load process ,.[kW]

3.8.4 2nd Law Analysis For The SIMPLE HEAT LOAD Device

The working fluid availability at each node denoted in Figure 3-14 is defined as

$$AHLDI = HHLDI - HDEAD - TDEAD \cdot [SHLDI - SDEAD] \qquad 3\text{-}91$$

$$AHLDO = HHLDO - HDEAD - TDEAD \cdot [SHLDO - SDEAD] \qquad 3\text{-}92$$

Where: AHLDI = working fluid availability at heat load inlet, [kW]
HHLDI = working fluid enthalpy at heat load inlet, [kJ/kg]
HDEAD=working fluid enthalpy at dead state conditions, [kJ/Kg]
TDEAD = Dead state temperature, [K]
SHLDI = working fluid entropy at heat load inlet, [kJ/kg/K]
SDEAD = working fluid entropy at dead state conditions, [kJ/kg/K]

AHLDO = working fluid availability at heat load exit, [kW]
HHLDO = working fluid enthalpy at heat load exit [kJ/kg]
SHLDO = working fluid entropy at heat load exit, [kJ/kg/K]

With a control volume selected around the physical boundaries of the SIMPLE HEAT LOAD device, a steady state steady flow 2nd Law control volume analysis neglecting the kinetic and potential terms yields

$$WRHLDO = MHLDI \cdot [HHLDI - HHLDO - TDEAD \cdot (SHLDI - SHLDO)] \qquad 3\text{-}93$$

Where: WRHLDO = reversible work of heat load process, [kW]
MHLDI = working fluid mass flow rate at heat load inlet, [kg/sec]
HHLDI = working fluid enthalpy at heat load inlet, [kJ/kg]
HHLDO = working fluid enthalpy at heat load exit, [kJ/kg]
TDEAD = dead state temperature, [K]
SHLDI = working fluid entropy at heat load inlet, [kJ/kg/K]
SHLDO = working fluid entropy at heat load exit, [kJ/kg/K]

For the SIMPLE HEAT LOAD device, the irreversibility is defined as

$$IRHLDO = WRHLDO - WKHLDO \qquad 3\text{-}94$$

Where: IRHLDO = irreversibility of heat load process, [kW]
WRHLDO = reversible work of heat load process, [kW]
WKHLDO = work done on the surrounds during the heat load process,.[kW]

Section 3.8.5 The SIMPLE HEAT LOAD Device Mass and Energy Balance

For the SIMPLE HEAT LOAD device, the mass balance error is defined as

$$MB = MHLDI - MHLDO \qquad 3\text{-}95$$

Where: MB= mass balance error for heat load device, [kg/sec]
MHLDI = working fluid mass flow rate at heat load inlet, [kg/sec]

MHLDO = working fluid mass flow rate at heat load exit, [kg/sec].

For the SIMPLE HEAT LOAD device, the energy balance error is defined as

$$EB = MHLDI * HHLDI - MHLDO * HHLDO + XHLDO - WKHLDO \qquad 3\text{-}96$$

Where: EB= energy balance error for heat load device, [kW]
MHLDI = working fluid mass flow rate at heat load inlet, [kg/sec]
HHLDI = working fluid enthalpy at heat load inlet, [kJ/kg]
MHLDO = working fluid mass flow rate at heat load exit, [kg/sec]
HHLDO = working fluid enthalpy at heat load exit, [kJ/kg].
XHLDO = heat transferred from the surrounds during the heat load process, [kW]
WKHLDO = work done on the surrounds by the heat load process ,.[kW].

3.9.0 The SIMPLE OFW HEATER Device

An open feed water (OFW) heater device is a mixing chamber in which streams of different energies are mixed to form a stream with an intermediate energy. Ideally, the mixture leaves the open feed water heater as a saturated liquid. It should be noted that since mixing occurs, the mixing of the extracted steam and the feed water is a constant pressure process.

The symbolic representation for a SIMPLE OFW HEATER device is shown in Figure 3-15.

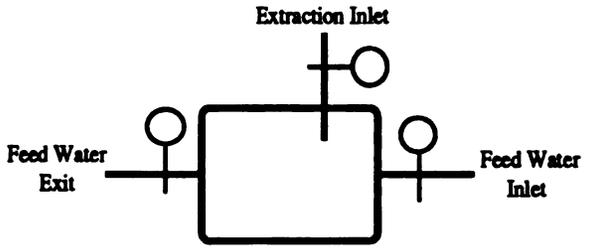


Figure 3-15. Symbol for a SIMPLE OFW HEATER device

Figure 3-16 shows the relevant state and device variables utilized within the RANKINE 3.0 source code. The conservation of mass, 1st law, and 2nd law application to the SIMPLE OFW HEATER device will utilize the identical state and device variable nomenclature utilized with the RANKINE 3.0 source code. The variable nomenclature utilized by RANKINE 3.0 is defined in Table 2-12.

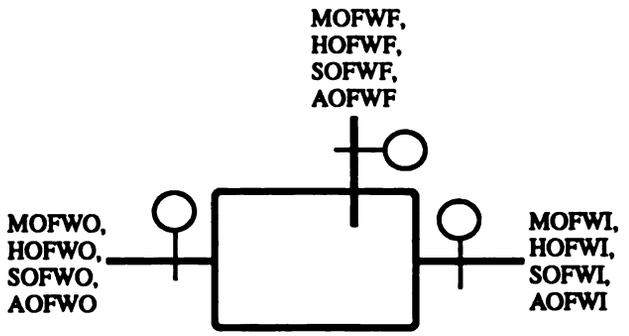


Figure 3-16. RANKINE 3.0 variables for the SIMPLE OFW HEATER device

For the SIMPLE OFW HEATER device, the conservation of mass, the 1st law of thermodynamics, and the 2nd law of thermodynamics are applied with a single control volume selected around the physical boundary of the device.

3.9.1 The SIMPLE OFW HEATER Device Performance Parameters

The SIMPLE OFW HEATER device does not have any device performance parameters.

3.92 Mass Conservation For The SIMPLE OFW HEATER Device

With a control volume selected around the physical boundaries of the SIMPLE OFW HEATER Device, the steady state steady flow mass conservation principle yields

$$MOFWI + MOFWF = MOFWO \qquad 3\text{-}97$$

Where: MOFWII = working fluid mass flow rate at the open feed water heater inlet, [kg/sec]

MOFWF = working fluid mass flow rate at the open feed water extraction

inlet exit, [kg/sec].

MOFWO = working fluid mass flow rate at the open feed water heater exit, [kg/sec].

3.9.3 1st Law Analysis For The SIMPLE OFW HEATER Device

With a control volume selected around the physical boundaries of the SIMPLE OFW device, a steady state steady flow 1st Law control volume analysis neglecting the kinetic and potential terms yields

$$0 = MOFWI \cdot HOFWI + MOFWF \cdot HOFWF - MOFWO \cdot HOFWO \qquad 3\text{-}98$$

Where:

MOFWI = working fluid mass flow rate at the open feed water heater inlet, [kg/sec]

HOFWI = working fluid enthalpy at open feed water heater inlet, [kJ/kg]

MOFWF = working fluid mass flow rate at the open feed water extraction inlet exit, [kg/sec].

HOFWF = working fluid enthalpy at open feed water heater extraction inlet, [kJ/kg]

MOFWO = working fluid mass flow rate at the open feed water heater exit, [kg/sec].

HOFWO = working fluid enthalpy at open feed water heater exit, [kJ/kg]

Since the SIMPLE OFW HEATER device does no work on the surrounds and does not exchange heat with the surrounds, all SIMPLE OFW HEATER device work terms and heat transfer terms are zero. These terms are stated below as

$$WKOFWO(I) = 0 \qquad 3\text{-}99$$

$$XOFWO(I) = 0 \qquad 3\text{-}100$$

Where:

WKOFWO(I) = work done on the surrounds by the open feed water heater device,.[kW]

XOFWO(I) = heat transferred from the surrounds during the open feed water heater process, [kW].

3.9.4 2nd Law Analysis For The SIMPLE OFW HEATER Device

The working fluid availability at each node denoted in Figure 3-16 is defined as

$$AOFWI = HOFWI - HDEAD - TDEAD \cdot [SOFWI - SDEAD] \quad 3\text{-}101$$

$$AOFWF = HOFWF - HDEAD - TDEAD \cdot [SOFWF - SDEAD] \quad 3\text{-}102$$

$$AOFWO = HOFWO - HDEAD - TDEAD \cdot [SOFWO - SDEAD] \quad 3\text{-}103$$

Where:
AOFWI = working fluid availability at open feed water heater inlet, [kW]
HOFWI = working fluid enthalpy at open feed water heater inlet, [kJ/kg]
HDEAD=working fluid enthalpy at dead state conditions, [kJ/Kg]
TDEAD = Dead state temperature, [K]
SOFWI = working fluid entropy at open feed water heater inlet, [kJ/kg/K]
SDEAD = working fluid entropy at dead state conditions, [kJ/kg/K]
AOFWF = working fluid availability at extraction inlet, [kW]
HOFWF = working fluid enthalpy at extraction inlet [kJ/kg]
SOFWF = working fluid entropy at extraction inlet, [kJ/kg/K]
AOFWO = working fluid availability at open feed water exit, [kW]
HOFWO = working fluid enthalpy at open feed water exit [kJ/kg]
SOFWO = working fluid entropy at open feed water exit, [kJ/kg/K].

With a control volume selected around the physical boundaries of the SIMPLE OFW HEATER device, a steady state steady flow 2nd Law control volume analysis neglecting the kinetic and potential terms yields

$$WROFWO = MOFWI \cdot [HOFWI - HOFWO - TDEAD \cdot (SOFWI - SOFWO)] + MOFWF \cdot [HOFWF - HOFWO - TDEAD \cdot (SOFWF - SOFWO)] \quad 3\text{-}104$$

Where:
WROFWO = reversible work of open feed water heater process, [kW]
MOFWI = working fluid mass flow rate at the open feed water heater inlet, [kg/sec]

HOFWI = working fluid enthalpy at open feed water heater inlet, [kJ/kg]
HOFWO = working fluid enthalpy at open feed water heater exit, [kJ/kg]
TDEAD = Dead state temperature, [K]
SOFWI = working fluid entropy at open feed water heater inlet, [kJ/kg/K]
SOFWO = working fluid entropy at open feed water exit, [kJ/kg/K].
MOFWF = working fluid mass flow rate at the open feed water extraction, [kg/sec]
HOFWF = working fluid enthalpy at open feed water heater extraction inlet, [kJ/kg]
SOFWF = working fluid entropy at extraction inlet, [kJ/kg/K]

For the SIMPLE OFW HEATER device, the irreversibility is defined as

$$IROFWO = WROFWO - WKOFWO \qquad 3\text{-}105$$

Where: IROFWO = irreversibility of open feed water heater process, [kW]
WROFWO = reversible work of open feed water heater process, [kW]
WKBRO = work done on the surrounds during open feed water heater process,.[kW]

Section 3.9.5 The SIMPLE OFW HEATER Device Mass and Energy Balance

For the SIMPLE OFW HEATER device, the mass balance error is defined as

$$MB = MOFWI + MOFWF - MOFWO \qquad 3\text{-}106$$

Where: MB= mass balance error for open feed water heater device, [kg/sec]
MOFWI = working fluid mass flow rate at the open feed water heater inlet, [kg/sec]
MOFWF = working fluid mass flow rate at the open feed water extraction, [kg/sec]
MOFWO = working fluid mass flow rate at the open feed water heater exit, [kg/sec].

For the SIMPLE OFW HEATER device, the energy balance error is defined as

$$EB = MOFWI \cdot HOFWI + MOFWF \cdot HOFWF - MOFWO \cdot HOFWO + XOFWO - WKOFWO \quad \text{3-107}$$

Where:

EB= energy balance error for open feed water heater device, [kW]

MOFWI = working fluid mass flow rate at the open feed water heater inlet, [kg/sec]

HOFWI = working fluid enthalpy at the open feed water heater inlet, [kJ/kg]

MOFWF = working fluid mass flow rate at the open feed water extraction, [kg/sec]

HOFWF = working fluid enthalpy at the open feed water extraction, [kJ/kg]

MOFWO = working fluid mass flow rate at the open feed water heater exit, [kg/sec].

HOFWO = working fluid enthalpy at the open feed water heater exit, [kg/sec].

WKOFWO(I) = work done on the surrounds by the open feed water heater device,.[kW]

XOFWO(I) = heat transferred from the surrounds during the open feed water heater process, [kW].

3.10.0 The SIMPLE STEAM TRAP CFW Device

A steam trap closed feed water (CFW) heater is a heat transfer device where heat is transferred between two fluid streams at different temperatures. Since the two streams do not mix, the streams can be at different pressures. The steam trap within the device permits the shell side liquid to pass but restricts the flow of steam from the shell side exit. As a result of the steam trap, the shell side working fluid usually exits the device as a saturated or subcooled liquid.

The symbolic representation for a SIMPLE STEAM TRAP CFW device with one drain inlet is shown in Figure 3-17. Even though RANKINE 3.0 is capable of modeling upto 10 drain inlets, only one drain inlet is shown in Fig. 3-17.

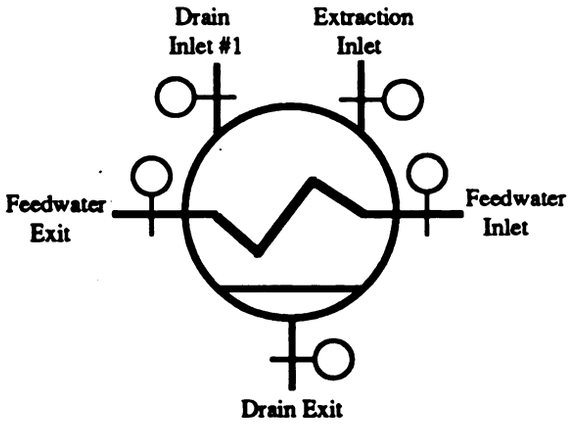


Figure 3-17. Symbol for a SIMPLE STEAM TRAP CFW device

Figure 3-18 shows the relevant state and device variables utilized within the RANKINE 3.0 source code. The conservation of mass, 1st law, and 2nd law application to the SIMPLE STEAM TRAP CFW device will utilize the identical state and device variable nomenclature utilized with the RANKINE 3.0 source code. The variable nomenclature utilized by RANKINE 3.0 is defined in Table 2-12.

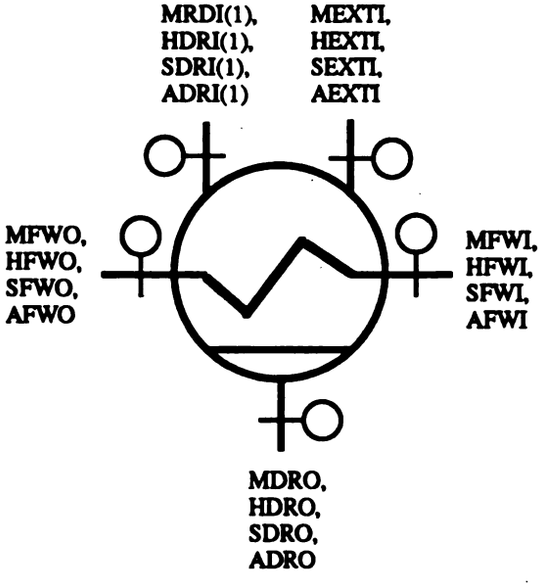


Figure 3-18. RANKINE 3.0 variables for the SIMPLE STEAM TRAP CFW device

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In order to provide the maximum amount of thermodynamic information to the user, the conservation of mass, the 1st law of thermodynamics, and the 2nd law of thermodynamics are applied to multiple control volumes within the SIMPLE BOILER device. The first control volume is selected around the heat exchanger shell side volume and the second control volume is selected around the heat exchanger tube side volume.

3.10.1 The SIMPLE STEAM TRAP CFW Device Performance Parameters

The working fluid pressure drop within the SIMPLE STEAM TRAP CFW device is quantified with a user specified pressure drop or percentage pressure drop.

If a user specified pressure drop is specified for either the feed water or the extraction steam, than the relationships between inlet and exit pressure are defined as

$$PDRO = PEXTI - PLEXT \qquad 3\text{-}108$$

$$PFWO = PFWI - PLFW \qquad 3\text{-}109$$

Where: PDRO = working fluid pressure at drain exit, [MPa]
PEXTI = working fluid pressure at extraction inlet, [MPa]
PLEXT = working fluid pressure drop between extraction inlet and drain exit, [MPa]
PFWO = working fluid pressure at feed water exit, [MPa]
PFWI = working fluid pressure at feed water inlet, [MPa]
PLFW = working fluid pressure loss between feed water inlet and exit, [MPa]

If a user specified percentage pressure drop is specified for either the feed water or the extraction steam, than the relationships between inlet and exit pressure are defined below

$$PDRO = PEXTI \cdot [1 - PPLEXT] \qquad 3\text{-}110$$

$$PFWO = PFWI \cdot [1 - PPLFW] \qquad 3\text{-}111$$

Where: PDRO = working fluid pressure at drain exit, [MPa]

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PEXTI = working fluid pressure at extraction inlet, [MPa]
PPLEXT = working fluid percentage pressure drop between extraction inlet and drain exit, [-]
PFWO = working fluid pressure at feed water exit, [MPa]
PFWI = working fluid pressure at feed water inlet, [MPa]
PPLFW = working fluid percentage pressure drop between feed water inlet and exit, [-]

It should be noted that percent pressure losses are based upon percent of inlet pressure, not percent of exit pressure.

The thermodynamic performance of a steam trap closed feed water heater may be defined with two user specified parameters; the terminal temperature difference and the approach temperature difference.

If a user specified terminal temperature difference is provided, then the relationship between the extraction inlet saturation temperature and the feed water exit temperature is defined as

$$TD = T_{sat}(@PEXTI) - TFWO \qquad 3\text{-}112$$

Where: TD = terminal temperature difference, [K]
Tsat(@PEXTI) = saturation temperature of extraction inlet pressure, [K]
TFWO = working fluid temperature at feed water exit, [K]

If a user specified approach temperature difference is provided, then the relationship between the drain exit temperature and the feed water inlet temperature is defined as

$$APPRCH = TDRO - TFWI \qquad 3\text{-}113$$

Where: APPRCH = approach temperature difference, [K]
TDRO = working fluid temperature at drain exit, [K]
TFWI = working fluid temperature at feed water inlet, [K]

3.10.2 Mass Conservation For The SIMPLE STEAM TRAP CFW Device

With a control volume selected around the physical boundaries of the heat exchanger shell side, the steady state steady flow mass conservation principle yields

$$MEXTI + \sum_{I} MDRI(I) = MDRO \qquad 3\text{-}114$$

Where: MEXTI = working fluid mass flow rate at the extraction inlet, [kg/sec]
MDRI(I) = working fluid mass flow rate at drain inlet #I, [kg/sec].
MDRO = working fluid mass flow rate at the drain exit, [kg/sec].

With a control volume selected around the physical boundaries of the heat exchanger tube side, the steady state conservation of mass yields

$$MFWI = MFWO \qquad 3\text{-}115$$

Where: MFWI = working fluid mass flow rate at the feed water inlet, [kg/sec]
MFWO = working fluid mass flow rate at the feed water exit, [kg/sec].

3.10.3 1st Law Analysis For The SIMPLE STEAM TRAP CFW Device

With a control volume selected around the physical boundaries of the heat exchanger shell side, a steady state steady flow 1st law control volume analysis neglecting the kinetic and potential terms yields

$$XDRO = MEXTI \cdot [HEXTI - HDRO] + \sum_{I} (MDRI(I) \cdot [HDRI(I) - HDRO]) \qquad 3\text{-}116$$

Where: XDRO = heat transferred from the heat exchanger tube side during the shell side process, [kW]
MEXTI = working fluid mass flow rate at extraction inlet, [kg/sec]
HEXTIO = working fluid enthalpy at extraction inlet, [kJ/kg]
HDRO = working fluid enthalpy at drain exit, [kJ/kg].
MDRI(I) = working fluid mass flow rate at drain inlet #I, [kg/sec]
HDRI(I) = working fluid enthalpy at drain inlet #I, [kJ/kg].

With a control volume selected around the physical boundaries of the heat exchanger tube side, a steady state 1st law control volume analysis neglecting the kinetic and potential terms yields

$$XFWO = MFWO \cdot HFWO - MFWI \cdot HFWI \qquad 3\text{-}117$$

Where: XFWO = heat transferred from the heat exchanger tube side during the tube side process, [kW]
MFWO = working fluid mass flow rate at feed water exit, [kg/sec]
HFWO = working fluid enthalpy at feed water exit, [kJ/kg]
MFWI = working fluid mass flow rate at feed water inlet, [kg/sec]
HFWI = working fluid enthalpy at feed water inlet, [kJ/kg].

Since the SIMPLE STEAM TRAP CFW device does no work, all SIMPLE STEAM TRAP CFW device work terms are zero. These terms are stated below as

$$WKFWO = 0 \qquad 3\text{-}118$$

$$WKDRO = 0 \qquad 3\text{-}119$$

Where: WKFWO = work done on the surrounds during the heat exchanger tube side process , [kW].
WKDRO = work done on the surrounds during the heat exchanger shell side process,.[kW]

3.10.4 2nd Law Analysis For The SIMPLE STEAM TRAP CFW Device

The working fluid availability at each node denoted in Figure 3-18 is defined as

$$AFWI = HFWI - HDEAD - TDEAD \cdot [SFWI - SDEAD] \qquad 3\text{-}120$$

$$AFWO = HFWO - HDEAD - TDEAD \cdot [SFWO - SDEAD] \qquad 3\text{-}121$$

$$ADRI(I) = HDRI(I) - HDEAD - TDEAD \cdot [SDRI(I) - SDEAD] \qquad 3\text{-}122$$

$$AEXTI = HEXTI - HDEAD - \text{TDEAD} \cdot [SEXTI - SDEAD] \qquad 3\text{-}123$$

$$ADRO = HDRO - HDEAD - \text{TDEAD} \cdot [SDRO - SDEAD] \qquad 3\text{-}124$$

Where:

AFWI = working fluid availability at feed water inlet, [kW]
HFWI = working fluid enthalpy at feed water inlet, [kJ/kg]
HDEAD=working fluid enthalpy at dead state conditions, [kJ/Kg]
TDEAD = Dead state temperature, [K]
SFWI = working fluid entropy at feed water inlet, [kJ/kg/K]
SDEAD = working fluid entropy at dead state conditions, [kJ/kg/K]
AFWO = working fluid availability at feed water exit, [kW]
HFWO = working fluid enthalpy at feed water exit [kJ/kg]
SFWO = working fluid entropy at feed water exit, [kJ/kg/K]
ADRI(I) = working fluid availability at drain inlet #I, [kW]
HDRI(I) = working fluid enthalpy at drain inlet #I, [kJ/kg]
SDRI(I) = working fluid entropy at drain inlet #I, [kJ/kg/K]
AEXTI = working fluid availability at extraction inlet, [kW]
HEXTI = working fluid enthalpy at extraction inlet, [kJ/kg]
SEXTI = working fluid entropy at extraction inlet,[kJ/kg/K]
ADRO = working fluid availability at drain exit, [kW]
HDRO = working fluid enthalpy at drain exit, [kJ/kg]
SDRO = working fluid entropy at drain exit,[kJ/kg/K]

With a control volume selected around the physical boundaries of the heat exchanger shell side, a steady state steady flow 2nd law control volume analysis neglecting the kinetic and potential terms yields

$$WRDRO = MEXTI \cdot [HEXTI - HDRO - \left(\frac{TFWO + TFWI}{2}\right) \cdot (SEXTI - SDRO)] + \sum_I MDRI(I) \cdot [HDRI(I) - HDRO - \left(\frac{TFWO + TFWI}{2}\right) \cdot (SDRI(I) - SDRO)] \qquad 3\text{-}125$$

Where:

WRDRO = reversible work of shell side process, [kW]
MEXTI = working fluid mass flow rate at the extraction inlet, [kg/sec]

HEXTI = working fluid enthalpy at extraction inlet, [kJ/kg]
HDRO = working fluid enthalpy at drain exit, [kJ/kg]
TFWO = working fluid temperature at feed water exit, [K]
TFWI = working fluid temperature at feed water inlet, [K]
SEXTI = working fluid entropy at extraction inlet,[kJ/kg/K]
SDRO = working fluid entropy at drain exit,[kJ/kg/K]
MDRI(I) = working fluid mass flow rate at drain inlet #I, [kg/sec].
HDRI(I) = working fluid enthalpy at drain inlet #I, [kJ/kg]
SDRI(I) = working fluid entropy at drain inlet #I, [kJ/kg/K]

With a control volume selected around the physical boundaries of heat exchanger tube side, a steady state 2nd law control volume analysis neglecting the kinetic and potential terms yields

$$WRFWO = MFWO \cdot [HFWI - HFWO - T_{sat}(@PEXTI) \cdot (SFWI - SFWO)] \qquad 3\text{-}126$$

Where:
WRFWO = reversible work of tube side process, [kW]
MFWO = working fluid mass flow rate at feed water exit, [kg/sec]
HFWI = working fluid enthalpy at feed water inlet, [kJ/kg]
HFWO = working fluid enthalpy at feed water exit [kJ/kg]
Tsat(@PEXTI) = saturation temperature of extraction inlet pressure, [K]
SFWI = working fluid entropy at feed water inlet, [kJ/kg/K]
SFWO = working fluid entropy at feed water exit, [kJ/kg/K]

For the working fluid traveling within the heat exchanger shell side, the irreversibility is defined as

$$IRDRO = WRDRO - WKDRO \qquad 3\text{-}127$$

Where:
IRDRO = irreversibility of heat exchanger shell side process, [kW]
WRDRO = reversible work of heat exchanger shell side process, [kW]
WKDRO = work done on the surrounds during the heat exchanger shell side process,.[kW]

For the working fluid traveling within the heat exchanger tube side, the irreversibility is defined as

$$IRFWO = WRFWO - WKFWO \qquad 3\text{-}128$$

Where: IRFWO = irreversibility of heat exchanger tube side process, [kW]
WRFWO = reversible work of heat exchanger tube side process, [kW]
WKFWO = work done on the surrounds during the heat exchanger tube side process , [kW].

Section 3.10.5 The SIMPLE STEAM TRAP CFW Device Mass and Energy Balance

For the working fluid traveling within heat exchanger shell side, the mass balance error is defined as

$$MB = MEXTI + \sum_{I} MDRI(I) - MDRO \qquad 3\text{-}129$$

Where: MB= mass balance error for heat exchanger shell side, [kg/sec]
MEXTI = working fluid mass flow rate at the extraction inlet, [kg/sec]
MDRI(I) = working fluid mass flow rate at drain inlet #I, [kg/sec].
MDRO = working fluid mass flow rate at the drain exit, [kg/sec].

For the working fluid traveling within heat exchanger tube side, the mass balance error is defined as

$$MB = MFWI - MFWO \qquad 3\text{-}130$$

Where: MB= mass balance error for heat exchanger tube side, [kg/sec]
MFWI = working fluid mass flow rate at feed water inlet, [kg/sec]
MFWO = working fluid mass flow rate at feed water exit, [kg/sec]

For the working fluid traveling within the heat exchanger shell side, the energy balance error is defined as

$$EB = MEXTI \cdot HEXTI + \sum_{I} MDRI(I) \cdot HDRI(I) - MDRO \cdot HDRO + XDRO - WKDRO \qquad 3\text{-}131$$

Where: EB= energy balance error for heat exchanger shell side, [kW]
MEXTI = working fluid mass flow rate at the extraction inlet, [kg/sec]
HEXTI = working fluid enthalpy at extraction inlet, [kJ/kg]
MDRI(I) = working fluid mass flow rate at drain inlet #I, [kg/sec].
HDRI(I) = working fluid enthalpy at drain inlet #I, [kJ/kg]
MDRO = working fluid mass flow rate at drain exit, [kJ/kg]
HDRO = working fluid enthalpy at drain exit, [kJ/kg]
XDRO = heat transferred from the heat exchanger tube side during the shell side process, [kW]
WKDRO = work done on the surrounds during the heat exchanger shell side process,.[kW]

For the working fluid traveling within the heat exchanger tube side, the energy balance error is defined as

$$EB = MFWI \cdot HFWI - MFWO \cdot HFWO + XFWO - WKFWO \qquad 3\text{-}132$$

Where: EB(I)= energy balance error for heat exchanger tube side,[kW]
MFWI = working fluid mass flow rate at feed water inlet, [kg/sec]
HFWI = working fluid enthalpy at feed water inlet, [kJ/kg]
MFWO = working fluid mass flow rate at feed water exit, [kg/sec]
HFWO = working fluid enthalpy at feed water exit [kJ/kg]
XFWO = heat transferred from the heat exchanger tube side during the tube side process, [kW]
WKFWO= work done on the heat exchanger shell side by the heat exchanger tube side,.[kW]

3.11.0 The SIMPLE MOISTURE SEPARATOR Device

A moisture separator is a device that removes entrained water vapor from a two phase flow. Usually, the moisture separation is accomplished by forcing the two phase flow through a torturous path and providing surfaces for the collection of condensate.

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The symbolic representation for a SIMPLE MOISTURE SEPARATOR device is shown in Figure 3-19.

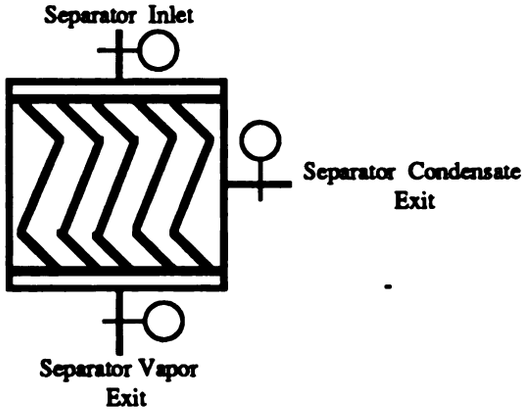


Figure 3-19. Symbol for a SIMPLE MOISTURE SEPARATOR device

Figure 3-20 shows the relevant state and device variables utilized within the RANKINE 3.0 source code. The conservation of mass, 1st law, and 2nd law application to the SIMPLE MOISTURE SEPARATOR device will utilize the identical state and device variable nomenclature utilized with the RANKINE 3.0 source code. The variable nomenclature utilized by RANKINE 3.0 is defined in Table 2-12.

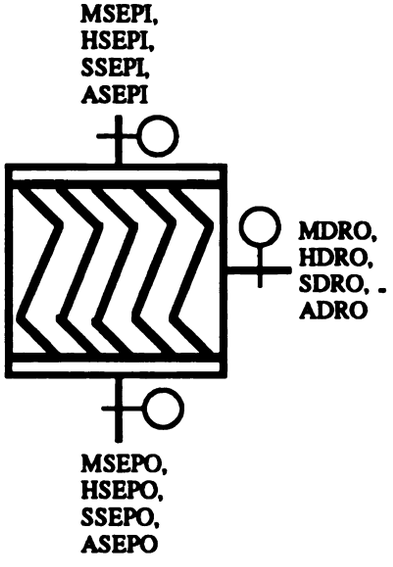


Figure 3-20. RANKINE 3.0 variables for the SIMPLE MOISTURE SEPARATOR device

For the SIMPLE MOISTURE SEPARATOR device, the conservation of mass, the 1st law of thermodynamics, and the 2nd law of thermodynamics are applied with a single control volume selected around the physical boundary of the device.

3.11.1 The SIMPLE MOISTURE SEPARATOR Device Performance Parameters

The working fluid pressure drop within the SIMPLE MOISTURE SEPARATOR device is quantified with a user specified pressure drop or percentage pressure drop.

If a user specified pressure drop is specified , than the relationships between the inlet pressure, drain pressure and exit pressure are

$$PSEPO = PSEPI - PLSEP \qquad 3\text{-}133$$

$$PDRO = PSEPI - PLSEP \qquad 3\text{-}134$$

Where:
PSEPO = working fluid pressure at separator vapor exit, [MPa]
PSEPI = working fluid pressure at separator inlet, [MPa]
PLSEP = working fluid pressure loss between separator inlet and separator vapor exit, [MPa]
PDRO = working fluid pressure at condensate exit, [MPa]

It should be noted that pressure drops are identical for both the separator condensate exit and separator vapor exit.

If a user specified percentage pressure drop is specified , than the relationships between the inlet pressure, drain pressure and exit pressure are

$$PSEPO = PSEPI \cdot [1 - PPLSEP] \qquad 3\text{-}135$$

$$PDRO = PSEPI \cdot [1 - PPLSEP] \qquad 3\text{-}136$$

Where: PSEPO = working fluid pressure at separator vapor exit, [MPa]
PSEPI = working fluid pressure at separator inlet, [MPa]
PPLBOL = working fluid percentage pressure drop between separator inlet and separator vapor exit, [-]
PDRO = working fluid pressure at condensate exit, [MPa]

It should be noted that percent pressure losses are based upon percent of inlet pressure, not percent of exit pressure.

3.11.2 Mass Conservation For The SIMPLE MOISTURE SEPARATOR Device

With a control volume selected around the physical boundaries of the SIMPLE MOISTURE SEPARATOR device, the steady state steady flow mass conservation principle yields

$$MSEPI = MSEPO + MDRO \qquad 3\text{-}137$$

Where: MSEPI = working fluid mass flow rate at separator inlet, [kg/sec]
MSEPO = working fluid mass flow rate at separator vapor exit, [kg/sec].
MDRO = working fluid mass flow rate at condensate exit, [kg/sec].

3.11.3 1st Law Analysis For The SIMPLE MOISTURE SEPARATOR Device

With a control volume selected around the physical boundaries of the SIMPLE MOISTURE SEPARATOR device, a steady state steady flow 1st law control volume analysis neglecting the kinetic and potential terms yields

$$0 = MSEPI \cdot HSEPI - MSEPO \cdot HSEPO - MDRO \cdot HDRO \qquad 3\text{-}138$$

Where: MSEPI = working fluid mass flow rate at separator inlet, [kg/sec]
HSEPI = working fluid enthalpy at separator inlet, [kJ/kg]
MSEPO = working fluid mass flow rate at separator vapor exit, [kg/sec].
HSEPO = working fluid enthalpy at separator vapor exit, [kJ/kg]

MDRO = working fluid mass flow rate at condensate exit, [kg/sec].
HDRO = working fluid enthalpy at condensate exit, [kJ/kg]

Since the SIMPLE MOISTURE SEPARATOR device does no work on the surrounds and does not exchange heat with the surrounds, the SIMPLE MOISTURE SEPARATOR device work term and heat transfer terms are zero. These terms are stated below as

$$WKSEPO = 0 \qquad 3\text{-}139$$

$$WKDRO = 0 \qquad 3\text{-}140$$

$$XSEPO = 0 \qquad 3\text{-}141$$

$$XDRO = 0 \qquad 3\text{-}142$$

Where: WKSEPO = work done on the surrounds by the moisture separator,.[kW]
WKDRO = work done on the surrounds by the moisture separator,.[kW]
XSEPO = heat transferred from the surrounds during the moisture separator process, [kW].
XDRO = heat transferred from the surrounds during the moisture separator process, [kW].

3.11.4 2nd Law Analysis For The SIMPLE MOISTURE SEPARATOR Device

The working fluid availability at each node denoted in Figure 3-20 is defined as

$$ASEPI = HSEPI - HDEAD - TDEAD \cdot [SSEPI - SDEAD] \qquad 3\text{-}143$$

$$ASEPO = HSEPO - HDEAD - TDEAD \cdot [SSEPO - SDEAD] \qquad 3\text{-}144$$

$$ADRO = HDRO - HDEAD - TDEAD \cdot [SDRO - SDEAD] \qquad 3\text{-}145$$

Where: ASEPI = working fluid availability at separator inlet, [kW]

HSEPI = working fluid enthalpy at separator inlet, [kJ/kg]
HDEAD=working fluid enthalpy at dead state conditions, [kJ/Kg]
TDEAD = Dead state temperature, [K]
SSEPI = working fluid entropy at separator inlet, [kJ/kg/K]
SDEAD = working fluid entropy at dead state conditions, [kJ/kg/K]
ASEPO = working fluid availability at separator vapor exit, [kW]
HSEPO = working fluid enthalpy at separator vapor exit, [kJ/kg]
SSEPO = working fluid entropy at separator vapor exit, [kJ/kg/K]
ADRO = working fluid availability at condensate exit, [kW]
HDRO = working fluid enthalpy at condensate exit, [kJ/kg]
SDRO = working fluid entropy at condensate exit, [kJ/kg/K]

For the SIMPLE MOISTURE SEPARATOR device, a steady state steady flow 2nd law control volume analysis neglecting the kinetic and potential terms yields

$$WRSEPO = MSEPO \cdot [HSEPI - HSEPO - TDEAD \cdot (SSEPI - SSEPO)] + MDRO \cdot [HSEPI - HDRO - TDEAD \cdot (SSEPI - SDRO)] \quad 3\text{-}146$$

Where:
WRSEPO = reversible work of moisture separator process, [kW]
MSEPO = working fluid mass flow rate at separator vapor exit, [kg/sec].
HSEPI = working fluid enthalpy at separator inlet, [kJ/kg]
HSEPO = working fluid enthalpy at separator vapor exit, [kJ/kg]
TDEAD = Dead state temperature, [K]
SSEPI = working fluid entropy at separator inlet, [kJ/kg/K]
SSEPO = working fluid entropy at separator vapor exit, [kJ/kg/K]
MDRO = working fluid mass flow rate at condensate exit, [kg/sec].
HDRO = working fluid enthalpy at condensate exit, [kJ/kg]
SDRO = working fluid entropy at condensate exit, [kJ/kg/K]

For the SIMPLE MOISTURE SEPARATOR device, the irreversibility is defined as

$$IRSEPO = WRSEPO - WKSEPO \quad 3\text{-}147$$

$$IRDRO = 0 \quad 3\text{-}148$$

Where: IRSEPO = irreversibility of moisture separator process, [kW]
WRSEPO = reversible work of moisture separator process, [kW]
WKSEPO = work done on the surrounds by the moisture separator,.[kW]

Section 3.11.5 The SIMPLE MOISTURE SEPARATOR Device Mass and Energy Balance

For the SIMPLE MOISTURE SEPARATOR device, the mass balance error is defined as

$$MB = MSEPI - MSEPO - MDRO \qquad 3\text{-}149$$

Where: MB= mass balance error for moisture separator device, [kg/sec]
MSEPI = working fluid mass flow rate at separator inlet, [kg/sec]
MSEPO = working fluid mass flow rate at separator vapor exit, [kg/sec].
MDRO = working fluid mass flow rate at condensate exit, [kg/sec].

For the SIMPLE MOISTURE SEPARATOR device, the energy balance error is defined as

$$EB = MSEPI \cdot HSEPI - MSEPO \cdot HSEPO - MDRO \cdot HDRO + XSEPO + XDRO - WKSEPO - WKDRO \qquad 3\text{-}150$$

Where: EB= energy balance error for moisture separator device, [kW]
MSEPI = working fluid mass flow rate at separator inlet, [kg/sec]
HSEPI = working fluid enthalpy at separator inlet, [kJ/kg]
MSEPO = working fluid mass flow rate at separator vapor exit, [kg/sec].
HSEPO = working fluid enthalpy at separator vapor exit, [kJ/kg]
MDRO = working fluid mass flow rate at condensate exit, [kg/sec].
HDRO = working fluid enthalpy at condensate exit, [kJ/kg]
WKSEPO = work done on the surrounds by the moisture separator,.[kW]
WKDRO = work done on the surrounds by the moisture separator,.[kW]
XSEPO = heat transferred from the surrounds during the moisture separator process, [kW].
XDRO = heat transferred from the surrounds during the moisture separator process, [kW].

3.12.0 The SIMPLE REHEATER Device

A reheater is a device which transfers heat from a reheat steam mass stream to a cycle steam mass stream. Usually, the reheat steam enters as a superheated vapor and exits as a saturated liquid and the cycle steam enters as a two phase mixture and exits as a superheated vapor.

The symbolic representation for a SIMPLE REHEATER device is shown in Figure 3-21.

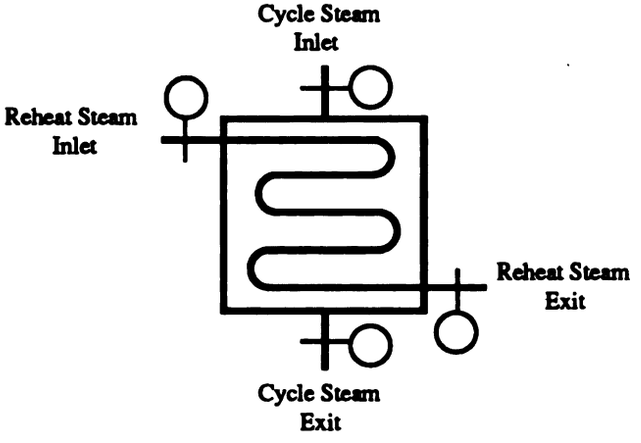


Figure 3-21. Symbol for a SIMPLE REHEATER device

Figure 3-22 shows the relevant state and device variables utilized within the RANKINE 3.0 source code. The conservation of mass, 1st law, and 2nd law application to the SIMPLE REHEATER device will utilize the identical state and device variable nomenclature utilized with the RANKINE 3.0 source code. The variable nomenclature utilized by RANKINE 3.0 is defined in Table 2-12.

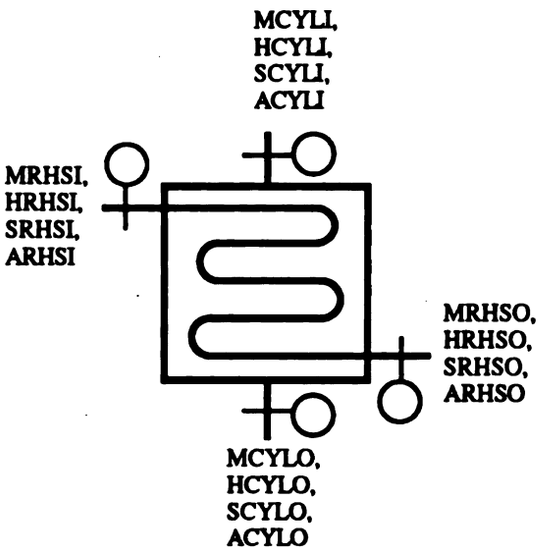


Figure 3-22. RANKINE 3.0 variables for the SIMPLE REHEATER device

The conservation of mass, the 1st law, and the 2nd law analysis considers multiple control volumes for the SIMPLE REHEATER device. The first control volume is selected around the cycle steam inlet to exit fluid path, the second control volume is selected around the reheat steam inlet to exit path and, if required, the third control volume is selected around the physical boundaries of the device.

3.12.1 The SIMPLE REHEATER Device Performance Parameters

The thermodynamic performance of the SIMPLE REHEATER device is quantified with three device performance parameters: 1) cycle steam pressure drop or percentage pressure drop, 2) reheat steam pressure drop or percentage pressure drop, 3) terminal temperature difference.

If a SIMPLE REHEATER device terminal temperature difference is specified, then the relationship between the reheat steam inlet saturation steam and cycle steam exit temperature is defined below

$$TD = T_{sat}(@PRHSI) - TCYLO \qquad 3\text{-}151$$

Where: TD = terminal temperature difference, [K]

Tsat(@PRHSI) = working fluid saturation temperature at reheat steam

inlet pressure, [K]

TCYLO = working fluid temperature at cycle steam exit, [K]

It should be noted that the RANKINE 3.0 program assumes that the reheat steam exit state is a saturated liquid. This assumption, however, can be suppressed.

The working fluid pressure drop within the SIMPLE REHEATER device is quantified with a user specified cycle steam pressure drop or cycle steam percentage pressure drop. If a user specified cycle steam pressure drop is specified than the relationships between the cycle steam inlet and exit pressure are defined below

$$PCYLO = PCYLI - PLCYL \qquad 3\text{-}152$$

Where: PCYLO = working fluid pressure at cycle steam exit, [MPa]
PCYLI = working fluid pressure at cycle steam inlet, [MPa]
PLCYL = working fluid pressure loss between cycle steam inlet and cycle steam exit, [MPa]

If a user specified cycle steam percentage pressure drop is specified, than the relationships between the cycle steam inlet and exit pressure are defined below

$$PCYLO = PCYLI \cdot [1 - PPLCYL] \qquad 3\text{-}153$$

Where: PCYLO = working fluid pressure at cycle steam exit, [MPa]
PCYLI = working fluid pressure at cycle steam inlet, [MPa]
PPLCYL = working fluid percentage pressure drop between cycle steam inlet and exit path, [-]

It should be noted that cycle steam percent pressure losses are based upon percent of inlet pressure, not percent of exit pressure.

The working fluid pressure drop within the SIMPLE REHEATER device is quantified with a user specified reheat steam pressure drop or reheat steam percentage pressure drop. If a user specified reheat steam pressure drop is specified than the relationships between the reheat steam inlet and exit pressure are defined below

$$PRHSO = PRHSI - PLRHS \qquad 3\text{-}154$$

Where: PRHSO = working fluid pressure at reheat steam exit, [MPa]
PRHSI = working fluid pressure at reheat steam inlet, [MPa]
PLRHS = working fluid pressure loss between reheat steam inlet and reheat steam exit, [MPa]

If a user specified reheat steam percentage pressure drop is specified, than the relationships between the reheat steam inlet and exit pressure are defined below

$$PRHSO = PRHSI \cdot [1 - PPLRHS] \qquad 3\text{-}155$$

Where: PRHSO = working fluid pressure at reheat steam exit, [MPa]
PRHSI = working fluid pressure at reheat steam inlet, [MPa]
PPLRHS = working fluid percentage pressure drop between reheat steam inlet and exit path, [-]

It should be noted that reheat steam percent pressure losses are based upon percent of inlet pressure, not percent of exit pressure.

3.12.2 Mass Conservation For The SIMPLE REHEATER Device

With a control volume selected around the physical boundaries of the cycle steam inlet to exit fluid flow path, the steady state steady flow mass conservation principle yields

$$MCYLI = MCYLO \qquad 3\text{-}156$$

Where: MCYLI = working fluid mass flow rate at the cycle steam inlet, [kg/sec]
MCYLO = working fluid mass flow rate at the cycle steam exit, [kg/sec].

With a control volume selected around the physical boundaries of the reheat steam inlet to exit fluid flow path, the steady state conservation of mass yields

$$MRHSI = MRHSO \qquad 3\text{-}157$$

Where: MRHSI = working fluid mass flow rate at the reheat steam inlet, [kg/sec]
MRHSO = working fluid mass flow rate at the reheat steam exit, [kg/sec].

3.12.3 1st Law Analysis For The SIMPLE REHEATER Device

With a control volume selected around the physical boundaries of the cycle steam inlet to exit fluid flow path, a steady state steady flow 1st law control volume analysis neglecting the kinetic and potential terms yields

$$XCYLO = MCYLO \cdot [HCYLO - HCYLI] \qquad 3\text{-}158$$

Where: XCYLO = heat transferred from the working fluid in the reheat steam fluid path to the working fluid in the cycle steam inlet to exit fluid path, [kW]
MCYLO = working fluid mass flow rate at cycle steam exit, [kg/sec]
HCYLO = working fluid enthalpy at cycle steam exit, [kJ/kg]
HCYLI = working fluid enthalpy at cycle steam inlet, [kJ/kg].

With a control volume selected around the physical boundaries of the reheat steam inlet to exit fluid flow path, a steady state steady flow 1st Law control volume analysis neglecting the kinetic and potential terms yields

$$XRHSO = MRHSO \cdot [HRHSO - HRHSI] \qquad 3\text{-}159$$

Where: XRHSO = heat transferred from the working fluid in the cycle steam fluid path to the working fluid in the reheat steam inlet to exit fluid path, [kW]
MRHSO = working fluid mass flow rate at reheat steam exit, [kg/sec]
HRHSO = working fluid enthalpy at reheat steam exit, [kJ/kg]
HRHSI = working fluid enthalpy at reheat steam inlet, [kJ/kg].

Since the SIMPLE REHEATER device does no work on the surrounds, all SIMPLE REHEATER device work terms are zero. These terms are stated below as

$$WKCYLO = 0 \qquad 3\text{-}160$$

$$WKRHSO = 0 \qquad 3\text{-}161$$

Where: WKCYLO = work done on the surrounds by the working fluid in the cycle steam inlet to exit process,.[kW]
WKRHSO = work done on the surrounds by the working fluid in the reheat steam inlet to exit process, [kW].

3.12.4 2nd Law Analysis For The SIMPLE REHEATER Device

The working fluid availability at each node denoted in Figure 3-22 is defined as

$$ACYLI = HCYLI - HDEAD - TDEAD \cdot [SCYLI - SDEAD] \qquad 3\text{-}162$$

$$ACYLO = HCYLO - HDEAD - TDEAD \cdot [SCYLO - SDEAD] \qquad 3\text{-}163$$

$$ARHSI = HRHSI - HDEAD - TDEAD \cdot [SRHSI - SDEAD] \qquad 3\text{-}164$$

$$ARHSO = HRHSO - HDEAD - \mathrm{TDEAD} \cdot [SRHOS - SDEAD] \qquad 3\text{-}165$$

Where: ACYLI = working fluid availability at cycle steam inlet, [kW]
HCYLI = working fluid enthalpy at cycle steam inlet, [kJ/kg]
HDEAD=working fluid enthalpy at dead state conditions, [kJ/Kg]
TDEAD = Dead state temperature, [K]
SCYLI = working fluid entropy at cycle steam inlet, [kJ/kg/K]
SDEAD = working fluid entropy at dead state conditions, [kJ/kg/K]
ACYLO = working fluid availability at cycle steam exit, [kW]
HCYLO = working fluid enthalpy at cycle steam exit, [kJ/kg]
SCYLO = working fluid entropy at cycle steam exit, [kJ/kg/K]
ARHSI = working fluid availability at reheat steam inlet, [kW]
HRHSI = working fluid enthalpy at reheat steam inlet, [kJ/kg]
SRHSI = working fluid entropy at reheat steam inlet, [kJ/kg/K]
ARHSO = working fluid availability at reheat steam exit, [kW]
HRHSO = working fluid enthalpy at reheat steam exit, [kJ/kg]
SRHSO = working fluid entropy at reheat steam exit, [kJ/kg/K].

With a control volume selected around the physical boundaries of the cycle steam inlet to exit fluid flow path, a steady state steady flow 2nd Law control volume analysis neglecting the kinetic and potential terms yields

$$WRCYLO = MCYLI \cdot [HCYLI - HCYLO - \frac{\left(T_{sat}(@PRHSI) + T_{sat}(@PRHSO)\right)}{2} \cdot (SCYLI - SCYLO)] \quad 3\text{-}166$$

Where:
WRCYLO = reversible work of cycle steam inlet to exit process, [kW]
MCYLI = working fluid mass flow rate at the cycle steam inlet, [kg/sec]
HCYLI = working fluid enthalpy at cycle steam inlet, [kJ/kg]
HCYLO = working fluid enthalpy at cycle steam exit, [kJ/kg]
PRHSI = working fluid pressure at reheat steam inlet, [MPa]
PRHSO = working fluid pressure at reheat steam exit, [MPa]
SCYLI = working fluid entropy at cycle steam inlet, [kJ/kg/K]
SCYLO = working fluid entropy at cycle steam exit, [kJ/kg/K].

With a control volume selected around the physical boundaries of the reheat steam fluid flow path, a steady state 2nd Law control volume analysis neglecting the kinetic and potential terms yields

$$WRRHSO = MRHSI \cdot [HRHSI - HRHSO - \frac{(TCYLI + TCYLO)}{2} \cdot (SRHSI - SRHSO)] \quad 3\text{-}167$$

Where:
WRRHSO = reversible work of working fluid in reheat steam inlet to exit process, [kW]
MRHSI = working fluid mass flow rate at the reheat steam inlet, [kg/sec]
HRHSI = working fluid enthalpy at reheat steam inlet, [kJ/kg]
HRHSO = working fluid enthalpy at reheat steam exit, [kJ/kg]
TCYLI = working fluid temperature at cycle steam inlet, [K]
TCYLO = working fluid temperature at cycle steam exit, [K]
SRHSI = working fluid entropy at reheat steam inlet, [kJ/kg/K]
SRHSO = working fluid entropy at reheat steam exit, [kJ/kg/K].

For the working fluid traveling within the cycle steam inlet to exit fluid flow path, the irreversibility is defined as

$$IRCYLO = WRCYLO - WKCYLO \qquad 3\text{-}168$$

Where: IRCYLO = irreversibility of cycle steam inlet to exit process, [kW]
WRCYLO = reversible work of cycle steam inlet to exit process, [kW]
WKCYLO = work done on the surrounds by the working fluid in the cycle steam inlet to exit process,.[kW]

For the working fluid traveling within the reheat steam fluid flow path, the irreversibility is defined as

$$IRRHSO = WRRHSO - WKRHSO \qquad 3\text{-}169$$

Where: IRRHSO = irreversibility of reheat steam inlet to exit process, [kW]
WRRHSO = reversible work of working fluid in reheat steam inlet to exit process, [kW].
WKRHSO = work done on the surrounds by the working fluid in the reheat steam inlet to exit process, [kW].

Section 3.12.5 The SIMPLE REHEATER Device Mass and Energy Balance

For the working fluid traveling within the cycle steam inlet to exit fluid flow path, the mass balance error is defined as

$$MB = MCYLI - MCYLO \qquad 3\text{-}170$$

Where: MB= mass balance error for cycle steam inlet to exit path, [kg/sec]
MCYLI = working fluid mass flow rate at the cycle steam inlet, [kg/sec]
MCYLO = working fluid mass flow rate at the cycle steam exit, [kg/sec].

For the working fluid traveling within the reheat steam inlet to exit fluid flow path, the mass balance error is defined as

$$MB = MRHSI - MRHSO \qquad 3\text{-}171$$

Where: MB = mass balance flow rate error for reheat steam inlet to exit path, [kg/sec]
MRHSI = working fluid mass flow rate at the reheat steam inlet, [kg/sec]
MRHSO = working fluid mass flow rate at the reheat steam exit, [kg/sec].

For the working fluid traveling within the cycle steam inlet to exit fluid flow path, the energy balance error is defined as

$$EB = MCYLI * HCYLI - MCYLO * HCYLO + XCYLO - WKCYLO \qquad 3\text{-}172$$

Where: EB= energy balance error for cycle steam inlet to exit path, [kW]
MCYLI = working fluid mass flow rate at the cycle steam inlet, [kg/sec]
HCYLI = working fluid enthalpy at cycle steam inlet, [kJ/kg]
MCYLO = working fluid mass flow rate at the cycle steam exit, [kg/sec].
HCYLO = working fluid enthalpy at cycle steam exit, [kJ/kg]
XCYLO = heat transferred from the working fluid in the reheat steam fluid path to the working fluid in the cycle steam inlet to exit fluid path, [kW]
WKCYLO = work done on the surrounds by the working fluid in the cycle steam inlet to exit process,.[kW]

For the working fluid traveling within the reheat steam inlet to exit fluid flow path, the energy balance error is defined as

$$EB = MRHSI \cdot HRHSI - MRHSO \cdot HRHSO + XRHSO - WKRHSO \qquad 3\text{-}173$$

Where: EB= energy balance error for reheat steam inlet to exit fluid flow process, [kW]
MRHSI = working fluid mass flow rate at the reheat steam inlet, [kg/sec]
HRHSI = working fluid enthalpy at reheat steam inlet, [kJ/kg]
MRHSO = working fluid mass flow rate at the reheat steam exit, [kg/sec].
HRHSO = working fluid enthalpy at reheat steam exit, [kJ/kg]
XRHSO = heat transferred from the working fluid in the cycle steam fluid path to the working fluid in the reheat steam inlet to exit fluid path, [kW]

WKRHSO = work done on the surrounds by the working fluid in the reheat steam inlet to exit process, [kW].

Section 3.13.0 System Performance Evaluations

The overall cycle performance is quantified with five parameters: 1) Carnot cycle efficiency, 2) 1st law efficiency, 3) heat rate, 4) 2nd law effectiveness, and 5) 2nd law efficiency.

The Carnot cycle efficiency establishes the thermodynamically best obtainable 1st law thermal efficiency for any cycle operating between two constant temperature reservoirs. Even though the Carnot cycle is very difficult to operate in reality, the Carnot cycle it is very important since it establishes the maximum obtainable 1st law thermal efficiency for a cycle operating between two constant temperature reservoirs. The Carnot cycle efficiency is defined mathematically as

$$CCEFF = 1 - \frac{TLRES}{THRES} \qquad 3\text{-}174$$

Where: CCEFF = carnot cycle efficiency, [-]
TLRES = absolute temperature of low temperature reservoir, [K]
THRES = absolute temperature of high temperature reservoir, [K].

The 1st law thermal efficiency is defined as the ratio of net work produced by the system divided by the heat supplied to the system. Mathematically, the 1st law thermal efficiency is defined as

$$FLEFF = \frac{\sum_{turbine} WK + \sum_{pump} WK - GENML - GENEL}{\sum_{boiler} X} \qquad 3\text{-}175$$

Where: FLEFF = 1st law thermal efficiency, [-]
WK = device work, [kW]
GENML = generator mechanical losses, [kW]
GENEL = generator electrical losses, [kW]

X = device heat transfer, [kW].

The system heat rate is defined as the amount of heat supplied to the cycle (in BTUs) required to produce 1 kWh of electricity. In reality, the system heat rate is only an algebraic manipulation of the 1st law thermal efficiency calculated in equation 3-175, however, the system heat rate is an important system parameter since it quantifies the amount of heat which must be supplied to the system (and, hence, the cost of producing the heat) required to produce a fixed amount of electricity (and, hence, the income generated by selling the electricity). Mathematically, the heat rate is defined as

$$HRSYS = \frac{3412}{FLEFF} \qquad 3\text{-}176$$

Where: HRSYS = system heat rate, [BTU/kWh]
FLEFF = 1st law thermal efficiency, [-].

The 2nd law effectiveness is defined as the ratio of the system's 1st law efficiency divided by the thermodynamically best obtainable 1st law efficiency for a system operating between the same constant temperature reservoirs. The 2nd law effectiveness is an important system parameter since it quantifies how closely a system approaches the best thermodynamic performance. Mathematically, the 2nd law effectiveness is defined as

$$SLAWE = \frac{FLEFF}{CCEFF} \qquad 3\text{-}177$$

Where: SLAWE = second law effectiveness, [-]
FLEFF = 1st law thermal efficiency, [-]
CCEFF = carnot cycle efficiency, [-].

The 2nd law efficiency is defined as the ratio of availability produced by the cycle divided by the availability consumed by the cycle. The 2nd law efficiency is important since it provides "credit" for availability transferred to or from the cycle. Mathematically, the 2nd law efficiency is defined as

$$SLEFF = \frac{\sum_{system} \text{Availability Produced} + \sum_{turbines} WK}{\left(\sum_{system} \text{Availability Supplied} + \sum_{pumps} WK + GENML + GENEL + \sum_{boiler} AJQBOL \right)} \qquad 3\text{-}178$$

Where: SLEFF = 2nd law efficiency, [-]

WK = device work, [kW]

GENML = generator mechanical losses, [kW]

GENEL = generator electrical losses, [kW]

AJQBOL = adjusted boiler heat, [kW].

It should be noted that AJQBOL is defined by equation 1-7.

Chapter 4 Code Testing and Verification

4.0.0 Code Testing and Verification Overview

The code testing and verification efforts may be separated into two categories; active testing and passive testing. The active testing represents the efforts of the author to verify the RANKINE 3.0 program by bench marking against hand calculations, RANKINE 2.4, and the industry equivalent of RANKINE 3.0, PEPSE version 58H (Performance Evaluation of Plant System Efficiencies by Nuclear Utilities Services (NUS), Idaho Falls, ID, created march 12, 1993). The passive testing efforts represent the hard wired internal checks integrated within the program structure by the author which insure that program calculations are consistent with the physical and thermodynamic constraints imposed on any thermal system. The combination of active and passive testing result in a high level of program creditability.

4.1.0 Active Testing Efforts

The active testing efforts may be subdivided into three phases; 1) individual device testing via comparison with hand calculations, 2) complete cycle testing via comparison with hand calculations and RANKINE 2.4, and 3) complete cycle testing via comparison with hand calculations and PEPSE version 58H. It is the intent of the active testing efforts to insure that RANKINE 3.0 possesses both the flexibility and the creditability to be used as a tool during steam power plant design and optimization studies.

4.1.1 Individual Device Testing

The individual device testing efforts consists of a series of 11 tests. Each test focuses on one individual device type and is intended to test all aspects associated with that single device including input processing, input checking, thermodynamic calculations and output processing.

As an example, consider the individual device test associated with the simple pipe device. For the simple pipe device, six unique sets of information exist which define a well posed device. For this discussion, a well posed device is defined as a device which possesses at least the minimum amount of independent thermodynamic information and performance

parameters required to 'fix' the thermal performance of the device. For the simple pipe device, the six unique sets of information are shown in Table 4-1

Table 4-1. Unique sets of information required to fix a simple pipe device.

Quanity	Set #1	Set #2	Set #3	Set #4	Set #5	Set #6
Inlet temperature	Yes				Yes	Yes
Inlet pressure	Yes		Yes		Yes	Yes
Inlet enthalpy				Yes		
Inlet mass flow rate	Yes		Yes			
Exit temperature		Yes			Yes	
Exit pressure		Yes		Yes	Yes	Yes
Exit enthalpy			Yes			
Exit mass flow rate		Yes		Yes	Yes	Yes
Pressure loss	Yes	Yes				
% Pressure loss			Yes	Yes		
Enthalpy loss	Yes	Yes				
% Enthalpy loss			Yes	Yes		Yes

In order to test the simple pipe device, a RANKINE 3.0 input file was created which modeled six unconnected well posed simple pipe devices each possessing a different set of user provided information. After the input file was created, RANKINE 3.0 was executed, and the RANKINE 3.0 output file was compared to hand calculations performed by the author. Based on the comparison between the RANKINE 3.0 output file and the hand calculations, the simple pipe device model was verified.

For each of the eleven devices modeled by RANKINE 3.0, a matrix was developed similar to Table 4-1 and RANKINE 3.0 was used to model the thermal performance of each device within the matrices. In order to maximize the effectiveness of the testing, the source code was consulted to insure that the maximum number of logic paths within the program were tested. The RANKINE 3.0 output file was compared to hand calculations performed by the author and any discrepancies between the RANKINE 3.0 output file and the hand calculations were addressed. After this phase of the code testing, the only discrepancies that existed between the RANKINE 3.0 output files and the hand calculations were attributed to steam table rounding errors in the hand calculation.

Additional details associated this phase of the code testing can be found in Appendix A, B, and C. Appendix A contains a detailed summary associated with the comparison between the RANKINE 3.0 output files and the hand calculations. Appendix B contains a listing of all RANKINE 3.0 input files used during this phase of the testing and

Appendix C contains a listing of each RANKINE 3.0 output file obtained during the individual device testing phase.

4.1.2 Cycle Testing via Comparison to Hand Calculations and RANKINE 2.4

The second phase of the active code testing consisted of bench marking RANKINE 3.0 to hand calculations performed by the author and RANKINE 2.4. In order to accomplish this objective, five representative RANKINE 2.4 configurations were chosen and were designated as benchmark case #1 through case #5. The five benchmark cases ranged in complexity from the Simple Rankine cycle (case #1) to a co-generation system which employed two reheat legs and four regenerative open feed water heaters (case #5). The design variations incorporated within the five benchmark cases insured that the RANKINE 3.0 program possessed the flexibility required to model complex steam power systems.

The system layout for benchmark cases #1 to #5 are presented in Figure 4-1 to Figure 4-5 respectively and the input parameters utilized in benchmark cases #1 to #5 are presented in Table 4-2.

Using the system layout and the input parameters, input files were created for each benchmark cases and the thermal performance of each benchmark case was evaluated using RANKINE 2.4 and RANKINE 3.0. In addition, a hand calculation was performed by the author which included a first and second law analysis for each device and for the entire system. A detailed comparison between the RANKINE 3.0 output file, RANKINE 2.4 output file and the hand calculation was made and any discrepancies were addressed. A comparison of the figures of merit for each of the five benchmark sequences is presented in Table 4-3 to Table 4-7. Based on the comparison between the RANKINE 3.0 results, RANKINE 2.4 results and the hand calculations, the flexibility and accuracy of RANKINE 3.0 is verified.

Additional details associated this phase of the code testing can be found in Appendix D, E, and F. Appendix D contains a copy of the hand calculations performed by the author applicable to this phase of the code testing. Appendix E contains a listing of all RANKINE 3.0 input files used during this phase of the testing and Appendix F contains a listing of each RANKINE 3.0 output file obtained. It should be noted that the RANKINE

2.4 input and output files are not include within the appendices since the nodilization scheme employed by RANKINE 2.4 is not consistent with Figures 4-1 to 4-5.

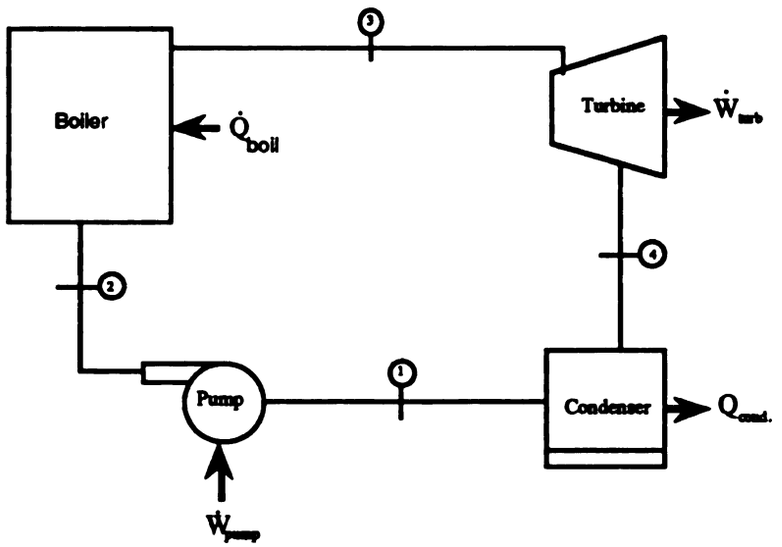


Figure 4-1. System layout for benchmark case #1

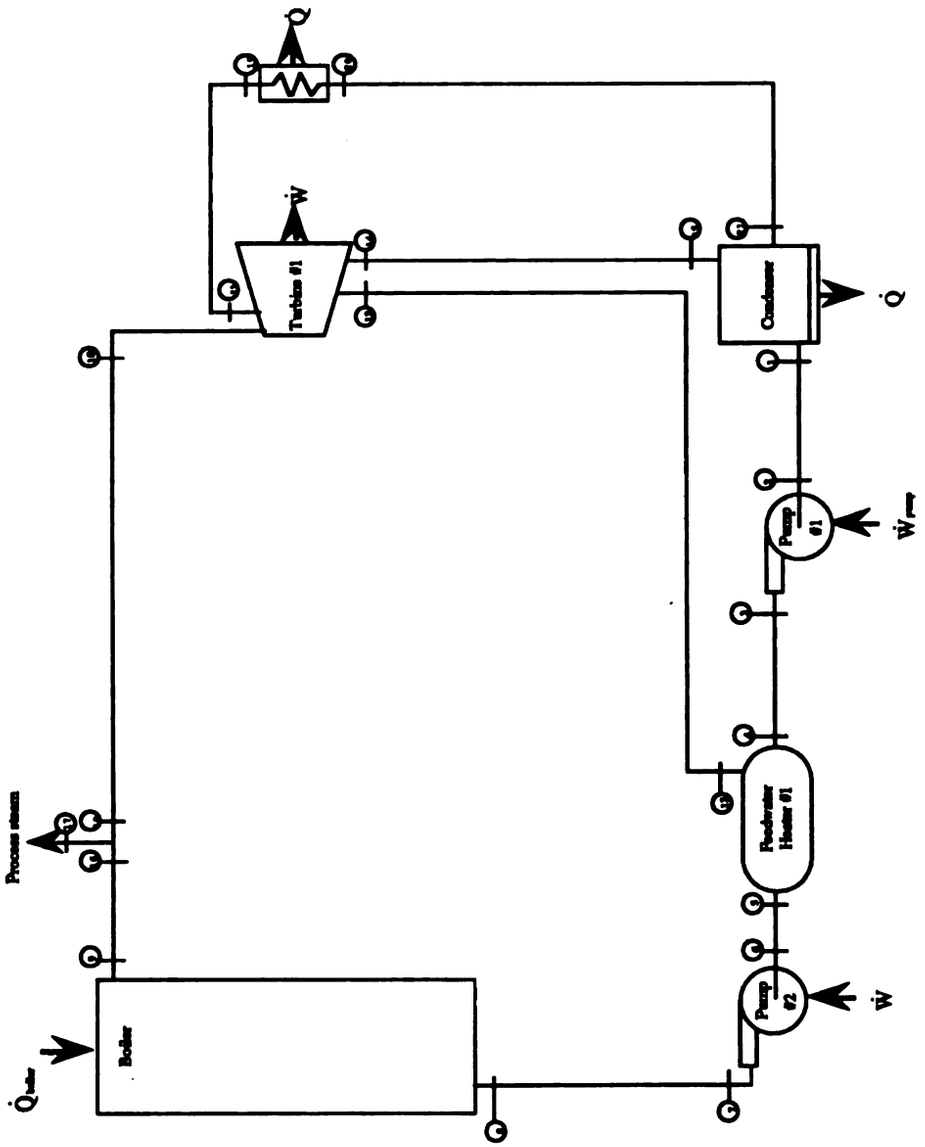


Figure 4-2. System layout for benchmark case #2

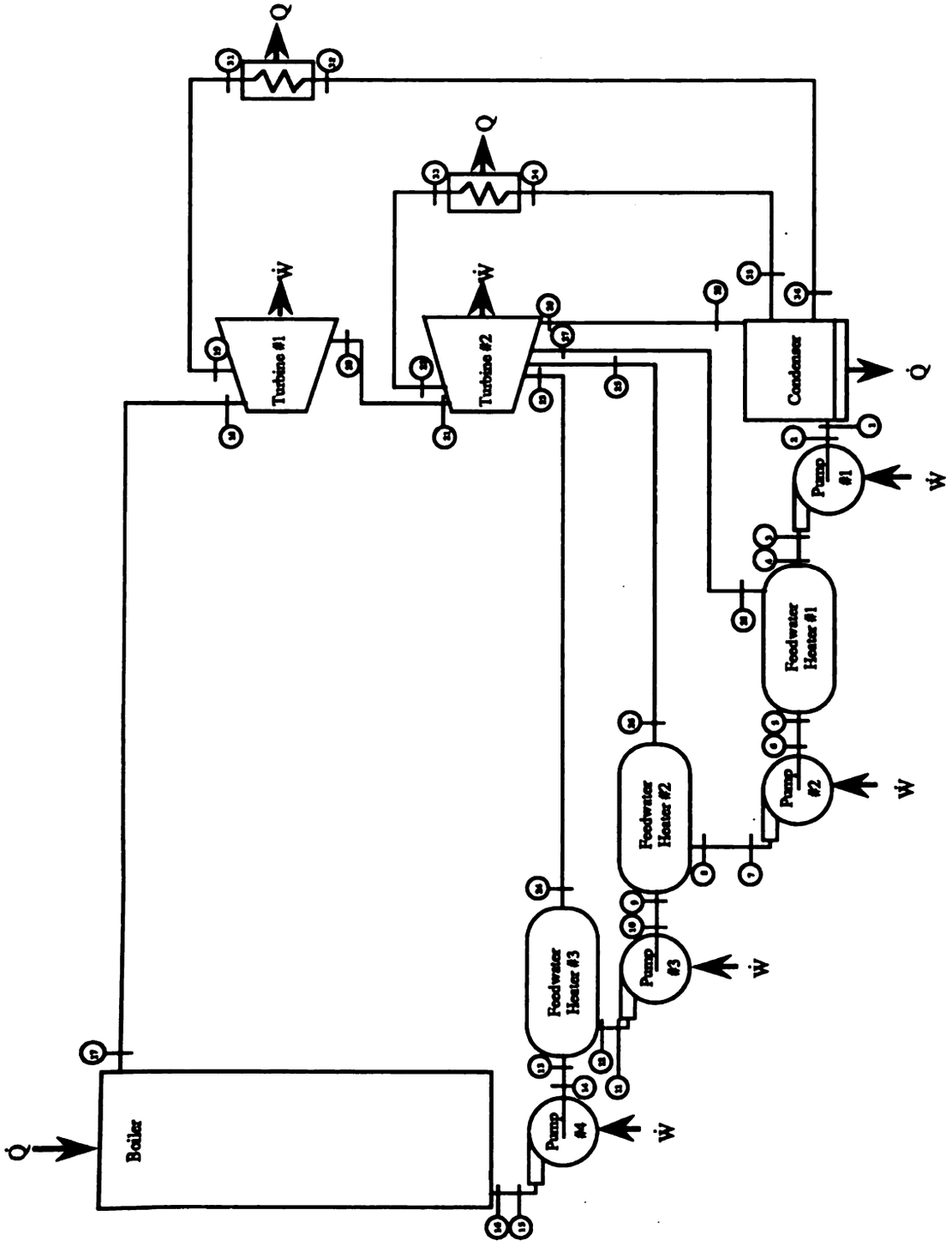


Figure 4-3. System layout for benchmark case #3

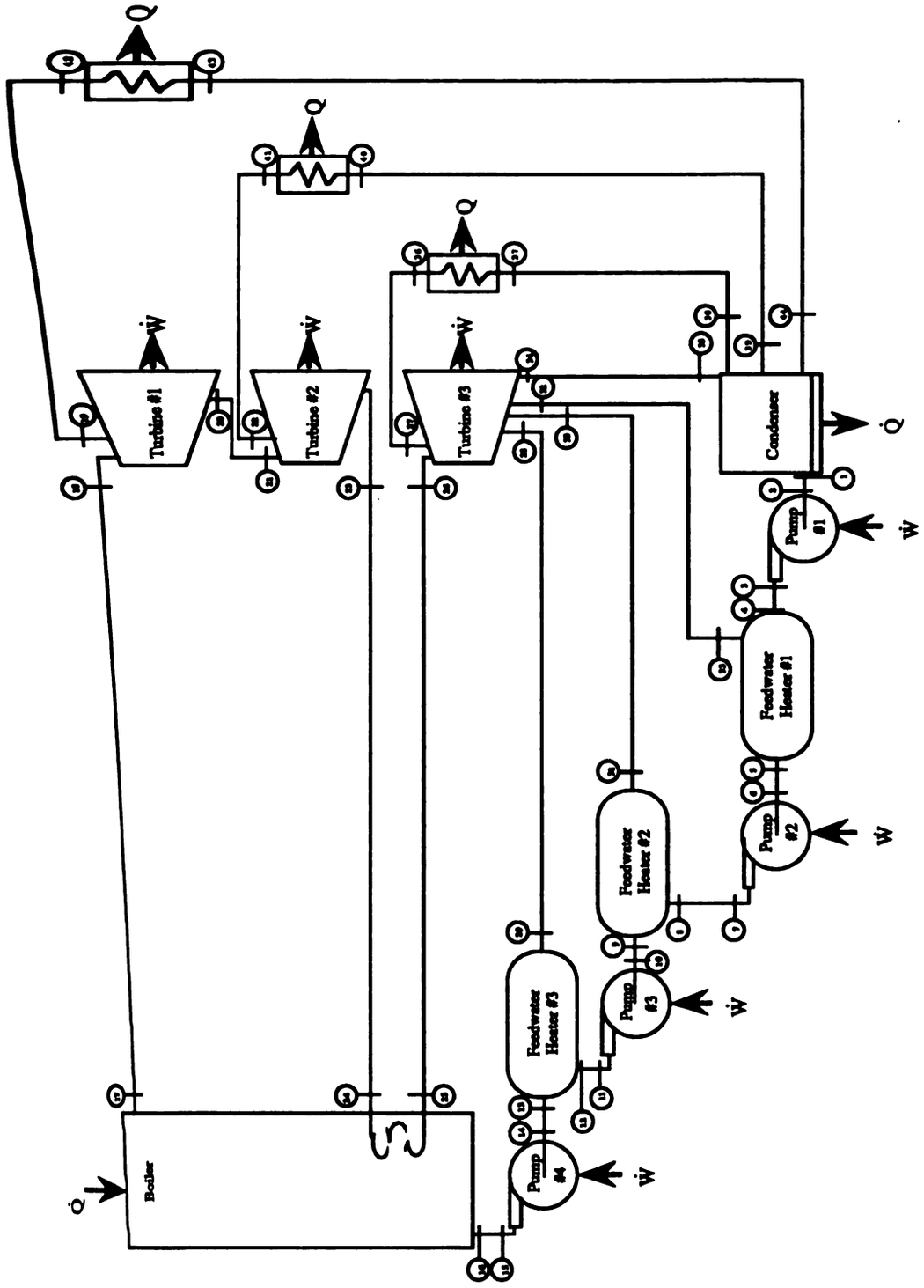


Figure 4-4. System layout for benchmark case #4

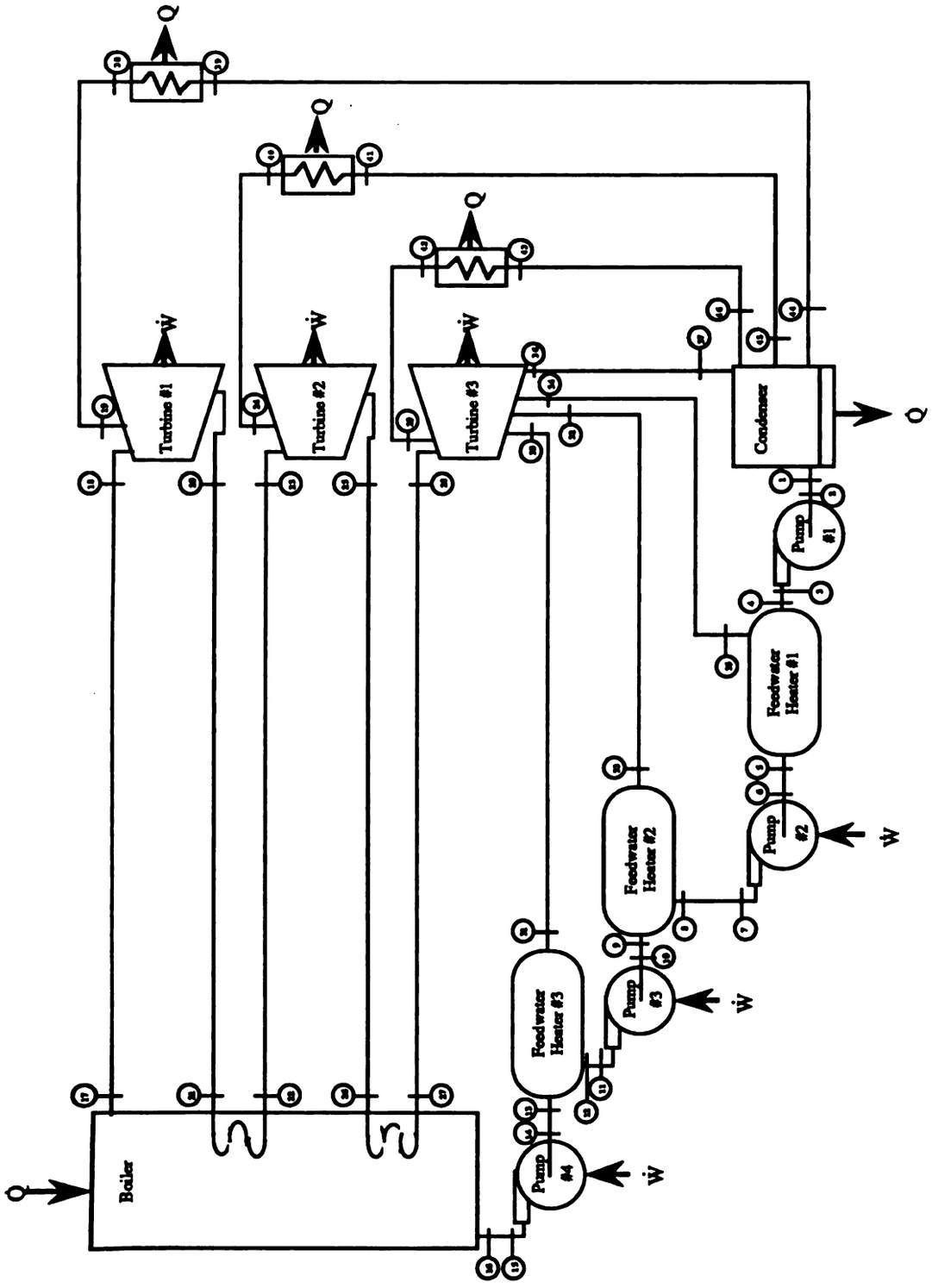


Figure 4-5. System layout for benchmark case #5

Table 4-2. Summary of input parameters for benchmark case #1 to #5

Quanity	Units	Case #1	Case #2	Case #3	Case #4	Case #5
RANKINE 2.4 equivalent	XXXXXXX	Configuration #1	Configuration #4	Configuration #13	Configuration #23	Configuration #28
T dead	Deg C	25.0	25.0	25.0	25.0	25.0
P dead	MPa	0.101	0.101	0.101	0.101	0.101
T high	Deg C	600.0	500.0	500.0	400.0	600.0
T low	Deg C	25.0	25.0	25.0	25.0	25.0
P3	MPa	20.0	XXXXXXX	XXXXXXX	XXXXXXX	XXXXXXX
T3	Deg C	600.0	XXXXXXX	XXXXXXX	XXXXXXX	XXXXXXX
M3	Kg/sec	50.0	XXXXXXX	XXXXXXX	XXXXXXX	XXXXXXX
P4	MPa	0.10	XXXXXXX	XXXXXXX	XXXXXXX	XXXXXXX
P9	MPa	XXXXXXX	10.0	XXXXXXX	XXXXXXX	XXXXXXX
T9	Deg C	XXXXXXX	500.0	XXXXXXX	XXXXXXX	XXXXXXX
M9	Kg/sec	XXXXXXX	25.0	XXXXXXX	XXXXXXX	XXXXXXX
P11	MPa	XXXXXXX	8.0	XXXXXXX	XXXXXXX	XXXXXXX
M11	Kg/sec	XXXXXXX	5.0	XXXXXXX	XXXXXXX	XXXXXXX
P12	MPa	XXXXXXX	6.0	XXXXXXX	XXXXXXX	XXXXXXX
P14	MPa	XXXXXXX	4.0	XXXXXXX	XXXXXXX	XXXXXXX
P17	MPa	XXXXXXX	XXXXXXX	10.0	10.0	20.0
T17	Deg C	XXXXXXX	XXXXXXX	500.0	XXXXXXX	600.0
H17	KJ/Kg	XXXXXXX	XXXXXXX	XXXXXXX	3099.1	XXXXXXX
M17	Kg/sec	XXXXXXX	0.0	22.0	45.0	50.0
P19	MPa	XXXXXXX	XXXXXXX	8.0	8.0	15.0
M19	Kg/sec	XXXXXXX	XXXXXXX	2.0	2.0	1.0
P20	MPa	XXXXXXX	XXXXXXX	6.0	6.0	10.0
T20	Deg C	XXXXXXX	380.21	XXXXXXX	XXXXXXX	XXXXXXX
P22	MPa	XXXXXXX	XXXXXXX	4.0	4.0	XXXXXXX
T22	Deg C	XXXXXXX	XXXXXXX	XXXXXXX	XXXXXXX	600.0
M22	Kg/sec	XXXXXXX	XXXXXXX	2.0	2.0	XXXXXXX
P23	MPa	XXXXXXX	XXXXXXX	3.0	3.0	XXXXXXX
P24	MPa	XXXXXXX	XXXXXXX	XXXXXXX	XXXXXXX	7.5
M24	Kg/sec	XXXXXXX	XXXXXXX	XXXXXXX	XXXXXXX	5.0
P25	MPa	XXXXXXX	XXXXXXX	2.0	XXXXXXX	5.0
T25	Deg C	XXXXXXX	XXXXXXX	XXXXXXX	400.0	XXXXXXX
P27	MPa	XXXXXXX	XXXXXXX	1.5	2.0	XXXXXXX
T27	Deg C	XXXXXXX	XXXXXXX	XXXXXXX	XXXXXXX	600.0
M27	Kg/sec	XXXXXXX	XXXXXXX	XXXXXXX	2.0	XXXXXXX
P28	MPa	XXXXXXX	XXXXXXX	XXXXXXX	1.0	XXXXXXX
P29	MPa	XXXXXXX	XXXXXXX	1.0	XXXXXXX	2.5
M29	Kg/sec	XXXXXXX	XXXXXXX	XXXXXXX	XXXXXXX	5.0
P30	MPa	XXXXXXX	XXXXXXX	XXXXXXX	0.5	1.0
P32	MPa	XXXXXXX	XXXXXXX	XXXXXXX	0.25	0.5
T32	Deg C	XXXXXXX	XXXXXXX	297.54	XXXXXXX	XXXXXXX
P34	MPa	XXXXXXX	XXXXXXX	XXXXXXX	0.05	0.25
T34	Deg C	XXXXXXX	XXXXXXX	297.54	XXXXXXX	XXXXXXX
P36	MPa	XXXXXXX	XXXXXXX	XXXXXXX	XXXXXXX	0.1
H37	KJ/Kg	XXXXXXX	XXXXXXX	XXXXXXX	2580.28	XXXXXXX
T39	Deg C	XXXXXXX	XXXXXXX	XXXXXXX	XXXXXXX	175.7
H40	KJ/Kg	XXXXXXX	XXXXXXX	XXXXXXX	2580.28	XXXXXXX
T41	Deg C	XXXXXXX	XXXXXXX	XXXXXXX	XXXXXXX	175.7
T43	Deg C	XXXXXXX	XXXXXXX	XXXXXXX	XXXXXXX	175.7
H43	KJ/Kg	XXXXXXX	XXXXXXX	XXXXXXX	2580.28	XXXXXXX
All turbine efficiency	(-)	0.75	0.75	0.5	0.75	0.75

Table 4-2. (Cont'd)

Quanity	Units	Case #1	Case #2	Case #3	Case #4	Case #5
All pump efficiency	(-)	0.75	0.75	0.5	0.75	0.75
All device pressure losses	MPa	0.0	0.0	0.0	0.0	0.0
All pipe enthalpy losses	KJ/Kg	0.0	0.0	0.0	0.0	0.0

Table 4-3. Figures of merit comparison for benchmark case #1

Quanity	Units	RANKINE 3.0	RANKINE 2.4	Hand Calculation
Quality at node 4	(-)	0.99	0.99	0.99
Boiler heat transferred	KW	154405.60	154405.60	154405.60
Total turbine work	KW	44235.28	44235.28	44235.26
Condenser heat transferred	KW	-111729.90	111729.90	-111729.94
Total Pump work	KW	-1559.60	-1559.610	-1559.60
Carnot cycle efficiency	%	65.85	XXXXXXXXX	65.85
1st law efficiency	%	27.64	27.64	27.64
2nd law efficiency	%	42.85	42.85	42.85
2nd law effectiveness	%	41.97	XXXXXXXXX	41.97

Table 4-4. Figures of merit comparison for benchmark case #2

Quanity	Units	RANKINE 3.0	RANKINE 2.4	Hand Calculation
Boiler heat transferred	KW	53478.70	53478.70	53478.70
Total turbine work	KW	4298.61	4298.61	4291.10
Heat load heat transferred	KW	-769.69	XXXXXXXXX	-771.34
Condenser heat transferred	KW	-49221.96	-49221.98	-49227.83
Total pump work	KW	-811.56	-811.57	-811.57
Carnot cycle efficiency	%	61.44	XXXXXXXXX	61.44
1st law efficiency	%	6.52	6.52	6.51
2nd law efficiency	%	27.96	27.96	27.94
2nd law effectiveness	%	10.61	XXXXXXXXX	10.59

Table 4-5. Figures of merit comparison for benchmark case #3

Quanity	Units	RANKINE 3.0	RANKINE 2.4	Hand Calculation
Boiler heat transferred	KW	51510.73	51510.73	51510.71
Total turbine work	KW	6051.55	6051.55	6051.51
Total heat load heat transferred	KW	-962.54	XXXXXXXXX	-962.54
Condenser heat transferred	KW	-45316.91	-45316.86	-45316.93
Total pump work	KW	-820.25	-820.26	-820.25
Carnot cycle efficiency	%	61.44	XXXXXXXXX	61.44
1st law efficiency	%	10.16	10.16	10.16
2nd law efficiency	%	30.95	30.95	30.95
2nd law effectiveness	%	16.53	XXXXXXXXX	16.53

Table 4-6. Figures of merit comparison for benchmark case #4

Quanity	Units	RANKINE 3.0	RANKINE 2.4	Hand Calculation
Quality at node 34	(-)	0.97	0.97	0.97
Boiler heat transferred	KW	118684.90	118684.90	118685.07
Total turbine work	KW	32560.19	32560.173	32560.30
Total heat load heat transferred	KW	-2781.70	XXXXXXXXX	-2781.70
Condenser heat transferred	KW	-84138.79	-84138.80	-84138.73
Total pump work	KW	-795.74	-795.75	795.70
Carnot cycle efficiency	%	55.71	XXXXXXXXX	55.71
1st law efficiency	%	26.76	26.76	26.76
2nd law efficiency	%	56.69	56.69	56.69
2nd law effectiveness	%	48.04	XXXXXXXXX	48.04

Table 4-7. Figures of merit comparison for benchmark case #5

Quanity	Units	RANKINE 3.0	RANKINE 2.4	Hand Calculation
Boiler heat transferred	KW	159915.70	159915.70	159915.49
Total turbine work	KW	48990.78	48990.78	48989.97
Total heat load heat transferred	KW	-7428.97	XXXXXXXXX	-7428.96
Condenser heat transferred	KW	-105199.70	-105199.30	-105200.30
Total pump work	KW	-1703.75	-1703.74	-1703.73
Carnot cycle efficiency	%	65.85	XXXXXXXXX	65.85
1st law efficiency	%	29.57	29.57	29.57
2nd law efficiency	%	57.04	57.04	57.04
2nd law effectiveness	%	44.90	XXXXXXXXX	44.90

4.1.3 Cycle Verification via Comparison to Hand Calculations and PEPSE

The third and final phase of the active code testing consisted of bench marking RANKINE 3.0 to hand calculations performed by the author and the industry equivalent of RANKINE 3.0, PEPSE version 58H. In order to accomplish this objective, a representative Pressurized Water Reactor Nuclear Power Station (PWR NPS) was selected and the systems layout and operating conditions were obtained. The system layout for the representative PWR NPS, designated as benchmark case #6, consists of one high pressure turbine, three low pressure turbines, two 2-stage moisture separator reheaters, two parallel strings of three high pressure steam trap closed feed water heaters, and three parallel strings of four low pressure steam trap closed feed water heaters. For modeling purposes, the three low pressure turbines were treated as a single low pressure turbine and the two 2-stage moisture separator reheaters were treated as a single moisture separator in series with two reheating stages. In addition, the parallel string strings of closed feed water heaters were combined into a single string of seven closed feed water heaters. After all model condensing was completed, the system layout is shown in Figure 4-6.

The operating conditions and the device performance parameters obtained by the author are provided in Table 4-8.

Using the system layout, operation conditions, and device performance parameters, a RANKINE 3.0 input file was created and RANKINE 3.0 was executed. Due to the iterative nature of benchmark case #6, RANKINE 2.4 was unable to model this system. Using the converged results obtained from the RANKINE 3.0 program, a hand calculation was performed which consisted of a first and second law analysis for each device and for the entire system. A figure of merit comparison between the RANKINE 3.0 output file, the hand calculation performed by the author, and PEPSE version 58H results are presented in Table 4-9.

Additional details associated with this phase of the code testing can be found in Appendix G, H, and I. Appendix G contains a copy of the hand calculations performed by the author applicable to this phase of the code testing. Appendix H contains a listing of all RANKINE 3.0 input files used during this phase of the code testing and Appendix I contains a listing of each RANKINE 3.0 output file obtained from each input file.

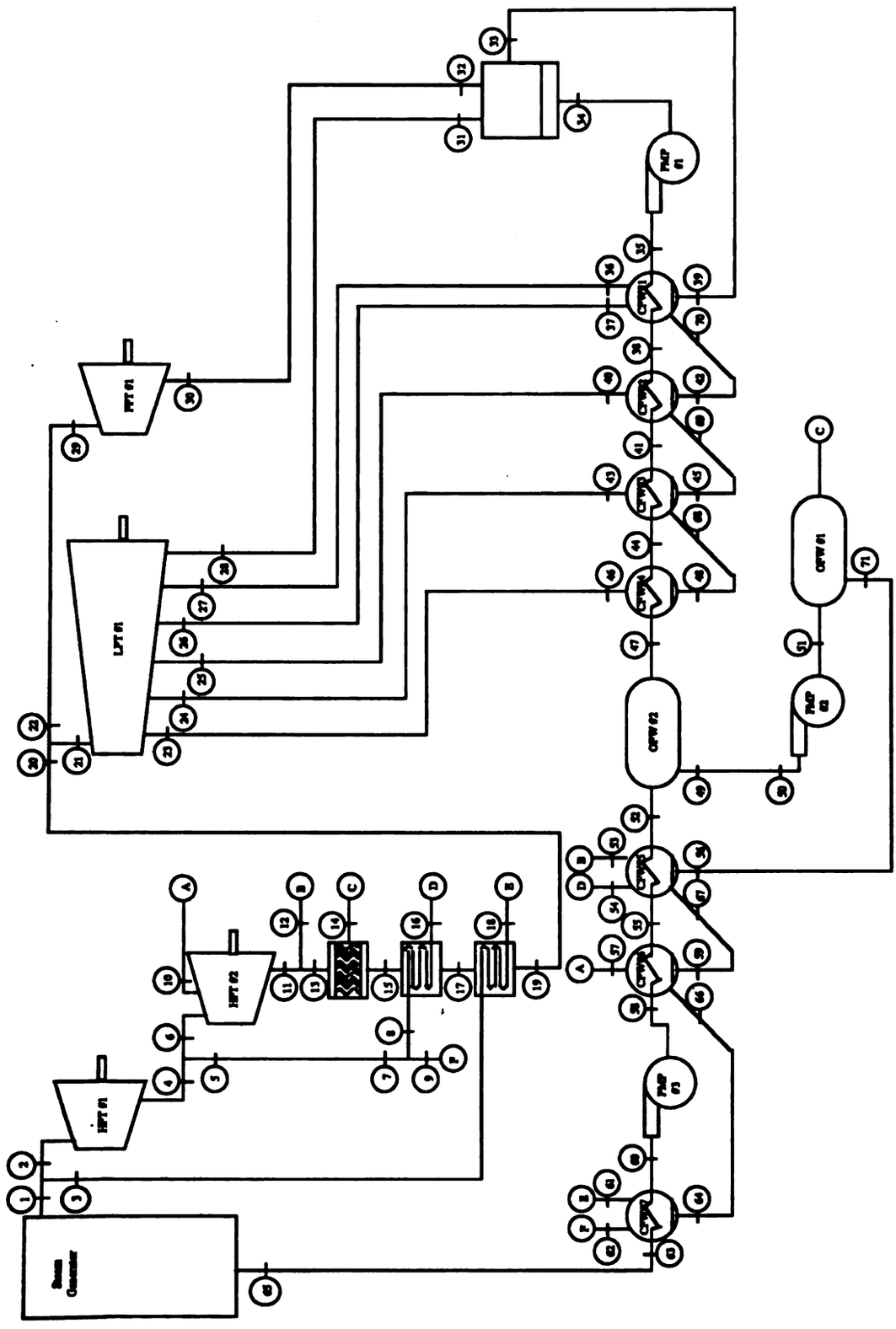


Figure 4-6. System layout for benchmark case #6

Table 4-8. Input parameters for benchmark case #6

Quanity	Value
High temperature reservoir	543.4 Deg F
Low temperature reservoir	55.0 Deg F
Generator mechanical losses	5725 KW electric
Generator electrical losses	15150 KW electric
Boiler exit temperature	543.4 Deg F
Boiler exit pressure	990 PSIA
Boiler exit mass flow rate	15913429 Lbm/hr
PMP #1 efficiency	95 percent
PMP #2 efficiency	95 percent
PMP #3 efficiency	65 percent
HPT #1 stage group #1 efficiency	81.0 percent
HPT #2 stage group #1 efficiency	84.0 percent
HPT #2 stage group #2 efficiency	83.0 percent
LPT stage group #1 efficiency	91.5 percent
LPT stage group #2 efficiency	91.0 percent
LPT stage group #3 efficiency	91.0 percent
LPT stage group #4 efficiency	87.8 percent
LPT stage group #5 efficiency	86.7 percent
LPT stage group #6 efficiency	70.0 percent
FPT stage group #1 efficiency	78.0 percent
HPT #1 stage group #1 exit pressure	431.3 PSIA
HPT #2 stage group #1 exit pressure	293.0 PSIA
HPT #2 stage group #2 exit pressure	182.0 PSIA
LPT stage group #1 exit pressure	89.4 PSIA
LPT stage group #2 exit pressure	41.3 PSIA
LPT stage group #3 exit pressure	17.1 PSIA
LPT stage group #4 exit pressure	10.7 PSIA
LPT stage group #5 exit pressure	6.0 PSIA
LPT stage group #6 exit pressure	1.7 PSIA
Separator pressure loss	5.4 PSID
Pipe (node 9- node 62) pressure loss	12.0 PSID
Pipe (node 10- node 57) pressure loss	9.0 PSID
Pipe (node 12- node 53) pressure loss	5.4 PSID
Pipe (node 19- node 20) pressure loss	0.0 PSID
Pipe (node 22- node 29) pressure loss	0.0 PSID
Pipe (node 23- node 46) pressure loss	2.7 PSID
Pipe (node 24- node 43) pressure loss	1.3 PSID
Pipe (node 25- node 40) pressure loss	0.5 PSID
Pipe (node 27- node 36) pressure loss	0.2 PSID
Pipe (node 28- node 31) pressure loss	0.0 PSID
Pipe (node 30- node 32) pressure loss	0.0 PSID
Pipe (node 63- node 65) pressure loss	0.0 PSID
Pipe (node 5- node 7) pressure loss	1.0 PSID
Pipe (node 50- node 49) pressure loss	0.0 PSID
Pipe (node 16- node 54) pressure loss	unspecified pressure loss
Pipe (node 18- node 61) pressure loss	unspecified pressure loss
Pipe (node 26- node 37) pressure loss	unspecified pressure loss
Pipe (node 39- node 33) pressure loss	unspecified pressure loss
Pipe (node 64- node 66) pressure loss	unspecified pressure loss
Pipe (node 59- node 67) pressure loss	unspecified pressure loss
Pipe (node 45- node 69) pressure loss	unspecified pressure loss
Pipe (node 42- node 70) pressure loss	unspecified pressure loss
Pipe (node 56- node 71) pressure loss	unspecified pressure loss

Table 4-8. (Cont'd)

Quanity	Value
Reheater (node 15-17) cycle steam pressure loss	2.6 PSID
Reheater (node 18-16) reheat steam pressure loss	4.3 PSID
Reheater (node 17-19) cycle steam pressure loss	2.6 PSID
Reheater (node 3-18) reheat steam pressure loss	10.0 PSID
All CFW extraction pressure loss	0.0 PSID
All CFW feed water pressure loss	0.0 PSID
Reheater terminal temperature difference (both)	25.0 Deg F
CFW #1 terminal temperature difference	5.0 Deg F
CFW #2 terminal temperature difference	5.0 Deg F
CFW #3 terminal temperature difference	5.0 Deg F
CFW #4 terminal temperature difference	unspecified
CFW #5 terminal temperature difference	5.0 Deg F
CFW #6 terminal temperature difference	5.0 Deg F
CFW #7 terminal temperature difference	5.0 Deg F
CFW #1 approach temperature difference	10.0 Deg F
CFW #2 approach temperature difference	10.0 Deg F
CFW #3 approach temperature difference	10.0 Deg F
CFW #4 approach temperature difference	10.0 Deg F
CFW #5 approach temperature difference	39.593 Deg F
CFW #6 approach temperature difference	10.0 Deg F
CFW #7 approach temperature difference	10.0 Deg F
CFW #5 drain exit	Saturated liquid with 0.0 quality
OFW #1 feed water exit	not saturated liquid
OFW #2 feed water exit	not saturated liquid
Node #2 flow fraction (Initial guess)	94 percent
Node #6 flow fraction (Initial guess)	91 percent
Node #22 mass flow rate	198275 Lbm/hr
Node #27 mass flow rate	158865 Lbm/hr
Node #35 pressure	540 PSIA

Table 4-9. Figure of merit comparison for benchmark case #6

Quanity	Units	Hand Calculation	RANKINE 3.0	PEPSE version 58H	% Difference
Low temperature reheater terminal temperature difference	Deg C	13.84	13.84	13.89	+3.60
High temperature reheater terminal temperature difference	Deg C	13.94	13.93	13.88	-3.60
Quality at node 4	(-)	0.915	0.915	0.919	+0.44
Quality at node 10	(-)	0.891	0.891	0.857	-3.97
Quality at node 11	(-)	0.868	0.868	0.873	+0.57
Quality at node 24	(-)	0.995	0.995	0.997	+0.20
Quality at node 25	(-)	0.952	0.952	0.841	-13.20
Quality at node 26	(-)	0.933	0.933	0.401	-132.67
Quality at node 27	(-)	0.912	0.912	0.692	-31.79
Quality at node 28	(-)	0.884	0.884	0.906	+2.43
Quality at node 30	(-)	0.912	0.912	0.916	+4.37
Boiler heat transferred	KW	3587169	3587170	3580451	-1.88
Total gross turbine work	KW	1269190	1269168	1265837	-0.26
Condenser heat transferred	KW	-2342803	-2342823	-2334998	-0.34
Total pump work	KW	-24824.04	-24820.84	-20401	-21.66
Carnot cycle efficiency	%	48.69	48.69	XXXXXXXX	XXXXXXXX
1st law efficiency	%	34.1074	34.1069	34.146	+0.11
2nd law efficiency	%	74.6621	74.6609	XXXXXXXX	XXXXXXXX
2nd law effectiveness	%	70.0494	70.0483	XXXXXXXX	XXXXXXXX

Inspection of Table 4-9 shows excellent agreement between the RANKINE 3.0 results and the hand calculation and moderate agreement between the RANKINE 3.0 results and PEPSE version 58H results. Each major difference encountered in Table 4-9 is discussed below.

1) The RANKINE 3.0 reheater terminal temperature difference tolerance is internally set at ±0.05 °C. For PEPSI version 58H, this tolerance appears to be approximately ±0.005 °F. This difference could be reduced by internally adjusting the terminal temperature difference tolerance, however, at the expense of computer computational time.

2) The turbine models employed by RANKINE 3.0 and PEPSE version 58H are significantly different. The RANKINE 3.0 SIMPLE TURBINE device requires a user specified stage group adiabatic efficiency while the PEPSE version 58H turbine device internally calculates the stage group adiabatic efficiency based on the working fluid state and the mass flow rate. In addition, the PEPSE version 58H code accounts for the moisture removal provisions between stage groups and the effects of turbine shaft leakage. In the RANKINE 3.0 SIMPLE TURBINE

device, neither is consider. This problem may be addressed with the development of a more sophisticated turbine device and its integration into the existing RANKINE 3.0 structure.

3) The accuracy of the total pump work predicted by PEPSE version 58H is questionable. The PEPSE version 58H results indicated that the electric pump drawing from the condenser possessed an overall adiabatic efficiency of 186%. Based on the authors experience, this error is most likely due to a saturated liquid/ compressed liquid discontinuity problem in the computerized steam tables employed by PEPSE version 58H.

4) The turbine driver feed pump is modeled differently in RANKINE 3.0 and PEPSE version 58H. Since RANKINE 3.0 does not possess a "SIMPLE TURBINE DRIVER FEED PUMP" device, the turbine driven feed pump was modeled in the RANKINE 3.0 input file as two unconnected devices; a SIMPLE PUMP and a single stage SIMPLE TURBINE. In order to account for this modeling difference, the total net work to generators for PEPSE version 58H was adjusted and Table 4-9 presents this adjusted value. This problem may be corrected by developing a "SIMPLE TURBINE DRIVEN FEED PUMP" device and integrating it into the existing RANKINE 3.0 structure.

Disspite theses differences, the excellent agreement between the RANKINE 3.0 1st law efficiency and PEPSE version 58H 1st law efficiency increases the overall program creditability and demonstrates the flexibility of the RANKINE 3.0 program.

4.2.0 Passive Code Testing

The passive code testing efforts may be subdivided into two areas; 1) the hard wired checks distributed throughout the program, and 2) the mass and energy balances performed on the various control volumes within the system. It is the intent of the passive code testing to provide an additional level of program creditability and to insure that any untested code logic performs as intended by the author.

The hard wired checks distributed though out the program structure are intended to identify problems during program execution and, when a problem exists, provide a message to the user. These checks are distributed throughout the entire program and, hence, all input files are checked for consistency and all program results are checked for validity. Additional information associated with the input file checks may be found in

Sections 2.2.0 through 2.2.3 and additional information associated with the checks associated with the internally calculated results may be found in Section 2.3.3.

The mass and energy balances performed on each of the various control volumes within the system is intended to identify fundamental program errors not identified by the author during active code testing or by the hard wired checks distributed throughout the program. The mass and energy balances are performed on each device within the system and on the entire system and, hence, a failure of the program to conserve mass or energy within any system will be quickly identified. Additional information associated with the mass and energy balances performed on the various control volumes within the system may be found in Section 2.4.1.

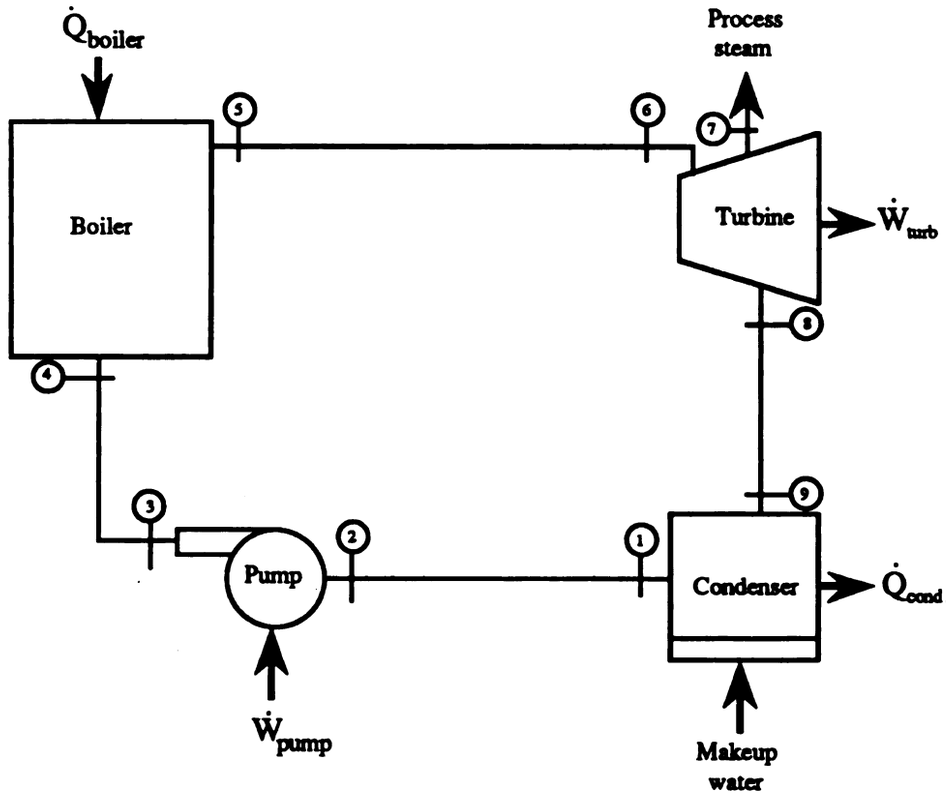
Chapter 5: RANKINE 3.0 User's Guide

RANKINE 3.0: A Steam Power Plant Computer Simulation

USERS MANUAL

by

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Introduction

RANKINE 3.0 is a PC-DOS compatible program capable of modeling a complex, user specified steam power system and providing a basis for optimization of the design and operation of a steam power system. The user specified system may include up to 100 thermal equipment components commonly found in commercial steam power systems such as boilers, turbines, pumps, pipes, junctions, heat loads, condensers, open feed water heaters, closed feed water heaters, moisture separators, and reheaters. In addition to the system layout, the user also specifies the system operating conditions and equipment performance parameters required for the analysis. The output generated by RANKINE 3.0 summarizes the results of a first and second law analysis for the system operating under the given conditions. It is the intent of RANKINE 3.0 to provide a fast and detailed thermal analysis which permits innovative steam power system designs to be investigated for the potential of increased system efficiency.

Input File Construction

The first step required in using RANKINE 3.0 is to sketch the complete system layout that will be modeled. On this sketch, every thermal equipment device should be assigned a device number and every device inlet/exit should be assigned a node number. Due to program limitations, the device numbers and node numbers should begin at 1 and not exceed 100.

The second step is to convert the information on this sketch into a format which may be used by the program. Since RANKINE 3.0 operates in a batch mode, the information on this sketch must be translated into an input file. The creation of the input file may be accomplished with the DOS editor.

The purpose of the input file is to communicate the system layout, operating conditions, and device performance parameters to the program. All input files contain two types of information; system information and device information. The system information is applicable to the entire system and may be used during the analysis of each device in the system. An example of system information is the system's dead state temperature. The device information consists of a summary of all known information pertaining to each device within the system including the nodes on the device, all known operating

conditions, and all known device performance parameters. Due to the calculation procedure, the order in which the device information appears within the input file is not important, but the information within the input file must represent a well posed system. In the event that a required piece of information is neglected within the input file (such as a pump without a specified adiabatic efficiency), internal checks within the program will identify the error, provide a message to the user, and stop program execution.

In an attempt to maximize the program's user friendliness, RANKINE 3.0 was developed with an input processor that recognizes a key phrase library. The input processor reads the input file line by line and searches the first 80 characters of each line for key phrases. In general, two key phrases are required to specify information about the system. The 1st key phrase identifies a location in the system (such as a turbine inlet) and a 2nd key phrase specifies some information about the position (such as the pressure or temperature). By combining 1st and 2nd key phrases, information pertaining to the system of interest can be communicated to the program. In addition, the user can specify units for each operating condition; and, hence, RANKINE 3.0 can account for a variety of units within an input file.

As an example, consider using RANKINE 3.0 to perform a 1st and 2nd law analysis for a non-ideal turbine with 375,000 lbm/hr of steam entering the turbine at 850 psig and 860 °F. With a control volume selected around the physical boundaries of the turbine, the turbine is modeled as a thermodynamic control volume with one inlet and 'n' extractions. In this example, the turbine has three extractions; one at 188 psig, one at 88 psig, and the third at -21 inches HG gauge. In addition, the mass flow rate of extraction #1 is 9.5 kg/sec, the mass flow rate of extraction #2 is 225,000 lbm/hr, and all stage groups have an adiabatic efficiency of 91 percent. A diagram of this turbine can be seen in Figure 5-1.

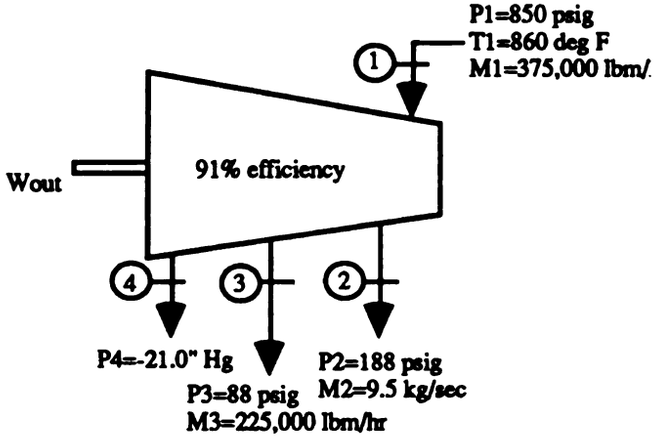


Figure 5-1. Schematic for single turbine example problem

Since this example problem is well posed, the work produced from this system may be calculated. In this example, the 'system' consists of a single turbine.

In order to use RANKINE 3.0 to model this system, an input file, as described above, must be created. The general key phrases, 1st key phrases, and 2nd key phrases recognized by RANKINE 3.0 are summarized in Tables 5-1, 5-2, and 5-3 respectively.

Table 5-1. Summary of general key phrases

1st Key Phrase	Interpretation
COMMENT	Stops RANKINE 3.0 from scanning the current line.
ECHO OFF	Indicates that input file information should not be written to the external data file ECHO.DAT.
INPUT CHECK OFF	Indicates that input file checking will be bypassed. It is recommended that this feature not be used.
ITERATION OFF	Indicates that RANKINE 3.0 should not iterate to converge on a solution to the system.
TITLE	Indicates the beginning of title information. If a title is include within the input deck, the title information will be written to the output file. The title may be up to 10 lines long.
END TITLE	Indicates the end of the title information.
NUMBER OF NODES	Indicates the number of nodes in the system. This key phrase is followed by a number corresponding to the number of nodes (up to 100) in the system.
HIGH TEMPERATURE RESERVOIR	Indicates the temperature of the hot reservoir with which the system is interacting. Acceptable units are 'DEG C', 'DEG F', 'DEG R', 'DEG K'.
LOW TEMPERATURE RESERVOIR	Indicates the temperature of the cold reservoir with which the system is interacting. Acceptable units are 'DEG C', 'DEG F', 'DEG R', 'DEG K'.
DEAD STATE	Indicates a property of the dead state will be specified (such as a temperature or pressure). A second key phrase is expected.
GENERATOR MECHANICAL LOSSES	Indicates that the Generator Mechanical Losses are known and should be considered. Acceptable units are KW, MW, BTU/HR, HP.
GENERATOR ELECTRICAL LOSSES	Indicates that the Generator Electrical Losses are known and should be considered. Acceptable units are KW, MW, BTU/HP, HP.
SIMPLE TURBINE	Indicates that information pertaining to a simple turbine device will be specified.
SIMPLE PUMP	Indicates that information pertaining to a simple pump device will be specified.
SIMPLE PIPE	Indicates that information pertaining to a simple pipe device will be specified.
SIMPLE JUNCTION	Indicates that information pertaining to a simple junction device will be specified.
SIMPLE CONDENSER	Indicates that information pertaining to a simple condenser device will be specified.
SIMPLE HEAT LOAD	Indicates that information pertaining to a simple heat load device will be specified.
SIMPLE OFW HEATER	Indicates that information pertaining to a simple open feed water heater device will be specified.
SIMPLE BOILER	Indicates that information pertaining to a simple boiler device will be specified.
SIMPLE STEAM TRAP CFW	Indicates that information pertaining to a simple steam trap closed feed water heater device will be specified.

Table 5-1. (cont'd)

1st Key Phrase	Interpretation
SIMPLE MOISTURE SEPARATOR	Indicates that information pertaining to a simple moisture separator device will be specified.
SIMPLE REHEATER	Indicates that information pertaining to a simple reheater device will be specified.

Table 5-2. Summary of device specific key phrases

Device Name	1st Key Phrase	2nd Key Phrase	Units
SIMPLE TURBINE	INLET	Yes	Per 2nd key phrase
	EXTRACTION #_	Yes	Per 2nd key phrase
	STAGE GROUP #_ EFFICIENCY	No	%, PERCENT
	END DEVICE	No	None expected
SIMPLE PUMP	SUCTION	Yes	Per 2nd key phrase
	DISCHARGE	Yes	Per 2nd key phrase
	EFFICIENCY	No	%, PERCENT
	END DEVICE	No	None expected
SIMPLE PIPE	INLET	Yes	Per 2nd key phrase
	EXIT	Yes	Per 2nd key phrase
	PIPE PRESSURE LOSS	No	Per 2nd key phrase PRESSURE
	PIPE PERCENTAGE PRESSURE LOSS	No	%, PERCENT
	PIPE ENTHALPY LOSS	No	Per 2nd key phrase ENTHALPY
	PIPE PERCENTAGE ENTHALPY LOSS	No	%, PERCENT
	END DEVICE	No	None expected
SIMPLE JUNCTION	INLET #_	Yes	Per 2nd key phrase
	EXIT #_	Yes	Per 2nd key phrase
	END DEVICE	No	None expected
SIMPLE CONDENSER	EXIT	Yes	Per 2nd key phrase
	INLET #_	Yes	Per 2nd key phrase
	END DEVICE	No	None expected
SIMPLE HEAT LOAD	INLET	Yes	Per 2nd key phrase
	EXIT	Yes	Per 2nd key phrase
	END DEVICE	No	None expected

Table 5-2. (Cont'd)

Device Name	1st Key Phrase	2nd Key Phrase	Units
SIMPLE OFW HEATER	FEED WATER EXIT	Yes	Per 2nd key phrase
	FEED WATER EXIT IS NOT SATURATED	No	None expected
	FEED WATER INLET	Yes	Per 2nd key phrase
	EXTRACTION INLET	Yes	Per 2nd key phrase
	END DEVICE	No	None expected
SIMPLE BOILER	BOILER INLET	Yes	Per 2nd key phrase
	BOILER EXIT	Yes	Per 2nd key phrase
	BOILER PRESSURE LOSS	No	Per 2nd key phrase PRESSURE
	BOILER PERCENTAGE PRESSURE LOSS	No	%, PERCENT
	REHEAT LEG #_ INLET	Yes	Per 2nd key phrase
	REHEAT LEG #_ EXIT	Yes	Per 2nd key phrase
	REHEAT LEG #_ PERCENTAGE PRESSURE LOSS	No	%, PERCENT
	REHEAT LEG #_ PRESSURE LOSS	No	Per 2nd key phrase PRESSURE
	END DEVICE	No	None expected
SIMPLE STEAM TRAP CFW	FEED WATER INLET	Yes	Per 2nd key phrase
	FEED WATER EXIT	Yes	Per 2nd key phrase
	EXTRACTION INLET	Yes	Per 2nd key phrase
	DRAIN INLET #_	Yes	Per 2nd key phrase
	DRAIN EXIT	Yes	Per 2nd key phrase
	FEED WATER PRESSURE LOSS	No	Per 2nd key phrase PRESSURE
	FEED WATER PERCENTAGE PRESSURE	No	%, PERCENTAGE
	EXTRACTION PRESSURE LOSS	No	Per 2nd key phrase PRESSURE
	EXTRACTION PERCENTAGE PRESSURE	No	%, PERCENTAGE
	TERMINAL TEMPERATURE DIFFERENCE	No	Per 2nd key phrase TEMPERATURE
	APPROACH TEMPERATURE DIFFERENCE	No	Per 2nd key phrase TEMPERATURE
	END DEVICE	No	None expected

Table 5-2. (Cont'd)

Device Name	1st Key Phrase	2nd Key Phrase	Units
SIMPLE MOISTURE SEPARATOR	SEPARATOR INLET	Yes	Per 2nd key phrase
	SEPARATOR VAPOR EXIT	Yes	Per 2nd key phrase
	SEPARATOR CONDENSATE EXIT	Yes	Per 2nd key phrase
	SEPARATOR PRESSURE LOSS	No	Per 2nd key phrase PRESSURE
	SEPARATOR PERCENTAGE PRESSURE LOSS	No	%, PERCENTAGE
	END DEVICE	No	None expected
SIMPLE REHEATER	CYCLE STEAM INLET	Yes	Per 2nd key phrase
	CYCLE STEAM EXIT	Yes	Per 2nd key phrase
	REHEAT STEAM INLET	Yes	Per 2nd key phrase
	REHEAT STEAM EXIT	Yes	Per 2nd key phrase
	REHEAT STEAM EXIT IS NOT A SATURATED LIQUID	No	None expected
	FLOW FRACTION CONTROLLED BY	No	Per 2nd key phrase JUNCTION DEVICE
	TERMINAL TEMPERATURE DIFFERENCE	No	Per 2nd key phrase TEMPERATURE
	CYCLE STEAM PRESSURE LOSS	No	Per 2nd key phrase PRESSURE
	CYCLE STEAM PERCENTAGE PRESSURE	No	%, PERCENTAGE
	REHEAT STEAM PRESSURE LOSS	No	Per 2nd key phrase PRESSURE
	REHEAT STEAM PERCENTAGE PRESSURE	No	%, PERCENTAGE
	END DEVICE	No	None expected

Table 5-3. Summary of 2nd key phrases

2nd Key Phrase	Number	Acceptable Units
NODE	Yes	**** NONE EXPECTED ****
PRESSURE	Yes	MPA, KPA, PA, PSIA, PSIG, PSID, INCHES HG GAUGE, INCHES HG ABSOLUTE, INCHES H20 GAUGE, INCHES H2O ABSOLUTE
TEMPERATURE	Yes	DEG C, DEG K, KELVIN, DEG F, DEG R, KELVIN
TEMPERATURE DIFFERENCE	Yes	DEG C, DEG K, KELVIN, DEG F, DEG R, KELVIN
ENTHALPY	Yes	KJ/KG, J/KG, BTU/LBM
ENTROPY	Yes	KJ/KG/K, J/KG/K, BTU/LBM/R

Table 5-3. (cont'd)

2nd Key Phrase	Number	Acceptable Units
MASS FLOW	Yes	KG/SEC, KG/HR, LBM/SEC, LBM/HR
SATURATED LIQUID	No	**** NONE EXPECTED ****
SATURATED VAPOR	No	**** NONE EXPECTED ****
SUPERHEATED	Yes	DEG C, DEG K, KELVIN, DEG F, DEG R
SUBCOOLED	Yes	DEG C, DEG K, KELVIN, DEG F, DEG R
FLUID PHASE	No	SUBCOOLED LIQUID, SATURATED LIQUID, 2 PHASE MIXTURE, SATURATED VAPOR, SUPERHEATED VAPOR
QUALITY	Yes	PERCENT, %
JUNCTION DEVICE	Yes	**** NONE EXPECTED ****
FLOW FRACTION	Yes	PERCENT, %

For the single turbine example problem, the input file consists of the following statements.

NUMBER OF NODES IN THIS SYSTEM IS **4**
THE DEAD STATE TEMPERATURE IS 25 DEG C
THE DEAD STATE PRESSURE IS 101 KPA
THE HIGH TEMPERATURE RESERVOIR IS 860 DEG F
THE LOW TEMPERATURE RESERVOIR IS 25 DEG C
DEVICE 1 IS A **SIMPLE TURBINE**
THE INLET NODE NUMBER IS **1**
EXTRACTION #1 NODE NUMBER IS **2**
EXTRACTION #2 NODE NUMBER IS **3**
EXTRACTION #3 NODE NUMBER IS **4**
INLET TEMPERATURE IS 860 DEG F
INLET PRESSURE IS 850 PSIG
INLET MASS FLOW RATE IS **375000 LBM/HR**
EXTRACTION #1 PRESSURE IS 188 PSIG
EXTRACTION #1 MASS FLOW RATE IS **9.5 KG/SEC**
EXTRACTION #2 PRESSURE IS 88 PSIG
EXTRACTION #2 MASS FLOW RATE IS **225000 LBM/HR**
EXTRACTION #3 PRESSURE IS -21.0 INCHES HG GAUGE
STAGE GROUP #1 EFFICIENCY IS 91 PERCENT
STAGE GROUP #2 EFFICIENCY IS 91 PERCENT
STAGE GROUP #3 EFFICIENCY IS 91 PERCENT
END DEVICE

For clarity, the key phrases have been emphasized with bold typeface. All phrases not emphasized with bold typeface are not key phrases and, hence, are ignored by the program.

After the input file has been created and saved, RANKINE 3.0 may be executed by typing the executable file name at the DOS prompt. This command is shown below.

a:/> RANK30

During program execution, the program will prompt the user for the input file name, analyze the system with the given operating conditions, and prompt the user for an output file name. An internal check verifies that the output file name is not identical to the input file name. It should be noted that the input file name and output file name may be a maximum of 12 characters long (including all extensions).

The execution of RANKINE 3.0 generates three types of data; 1) Node data, 2) Device data, and 3) System data. For any given system, the information associated with each type of data is summarized within the user specified output file. Table 5-4 defines the abbreviations contained within the output file.

Table 5-4. Summary of output file abbreviations

Abbreviation	Definition	Units
T	Temperature	Deg C
P	Pressure	MPA
L	Fluid phase index 1-subcooled liquid 2-two phase mixture 3-superheated vapor 4-saturated liquid 5-saturated vapor	-
Q	Quality	-
S	Entropy	KJ/kg/k
H	Enthalpy	KJ/kg
V	Specific volume	m^3/kg
M	Mass flow rate	kg/sec
A	Availability	KJ/kg
REV WRK	The reversible work associated with the device before the node.	KW
ACT WRK	The actual work associated with the device before the node.	KW
IRREV	The irreversibility associated with the device before the node.	KW
HEAT X-FER	The heat transferred into the device before the node.	KW

Table 5-4. (Cont'd)

Abbreviation	Definition	Units
MASS ERR	The mass balance error associated with the device before the node.	kg/sec
ENG ERR	The energy balance error associated with the device before the node	KW

In addition to providing the results of the thermodynamic analysis, the execution of RANKINE 3.0 also generates a file named ECHO.DAT. The ECHO.DAT file contains a listing of the input file information identified by RANKINE 3.0. By inspecting the ECHO.DAT file, questions associated with the interpretation of an input file may be easily addressed.

For the single turbine example problem, the output generated by RANKINE 3.0 is shown below.

```
          RANKINE 3.0: A steam power plant computer simulation

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                          W.A. Thelen, C.W. Somerton

********************************* NODE DATA ***********************************

NODE  T(C)    P(MPa)  L    Q  S(KJ/KG/K) H(KJ/KG) V(M^3/KG) M(KG/S) A(KJ/KG)
-------------------------------------------------------------------------------
  1  460.00   5.9619  3  ***** 6.7569    3326.99   .05340    47.2500 1316.75
  2  267.38   1.3975  3  ***** 6.8236    2967.67   .17059     9.5000  937.54
  3  194.21    .7081  3  ***** 6.8527    2831.16   .29217    28.3500  792.37
  4   69.29    .0302  2   .886 6.9889    2359.46  4.60281     9.4000  280.05

********************** DEVICE DATA (DEVICE BEFORE NODE) ***********************

NODE     REV. WRK    ACT. WRK     IRREV    HEAT X-FER    MASS ERROR  ENERGY ERROR
           (KW)        (KW)       (KW)       (KW)          (KG/S)       (KW)
-------------------------------------------------------------------------------
  1       -1.00       -1.00      -1.00       -1.00        -1.000       -1.000
  2    17917.62    16977.93     939.69         .00          .000         .000
  3     5480.34     5153.16     327.18         .00          .000         .000
  4     4815.80     4434.00     381.80         .00          .000        -.004

******************************** SYSTEM DATA **********************************

TOTAL MASS FLOW RATE EXITING SYSTEM:            47.2500 KG/SEC
TOTAL MASS FLOW RATE ENTERING SYSTEM:           47.2500 KG/SEC
TOTAL ENTHALPY FLOW RATE EXITING SYSTEM:    130635.3000 KW
TOTAL ENTHALPY FLOW RATE ENTERING SYSTEM:   157200.4000 KW
TOTAL HEAT AND WORK ENTERING SYSTEM:        -26565.0900 KW

TOTAL BOILER HEAT:                              .0000 KW
TOTAL HEAT LOAD HEAT:                           .0000 KW
TOTAL PIPE ENERGY LOSSES:                       .0000 KW

TURBINE WORK (DEVICE #  1):                 26565.0900 KW
NET WORK TO GENERATORS:                     26565.0900 KW
```

```
TOTAL PUMP WORK:                          .0000 KW
GENERATOR MECHANICAL LOSSES:              .0000 KW
GENERATOR ELECTRICAL LOSSES:              .0000 KW
NET ELECTRICAL POWER:                 26565.0900 KW

SYSTEM HEAT RATE:                        -1.0000 BTU/KW*HR
CARNOT CYCLE EFFICIENCY:                 59.3330 PERCENT
1ST LAW EFFICIENCY:                    -100.0000 PERCENT
2ND LAW EFFICIENCY:                      97.3501 PERCENT
2ND LAW EFFECTIVENESS:                 -100.0000 PERCENT
```

The procedure utilized to specify any device type within an input file may be interpreted to be strictly analog to the single turbine example problem. In the event that the system of interest contained several devices, the information required to describe the other devices within the system would proceed the simple turbine device in the input file.

Using the DOS editor and the key phrase library provided in Tables 1-3, an input file for any steam system may be created. The only limitation with respect to the system layout is that the system must have less than 100 device, less than 100 nodes, and the system must be well posed. It is recommended that a hard copy of an existing input file be referred to as questions arise associated with input file construction. For the more experienced RANKINE users, it may be easier to modify an existing input file to represent a new system than to construct a new input file from scratch.

Thermodynamic Models

RANKINE 3.0 can model eleven different thermal devices commonly found in steam power systems. Each of these thermal devices are modeled by RANKINE 3.0 as thermodynamic control volumes capable of performing as specified within the input file. The performance of each thermal device is calculated with hard wired code logic, which applies the 1st and 2nd law of thermodynamics for a control volume (neglecting kinetic and potential energy) and the appropriate performance parameters to calculate the performance of each device. The control volume for the thermodynamic analysis is selected around the physical boundaries of each device, and hence, the only information acquired from the analysis is the state of the working fluid as it crosses the boundary of the control volume and the net work and/or heat transferred across the boundary of the control volume.

RANKINE 3.0 was developed to utilize several different combinations of known information to calculate the thermodynamic performance of each device type. The conditions in which RANKINE 3.0 can perform calculations are based on the standard methods to model each device type. A summary of these methods can be found in reference [1].

The device performance parameters utilized in the thermodynamic analysis depends on the device type. The device performance parameter captures the physics of the device and may be provided to RANKINE 3.0 for the analysis. For example, the physics of a 'pipe device' may be captured with a user specified pressure loss and a user specified enthalpy loss. These two parameters quantify the pressure loss encountered when a viscous fluid (in our case, steam) moves within a pipe and the heat loss (which appears in the form of a steam enthalpy decrease) when a 'hot' pipe interacts thermally with its environment.

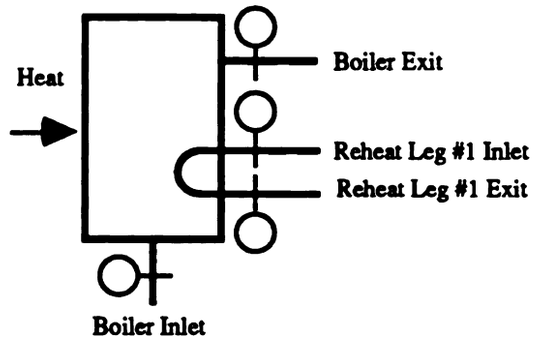
Each of the eleven thermodynamic devices which can be modeled by RANKINE 3.0 is discussed below. For each device type, the device purpose, common symbol, performance parameters and program limitations are discussed.

Device: SIMPLE BOILER

Purpose: A boiler is a device where heat originating from combustion gasses, a nuclear reactor, or other source is transferred to the working fluid traveling through the boiler. In an ideal boiler, the heat addition occurs as a constant pressure processes.

Frequently, a boiler will have one or more reheat legs. A boiler with a reheat leg permits the working fluid to reenter the boiler after the working fluid has traveled through a high pressure turbine. Since the performance of a turbine decreases with increasing working fluid moisture, the reheat leg is a practical solution to the excessive moisture problem in turbines.

Symbol:



Performance Parameters:
1) Boiler pressure loss or boiler percentage pressure loss.
2) For each reheat leg, a reheat leg pressure loss or reheat leg percentage pressure loss.

Program Limitations:
1) Each boiler device may have a maximum of 10 reheat legs.

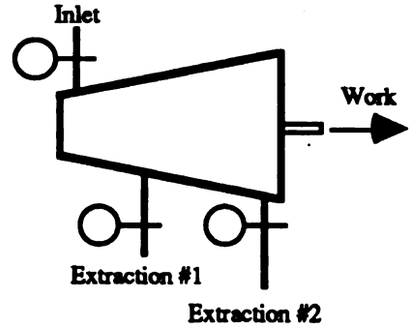
Comments:
1) Percentage pressure losses are based upon the inlet pressure.

Device: SIMPLE TURBINE

Purpose: A turbine is a device which converts the energy contained within the working fluid into rotating mechanical energy. As the working fluid passes through the turbine, work is done against rotor blades which are attached to a shaft. When the rotating shaft is connected to an electrical generator, electricity is produced.

Frequently, a turbine is divided into stage groups. A stage group is defined as a set of stator and rotor blades in which the working fluid undergoes a continuous expansion. Usually, the end of a stage group is indicated by an extraction point.

Symbol:



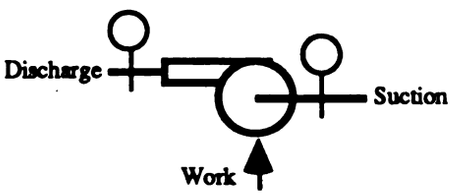
Performance Parameters:
1) For each stage group, an adiabatic stage group efficiency.

Program Limitations:
1) A simple turbine may have a maximum of 10 extractions.
2) Shaft leakage is not modeled.

Device: SIMPLE PUMP

Purpose: A pump is a device used to increase the pressure of a working fluid. Work is supplied to this device from an external source through a rotating shaft.

Symbol:



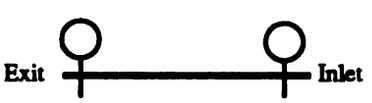
Performance Parameters:
1) An adiabatic pump efficiency.

Program Limitations: None

Device: SIMPLE PIPE

Purpose: A pipe is a device which directs a working fluid from one location to a second location. The thermodynamic behavior of a pipe device is a working fluid pressure drop and a working fluid enthalpy decreases. Physically, the pressure drop is a result of a flow restriction within the pipe (such as a valve) or the interaction of a viscous working fluid and the pipe walls. The working fluid enthalpy decrease is a result of a hot working fluid interacting thermally with the pipe surrounds.

Symbol:



Performance Parameters:
1) Pipe pressure loss or pipe percentage pressure loss.
2) Pipe enthalpy loss or pipe percentage enthalpy loss.

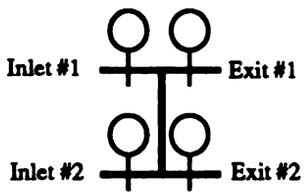
Program Limitations: None

Comments:
1) Percentage pressure loss and percentage enthalpy loss are based upon the inlet pressure and inlet enthalpy.

Device: SIMPLE JUNCTION

Purpose: A junction is a device which is used to divide (or connect) a working fluid mass stream into multiple (or one) working fluid mass streams. The thermodynamic state of each mass steam is unaffected by the junction device.

Symbol:



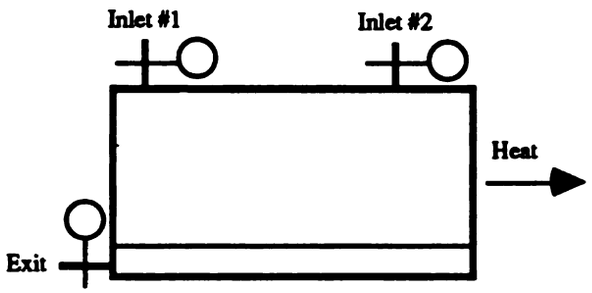
Performance Parameters: None

Program Limitations:
1) A simple junction device may have a maximum of 10 inlets and 10 exits.

Device: SIMPLE CONDENSER

Purpose: A condenser is a device where working fluid energy is rejected to a cooling medium such as a lake, a river, or the atmosphere. In an ideal condenser, the working fluid experiences no pressure drop as it travels through the condenser and the fluid exits the condenser as a saturated liquid.

Symbol:



Performance Parameters: None

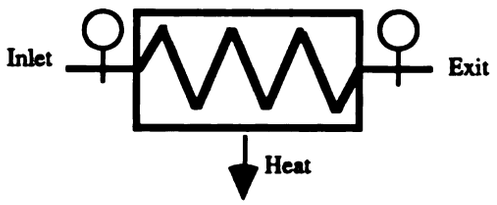
Program Limitations:
1) A simple condenser device may have a maximum of 27 inlets.

Comments:
1) The condenser exit state is assumed to be a saturated liquid.

Device: SIMPLE HEAT LOAD

Purpose: A heat load is a device which transfers heat from the working fluid to the surrounds. Usually, a heat load device is used in the modeling of co-generation power systems.

Symbol:



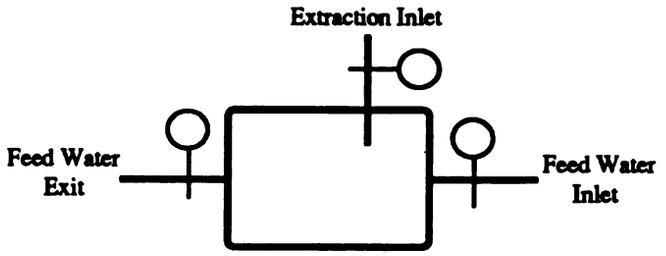
Performance Parameters: None

Program Limitations: None

Device: SIMPLE OFW HEATER

Purpose: An open feed water heater device is a mixing chamber in which streams of different energies are mixed to form a stream with an intermediate energy. Ideally, the mixture leaves the open feed water heater as a saturated liquid. It should be noted that since mixing occurs, the mixing of the extracted steam and the feed water is a constant pressure process.

Symbol:



Performance Parameters: None

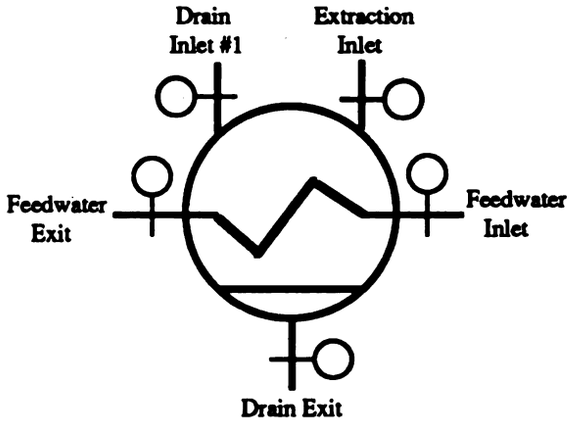
Program Limitations:
1) Open feed water heater pressure drops can not be modeled.

Comment:
1) The feed water exit state is assumed to be a saturated liquid. (this assumption can be suppressed)

Device: SIMPLE STEAM TRAP CFW

Purpose: A steam trap closed feed water heater is a heat transfer device where heat is transferred between two fluid streams at different temperatures. Since the two streams do not mix, the streams can be at different pressures. The steam trap within the device permits the shell side liquid to pass but restricts the flow of steam from the shell side exit. As a result of the steam trap, the shell side working fluid usually exits the device as a saturated or subcooled liquid.

Symbol:



Performance Parameters:

1) Feed water pressure loss or feed water percentage pressure loss.
2) Extraction pressure loss or extraction percentage pressure loss.
3) Terminal temperature difference.
4) Approach temperature difference.

Program Limitations:

1) A steam trap closed feed water heater device may have a maximum of 10 drain inlets.

Comments:

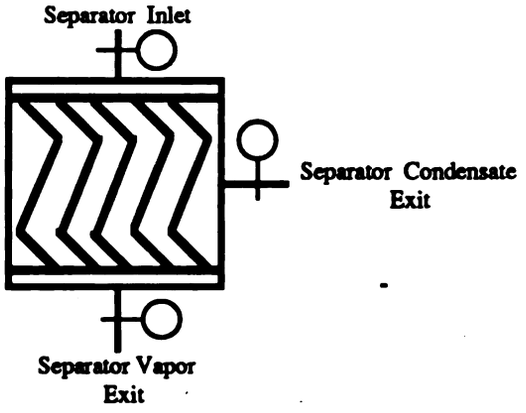
1) The performance of a steam trap closed feed water heater is defined with two parameters; the terminal temperature difference and the approach temperature difference. The terminal temperature difference is defined as the difference between the extraction inlet saturation temperature and the feed water exit temperature. The approach temperature difference is defined as the difference between the drain exit temperature and the feed water inlet temperature.

Device: SIMPLE MOISTURE SEPARATOR

Purpose: A moisture separator is a device that removes entrained water vapor from a two phase flow. Usually, the moisture separation is accomplished by

forcing the two phase flow through a torturous path and providing surfaces for the collection of condensate.

Symbol:



Performance Parameters: 1) Separator pressure loss or separator percentage pressure loss.

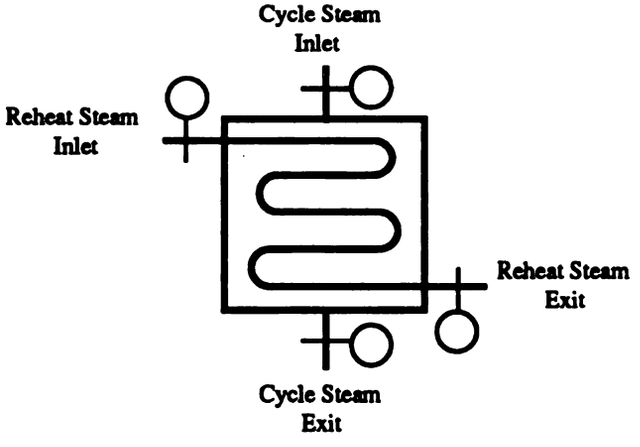
Program Limitations: None

Comments: 1) Separator percentage pressure loss is based upon the inlet pressure.
2) Pressure drops are identical for both the separator condensate exit and separator vapor exit.

Device: SIMPLE REHEATER

Purpose: A reheater is a device which transfers heat from a reheat steam mass stream to a cycle steam mass stream. Usually, the reheat steam enters as a superheated vapor and exits as a saturated liquid and the cycle steam enters as a two phase mixture and exits as a superheated vapor.

Symbol:



Performance Parameters:
1) Terminal temperature difference.
2) Cycle steam pressure drop or percentage pressure drop.
3) Reheat steam pressure drop or percentage pressure drop.

Program Limitations: None

Comments:
1) The reheat steam exit state is assumed to be saturated liquid. (this assumption can be suppressed)
2) The 'FLOW FRACTION CONTROLLED BY JUNCTION DEVICE NUMBER' statement required for the simple reheater model indicates the junction device number which controls the ratio of mass flow through the cycle steam path to the mass flow through the reheat steam path. The program iterates with this flow fraction until the user specified terminal temperature difference is achieved. An initial guess for this flow fraction must be provided to the program.
3) The terminal temperature difference for the simple reheater model is defined as the temperature difference between the reheat steam exit temperature and the cycle steam exit temperature.

Computerized steam tables

RANKINE 3.0 incorporates a set of computerized steam tables which represent fundamental equation for steam. Even though the state postulate requires two independent intensive properties to fix a thermodynamic state, the information required by RANKINE 3.0 to fix a thermodynamic state is based upon the requirements (or limitations) of the computerized steam tables. Table 5-5 contains a summary of the thermodynamic conditions for which a state is fixed and all unknown thermodynamic information which may be calculated.

Table 5-5. Requirements to fix a thermodynamic state

Known	Calculates
Temperature Pressure Subcooled liquid or Superheated vapor	Specific volume Enthalpy Entropy
Temperature Quality Two phase mixture	Saturation pressure Specific volume Enthalpy Entropy
Pressure Quality Two phase mixture	Saturation temperature Specific volume Enthalpy
Pressure Entropy	Temperature Specific volume Enthalpy Quality Fluid phase index
Pressure Enthalpy	Temperature Specific volume Entropy Quality Fluid phase index

It should be noted that the numerical methods used to calculate the steam table properties introduce considerable error whenever the pressure is greater than the critical pressure. Therefore, the maximum allowable pressure is 22.09 MPa and the maximum allowable temperature is 1300 Deg C. In addition, the computerized steam tables incorporated by RANKINE 3.0 possess a very slight discontinuity between the 2-phase correlation and the compressed liquid and superheated steam correlations. As a result of this discontinuity, RANKINE 3.0 may calculate a working fluid entropy decrease across a device or a negative irreversibility for a device. Since both conditions are physically impossible, RANKINE 3.0 checks each device in the system to insure that neither condition exists and, if necessary, provides a warning message to the user during program execution. Usually, the discontinuity problem may be avoided by not modeling very small device pressure losses when the working fluid is close to the saturated liquid or saturated vapor line.

Program Limitations

Even though RANKINE 3.0 was developed to be as flexible as possible, the program does contain some limitations. A summary of these limitations are presented below.

1) The system must have less than 100 devices.
2) The system must have less than 100 nodes.
3) A SIMPLE TURBINE device may have a maximum of 10 extractions.
4) A SIMPLE CONDENSER device may have a maximum of 27 inlets.
5) A SIMPLE BOILER device may have a maximum of 10 reheat legs.
6) A SIMPLE JUNCTION device may have a maximum of 10 inlets and a maximum of 10 exits.
7) Transients can not be modeled by RANKINE 3.0.
8) Working fluid other than steam can not be modeled by RANKINE 3.0 (such as non condensable gasses).
9) RANKINE 3.0 does not provide insight into the physics within the thermodynamic control volumes.
10) The performance characteristics (such as pipe pressure loss or adiabatic stage group efficiency) of each device must be known before the system performance is analyzed.
11) Due to steam table limitations, the maximum allowable pressure is 22.09 MPa and the maximum allowable temperature is 1300 Deg C.

Example Problem #1

As an example, consider the problem of determining the 1st and 2nd law efficiency for a steam power system consisting of one boiler, one turbine, one condenser and one pump. The system layout for this example is shown in Figure 5-2.

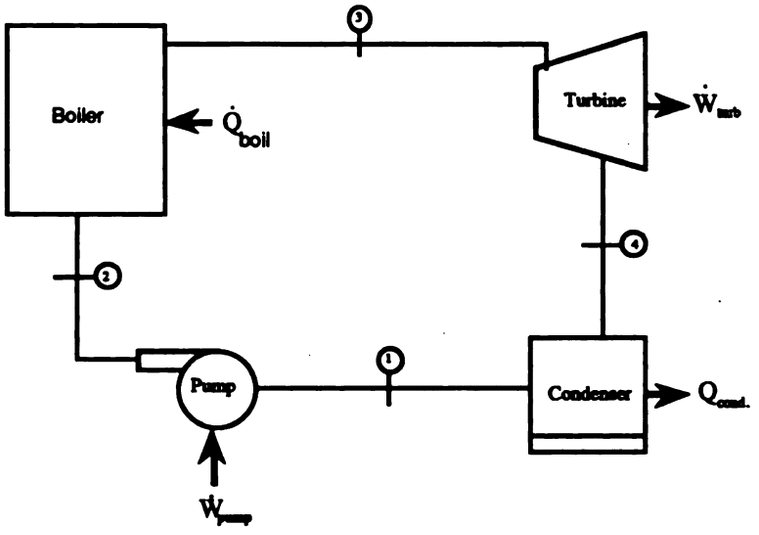


Figure 5-2. Schematic for example problem #1

For this example problem, it will be assumed that:

(1) The boiler operates at 20.0 MPa, 600°C and generates 50 kg/sec of steam.
(2) The condenser operating pressure is 0.1 MPa.
(3) All stage groups and pumps are 75% efficient.
(4) No pipe pressure losses or enthalpy losses.
(5) No boiler pressure losses.

Since this is a well posed problem, obtaining the 1st and 2nd law efficiency is a task ideally suited for RANKINE 3.0.

In order to use RANKINE 3.0 to model this system, an input file must be created that describes the system layout, operating conditions and performance parameters for example problem #1. Using Tables 5-1, 5-2, and 5-3, the system may be traversed and all information required to specify a well posed problem can be communicated to the program.

For example problem #1, the input file generated by RANKINE 3.0 is presented below.

```
TITLE LINE
  SIMPLE RANKINE CYCLE - EXAMPLE
PROBLEM #1
  END TITLE

NUMBER OF NODES IS 4

HIGH TEMPERATURE RESERVOIR: 600.0 DEG C
LOW TEMPERATURE RESERVOIR: 25.0 DEG C
DEAD STATE TEMPERATURE: 25.0 DEG C
DEAD STATE PRESSURE: 101 KPA
GENERATOR MECHANICAL LOSS IS 0.0 MW
GENERATOR ELECTRICAL LOSS IS 0.0 MW
```

```
DEVICE #1: SIMPLE TURBINE
  INLET NODE NUMBER IS 3
  EXTRACTION #1 NODE NUMBER IS 4
  STAGE GROUP #1 EFFICIENCY IS 75 %
  EXTRACTION #1 PRESSURE IS 0.1 MPA
  END DEVICE

DEVICE #2: SIMPLE CONDENSER
  EXIT NODE NUMBER IS 1
  INLET #1 NODE NUMBER IS 4
  END DEVICE

DEVICE #3: SIMPLE PUMP
  SUCTION NODE NUMBER IS 1
  DISCHARGE NODE NUMBER IS 2
  PUMP EFFICIENCY IS 75 PERCENT
  END DEVICE

DEVICE #4: SIMPLE BOILER
  BOILER INLET NODE NUMBER IS 2
  BOILER EXIT NODE NUMBER IS 3
  BOILER EXIT PRESSURE IS 20.0 MPA
  BOILER EXIT TEMPERATURE IS 600 DEG C
  BOILER EXIT MASS FLOW RATE IS 50 KG/SEC
  BOILER PRESSURE LOSS IS 0.0 MPA
  END DEVICE
```

The output file for example problem #1 is presented below.

```
          RANKINE 3.0: A steam power plant computer simulation

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                          W.A. Thelen, C.W. Somerton

 ********************************** TITLE ************************************

   SIMPLE RANKINE CYCLE - EXAMPLE PROBLEM #1

 ******************************** NODE DATA **********************************

 NODE   T(C)     P(MPa)  L     Q   S(KJ/KG/K) H(KJ/KG) V(M^3/KG) M(KG/S) A(KJ/KG)
 ------------------------------------------------------------------------------
   1    99.63     .1000  4  *****   1.3020    417.31    .00104   50.0000   33.47
   2   103.52   20.0000  1  *****   1.3228    448.50    .00105   50.0000   58.45
   3   600.00   20.0000  3  *****   6.5052   3536.61    .01808   50.0000 1601.44
   4    99.63     .1000  2   .990   7.2962   2651.90   1.67621   50.0000  480.88


 ********************** DEVICE DATA (DEVICE BEFORE NODE) **********************

 NODE      REV. WRK    ACT. WRK     IRREV     HEAT X-FER    MASS ERROR  ENERGY ERROR
             (KW)        (KW)       (KW)       (KW)          (KG/S)       (KW)
 ------------------------------------------------------------------------------
   1     22370.37         .00   22370.37   -111729.90         .000        -.008
   2     -1249.04    -1559.60     310.56          .00         .000         .000
   3     71843.58         .00   71843.58    154405.60         .000         .000
   4     56028.13    44235.28   11792.86          .00         .000         .000

 ********************************* SYSTEM DATA ********************************

 TOTAL MASS FLOW RATE EXITING SYSTEM:                .0000 KG/SEC
 TOTAL MASS FLOW RATE ENTERING SYSTEM:               .0000 KG/SEC
 TOTAL ENTHALPY FLOW RATE EXITING SYSTEM:            .0000 KW
 TOTAL ENTHALPY FLOW RATE ENTERING SYSTEM:           .0000 KW
 TOTAL HEAT AND WORK ENTERING SYSTEM:              -.0039 KW

 BOILER HEAT (DEVICE #  4):                     154405.6000 KW
 TOTAL BOILER HEAT:                             154405.6000 KW
 TOTAL HEAT LOAD HEAT:                               .0000 KW
 CONDENSER HEAT (DEVICE #  2):                 -111729.9000 KW
 TOTAL PIPE ENERGY LOSSES:                           .0000 KW

 TURBINE WORK (DEVICE #  1):                     44235.2800 KW
 NET WORK TO GENERATORS:                         44235.2800 KW

 PUMP WORK (DEVICE #  3):                        -1559.6010 KW
```

```
TOTAL PUMP WORK:                        -1559.6010 KW
GENERATOR MECHANICAL LOSSES:                .0000 KW
GENERATOR ELECTRICAL LOSSES:                .0000 KW
NET ELECTRICAL POWER:                   42675.6800 KW

SYSTEM HEAT RATE:                       12345.0200 BTU/KW*HR
CARNOT CYCLE EFFICIENCY:                   65.8535 PERCENT
1ST LAW EFFICIENCY:                        27.6387 PERCENT
2ND LAW EFFICIENCY:                        42.8466 PERCENT
2ND LAW EFFECTIVENESS:                     41.9699 PERCENT
```

From this output file, it can be seen that system's 1st law efficiency is 27.6387 percent and the 2nd law efficiency is 42.8466 percent.

Example Problem #2

As an example, consider the problem of determining the 1st and 2nd law efficiency for a co-generation steam power system consisting of three turbines, two reheat legs, three open feed water heaters, and three heat loads. The system layout for this example is shown in Figure 5-3.

For this example problem, it will be assume that

(1) The boiler operates at 20.0 MPa, 600°C and generates 50 kg/sec of steam.
(2) Both reheat legs raise the temperature of the working fluid to 600°C.
(3) Extraction pressures are 15.0, 10.0, 7.5, 5.0, 2.5, 1.0, 0.5, 0.25, and 0.1 MPa.
(4) All stage groups and pumps are 75% efficient.
(5) The heat load mass flow rates are 1.0, 5.0 and 5.0 kg/sec.
(6) No pipe pressure losses or enthalpy losses.
(7) No boiler pressure losses.

Since this is a well posed problem, obtaining the 1st and 2nd law efficiency is a task ideally suited for RANKINE 3.0.

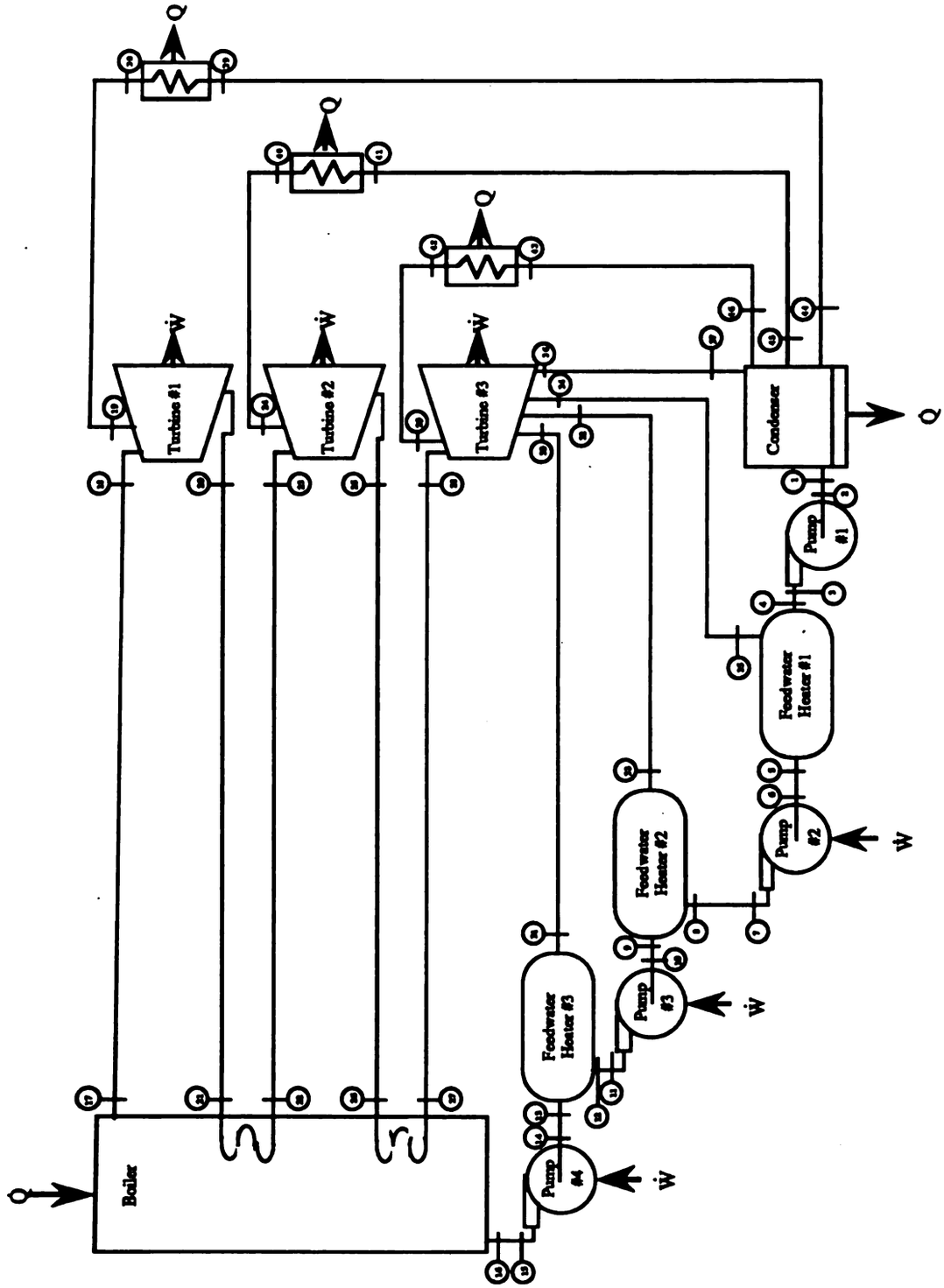


Figure 5-3. Schematic for example problem #2

In order to use RANKINE 3.0 to model this system, an input file must be created that describes the system layout, operating conditions and performance parameters for example problem #2. The input file for example problem #2 is presented below.

```
TITLE LINE
  EXAMPLE PROBLEM #2
  END TITLE LINE

NUMBER OF NODES: 46
HIGH TEMPERATURE RESERVOIR: 600.0 DEG C
LOW TEMPERATURE RESERVOIR: 25.0 DEG C
DEAD STATE TEMPERATURE: 25.0 DEG C
DEAD STATE PRESSURE: 101 KPA
GENERATOR MECHANICAL LOSS: 0.0 MW
GENERATOR ELECTRICAL LOSS: 0.0 MW

DEVICE #1: SIMPLE BOILER
  BOILER INLET NODE NUMBER IS 16
  BOILER EXIT NODE NUMBER IS 17
  BOILER REHEAT LEG #1 INLET NODE
NUMBER IS 21
  BOILER REHEAT LEG #1 EXIT NODE NUMBER
IS 22
  BOILER REHEAT LEG #2 INLET NODE
NUMBER IS 26
  BOILER REHEAT LEG #2 EXIT NODE NUMBER
IS 27
  BOILER EXIT TEMPERATURE IS 600.0
DEG C
  BOILER EXIT PRESSURE IS 20 MPA
  BOILER EXIT MASS FLOW RATE IS 50.0
KG/SEC
  BOILER REHEAT LEG #1 EXIT TEMPERATURE
IS 600.0 DEG C
  BOILER REHEAT LEG #2 EXIT TEMPERATURE
IS 600.0 DEG C
  BOILER PERCENTAGE PRESSURE LOSS IS 0.0
PERCENT
  REHEAT LEG #1 PERCENTAGE PRESSURE
LOSS IS 0.0 PERCENT
  REHEAT LEG #2 PERCENTAGE PRESSURE
LOSS IS 0.0 PERCENT
  END DEVICE

DEVICE #2: SIMPLE PIPE
  INLET NODE NUMBER IS 17
  EXIT NODE NUMBER IS 18
  PIPE PRESSURE LOSS IS 0.0 MPA
  PIPE ENTHALPY LOSS IS 0.0 KJ/KG
  END DEVICE

DEVICE #3: SIMPLE TURBINE
  INLET NODE NUMBER IS 18
  EXTRACTION #1 NODE NUMBER IS 19
  EXTRACTION #2 NODE NUMBER IS 20
  STAGE GROUP #1 EFFICIENCY IS 75%
  STAGE GROUP #2 EFFICIENCY IS 75%
  EXTRACTION #1 PRESSURE IS 15.0 MPA
  EXTRACTION #2 PRESSURE IS 10.0 MPA
  EXTRACTION #1 MASS FLOW RATE IS 1.0
KG/SEC
  END DEVICE

DEVICE #4: SIMPLE PIPE
  INLET NODE NUMBER IS 20
  EXIT NODE NUMBER IS 21
  PIPE PERCENTAGE PRESSURE LOSS IS 0.0
PERCENT
  PIPE PERCENTAGE ENTHALPY LOSS IS 0.0
PERCENT
  END DEVICE

DEVICE #5: SIMPLE PIPE
  INLET NODE NUMBER IS 22
  EXIT NODE NUMBER IS 23
  PIPE PRESSURE LOSS IS 0.0 MPA
  PIPE ENTHALPY LOSS IS 0.0 KJ/KG
  END DEVICE

DEVICE #6: SIMPLE TURBINE
  INLET NODE NUMBER IS 23
  EXTRACTION #1 NODE NUMBER IS 24
  EXTRACTION #2 NODE NUMBER IS 25
  STAGE GROUP #1 EFFICIENCY IS 75%
  STAGE GROUP #2 EFFICIENCY IS 75%
  EXTRACTION #1 PRESSURE IS 7.5 MPA
  EXTRACTION #2 PRESSURE IS 5.0 MPA
  EXTRACTION #1 MASS FLOW RATE IS 5.0
KG/SEC
  END DEVICE

DEVICE #7: SIMPLE PIPE
  INLET NODE NUMBER IS 25
  EXIT NODE NUMBER IS 26
  PIPE PRESSURE LOSS IS 0.0 MPA
  PIPE ENTHALPY LOSS IS 0.0 KJ/KG
  END DEVICE

DEVICE #8: SIMPLE PIPE
  INLET NODE NUMBER IS 27
  EXIT NODE NUMBER IS 28
  PIPE PRESSURE LOSS IS 0.0 MPA
  PIPE ENTHALPY LOSS IS 0.0 KJ/KG
  END DEVICE

DEVICE #9:  SIMPLE TURBINE
  INLET NODE NUMBER IS 28
  EXTRACTION #1 NODE NUMBER IS 29
  EXTRACTION #2 NODE NUMBER IS 30
  EXTRACTION #3 NODE NUMBER IS 32
  EXTRACTION #4 NODE NUMBER IS 34
  EXTRACTION #5 NODE NUMBER IS 36
  STAGE GROUP #1 EFFICIENCY IS 75%
  STAGE GROUP #2 EFFICIENCY IS 75%
  STAGE GROUP #3 EFFICIENCY IS 75%
  STAGE GROUP #4 EFFICIENCY IS 75%
  STAGE GROUP #5 EFFICIENCY IS 75%
  EXTRACTION #1 PRESSURE IS 2.5 MPA
  EXTRACTION #2 PRESSURE IS 1.0 MPA
  EXTRACTION #3 PRESSURE IS 0.5 MPA
```

```
    EXTRACTION #4 PRESSURE IS 0.25 MPA
    EXTRACTION #5 PRESSURE IS 0.10 MPA
    EXTRACTION #1 MASS FLOW RATE IS 5.0
  KG/SEC
    END DEVICE

  DEVICE #10: SIMPLE PIPE
    INLET NODE NUMBER IS 30
    EXIT NODE NUMBER IS 31
    PIPE PRESSURE LOSS IS 0.0 MPA
    PIPE ENTHALPY LOSS IS 0.0 KJ/KG
    END DEVICE

  DEVICE #11: SIMPLE PIPE
    INLET NODE NUMBER IS 32
    EXIT NODE NUMBER IS 33
    PIPE PRESSURE LOSS IS 0.0 MPA
    PIPE ENTHALPY LOSS IS 0.0 KJ/KG
    END DEVICE

  DEVICE #12: SIMPLE PIPE
    INLET NODE NUMBER IS 34
    EXIT NODE NUMBER IS 35
    PIPE PRESSURE LOSS IS 0.0 MPA
    PIPE ENTHALPY LOSS IS 0.0 KJ/KG
    END DEVICE

  DEVICE #13: SIMPLE PIPE
    INLET NODE NUMBER IS 36
    EXIT NODE NUMBER IS 37
    PIPE PRESSURE LOSS IS 0.0 MPA
    PIPE ENTHALPY LOSS IS 0.0 KJ/KG
    END DEVICE

  DEVICE #14: SIMPLE CONDENSER
    EXIT NODE NUMBER IS 1
    INLET #1 NODE NUMBER IS 37
    INLET #2 NODE NUMBER IS 44
    INLET #3 NODE NUMBER IS 45
    INLET #4 NODE NUMBER IS 46
    END DEVICE

  DEVICE #15: SIMPLE PIPE
    INLET NODE NUMBER IS 1
    EXIT NODE NUMBER IS 2
    PIPE PRESSURE LOSS IS 0.0 MPA
    PIPE ENTHALPY LOSS IS 0.0 KJ/KG
    END DEVICE

  DEVICE #16: SIMPLE PUMP
    SUCTION NODE NUMBER IS 2
    DISCHARGE NODE NUMBER IS 3
    PUMP EFFICIENCY IS 75%
    END DEVICE

  DEVICE #17: SIMPLE PIPE
    INLET NODE NUMBER IS 3
    EXIT NODE NUMBER IS 4
    PIPE PRESSURE LOSS IS 0.0 MPA
    PIPE ENTHALPY LOSS IS 0.0 KJ/KG
    END DEVICE

  DEVICE #18: SIMPLE OFW HEATER
    FEED WATER INLET NODE NUMBER IS 4
    FEED WATER EXIT NODE NUMBER IS 5
    EXTRACTION INLET NODE NUMBER IS 35
    END DEVICE

  DEVICE #19: SIMPLE PIPE
    INLET NODE NUMBER IS 5
    EXIT NODE NUMBER IS 6
    PIPE PRESSURE LOSS IS 0.0 MPA
    PIPE ENTHALPY LOSS IS 0.0 KJ/KG
    END DEVICE

  DEVICE #20: SIMPLE PUMP
    SUCTION NODE NUMBER IS 6
    DISCHARGE NODE NUMBER IS 7
    PUMP EFFICIENCY IS 75%
    END DEVICE

  DEVICE #21: SIMPLE PIPE
    INLET NODE NUMBER IS 7
    EXIT NODE NUMBER IS 8
    PIPE PRESSURE LOSS IS 0.0 MPA
    PIPE ENTHALPY LOSS IS 0.0 KJ/KG
    END DEVICE

  DEVICE #22: SIMPLE OFW HEATER
    FEED WATER INLET NODE NUMBER IS 8
    FEED WATER EXIT NODE NUMBER IS 9
    EXTRACTION INLET NODE NUMBER IS 33
    END DEVICE

  DEVICE #23: SIMPLE PIPE
    INLET NODE NUMBER IS 9
    EXIT NODE NUMBER IS 10
    PIPE PRESSURE LOSS IS 0.0 MPA
    PIPE ENTHALPY LOSS IS 0.0 KJ/KG
    END DEVICE

  DEVICE #24: SIMPLE PUMP
    SUCTION NODE NUMBER IS 10
    DISCHARGE NODE NUMBER IS 11
    PUMP EFFICIENCY IS 75%
    END DEVICE

  DEVICE #25: SIMPLE PIPE
    INLET NODE NUMBER IS 11
    EXIT NODE NUMBER IS 12
    PIPE PRESSURE LOSS IS 0.0 MPA
    PIPE ENTHALPY LOSS IS 0.0 KJ/KG
    END DEVICE

  DEVICE #26: SIMPLE OFW HEATER
    FEED WATER EXIT NODE NUMBER IS 13
    FEED WATER INLET NODE NUMBER IS 12
    EXTRACTION INLET NODE NUMBER IS 31
    END DEVICE

  DEVICE #27: SIMPLE PIPE
    INLET NODE NUMBER IS 13
    EXIT NODE NUMBER IS 14
    PIPE PRESSURE LOSS IS 0.0 MPA
    PIPE ENTHALPY LOSS IS 0.0 KJ/KG
    END DEVICE

  DEVICE #28: SIMPLE PUMP
```

SUCTION NODE NUMBER IS 14
DISCHARGE NODE NUMBER IS 15
PUMP EFFICIENCY IS 75%
END DEVICE

DEVICE #29: SIMPLE PIPE
INLET NODE NUMBER IS 15
EXIT NODE NUMBER IS 16
PIPE PRESSURE LOSS IS 0.0 MPA
PIPE ENTHALPY LOSS IS 0.0 KJ/KG
END DEVICE

DEVICE #30: SIMPLE PIPE
INLET NODE NUMBER IS 19
EXIT NODE NUMBER IS 38
PIPE PRESSURE LOSS IS 0.0 MPA
PIPE ENTHALPY LOSS IS 0.0 KJ/KG
END DEVICE

DEVICE #31: SIMPLE HEAT LOAD
INLET NODE NUMBER IS 38
EXIT NODE NUMBER IS 39
EXIT TEMPERATURE IS 175.7 DEG C
END DEVICE

DEVICE #32: SIMPLE PIPE
INLET NODE NUMBER IS 39
EXIT NODE NUMBER IS 44
PIPE PRESSURE LOSS IS 0.0 MPA
PIPE ENTHALPY LOSS IS 0.0 KJ/KG
END DEVICE

DEVICE #33: SIMPLE PIPE
INLET NODE NUMBER IS 24
EXIT NODE NUMBER IS 40
PIPE PRESSURE LOSS IS 0.0 MPA
PIPE ENTHALPY LOSS IS 0.0 KJ/KG
END DEVICE

DEVICE #34: SIMPLE HEAT LOAD
INLET NODE NUMBER IS 40
EXIT NODE NUMBER IS 41
EXIT TEMPERATURE IS 175.7 DEG C
END DEVICE

DEVICE #35: SIMPLE PIPE
INLET NODE NUMBER IS 41
EXIT NODE NUMBER IS 45
PIPE PRESSURE LOSS IS 0.0 MPA
PIPE ENTHALPY LOSS IS 0.0 KJ/KG
END DEVICE

DEVICE #36: SIMPLE PIPE
INLET NODE NUMBER IS 29
EXIT NODE NUMBER IS 42
PIPE PRESSURE LOSS IS 0.0 MPA
PIPE ENTHALPY LOSS IS 0.0 KJ/KG
END DEVICE

DEVICE #37: SIMPLE HEAT LOAD
INLET NODE NUMBER IS 42
EXIT NODE NUMBER IS 43
EXIT TEMPERATURE IS 175.7 DEG C
END DEVICE

DEVICE #38: SIMPLE PIPE
INLET NODE NUMBER IS 43
EXIT NODE NUMBER IS 46
PIPE PRESSURE LOSS IS 0.0 MPA
PIPE ENTHALPY LOSS IS 0.0 KJ/KG
END DEVICE

For example problem #2, the output file generated by RANKINE 3.0 is presented below.

```
RANKINE 3.0: A steam power plant computer simulation

                    Copyright 1994
                W.A. Thelen, C.W. Somerton

********************************** TITLE ************************************

  EXAMPLE PROBLEM #2

******************************** NODE DATA **********************************

NODE   T(C)     P(MPa)   L     Q   S(KJ/KG/K) H(KJ/KG) V(M^3/KG) M(KG/S) A(KJ/KG)
-------------------------------------------------------------------------------
  1    99.63     .1000   4  *****   1.3020    417.31    .00104   43.6475   33.47
  2    99.63     .1000   4  *****   1.3020    417.31    .00104   43.6475   33.47
  3    99.68     .2500   1  *****   1.3022    417.59    .00104   43.6475   33.70
  4    99.68     .2500   1  *****   1.3022    417.59    .00104   43.6475   33.70
  5   127.43     .2500   4  *****   1.6065    535.09    .00107   45.7481   60.45
  6   127.43     .2500   4  *****   1.6065    535.09    .00107   45.7481   60.45
  7   127.52     .5000   1  *****   1.6069    535.66    .00107   45.7481   60.91
  8   127.52     .5000   1  *****   1.6069    535.66    .00107   45.7481   60.91
  9   151.84     .5000   4  *****   1.8595    639.79    .00109   47.6790   89.73
 10   151.84     .5000   4  *****   1.8595    639.79    .00109   47.6790   89.73
 11   152.05    1.0000   1  *****   1.8601    640.98    .00109   47.6790   90.71
 12   152.05    1.0000   1  *****   1.8601    640.98    .00109   47.6790   90.71
 13   179.87    1.0000   4  *****   2.1367    762.23    .00113   50.0000  129.52
```

14	179.87	1.0000	4	*****	2.1367	762.23	.00113	50.0000	129.52
15	185.00	20.0000	1	*****	2.1542	794.40	.00113	50.0000	156.46
16	185.00	20.0000	1	*****	2.1542	794.40	.00113	50.0000	156.46
17	600.00	20.0000	3	*****	6.5052	3536.61	.01808	50.0000	1601.44
18	600.00	20.0000	3	*****	6.5052	3536.61	.01808	50.0000	1601.44
19	554.33	15.0000	3	*****	6.5358	3460.98	.02304	1.0000	1516.67
20	494.41	10.0000	3	*****	6.5799	3360.38	.03242	49.0000	1402.94
21	494.41	10.0000	3	*****	6.5799	3360.38	.03242	49.0000	1402.94
22	600.00	10.0000	3	*****	6.8991	3621.73	.03828	49.0000	1569.12
23	600.00	10.0000	3	*****	6.8991	3621.73	.03828	49.0000	1569.12
24	557.45	7.5000	3	*****	6.9314	3541.65	.04878	5.0000	1479.39
25	501.09	5.0000	3	*****	6.9777	3435.14	.06862	44.0000	1359.07
26	501.09	5.0000	3	*****	6.9777	3435.14	.06862	44.0000	1359.07
27	600.00	5.0000	3	*****	7.2540	3662.39	.07860	44.0000	1503.96
28	600.00	5.0000	3	*****	7.2540	3662.39	.07860	44.0000	1503.96
29	505.66	2.5000	3	*****	7.3367	3472.55	.14102	5.0000	1289.44
30	395.43	1.0000	3	*****	7.4490	3253.16	.30442	2.3210	1036.57
31	395.43	1.0000	3	*****	7.4490	3253.16	.30442	2.3210	1036.57
32	320.86	.5000	3	*****	7.5329	3106.73	.54259	1.9309	865.14
33	320.86	.5000	3	*****	7.5329	3106.73	.54259	1.9309	865.14
34	253.64	.2500	3	*****	7.6171	2976.46	.96451	2.1007	709.77
35	253.64	.2500	3	*****	7.6171	2976.46	.96451	2.1007	709.77
36	175.68	.1000	3	*****	7.7309	2827.51	2.05840	32.6475	526.88
37	175.68	.1000	3	*****	7.7309	2827.51	2.05840	32.6475	526.88
38	554.33	15.0000	3	*****	6.5358	3460.98	.02304	1.0000	1516.67
39	175.70	.1000	3	*****	7.7310	2827.54	2.05849	1.0000	526.90
40	557.45	7.5000	3	*****	6.9314	3541.65	.04878	5.0000	1479.39
41	175.70	.1000	3	*****	7.7310	2827.54	2.05849	5.0000	526.90
42	505.66	2.5000	3	*****	7.3367	3472.55	.14102	5.0000	1289.44
43	175.70	.1000	3	*****	7.7310	2827.54	2.05849	5.0000	526.90
44	175.70	.1000	3	*****	7.7310	2827.54	2.05849	1.0000	526.90
45	175.70	.1000	3	*****	7.7310	2827.54	2.05849	5.0000	526.90
46	175.70	.1000	3	*****	7.7310	2827.54	2.05849	5.0000	526.90

********** DEVICE DATA (DEVICE BEFORE NODE) **********

NODE	REV. WRK (KW)	ACT. WRK (KW)	IRREV (KW)	HEAT X-FER (KW)	MASS ERROR (KG/S)	ENERGY ERROR (KW)
1	21536.46	.00	21536.46	-105199.70	.000	.016
2	.00	.00	.00	.00	.000	.000
3	-10.11	-12.63	2.53	.00	.000	.000
4	.00	.00	.00	.00	.000	.001
5	196.52	.00	196.52	.00	.000	.000
6	.00	.00	.00	.00	.000	.000
7	-21.30	-26.17	4.87	.00	.000	.000
8	.00	.00	.00	.00	.000	.001
9	178.76	.00	178.76	.00	.000	.000
10	.00	.00	.00	.00	.000	.000
11	-46.72	-56.63	9.91	.00	.000	.000
12	.00	.00	.00	.00	.000	.000
13	254.86	.00	254.86	.00	.000	.002
14	.00	.00	.00	.00	.000	.002
15	-1346.88	-1608.31	261.43	.00	.000	.002
16	.00	.00	.00	.00	.000	.000
17	52840.78	.00	52840.78	137110.60	.000	.000
18	.00	.00	.00	.00	.000	.000
19	4238.50	3781.70	456.80	.00	.000	.000
20	5572.79	4929.13	643.66	.00	.000	.005
21	.00	.00	.00	.00	.000	-.006
22	850.56	.00	850.56	12806.20	.000	-.006
23	.01	.00	.01	.00	.000	-.005
24	4396.73	3924.03	472.70	.00	.000	.000
25	5294.03	4686.43	607.60	.00	.000	-.007

26	.00	.00	.00	.00	.000	.001
27	613.13	.00	613.13	9998.87	.000	.001
28	.01	.00	.01	.00	.000	.005
29	9438.87	8352.90	1085.97	.00	.000	.000
30	9861.99	8556.09	1305.90	.00	.000	.000
31	.00	.00	.00	.00	.000	.000
32	6287.99	5370.97	917.02	.00	.000	.000
33	.00	.00	.00	.00	.000	.000
34	5398.73	4526.77	871.96	.00	.000	.000
35	.00	.00	.00	.00	.000	.000
36	5970.83	4862.75	1108.08	.00	.000	.000
37	.00	.00	.00	.00	.000	.002
38	.00	.00	.00	.00	.000	.000
39	989.77	.00	989.77	-633.43	.000	.000
40	.00	.00	.00	.00	.000	.000
41	4762.47	.00	4762.47	-3570.52	.000	.000
42	.00	.00	.00	.00	.000	.000
43	3812.74	.00	3812.74	-3225.02	.000	.000
44	.00	.00	.00	.00	.000	.000
45	.00	.00	.00	.00	.000	.000
46	.00	.00	.00	.00	.000	.000

********** SYSTEM DATA **********

TOTAL MASS FLOW RATE EXITING SYSTEM:	.0000	KG/SEC
TOTAL MASS FLOW RATE ENTERING SYSTEM:	.0000	KG/SEC
TOTAL ENTHALPY FLOW RATE EXITING SYSTEM:	.0000	KW
TOTAL ENTHALPY FLOW RATE ENTERING SYSTEM:	.0000	KW
TOTAL HEAT AND WORK ENTERING SYSTEM:	-.0039	KW
BOILER HEAT (DEVICE # 1):	159915.7000	KW
TOTAL BOILER HEAT:	159915.7000	KW
HEAT LOAD HEAT (DEVICE # 31):	-633.4307	KW
HEAT LOAD HEAT (DEVICE # 34):	-3570.5250	KW
HEAT LOAD HEAT (DEVICE # 37):	-3225.0180	KW
TOTAL HEAT LOAD HEAT:	-7428.9740	KW
CONDENSER HEAT (DEVICE # 14):	-105199.7000	KW
TOTAL PIPE ENERGY LOSSES:	.0000	KW
TURBINE WORK (DEVICE # 3):	8710.8320	KW
TURBINE WORK (DEVICE # 6):	8610.4610	KW
TURBINE WORK (DEVICE # 9):	31669.4800	KW
NET WORK TO GENERATORS:	48990.7800	KW
PUMP WORK (DEVICE # 16):	-12.6342	KW
PUMP WORK (DEVICE # 20):	-26.1689	KW
PUMP WORK (DEVICE # 24):	-56.6334	KW
PUMP WORK (DEVICE # 28):	-1608.3100	KW
TOTAL PUMP WORK:	-1703.7460	KW
GENERATOR MECHANICAL LOSSES:	.0000	KW
GENERATOR ELECTRICAL LOSSES:	.0000	KW
NET ELECTRICAL POWER:	47287.0400	KW
SYSTEM HEAT RATE:	11538.7300	BTU/KW*HR
CARNOT CYCLE EFFICIENCY:	65.8535	PERCENT
1ST LAW EFFICIENCY:	29.5700	PERCENT
2ND LAW EFFICIENCY:	57.0444	PERCENT
2ND LAW EFFECTIVENESS:	44.9027	PERCENT

From this output file, it can be seen that the 1st law efficiency is 29.5700 percent and the 2nd law efficiency is 57.0444 percent.

Example Problem #3

As an example, consider the problem of determining the 1st and 2nd law efficiency for a typical Pressurized Water Reactor nuclear power station. A typical system layout consists of one high pressure turbine, three low pressure turbines, two 2-stage moisture separator reheaters, two parallel strings of three high pressure steam trap closed feed water heaters, and three parallel strings of four low pressure steam trap closed feed water heaters.

For modeling purposes, the three low pressure turbines can be treated as a single low pressure turbine and the two 2-stage moisture separator reheaters can be treated as one moisture separator in series with two reheating stages. In addition the parallel strings of closed feed water heaters can be combined into a single string of seven feed water heaters. After all model condensing has been completed, the system layout is shown in Figure 5-4.

The operating conditions and device performance parameters are provided in Table 5-6 below.

Table 5-6: Data for example problem #3

Parameter	Value
High temperature reservoir	543.4 Deg F
Low temperature reservoir	55.0 Deg F
Generator mechanical losses	5725 KW electric
Generator electrical losses	15150 KW electric
Boiler exit temperature	543.4 Deg F
Boiler exit pressure	990 PSIA
Boiler exit mass flow rate	15913429 Lbm/hr
PMP #1 efficiency	95 percent
PMP #2 efficiency	95 percent
PMP #3 efficiency	65 percent
HPT #1 stage group #1 efficiency	81.0 percent
HPT #2 stage group #1 efficiency	84.0 percent
HPT #2 stage group #2 efficiency	83.0 percent
LPT stage group #1 efficiency	91.5 percent
LPT stage group #2 efficiency	91.0 percent
LPT stage group #3 efficiency	91.0 percent
LPT stage group #4 efficiency	87.8 percent
LPT stage group #5 efficiency	86.7 percent
LPT stage group #6 efficiency	70.0 percent
FPT stage group #1 efficiency	78.0 percent
HPT #1 stage group #1 exit pressure	431.3 PSIA
HPT #2 stage group #1 exit pressure	293.0 PSIA
HPT #2 stage group #2 exit pressure	182.0 PSIA
LPT stage group #1 exit pressure	89.4 PSIA
LPT stage group #2 exit pressure	41.3 PSIA
LPT stage group #3 exit pressure	17.1 PSIA
LPT stage group #4 exit pressure	10.7 PSIA
LPT stage group #5 exit pressure	6.0 PSIA
LPT stage group #6 exit pressure	1.7 PSIA
Separator pressure loss	5.4 PSID
Pipe (node 9- node 62) pressure loss	12.0 PSID
Pipe (node 10- node 57) pressure loss	9.0 PSID
Pipe (node 12- node 53) pressure loss	5.4 PSID
Pipe (node 19- node 20) pressure loss	0.0 PSID
Pipe (node 22- node 29) pressure loss	0.0 PSID
Pipe (node 23- node 46) pressure loss	2.7 PSID
Pipe (node 24- node 43) pressure loss	1.3 PSID
Pipe (node 25- node 40) pressure loss	0.5 PSID
Pipe (node 27- node 36) pressure loss	0.2 PSID
Pipe (node 28- node 31) pressure loss	0.0 PSID
Pipe (node 30- node 32) pressure loss	0.0 PSID
Pipe (node 63- node 65) pressure loss	0.0 PSID
Pipe (node 5- node 7) pressure loss	1.0 PSID
Pipe (node 50- node 49) pressure loss	0.0 PSID
Pipe (node 16- node 54) pressure loss	unspecified pressure loss
Pipe (node 18- node 61) pressure loss	unspecified pressure loss
Pipe (node 26- node 37) pressure loss	unspecified pressure loss
Pipe (node 39- node 33) pressure loss	unspecified pressure loss
Pipe (node 64- node 66) pressure loss	unspecified pressure loss
Pipe (node 59- node 67) pressure loss	unspecified pressure loss
Pipe (node 45- node 69) pressure loss	unspecified pressure loss
Pipe (node 42- node 70) pressure loss	unspecified pressure loss
Pipe (node 56- node 71) pressure loss	unspecified pressure loss

Table 5-6. (Cont'd)

Parameter	Value
Reheater (node 15-17) cycle steam pressure loss	2.6 PSID
Reheater (node 18-16) reheat steam pressure loss	4.3 PSID
Reheater (node 17-19) cycle steam pressure loss	2.6 PSID
Reheater (node 3-18) reheat steam pressure loss	10.0 PSID
All CFW extraction pressure loss	0.0 PSID
All CFW feed water pressure loss	0.0 PSID
Reheater terminal temperature difference (both)	25.0 Deg F
CFW #1 terminal temperature difference	5.0 Deg F
CFW #2 terminal temperature difference	5.0 Deg F
CFW #3 terminal temperature difference	5.0 Deg F
CFW #4 terminal temperature difference	unspecified
CFW #5 terminal temperature difference	5.0 Deg F
CFW #6 terminal temperature difference	5.0 Deg F
CFW #7 terminal temperature difference	5.0 Deg F
CFW #1 approach temperature difference	10.0 Deg F
CFW #2 approach temperature difference	10.0 Deg F
CFW #3 approach temperature difference	10.0 Deg F
CFW #4 approach temperature difference	10.0 Deg F
CFW #5 approach temperature difference	39.593 Deg F
CFW #6 approach temperature difference	10.0 Deg F
CFW #7 approach temperature difference	10.0 Deg F
CFW #5 drain exit	Saturated liquid with 0.0 quality
OFW #1 feed water exit	not saturated liquid
OFW #2 feed water exit	not saturated liquid
Node #2 flow fraction (Initial guess)	94 percent
Node #6 flow fraction (Initial guess)	91 percent
Node #22 mass flow rate	198275 Lbm/hr
Node #27 mass flow rate	158865 Lbm/hr
Node #35 pressure	540 PSIA

Since this is a well posed problem, obtaining the 1st and 2nd law efficiency is a task ideally suited for RANKINE 3.0. The iterative nature of this problem makes this type of problem exceptionally difficult (if not impossible) without a computer program such as RANKINE 3.0.

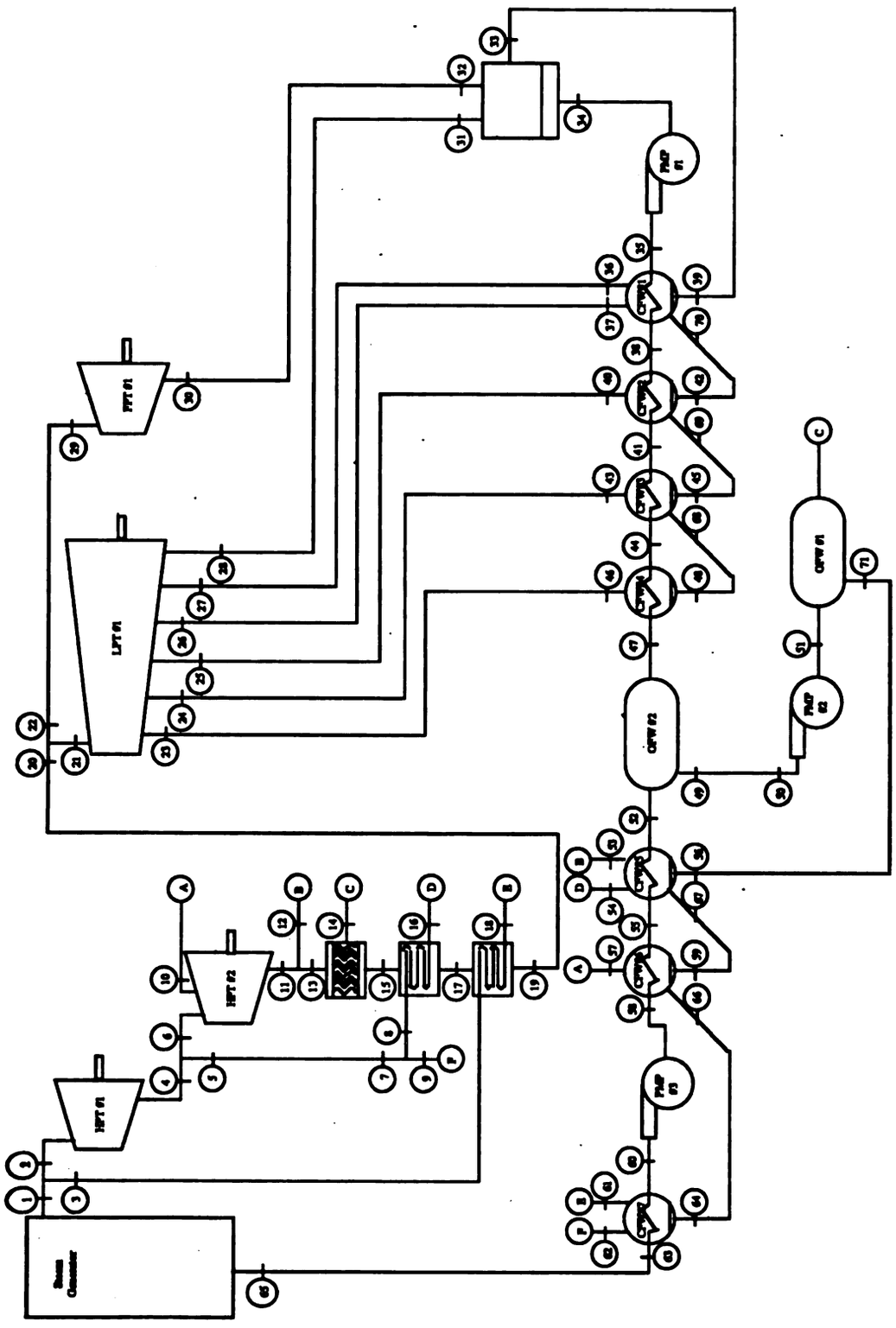


Figure 5-4. Schematic for example problem #3

In order to use RANKINE 3.0 to model this system, an input file must be created which describes the system layout, operating conditions and performance parameters to the program. For example problem #3, the input file is presented below.

```
TITLE LINE
  EXAMPLE PROBLEM #3
  END TITLE LINE

NUMBER OF NODES IS 71

HIGH TEMPERATURE RESERVOIR: 543.4 DEG F
LOW TEMPERATURE RESERVOIR: 55.0 DEG F
DEAD STATE TEMPERATURE: 75.0 DEG F
DEAD STATE PRESSURE: 14.7 PSIA
GENERATOR MECHANICAL LOSS: 5725 KW
GENERATOR ELECTRICAL LOSS: 15150 KW

DEVICE #1: SIMPLE BOILER
  BOILER INLET NODE NUMBER IS 65
  BOILER EXIT NODE NUMBER IS 1
  BOILER EXIT TEMPERATURE IS 543.4
DEG F
  BOILER EXIT PRESSURE IS 990 PSIA
  BOILER EXIT MASS FLOW RATE IS 15913429
LBM/HR
  BOILER PRESSURE LOSS IS 138.2 PSID
  END DEVICE

DEVICE #2: SIMPLE JUNCTION
  INLET #1 NODE NUMBER IS 1
  EXIT #1 NODE NUMBER IS 2
  EXIT #2 NODE NUMBER IS 3
  EXIT #1 FLOW FRACTION IS 94 PERCENT
  END DEVICE

DEVICE #3: SIMPLE TURBINE
  INLET NODE NUMBER IS 2
  EXTRACTION #1 NODE NUMBER IS 4
  EXTRACTION #1 PRESSURE IS 431.3 PSIA
  STAGE GROUP #1 EFFICIENCY IS 81 %
  END DEVICE

DEVICE #4: SIMPLE JUNCTION
  INLET #1 NODE NUMBER IS 4
  EXIT #1 NODE NUMBER IS 6
  EXIT #2 NODE NUMBER IS 5
  EXIT #1 FLOW FRACTION IS 91 PERCENT
  END DEVICE

DEVICE #5: SIMPLE TURBINE
  INLET NODE NUMBER IS 6
  EXTRACTION #1 NODE NUMBER IS 10
  EXTRACTION #2 NODE NUMBER IS 11
  STAGE GROUP #1 EFFICIENCY IS 84 %
  STAGE GROUP #2 EFFICIENCY IS 83 %
  EXTRACTION #1 PRESSURE IS 293 PSIA
  EXTRACTION #2 PRESSURE IS 182 PSIA
  END DEVICE

DEVICE #6: SIMPLE JUNCTION
  INLET #1 NODE NUMBER IS 11
  EXIT #1 NODE NUMBER IS 12
  EXIT #2 NODE NUMBER IS 13
  END DEVICE

DEVICE #7: SIMPLE MOISTURE SEPARATOR
  SEPARATOR INLET NODE NUMBER IS 13
  SEPARATOR VAPOR EXIT NODE NUMBER
IS 15
  SEPARATOR CONDENSATE EXIT NODE
NUMBER IS 14
  SEPARATOR PRESSURE LOSS IS 5.4 PSID
  END DEVICE

DEVICE #8: SIMPLE JUNCTION
  INLET #1 NODE NUMBER IS 7
  EXIT #1 NODE NUMBER IS 9
  EXIT #2 NODE NUMBER IS 8
  END DEVICE

DEVICE #9: SIMPLE PIPE
  INLET NODE NUMBER IS 9
  EXIT NODE NUMBER IS 62
  PIPE PRESSURE LOSS IS 12.0 PSID
  PIPE ENTHALPY LOSS IS 0.0 BTU/LBM
  END DEVICE

DEVICE #10: SIMPLE REHEATER
  CYCLE STEAM INLET NODE NUMBER IS 15
  CYCLE STEAM EXIT NODE NUMBER IS 17
  REHEAT STEAM INLET NODE NUMBER IS 8
  REHEAT STEAM EXIT NODE NUMBER IS 16
  FLOW FRACTION CONTROLLED BY
JUNCTION DEVICE NUMBER 4
  TERMINAL TEMPERATURE DIFFERENCE IS
25.0 DEG F
  CYCLE STEAM PRESSURE LOSS IS 2.6 PSID
  REHEAT STEAM PRESSURE LOSS IS 4.3 PSID
  END DEVICE

DEVICE #11: SIMPLE REHEATER
  CYCLE STEAM INLET NODE NUMBER IS 17
  CYCLE STEAM EXIT NODE NUMBER IS 19
  REHEAT STEAM INLET NODE NUMBER IS 3
  REHEAT STEAM EXIT NODE NUMBER IS 18
  FLOW FRACTION CONTROLLED BY
JUNCTION DEVICE NUMBER 2
  TERMINAL TEMPERATURE DIFFERENCE IS
25.0 DEG F
  CYCLE STEAM PRESSURE LOSS IS 2.6 PSID
  REHEAT STEAM PRESSURE LOSS IS 10.0 PSID
  END DEVICE

DEVICE #12: SIMPLE PIPE
  INLET NODE NUMBER IS 10
  EXIT NODE NUMBER IS 57
  PIPE PRESSURE LOSS IS 9.0 PSID
  PIPE ENTHALPY LOSS IS 0.0 BTU/LBM
  END DEVICE
```

DEVICE #13: SIMPLE PIPE
INLET NODE NUMBER IS 12
EXIT NODE NUMBER IS 53
PIPE PRESSURE LOSS IS 5.4 PSID
PIPE ENTHALPY LOSS IS 0.0 BTU/LBM
END DEVICE

DEVICE #14: SIMPLE PIPE
INLET NODE NUMBER IS 16
EXIT NODE NUMBER IS 54
PIPE ENTHALPY LOSS IS 0.0 BTU/LBM
END DEVICE

DEVICE #15: SIMPLE PIPE
INLET NODE NUMBER IS 18
EXIT NODE NUMBER IS 61
PIPE ENTHALPY LOSS IS 0.0 BTU/LBM
END DEVICE

DEVICE #16: SIMPLE PIPE
INLET NODE NUMBER IS 19
EXIT NODE NUMBER IS 20
PIPE PRESSURE LOSS IS 0.0 PSID
PIPE ENTHALPY LOSS IS 0.0 BTU/LBM
END DEVICE

DEVICE #17: SIMPLE JUNCTION
INLET #1 NODE NUMBER IS 20
EXIT #1 NODE NUMBER IS 21
EXIT #2 NODE NUMBER IS 22
EXIT #2 MASS FLOW RATE IS 198275 LBM/HR
END DEVICE

DEVICE #18: SIMPLE TURBINE
INLET NODE NUMBER IS 21
EXTRACTION #1 NODE NUMBER IS 23
EXTRACTION #2 NODE NUMBER IS 24
EXTRACTION #3 NODE NUMBER IS 25
EXTRACTION #4 NODE NUMBER IS 26
EXTRACTION #5 NODE NUMBER IS 27
EXTRACTION #6 NODE NUMBER IS 28
STAGE GROUP #1 EFFICIENCY IS 91.5 %
STAGE GROUP #2 EFFICIENCY IS 91.0 %
STAGE GROUP #3 EFFICIENCY IS 91.0 %
STAGE GROUP #4 EFFICIENCY IS 87.8 %
STAGE GROUP #5 EFFICIENCY IS 86.7 %
STAGE GROUP #6 EFFICIENCY IS 70.0 %
EXTRACTION #1 PRESSURE IS 89.4 PSIA
EXTRACTION #2 PRESSURE IS 41.3 PSIA
EXTRACTION #3 PRESSURE IS 17.1 PSIA
EXTRACTION #4 PRESSURE IS 10.7 PSIA
EXTRACTION #5 PRESSURE IS 6.0 PSIA
EXTRACTION #5 MASS FLOW RATE IS 158865 LBM/HR
EXTRACTION #6 PRESSURE IS 1.7 PSIA
END DEVICE

DEVICE #19: SIMPLE PIPE
INLET NODE NUMBER IS 22
EXIT NODE NUMBER IS 29
PIPE PRESSURE LOSS IS 0.0 PSID
PIPE ENTHALPY LOSS IS 0.0 BTU/LBM
END DEVICE

DEVICE #20: SIMPLE TURBINE
INLET NODE NUMBER IS 29
EXTRACTION #1 NODE NUMBER IS 30
STAGE GROUP #1 EFFICIENCY IS 78.0 %
END DEVICE

DEVICE #21: SIMPLE PIPE
INLET NODE NUMBER IS 23
EXIT NODE NUMBER IS 46
PIPE PRESSURE LOSS IS 2.7 PSID
PIPE ENTHALPY LOSS IS 0.0 BTU/LBM
END DEVICE

DEVICE #22: SIMPLE PIPE
INLET NODE NUMBER IS 24
EXIT NODE NUMBER IS 43
PIPE PRESSURE LOSS IS 1.3 PSID
PIPE ENTHALPY LOSS IS 0.0 BTU/LBM
END DEVICE

DEVICE #23: SIMPLE PIPE
INLET NODE NUMBER IS 25
EXIT NODE NUMBER IS 40
PIPE PRESSURE LOSS IS 0.5 PSID
PIPE ENTHALPY LOSS IS 0.0 BTU/LBM
END DEVICE

DEVICE #24: SIMPLE PIPE
INLET NODE NUMBER IS 26
EXIT NODE NUMBER IS 37
PIPE ENTHALPY LOSS IS 0.0 BTU/LBM
END DEVICE

DEVICE #25: SIMPLE PIPE
INLET NODE NUMBER IS 27
EXIT NODE NUMBER IS 36
PIPE PRESSURE LOSS IS 0.2 PSID
PIPE ENTHALPY LOSS IS 0.0 BTU/LBM
END DEVICE

DEVICE #26: SIMPLE PIPE
INLET NODE NUMBER IS 28
EXIT NODE NUMBER IS 31
PIPE PRESSURE LOSS IS 0.0 PSID
PIPE ENTHALPY LOSS IS 0.0 BTU/LBM
END DEVICE

DEVICE #27: SIMPLE PIPE
INLET NODE NUMBER IS 30
EXIT NODE NUMBER IS 32
PIPE PRESSURE LOSS IS 0.0 PSID
PIPE ENTHALPY LOSS IS 0.0 BTU/LBM
END DEVICE

DEVICE #28: SIMPLE CONDENSER
EXIT NODE NUMBER IS 34
INLET #1 NODE NUMBER IS 31
INLET #2 NODE NUMBER IS 32
INLET #3 NODE NUMBER IS 33
END DEVICE

DEVICE #29: SIMPLE PUMP
SUCTION NODE NUMBER IS 34

DISCHARGE NODE NUMBER IS 35
DISCHARGE PRESSURE IS 540 PSIA
PUMP EFFICIENCY IS 95.0 PERCENT
END DEVICE

DEVICE #30: SIMPLE PIPE
INLET NODE NUMBER IS 39
EXIT NODE NUMBER IS 33
PIPE ENTHALPY LOSS IS 0.0 BTU/LBM
END DEVICE

DEVICE #31: SIMPLE STEAM TRAP CFW
FEED WATER INLET NODE NUMBER IS 35
FEED WATER EXIT NODE NUMBER IS 38
EXTRACTION INLET NODE NUMBER IS 36
DRAIN INLET #1 NODE NUMBER IS 37
DRAIN INLET #2 NODE NUMBER IS 70
DRAIN EXIT NODE NUMBER IS 39
EXTRACTION PRESSURE LOSS IS 0.0 PSID
FEED WATER PRESSURE LOSS IS 0.0 PSID
TERMINAL TEMPERATURE DIFFERENCE IS 5.0 DEG F
APPROACH TEMPERATURE DIFFERENCE IS 10.0 DEG F
END DEVICE

DEVICE #32: SIMPLE STEAM TRAP CFW
FEED WATER INLET NODE NUMBER IS 38
FEED WATER EXIT NODE NUMBER IS 41
EXTRACTION INLET NODE NUMBER IS 40
DRAIN INLET #1 NODE NUMBER IS 69
DRAIN EXIT NODE NUMBER IS 42
EXTRACTION PRESSURE LOSS IS 0.0 PSID
FEED WATER PRESSURE LOSS IS 0.0 PSID
TERMINAL TEMPERATURE DIFFERENCE IS 5.0 DEG F
APPROACH TEMPERATURE DIFFERENCE IS 10.0 DEG F
END DEVICE

DEVICE #33: SIMPLE STEAM TRAP CFW
FEED WATER INLET NODE NUMBER IS 41
FEED WATER EXIT NODE NUMBER IS 44
EXTRACTION INLET NODE NUMBER IS 43
DRAIN INLET #1 NODE NUMBER IS 68
DRAIN EXIT NODE NUMBER IS 45
EXTRACTION PRESSURE LOSS IS 0.0 PSID
FEED WATER PRESSURE LOSS IS 0.0 PSID
TERMINAL TEMPERATURE DIFFERENCE IS 5.0 DEG F
APPROACH TEMPERATURE DIFFERENCE IS 10.0 DEG F
END DEVICE

DEVICE #34: SIMPLE STEAM TRAP CFW
FEED WATER INLET NODE NUMBER IS 44
FEED WATER EXIT NODE NUMBER IS 47
EXTRACTION INLET NODE NUMBER IS 46
DRAIN EXIT NODE NUMBER IS 48
EXTRACTION PRESSURE LOSS IS 0.0 PSID
FEED WATER PRESSURE LOSS IS 0.0 PSID
APPROACH TEMPERATURE DIFFERENCE IS 10.0 DEG F
END DEVICE

DEVICE #35: SIMPLE OFW HEATER
FEED WATER EXIT NODE NUMBER IS 52
EXTRACTION INLET NODE NUMBER IS 49
FEED WATER INLET NODE NUMBER IS 47
FEED WATER EXIT IS NOT SATURATED
END DEVICE

DEVICE #36: SIMPLE PUMP
SUCTION NODE NUMBER IS 51
DISCHARGE NODE NUMBER IS 50
PUMP EFFICIENCY IS 95.0 PERCENT
END DEVICE

DEVICE #37: SIMPLE OFW HEATER
FEED WATER EXIT NODE NUMBER IS 51
EXTRACTION INLET NODE NUMBER IS 71
FEED WATER INLET NODE NUMBER IS 14
FEED WATER EXIT IS NOT SATURATED
END DEVICE

DEVICE #38: SIMPLE STEAM TRAP CFW
FEED WATER INLET NODE NUMBER IS 52
FEED WATER EXIT NODE NUMBER IS 55
EXTRACTION INLET NODE NUMBER IS 53
DRAIN INLET #1 NODE NUMBER IS 54
DRAIN INLET #2 NODE NUMBER IS 67
DRAIN EXIT NODE NUMBER IS 56
DRAIN EXIT FLUID PHASE IS A SATURATED LIQUID
DRAIN EXIT QUALITY IS 0.0 PERCENT
EXTRACTION PRESSURE LOSS IS 0.0 PSID
FEED WATER PRESSURE LOSS IS 0.0 PSID
TERMINAL TEMPERATURE DIFFERENCE IS 5.0 DEG F
APPROACH TEMPERATURE DIFFERENCE IS 39.593 DEG F
END DEVICE

DEVICE #39: SIMPLE STEAM TRAP CFW
FEED WATER INLET NODE NUMBER IS 55
FEED WATER EXIT NODE NUMBER IS 58
EXTRACTION INLET NODE NUMBER IS 57
DRAIN INLET #1 NODE NUMBER IS 66
DRAIN EXIT NODE NUMBER IS 59
EXTRACTION PRESSURE LOSS IS 0.0 PSID
FEED WATER PRESSURE LOSS IS 0.0 PSID
TERMINAL TEMPERATURE DIFFERENCE IS 5.0 DEG F
APPROACH TEMPERATURE DIFFERENCE IS 10.0 DEG F
END DEVICE

DEVICE #40: SIMPLE PUMP
SUCTION NODE NUMBER IS 58
DISCHARGE NODE NUMBER IS 60
PUMP EFFICIENCY IS 65.0 %
END DEVICE

DEVICE #41: SIMPLE STEAM TRAP CFW
FEED WATER INLET NODE NUMBER IS 60
FEED WATER EXIT NODE NUMBER IS 63
EXTRACTION INLET NODE NUMBER IS 61
DRAIN INLET #1 NODE NUMBER IS 62

DRAIN EXIT NODE NUMBER IS 64
EXTRACTION PRESSURE LOSS IS 0.0 PSID
FEED WATER PRESSURE LOSS IS 0.0 PSID
TERMINAL TEMPERATURE DIFFERENCE IS 5.0 DEG F
APPROACH TEMPERATURE DIFFERENCE IS 10.0 DEG F
END DEVICE

DEVICE #42: SIMPLE PIPE
INLET NODE NUMBER IS 63
EXIT NODE NUMBER IS 65
PIPE PRESSURE LOSS IS 0.0 PSID
PIPE ENTHALPY LOSS IS 0.0 BTU/LBM
END DEVICE

DEVICE #43: SIMPLE PIPE
INLET NODE NUMBER IS 5
EXIT NODE NUMBER IS 7
PIPE PRESSURE LOSS IS 1.0 PSID
PIPE ENTHALPY LOSS IS 0.0 BTU/LBM
END DEVICE

DEVICE #44: SIMPLE PIPE
INLET NODE NUMBER IS 64
EXIT NODE NUMBER IS 66
PIPE ENTHALPY LOSS IS 0.0 BTU/LBM
END DEVICE

DEVICE #45: SIMPLE PIPE
INLET NODE NUMBER IS 59
EXIT NODE NUMBER IS 67
PIPE ENTHALPY LOSS IS 0.0 BTU/LBM
END DEVICE

DEVICE #46: SIMPLE PIPE
INLET NODE NUMBER IS 50
EXIT NODE NUMBER IS 49
PIPE PRESSURE LOSS IS 0.0 PSID
PIPE ENTHALPY LOSS IS 0.0 BTU/LBM
END DEVICE

DEVICE #47: SIMPLE PIPE
INLET NODE NUMBER IS 48
EXIT NODE NUMBER IS 68
PIPE ENTHALPY LOSS IS 0.0 BTU/LBM
END DEVICE

DEVICE #48: SIMPLE PIPE
INLET NODE NUMBER IS 45
EXIT NODE NUMBER IS 69
PIPE ENTHALPY LOSS IS 0.0 BTU/LBM
END DEVICE

DEVICE #49: SIMPLE PIPE
INLET NODE NUMBER IS 42
EXIT NODE NUMBER IS 70
PIPE ENTHALPY LOSS IS 0.0 BTU/LBM
END DEVICE

DEVICE #50: SIMPLE PIPE
INLET NODE NUMBER IS 56
EXIT NODE NUMBER IS 71
PIPE ENTHALPY LOSS IS 0.0 BTU/LBM
END DEVICE

For example problem #3, the output file generated by RANKINE 3.0 is presented below.

```
          RANKINE 3.0: A steam power plant computer simulation

                              Copyright 1994
                          W.A. Thelen, C.W. Somerton

********************************** TITLE ************************************

  EXAMPLE PROBLEM #3

******************************** NODE DATA **********************************

NODE   T(C)     P(MPa)   L     Q    S(KJ/KG/K) H(KJ/KG) V(M^3/KG) M(KG/S) A(KJ/KG)
-------------------------------------------------------------------------------
  1   284.11    6.8258   3   *****   5.8269    2774.96    .02818  2005.0920 1048.06
  2   284.11    6.8258   3   *****   5.8269    2774.96    .02818  1900.2050 1048.06
  3   284.11    6.8258   3   *****   5.8269    2774.96    .02818   104.8874 1048.06
  4   233.35    2.9737   2    .915   5.8851    2649.43    .06170  1900.2050  905.25
  5   233.35    2.9737   2    .915   5.8851    2649.43    .06170   145.5357  905.25
  6   233.35    2.9737   2    .915   5.8851    2649.43    .06170  1754.6690  905.25
  7   233.22    2.9668   2    .915   5.8859    2649.43    .06184   145.5357  905.00
  8   233.22    2.9668   2    .915   5.8859    2649.43    .06184    65.0102  905.00
  9   233.22    2.9668   2    .915   5.8859    2649.43    .06184    80.5255  905.00
 10   212.88    2.0202   2    .891   5.9081    2590.77    .08803   103.1886  839.76
 11   189.98    1.2548   2    .868   5.9383    2522.44    .13594  1651.4800  762.45
 12   189.98    1.2548   2    .868   5.9383    2522.44    .13594    88.3536  762.45
 13   189.98    1.2548   2    .868   5.9383    2522.44    .13594  1563.1270  762.45
```

14	188.61	1.2176	4	*****	2.2207	801.00	.00114	205.6862	145.28
15	188.61	1.2176	5	*****	6.5144	2783.28	.16110	1357.4410	852.18
16	232.67	2.9372	4	*****	2.6329	1002.59	.00121	65.0102	224.43
17	218.83	1.1997	3	*****	6.6859	2862.15	.17840	1357.4410	880.10
18	283.42	6.7568	4	*****	3.0974	1254.43	.00134	104.8874	338.30
19	269.49	1.1818	3	*****	6.9200	2979.64	.20420	1357.4410	928.05
20	269.49	1.1818	3	*****	6.9200	2979.64	.20420	1357.4410	928.05
21	269.49	1.1818	3	*****	6.9200	2979.64	.20420	1332.4580	928.05
22	269.49	1.1818	3	*****	6.9200	2979.64	.20420	24.9826	928.05
23	198.59	.6164	3	*****	6.9464	2846.25	.34131	70.4334	786.81
24	131.77	.2848	2	.995	6.9795	2710.82	.63268	65.3857	641.56
25	104.30	.1179	2	.952	7.0154	2573.78	1.38167	62.9030	493.85
26	91.35	.0738	2	.933	7.0403	2508.55	2.09972	31.0590	421.24
27	76.70	.0414	2	.912	7.0732	2433.39	3.52771	20.0170	336.29
28	48.98	.0117	2	.884	7.2335	2312.92	11.16561	1082.6600	168.21
29	269.49	1.1818	3	*****	6.9200	2979.64	.20420	24.9826	928.05
30	48.98	.0117	2	.912	7.4443	2380.83	11.52524	24.9826	173.51
31	48.98	.0117	2	.884	7.2335	2312.92	11.16561	1082.6600	168.21
32	48.98	.0117	2	.912	7.4443	2380.83	11.52524	24.9826	173.51
33	48.98	.0117	2	.010	.7663	229.52	.13157	249.7981	5.82
34	48.98	.0117	4	*****	.6898	204.87	.00101	1357.4410	3.89
35	49.32	3.7232	1	*****	.6905	209.53	.00101	1357.4410	8.34
36	75.88	.0400	2	.912	7.0874	2433.39	3.64422	20.0170	332.09
37	75.88	.0400	2	.945	7.3027	2508.55	3.77363	31.0590	343.28
38	73.10	3.7232	1	*****	.9877	308.76	.00102	1357.4410	19.30
39	54.87	.0400	1	*****	.7654	229.52	.00101	249.7981	6.08
40	103.45	.1145	2	.952	7.0282	2573.78	1.42151	62.9030	490.04
41	100.67	3.7232	1	*****	1.3094	424.39	.00104	1357.4410	39.38
42	78.66	.1145	1	*****	1.0582	329.12	.00103	198.7221	18.71
43	130.69	.2758	2	.995	6.9937	2710.82	.65238	65.3857	637.33
44	127.91	3.7232	1	*****	1.6069	539.53	.00107	1357.4410	66.13
45	106.23	.2758	1	*****	1.3757	445.26	.00105	135.8191	40.55
46	198.13	.5978	3	*****	6.9601	2846.25	.35194	70.4334	782.74
47	155.63	3.7232	1	*****	1.8924	658.10	.00110	1357.4410	99.90
48	133.47	.5978	1	*****	1.6695	561.07	.00107	70.4334	69.09
49	189.31	3.7232	1	*****	2.2212	805.27	.00114	647.6515	149.42
50	189.31	3.7232	1	*****	2.2212	805.27	.00114	647.6515	149.42
51	188.61	1.2176	4	*****	2.2207	801.00	.00114	647.6515	145.28
52	166.61	3.7232	1	*****	2.0015	705.64	.00111	2005.0920	115.03
53	188.61	1.2176	2	.868	5.9494	2522.44	.14005	88.3536	759.16
54	188.61	1.2176	2	.102	2.6574	1002.59	.01741	65.0102	217.17
55	185.83	3.7232	1	*****	2.1879	789.86	.00114	2005.0920	143.87
56	188.61	1.2176	4	*****	2.2207	801.00	.00114	441.9653	145.28
57	211.30	1.9581	2	.891	5.9195	2590.77	.09082	103.1886	836.37
58	208.52	3.7232	1	*****	2.4021	891.41	.00117	2005.0920	181.82
59	191.39	1.9581	1	*****	2.2439	813.69	.00114	288.6014	151.08
60	209.94	7.7786	1	*****	2.4077	899.25	.00117	2005.0920	187.99
61	231.67	2.8841	2	.142	3.1321	1254.43	.01091	104.8874	328.00
62	231.67	2.8841	2	.915	5.8963	2649.43	.06364	80.5255	901.92
63	228.89	7.7786	1	*****	2.5816	985.93	.00121	2005.0920	223.03
64	215.49	2.8841	1	*****	2.4684	922.92	.00118	185.4129	193.62
65	228.89	7.7786	1	*****	2.5816	985.93	.00121	2005.0920	223.03
66	211.30	1.9581	2	.010	2.4754	922.92	.00221	185.4129	191.56
67	188.61	1.2176	2	.006	2.2482	813.69	.00216	288.6014	149.80
68	130.69	.2758	2	.006	1.6709	561.07	.00470	70.4334	68.66
69	103.45	.1145	2	.005	1.3764	445.26	.00891	135.8191	40.33
70	75.88	.0400	2	.005	1.0586	329.12	.02115	198.7221	18.60
71	188.61	1.2176	4	*****	2.2207	801.00	.00114	441.9653	145.28

********** DEVICE DATA (DEVICE BEFORE NODE) **********

NODE	REV. WRK (KW)	ACT. WRK (KW)	IRREV (KW)	HEAT X-FER (KW)	MASS ERROR (KG/S)	ENERGY ERROR (KW)

1	39073.68	.00	39073.68	3587170.00	.000	.000
2	.00	.00	.00	.00	.000	.022
3	.00	.00	.00	.00	.000	.000
4	271364.90	238541.50	32823.39	.00	.000	.109
5	.00	.00	.00	.00	.000	.000
6	.00	.00	.00	.00	.000	.112
7	36.71	.00	36.71	.00	.000	-.013
8	.00	.00	.00	.00	.000	.000
9	.00	.00	.00	.00	.000	-.020
10	114907.50	102921.40	11986.09	.00	.000	.000
11	127678.00	112850.60	14827.36	.00	.000	.219
12	.00	.00	.00	.00	.000	.177
13	.00	.00	.00	.00	.000	.000
14	.00	.00	.00	.00	.000	.000
15	5138.71	.00	5138.71	.00	.000	-.198
16	6213.08	.00	6213.08	-107061.50	.000	-.008
17	10790.37	.00	10790.37	107061.50	.000	.063
18	11382.03	.00	11382.03	-159484.80	.000	.000
19	17484.69	.00	17484.69	159484.70	.000	.078
20	.00	.00	.00	.00	.000	-.113
21	.00	.00	.00	.00	.000	-.064
22	.00	.00	.00	.00	.000	.000
23	188197.70	177739.30	10458.38	.00	.000	.000
24	183304.60	170906.30	12398.25	.00	.000	.000
25	176759.10	163995.60	12763.52	.00	.000	.000
26	82320.40	73947.20	8373.20	.00	.000	.000
27	93674.75	82880.06	10794.69	.00	.000	.000
28	181965.40	130425.60	51539.79	.00	.000	-.219
29	.00	.00	.00	.00	.000	-.001
30	18850.46	14959.90	3890.56	.00	.000	-.001
31	.00	.00	.00	.00	.000	-.087
32	.00	.00	.00	.00	.000	-.001
33	65.34	.00	65.34	.00	.000	-.001
34	263424.80	.00	263424.80	-2342823.00	.000	-.250
35	-6035.67	-6327.46	291.79	.00	.000	-.012
36	84.08	.00	84.08	.00	.000	.000
37	2421.21	.00	2421.21	.00	.000	-.002
38	6095.37	.00	6095.37	134691.70	.000	.000
39	5012.34	.00	5012.34	-134691.70	.000	.000
40	239.35	.00	239.35	.00	.000	.001
41	7493.96	.00	7493.96	156968.90	.000	.000
42	6205.63	.00	6205.63	-156968.90	.000	.016
43	276.63	.00	276.63	.00	.000	-.004
44	6811.39	.00	6811.39	156292.90	.000	-.016
45	5911.38	.00	5911.38	-156292.90	.000	-.016
46	286.20	.00	286.20	.00	.000	-.002
47	6401.92	.00	6401.92	160952.70	.000	.000
48	6337.50	.00	6337.50	-160952.70	.000	.000
49	.00	.00	.00	.00	.000	.002
50	-2680.83	-2769.12	88.29	.00	.000	-.002
51	.00	.00	.00	.00	.000	.029
52	1729.77	.00	1729.77	.00	.000	.020
53	290.46	.00	290.46	.00	.000	-.004
54	472.40	.00	472.40	.00	.000	.000
55	3752.41	.00	3752.41	168862.50	.000	.016
56	4500.66	.00	4500.66	-168862.50	.000	-.016
57	349.84	.00	349.84	.00	.000	-.014
58	4371.07	.00	4371.07	203627.80	.000	-.031
59	5058.86	.00	5058.86	-203627.80	.000	-.016
60	-12370.51	-15724.26	3353.75	.00	.000	.002
61	1080.70	.00	1080.70	.00	.000	-.006
62	247.92	.00	247.92	.00	.000	.007
63	2183.92	.00	2183.92	173798.70	.000	.000
64	3551.05	.00	3551.05	-173798.70	.000	-.016

```
65        .00        .00        .00        .00        .000       -.053
66     380.60        .00     380.60        .00        .000       -.006
67     368.90        .00     368.90        .00        .000        .004
68      29.95        .00      29.95        .00        .000        .000
69      29.64        .00      29.64        .00        .000        .000
70      21.05        .00      21.05        .00        .000        .001
71        .00        .00        .00        .00        .000       -.004

******************************** SYSTEM DATA *********************************

TOTAL MASS FLOW RATE EXITING SYSTEM:                .0000 KG/SEC
TOTAL MASS FLOW RATE ENTERING SYSTEM:               .0000 KG/SEC
TOTAL ENTHALPY FLOW RATE EXITING SYSTEM:            .0000 KW
TOTAL ENTHALPY FLOW RATE ENTERING SYSTEM:           .0000 KW
TOTAL HEAT AND WORK ENTERING SYSTEM:              -.1250 KW

BOILER HEAT (DEVICE #  1):                   3587170.0000 KW
TOTAL BOILER HEAT:                           3587170.0000 KW
TOTAL HEAT LOAD HEAT:                              .0000 KW
CONDENSER HEAT (DEVICE # 28):               -2342823.0000 KW
TOTAL PIPE ENERGY LOSSES:                          .0000 KW

TURBINE WORK (DEVICE #  3):                   238541.5000 KW
TURBINE WORK (DEVICE #  5):                   215772.1000 KW
TURBINE WORK (DEVICE # 18):                   799894.2000 KW
TURBINE WORK (DEVICE # 20):                    14959.9000 KW
NET WORK TO GENERATORS:                      1269168.0000 KW

PUMP WORK (DEVICE # 29):                      -6327.4590 KW
PUMP WORK (DEVICE # 36):                      -2769.1210 KW
PUMP WORK (DEVICE # 40):                     -15724.2600 KW
TOTAL PUMP WORK:                             -24820.8400 KW
GENERATOR MECHANICAL LOSSES:                   5725.0000 KW
GENERATOR ELECTRICAL LOSSES:                  15150.0000 KW
NET ELECTRICAL POWER:                        1223472.0000 KW

SYSTEM HEAT RATE:                              10003.8400 BTU/KW*HR
CARNOT CYCLE EFFICIENCY:                          48.6905 PERCENT
1ST LAW EFFICIENCY:                               34.1069 PERCENT
2ND LAW EFFICIENCY:                               74.6609 PERCENT
2ND LAW EFFECTIVENESS:                            70.0483 PERCENT
```

From this output file, it can be seen that the 1st law efficiency is 34.1069 percent and the 2nd law efficiency is 74.6609 percent.

Selected References

1) W.A. Thelen, RANKINE 3.0: A Steam Power Plant Computer Simulation, M.S. Thesis, Michigan State University, 1995.

Chapter 6 Conclusions and Recommendations

6.1.0 Conclusions

The following conclusions are supported by this analysis:

- The RANKINE 3.0 computer program represents a major revision of the RANKINE family of computer software and provides the engineering community with an additional tool for modeling Rankine cycle based systems.

- The modular structure of RANKINE 3.0 establishes a framework from which additional thermodynamic models may be developed and easily integrated into the RANKINE 3.0 program.

- The RANKINE 3.0 input/output format permits the entire array of computer users the ability to utilize the RANKINE 3.0 computer software package with confidence that program predicted results are accurate.

- The active and passive code testing permits a high level of confidence associated with program results.

- The eleven thermodynamic models within RANKINE 3.0 permit modern power plant designs to be studied and provided results which are consistent with power plant industry programs.

6.2.0 Recommendations

The following recommendations are suggested by the author:

- Rankine 3.0 program improvements
  - Additional thermodynamic model integration
    - Detailed turbine model
    - Turbine drive feed water pump model
    - Forward draining closed feed water heater model

  - Electrical Generator model
  - Cooling tower model (Mechanical and Natural)
- Include real device models which utilize physical parameters such as pipe diameter, pipe materials, pipe geometry, ect. rather than total pipe pressure drop.
- Include effects such as elevation and velocity changes between components.
- Utilize a visual programming language to automate the development of the input file.
- Provide for graphically based outputs for system layouts and parameter studies.
- Integrate optimization techniques within code structure.
- Permit user input device performance parameters in table format.
- Permit user input cost functions.

- Additional benchmarking to industry programs and to data obtained from operating power plants.

Appendix A:

Summary of comparison between RANKINE 3.0 and hand calculations for individual device verification

Simple Boiler model

T high=	873.15	Kelvin
T dead=	298.15	Kelvin
P dead=	0.101	MPa
h dead=	105.1	KJ/Kg
s dead=	0.367	KJ/Kg/K

Quantity	Units
Inlet temperature	Deg C
Inlet pressure	MPa
Inlet fluid phase	(-)
Inlet quality	(-)
Inlet entropy	KJ/Kg/K
Inlet enthalpy	KJ/Kg
Inlet mass flow	Kg/sec
Inlet availability	KJ/Kg
Exit temperature	Deg C
Exit pressure	MPa
Exit fluid phase	(-)
Exit quality	(-)
Exit entropy	KJ/Kg/K
Exit enthalpy	KJ/Kg
Exit mass flow	Kg/sec
Exit availability	KJ/Kg
RHL #1 inlet temperature	Deg C
RHL #1 inlet pressure	MPa
RHL #1 inlet fluid phase	(-)
RHL #1 inlet quality	(-)
RHL #1 inlet entropy	KJ/Kg/K
RHL #1 inlet enthalpy	KJ/Kg
RHL #1 inlet mass flow	Kg/sec
RHL #1 inlet availability	KJ/Kg
RHL #1 exit temperature	Deg C
RHL #1 exit pressure	MPa
RHL #1 exit fluid phase	(-)
RHL #1 exit quality	(-)
RHL #1 exit entropy	KJ/Kg/K
RHL #1 exit enthalpy	KJ/Kg
RHL #1 exit mass flow	Kg/sec
RHL #1 exit availability	KJ/Kg
RHL #2 inlet temperature	Deg C
RHL #2 inlet pressure	MPa
RHL #2 inlet fluid phase	(-)
RHL #2 inlet quality	(-)
RHL #2 inlet entropy	KJ/Kg/K
RHL #2 inlet enthalpy	KJ/Kg
RHL #2 inlet mass flow	Kg/sec
RHL #2 inlet availability	KJ/Kg
RHL #2 exit temperature	Deg C
RHL #2 exit pressure	MPa
RHL #2 exit fluid phase	(-)
RHL #2 exit quality	(-)
RHL #2 exit entropy	KJ/Kg/K
RHL #2 exit enthalpy	KJ/Kg
RHL #2 exit mass flow	Kg/sec
RHL #2 exit availability	KJ/Kg

CASE #1

Given	RANKINE 3.0	Hand calc	% difference
100.00	100.00	100.00	0.00
XXXXXXXXXX	20.00	20.00	0.00
XXXXXXXXXX	1	1	0.00
XXXXXXXXXX	-1.00	-1.00	0.00
XXXXXXXXXX	1.2834	1.2834	0.00
XXXXXXXXXX	433.79	433.79	0.00
XXXXXXXXXX	5.00	5.00	0.00
XXXXXXXXXX	55.48	55.46	0.03
600.00	600.00	600.00	0.00
18.00	18.00	18.00	0.00
XXXXXXXXXX	3	3	0.00
XXXXXXXXXX	-1.00	-1.00	0.00
XXXXXXXXXX	6.5690	6.5690	0.00
XXXXXXXXXX	3554.01	3554.01	0.00
5.00	5.00	5.00	0.00
XXXXXXXXXX	1599.81	1599.79	0.00
100.00	100.00	100.00	0.00
20.00	20.00	20.00	0.00
XXXXXXXXXX	1	1	0.00
XXXXXXXXXX	-1.00	-1.00	0.00
XXXXXXXXXX	1.2834	1.2834	0.00
XXXXXXXXXX	433.79	433.79	0.00
XXXXXXXXXX	5.00	5.00	0.00
XXXXXXXXXX	55.48	55.46	0.03
600.00	600.00	600.00	0.00
XXXXXXXXXX	18.00	18.00	0.00
XXXXXXXXXX	3	3	0.00
XXXXXXXXXX	-1.00	-1.00	0.00
XXXXXXXXXX	6.5690	6.5690	0.00
XXXXXXXXXX	3554.01	3554.01	0.00
XXXXXXXXXX	5.00	5.00	0.00
XXXXXXXXXX	1599.81	1599.79	0.00
100.00	100.00	100.00	0.00
20.00	20.00	20.00	0.00
XXXXXXXXXX	1	1	0.00
XXXXXXXXXX	-1.00	-1.00	0.00
XXXXXXXXXX	1.2834	1.2834	0.00
XXXXXXXXXX	433.79	433.79	0.00
XXXXXXXXXX	5.00	5.00	0.00
XXXXXXXXXX	55.48	55.46	0.03
600.00	600.00	600.00	0.00
XXXXXXXXXX	18.00	18.00	0.00
XXXXXXXXXX	3	3	0.00
XXXXXXXXXX	-1.00	-1.00	0.00
XXXXXXXXXX	6.5690	6.5690	0.00
XXXXXXXXXX	3554.01	3554.01	0.00
XXXXXXXXXX	5.00	5.00	0.00
XXXXXXXXXX	1599.81	1599.79	0.00

Quantity	Units
RHL #3-10 inlet temperature	Deg C
RHL #3-10 inlet pressure	MPa
RHL #3-10 inlet fluid phase	(-)
RHL #3-10 inlet quality	(-)
RHL #3-10 inlet entropy	KJ/Kg/K
RHL #3-10 inlet enthalpy	KJ/Kg
RHL #3-10 inlet mass flow	Kg/sec
RHL #3-10 inlet availability	KJ/Kg
RHL #3-10 exit temperature	Deg C
RHL #3-10 exit pressure	MPa
RHL #3-10 exit fluid phase	(-)
RHL #3-10 exit quality	(-)
RHL #3-10 exit entropy	KJ/Kg/K
RHL #3-10 exit enthalpy	KJ/Kg
RHL #3-10 exit mass flow	Kg/sec
RHL #3-10 exit availability	KJ/Kg
Boiler pressure loss	MPa
Boiler percentage pressure loss	(-)
RHL #1 pressure loss	MPa
RHL #1 percentage pressure loss	(-)
RHL #2 pressure loss	MPa
RHL #2 percentage pressure loss	(-)
RHL #3-10 pressure loss	MPa
RHL #3-10 percentage pressure loss	(-)
Boiler Actual work	KW
RHL #1 actual work	KW
RHL #2 actual work	KW
RHL #3-10 actual work	KW
Boiler reversible work	KW
RHL #1 reversible work	KW
RHL #2 reversible work	KW
RHL #3 reversible work	KW
Boiler irreversibility	KW
RHL #1 irreversibility	KW
RHL #2 irreversibility	KW
RHL #3-10 irreversibility	KW
Boiler heat transfer	KW
RHL #1 heat transfer	KW
RHL #2 heat transfer	KW
RHL #3 heat transfer	KW

CASE #1 (Cont)

Given	RANKINE 3.0	Hand calc	% difference
100.00	100.00	100.00	0.00
XXXXXXXXXX	20.00	20.00	0.00
XXXXXXXXXX	1	1	0.00
XXXXXXXXXX	-1.00	-1.00	0.00
XXXXXXXXXX	1.2834	1.2834	0.00
XXXXXXXXXX	433.79	433.79	0.00
5.00	5.00	5.00	0.00
XXXXXXXXXX	55.48	55.46	0.03
600.00	600.00	600.00	0.00
18.00	18.00	18.00	0.00
XXXXXXXXXX	3	3	0.00
XXXXXXXXXX	-1.00	-1.00	0.00
XXXXXXXXXX	6.5690	6.5690	0.00
XXXXXXXXXX	3554.01	3554.01	0.00
XXXXXXXXXX	5.00	5.00	0.00
XXXXXXXXXX	1599.81	1599.79	0.00
XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX
0.10	0.10	0.10	0.00
XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX
0.10	0.10	0.10	0.00
2.00	2.00	2.00	0.00
XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX
2.00	2.00	2.00	0.00
XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX
XXXXXXXXXX	0.00	0.00	Not calculated
XXXXXXXXXX	0.00	0.00	Not calculated
XXXXXXXXXX	0.00	0.00	Not calculated
XXXXXXXXXX	0.00	0.00	Not calculated
XXXXXXXXXX	7474.36	7474.36	0.00
XXXXXXXXXX	7474.36	7474.36	0.00
XXXXXXXXXX	7474.36	7474.36	0.00
XXXXXXXXXX	7474.36	7474.36	0.00
XXXXXXXXXX	7474.36	7474.36	0.00
XXXXXXXXXX	7474.36	7474.36	0.00
XXXXXXXXXX	7474.36	7474.36	0.00
XXXXXXXXXX	7474.36	7474.36	0.00
XXXXXXXXXX	15601.11	15601.11	0.00
XXXXXXXXXX	15601.11	15601.11	0.00
XXXXXXXXXX	15601.11	15601.11	0.00
XXXXXXXXXX	15601.11	15601.11	0.00

Simple Turbine Device

T dead=	298.15	Kelvin
P dead=	0.101	kPa
h dead=	105.1	KJ/Kg
s dead=	3.67E-01	KJ/Kg/K

Quantity	Units	Case #1			
		Given	RANKINE 3.0	Hand calc	% difference
Inlet temperature	Deg C	600.00	600.00	600.00	0.00
Inlet pressure	kPa	20.00	20.00	20.00	0.00
Inlet fluid phase	(-)	XXXXXXXXX	3	3	0.00
Inlet quality	(-)	XXXXXXXXX	-1.00	-1.00	0.00
Inlet entropy	KJ/Kg/K	XXXXXXXXX	6.5052	6.5052	0.00
Inlet enthalpy	KJ/Kg	XXXXXXXXX	3536.61	3536.61	0.00
Inlet mass flow	Kg/sec	5.00	5.00	5.00	0.00
Inlet availability	KJ/Kg	XXXXXXXXX	1601.44	1601.42	0.00
Extraction #1 temperature	Deg C	XXXXXXXXX	481.53	481.53	0.00
Extraction #1 pressure	kPa	10.00	10.00	10.00	0.00
Extraction #1 fluid phase	(-)	XXXXXXXXX	3	3	0.00
Extraction #1 quality	(-)	XXXXXXXXX	-1.00	-1.00	0.00
Extraction #1 entropy	KJ/Kg/K	XXXXXXXXX	6.5362	6.5362	0.00
Extraction #1 isentropic enthalpy	KJ/Kg	XXXXXXXXX	XXXXXXXXX	3303.86	XXXXXXXXX
Extraction #1 enthalpy	KJ/Kg	XXXXXXXXX	3327.14	3327.13	0.00
Extraction #1 mass flow	Kg/sec	1.00	1.00	1.00	0.00
Extraction #1 availability	KJ/Kg	XXXXXXXXX	1382.72	1382.69	0.00
Extraction #2 temperature	Deg C	XXXXXXXXX	382.71	382.71	0.00
Extraction #2 pressure	kPa	5.00	5.00	5.00	0.00
Extraction #2 fluid phase	(-)	XXXXXXXXX	3	3	0.00
Extraction #2 quality	(-)	XXXXXXXXX	-1.00	-1.00	0.00
Extraction #2 entropy	KJ/Kg/K	XXXXXXXXX	6.5832	6.5832	0.00
Extraction #2 isentropic enthalpy	KJ/Kg	XXXXXXXXX	XXXXXXXXX	3123.42	XXXXXXXXX
Extraction #2 enthalpy	KJ/Kg	XXXXXXXXX	3153.98	3153.98	0.00
Extraction #2 mass flow	Kg/sec	2.00	2.00	2.00	0.00
Extraction #2 availability	KJ/Kg	XXXXXXXXX	1195.54	1195.51	0.00
Extraction #3 temperature	Deg C	XXXXXXXXX	99.63	99.63	0.00
Extraction #3 pressure	kPa	0.10	0.10	0.10	0.00
Extraction #3 fluid phase	(-)	XXXXXXXXX	2	2	0.00
Extraction #3 quality	(-)	XXXXXXXXX	0.94	0.94	0.01
Extraction #3 entropy	KJ/Kg/K	XXXXXXXXX	6.9952	6.9952	0.00
Extraction #3 isentropic enthalpy	KJ/Kg	XXXXXXXXX	XXXXXXXXX	2386.10	XXXXXXXXX
Extraction #3 enthalpy	KJ/Kg	XXXXXXXXX	2539.67	2539.67	0.00
Extraction #3 mass flow	Kg/sec	XXXXXXXXX	2.00	2.00	0.00
Extraction #3 availability	KJ/Kg	XXXXXXXXX	458.40	458.39	0.00
Stage group #1 efficiency	(-)	0.90	0.90	0.90	0.00
Stage group #2 efficiency	(-)	0.85	0.85	0.85	0.00
Stage group #3 efficiency	(-)	0.80	0.80	0.80	0.00
Actual stage group #1 work	KW	XXXXXXXXX	1047.36	1047.37	0.00
Actual stage group #2 work	KW	XXXXXXXXX	692.64	692.64	0.00
Actual stage group #3 work	KW	XXXXXXXXX	1228.61	1228.61	0.00
Reversiable stage group #1 work	KW	XXXXXXXXX	1093.61	1093.61	0.00
Reversiable stage group #2 work	KW	XXXXXXXXX	748.72	748.72	0.00
Reversiable stage group #3 work	KW	XXXXXXXXX	1474.26	1474.25	0.00
Stage group #1 irreversibility	KW	XXXXXXXXX	46.25	46.24	0.01
Stage group #2 irreversibility	KW	XXXXXXXXX	56.08	56.08	-0.01
Stage group #3 irreversibility	KW	XXXXXXXXX	245.65	245.65	0.00
Total turbine work	KW	XXXXXXXXX	2968.61	2968.61	0.00

Simple Pump Device

T dead=	298.15	Kelvins
P dead=	0.101	MPa
h dead=	105.1	KJ/Kg
s dead=	3.67E-01	KJ/Kg/K

Quanity	Units
Suction temperature	Deg C
Suction pressure	MPa
Suction fluid phase	(-)
Suction quality	(-)
Suction entropy	KJ/Kg/K
Isentropic suction enthalpy	KJ/Kg
Suction enthalpy	KJ/Kg
Suction mass flow rate	Kg/sec
Suction availability	KJ/Kg
Discharge temperature	Deg C
Discharge pressure	MPa
Discharge fluid phase	(-)
Discharge quality	(-)
Discharge entropy	KJ/Kg/K
Isentropic discharge enthalpy	KJ/Kg
Discharge enthalpy	KJ/Kg
Discharge mass flow rate	Kg/sec
Discharge availability	KJ/Kg
Pump efficiency	(-)
Actual pump work	KW
Reversible pump work	KW
Pump irreversibility	KW
Pump heat transfer	KW

CASE #1			
Given	RANKINE 3.0	Hand Calc	% difference
130.00	130.00	0.50	0.00
0.50	0.50	130.00	0.00
XXXXXXXXXX	1.00	1.00	0.00
XXXXXXXXXX	-1.00	-1.00	0.00
XXXXXXXXXX	1.6331	1.6331	0.00
XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX
XXXXXXXXXX	546.21	546.21	0.00
1.00	1.00	1.00	0.00
XXXXXXXXXX	63.64	63.62	0.03
XXXXXXXXXX	131.15	131.15	0.00
10.00	10.00	10.00	0.00
XXXXXXXXXX	1.00	1.00	0.00
XXXXXXXXXX	-1.00	-1.00	0.00
XXXXXXXXXX	1.6331	1.63318	0.00
XXXXXXXXXX	XXXXXXXXXX	557.57	XXXXXXXXXX
XXXXXXXXXX	557.57	557.57	0.00
XXXXXXXXXX	1.00	1.00	0.00
XXXXXXXXXX	74.99	74.98	0.01
1.00	1.00	1.00	0.00
XXXXXXXXXX	-11.35	-11.35	-0.04
XXXXXXXXXX	-11.35	-11.36	-0.08
XXXXXXXXXX	0.00	-0.01	Not calculated
XXXXXXXXXX	0.00	0.00	Not calculated

CASE #2			
Given	RANKINE 3.0	Hand Calc	% difference
XXXXXXXXXX	167.98	167.98	0.00
1.00	1.00	1.00	0.00
XXXXXXXXXX	1.00	1.00	0.00
XXXXXXXXXX	-1.00	-1.00	0.00
XXXXXXXXXX	2.0191	2.0191	0.00
XXXXXXXXXX	XXXXXXXXXX	712.84	XXXXXXXXXX
XXXXXXXXXX	710.08	710.08	0.00
XXXXXXXXXX	1.00	1.00	0.00
XXXXXXXXXX	112.42	112.40	0.01
10.00	10.00	10.00	0.00
170.00	170.00	170.00	0.00
XXXXXXXXXX	1.00	1.00	0.00
XXXXXXXXXX	-1.00	-1.00	0.00
XXXXXXXXXX	2.0253	2.0253	0.00
XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX
XXXXXXXXXX	723.88	723.8768	0.00
1.00	1.00	1.00	0.00
XXXXXXXXXX	124.37	124.35	0.02
0.80	0.80	0.80	0.00
XXXXXXXXXX	-13.80	-13.80	0.02
XXXXXXXXXX	-11.94	-11.94	-0.02
XXXXXXXXXX	1.85	1.86	-0.27
XXXXXXXXXX	0.00	0.00	Not Calculated

Simple Pipe Device

T dead-	298.15	Kelvin
P dead-	0.101	MPa
h dead-	105.1	KJ/Kg
s dead-	0.367	KJ/Kg/K

Quantity	Units
Inlet temperature	Deg C
Inlet pressure	MPa
Inlet fluid phase	(-)
Inlet quality	(-)
Inlet entropy	KJ/Kg/K
Inlet enthalpy	KJ/Kg
Inlet mass flow	Kg/sec
Inlet availability	KJ/Kg
Exit temperature	Deg C
Exit pressure	MPa
Exit fluid phase	(-)
Exit quality	(-)
Exit entropy	KJ/Kg/K
Exit enthalpy	KJ/Kg
Exit mass flow	Kg/sec
Exit availability	KJ/Kg
Pipe PL	MPa
Pipe % PL	(-)
Pipe QL	KJ/Kg
Pipe % QL	(-)
Actual work	KJ/Kg
Rev work	KJ/Kg
Pipe irrev	KJ/Kg
Pipe X-fer	KJ/Kg

Case #1

Given	RANKINE 3.0	Hand Calc	% difference
500.00	500.00	500.00	0.00
10.00	10.00	10.00	0.00
XXXXXXXXXX	3	3	0.00
XXXXXXXXXX	-1.00	-1.00	0.00
XXXXXXXXXX	6.5984	6.5984	0.00
XXXXXXXXXX	3374.66	3374.66	0.00
1.00	1.00	1.00	0.00
XXXXXXXXXX	1411.69	1411.67	0.00
XXXXXXXXXX	456.09	456.09	0.00
XXXXXXXXXX	9.00	9.00	0.00
XXXXXXXXXX	3	3	0.00
XXXXXXXXXX	-1.00	-1.00	0.00
XXXXXXXXXX	6.5096	6.5096	0.00
XXXXXXXXXX	3274.66	3274.66	0.00
XXXXXXXXXX	1.00	1.00	0.00
XXXXXXXXXX	1338.17	1338.15	0.00
1.00	1.00	1.00	0.00
XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX
100.00	100.00	100.00	0.00
XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX
XXXXXXXXXX	0.00	0.00	Not calculated
XXXXXXXXXX	73.52	73.52	0.00
XXXXXXXXXX	73.52	73.52	0.00
XXXXXXXXXX	-100.00	-100.00	0.00

Case #2

Given	RANKINE 3.0	Hand Calc	% difference
XXXXXXXXXX	500.01	500.01	0.00
XXXXXXXXXX	10.00	10.00	0.00
XXXXXXXXXX	3	3	0.00
XXXXXXXXXX	-1.00	-1.00	0.00
XXXXXXXXXX	6.5984	6.5984	0.00
XXXXXXXXXX	3374.69	3374.69	0.00
XXXXXXXXXX	1.00	1.00	0.00
XXXXXXXXXX	1411.71	1411.69	0.00
456.095	456.10	456.10	0.00
9	9.00	9.00	0.00
XXXXXXXXXX	3	3	0.00
XXXXXXXXXX	-1.00	-1.00	0.00
XXXXXXXXXX	6.5096	6.5096	0.00
XXXXXXXXXX	3274.69	3274.69	0.00
1.00	1.00	1.00	0.00
XXXXXXXXXX	1338.18	1338.17	0.00
1	1.00	1.00	0.00
XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX
100	100.00	100.00	0.00
XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX
XXXXXXXXXX	0.00	0.00	Not Calculated
XXXXXXXXXX	73.52	73.52	0.00
XXXXXXXXXX	73.52	73.52	0.00
XXXXXXXXXX	-100.00	-100.00	0.00

Case #3

Given	RANKINE 3.0	Hand Calc	% difference
XXXXXXXXXX	499.94	499.94	0.00
10.00	10.00	10.00	0.00
XXXXXXXXXX	3	3	0.00
XXXXXXXXXX	-1	-1	0.00
XXXXXXXXXX	6.5982	6.5982	0.00
XXXXXXXXXX	3374.51	3374.51	0.00
1.00	1.00	1.00	0.00
XXXXXXXXXX	1411.60	1411.58	0.00
XXXXXXXXXX	456.09	456.09	0.00
XXXXXXXXXX	9.00	9.00	0.00
XXXXXXXXXX	3	3	0.00
XXXXXXXXXX	-1.0000	-1.0000	0.00
XXXXXXXXXX	6.51	6.51	0.00
3274.66	3274.66	3274.66	0.00
XXXXXXXXXX	1.00	1.00	0.00
XXXXXXXXXX	1338.11	1338.15	0.00
XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX
10.00	10.00	10.00	0.00
XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX
2.959	2.959	2.959	0.00
XXXXXXXXXX	0.00	0.00	#DIV/0!
XXXXXXXXXX	73.43	73.43	0.00
XXXXXXXXXX	73.43	73.43	0.00
XXXXXXXXXX	-99.85	-99.85	0.00

Quantity	Units
Inlet temperature	Deg C
Inlet pressure	MPa
Inlet fluid phase	(-)
Inlet quality	(-)
Inlet entropy	KJ/Kg/K
Inlet enthalpy	KJ/Kg
Inlet mass flow	Kg/sec
Inlet availability	KJ/Kg
Exit temperature	Deg C
Exit pressure	MPa
Exit fluid phase	(-)
Exit quality	(-)
Exit entropy	KJ/Kg/K
Exit enthalpy	KJ/Kg
Exit mass flow	Kg/sec
Exit availability	KJ/Kg
Pipe PL	MPa
Pipe % PL	(-)
Pipe QL	KJ/Kg
Pipe % QL	(-)
Actual work	KJ/Kg
Rev work	KJ/Kg
Pipe irrev	KJ/Kg
Pipe X-fer	KJ/Kg

Case #4

Given	RANKINE 3.0	Hand Calc	% difference
XXXXXXXXXX	500.00	500.07	-0.01
10.00	10.00	10.00	0.00
XXXXXXXXXX	3	3	0.00
XXXXXXXXXX	-1	-1	0.00
XXXXXXXXXX	6.5984	6.5984	0.00
3374.66	3374.66	3374.66	0.00
XXXXXXXXXX	1.00	1.00	0.00
XXXXXXXXXX	1411.69	1411.67	0.00
XXXXXXXXXX	456.14	456.14	0.00
9.00	9.00	9.00	0.00
XXXXXXXXXX	3	3	0.00
XXXXXXXXXX	-1	-1	0.00
XXXXXXXXXX	6.5098	6.5098	0.00
XXXXXXXXXX	3274.80	3274.80	0.00
1.00	1.00	1.00	0.00
XXXXXXXXXX	1338.26	1338.24	0.00
XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX
10.00	10.00	10.00	0.00
XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX
2.96	2.96	2.96	0.00
XXXXXXXXXX	0.00	0.00	Not calculated
XXXXXXXXXX	73.43	73.43	-0.01
XXXXXXXXXX	73.43	73.43	-0.01
XXXXXXXXXX	-99.86	-99.86	0.00

Case #5

Given	RANKINE 3.0	Hand Calc	% difference
500.00	500.00	500.00	0.00
10.00	10.00	10.00	0.00
XXXXXXXXXX	3	3	0.00
XXXXXXXXXX	-1	-1	0.00
XXXXXXXXXX	6.5984	6.5984	0.00
XXXXXXXXXX	3374.66	3374.66	0.00
XXXXXXXXXX	1.00	1.00	0.00
XXXXXXXXXX	1411.69	1411.67	0.00
456.14	456.14	456.14	0.00
9.00	9.00	9.00	0.00
XXXXXXXXXX	3	3	0.00
XXXXXXXXXX	-1	-1	0.00
XXXXXXXXXX	6.5098	6.5098	0.00
XXXXXXXXXX	3274.80	3274.80	0.00
1.00	1.00	1.00	0.00
XXXXXXXXXX	1338.25	1338.23	0.00
XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX
XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX
XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX
XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX
XXXXXXXXXX	0.00	0.00	Not Calculated
XXXXXXXXXX	73.44	73.44	0.00
XXXXXXXXXX	73.44	73.44	0.00
XXXXXXXXXX	-99.86	-99.86	0.00

Case #6

Given	RANKINE 3.0	Hand Calc	% difference
500.00	500.00	500.00	0.00
10.00	10.00	10.00	0.00
XXXXXXXXXX	3	3	0.00
XXXXXXXXXX	-1	-1	0.00
XXXXXXXXXX	6.5984	6.5984	0.00
XXXXXXXXXX	3374.66	3374.66	0.00
XXXXXXXXXX	1.00	1.00	0.00
XXXXXXXXXX	1411.69	1411.67	0.00
XXXXXXXXXX	456.09	456.09	0.00
9.00	9.00	9.00	0.00
XXXXXXXXXX	3	3	0.00
XXXXXXXXXX	-1	-1	0.00
XXXXXXXXXX	6.5096	6.5096	0.00
XXXXXXXXXX	3274.66	3274.66	0.00
1.00	1.00	1.00	0.00
XXXXXXXXXX	1338.17	1338.15	0.00
XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX
XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX
100.00	100.00	100.00	0.00
XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX
XXXXXXXXXX	0.00	0.00	Not calculated
XXXXXXXXXX	73.52	73.52	0.00
XXXXXXXXXX	73.52	73.52	0.00
XXXXXXXXXX	-100.00	-100.00	0.00

Simple Junction Model

T dead= 298.15 Kelvin
P dead= 0.101 MPa

h dead= 105.1 KJ/Kg
s dead= 0.367 KJ/Kg/K

Quantity	Units
Inlet #1 temperature	Deg C
Inlet #1 pressure	MPa
Inlet #1 fluid phase	(-)
Inlet #1 quality	(-)
Inlet #1 entropy	KJ/Kg/K
Inlet #1 enthalpy	KJ/Kg
Inlet #1 mass flow	Kg/sec
Inlet #1 availability	Kg/sec
Inlet #1 flow fraction	(-)
Inlet #2 temperature	Deg C
Inlet #2 pressure	MPa
Inlet #2 fluid phase	(-)
Inlet #2 quality	(-)
Inlet #2 entropy	KJ/Kg/K
Inlet #2 enthalpy	KJ/Kg
Inlet #2 mass flow	Kg/sec
Inlet #2 availability	KJ/Kg
Inlet #2 flow fraction	(-)
Inlet #3 temperature	Deg C
Inlet #3 pressure	MPa
Inlet #3 fluid phase	(-)
Inlet #3 quality	(-)
Inlet #3 entropy	KJ/Kg/K
Inlet #3 enthalpy	KJ/Kg
Inlet #3 mass flow	Kg/sec
Inlet #3 availability	KJ/Kg
Inlet #3 flow fraction	(-)
Exit #1 temperature	Deg C
Exit #1 pressure	MPa
Exit #1 fluid phase	(-)
Exit #1 quality	(-)
Exit #1 entropy	KJ/Kg/K
Exit #1 enthalpy	KJ/Kg
Exit #1 mass flow	Kg/sec
Exit #1 availability	KJ/Kg
Exit #1 flow fraction	(-)
Exit #2 temperature	Deg C
Exit #2 pressure	MPa
Exit #2 fluid phase	(-)
Exit #2 quality	(-)
Exit #2 entropy	KJ/Kg/K
Exit #2 enthalpy	KJ/Kg
Exit #2 mass flow	Kg/sec
Exit #2 availability	KJ/Kg
Exit #2 flow fraction	(-)
Exit #3 temperature	Deg C
Exit #3 pressure	MPa
Exit #3 fluid phase	(-)
Exit #3 quality	(-)
Exit #3 entropy	KJ/Kg/K
Exit #3 enthalpy	KJ/Kg
Exit#3 mass flow	Kg/sec
Exit #3 availability	KJ/Kg
Exit #3 flow fraction	(-)

CASE #1

Given	RANKINE 3.0	Hand Calc	% difference
XXXXXXXXX	445.00	445.00	0.00
XXXXXXXXX	5.00	5.00	0.00
XXXXXXXXX	3	3	0.00
XXXXXXXXX	-1.00	-1.00	0.00
XXXXXXXXX	6.8027	6.8027	0.00
XXXXXXXXX	3304.57	3304.57	0.00
0.31	0.31	0.31	0.00
XXXXXXXXX	1280.70	1280.68	0.00
XXXXXXXXX	XXXXXXXXX	0.31	XXXXXXXXX
445.00	445.00	445.00	0.00
5.00	5.00	5.00	0.00
XXXXXXXXX	3	3	0.00
XXXXXXXXX	-1.00	-1.00	0.00
XXXXXXXXX	6.8027	6.8027	0.00
XXXXXXXXX	3304.57	3304.57	0.00
XXXXXXXXX	0.22	0.22	0.00
XXXXXXXXX	1280.70	1280.68	0.00
0.22	XXXXXXXXX	0.22	XXXXXXXXX
XXXXXXXXX	445.00	445.00	0.00
XXXXXXXXX	5.00	5.00	0.00
XXXXXXXXX	3	3	0.00
XXXXXXXXX	-1.00	-1.00	0.00
XXXXXXXXX	6.8027	6.8027	0.00
XXXXXXXXX	3304.57	3304.57	0.00
XXXXXXXXX	0.47	0.47	0.00
XXXXXXXXX	1280.70	1280.68	0.00
0.47	XXXXXXXXX	0.47	XXXXXXXXX
XXXXXXXXX	445.00	445.00	0.00
XXXXXXXXX	5.00	5.00	0.00
XXXXXXXXX	3	3	0.00
XXXXXXXXX	-1.00	-1.00	0.00
XXXXXXXXX	6.8027	6.8027	0.00
XXXXXXXXX	3304.57	3304.57	0.00
XXXXXXXXX	0.41	0.41	0.00
XXXXXXXXX	1280.70	1280.68	0.00
0.41	XXXXXXXXX	0.41	XXXXXXXXX
XXXXXXXXX	445.00	445.00	0.00
XXXXXXXXX	5.00	5.00	0.00
XXXXXXXXX	3	3	0.00
XXXXXXXXX	-1.00	-1.00	0.00
XXXXXXXXX	6.8027	6.8027	0.00
XXXXXXXXX	3304.57	3304.57	0.00
XXXXXXXXX	0.50	0.50	0.00
XXXXXXXXX	1280.70	1280.68	0.00
0.50	XXXXXXXXX	0.50	XXXXXXXXX
XXXXXXXXX	445.00	445.00	0.00
XXXXXXXXX	5.00	5.00	0.00
XXXXXXXXX	3	3	0.00
XXXXXXXXX	-1.00	-1.00	0.00
XXXXXXXXX	6.8027	6.8027	0.00
XXXXXXXXX	3304.57	3304.57	0.00
XXXXXXXXX	0.09	0.09	0.00
XXXXXXXXX	1280.70	1280.68	0.00
XXXXXXXXX	XXXXXXXXX	0.09	XXXXXXXXX

CASE #2

Given	RANKINE 3.0	Hand Calc	% difference
XXXXXXXXX	445.00	445.00	0.00
XXXXXXXXX	5.00	5.00	0.00
XXXXXXXXX	3.00	3.00	0.00
XXXXXXXXX	-1.00	-1.00	0.00
XXXXXXXXX	6.80	6.80	0.00
XXXXXXXXX	3304.57	3304.57	0.00
10.00	10.00	10.00	0.00
XXXXXXXXX	1280.70	1280.68	0.00
XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX

Simple Junction Model (cont'd)

Quantity	Units
Actual work	KW
Reversiable work	KW
Irreversibility	KW
Heat transfer	KW

CASE #1 (cont'd)			
Given	RANKINE 3.0	Hand Calc	% difference
XXXXXXXXX	0.00	0.00	Not calc
XXXXXXXXX	0.00	0.00	Not calc
XXXXXXXXX	0.00	0.00	Not calc
XXXXXXXXX	0.00	0.00	Not calc

CASE #2 (cont'd)			
Given	RANKINE 3.0	Hand Calc	% difference
XXXXXXXXX	0.00	0.00	Not calc
XXXXXXXXX	0.00	0.00	Not calc
XXXXXXXXX	0.00	0.00	Not calc
XXXXXXXXX	0.00	0.00	Not calc

CASE #3 (cont'd)			
Given	RANKINE 3.0	Hand Calc	% difference
XXXXXXXXX	0.00	0.00	Not calc
XXXXXXXXX	0.00	0.00	Not calc
XXXXXXXXX	0.00	0.00	Not calc
XXXXXXXXX	0.00	0.00	Not calc

Quantity	Units
Inlet #1 temperature	Deg C
Inlet #1 pressure	MPa
Inlet #1 fluid phase	(-)
Inlet #1 quality	(-)
Inlet #1 entropy	KJ/Kg/K
Inlet #1 enthalpy	KJ/Kg
Inlet #1 mass flow	Kg/sec
Inlet #1 availability	Kg/sec
Inlet #1 flow fraction	(-)
Exit #1-10 temperature	Deg C
Exit #1-10 pressure	MPa
Exit #1-10 fluid phase	(-)
Exit #1-10 quality	(-)
Exit #1-10 entropy	KJ/Kg/K
Exit #1-10 enthalpy	KJ/Kg
Exit#1-10 mass flow	Kg/sec
Exit #1-10 availability	KJ/Kg
Exit #1-10 flow fraction	(-)
Actual work	KW
Reversiable work	KW
Irreversibility	KW
Heat transfer	KW

CASE #4			
Given	RANKINE 3.0	Hand Calc	% difference
445.00	445.00	445.00	0.00
5.00	5.00	5.00	0.00
XXXXXXXXX	3	3	0.00
XXXXXXXXX	-1.00	-1.00	0.00
XXXXXXXXX	6.8027	6.8027	0.00
XXXXXXXXX	3304.57	3304.57	0.00
10.00	10.00	10.00	0.00
XXXXXXXXX	1280.70	1280.68	0.00
XXXXXXXXX	XXXXXXXXX	1.00	XXXXXXXXX
XXXXXXXXX	445.00	445.00	0.00
XXXXXXXXX	5.00	5.00	0.00
XXXXXXXXX	3	3	0.00
XXXXXXXXX	-1.00	-1.00	0.00
XXXXXXXXX	6.8027	6.8027	0.00
XXXXXXXXX	3304.57	3304.57	0.00
XXXXXXXXX	1.00	1.00	0.00
XXXXXXXXX	1280.70	1280.68	0.00
0.10	0.10	0.10	0.00
XXXXXXXXX	0.00	0.00	Not calculated
XXXXXXXXX	0.00	0.00	Not calculated
XXXXXXXXX	0.00	0.00	Not calculated
XXXXXXXXX	0.00	0.00	Not calculated

Simple Condenser Device

T low=	298.15	Kelvin
T dead=	298.15	Kelvin
P dead=	0.101	MPa
h dead=	105.1	KJ/Kg
s dead=	0.367	KJ/Kg/K

Quantity	Units
Exit temperature	Deg C
Exit pressure	MPa
Exit fluid phase	(-)
Exit quality	(-)
Exit entropy	KJ/Kg/K
Exit enthalpy	KJ/Kg
Exit mass flow	Kg/sec
Exit availability	KJ/Kg
Inlet #1 temperature	Deg C
Inlet #1 pressure	MPa
Inlet #1 fluid phase	(-)
Inlet #1 quality	(-)
Inlet #1 entropy	KJ/Kg/K
Inlet #1 enthalpy	KJ/Kg
Inlet #1 mass flow	Kg/sec
Inlet #1 availability	KJ/Kg
Inlet #2 temperature	Deg C
Inlet #2 pressure	MPa
Inlet #2 fluid phase	(-)
Inlet #2 quality	(-)
Inlet #2 entropy	KJ/Kg/K
Inlet #2 enthalpy	KJ/Kg
Inlet #2 mass flow	Kg/sec
Inlet #2 availability	KJ/Kg
Inlet #1-#27 temperature	Deg C
Inlet #1-#27 pressure	MPa
Inlet #1-#27 fluid phase	(-)
Inlet #1-#27 quality	(-)
Inlet #1-#27 entropy	KJ/Kg/K
Inlet #1-#27 enthalpy	KJ/Kg
Inlet #1-#27 mass flow	Kg/sec
Inlet #1-#27 availability	KJ/Kg
Actual work	KW
Reversiable work	KW
Device Irreversiability	KW
Device heat transfer	KW

Case #1

Given	RANKINE 3.0	Hand Calc	% Difference
XXXXXXXXXX	151.84	151.84	0.00
XXXXXXXXXX	0.50	0.50	0.00
4	4	4	0.00
0.00	0.00	0.00	Not Calc.
XXXXXXXXXX	1.8595	1.8595	0.00
XXXXXXXXXX	639.79	639.79	0.00
XXXXXXXXXX	10.00	10.00	0.00
XXXXXXXXXX	89.73	89.71	0.02
200.00	200.00	200.00	0.00
0.50	0.50	0.50	0.00
XXXXXXXXXX	3	3	0.00
XXXXXXXXXX	-1.00	-1.00	0.00
XXXXXXXXXX	7.0598	7.0598	0.00
XXXXXXXXXX	2855.58	2855.58	0.00
10.00	10.00	10.00	0.00
XXXXXXXXXX	755.03	755.00	0.00
XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX
XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX
XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX
XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX
XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX
XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX
XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX
XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX
XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX
XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX
XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX
XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX
XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX
XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX
XXXXXXXXXX	0.00	0.00	Not Calc.
XXXXXXXXXX	6652.92	6652.91	0.00
XXXXXXXXXX	6652.92	6652.91	0.00
XXXXXXXXXX	-22157.89	-22157.89	0.00

Case #2

Given	RANKINE 3.0	Hand Calc	% difference
XXXXXXXXXX	151.84	151.84	0.00
0.50	0.50	0.50	0.00
4	4	4	0.00
0.00	0.00	0.00	Not Calc.
XXXXXXXXXX	1.8595	1.8595	0.00
XXXXXXXXXX	639.79	639.79	0.00
10.00	10.00	10.00	0.00
XXXXXXXXXX	89.73	89.71	0.02
200.00	200.00	200.00	0.00
XXXXXXXXXX	0.50	0.50	0.00
XXXXXXXXXX	3	3	0.00
XXXXXXXXXX	-1.00	-1.00	0.00
XXXXXXXXXX	7.0598	7.0598	0.00
XXXXXXXXXX	2855.58	2855.58	0.00
5.00	5.00	5.00	0.00
XXXXXXXXXX	755.03	755.00	0.00
200.00	200.00	200.00	0.00
XXXXXXXXXX	0.50	0.50	0.00
XXXXXXXXXX	3	3	0.00
XXXXXXXXXX	-1.00	-1.00	0.00
XXXXXXXXXX	7.0598	7.0598	0.00
XXXXXXXXXX	2855.58	2855.58	0.00
XXXXXXXXXX	5.00	5.00	0.00
XXXXXXXXXX	755.03	755.00	0.00
XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX
XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX
XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX
XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX
XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX
XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX
XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX
XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX
XXXXXXXXXX	0.00	0.00	Not Calc.
XXXXXXXXXX	6652.92	6652.91	0.00
XXXXXXXXXX	6652.92	6652.91	0.00
XXXXXXXXXX	-22157.89	-22157.89	0.00

Case #3

Given	RANKINE 3.0	Hand Calc	% difference
XXXXXXXXXX	151.84	151.84	0.00
0.50	0.50	0.50	0.00
4	4	4	0.00
0.00	0.00	0.00	Not Calc.
XXXXXXXXXX	1.8595	1.8595	0.00
XXXXXXXXXX	639.79	639.79	0.00
XXXXXXXXXX	9.9981	9.9981	0.00
XXXXXXXXXX	89.73	89.71	0.02
XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX
XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX
XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX
XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX
XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX
XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX
XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX
XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX
XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX
XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX
XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX
XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX
XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX
XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX
200.00	200.00	200.00	0.00
XXXXXXXXXX	0.50	0.50	0.00
XXXXXXXXXX	3	3	0.00
XXXXXXXXXX	-1.00	-1.00	0.00
XXXXXXXXXX	7.0598	7.0598	0.00
XXXXXXXXXX	2855.58	2855.58	0.00
0.3703	0.3703	0.3703	0.00
XXXXXXXXXX	755.03	755.00	0.00
XXXXXXXXXX	0.00	0.00	Not Calc.
XXXXXXXXXX	6651.65	6651.65	0.00
XXXXXXXXXX	6651.65	6651.65	0.00
XXXXXXXXXX	-22153.67	-22153.68	0.00

Simple Heat Load Model

T dead=	298.15	Kelvins
P dead=	0.101	kPa
h dead=	105.1	KJ/Kg
s dead=	0.367	KJ/Kg/K

Quantity	Units
Inlet temperature	Deg C
Inlet pressure	kPa
Inlet fluid phase	(-)
Inlet quality	(-)
Inlet entropy	KJ/Kg/K
Inlet enthalpy	KJ/Kg
Inlet mass flow	Kg/sec
Inlet availibility	KJ/Kg
Exit temperature	Deg C
Exit pressure	kPa
Exit fluid phase	(-)
Exit quality	(-)
Exit entropy	KJ/Kg/K
Exit enthalpy	KJ/Kg
Exit mass flow	Kg/sec
Exit availibility	KJ/Kg
Actual work	KW
Reversiable work	KW
Device Irreversiability	KW
Device heat transfer	KW

Case #1			
Given	RANKINE 3.0	Hand Calc	% difference
500.00	500.00	500.00	0.00
10.00	10.00	10.00	0.00
XXXXXXXXXXXX	3	3	0.00
XXXXXXXXXXXX	-1.00	-1.00	0.00
XXXXXXXXXXXX	6.5984	6.5984	0.00
XXXXXXXXXXXX	3374.66	3374.66	0.00
1.00	1.00	1.00	0.00
XXXXXXXXXXXX	1411.69	1411.67	0.00
400.00	400.00	400.00	0.00
9.00	9.00	9.00	0.00
XXXXXXXXXXXX	3	3	0.00
XXXXXXXXXXXX	-1.00	-1.00	0.00
XXXXXXXXXXXX	6.2890	6.2890	0.00
XXXXXXXXXXXX	3120.18	3120.18	0.00
XXXXXXXXXXXX	1.00	1.00	0.00
XXXXXXXXXXXX	1249.46	1249.44	0.00
XXXXXXXXXXXX	0.00	0.00	Not calculated
XXXXXXXXXXXX	162.23	162.23	0.00
XXXXXXXXXXXX	162.23	162.23	0.00
XXXXXXXXXXXX	-254.48	-254.48	0.00

Case #2			
Given	RANKINE 3.0	Hand Calc	% difference
500.00	500.00	500.00	0.00
10.00	10.00	10.00	0.00
XXXXXXXXXXXX	3	3	0.00
XXXXXXXXXXXX	-1.00	-1.00	0.00
XXXXXXXXXXXX	6.5984	6.5984	0.00
XXXXXXXXXXXX	3374.66	3374.66	0.00
XXXXXXXXXXXX	1.00	1.00	0.00
XXXXXXXXXXXX	1411.69	1411.67	0.00
400.00	400.00	400.00	0.00
8.00	9.00	9.00	0.00
XXXXXXXXXXXX	3	3	0.00
XXXXXXXXXXXX	-1.00	-1.00	0.00
XXXXXXXXXXXX	6.2890	6.2890	0.00
XXXXXXXXXXXX	3120.18	3120.18	0.00
1.00	1.00	1.00	0.00
XXXXXXXXXXXX	1249.46	1249.44	0.00
XXXXXXXXXXXX	0.00	0.00	Not calculated
XXXXXXXXXXXX	162.23	162.23	0.00
XXXXXXXXXXXX	162.23	162.23	0.00
XXXXXXXXXXXX	-254.48	-254.48	0.00

Simple Open Feedwater Heater Device

T dead-	298.15	Kelvin	h dead-	105.1	KJ/Kg
P dead-	0.101	MPa	s dead-	3.67E-01	KJ/Kg/K

Quanity	Units
Feedwater inlet temperature	Deg C
Feedwater inlet Pressure	MPa
Feedwater inlet fluid phase	(-)
Feedwater inlet quality	(-)
Feedwater inlet entropy	KJ/Kg/K
Feedwater inlet enthalpy	KJ/Kg
Feedwater inlet mass flow	Kg/sec
Feedwater inlet availability	KJ/Kg
Extraction inlet temperature	Deg C
Extraction inlet pressure	MPa
Extraction inlet fluid phase	(-)
Extraction inlet quality	(-)
Extraction inlet entropy	KJ/Kg/K
Extraction inlet enthalpy	KJ/Kg
Extraction inlet mass flow	Kg/sec
Extraction inlet availability	KJ/Kg
Feedwater exit temperature	Deg C
Feedwater exit pressure	MPa
Feedwater exit fluid phase	(-)
Feedwater exit quality	(-)
Feedwater exit entropy	KJ/Kg/K
Feedwater exit enthalpy	KJ/Kg
Feedwater exit mass flow	Kg/sec
Feedwater exit availability	KJ/Kg
Actual OFW work	KW
Reversiable OFW work	KW
OFW Irreversiability	KW
OFW heat transfer	KW

CASE #1			
Given	RANKINE 3.0	Hand Calc	% Difference
251.07	251.07	251.07	0.00
XXXXXXXXX	6.00	6.00	0.00
XXXXXXXXX	1	1	0.00
XXXXXXXXX	-1.00	-1.00	0.00
XXXXXXXXX	2.7861	2.7861	0.00
XXXXXXXXX	1090.73	1090.73	0.00
23.5837	23.5837	23.5837	0.00
XXXXXXXXX	264.39	264.37	0.01
430.6	430.6	430.6	0.00
XXXXXXXXX	6.00	6.00	0.00
XXXXXXXXX	3	3	0.00
XXXXXXXXX	-1.00	-1.00	0.00
XXXXXXXXX	6.6542	6.6521	0.03
XXXXXXXXX	3255.19	3255.19	0.00
XXXXXXXXX	1.4165	1.4165	0.00
XXXXXXXXX	1275.58	1276.18	-0.05
XXXXXXXXX	275.56	275.5585	0.00
6.00	6.00	6.00	0.00
4	4	4	0.00
XXXXXXXXX	0.00	0.00	Not calc
XXXXXXXXX	3.0251	3.0251	0.00
XXXXXXXXX	1213.37	1213.37	0.00
XXXXXXXXX	25.0002	25.0002	0.00
XXXXXXXXX	315.78	315.78	0.01
XXXXXXXXX	0.00	0.00	Not calc
XXXXXXXXX	147.46	148.35	-0.60
XXXXXXXXX	147.46	148.35	-0.60
XXXXXXXXX	0.00	0.00	Not calc

CASE #2			
Given	RANKINE 3.0	Hand Calc	% Difference
251.07	251.07	251.07	0.00
6.00	6.00	6.00	0.00
XXXXXXXXX	1	1	0.00
XXXXXXXXX	-1.00	-1.00	0.00
XXXXXXXXX	2.7861	2.786125	0.00
XXXXXXXXX	1090.73	1090.73	0.00
XXXXXXXXX	23.5805	23.5806	0.00
XXXXXXXXX	264.39	264.37	0.01
430.60	430.60	430.60	0.00
XXXXXXXXX	6.00	6.00	0.00
XXXXXXXXX	3	3	0.00
XXXXXXXXX	-1.00	-1.00	0.00
XXXXXXXXX	6.6542	6.6542	0.00
XXXXXXXXX	3255.19	3255.19	0.00
1.4183	1.4183	1.4183	0.00
XXXXXXXXX	1275.56	1275.55	0.00
XXXXXXXXX	275.56	275.558	0.00
XXXXXXXXX	6.00	6.00	0.00
4	4	4	0.00
XXXXXXXXX	0.00	0.00	Not calc
XXXXXXXXX	3.0251	3.0251	0.00
XXXXXXXXX	1213.37	1213.366	0.00
XXXXXXXXX	24.9968	24.9969	0.00
XXXXXXXXX	315.78	315.76	0.01
XXXXXXXXX	0.00	0.00	Not calc
XXXXXXXXX	147.44	147.44	0.00
XXXXXXXXX	147.44	147.44	0.00
XXXXXXXXX	0.00	0.00	Not calc

CASE #3			
Given	RANKINE 3.0	Hand Calc	% Difference
251.07	251.07	251.07	0.00
XXXXXXXXX	6.00	6.00	0.00
XXXXXXXXX	1	1	0.00
XXXXXXXXX	-1.00	-1.00	0.00
XXXXXXXXX	2.7861	2.7861	0.00
XXXXXXXXX	1090.73	1090.73	0.00
XXXXXXXXX	23.5835	23.5835	0.00
XXXXXXXXX	264.39	264.38	0.01
430.60	430.60	430.60	0.00
6.00	6.00	6.00	0.00
XXXXXXXXX	3	3	0.00
XXXXXXXXX	-1.00	-1.00	0.00
XXXXXXXXX	6.6542	6.6542	0.00
XXXXXXXXX	3255.19	3255.193	0.00
XXXXXXXXX	1.4165	1.4165	0.00
XXXXXXXXX	1275.58	1275.56	0.00
XXXXXXXXX	275.56	275.558	0.00
XXXXXXXXX	6.00	6.00	0.00
4	4	4	0.00
XXXXXXXXX	0.00	0.00	Not calc
XXXXXXXXX	3.0251	3.0251	0.00
XXXXXXXXX	1213.37	1213.366	0.00
25.0000	25.0000	25.0000	0.00
XXXXXXXXX	315.78	315.76	0.01
XXXXXXXXX	0.00	0.00	Not calc
XXXXXXXXX	147.46	147.64	-0.12
XXXXXXXXX	147.46	147.64	-0.12
XXXXXXXXX	0.00	0.00	Not calc

Simple Open Feedwater Heater Device (Cont'd)

Quantity	Units
Feedwater inlet temperature	Deg C
Feedwater inlet Pressure	MPa
Feedwater inlet fluid phase	(-)
Feedwater inlet quality	(-)
Feedwater inlet entropy	KJ/Kg/K
Feedwater inlet enthalpy	KJ/Kg
Feedwater inlet mass flow	Kg/sec
Feedwater inlet availability	KJ/Kg
Extraction inlet temperature	Deg C
Extraction inlet pressure	MPa
Extraction inlet fluid phase	(-)
Extraction inlet quality	(-)
Extraction inlet entropy	KJ/Kg/K
Extraction inlet enthalpy	KJ/Kg
Extraction inlet mass flow	Kg/sec
Extraction inlet availability	KJ/Kg
Feedwater exit temperature	Deg C
Feedwater exit pressure	MPa
Feedwater exit fluid phase	(-)
Feedwater exit quality	(-)
Feedwater exit entropy	KJ/Kg/K
Feedwater exit enthalpy	KJ/Kg
Feedwater exit mass flow	Kg/sec
Feedwater exit availability	KJ/Kg
Actual OFW work	KW
Reversible OFW work	KW
OFW irreversibility	KW
OFW heat transfer	KW

CASE #4			
Given	RANKINE 3.0	Hand Calc	% Difference
XXXXXXXXX	251.07	251.0742	0.00
XXXXXXXXX	6.00	6.00	0.00
XXXXXXXXX	1	1	0.00
XXXXXXXXX	-1.00	-1.00	0.00
XXXXXXXXX	2.7862	2.7862	0.00
XXXXXXXXX	1090.75	1090.75	0.00
23.5837	23.5837	23.5837	0.00
XXXXXXXXX	264.4	264.37	0.01
430.60	430.60	430.60	0.00
6.00	6.00	6.00	0.00
XXXXXXXXX	3	3	0.00
XXXXXXXXX	-1.00	-1.00	0.00
XXXXXXXXX	6.6542	6.6542	0.00
XXXXXXXXX	3255.19	3255.193	0.00
XXXXXXXXX	1.4163	1.4163	0.00
XXXXXXXXX	1275.58	1275.56	0.00
XXXXXXXXX	275.56	275.56	0.00
XXXXXXXXX	6.00	6.00	0.00
4	4	4	0.00
XXXXXXXXX	0.00	0.00	Not calc
XXXXXXXXX	3.0251	3.0251	0.00
XXXXXXXXX	1213.37	1213.37	0.00
25.0000	25.0000	25.0000	0.00
XXXXXXXXX	315.78	315.76	0.01
XXXXXXXXX	0.00	0.00	Not calc
XXXXXXXXX	147.45	147.39	0.04
XXXXXXXXX	147.45	147.39	0.04
XXXXXXXXX	0.00	0.00	Not calc

CASE #5			
Given	RANKINE 3.0	Hand Calc	% Difference
251.07	251.07	251.07	0.00
6.00	6.00	6.00	0.00
XXXXXXXXX	1	1	0.00
XXXXXXXXX	-1.00	-1.00	0.00
XXXXXXXXX	2.7861	2.786125	0.00
XXXXXXXXX	1090.73	1090.73	0.00
XXXXXXXXX	23.5837	23.5837	0.00
XXXXXXXXX	264.39	264.37	0.01
XXXXXXXXX	430.71	430.70	0.00
XXXXXXXXX	6.00	6.00	0.00
XXXXXXXXX	3	3	0.00
XXXXXXXXX	-1.00	-1.00	0.00
XXXXXXXXX	6.6549	6.6546	0.00
XXXXXXXXX	3255.47	3255.45	0.00
1.4163	1.4163	1.4163	0.00
XXXXXXXXX	1275.73	1275.71	0.00
XXXXXXXXX	275.56	275.5585	0.00
XXXXXXXXX	6.00	6.00	0.00
4	4	4	0.00
XXXXXXXXX	0.00	0.00	Not calc
XXXXXXXXX	3.0251	3.025071	0.00
XXXXXXXXX	1213.37	1213.37	0.00
25.0000	25.0000	25.0000	0.00
XXXXXXXXX	315.78	315.76	0.01
XXXXXXXXX	0.00	0.00	Not calc
XXXXXXXXX	147.50	147.51	0.00
XXXXXXXXX	147.50	147.51	0.00
XXXXXXXXX	0.00	0.00	Not calc

CASE #6			
Given	RANKINE 3.0	Hand Calc	% Difference
251.07	251.07	251.07	0.00
XXXXXXXXX	6.00	6.00	0.00
XXXXXXXXX	1	1	0.00
XXXXXXXXX	-1.00	-1.00	0.00
XXXXXXXXX	2.7861	2.79	0.00
XXXXXXXXX	1090.73	1090.73	0.00
23.5837	23.5837	23.5837	0.00
XXXXXXXXX	264.39	264.37	0.01
430.60	430.60	430.60	0.00
6.00	6.00	6.00	0.00
XXXXXXXXX	3	3	0.00
XXXXXXXXX	-1.00	-1.00	0.00
XXXXXXXXX	6.6542	6.6542	0.00
XXXXXXXXX	3255.19	3255.193	0.00
1.4163	1.4163	1.4163	0.00
XXXXXXXXX	1275.58	1275.56	0.00
XXXXXXXXX	275.67	275.6713	0.00
XXXXXXXXX	6.00	6.00	0.00
XXXXXXXXX	1	1	0.00
XXXXXXXXX	-1.00	-1.00	0.00
XXXXXXXXX	3.0066	3.006627	0.00
XXXXXXXXX	1213.35	1213.35	0.00
XXXXXXXXX	25.0000	25.0000	0.00
XXXXXXXXX	321.27	321.25	0.01
XXXXXXXXX	0.00	0.00	Not calc
XXXXXXXXX	10.20	10.18	0.16
XXXXXXXXX	10.20	10.18	0.16
XXXXXXXXX	0.00	0.00	Not calc

Simple Closed Feed Water Heater Device

T dead=	298.15	Kelvin
P dead=	0.101	MPa
h dead=	105.1	KJ/Kg
s dead=	0.367	KJ/Kg/K

Quantity	Units	CASE #1 Given	CASE #1 RANKINE 3.0	CASE #1 Hand calc	CASE #1 % difference	CASE #2 Given	CASE #2 RANKINE 3.0	CASE #2 Hand calc	CASE #2 % difference
Feedwater inlet temperature	Deg C	80.00	80.00	80.00	0.00	80.00	80.00	80.00	0.00
Feedwater inlet pressure	MPa	2.50	2.50	2.50	0.00	XXXXXXXXX	2.50	2.50	0.00
Feedwater inlet fluid phase	(-)	XXXXXXXXX	1	1	0.00	XXXXXXXXX	1	1	0.00
Feedwater inlet quality	(-)	XXXXXXXXX	-1.00	-1.00	0.00	XXXXXXXXX	-1.00	-1.00	0.00
Feedwater inlet entropy	KJ/Kg/K	XXXXXXXXX	1.0716	1.0716	0.00	XXXXXXXXX	1.0716	1.0716	0.00
Feedwater inlet enthalpy	KJ/Kg	XXXXXXXXX	336.65	336.65	0.00	XXXXXXXXX	336.65	336.65	0.00
Feedwater inlet mass flow	Kg/sec	10.00	10.00	10.00	0.00	XXXXXXXXX	10.00	10.00	0.00
Feedwater inlet availability	KJ/Kg	XXXXXXXXX	21.48	21.46	0.07	XXXXXXXXX	21.48	21.46	0.07
Feedwater exit temperature	Deg C	XXXXXXXXX	199.95	199.95	0.00	XXXXXXXXX	199.95	199.95	0.00
Feedwater exit pressure	MPa	XXXXXXXXX	2.25	2.25	0.00	2.25	2.25	2.25	0.00
Feedwater exit fluid phase	(-)	XXXXXXXXX	1	1	0.00	XXXXXXXXX	1	1	0.00
Feedwater exit quality	(-)	XXXXXXXXX	-1.00	-1.00	0.00	XXXXXXXXX	-1.00	-1.00	0.00
Feedwater exit entropy	KJ/Kg/K	XXXXXXXXX	2.3245	2.3245	0.00	XXXXXXXXX	2.3245	2.3245	0.00
Feedwater exit enthalpy	KJ/Kg	XXXXXXXXX	852.14	852.14	0.00	XXXXXXXXX	852.14	852.14	0.00
Feedwater exit mass flow	Kg/sec	XXXXXXXXX	10.00	10.00	0.00	10.00	10.00	10.00	0.00
Feedwater exit availability	KJ/Kg	XXXXXXXXX	163.44	163.42	0.01	XXXXXXXXX	163.44	163.42	0.01
Extraction inlet temperature	Deg C	320.00	320.00	320.00	0.00	320.00	320.00	320.00	0.00
Extraction inlet pressure	MPa	10.00	10.00	10.00	0.00	XXXXXXXXX	10.00	10.00	0.00
Extraction inlet saturation temp	Deg C	XXXXXXXXX	XXXXXXXXX	311.01	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	311	XXXXXXXXX
Extraction inlet fluid phase	(-)	XXXXXXXXX	3	3	0.00	XXXXXXXXX	3	3.00	0.00
Extraction inlet quality	(-)	XXXXXXXXX	-1.00	-1.00	0.00	XXXXXXXXX	-1.00	-1.0000	0.00
Extraction inlet entropy	KJ/Kg/K	XXXXXXXXX	5.7144	5.7144	0.00	XXXXXXXXX	5.7144	5.7144	0.00
Extraction inlet enthalpy	KJ/Kg	XXXXXXXXX	2783.86	2783.86	0.00	XXXXXXXXX	2783.86	2783.86	0.00
Extraction inlet mass flow	Kg/sec	XXXXXXXXX	2.11	2.11	0.00	XXXXXXXXX	2.11	2.11	0.00
Extraction inlet availability	KJ/Kg	XXXXXXXXX	1084.45	1084.43	0.00	XXXXXXXXX	1084.45	1084.43	0.00
Drain inlet #1 temperature	Deg C	140.00	140.00	140.00	0.00	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX
Drain inlet #1 pressure	MPa	XXXXXXXXX	10.00	10.00	0.00	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX
Drain inlet #1 fluid phase	(-)	XXXXXXXXX	1	1	0.00	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX
Drain inlet #1 quality	(-)	XXXXXXXXX	-1.00	-1.00	0.00	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX
Drain inlet #1 entropy	KJ/Kg/K	XXXXXXXXX	1.7250	1.7250	0.00	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX
Drain inlet #1 enthalpy	KJ/Kg	XXXXXXXXX	595.13	595.13	0.00	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX
Drain inlet #1 mass flow	Kg/sec	1.00	1.00	1.00	0.00	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX
Drain inlet #1 availability	KJ/Kg	XXXXXXXXX	85.15	85.13	0.03	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX
Drain inlet #1-10 temperature	Deg C	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	140.00	140.00	140.00	0.00
Drain inlet #1-10 pressure	MPa	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	10.00	10.00	0.00
Drain inlet #1-10 fluid phase	(-)	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	1	1	0.00
Drain inlet #1-10 quality	(-)	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	-1.00	-1.00	0.00
Drain inlet #1-10 entropy	KJ/Kg/K	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	1.7250	1.7250	0.00
Drain inlet #1-10 enthalpy	KJ/Kg	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	595.13	595.13	0.00
Drain inlet #1-10 mass flow	Kg/sec	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	0.10	0.10	0.10	0.00
Drain inlet #1-10 availability	KJ/Kg	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	85.15	85.13	0.03
Drain exit temperature	Deg C	XXXXXXXXX	100.00	100.00	0.00	XXXXXXXXX	100.00	100.00	0.00
Drain exit pressure	MPa	XXXXXXXXX	9.50	9.50	0.00	9.50	9.50	9.50	0.00
Drain exit fluid phase	(-)	XXXXXXXXX	1	1	0.00	XXXXXXXXX	1	1	0.00
Drain exit quality	(-)	XXXXXXXXX	-1.00	-1.00	0.00	XXXXXXXXX	-1.00	-1.00	0.00
Drain exit entropy	KJ/Kg/K	XXXXXXXXX	1.2952	1.2952	0.00	XXXXXXXXX	1.2952	1.2952	0.00
Drain exit enthalpy	KJ/Kg	XXXXXXXXX	425.90	425.90	0.00	XXXXXXXXX	425.90	425.90	0.00
Drain exit mass flow	Kg/sec	XXXXXXXXX	3.11	3.11	0.00	XXXXXXXXX	3.11	3.11	0.00
Drain exit availability	KJ/Kg	XXXXXXXXX	44.08	44.06	0.05	XXXXXXXXX	44.08	44.06	0.05
Terminal temperature diff	Deg C	111.06	111.06	111.06	0.00	111.06	111.06	111.06	0.00
Approach temperature diff	Deg C	20.00	20.00	20.00	0.00	20.00	20.00	20.00	0.00
Feed water pressure loss	MPa	0.25	0.25	0.25	0.00	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX
Feedwater % pressure loss	(-)	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	0.10	0.10	0.10	0.00
Extraction pressure loss	MPa	0.50	0.50	0.50	0.00	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX
Extraction % pressure loss	(-)	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	0.05	0.05	0.05	0.00
Feedwater actual work	KW	XXXXXXXXX	0.00	0.00	Not calc	XXXXXXXXX	0.00	0.00	Not calc
Feedwater reversible work	KW	XXXXXXXXX	2163.68	2163.67	0.00	XXXXXXXXX	2163.68	2163.83	-0.01
Feedwater irreversibility	KW	XXXXXXXXX	2163.68	2163.67	0.00	XXXXXXXXX	2163.68	2163.83	-0.01
Feedwater heat transfer	KW	XXXXXXXXX	5154.93	5154.93	0.00	XXXXXXXXX	5154.93	5154.93	0.00
Extraction actual work	KW	XXXXXXXXX	0.00	0.00	Not calc	XXXXXXXXX	0.00	0.00	Not calc
Extraction reversible work	KW	XXXXXXXXX	1117.10	1117.10	0.00	XXXXXXXXX	1117.10	1117.10	0.00
Extraction irreversibility	KW	XXXXXXXXX	1117.10	1117.10	0.00	XXXXXXXXX	1117.10	1117.10	0.00
Extraction heat transfer	KW	XXXXXXXXX	-5154.93	-5154.93	0.00	XXXXXXXXX	-5154.93	-5154.93	0.00

Simple Separator Device

T dead=	298.15	Kelvin
P dead=	0.101	MPa
h dead=	105.1	KJ/Kg
s dead=	0.367	KJ/Kg/K

Quantity	Units
Inlet temperature	Deg C
Inlet pressure	MPa
Inlet fluid phase	(-)
Inlet quality	(-)
Inlet entropy	KJ/Kg/K
Inlet enthalpy	KJ/Kg
Inlet mass flow	Kg/sec
Inlet availability	KJ/Kg
Vapor exit temperature	Deg C
Vapor exit pressure	MPa
Vapor exit fluid phase	(-)
Vapor exit quality	(-)
Vapor exit entropy	KJ/Kg/K
Vapor exit enthalpy	KJ/Kg
Vapor exit mass flow	Kg/sec
Vapor exit availability	KJ/Kg
Condensate exit temperature	Deg C
Condensate exit pressure	MPa
Condensate exit fluid phase	(-)
Condensate exit quality	(-)
Condensate exit entropy	KJ/Kg/K
Condensate exit enthalpy	KJ/Kg
Condensate exit mass flow	Kg/sec
Condensate exit availability	KJ/Kg
Separator pressure loss	MPa
Separator % pressure loss	(-)
Device actual work	KW
Device reversible work	KW
Device irreversibility	KW
Device heat transfer	KW

CASE #1

Given	RANKINE 3.0	Hand Calc	% difference
XXXXXXXXX	179.87	179.87	0.00
1.00	1.00	1.00	0.00
2	2	2	0.00
0.50	0.50	0.50	0.00
XXXXXXXXX	4.3598	4.3598	0.00
XXXXXXXXX	1769.26	1769.26	0.00
1.00	1.0000	1.0000	0.00
XXXXXXXXX	473.74	473.72	0.01
XXXXXXXXX	175.35	175.35	0.00
XXXXXXXXX	0.90	0.90	0.00
5	5	5	0.00
1.00	1.00	1.00	0.00
XXXXXXXXX	6.8191	6.8191	0.00
XXXXXXXXX	2772.27	2772.27	0.00
XXXXXXXXX	0.5059	0.5059	0.00
XXXXXXXXX	803.12	803.10	0.00
XXXXXXXXX	175.35	175.35	0.00
XXXXXXXXX	0.90	0.90	0.00
4	4	4	0.00
0.00	0.00	0.00	Not calc
XXXXXXXXX	2.0927	2.0927	0.00
XXXXXXXXX	742.27	742.27	0.00
XXXXXXXXX	0.4941	0.4941	0.00
XXXXXXXXX	122.66	122.64	0.01
0.10	0.10	0.10	0.00
XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX
XXXXXXXXX	0.00	0.00	Not calc
XXXXXXXXX	6.83	6.83	0.02
XXXXXXXXX	6.83	6.83	0.02
XXXXXXXXX	0.00	0.00	Not calc

CASE #2

Given	RANKINE 3.0	Hand Calc	% difference
500.00	500.00	500.00	0.00
1.00	1.00	1.00	0.00
XXXXXXXXX	3	3	0.00
XXXXXXXXX	-1.00	-1.00	0.00
XXXXXXXXX	7.7586	7.7586	0.00
XXXXXXXXX	3475.99	3475.99	0.00
1.00	1.00	1.00	0.00
XXXXXXXXX	1167.10	1167.08	0.00
XXXXXXXXX	499.51	499.51	0.00
XXXXXXXXX	0.90	0.90	0.00
XXXXXXXXX	3	3	0.00
XXXXXXXXX	-1.00	-1.00	0.00
XXXXXXXXX	7.8068	7.8068	0.00
XXXXXXXXX	3475.99	3475.99	0.00
XXXXXXXXX	1.00	1.00	0.00
XXXXXXXXX	1152.52	1152.69	-0.02
XXXXXXXXX	175.35	175.35	0.00
XXXXXXXXX	0.90	0.90	0.00
XXXXXXXXX	4	4	0.00
XXXXXXXXX	0.00	0.00	Not calc
XXXXXXXXX	2.0927	2.0927	0.00
XXXXXXXXX	742.27	742.27	0.00
XXXXXXXXX	0.00	0.00	Not calc
XXXXXXXXX	122.66	122.64	0.01
XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX
0.10	0.10	0.10	0.00
XXXXXXXXX	0.00	0.00	Not calc
XXXXXXXXX	14.39	14.39	0.02
XXXXXXXXX	14.39	14.39	0.02
XXXXXXXXX	0.00	0.00	Not calc

CASE #3

Given	RANKINE 3.0	Hand Calc	% difference
100.00	100.00	100.00	0.00
1.00	1.00	1.00	0.00
XXXXXXXXX	1	1	0.00
XXXXXXXXX	-1.00	-1.00	0.00
XXXXXXXXX	1.3049	1.3049	0.00
XXXXXXXXX	419.52	419.52	0.00
1.00	1.00	1.00	0.00
XXXXXXXXX	34.79	34.77	0.05
XXXXXXXXX	175.35	175.35	0.00
XXXXXXXXX	0.90	0.90	0.00
XXXXXXXXX	5	5	0.00
XXXXXXXXX	1.00	1.00	0.00
XXXXXXXXX	6.5191	6.6191	0.00
XXXXXXXXX	2772.27	2772.27	0.00
XXXXXXXXX	0.00	0.00	Not calc
XXXXXXXXX	803.12	803.10	0.00
XXXXXXXXX	100.02	100.02	0.00
XXXXXXXXX	0.90	0.90	0.00
XXXXXXXXX	1	1	0.00
XXXXXXXXX	-1.00	-1.00	0.00
XXXXXXXXX	1.3053	1.3053	0.00
XXXXXXXXX	419.52	419.52	0.00
XXXXXXXXX	1.00	1.00	0.00
XXXXXXXXX	34.70	34.68	0.06
XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX
0.10	0.10	0.10	0.00
XXXXXXXXX	0.00	0.00	Not calc
XXXXXXXXX	0.09	0.09	Not calc
XXXXXXXXX	0.09	0.09	Not calc
XXXXXXXXX	0.00	0.00	Not calc

Simple Reheater Device

T dead=	298.15	Deg C
P dead=	0.101	MPa
h dead=	105.1	KJ/Kg/K
s dead=	0.367	KJ/Kg

Quantity	Units
Cycle steam inlet temperature	Deg C
Cycle steam inlet pressure	MPa
Cycle steam inlet fluid phase	(-)
Cycle steam inlet quality	(-)
Cycle steam inlet entropy	KJ/Kg/K
Cycle steam inlet enthalpy	KJ/Kg
Cycle steam inlet mass flow	Kg/sec
Cycle steam inlet availability	KJ/Kg
Cycle steam exit temperature	Deg C
Cycle steam exit pressure	MPa
Cycle steam exit fluid phase	(-)
Cycle steam exit quality	(-)
Cycle steam exit entropy	KJ/Kg/K
Cycle steam exit enthalpy	KJ/Kg
Cycle steam exit mass flow	Kg/sec
Cycle steam exit availability	KJ/Kg
Reheat steam inlet temperature	Deg C
Reheat steam inlet pressure	MPa
Reheat steam inlet sat. temp	Deg C
Reheat steam inlet fluid phase	(-)
Reheat steam inlet quality	(-)
Reheat steam inlet entropy	KJ/Kg/K
Reheat steam inlet enthalpy	KJ/Kg
Reheat steam inlet mass flow	Kg/sec
Reheat steam inlet availability	KJ/Kg
Reheat steam exit temperature	Deg C
Reheat steam exit pressure	MPa
Reheat steam exit sat. temp	Deg C
Reheat steam exit fluid phase	(-)
Reheat steam exit quality	(-)
Reheat steam exit entropy	KJ/Kg/K
Reheat steam exit enthalpy	KJ/Kg
Reheat steam exit mass flow	Kg/sec
Reheat steam exit availability	KJ/Kg
Inputed terminal temp diff	Deg C
Cycle steam pressure loss	MPa
Cycle steam % pressure loss	(-)
Reheat steam pressure loss	MPa
Reheat steam % pressure loss	(-)
Calculated terminal temp diff	Deg C
Cycle steam actual work	KW
Cycle steam reversiable work	KW
Cycle steam irreversibility	KW
Cycle steam heat transfer	KW
Reheat steam actual work	KW
Reheat steam reversiable work	KW
Reheat steam irreversibility	KW
Reheat steam heat transfer	KW

Case #1

Given	RANKINE 3.0	Hand Calc	% difference
180.00	180.00	180.00	0.00
1.00	1.00	1.00	0.00
XXXXXXX	3	3	0.00
XXXXXXX	-1.00	-1.00	0.00
XXXXXXX	6.5832	6.5832	0.00
XXXXXXX	2776.53	2776.53	0.00
90.3395	90.3395	90.3395	0.00
XXXXXXX	818.08	818.08	0.00
XXXXXXX	183.38	183.38	0.00
XXXXXXX	0.90	0.90	0.00
XXXXXXX	3	3	0.00
XXXXXXX	-1.00	-1.00	0.00
XXXXXXX	6.6643	6.6643	0.00
XXXXXXX	2792.73	2792.73	0.00
XXXXXXX	90.3395	90.3395	0.00
XXXXXXX	810.11	810.09	0.00
300.00	300.00	300.00	0.00
XXXXXXX	1.50	1.50	0.00
XXXXXXX	XXXXXXX	198.32	XXXXXXX
XXXXXXX	3	3	0.00
XXXXXXX	-1.00	-1.00	0.00
XXXXXXX	8.9184	8.9184	0.00
XXXXXXX	3037.88	3037.88	0.00
0.8605	0.8605	0.8605	0.00
XXXXXXX	979.49	979.47	0.00
XXXXXXX	193.34	193.34	0.00
XXXXXXX	1.35	1.35	0.00
XXXXXXX	XXXXXXX	193.34	XXXXXXX
4	4	4	0.00
0.00	0.00	0.00	Not calc
XXXXXXX	2.2659	2.2659	0.00
XXXXXXX	822.13	822.13	0.00
0.8605	0.8605	0.8605	0.00
XXXXXXX	150.91	150.89	0.01
10.00	10.00	10.00	0.00
0.10	0.10	0.10	0.00
XXXXXXX	XXXXXXX	XXXXXXX	XXXXXXX
0.15	0.15	0.15	0.00
XXXXXXX	XXXXXXX	XXXXXXX	XXXXXXX
XXXXXXX	9.96	9.96	0.02
XXXXXXX	0.00	0.00	Not calc
XXXXXXX	1971.08	1971.48	-0.02
XXXXXXX	1971.08	1971.48	-0.02
XXXXXXX	1463.54	1463.50	0.00
XXXXXXX	0.00	0.00	Not calc
XXXXXXX	65.76	65.76	0.01
XXXXXXX	65.76	65.76	0.01
XXXXXXX	-1463.54	-1463.50	0.00

Case #2

Given	RANKINE 3.0	Hand Calc	% difference
180.00	180.00	180.00	0.00
XXXXXXX	1.00	1.00	0.00
XXXXXXX	3	3	0.00
XXXXXXX	-1.00	-1.00	0.00
XXXXXXX	6.5832	6.5832	0.00
XXXXXXX	2776.53	2776.53	0.00
XXXXXXX	90.3395	90.3395	0.00
XXXXXXX	818.08	818.06	0.00
XXXXXXX	183.38	183.38	0.00
0.90	0.90	0.90	0.00
XXXXXXX	3	3	0.00
XXXXXXX	-1.00	-1.00	0.00
XXXXXXX	6.6643	6.6643	0.00
XXXXXXX	2792.73	2792.73	0.00
90.3395	90.3395	90.3395	0.00
XXXXXXX	810.11	810.09	0.00
300.00	300.00	300.00	0.00
XXXXXXX	1.50	1.50	0.00
XXXXXXX	XXXXXXX	198.32	XXXXXXX
XXXXXXX	3	3	0.00
XXXXXXX	-1.00	-1.00	0.00
XXXXXXX	8.9184	8.9184	0.00
XXXXXXX	3037.88	3037.88	0.00
XXXXXXX	0.8605	0.8605	0.00
XXXXXXX	979.49	979.47	0.00
XXXXXXX	193.34	193.34	0.00
1.35	1.35	1.35	0.00
XXXXXXX	XXXXXXX	193.34	XXXXXXX
4	4	4	0.00
0.00	0.00	0.00	Not calc
XXXXXXX	2.2659	2.2659	0.00
XXXXXXX	822.13	822.13	0.00
0.8605	0.8605	0.8605	0.00
XXXXXXX	150.91	150.89	0.01
25.00	25.00	25.00	0.00
XXXXXXX	XXXXXXX	XXXXXXX	XXXXXXX
0.10	0.10	0.10	0.00
XXXXXXX	XXXXXXX	XXXXXXX	XXXXXXX
0.10	0.10	0.10	0.00
XXXXXXX	9.96	9.96	0.02
XXXXXXX	0.00	0.00	Not calc
XXXXXXX	1971.08	1971.48	-0.02
XXXXXXX	1971.08	1971.48	-0.02
XXXXXXX	1463.54	1463.50	0.00
XXXXXXX	0.00	0.00	Not calc
XXXXXXX	65.76	65.76	0.01
XXXXXXX	65.76	65.76	0.01
XXXXXXX	-1463.54	-1463.50	0.00

Case #3

Given	RANKINE 3.0	Hand Calc	% difference
180.00	180.00	180.00	0.00
1.00	1.00	1.00	0.00
XXXXXXX	3	3	0.00
XXXXXXX	-1.00	-1.00	0.00
XXXXXXX	6.5832	6.5832	0.00
XXXXXXX	2776.53	2776.53	0.00
90.3740	90.3740	90.3740	0.00
XXXXXXX	818.08	818.06	0.00
XXXXXXX	183.05	183.05	0.00
XXXXXXX	0.90	0.90	0.00
XXXXXXX	3	3	0.00
XXXXXXX	-1.00	-1.00	0.00
XXXXXXX	6.6625	6.6625	0.00
XXXXXXX	2791.89	2791.89	0.00
XXXXXXX	90.37	90.37	0.00
XXXXXXX	809.82	809.79	0.00
300.00	300.00	300.00	0.00
1.50	1.50	1.50	0.00
XXXXXXX	XXXXXXX	198.32	XXXXXXX
XXXXXXX	3	3	0.00
XXXXXXX	-1.00	-1.00	0.00
XXXXXXX	8.9184	8.9184	0.00
XXXXXXX	3037.88	3037.88	0.00
0.8260	0.8260	0.8260	0.00
XXXXXXX	979.49	979.47	0.00
193.00	193.00	193.00	0.00
XXXXXXX	1.35	1.35	0.00
XXXXXXX	XXXXXXX	193.34	XXXXXXX
XXXXXXX	1	1	0.00
XXXXXXX	-1.00	-1.00	0.00
XXXXXXX	2.2603	2.2603	0.00
XXXXXXX	820.61	820.68	-0.01
XXXXXXX	0.6260	0.6260	0.00
XXXXXXX	151.05	151.10	-0.03
25.00	25.00	25.00	0.00
XXXXXXX	XXXXXXX	XXXXXXX	XXXXXXX
0.10	0.10	0.10	0.00
XXXXXXX	XXXXXXX	XXXXXXX	XXXXXXX
0.10	0.10	0.10	0.00
XXXXXXX	9.95	9.95	0.01
XXXXXXX	0.00	0.00	Not calc
XXXXXXX	1969.77	1970.34	-0.03
XXXXXXX	1969.77	1970.34	-0.03
XXXXXXX	1387.98	1387.97	0.00
XXXXXXX	0.00	0.00	Not calc
XXXXXXX	62.17	62.13	0.07
XXXXXXX	62.17	62.13	0.07
XXXXXXX	-1387.97	-1387.97	0.00

Appendix B:

RANKINE 3.0 input files for individual device verification

```
TITLE LINE
  SIMPLE BOILER MODEL TEST
  END TITLE

NUMBER OF NODES IS 22
HIGH TEMPERATURE RESERVOIR: 600 DEG C
LOW TEMPERATURE RESERVOIR: 25.0 DEG C
DEAD STATE TEMPERATURE: 25.0 DEG C
DEAD STATE PRESSURE: 101 KPA
GENERATOR MECHANICAL LOSS IS 10.0 KW
GENERATOR ELECTRICAL LOSS IS 5.0 KW

DEVICE #1: SIMPLE BOILER
  COMMENT: THIS DEVICE WILL TEST ICALL=1, IFIND=1,2
  COMMENT: THIS DEVICE WILL TEST ICALL=2, IFIND=2,2
  COMMENT: THIS DEVICE WILL TEST ICALL=3, IFIND=1
  COMMENT: THIS DEVICE WILL TEST ICALL=4, IFIND=1
  BOILER INLET NODE NUMBER IS 1
  BOILER EXIT NODE NUMBER IS 2.
  BOILER INLET TEMPERATURE IS 100.0 DEG C
  BOILER EXIT TEMPERATURE IS 600.0 DEG C
  BOILER EXIT PRESSURE IS 18 MPA
  BOILER EXIT MASS FLOW RATE IS 5.0 KG/SEC
  BOILER PERCENTAGE PRESSURE LOSS IS 10 PERCENT
  BOILER REHEAT LEG #1 INLET NODE NUMBER IS 3
  BOILER REHEAT LEG #1 EXIT NODE NUMBER IS 4
  BOILER REHEAT LEG #1 INLET TEMPERATURE IS 100.0 DEG C
  BOILER REHEAT LEG #1 INLET PRESSURE IS 20.0 MPA
  BOILER REHEAT LEG #1 EXIT TEMPERATURE IS 600.0 DEG C
  BOILER REHEAT LEG #1 EXIT MASS FLOW RATE IS 5.0 KG/SEC
  BOILER REHEAT LEG #1 PERCENTAGE PRESSURE LOSS IS 10 PERCENT
  BOILER REHEAT LEG #2 INLET NODE NUMBER IS 5
  BOILER REHEAT LEG #2 EXIT NODE NUMBER IS 6
  BOILER REHEAT LEG #2 INLET TEMPERATURE IS 100.0 DEG C
  BOILER REHEAT LEG #2 INLET PRESSURE IS 20.0 MPA
  BOILER REHEAT LEG #2 INLET MASS FLOW RATE IS 5.0 KG/SEC
  BOILER REHEAT LEG #2 EXIT TEMPERATURE IS 600.0 DEG C
  BOILER REHEAT LEG #2 PRESSURE LOSS IS 2 MPA
  BOILER REHEAT LEG #3 INLET NODE NUMBER IS 7
  BOILER REHEAT LEG #3 EXIT NODE NUMBER IS 8
  BOILER REHEAT LEG #3 INLET TEMPERATURE IS 100.0 DEG C
  BOILER REHEAT LEG #3 INLET MASS FLOW RATE IS 5.0 KG/SEC
  BOILER REHEAT LEG #3 EXIT TEMPERATURE IS 600.0 DEG C
  BOILER REHEAT LEG #3 EXIT PRESSURE IS 18.0 MPA
  BOILER REHEAT LEG #3 PRESSURE LOSS IS 2.0 MPA
  BOILER REHEAT LEG #4 INLET NODE NUMBER IS 9
  BOILER REHEAT LEG #4 EXIT NODE NUMBER IS 10
  BOILER REHEAT LEG #4 INLET TEMPERATURE IS 100.0 DEG C
  BOILER REHEAT LEG #4 INLET MASS FLOW RATE IS 5.0 KG/SEC
  BOILER REHEAT LEG #4 EXIT TEMPERATURE IS 600.0 DEG C
  BOILER REHEAT LEG #4 EXIT PRESSURE IS 18.0 MPA
  BOILER REHEAT LEG #4 PRESSURE LOSS IS 2.0 MPA
  BOILER REHEAT LEG #5 INLET NODE NUMBER IS 11
  BOILER REHEAT LEG #5 EXIT NODE NUMBER IS 12
  BOILER REHEAT LEG #5 INLET TEMPERATURE IS 100.0 DEG C
  BOILER REHEAT LEG #5 INLET MASS FLOW RATE IS 5.0 KG/SEC
  BOILER REHEAT LEG #5 EXIT TEMPERATURE IS 600.0 DEG C
  BOILER REHEAT LEG #5 EXIT PRESSURE IS 18.0 MPA
  BOILER REHEAT LEG #5 PRESSURE LOSS IS 2.0 MPA
  BOILER REHEAT LEG #6 INLET NODE NUMBER IS 13
  BOILER REHEAT LEG #6 EXIT NODE NUMBER IS 14
  BOILER REHEAT LEG #6 INLET TEMPERATURE IS 100.0 DEG C
  BOILER REHEAT LEG #6 INLET MASS FLOW RATE IS 5.0 KG/SEC
  BOILER REHEAT LEG #6 EXIT TEMPERATURE IS 600.0 DEG C
```

BOILER REHEAT LEG #6 EXIT PRESSURE IS 18.0 MPA
BOILER REHEAT LEG #6 PRESSURE LOSS IS 2.0 MPA
BOILER REHEAT LEG #7 INLET NODE NUMBER IS 15
BOILER REHEAT LEG #7 EXIT NODE NUMBER IS 16
BOILER REHEAT LEG #7 INLET TEMPERATURE IS 100.0 DEG C
BOILER REHEAT LEG #7 INLET MASS FLOW RATE IS 5.0 KG/SEC
BOILER REHEAT LEG #7 EXIT TEMPERATURE IS 600.0 DEG C
BOILER REHEAT LEG #7 EXIT PRESSURE IS 18.0 MPA
BOILER REHEAT LEG #7 PRESSURE LOSS IS 2.0 MPA
BOILER REHEAT LEG #8 INLET NODE NUMBER IS 17
BOILER REHEAT LEG #8 EXIT NODE NUMBER IS 18
BOILER REHEAT LEG #8 INLET TEMPERATURE IS 100.0 DEG C
BOILER REHEAT LEG #8 INLET MASS FLOW RATE IS 5.0 KG/SEC
BOILER REHEAT LEG #8 EXIT TEMPERATURE IS 600.0 DEG C
BOILER REHEAT LEG #8 EXIT PRESSURE IS 18.0 MPA
BOILER REHEAT LEG #8 PRESSURE LOSS IS 2.0 MPA
BOILER REHEAT LEG #9 INLET NODE NUMBER IS 19
BOILER REHEAT LEG #9 EXIT NODE NUMBER IS 20
BOILER REHEAT LEG #9 INLET TEMPERATURE IS 100.0 DEG C
BOILER REHEAT LEG #9 INLET MASS FLOW RATE IS 5.0 KG/SEC
BOILER REHEAT LEG #9 EXIT TEMPERATURE IS 600.0 DEG C
BOILER REHEAT LEG #9 EXIT PRESSURE IS 18.0 MPA
BOILER REHEAT LEG #9 PRESSURE LOSS IS 2.0 MPA
BOILER REHEAT LEG #10 INLET NODE NUMBER IS 21
BOILER REHEAT LEG #10 EXIT NODE NUMBER IS 22
BOILER REHEAT LEG #10 INLET TEMPERATURE IS 100.0 DEG C
BOILER REHEAT LEG #10 INLET MASS FLOW RATE IS 5.0 KG/SEC
BOILER REHEAT LEG #10 EXIT TEMPERATURE IS 600.0 DEG C
BOILER REHEAT LEG #10 EXIT PRESSURE IS 18.0 MPA
BOILER REHEAT LEG #10 PRESSURE LOSS IS 2.0 MPA
END DEVICE

```
TITLE LINE
   SIMPLE TURBINE MODEL TEST
   END TITLE

NUMBER OF NODES IS 4
HIGH TEMPERATURE RESERVOIR IS 600 DEG C
LOW TEMPERATURE RESERVOIR IS 25.0 DEG C
DEAD STATE TEMPERATURE IS 25.0 DEG C
DEAD STATE PRESSURE IS 101 KPA
GENERATOR MECHANICAL LOSS IS 10.0 KW
GENERATOR ELECTRICAL LOSS IS 5.0 KW

DEVICE #1:  SIMPLE TURBINE
  COMMENT: THIS DEVICE WILL TEST ICALL=1, IFIND=1
  COMMENT: THIS DEVICE WILL TEST ICALL=2, IFIND=1
  COMMENT: THIS DEVICE WILL TEST ICALL=3, IFIND=1
  COMMENT: THIS DEVICE WILL TEST ICALL=4, IFIND=1
  INLET NODE NUMBER IS 1
  EXTRACTION #1 NODE NUMBER IS 2
  EXTRACTION #2 NODE NUMBER IS 3
  EXTRACTION #3 NODE NUMBER IS 4
  STAGE GROUP #1 EFFICIENCY IS 90 PERCENT
  STAGE GROUP #2 EFFICIENCY IS 85 PERCENT
  STAGE GROUP #3 EFFICIENCY IS 80 PERCENT
  INLET TEMPERATURE IS 600 DEG C
  INLET PRESSURE IS 20 MPA
  INLET MASS FLOW RATE IS 5.0 KG.SEC
  EXTRACTION #1 PRESSURE IS 10.0 MPA
  EXTRACTION #1 MASS FLOW RATE IS 1.0 KG/SEC
  EXTRACTION #2 PRESSURE IS 5.0 MPA
  EXTRACTION #2 MASS FLOW RATE IS 2.0 KG/SEC
  EXTRACTION #3 PRESSURE IS 0.1 MPA
  END DEVICE
```

```
TITLE LINE
    SIMPLE PUMP MODEL TEST
   END TITLE

NUMBER OF NODES IS 4
HIGH TEMPERATURE RESERVOIR IS 500 DEG C
LOW TEMPERATURE RESERVOIR IS 25.0 DEG C
DEAD STATE TEMPERATURE IS 25.0 DEG C
DEAD STATE PRESSURE IS 101 KPA
GENERATOR MECHANICAL LOSS IS 0.0 MW
GENERATOR ELECTRICAL LOSS IS 0.0 MW

DEVICE #1:  SIMPLE PUMP
  COMMENT: THIS DEVICE WILL TEST ICALL=1, IFIND=1
  COMMENT: THIS DEVICE WILL TEST ICALL=2, IFIND=1,2
  COMMENT: THIS DEVICE WILL TEST ICALL=3, IFIND=1
  COMMENT: THIS DEVICE WILL TEST ICALL=4, IFIND=1
  SUCTION NODE NUMBER IS 1
  DISCHARGE NODE NUMBER IS 2
  SUCTION PRESSURE IS 0.5 MPA
  SUCTION TEMPERATURE IS 130.0 DEG C
  SUCTION MASS FLOW RATE IS 1.0 KG/SEC
  DISCHARGE PRESSURE IS 10.0 MPA
  PUMP EFFICIENCY IS 100 PERCENT
  END DEVICE

DEVICE #2:  SIMPLE PUMP
  COMMENT: THIS DEVICE WILL TEST ICALL=1, IFIND=2
  COMMENT: THIS DEVICE WILL TEST ICALL=2, IFIND=1,2
  COMMENT: THIS DEVICE WILL TEST ICALL=3, IFIND=1
  COMMENT: THIS DEVICE WILL TEST ICALL=4, IFIND=1
  SUCTION NODE NUMBER IS 3
  DISCHARGE NODE NUMBER IS 4
  SUCTION PRESSURE IS 1.0 MPA
  DISCHARGE TEMPERATURE IS 170 DEG C
  DISCHARGE PRESSURE IS 10 MPA
  DISCHARGE MASS FLOW RATE IS 1.0 KG/SEC
  PUMP EFFICIENCY IS 80 PERCENT
  END DEVICE
```

```
TITLE LINE
  SIMPLE PIPE MODEL TEST
  END TITLE

NUMBER OF NODES IS 12
HIGH TEMPERATURE RESERVOIR IS 500 DEG C
LOW TEMPERATURE RESERVOIR IS 25.0 DEG C
DEAD STATE TEMPERATURE IS 25.0 DEG C
DEAD STATE PRESSURE IS 101 KPA
GENERATOR MECHANICAL LOSS IS 0.0 MW
GENERATOR ELECTRICAL LOSS IS 0.0 MW

DEVICE #1:  SIMPLE PIPE
  COMMENT: THIS DEVICE WILL TEST ICALL=1, IFIND=1,3,5
  COMMENT: THIS DEVICE WILL TEST ICALL=2, IFIND=1,2
  COMMENT: THIS DEVICE WILL TEST ICALL=3, IFIND=1
  COMMENT: THIS DEVICE WILL TEST ICALL=4, IFIND=1
  INLET NODE NUMBER IS 1
  EXIT NODE NUMBER IS 2
  INLET TEMPERATURE IS 500 DEG C
  INLET PRESSURE IS 10 MPA
  INLET MASS FLOW RATE IS 1 KG/SEC
  PIPE PRESSURE LOSS IS 1.0 MPA
  PIPE ENTHALPY LOSS IS 100 KJ/KG
  END DEVICE

DEVICE #2:  SIMPLE PIPE
  COMMENT: THIS DEVICE WILL TEST ICALL=1, IFIND=2,4,5
  COMMENT: THIS DEVICE WILL TEST ICALL=2, IFIND=1,2
  COMMENT: THIS DEVICE WILL TEST ICALL=3, IFIND=1
  COMMENT: THIS DEVICE WILL TEST ICALL=4, IFIND=1
  INLET NODE NUMBER IS 3
  EXIT NODE NUMBER IS 4
  EXIT TEMPERATURE IS 456.10 DEG C
  EXIT PRESSURE IS 9 MPA
  EXIT MASS FLOW RATE IS 1 KG/SEC
  PIPE PRESSURE LOSS IS 1.0 MPA
  PIPE ENTHALPY LOSS IS 100 KJ/KG
  END DEVICE

DEVICE #3:  SIMPLE PIPE
  COMMENT: THIS DEVICE WILL TEST ICALL=1, IFIND=1,4,5
  COMMENT: THIS DEVICE WILL TEST ICALL=2, IFIND=1,2
  COMMENT: THIS DEVICE WILL TEST ICALL=3, IFIND=1
  COMMENT: THIS DEVICE WILL TEST ICALL=4, IFIND=1
  INLET NODE NUMBER IS 5
  EXIT NODE NUMBER IS 6
  INLET PRESSURE IS 10.0 MPA
  EXIT ENTHALPY IS 3274.66 KJ/KG
  INLET MASS FLOW RATE IS 1 KG/SEC
  PIPE PERCENTAGE PRESSURE LOSS IS 10 PERCENT
  PIPE PERCENTAGE ENTHALPY LOSS IS 2.959 %
  END DEVICE
```

DEVICE #4: SIMPLE PIPE
COMMENT: THIS DEVICE WILL TEST ICALL=1, IFIND=2,3,5
COMMENT: THIS DEVICE WILL TEST ICALL=2, IFIND=1,2
COMMENT: THIS DEVICE WILL TEST ICALL=3, IFIND=1
COMMENT: THIS DEVICE WILL TEST ICALL=4, IFIND=1
INLET NODE NUMBER IS 7
EXIT NODE NUMBER IS 8
EXIT PRESSURE IS 9.0 MPA
INLET ENTHALPY IS 3374.66 KJ/KG
EXIT MASS FLOW RATE IS 1 KG/SEC
PIPE PERCENTAGE PRESSURE LOSS IS 10 PERCENT
PIPE PERCENTAGE ENTHALPY LOSS IS 2.959 %
END DEVICE

DEVICE #5: SIMPLE PIPE
COMMENT: THIS DEVICE WILL TEST ICALL=1, IFIND=5
COMMENT: THIS DEVICE WILL TEST ICALL=2, IFIND=1,2
COMMENT: THIS DEVICE WILL TEST ICALL=3, IFIND=1
COMMENT: THIS DEVICE WILL TEST ICALL=4, IFIND=1
INLET NODE NUMBER IS 9
EXIT NODE NUMBER IS 10
INLET TEMPERATURE IS 500.0 DEG C
INLET PRESSURE IS 10.0 MPA
EXIT TEMPERATURE IS 456.14 DEG C
EXIT PRESSURE IS 9.0 MPA
EXIT MASS FLOW RATE IS 1 KG/SEC
END DEVICE

DEVICE #6: SIMPLE PIPE
COMMENT: THIS DEVICE WILL TEST ICALL=1, IFIND=3,5
COMMENT: THIS DEVICE WILL TEST ICALL=2, IFIND=1,2
COMMENT: THIS DEVICE WILL TEST ICALL=3, IFIND=1
COMMENT: THIS DEVICE WILL TEST ICALL=4, IFIND=1
INLET NODE NUMBER IS 11
EXIT NODE NUMBER IS 12
INLET TEMPERATURE IS 500.0 DEG C
INLET PRESSURE IS 10.0 MPA
EXIT PRESSURE IS 9.0 MPA
EXIT MASS FLOW RATE IS 1 KG/SEC
PIPE ENTHALPY LOSS IS 100 KJ/KG
END DEVICE

```
TITLE LINE
  SIMPLE JUNCTION MODEL TEST
  END TITLE

NUMBER OF NODES IS 25
HIGH TEMPERATURE RESERVOIR IS 500 DEG C
LOW TEMPERATURE RESERVOIR IS 25.0 DEG C
DEAD STATE TEMPERATURE IS 25.0 DEG C
DEAD STATE PRESSURE IS 101 KPA
GENERATOR MECHANICAL LOSS IS 0.0 MW
GENERATOR ELECTRICAL LOSS IS 0.0 MW

DEVICE #1: SIMPLE JUNCTION
   COMMENT: THIS DEVICE WILL TEST ICALL=1, IFIND=1
   COMMENT: THIS DEVICE WILL TEST ICALL=2, IFIND=2,3,4,6,8
   COMMENT: THIS DEVICE WILL TEST ICALL=3, IFIND=1
   COMMENT: THIS DEVICE WILL TEST ICALL=4, IFIND=1
   INLET #1 NODE NUMBER IS 1
   INLET #2 NODE NUMBER IS 2
   INLET #3 NODE NUMBER IS 3
   EXIT #1 NODE NUMBER IS 4
   EXIT #2 NODE NUMBER IS 5
   EXIT #3 NODE NUMBER IS 6
   INLET #1 MASS FLOW RATE IS .31 KG/SEC
   INLET #2 FLOW FRACTION IS 22 PERCENT
   INLET #3 FLOW FRACTION IS 47 PERCENT
   EXIT #1 FLOW FRACTION IS 41 PERCENT
   EXIT #2 FLOW FRACTION IS 50 PERCENT
   INLET #2 PRESSURE IS 5.0 MPA
   INLET #2 TEMPERATURE IS 445.0 DEG C
   END DEVICE

DEVICE #2: SIMPLE JUNCTION
   COMMENT: THIS DEVICE WILL TEST ICALL=1, IFIND=1
   COMMENT: THIS DEVICE WILL TEST ICALL=2, IFIND=1,2,8
   COMMENT: THIS DEVICE WILL TEST ICALL=3, IFIND=1
   COMMENT: THIS DEVICE WILL TEST ICALL=4, IFIND=1
   INLET #1 NODE NUMBER IS 7
   EXIT #1 NODE NUMBER IS 8
   EXIT #2 NODE NUMBER IS 9
   EXIT #3 NODE NUMBER IS 10
   INLET #1 MASS FLOW RATE IS 10 KG/SEC
   EXIT #1 MASS FLOW RATE IS 2 KG/SEC
   EXIT #3 MASS FLOW RATE IS 4 KG/SEC
   EXIT #2 PRESSURE IS 5.0 MPA
   EXIT #2 TEMPERATURE IS 445.0 DEG C
   END DEVICE

DEVICE #3: SIMPLE JUNCTION
  COMMENT: THIS DEVICE WILL TEST ICALL=1, IFIND=1
  COMMENT: THIS DEVICE WILL TEST ICALL=2, IFIND=2,3,4,8
  COMMENT: THIS DEVICE WILL TEST ICALL=3, IFIND=1
  COMMENT: THIS DEVICE WILL TEST ICALL=4, IFIND=1
  INLET #1 NODE NUMBER IS 11
  INLET #2 NODE NUMBER IS 12
  INLET #3 NODE NUMBER IS 13
  EXIT #1 NODE NUMBER IS 14
  INLET #1 PRESSURE IS 5.0 MPA
  INLET #1 TEMPERATURE IS 445.0 DEG C
  INLET #1 MASS FLOW IS 0.40 KG/SEC
  INLET #1 FLOW FRACTION IS 0.40
  INLET #2 FLOW FRACTION IS 22.9745%
  END DEVICE
```

```
DEVICE #4: SIMPLE JUNCTION
   COMMENT: THIS DEVICE WILL TEST ICALL=1, IFIND=1
   COMMENT: THIS DEVICE WILL TEST ICALL=2, IFIND=2,5,7,8
   COMMENT: THIS DEVICE WILL TEST ICALL=3, IFIND=1
   COMMENT: THIS DEVICE WILL TEST ICALL=4, IFIND=1
   INLET #1 NODE NUMBER IS 15
   EXIT #1 NODE NUMBER IS 16
   EXIT #2 NODE NUMBER IS 17
   EXIT #3 NODE NUMBER IS 18
   EXIT #4 NODE NUMBER IS 19
   EXIT #5 NODE NUMBER IS 20
   EXIT #6 NODE NUMBER IS 21
   EXIT #7 NODE NUMBER IS 22
   EXIT #8 NODE NUMBER IS 23
   EXIT #9 NODE NUMBER IS 24
   EXIT #10 NODE NUMBER IS 25
   INLET #1 PRESSURE IS 5.0 MPA
   INLET #1 TEMPERATURE IS 445.0 DEG C
   INLET #1 MASS FLOW RATE IS 10 KG/SEC
   EXIT #1 FLOW FRACTION IS 10.0 PERCENT
   EXIT #2 FLOW FRACTION IS 10.0 PERCENT
   EXIT #3 FLOW FRACTION IS 10.0 PERCENT
   EXIT #4 FLOW FRACTION IS 10.0 PERCENT
   EXIT #5 FLOW FRACTION IS 10.0 PERCENT
   EXIT #6 FLOW FRACTION IS 10.0 PERCENT
   EXIT #7 FLOW FRACTION IS 10.0 PERCENT
   EXIT #8 FLOW FRACTION IS 10.0 PERCENT
   EXIT #9 FLOW FRACTION IS 10.0 PERCENT
   EXIT #10 FLOW FRACTION IS 10.0 PERCENT
  END DEVICE
```

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TITLE LINE
   SIMPLE CONDENSER MODEL TEST
   END TITLE

NUMBER OF NODES IS 33
HIGH TEMPERATURE RESERVOIR IS 500 DEG C
LOW TEMPERATURE RESERVOIR IS 25.0 DEG C
DEAD STATE TEMPERATURE IS 25.0 DEG C
DEAD STATE PRESSURE IS 101 KPA
GENERATOR MECHANICAL LOSS IS 0.0 MW
GENERATOR ELECTRICAL LOSS IS 0.0 MW

DEVICE #1:  SIMPLE CONDENSER
  COMMENT: THIS DEVICE WILL TEST ICALL=1, IFIND=1,2
  COMMENT: THIS DEVICE WILL TEST ICALL=2, IFIND=1,2
  COMMENT: THIS DEVICE WILL TEST ICALL=3, IFIND=1
  COMMENT: THIS DEVICE WILL TEST ICALL=4, IFIND=1
  EXIT NODE NUMBER IS 1
  INLET #1 NODE NUMBER IS 2
  INLET #1 PRESSURE IS 0.5 MPA
  INLET #1 TEMPERATURE IS 200 DEG C
  INLET #1 MASS FLOW RATE IS 10 KG/SEC
  END DEVICE

DEVICE #2:  SIMPLE CONDENSER
  COMMENT: THIS DEVICE WILL TEST ICALL=1, IFIND=1,2
  COMMENT: THIS DEVICE WILL TEST ICALL=2, IFIND=1,2
  COMMENT: THIS DEVICE WILL TEST ICALL=3, IFIND=1
  COMMENT: THIS DEVICE WILL TEST ICALL=4, IFIND=1
  EXIT NODE NUMBER IS 3
  INLET #1 NODE NUMBER IS 4
  INLET #2 NODE NUMBER IS 5
  EXIT PRESSURE IS 0.5 MPA
  EXIT MASS FLOW IS 10 KG/SEC
  INLET #1 TEMPERATURE IS 200 DEG C
  INLET #2 TEMPERATURE IS 200 DEG C
  INLET #2 MASS FLOW RATE IS 5 KG/SEC
  END DEVICE

DEVICE #3:  SIMPLE CONDENSER
  COMMENT: THIS DEVICE WILL TEST ICALL=1, IFIND=1,2
  COMMENT: THIS DEVICE WILL TEST ICALL=2, IFIND=1,2
  COMMENT: THIS DEVICE WILL TEST ICALL=3, IFIND=1
  COMMENT: THIS DEVICE WILL TEST ICALL=4, IFIND=1
  EXIT NODE NUMBER IS 6
  INLET #1 NODE NUMBER IS 7
  INLET #2 NODE NUMBER IS 8
  INLET #3 NODE NUMBER IS 9
  INLET #4 NODE NUMBER IS 10
  INLET #5 NODE NUMBER IS 11
  INLET #6 NODE NUMBER IS 12
  INLET #7 NODE NUMBER IS 13
  INLET #8 NODE NUMBER IS 14
  INLET #9 NODE NUMBER IS 15
  INLET #10 NODE NUMBER IS 16
  INLET #11 NODE NUMBER IS 17
  INLET #12 NODE NUMBER IS 18
  INLET #13 NODE NUMBER IS 19
  INLET #14 NODE NUMBER IS 20
  INLET #15 NODE NUMBER IS 21
  INLET #16 NODE NUMBER IS 22
  INLET #17 NODE NUMBER IS 23
  INLET #18 NODE NUMBER IS 24
  INLET #19 NODE NUMBER IS 25
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INLET #20 NODE NUMBER IS 26
INLET #21 NODE NUMBER IS 27
INLET #22 NODE NUMBER IS 28
INLET #23 NODE NUMBER IS 29
INLET #24 NODE NUMBER IS 30
INLET #25 NODE NUMBER IS 31
INLET #26 NODE NUMBER IS 32
INLET #27 NODE NUMBER IS 33
INLET #17 PRESSURE IS 0.5 MPA
INLET #1 TEMPERATURE IS 200 DEG C
INLET #1 MASS FLOW RATE IS 0.3703 KG/SEC
INLET #2 TEMPERATURE IS 200 DEG C
INLET #2 MASS FLOW RATE IS 0.3703 KG/SEC
INLET #3 TEMPERATURE IS 200 DEG C
INLET #3 MASS FLOW RATE IS 0.3703 KG/SEC
INLET #4 TEMPERATURE IS 200 DEG C
INLET #4 MASS FLOW RATE IS 0.3703 KG/SEC
INLET #5 TEMPERATURE IS 200 DEG C
INLET #5 MASS FLOW RATE IS 0.3703 KG/SEC
INLET #6 TEMPERATURE IS 200 DEG C
INLET #6 MASS FLOW RATE IS 0.3703 KG/SEC
INLET #7 TEMPERATURE IS 200 DEG C
INLET #7 MASS FLOW RATE IS 0.3703 KG/SEC
INLET #8 TEMPERATURE IS 200 DEG C
INLET #8 MASS FLOW RATE IS 0.3703 KG/SEC
INLET #9 TEMPERATURE IS 200 DEG C
INLET #9 MASS FLOW RATE IS 0.3703 KG/SEC
INLET #10 TEMPERATURE IS 200 DEG C
INLET #10 MASS FLOW RATE IS 0.3703 KG/SEC
INLET #11 TEMPERATURE IS 200 DEG C
INLET #11 MASS FLOW RATE IS 0.3703 KG/SEC
INLET #12 TEMPERATURE IS 200 DEG C
INLET #12 MASS FLOW RATE IS 0.3703 KG/SEC
INLET #13 TEMPERATURE IS 200 DEG C
INLET #13 MASS FLOW RATE IS 0.3703 KG/SEC
INLET #14 TEMPERATURE IS 200 DEG C
INLET #14 MASS FLOW RATE IS 0.3703 KG/SEC
INLET #15 TEMPERATURE IS 200 DEG C
INLET #15 MASS FLOW RATE IS 0.3703 KG/SEC
INLET #16 TEMPERATURE IS 200 DEG C
INLET #16 MASS FLOW RATE IS 0.3703 KG/SEC
INLET #17 TEMPERATURE IS 200 DEG C
INLET #17 MASS FLOW RATE IS 0.3703 KG/SEC
INLET #18 TEMPERATURE IS 200 DEG C
INLET #18 MASS FLOW RATE IS 0.3703 KG/SEC
INLET #19 TEMPERATURE IS 200 DEG C
INLET #19 MASS FLOW RATE IS 0.3703 KG/SEC
INLET #20 TEMPERATURE IS 200 DEG C
INLET #20 MASS FLOW RATE IS 0.3703 KG/SEC
INLET #21 TEMPERATURE IS 200 DEG C
INLET #21 MASS FLOW RATE IS 0.3703 KG/SEC
INLET #22 TEMPERATURE IS 200 DEG C
INLET #22 MASS FLOW RATE IS 0.3703 KG/SEC
INLET #23 TEMPERATURE IS 200 DEG C
INLET #23 MASS FLOW RATE IS 0.3703 KG/SEC
INLET #24 TEMPERATURE IS 200 DEG C
INLET #24 MASS FLOW RATE IS 0.3703 KG/SEC
INLET #25 TEMPERATURE IS 200 DEG C
INLET #25 MASS FLOW RATE IS 0.3703 KG/SEC
INLET #26 TEMPERATURE IS 200 DEG C
INLET #26 MASS FLOW RATE IS 0.3703 KG/SEC
INLET #27 TEMPERATURE IS 200 DEG C
INLET #27 MASS FLOW RATE IS 0.3703 KG/SEC
END DEVICE

```
TITLE LINE
   SIMPLE HEAT LOAD MODEL TEST
   END TITLE

NUMBER OF NODES IS 4
HIGH TEMPERATURE RESERVOIR IS 500 DEG C
LOW TEMPERATURE RESERVOIR IS 25.0 DEG C
DEAD STATE TEMPERATURE IS 25.0 DEG C
DEAD STATE PRESSURE IS 101 KPA
GENERATOR MECHANICAL LOSS IS 0.0 KW
GENERATOR ELECTRICAL LOSS IS 0.0 KW

DEVICE #1:  SIMPLE HEAT LOAD
  COMMENT: THIS DEVICE WILL TEST ICALL=1, IFIND=1
  COMMENT: THIS DEVICE WILL TEST ICALL=2, IFIND=1,2
  COMMENT: THIS DEVICE WILL TEST ICALL=3, IFIND=1
  COMMENT: THIS DEVICE WILL TEST ICALL=4, IFIND=1
  INLET NODE NUMBER IS 1
  EXIT NODE NUMBER IS 2
  INLET TEMPERATURE IS 500 DEG C
  INLET PRESSURE IS 10 MPA
  INLET MASS FLOW RATE IS 1.0 KG/SEC
  EXIT TEMPERATURE IS 400 DEG C
  EXIT PRESSURE IS 9 MPA
  END DEVICE

DEVICE #2:  SIMPLE HEAT LOAD
  COMMENT: THIS DEVICE WILL TEST ICALL=1, IFIND=1
  COMMENT: THIS DEVICE WILL TEST ICALL=2, IFIND=1,2
  COMMENT: THIS DEVICE WILL TEST ICALL=3, IFIND=1
  COMMENT: THIS DEVICE WILL TEST ICALL=4, IFIND=1
  INLET NODE NUMBER IS 3
  EXIT NODE NUMBER IS 4
  INLET TEMPERATURE IS 500 DEG C
  INLET PRESSURE IS 10 MPA
  EXIT TEMPERATURE IS 400 DEG C
  EXIT PRESSURE IS 9 MPA
  EXIT MASS FLOW RATE IS 1.0 KG/SEC
  END DEVICE
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TITLE LINE
  SIMPLE OPEN FEED WATER HEATER MODEL TEST
  END TITLE

NUMBER OF NODES IS 18
HIGH TEMPERATURE RESERVOIR IS 500 DEG C
LOW TEMPERATURE RESERVOIR IS 25.0 DEG C
DEAD STATE TEMPERATURE IS 25.0 DEG C
DEAD STATE PRESSURE IS 101 KPA
GENERATOR MECHANICAL LOSS IS 0.0 MW
GENERATOR ELECTRICAL LOSS IS 0.0 MW

DEVICE #1: SIMPLE OFW HEATER
  COMMENT: THIS DEVICE WILL TEST ICALL=1, IFIND=1,2,3
  COMMENT: THIS DEVICE WILL TEST ICALL=2, IFIND=1,4
  COMMENT: THIS DEVICE WILL TEST ICALL=3, IFIND=1
  COMMENT: THIS DEVICE WILL TEST ICALL=4, IFIND=1
  FEED WATER EXIT NODE NUMBER IS 1
  EXTRACTION INLET NODE NUMBER IS 2
  FEED WATER INLET NODE NUMBER IS 3
  FEED WATER EXIT PRESSURE IS 6.0 MPA
  EXTRACTION INLET TEMPERATURE IS 430.6 DEG C
  FEED WATER INLET TEMPERATURE IS 251.07 DEG C
  FEED WATER INLET MASS FLOW IS 23.5837 KG/SEC
  END DEVICE

DEVICE #2: SIMPLE OFW HEATER
  COMMENT: THIS DEVICE WILL TEST ICALL=1, IFIND=1,2,4
  COMMENT: THIS DEVICE WILL TEST ICALL=2, IFIND=1,4
  COMMENT: THIS DEVICE WILL TEST ICALL=3, IFIND=1
  COMMENT: THIS DEVICE WILL TEST ICALL=4, IFIND=1
  FEED WATER EXIT NODE NUMBER IS 4
  EXTRACTION INLET NODE NUMBER IS 5
  FEED WATER INLET NODE NUMBER IS 6
  FEED WATER INLET PRESSURE IS 6.0 MPA
  EXTRACTION INLET TEMPERATURE IS 430.6 DEG C
  EXTRACTION INLET MASS FLOW IS 1.4163 KG/SEC
  FEED WATER INLET TEMPERATURE IS 251.07 DEG
  END DEVICE

DEVICE #3: SIMPLE OFW HEATER
  COMMENT: THIS DEVICE WILL TEST ICALL=1, IFIND=1,2,3
  COMMENT: THIS DEVICE WILL TEST ICALL=2, IFIND=1,4
  COMMENT: THIS DEVICE WILL TEST ICALL=3, IFIND=1
  COMMENT: THIS DEVICE WILL TEST ICALL=4, IFIND=1
  FEED WATER EXIT NODE NUMBER IS 7
  EXTRACTION INLET NODE NUMBER IS 8
  FEED WATER INLET NODE NUMBER IS 9
  FEED WATER EXIT MASS FLOW RATE IS 25.0 KG/SEC
  EXTRACTION INLET PRESSURE IS 6.0 MPA
  EXTRACTION INLET TEMPERATURE IS 430.6 DEG C
  FEED WATER INLET TEMPERATURE IS 251.07 DEG C
  END DEVICE
```

DEVICE #4: SIMPLE OFW HEATER
COMMENT: THIS DEVICE WILL TEST ICALL=1, IFIND=1,2,4
COMMENT: THIS DEVICE WILL TEST ICALL=2, IFIND=2,3,4
COMMENT: THIS DEVICE WILL TEST ICALL=3, IFIND=1
COMMENT: THIS DEVICE WILL TEST ICALL=4, IFIND=1
FEED WATER EXIT NODE NUMBER IS 10
EXTRACTION INLET NODE NUMBER IS 11
FEED WATER INLET NODE NUMBER IS 12
FEED WATER EXIT MASS FLOW IS 25.0000 KG/SEC
EXTRACTION INLET PRESSURE IS 6.0 MPA
EXTRACTION INLET TEMPERATURE IS 430.6 DEG C
FEED WATER INLET MASS FLOW IS 23.5837 KG/SEC
END DEVICE

DEVICE #5: SIMPLE OFW HEATER
COMMENT: THIS DEVICE WILL TEST ICALL=1, IFIND=1,2,4
COMMENT: THIS DEVICE WILL TEST ICALL=2, IFIND=2,3,4
COMMENT: THIS DEVICE WILL TEST ICALL=3, IFIND=1
COMMENT: THIS DEVICE WILL TEST ICALL=4, IFIND=1
FEED WATER EXIT NODE NUMBER IS 13
EXTRACTION INLET NODE NUMBER IS 14
FEED WATER INLET NODE NUMBER IS 15
FEED WATER INLET PRESSURE IS 6.0 MPA
FEED WATER INLET TEMPERATURE IS 251.07 DEG C
FEED WATER EXIT MASS FLOW IS 25.0000 KG/SEC
EXTRACTION INLET MASS FLOW IS 1.4163 KG/SEC
END DEVICE

DEVICE #6: SIMPLE OFW HEATER
COMMENT: THIS DEVICE WILL TEST ICALL=1, IFIND=1,2,4
COMMENT: THIS DEVICE WILL TEST ICALL=2, IFIND=2,3,4
COMMENT: THIS DEVICE WILL TEST ICALL=3, IFIND=1
COMMENT: THIS DEVICE WILL TEST ICALL=4, IFIND=1
FEED WATER EXIT NODE NUMBER IS 16
EXTRACTION INLET NODE NUMBER IS 17
FEED WATER INLET NODE NUMBER IS 18
EXTRACTION INLET PRESSURE IS 6.0 MPA
EXTRACTION INLET TEMPERATURE IS 430.6 DEG C
EXTRACTION INLET MASS FLOW IS 1.4163 KG/SEC
FEED WATER INLET TEMPERATURE IS 251.07 DEG C
FEED WATER INLET MASS FLOW IS 23.5837 KG/SEC
FEED WATER EXIT IS NOT SATURATED
END DEVICE

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TITLE LINE
  SIMPLE CLOSED FEED WATER HEATER MODEL TEST
  END TITLE

NUMBER OF NODES IS 19
HIGH TEMPERATURE RESERVOIR IS 500 DEG C
LOW TEMPERATURE RESERVOIR IS 25.0 DEG C
DEAD STATE TEMPERATURE IS 25.0 DEG C
DEAD STATE PRESSURE IS 101 KPA
GENERATOR MECHANICAL LOSS IS 0.0 MW
GENERATOR ELECTRICAL LOSS IS 0.0 MW

DEVICE #1: SIMPLE STEAM TRAP CFW
  COMMENT: THIS DEVICE WILL TEST ICALL=1, IFIND=1,2,3,4,5
  COMMENT: THIS DEVICE WILL TEST ICALL=2, IFIND=1,2,3,4
  COMMENT: THIS DEVICE WILL TEST ICALL=3, IFIND=1
  COMMENT: THIS DEVICE WILL TEST ICALL=4, IFIND=1
  FEED WATER INLET NODE NUMBER IS 1
  FEED WATER EXIT NODE NUMBER IS 2
  EXTRACTION INLET NODE NUMBER IS 3
  DRAIN INLET #1 NODE NUMBER IS 4
  DRAIN EXIT NODE NUMBER IS 5
  FEED WATER INLET TEMPERATURE IS 80 DEG C
  FEED WATER INLET PRESSURE IS 2.5 MPA
  FEED WATER INLET MASS FLOW RATE IS 10 KG/SEC
  FEED WATER PRESSURE LOSS IS 0.25 MPA
  EXTRACTION INLET PRESSURE IS 10.0 MPA
  EXTRACTION INLET TEMPERATURE IS 320 DEG C
  EXTRACTION PRESSURE LOSS IS 0.5 MPA
  DRAIN INLET #1 TEMPERATURE IS 140 DEG C
  DRAIN INLET #1 MASS FLOW IS 1.0 KG/SEC
  TERMINAL TEMPERATURE DIFFERENCE IS 111.06 DEG C
  APPROACH TEMPERATURE DIFFERENCE IS 20.0 DEG C
  END DEVICE

DEVICE #2: SIMPLE STEAM TRAP CFW
  COMMENT: THIS DEVICE WILL TEST ICALL=1, IFIND=1,2,3,4,5
  COMMENT: THIS DEVICE WILL TEST ICALL=2, IFIND=1,2,3,4
  COMMENT: THIS DEVICE WILL TEST ICALL=3, IFIND=1
  COMMENT: THIS DEVICE WILL TEST ICALL=4, IFIND=1
  FEED WATER INLET NODE NUMBER IS 6
  FEED WATER EXIT NODE NUMBER IS 7
  EXTRACTION INLET NODE NUMBER IS 8
  DRAIN INLET #1 NODE NUMBER IS 9
  DRAIN INLET #2 NODE NUMBER IS 10
  DRAIN INLET #3 NODE NUMBER IS 11
  DRAIN INLET #4 NODE NUMBER IS 12
  DRAIN INLET #5 NODE NUMBER IS 13
  DRAIN INLET #6 NODE NUMBER IS 14
  DRAIN INLET #7 NODE NUMBER IS 15
  DRAIN INLET #8 NODE NUMBER IS 16
  DRAIN INLET #9 NODE NUMBER IS 17
  DRAIN INLET #10 NODE NUMBER IS 18
  DRAIN EXIT NODE NUMBER IS 19
  FEED WATER INLET TEMPERATURE IS 80 DEG C
  FEED WATER EXIT PRESSURE IS 2.25 MPA
  FEED WATER EXIT MASS FLOW RATE IS 10 KG/SEC
  FEED WATER PERCENTAGE PRESSURE LOSS IS 10 PERCENT
  EXTRACTION INLET TEMPERATURE IS 320 DEG C
  EXTRACTION PERCENTAGE PRESSURE LOSS IS 5 PERCENT
  DRAIN INLET #1 TEMPERATURE IS 140 DEG C
  DRAIN INLET #1 MASS FLOW IS 0.1 KG/SEC
  DRAIN INLET #2 TEMPERATURE IS 140 DEG C
  DRAIN INLET #2 MASS FLOW IS 0.1 KG/SEC
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DRAIN INLET #3 TEMPERATURE IS 140 DEG C
DRAIN INLET #3 MASS FLOW IS 0.1 KG/SEC
DRAIN INLET #4 TEMPERATURE IS 140 DEG C
DRAIN INLET #4 MASS FLOW IS 0.1 KG/SEC
DRAIN INLET #5 TEMPERATURE IS 140 DEG C
DRAIN INLET #5 MASS FLOW IS 0.1 KG/SEC
DRAIN INLET #6 TEMPERATURE IS 140 DEG C
DRAIN INLET #6 MASS FLOW IS 0.1 KG/SEC
DRAIN INLET #7 TEMPERATURE IS 140 DEG C
DRAIN INLET #7 MASS FLOW IS 0.1 KG/SEC
DRAIN INLET #8 TEMPERATURE IS 140 DEG C
DRAIN INLET #8 MASS FLOW IS 0.1 KG/SEC
DRAIN INLET #9 TEMPERATURE IS 140 DEG C
DRAIN INLET #9 MASS FLOW IS 0.1 KG/SEC
DRAIN INLET #10 TEMPERATURE IS 140 DEG C
DRAIN INLET #10 MASS FLOW IS 0.1 KG/SEC
DRAIN EXIT PRESSURE IS 9.5 MPA
TERMINAL TEMPERATURE DIFFERENCE IS 111.06 DEG C
APPROACH TEMPERATURE DIFFERENCE IS 20.0 DEG C
END DEVICE

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TITLE LINE
  SIMPLE SEPARATOR MODEL TEST
  END TITLE LINE

NUMBER OF NODES IS 9
HIGH TEMPERATURE RESERVOIR IS 500.0 DEG C
LOW TEMPERATURE RESERVOIR IS 25.0 DEG C
DEAD STATE TEMPERATURE IS 25.0 DEG C
DEAD STATE PRESSURE IS 101 KPA
GENERATOR MECHANICAL LOSS IS 0.0 MW
GENERATOR ELECTRICAL LOSS IS 0.0 MW

DEVICE #1: SIMPLE MOISTURE SEPARATOR
  COMMENT: THIS DEVICE WILL TEST ICALL=1, IFIND=1,2
  COMMENT: THIS DEVICE WILL TEST ICALL=2, IFIND=1
  COMMENT: THIS DEVICE WILL TEST ICALL=3, IFIND=1
  COMMENT: THIS DEVICE WILL TEST ICALL=4, IFIND=1
  SEPARATOR INLET NODE NUMBER IS 1
  SEPARATOR VAPOR EXIT NODE NUMBER IS 2
  SEPARATOR CONDENSATE EXIT NODE NUMBER IS 3
  SEPARATOR INLET PRESSURE IS 1.00 MPA
  SEPARATOR INLET QUALITY IS 50 PERCENT
  SEPARATOR INLET FLUID PHASE IS A 2 PHASE MIXTURE
  SEPARATOR INLET MASS FLOW IS 1.0 KG/SEC
  SEPARATOR PRESSURE LOSS IS 0.1 MPA
  END DEVICE

DEVICE #2: SIMPLE MOISTURE SEPARATOR
  COMMENT: THIS DEVICE WILL TEST ICALL=1, IFIND=1,2
  COMMENT: THIS DEVICE WILL TEST ICALL=2, IFIND=1
  COMMENT: THIS DEVICE WILL TEST ICALL=3, IFIND=1
  COMMENT: THIS DEVICE WILL TEST ICALL=4, IFIND=1
  SEPARATOR INLET NODE NUMBER IS 4
  SEPARATOR VAPOR EXIT NODE NUMBER IS 5
  SEPARATOR CONDENSATE EXIT NODE NUMBER IS 6
  SEPARATOR INLET PRESSURE IS 1.00 MPA
  SEPARATOR INLET TEMPERATURE IS 500 DEG C
  SEPARATOR INLET MASS FLOW IS 1.0 KG/SEC
  SEPARATOR SEPERATOR PERCENTAGE PRESSURE LOSS IS 10%
  END DEVICE

DEVICE #3: SIMPLE MOISTURE SEPARATOR
  COMMENT: THIS DEVICE WILL TEST ICALL=1, IFIND=1,2
  COMMENT: THIS DEVICE WILL TEST ICALL=2, IFIND=1
  COMMENT: THIS DEVICE WILL TEST ICALL=3, IFIND=1
  COMMENT: THIS DEVICE WILL TEST ICALL=4, IFIND=1
  SEPARATOR INLET NODE NUMBER IS 7
  SEPARATOR VAPOR EXIT NODE NUMBER IS 8
  SEPARATOR CONDENSATE EXIT NODE NUMBER IS 9
  SEPARATOR INLET PRESSURE IS 1.00 MPA
  SEPARATOR INLET TEMPERATURE IS 100 DEG C
  SEPARATOR INLET MASS FLOW IS 1.0 KG/SEC
  SEPARATOR SEPERATOR PERCENTAGE PRESSURE LOSS IS 10%
  END DEVICE
```

```
TITLE LINE
  SIMPLE REHEATER MODEL TEST
  END TITLE LINE

NUMBER OF NODES: 18
HIGH TEMPERATURE RESERVOIR IS 500.0 DEG C
LOW TEMPERATURE RESERVOIR IS 25.0 DEG C
DEAD STATE TEMPERATURE IS 25.0 DEG C
DEAD STATE PRESSURE IS 101 KPA
GENERATOR MECHANICAL LOSS IS 0.0 MW
GENERATOR ELECTRICAL LOSS IS 0.0 MW

COMMENT: THESE 3 DEVICES WILL TEST SREH ICALL=1, FIND=1,2,3,4,6
COMMENT: THESE 3 DEVICES WILL TEST SREH ICALL=2, IFIND=1,2,3
COMMENT: THESE 3 DEVICES WILL TEST SREH ICALL=3, IFIND=1
COMMENT: THESE 3 DEVICES WILL TEST SREH ICALL=4, IFIND=1

DEVICE #1: SIMPLE JUNCTION
  INLET #1 NODE NUMBER IS 1
  EXIT #1 NODE NUMBER IS 2
  EXIT #2 NODE NUMBER IS 3
  INLET #1 MASS FLOW RATE IS 91 KG/SEC
  INLET #1 TEMPERATURE IS 300 DEG C
  INLET #1 PRESSURE IS 1.5 MPA
  EXIT #1 FLOW FRACTION IS 98.9011 PERCENT
  END DEVICE

DEVICE #2: SIMPLE HEAT LOAD
  INLET NODE NUMBER IS 2
  EXIT NODE NUMBER IS 4
  EXIT TEMPERATURE IS 180 DEG C
  EXIT PRESSURE IS 1.0 MPA
  END DEVICE

DEVICE #3: SIMPLE REHEATER
  CYCLE STEAM INLET NODE NUMBER IS 4
  CYCLE STEAM EXIT NODE NUMBER IS 5
  REHEAT STEAM INLET NODE NUMBER IS 3
  REHEAT STEAM EXIT NODE NUMBER IS 6
  FLOW FRACTION CONTROLED BY JUNCTION DEVICE NUMBER 1
  CYCLE STEAM PRESSURE LOSS IS 0.10 MPA
  REHEAT STEAM PRESSURE LOSS IS 0.15 MPA
  TERMINAL TEMPERATURE DIFFERENCE IS 10.0 DEG C
  END DEVICE

COMMENT: THESE 3 DEVICES WILL TEST SREH ICALL=1, IFIND=1,2,3,4
COMMENT: THESE 3 DEVICES WILL TEST SREH ICALL=2, IFIND=1,2,3
COMMENT: THESE 3 DEVICES WILL TEST SREH ICALL=3, IFIND=1
COMMENT: THESE 3 DEVICES WILL TEST SREH ICALL=4, IFIND=1

DEVICE #4: SIMPLE JUNCTION
  INLET #1 NODE NUMBER IS 7
  EXIT #1 NODE NUMBER IS 8
  EXIT #2 NODE NUMBER IS 9
  INLET #1 MASS FLOW RATE IS 91 KG/SEC
  EXIT #2 TEMPERATURE IS 300 DEG C
  EXIT #1 FLOW FRACTION IS 98.9011 PERCENT
  END DEVICE

DEVICE #5: SIMPLE HEAT LOAD
  INLET NODE NUMBER IS 8
  EXIT NODE NUMBER IS 10
  EXIT TEMPERATURE IS 180 DEG C
  END DEVICE
```

```
DEVICE #6: SIMPLE REHEATER
   CYCLE STEAM INLET NODE NUMBER IS 10
   CYCLE STEAM EXIT NODE NUMBER IS 12
   REHEAT STEAM INLET NODE NUMBER IS 9
   REHEAT STEAM EXIT NODE NUMBER IS 11
   FLOW FRACTION CONTROLED BY JUNCTION DEVICE NUMBER 4
   CYCLE STEAM EXIT PRESSURE IS 0.9 MPA
   CYCLE STEAM PERCENTAGE PRESSURE LOSS IS 10.0 PERCENT
   REHEAT STEAM EXIT PRESSURE IS 1.35 MPA
   REHEAT STEAM PRECENTAGE PRESSURE LOSS IS 10.0 PERCENT
   TERMINAL TEMPERATURE DIFFERENCE IS 10.0 DEG C
   END DEVICE

COMMENT: THESE 3 DEVICES WILL TEST SREH ICALL=1, IFIND=1,2,3,5
COMMENT: THESE 3 DEVICES WILL TEST SREH ICALL=2, IFIND=1,2,3
COMMENT: THESE 3 DEVICES WILL TEST SREH ICALL=3, IFIND=1
COMMENT: THESE 3 DEVICES WILL TEST SREH ICALL=4, IFIND=1

DEVICE #7: SIMPLE JUNCTION
  INLET #1 NODE NUMBER IS 13
  EXIT #1 NODE NUMBER IS 14
  EXIT #2 NODE NUMBER IS 15
  INLET #1 MASS FLOW RATE IS 91 KG/SEC
  INLET #1 TEMPERATURE IS 300 DEG C
  INLET #1 PRESSURE IS 1.5 MPA
  EXIT #1 FLOW FRACTION IS 98.9011 PERCENT
  END DEVICE

DEVICE #8: SIMPLE HEAT LOAD
  INLET NODE NUMBER IS 14
  EXIT NODE NUMBER IS 16
  EXIT TEMPERATURE IS 180 DEG C
  EXIT PRESSURE IS 1.0 MPA
  END DEVICE

DEVICE #9: SIMPLE REHEATER
   CYCLE STEAM INLET NODE NUMBER IS 16
   CYCLE STEAM EXIT NODE NUMBER IS 18
   REHEAT STEAM INLET NODE NUMBER IS 15
   REHEAT STEAM EXIT NODE NUMBER IS 17
   FLOW FRACTION CONTROLED BY JUNCTION DEVICE NUMBER 7
   CYCLE STEAM PERCENTAGE PRESSURE LOSS IS 10.0 PERCENT
   REHEAT STEAM EXIT TEMPERATURE IS 193 DEG C
   REHEAT STEAM EXIT IS NOT A SATURATED LIQUID
   REHEAT STEAM PRECENTAGE PRESSURE LOSS IS 10.0 PERCENT
   TERMINAL TEMPERATURE DIFFERENCE IS 10.0 DEG C
   END DEVICE
```

Appendix C:

RANKINE 3.0 output files for individual device verification

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********** TITLE **********

SIMPLE BOILER MODEL TEST

********** NODE DATA **********

NODE	T(C)	P(MPa)	L	Q	S(KJ/KG/K)	H(KJ/KG)	V(M^3/KG)	M(KG/S)	A(KJ/KG)
1	100.00	20.0000	1	*****	1.2834	433.79	.00104	5.0000	55.48
2	600.00	18.0000	3	*****	6.5690	3554.01	.02033	5.0000	1599.81
3	100.00	20.0000	1	*****	1.2834	433.79	.00104	5.0000	55.48
4	600.00	18.0000	3	*****	6.5690	3554.01	.02033	5.0000	1599.81
5	100.00	20.0000	1	*****	1.2834	433.79	.00104	5.0000	55.48
6	600.00	18.0000	3	*****	6.5690	3554.01	.02033	5.0000	1599.81
7	100.00	20.0000	1	*****	1.2834	433.79	.00104	5.0000	55.48
8	600.00	18.0000	3	*****	6.5690	3554.01	.02033	5.0000	1599.81
9	100.00	20.0000	1	*****	1.2834	433.79	.00104	5.0000	55.48
10	600.00	18.0000	3	*****	6.5690	3554.01	.02033	5.0000	1599.81
11	100.00	20.0000	1	*****	1.2834	433.79	.00104	5.0000	55.48
12	600.00	18.0000	3	*****	6.5690	3554.01	.02033	5.0000	1599.81
13	100.00	20.0000	1	*****	1.2834	433.79	.00104	5.0000	55.48
14	600.00	18.0000	3	*****	6.5690	3554.01	.02033	5.0000	1599.81
15	100.00	20.0000	1	*****	1.2834	433.79	.00104	5.0000	55.48
16	600.00	18.0000	3	*****	6.5690	3554.01	.02033	5.0000	1599.81
17	100.00	20.0000	1	*****	1.2834	433.79	.00104	5.0000	55.48
18	600.00	18.0000	3	*****	6.5690	3554.01	.02033	5.0000	1599.81
19	100.00	20.0000	1	*****	1.2834	433.79	.00104	5.0000	55.48
20	600.00	18.0000	3	*****	6.5690	3554.01	.02033	5.0000	1599.81
21	100.00	20.0000	1	*****	1.2834	433.79	.00104	5.0000	55.48
22	600.00	18.0000	3	*****	6.5690	3554.01	.02033	5.0000	1599.81

********** DEVICE DATA (DEVICE BEFORE NODE) **********

NODE	REV. WRK (KW)	ACT. WRK (KW)	IRREV (KW)	HEAT X-FER (KW)	MASS ERROR (KG/S)	ENERGY ERROR (KW)
1	-1.00	-1.00	-1.00	-1.00	-1.000	-1.000
2	7474.36	.00	7474.36	15601.11	.000	.000
3	-1.00	-1.00	-1.00	-1.00	-1.000	-1.000
4	7474.36	.00	7474.36	15601.11	.000	.000
5	-1.00	-1.00	-1.00	-1.00	-1.000	-1.000
6	7474.36	.00	7474.36	15601.11	.000	.000
7	-1.00	-1.00	-1.00	-1.00	-1.000	-1.000
8	7474.36	.00	7474.36	15601.11	.000	.000
9	-1.00	-1.00	-1.00	-1.00	-1.000	-1.000
10	7474.36	.00	7474.36	15601.11	.000	.000
11	-1.00	-1.00	-1.00	-1.00	-1.000	-1.000
12	7474.36	.00	7474.36	15601.11	.000	.000
13	-1.00	-1.00	-1.00	-1.00	-1.000	-1.000
14	7474.36	.00	7474.36	15601.11	.000	.000
15	-1.00	-1.00	-1.00	-1.00	-1.000	-1.000
16	7474.36	.00	7474.36	15601.11	.000	.000
17	-1.00	-1.00	-1.00	-1.00	-1.000	-1.000
18	7474.36	.00	7474.36	15601.11	.000	.000
19	-1.00	-1.00	-1.00	-1.00	-1.000	-1.000
20	7474.36	.00	7474.36	15601.11	.000	.000
21	-1.00	-1.00	-1.00	-1.00	-1.000	-1.000
22	7474.36	.00	7474.36	15601.11	.000	.000

********** SYSTEM DATA **********

TOTAL MASS FLOW RATE EXITING SYSTEM:	55.0000	KG/SEC
TOTAL MASS FLOW RATE ENTERING SYSTEM:	55.0000	KG/SEC
TOTAL ENTHALPY FLOW RATE EXITING SYSTEM:	195470.7000	KW
TOTAL ENTHALPY FLOW RATE ENTERING SYSTEM:	23858.4600	KW
TOTAL HEAT AND WORK ENTERING SYSTEM:	171612.2000	KW
BOILER HEAT (DEVICE # 1):	171612.2000	KW
TOTAL BOILER HEAT:	171612.2000	KW
TOTAL HEAT LOAD HEAT:	.0000	KW
TOTAL PIPE ENERGY LOSSES:	.0000	KW
NET WORK TO GENERATORS:	.0000	KW
TOTAL PUMP WORK:	.0000	KW
GENERATOR MECHANICAL LOSSES:	.0000	KW
GENERATOR ELECTRICAL LOSSES:	.0000	KW
NET ELECTRICAL POWER:	.0000	KW
SYSTEM HEAT RATE:	-1.0000	BTU/KW*HR
CARNOT CYCLE EFFICIENCY:	65.8535	PERCENT
1ST LAW EFFICIENCY:	.0000	PERCENT
2ND LAW EFFICIENCY:	69.0844	PERCENT
2ND LAW EFFECTIVENESS:	-100.0000	PERCENT

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********** TITLE **********

SIMPLE TURBINE MODEL TEST

********** NODE DATA **********

NODE	T(C)	P(MPa)	L	Q	S(KJ/KG/K)	H(KJ/KG)	V(M^3/KG)	M(KG/S)	A(KJ/KG)
1	600.00	20.0000	3	*****	6.5052	3536.61	.01808	5.0000	1601.44
2	481.53	10.0000	3	*****	6.5362	3327.14	.03167	1.0000	1382.72
3	382.71	5.0000	3	*****	6.5832	3153.98	.05586	2.0000	1195.54
4	99.63	.1000	2	.940	6.9952	2539.67	1.59208	2.0000	458.40

********** DEVICE DATA (DEVICE BEFORE NODE) **********

NODE	REV. WRK (KW)	ACT. WRK (KW)	IRREV (KW)	HEAT X-FER (KW)	MASS ERROR (KG/S)	ENERGY ERROR (KW)
1	-1.00	-1.00	-1.00	-1.00	-1.000	-1.000
2	1093.61	1047.36	46.25	.00	.000	.000
3	748.72	692.64	56.08	.00	.000	.000
4	1474.26	1228.61	245.65	.00	.000	.000

********** SYSTEM DATA **********

TOTAL MASS FLOW RATE EXITING SYSTEM:	5.0000	KG/SEC
TOTAL MASS FLOW RATE ENTERING SYSTEM:	5.0000	KG/SEC
TOTAL ENTHALPY FLOW RATE EXITING SYSTEM:	14714.4400	KW
TOTAL ENTHALPY FLOW RATE ENTERING SYSTEM:	17683.0500	KW
TOTAL HEAT AND WORK ENTERING SYSTEM:	-2968.6050	KW
TOTAL BOILER HEAT:	.0000	KW
TOTAL HEAT LOAD HEAT:	.0000	KW
TOTAL PIPE ENERGY LOSSES:	.0000	KW
TURBINE WORK (DEVICE # 1):	2968.6050	KW
NET WORK TO GENERATORS:	2968.6050	KW
TOTAL PUMP WORK:	.0000	KW
GENERATOR MECHANICAL LOSSES:	10.0000	KW
GENERATOR ELECTRICAL LOSSES:	5.0000	KW
NET ELECTRICAL POWER:	2953.6050	KW
SYSTEM HEAT RATE:	-1.0000	BTU/KW*HR
CARNOT CYCLE EFFICIENCY:	65.8535	PERCENT
1ST LAW EFFICIENCY:	-100.0000	PERCENT
2ND LAW EFFICIENCY:	95.6541	PERCENT
2ND LAW EFFECTIVENESS:	-100.0000	PERCENT

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********** TITLE **********

SIMPLE PUMP MODEL TEST

********** NODE DATA **********

NODE	T(C)	P(MPa)	L	Q	S(KJ/KG/K)	H(KJ/KG)	V(M^3/KG)	M(KG/S)	A(KJ/KG)
1	130.00	.5000	1	*****	1.6331	546.21	.00107	1.0000	63.64
2	131.15	10.0000	1	*****	1.6331	557.57	.00107	1.0000	74.99
3	167.98	1.0000	1	*****	2.0191	710.08	.00111	1.0000	112.42
4	170.00	10.0000	1	*****	2.0253	723.88	.00111	1.0000	124.37

********** DEVICE DATA (DEVICE BEFORE NODE) **********

NODE	REV. WRK (KW)	ACT. WRK (KW)	IRREV (KW)	HEAT X-FER (KW)	MASS ERROR (KG/S)	ENERGY ERROR (KW)
1	-1.00	-1.00	-1.00	-1.00	-1.000	-1.000
2	-11.35	-11.35	.00	.00	.000	.000
3	-1.00	-1.00	-1.00	-1.00	-1.000	-1.000
4	-11.94	-13.80	1.85	.00	.000	.000

********** SYSTEM DATA **********

TOTAL MASS FLOW RATE EXITING SYSTEM:	2.0000	KG/SEC
TOTAL MASS FLOW RATE ENTERING SYSTEM:	2.0000	KG/SEC
TOTAL ENTHALPY FLOW RATE EXITING SYSTEM:	1281.4440	KW
TOTAL ENTHALPY FLOW RATE ENTERING SYSTEM:	1256.2930	KW
TOTAL HEAT AND WORK ENTERING SYSTEM:	25.1510	KW
TOTAL BOILER HEAT:	.0000	KW
TOTAL HEAT LOAD HEAT:	.0000	KW
TOTAL PIPE ENERGY LOSSES:	.0000	KW
NET WORK TO GENERATORS:	.0000	KW
PUMP WORK (DEVICE # 1):	-11.3542	KW
PUMP WORK (DEVICE # 2):	-13.7968	KW
TOTAL PUMP WORK:	-25.1510	KW
GENERATOR MECHANICAL LOSSES:	.0000	KW
GENERATOR ELECTRICAL LOSSES:	.0000	KW
NET ELECTRICAL POWER:	-25.1510	KW
SYSTEM HEAT RATE:	-1.0000	BTU/KW*HR
CARNOT CYCLE EFFICIENCY:	61.4370	PERCENT
1ST LAW EFFICIENCY:	-100.0000	PERCENT
2ND LAW EFFICIENCY:	99.0782	PERCENT
2ND LAW EFFECTIVENESS:	-100.0000	PERCENT

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********** TITLE **********

SIMPLE PIPE MODEL TEST

********** NODE DATA **********

NODE	T(C)	P(MPa)	L	Q	S(KJ/KG/K)	H(KJ/KG)	V(M^3/KG)	M(KG/S)	A(KJ/KG)
1	500.00	10.0000	3	*****	6.5984	3374.66	.03275	1.0000	1411.69
2	456.09	9.0000	3	*****	6.5096	3274.66	.03389	1.0000	1338.17
3	500.01	10.0000	3	*****	6.5984	3374.69	.03275	1.0000	1411.71
4	456.10	9.0000	3	*****	6.5096	3274.69	.03390	1.0000	1338.19
5	499.94	10.0000	3	*****	6.5982	3374.51	.03274	1.0000	1411.60
6	456.09	9.0000	3	*****	6.5096	3274.66	.03389	1.0000	1338.17
7	500.00	10.0000	3	*****	6.5984	3374.66	.03275	1.0000	1411.69
8	456.14	9.0000	3	*****	6.5098	3274.80	.03390	1.0000	1338.26
9	500.00	10.0000	3	*****	6.5984	3374.66	.03275	1.0000	1411.69
10	456.14	9.0000	3	*****	6.5098	3274.80	.03390	1.0000	1338.25
11	500.00	10.0000	3	*****	6.5984	3374.66	.03275	1.0000	1411.69
12	456.09	9.0000	3	*****	6.5096	3274.66	.03389	1.0000	1338.17

********** DEVICE DATA (DEVICE BEFORE NODE) **********

NODE	REV. WRK (KW)	ACT. WRK (KW)	IRREV (KW)	HEAT X-FER (KW)	MASS ERROR (KG/S)	ENERGY ERROR (KW)
1	-1.00	-1.00	-1.00	-1.00	-1.000	-1.000
2	73.52	.00	73.52	-100.00	.000	.000
3	-1.00	-1.00	-1.00	-1.00	-1.000	-1.000
4	73.52	.00	73.52	-100.00	.000	.000
5	-1.00	-1.00	-1.00	-1.00	-1.000	-1.000
6	73.43	.00	73.43	-99.85	.000	.000
7	-1.00	-1.00	-1.00	-1.00	-1.000	-1.000
8	73.43	.00	73.43	-99.86	.000	.000
9	-1.00	-1.00	-1.00	-1.00	-1.000	-1.000
10	73.44	.00	73.44	-99.86	.000	.000
11	-1.00	-1.00	-1.00	-1.00	-1.000	-1.000
12	73.52	.00	73.52	-100.00	.000	.000

********** SYSTEM DATA **********

TOTAL MASS FLOW RATE EXITING SYSTEM: 6.0000 KG/SEC
TOTAL MASS FLOW RATE ENTERING SYSTEM: 6.0000 KG/SEC
TOTAL ENTHALPY FLOW RATE EXITING SYSTEM: 19648.2700 KW
TOTAL ENTHALPY FLOW RATE ENTERING SYSTEM: 20247.8400 KW
TOTAL HEAT AND WORK ENTERING SYSTEM: -599.5688 KW

TOTAL BOILER HEAT: .0000 KW
TOTAL HEAT LOAD HEAT: .0000 KW
TOTAL PIPE ENERGY LOSSES: -599.5688 KW

NET WORK TO GENERATORS: .0000 KW

TOTAL PUMP WORK: .0000 KW
GENERATOR MECHANICAL LOSSES: .0000 KW
GENERATOR ELECTRICAL LOSSES: .0000 KW
NET ELECTRICAL POWER: .0000 KW

SYSTEM HEAT RATE: -1.0000 BTU/KW*HR

CARNOT CYCLE EFFICIENCY:	**61.4370 PERCENT**
1ST LAW EFFICIENCY:	**-100.0000 PERCENT**
2ND LAW EFFICIENCY:	**94.7951 PERCENT**
2ND LAW EFFECTIVENESS:	**-100.0000 PERCENT**

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********** TITLE **********

SIMPLE JUNCTION MODEL TEST

********** NODE DATA **********

NODE	T(C)	P(MPa)	L	Q	S(KJ/KG/K)	H(KJ/KG)	V(M^3/KG)	M(KG/S)	A(KJ/KG)
1	445.00	5.0000	3	*****	6.8027	3304.57	.06274	.3100	1280.70
2	445.00	5.0000	3	*****	6.8027	3304.57	.06274	.2200	1280.70
3	445.00	5.0000	3	*****	6.8027	3304.57	.06274	.4700	1280.70
4	445.00	5.0000	3	*****	6.8027	3304.57	.06274	.4100	1280.70
5	445.00	5.0000	3	*****	6.8027	3304.57	.06274	.5000	1280.70
6	445.00	5.0000	3	*****	6.8027	3304.57	.06274	.0900	1280.70
7	445.00	5.0000	3	*****	6.8027	3304.57	.06274	10.0000	1280.70
8	445.00	5.0000	3	*****	6.8027	3304.57	.06274	2.0000	1280.70
9	445.00	5.0000	3	*****	6.8027	3304.57	.06274	4.0000	1280.70
10	445.00	5.0000	3	*****	6.8027	3304.57	.06274	4.0000	1280.70
11	445.00	5.0000	3	*****	6.8027	3304.57	.06274	.4000	1280.70
12	445.00	5.0000	3	*****	6.8027	3304.57	.06274	.2297	1280.70
13	445.00	5.0000	3	*****	6.8027	3304.57	.06274	.3703	1280.70
14	445.00	5.0000	3	*****	6.8027	3304.57	.06274	1.0000	1280.70
15	445.00	5.0000	3	*****	6.8027	3304.57	.06274	10.0000	1280.70
16	445.00	5.0000	3	*****	6.8027	3304.57	.06274	1.0000	1280.70
17	445.00	5.0000	3	*****	6.8027	3304.57	.06274	1.0000	1280.70
18	445.00	5.0000	3	*****	6.8027	3304.57	.06274	1.0000	1280.70
19	445.00	5.0000	3	*****	6.8027	3304.57	.06274	1.0000	1280.70
20	445.00	5.0000	3	*****	6.8027	3304.57	.06274	1.0000	1280.70
21	445.00	5.0000	3	*****	6.8027	3304.57	.06274	1.0000	1280.70
22	445.00	5.0000	3	*****	6.8027	3304.57	.06274	1.0000	1280.70
23	445.00	5.0000	3	*****	6.8027	3304.57	.06274	1.0000	1280.70
24	445.00	5.0000	3	*****	6.8027	3304.57	.06274	1.0000	1280.70
25	445.00	5.0000	3	*****	6.8027	3304.57	.06274	1.0000	1280.70

********** DEVICE DATA (DEVICE BEFORE NODE) **********

NODE	REV. WRK (KW)	ACT. WRK (KW)	IRREV (KW)	HEAT X-FER (KW)	MASS ERROR (KG/S)	ENERGY ERROR (KW)
1	-1.00	-1.00	-1.00	-1.00	-1.000	-1.000
2	-1.00	-1.00	-1.00	-1.00	-1.000	-1.000
3	-1.00	-1.00	-1.00	-1.00	-1.000	-1.000
4	.00	.00	.00	.00	.000	.000
5	.00	.00	.00	.00	.000	.000
6	.00	.00	.00	.00	.000	.000
7	-1.00	-1.00	-1.00	-1.00	-1.000	-1.000
8	.00	.00	.00	.00	.000	-.002
9	.00	.00	.00	.00	.000	.000
10	.00	.00	.00	.00	.000	.000
11	-1.00	-1.00	-1.00	-1.00	-1.000	-1.000
12	-1.00	-1.00	-1.00	-1.00	-1.000	-1.000
13	-1.00	-1.00	-1.00	-1.00	-1.000	-1.000
14	.00	.00	.00	.00	.000	.000
15	-1.00	-1.00	-1.00	-1.00	-1.000	-1.000
16	.00	.00	.00	.00	.000	-.003
17	.00	.00	.00	.00	.000	.000
18	.00	.00	.00	.00	.000	.000
19	.00	.00	.00	.00	.000	.000
20	.00	.00	.00	.00	.000	.000

21	.00	.00	.00	.00	.000	.000
22	.00	.00	.00	.00	.000	.000
23	.00	.00	.00	.00	.000	.000
24	.00	.00	.00	.00	.000	.000
25	.00	.00	.00	.00	.000	.000

********** SYSTEM DATA **********

TOTAL MASS FLOW RATE EXITING SYSTEM:	22.0000	KG/SEC
TOTAL MASS FLOW RATE ENTERING SYSTEM:	22.0000	KG/SEC
TOTAL ENTHALPY FLOW RATE EXITING SYSTEM:	72700.6300	KW
TOTAL ENTHALPY FLOW RATE ENTERING SYSTEM:	72700.6300	KW
TOTAL HEAT AND WORK ENTERING SYSTEM:	.0000	KW
TOTAL BOILER HEAT:	.0000	KW
TOTAL HEAT LOAD HEAT:	.0000	KW
TOTAL PIPE ENERGY LOSSES:	.0000	KW
NET WORK TO GENERATORS:	.0000	KW
TOTAL PUMP WORK:	.0000	KW
GENERATOR MECHANICAL LOSSES:	.0000	KW
GENERATOR ELECTRICAL LOSSES:	.0000	KW
NET ELECTRICAL POWER:	.0000	KW
SYSTEM HEAT RATE:	-1.0000	BTU/KW*HR
CARNOT CYCLE EFFICIENCY:	61.4370	PERCENT
1ST LAW EFFICIENCY:	-100.0000	PERCENT
2ND LAW EFFICIENCY:	68.1818	PERCENT
2ND LAW EFFECTIVENESS:	-100.0000	PERCENT

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********** TITLE **********

SIMPLE CONDENSER MODEL TEST

********** NODE DATA **********

NODE	T(C)	P(MPa)	L	Q	S(KJ/KG/K)	H(KJ/KG)	V(M^3/KG)	M(KG/S)	A(KJ/KG)
1	151.84	.5000	4	*****	1.8595	639.79	.00109	10.0000	89.73
2	200.00	.5000	3	*****	7.0598	2855.58	.42513	10.0000	755.03
3	151.84	.5000	4	*****	1.8595	639.79	.00109	10.0000	89.73
4	200.00	.5000	3	*****	7.0598	2855.58	.42513	5.0000	755.03
5	200.00	.5000	3	*****	7.0598	2855.58	.42513	5.0000	755.03
6	151.84	.5000	4	*****	1.8595	639.79	.00109	9.9981	89.73
7	200.00	.5000	3	*****	7.0598	2855.58	.42513	.3703	755.03
8	200.00	.5000	3	*****	7.0598	2855.58	.42513	.3703	755.03
9	200.00	.5000	3	*****	7.0598	2855.58	.42513	.3703	755.03
10	200.00	.5000	3	*****	7.0598	2855.58	.42513	.3703	755.03
11	200.00	.5000	3	*****	7.0598	2855.58	.42513	.3703	755.03
12	200.00	.5000	3	*****	7.0598	2855.58	.42513	.3703	755.03
13	200.00	.5000	3	*****	7.0598	2855.58	.42513	.3703	755.03
14	200.00	.5000	3	*****	7.0598	2855.58	.42513	.3703	755.03
15	200.00	.5000	3	*****	7.0598	2855.58	.42513	.3703	755.03
16	200.00	.5000	3	*****	7.0598	2855.58	.42513	.3703	755.03
17	200.00	.5000	3	*****	7.0598	2855.58	.42513	.3703	755.03
18	200.00	.5000	3	*****	7.0598	2855.58	.42513	.3703	755.03
19	200.00	.5000	3	*****	7.0598	2855.58	.42513	.3703	755.03
20	200.00	.5000	3	*****	7.0598	2855.58	.42513	.3703	755.03
21	200.00	.5000	3	*****	7.0598	2855.58	.42513	.3703	755.03
22	200.00	.5000	3	*****	7.0598	2855.58	.42513	.3703	755.03
23	200.00	.5000	3	*****	7.0598	2855.58	.42513	.3703	755.03
24	200.00	.5000	3	*****	7.0598	2855.58	.42513	.3703	755.03
25	200.00	.5000	3	*****	7.0598	2855.58	.42513	.3703	755.03
26	200.00	.5000	3	*****	7.0598	2855.58	.42513	.3703	755.03
27	200.00	.5000	3	*****	7.0598	2855.58	.42513	.3703	755.03
28	200.00	.5000	3	*****	7.0598	2855.58	.42513	.3703	755.03
29	200.00	.5000	3	*****	7.0598	2855.58	.42513	.3703	755.03
30	200.00	.5000	3	*****	7.0598	2855.58	.42513	.3703	755.03
31	200.00	.5000	3	*****	7.0598	2855.58	.42513	.3703	755.03
32	200.00	.5000	3	*****	7.0598	2855.58	.42513	.3703	755.03
33	200.00	.5000	3	*****	7.0598	2855.58	.42513	.3703	755.03

********** DEVICE DATA (DEVICE BEFORE NODE) **********

NODE	REV. WRK (KW)	ACT. WRK (KW)	IRREV (KW)	HEAT X-FER (KW)	MASS ERROR (KG/S)	ENERGY ERROR (KW)
1	6652.92	.00	6652.92	-22157.89	.000	.000
2	-1.00	-1.00	-1.00	-1.00	-1.000	-1.000
3	6652.92	.00	6652.92	-22157.89	.000	.000
4	-1.00	-1.00	-1.00	-1.00	-1.000	-1.000
5	-1.00	-1.00	-1.00	-1.00	-1.000	-1.000
6	6651.65	.00	6651.65	-22153.67	.000	.002
7	-1.00	-1.00	-1.00	-1.00	-1.000	-1.000
8	-1.00	-1.00	-1.00	-1.00	-1.000	-1.000
9	-1.00	-1.00	-1.00	-1.00	-1.000	-1.000
10	-1.00	-1.00	-1.00	-1.00	-1.000	-1.000
11	-1.00	-1.00	-1.00	-1.00	-1.000	-1.000
12	-1.00	-1.00	-1.00	-1.00	-1.000	-1.000

13	-1.00	-1.00	-1.00	-1.00	-1.000	-1.000
14	-1.00	-1.00	-1.00	-1.00	-1.000	-1.000
15	-1.00	-1.00	-1.00	-1.00	-1.000	-1.000
16	-1.00	-1.00	-1.00	-1.00	-1.000	-1.000
17	-1.00	-1.00	-1.00	-1.00	-1.000	-1.000
18	-1.00	-1.00	-1.00	-1.00	-1.000	-1.000
19	-1.00	-1.00	-1.00	-1.00	-1.000	-1.000
20	-1.00	-1.00	-1.00	-1.00	-1.000	-1.000
21	-1.00	-1.00	-1.00	-1.00	-1.000	-1.000
22	-1.00	-1.00	-1.00	-1.00	-1.000	-1.000
23	-1.00	-1.00	-1.00	-1.00	-1.000	-1.000
24	-1.00	-1.00	-1.00	-1.00	-1.000	-1.000
25	-1.00	-1.00	-1.00	-1.00	-1.000	-1.000
26	-1.00	-1.00	-1.00	-1.00	-1.000	-1.000
27	-1.00	-1.00	-1.00	-1.00	-1.000	-1.000
28	-1.00	-1.00	-1.00	-1.00	-1.000	-1.000
29	-1.00	-1.00	-1.00	-1.00	-1.000	-1.000
30	-1.00	-1.00	-1.00	-1.00	-1.000	-1.000
31	-1.00	-1.00	-1.00	-1.00	-1.000	-1.000
32	-1.00	-1.00	-1.00	-1.00	-1.000	-1.000
33	-1.00	-1.00	-1.00	-1.00	-1.000	-1.000

********** SYSTEM DATA **********

TOTAL MASS FLOW RATE EXITING SYSTEM:	29.9981	KG/SEC
TOTAL MASS FLOW RATE ENTERING SYSTEM:	29.9981	KG/SEC
TOTAL ENTHALPY FLOW RATE EXITING SYSTEM:	19192.4100	KW
TOTAL ENTHALPY FLOW RATE ENTERING SYSTEM:	85661.8800	KW
TOTAL HEAT AND WORK ENTERING SYSTEM:	-66469.4500	KW
TOTAL BOILER HEAT:	.0000	KW
TOTAL HEAT LOAD HEAT:	.0000	KW
CONDENSER HEAT (DEVICE # 1):	-22157.8900	KW
CONDENSER HEAT (DEVICE # 2):	-22157.8900	KW
CONDENSER HEAT (DEVICE # 3):	-22153.6700	KW
TOTAL PIPE ENERGY LOSSES:	.0000	KW
NET WORK TO GENERATORS:	.0000	KW
TOTAL PUMP WORK:	.0000	KW
GENERATOR MECHANICAL LOSSES:	.0000	KW
GENERATOR ELECTRICAL LOSSES:	.0000	KW
NET ELECTRICAL POWER:	.0000	KW
SYSTEM HEAT RATE:	-1.0000	BTU/KW*HR
CARNOT CYCLE EFFICIENCY:	61.4370	PERCENT
1ST LAW EFFICIENCY:	-100.0000	PERCENT
2ND LAW EFFICIENCY:	15.7808	PERCENT
2ND LAW EFFECTIVENESS:	-100.0000	PERCENT

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********** TITLE **********

SIMPLE HEAT LOAD MODEL TEST

********** NODE DATA **********

NODE	T(C)	P(MPa)	L	Q	S(KJ/KG/K)	H(KJ/KG)	V(M^3/KG)	M(KG/S)	A(KJ/KG)
1	500.00	10.0000	3	*****	6.5984	3374.66	.03275	1.0000	1411.69
2	400.00	9.0000	3	*****	6.2890	3120.18	.02995	1.0000	1249.46
3	500.00	10.0000	3	*****	6.5984	3374.66	.03275	1.0000	1411.69
4	400.00	9.0000	3	*****	6.2890	3120.18	.02995	1.0000	1249.46

********** DEVICE DATA (DEVICE BEFORE NODE) **********

NODE	REV. WRK (KW)	ACT. WRK (KW)	IRREV (KW)	HEAT X-FER (KW)	MASS ERROR (KG/S)	ENERGY ERROR (KW)
1	-1.00	-1.00	-1.00	-1.00	-1.000	-1.000
2	162.23	.00	162.23	-254.48	.000	.000
3	-1.00	-1.00	-1.00	-1.00	-1.000	-1.000
4	162.23	.00	162.23	-254.48	.000	.000

********** SYSTEM DATA **********

TOTAL MASS FLOW RATE EXITING SYSTEM:	2.0000	KG/SEC
TOTAL MASS FLOW RATE ENTERING SYSTEM:	2.0000	KG/SEC
TOTAL ENTHALPY FLOW RATE EXITING SYSTEM:	6240.3570	KW
TOTAL ENTHALPY FLOW RATE ENTERING SYSTEM:	6749.3160	KW
TOTAL HEAT AND WORK ENTERING SYSTEM:	-508.9595	KW
TOTAL BOILER HEAT:	.0000	KW
HEAT LOAD HEAT (DEVICE # 1):	-254.4797	KW
HEAT LOAD HEAT (DEVICE # 2):	-254.4797	KW
TOTAL HEAT LOAD HEAT:	-508.9595	KW
TOTAL PIPE ENERGY LOSSES:	.0000	KW
NET WORK TO GENERATORS:	.0000	KW
TOTAL PUMP WORK:	.0000	KW
GENERATOR MECHANICAL LOSSES:	.0000	KW
GENERATOR ELECTRICAL LOSSES:	.0000	KW
NET ELECTRICAL POWER:	.0000	KW
SYSTEM HEAT RATE:	-1.0000	BTU/KW*HR
CARNOT CYCLE EFFICIENCY:	61.4370	PERCENT
1ST LAW EFFICIENCY:	-100.0000	PERCENT
2ND LAW EFFICIENCY:	100.0000	PERCENT
2ND LAW EFFECTIVENESS:	-100.0000	PERCENT

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********** TITLE **********

SIMPLE OPEN FEED WATER HEATER MODEL TEST

********** NODE DATA **********

NODE	T(C)	P(MPa)	L	Q	S(KJ/KG/K)	H(KJ/KG)	V(M^3/KG)	M(KG/S)	A(KJ/KG)
1	275.56	6.0000	4	*****	3.0251	1213.37	.00132	25.0002	315.78
2	430.60	6.0000	3	*****	6.6542	3255.19	.05033	1.4165	1275.58
3	251.07	6.0000	1	*****	2.7861	1090.73	.00125	23.5837	264.39
4	275.56	6.0000	4	*****	3.0251	1213.37	.00132	24.9968	315.78
5	430.60	6.0000	3	*****	6.6542	3255.19	.05033	1.4163	1275.58
6	251.07	6.0000	1	*****	2.7861	1090.73	.00125	23.5805	264.39
7	275.56	6.0000	4	*****	3.0251	1213.37	.00132	25.0000	315.78
8	430.60	6.0000	3	*****	6.6542	3255.19	.05033	1.4165	1275.58
9	251.07	6.0000	1	*****	2.7861	1090.73	.00125	23.5835	264.39
10	275.56	6.0000	4	*****	3.0251	1213.37	.00132	25.0000	315.78
11	430.60	6.0000	3	*****	6.6542	3255.19	.05033	1.4163	1275.58
12	251.07	6.0000	1	*****	2.7862	1090.75	.00125	23.5837	264.40
13	275.56	6.0000	4	*****	3.0251	1213.37	.00132	25.0000	315.78
14	430.71	6.0000	3	*****	6.6546	3255.47	.05034	1.4163	1275.73
15	251.07	6.0000	1	*****	2.7861	1090.73	.00125	23.5837	264.39
16	275.67	6.0000	1	*****	3.0066	1213.35	.00132	25.0000	321.27
17	430.60	6.0000	3	*****	6.6542	3255.19	.05033	1.4163	1275.58
18	251.07	6.0000	1	*****	2.7861	1090.73	.00125	23.5837	264.39

********** DEVICE DATA (DEVICE BEFORE NODE) **********

NODE	REV. WRK (KW)	ACT. WRK (KW)	IRREV (KW)	HEAT X-FER (KW)	MASS ERROR (KG/S)	ENERGY ERROR (KW)
1	147.46	.00	147.46	.00	.000	.000
2	-1.00	-1.00	-1.00	-1.00	-1.000	-1.000
3	-1.00	-1.00	-1.00	-1.00	-1.000	-1.000
4	147.44	.00	147.44	.00	.000	.000
5	-1.00	-1.00	-1.00	-1.00	-1.000	-1.000
6	-1.00	-1.00	-1.00	-1.00	-1.000	-1.000
7	147.46	.00	147.46	.00	.000	.001
8	-1.00	-1.00	-1.00	-1.00	-1.000	-1.000
9	-1.00	-1.00	-1.00	-1.00	-1.000	-1.000
10	147.45	.00	147.45	.00	.000	.001
11	-1.00	-1.00	-1.00	-1.00	-1.000	-1.000
12	-1.00	-1.00	-1.00	-1.00	-1.000	-1.000
13	147.50	.00	147.50	.00	.000	.001
14	-1.00	-1.00	-1.00	-1.00	-1.000	-1.000
15	-1.00	-1.00	-1.00	-1.00	-1.000	-1.000
16	10.20	.00	10.20	.00	.000	.000
17	-1.00	-1.00	-1.00	-1.00	-1.000	-1.000
18	-1.00	-1.00	-1.00	-1.00	-1.000	-1.000

********** SYSTEM DATA **********

TOTAL MASS FLOW RATE EXITING SYSTEM: 149.9970 KG/SEC
TOTAL MASS FLOW RATE ENTERING SYSTEM: 149.9970 KG/SEC
TOTAL ENTHALPY FLOW RATE EXITING SYSTEM: 182001.0000 KW
TOTAL ENTHALPY FLOW RATE ENTERING SYSTEM: 182001.0000 KW
TOTAL HEAT AND WORK ENTERING SYSTEM: .0000 KW

TOTAL BOILER HEAT:	.0000	KW
TOTAL HEAT LOAD HEAT:	.0000	KW
TOTAL PIPE ENERGY LOSSES:	.0000	KW
NET WORK TO GENERATORS:	.0000	KW
TOTAL PUMP WORK:	.0000	KW
GENERATOR MECHANICAL LOSSES:	.0000	KW
GENERATOR ELECTRICAL LOSSES:	.0000	KW
NET ELECTRICAL POWER:	.0000	KW
SYSTEM HEAT RATE:	-1.0000	BTU/KW*HR
CARNOT CYCLE EFFICIENCY:	61.4370	PERCENT
1ST LAW EFFICIENCY:	-100.0000	PERCENT
2ND LAW EFFICIENCY:	118.1409	PERCENT
2ND LAW EFFECTIVENESS:	-100.0000	PERCENT

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********** TITLE **********

SIMPLE CLOSED FEED WATER HEATER MODEL TEST

********** NODE DATA **********

NODE	T(C)	P(MPa)	L	Q	S(KJ/KG/K)	H(KJ/KG)	V(M^3/KG)	M(KG/S)	A(KJ/KG)
1	80.00	2.5000	1	*****	1.0716	336.65	.00103	10.0000	21.48
2	199.95	2.2500	1	*****	2.3245	852.14	.00116	10.0000	163.44
3	320.00	10.0000	3	*****	5.7144	2783.86	.01930	2.1144	1084.45
4	140.00	10.0000	1	*****	1.7250	595.13	.00108	1.0000	85.15
5	100.00	9.5000	1	*****	1.2952	425.90	.00104	3.1144	44.08
6	80.00	2.5000	1	*****	1.0716	336.65	.00103	10.0000	21.48
7	199.95	2.2500	1	*****	2.3245	852.14	.00116	10.0000	163.44
8	320.00	10.0000	3	*****	5.7144	2783.86	.01930	2.1144	1084.45
9	140.00	10.0000	1	*****	1.7250	595.13	.00108	.1000	85.15
10	140.00	10.0000	1	*****	1.7250	595.13	.00108	.1000	85.15
11	140.00	10.0000	1	*****	1.7250	595.13	.00108	.1000	85.15
12	140.00	10.0000	1	*****	1.7250	595.13	.00108	.1000	85.15
13	140.00	10.0000	1	*****	1.7250	595.13	.00108	.1000	85.15
14	140.00	10.0000	1	*****	1.7250	595.13	.00108	.1000	85.15
15	140.00	10.0000	1	*****	1.7250	595.13	.00108	.1000	85.15
16	140.00	10.0000	1	*****	1.7250	595.13	.00108	.1000	85.15
17	140.00	10.0000	1	*****	1.7250	595.13	.00108	.1000	85.15
18	140.00	10.0000	1	*****	1.7250	595.13	.00108	.1000	85.15
19	100.00	9.5000	1	*****	1.2952	425.90	.00104	3.1144	44.08

********** DEVICE DATA (DEVICE BEFORE NODE) **********

NODE	REV. WRK (KW)	ACT. WRK (KW)	IRREV (KW)	HEAT X-FER (KW)	MASS ERROR (KG/S)	ENERGY ERROR (KW)
1	-1.00	-1.00	-1.00	-1.00	-1.000	-1.000
2	2163.68	.00	2163.68	5154.93	.000	.000
3	-1.00	-1.00	-1.00	-1.00	-1.000	-1.000
4	-1.00	-1.00	-1.00	-1.00	-1.000	-1.000
5	1117.10	.00	1117.10	-5154.93	.000	.000
6	-1.00	-1.00	-1.00	-1.00	-1.000	-1.000
7	2163.68	.00	2163.68	5154.93	.000	.000
8	-1.00	-1.00	-1.00	-1.00	-1.000	-1.000
9	-1.00	-1.00	-1.00	-1.00	-1.000	-1.000
10	-1.00	-1.00	-1.00	-1.00	-1.000	-1.000
11	-1.00	-1.00	-1.00	-1.00	-1.000	-1.000
12	-1.00	-1.00	-1.00	-1.00	-1.000	-1.000
13	-1.00	-1.00	-1.00	-1.00	-1.000	-1.000
14	-1.00	-1.00	-1.00	-1.00	-1.000	-1.000
15	-1.00	-1.00	-1.00	-1.00	-1.000	-1.000
16	-1.00	-1.00	-1.00	-1.00	-1.000	-1.000
17	-1.00	-1.00	-1.00	-1.00	-1.000	-1.000
18	-1.00	-1.00	-1.00	-1.00	-1.000	-1.000
19	1117.10	.00	1117.10	-5154.93	.000	.000

********** SYSTEM DATA **********

TOTAL MASS FLOW RATE EXITING SYSTEM: 26.2288 KG/SEC
TOTAL MASS FLOW RATE ENTERING SYSTEM: 26.2288 KG/SEC
TOTAL ENTHALPY FLOW RATE EXITING SYSTEM: 19695.6400 KW
TOTAL ENTHALPY FLOW RATE ENTERING SYSTEM: 19695.6500 KW

TOTAL HEAT AND WORK ENTERING SYSTEM:	.0010	KW
TOTAL BOILER HEAT:	.0000	KW
TOTAL HEAT LOAD HEAT:	.0000	KW
TOTAL PIPE ENERGY LOSSES:	.0000	KW
NET WORK TO GENERATORS:	.0000	KW
TOTAL PUMP WORK:	.0000	KW
GENERATOR MECHANICAL LOSSES:	.0000	KW
GENERATOR ELECTRICAL LOSSES:	.0000	KW
NET ELECTRICAL POWER:	.0000	KW
SYSTEM HEAT RATE:	-1.0000	BTU/KW*HR
CARNOT CYCLE EFFICIENCY:	61.4370	PERCENT
1ST LAW EFFICIENCY:	-100.0000	PERCENT
2ND LAW EFFICIENCY:	68.8929	PERCENT
2ND LAW EFFECTIVENESS:	-100.0000	PERCENT

RANKINE 3.0: A steam power plant computer simulation

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********** TITLE **********

SIMPLE SEPARATOR MODEL TEST

********** NODE DATA **********

NODE	T(C)	P(MPa)	L	Q	S(KJ/KG/K)	H(KJ/KG)	V(M^3/KG)	M(KG/S)	A(KJ/KG)
1	179.87	1.0000	2	.500	4.3598	1769.26	.09779	1.0000	473.74
2	175.35	.9000	5	*****	6.6191	2772.27	.21498	.5059	803.12
3	175.35	.9000	4	*****	2.0927	742.27	.00112	.4941	122.66
4	500.00	1.0000	3	*****	7.7586	3475.99	.35405	1.0000	1167.10
5	499.51	.9000	3	*****	7.8069	3475.99	.39345	1.0000	1152.71
6	175.35	.9000	4	*****	2.0927	742.27	.00112	.0000	122.66
7	100.00	1.0000	1	*****	1.3049	419.52	.00104	1.0000	34.79
8	175.35	.9000	5	*****	6.6191	2772.27	.21498	.0000	803.12
9	100.02	.9000	1	*****	1.3053	419.52	.00104	1.0000	34.70

********** DEVICE DATA (DEVICE BEFORE NODE) **********

NODE	REV. WRK (KW)	ACT. WRK (KW)	IRREV (KW)	HEAT X-FER (KW)	MASS ERROR (KG/S)	ENERGY ERROR (KW)
1	-1.00	-1.00	-1.00	-1.00	-1.000	-1.000
2	6.83	.00	6.83	.00	.000	.000
3	.00	.00	.00	.00	.000	.000
4	-1.00	-1.00	-1.00	-1.00	-1.000	-1.000
5	14.39	.00	14.39	.00	.000	.000
6	.00	.00	.00	.00	.000	.000
7	-1.00	-1.00	-1.00	-1.00	-1.000	-1.000
8	.09	.00	.09	.00	.000	.000
9	.00	.00	.00	.00	.000	.000

********** SYSTEM DATA **********

TOTAL MASS FLOW RATE EXITING SYSTEM:	3.0000	KG/SEC
TOTAL MASS FLOW RATE ENTERING SYSTEM:	3.0000	KG/SEC
TOTAL ENTHALPY FLOW RATE EXITING SYSTEM:	5664.7700	KW
TOTAL ENTHALPY FLOW RATE ENTERING SYSTEM:	5664.7700	KW
TOTAL HEAT AND WORK ENTERING SYSTEM:	.0000	KW
TOTAL BOILER HEAT:	.0000	KW
TOTAL HEAT LOAD HEAT:	.0000	KW
TOTAL PIPE ENERGY LOSSES:	.0000	KW
NET WORK TO GENERATORS:	.0000	KW
TOTAL PUMP WORK:	.0000	KW
GENERATOR MECHANICAL LOSSES:	.0000	KW
GENERATOR ELECTRICAL LOSSES:	.0000	KW
NET ELECTRICAL POWER:	.0000	KW
SYSTEM HEAT RATE:	-1.0000	BTU/KW*HR
CARNOT CYCLE EFFICIENCY:	61.4370	PERCENT
1ST LAW EFFICIENCY:	-100.0000	PERCENT
2ND LAW EFFICIENCY:	98.7282	PERCENT
2ND LAW EFFECTIVENESS:	-100.0000	PERCENT

RANKINE 3.0: A steam power plant computer simulation

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********** TITLE **********

SIMPLE REHEATER MODEL TEST

********** NODE DATA **********

NODE	T(C)	P(MPa)	L	Q	S(KJ/KG/K)	H(KJ/KG)	V(M^3/KG)	M(KG/S)	A(KJ/KG)
1	300.00	1.5000	3	*****	6.9184	3037.88	.16977	91.0000	979.49
2	300.00	1.5000	3	*****	6.9184	3037.88	.16977	90.3395	979.49
3	300.00	1.5000	3	*****	6.9184	3037.88	.16977	.6605	979.49
4	180.00	1.0000	3	*****	6.5832	2776.53	.19441	90.3395	818.08
5	183.38	.9000	3	*****	6.6643	2792.73	.22006	90.3395	810.11
6	193.34	1.3500	4	*****	2.2659	822.13	.00115	.6605	150.91
7	300.00	1.5000	3	*****	6.9184	3037.88	.16977	91.0000	979.49
8	300.00	1.5000	3	*****	6.9184	3037.88	.16977	90.3395	979.49
9	300.00	1.5000	3	*****	6.9184	3037.88	.16977	.6605	979.49
10	180.00	1.0000	3	*****	6.5832	2776.53	.19441	90.3395	818.08
11	193.34	1.3500	4	*****	2.2659	822.13	.00115	.6605	150.91
12	183.38	.9000	3	*****	6.6643	2792.73	.22006	90.3395	810.11
13	300.00	1.5000	3	*****	6.9184	3037.88	.16977	91.0000	979.49
14	300.00	1.5000	3	*****	6.9184	3037.88	.16977	90.3740	979.49
15	300.00	1.5000	3	*****	6.9184	3037.88	.16977	.6260	979.49
16	180.00	1.0000	3	*****	6.5832	2776.53	.19441	90.3740	818.08
17	193.00	1.3500	1	*****	2.2603	820.61	.00115	.6260	151.05
18	183.05	.9000	3	*****	6.6625	2791.89	.21985	90.3740	809.82

********** DEVICE DATA (DEVICE BEFORE NODE) **********

NODE	REV. WRK (KW)	ACT. WRK (KW)	IRREV (KW)	HEAT X-FER (KW)	MASS ERROR (KG/S)	ENERGY ERROR (KW)
1	-1.00	-1.00	-1.00	-1.00	-1.000	-1.000
2	.00	.00	.00	.00	.000	-.014
3	.00	.00	.00	.00	.000	.000
4	14581.51	.00	14581.51	-23610.50	.000	-.008
5	1971.08	.00	1971.08	1463.54	.000	.005
6	65.76	.00	65.76	-1463.54	.000	.000
7	-1.00	-1.00	-1.00	-1.00	-1.000	-1.000
8	.00	.00	.00	.00	.000	-.014
9	.00	.00	.00	.00	.000	.000
10	14581.51	.00	14581.51	-23610.50	.000	-.008
11	65.76	.00	65.76	-1463.54	.000	.000
12	1971.08	.00	1971.08	1463.54	.000	.005
13	-1.00	-1.00	-1.00	-1.00	-1.000	-1.000
14	.00	.00	.00	.00	.000	-.001
15	.00	.00	.00	.00	.000	.000
16	14587.08	.00	14587.08	-23619.52	.000	-.002
17	62.17	.00	62.17	-1387.97	.000	.000
18	1969.77	.00	1969.77	1387.98	.000	.005

********** SYSTEM DATA **********

TOTAL MASS FLOW RATE EXITING SYSTEM: 273.0000 KG/SEC
TOTAL MASS FLOW RATE ENTERING SYSTEM: 273.0000 KG/SEC
TOTAL ENTHALPY FLOW RATE EXITING SYSTEM: 758500.9000 KW
TOTAL ENTHALPY FLOW RATE ENTERING SYSTEM: 829341.4000 KW
TOTAL HEAT AND WORK ENTERING SYSTEM: -70840.5100 KW

TOTAL BOILER HEAT:	.0000	KW
HEAT LOAD HEAT (DEVICE # 2):	-23610.5000	KW
HEAT LOAD HEAT (DEVICE # 5):	-23610.5000	KW
HEAT LOAD HEAT (DEVICE # 8):	-23619.5200	KW
TOTAL HEAT LOAD HEAT:	-70840.5200	KW
TOTAL PIPE ENERGY LOSSES:	.0000	KW
NET WORK TO GENERATORS:	.0000	KW
TOTAL PUMP WORK:	.0000	KW
GENERATOR MECHANICAL LOSSES:	.0000	KW
GENERATOR ELECTRICAL LOSSES:	.0000	KW
NET ELECTRICAL POWER:	.0000	KW
SYSTEM HEAT RATE:	-1.0000	BTU/KW*HR
CARNOT CYCLE EFFICIENCY:	61.4370	PERCENT
1ST LAW EFFICIENCY:	-100.0000	PERCENT
2ND LAW EFFICIENCY:	99.2231	PERCENT
2ND LAW EFFECTIVENESS:	-100.0000	PERCENT

Appendix D:

Hand calculations for benchmark case #1 through case #5

Benchmark Case #1

P3=	20.00	MPa
T3=	600.00	Deg C
M3=	50.00	Kg/sec
P4=	0.10	MPa

Stage Grp #1 effi=	0.75	(-)
Pmp effi=	0.75	(-)
T dead=	298.15	Kelvin
Pdead=	0.101	MPa
h dead=	105.1	KJ/Kg
s dead=	3.67E-01	KJ/Kg/K
T high=	873.15	Kelvin
T low=	298.15	Kelvin

Node	Temperature (Deg C)	Presure (MPa)	Fluid Phase (-)	Quality (-)	Entropy (KJ/Kg/K)	Enthalpy (KJ/Kg)	Specific Volume (m^3/kg)	Mass flow rate (Kg/sec)	Aval (KJ/Kg)	Actual Work (KW)	Rev Work (KW)	Irrev (KW)	Heat X-fer (KW)
1	99.63	0.1000	4	0.00	1.3020	417.31	1.04E-03	50.0000	33.45	0.00	22370.48	22370.48	-111729.94
2s	XXXXXXXXXXX	20.0000	XXXXXXXXXXXXX	XXXXXXXXXXX	1.3020	440.70	XXXXXXXXXXX	XXXXXXXXXXX	XXXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX
2	103.52	20.0000	1	-1.00	1.3228	448.50	1.05E-03	50.0000	58.43	-1559.60	-1249.06	310.54	0.00
3	600.00	20.0000	3	-1.00	6.5052	3538.61	1.81E-02	50.0000	1601.42	0.00	71843.63	71843.63	154405.60
4S	XXXXXXXXXXX		XXXXXXXXXXXXX	XXXXXXXXXXX	6.5052	2357.00	XXXXXXXXXXX	XXXXXXXXXXX	XXXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX
4	99.63	0.1000	2	0.99	7.2962	2651.90	1.68E+00	50.0000	480.86	44235.26	56028.03	11792.77	0.00

Boiler heat x-fer=	154405.60	KW
Condenser heat x-fer=	-111729.94	KW
Turbine work=	44235.26	KW
Pump work=	-1559.60	KW
Net work=	42675.66	KW
1st law effi=	27.5387	Percent
Carnot Cycle effi=	65.8535	Percent
Adj boiler heat=	101681.52	KW
Avail prod by system=	0.00	KW
Avail supp to system=	0.00	KW
2nd law effi=	42.8466	Percent
2nd law effectiveness=	41.9899	Percent

Benchmark Case #2

P0=	10.0	MPa	Stage grp #1 eff=	0.75	(-)	PL 14-15=	0.0	MPa	QL 14-15= 0.0 KJ/Kg
T0=	500.0	Deg C	Stage grp #2 eff=	0.75	(-)	PL 12-13=	0.0	MPa	QL 12-13= 0.0 KJ/Kg
M0=	25.0	Kg/sec	Stage grp #3 eff=	0.75	(-)	PL 1-2=	0.0	MPa	QL 1-2= 0.0 KJ/Kg
P11=	8.0	MPa	Pump #1 eff=	0.75	(-)	PL 3-4=	0.0	MPa	QL 3-4= 0.0 KJ/Kg
P12=	6.0	MPa	Pump #2 eff=	0.75	(-)	PL 5-6=	0.0	MPa	QL 5-6= 0.0 KJ/Kg
M11=	5.0	Kg/sec	Tdead=	298.2	Kelvin	PL 7-8=	0.0	MPa	QL 7-8= 0.0 KJ/Kg
P14=	4.0	MPa	P dead=	0.101	MPa	PL 9-10=	0.0	MPa	QL 9-10= 0.0 KJ/Kg
M17=	0.0	Kg/sec	h dead=	105.1	KJ/Kg	PL 11-19=	0.0	MPa	QL 11-19= 0.0 KJ/Kg
T20=	380.21	Deg C	S dead=	3.67E-01	KJ/Kg/K	PL 20-21=	0.0	MPa	QL 20-21= 0.0 KJ/Kg
			T high=	773.2	Kelvin	PL 18-10=	0.0	MPa	QL 18-10= 0.0 KJ/Kg
			T Low=	298.2	Kelvin	Boiler PL=	0.0	MPa	

Node	Temperature (Deg C)	Pressure (MPa)	Fluid Phase (-)	Quality (-)	Entropy (KJ/KG/K)	Enthalpy (KJ/Kg)	Specific Volume (m^3/Kg)	Mass flow rate (Kg/sec)	Avail (KJ/Kg)	Actual Work (KW)	Rev Work (KW)	Irrev (KW)	Heat X-Fer (KW)
1	250.34	4.0	4	0.00	2.7947	1087.16	1.25E-03	23.6638	258.25	0.00	21676.93	21676.93	-49227.83
2	250.34	4.0	4	0.00	2.7947	1087.16	1.25E-03	23.6638	258.25	0.00	0.00	0.00	0.00
3a	XXXXXXXXXXX	6.0	XXXXXXXXXXXXXX	XXXXXXXXX	2.7947	1095.33	XXXXXXXXXXXXX	XXXXXXXXXXXXX	XXXXXXXXXXXX	XXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX
3	252.58	6.0	1	-1.00	2.7997	1098.06	1.26E-03	23.6638	267.64	-257.97	-222.34	35.62	0.00
4	252.58	6.0	1	-1.00	2.7997	1098.06	1.26E-03	23.6638	267.64	0.00	0.00	0.00	0.00
5	275.56	6.0	4	0.00	3.0251	1213.37	1.32E-03	25.0000	315.76	0.00	144.00	144.00	0.00
6	275.56	6.0	4	0.00	3.0251	1213.37	1.32E-03	25.0000	315.76	0.00	0.00	0.00	0.00
7a	XXXXXXXXXXX	10.0	XXXXXXXXXXXXXX	XXXXXXXXX	3.0251	1229.97	XXXXXXXXXXXXX	XXXXXXXXXXXXX	XXXXXXXXXXXX	XXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX
7	280.24	10.0	1	-1.00	3.0345	1235.51	1.33E-03	25.0000	335.08	-553.60	-483.05	70.55	0.00
8	280.24	10.0	1	-1.00	3.0345	1235.51	1.33E-03	25.0000	335.08	0.00	0.00	0.00	0.00
9	500.00	10.0	3	-1.00	6.5984	3374.66	3.27E-02	25.0000	1411.67	0.00	15406.16	15406.16	53478.70
10	500.00	10.0	3	-1.00	6.5984	3374.66	3.27E-02	25.0000	1411.67	0.00	0.00	0.00	0.00
11a	XXXXXXXXXXX	8.0	XXXXXXXXXXXXXX	XXXXXXXXX	6.5984	3303.78	XXXXXXXXXXXXX	XXXXXXXXXXXXX	XXXXXXXXXXXX	XXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX
11	488.93	8.0	3	-1.00	6.6230	3321.50	3.95E-02	5.0000	1351.17	1329.06	1512.41	183.35	0.00
12a	XXXXXXXXXXX	8.0	XXXXXXXXXXXXXX	XXXXXXXXX	6.6230	3233.34	XXXXXXXXXXXXX	XXXXXXXXXXXXX	XXXXXXXXXXXX	XXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX
12	430.88	8.0	3	-1.00	6.6545	3255.38	5.03E-02	1.3362	1275.66	1322.34	1510.19	187.85	0.00
13	430.88	8.0	3	-1.00	6.6545	3255.38	5.03E-02	1.3362	1275.66	0.00	0.00	0.00	0.00
14a	XXXXXXXXXXX	4.0	XXXXXXXXXXXXXX	XXXXXXXXX	6.6545	3138.24	XXXXXXXXXXXXX	XXXXXXXXXXXXX	XXXXXXXXXXXX	XXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX
14	380.33	4.0	3	-1.00	6.6997	3167.52	7.07E-02	18.6638	1174.32	1639.70	1891.42	251.71	0.00
15	380.33	4.0	3	-1.00	6.6997	3167.52	7.07E-02	18.6638	1174.32	0.00	0.00	0.00	0.00
16	500.00	10.0	3	-1.00	6.5984	3374.66	3.27E-02	25.0000	1411.67	0.00	0.00	0.00	0.00
17	500.00	10.0	3	-1.00	6.5984	3374.66	3.27E-02	0.0000	1411.67	0.00	0.00	0.00	0.00
18	500.00	10.0	3	-1.00	6.5984	3374.66	3.27E-02	25.0000	1411.67	0.00	0.00	0.00	0.00
19	488.93	8.0	3	-1.00	6.6230	3321.50	3.95E-02	5.0000	1351.17	0.00	0.00	0.00	0.00
20	380.21	4.0	3	-1.00	6.6993	3167.23	7.07E-02	5.0000	1174.16	0.00	885.06	885.06	-771.34
21	380.21	4.0	3	-1.00	6.6993	3167.23	7.07E-02	5.0000	1174.16	0.00	0.00	0.00	0.00

Boiler heat x-fer=	53478.7000	KW
Heat load heat x-fer=	-771.3386	KW
Condenser heat x-fer=	-49227.8305	KW
Trb #1 Stg Grp #1 work=	1329.0562	KW
Trb #1 Stg Grp #2 work=	1322.3362	KW
Trb #1 Stg Grp #3 work=	1639.7050	KW
total turbine work=	4291.0975	KW
Pump #1 work=	-257.9667	KW
Pump #2 work=	-553.6000	KW
Total net work=	3479.5308	KW
1st law eff=	6.5064	Percent
Carnot cycle eff=	61.4370	Percent
adj boiler heat=	32855.6975	KW
Avail prod by system=	6755.8617	KW
Avail supp to system=	5870.8010	KW
2nd law eff=	27.9401	Percent
2nd law effect=	10.5903	Percent

Benchmark Case #3

T17=	500.0	Deg C	TRB #1 Stg Grp #1 eff=	0.50	(-)	PL 17-18=	0.0	kPa	QL 17-18=	0.0	KJ/Kg
P17=	10.0	kPa	TRB #1 Stg Grp #2 eff=	0.50	(-)	PL 20-21=	0.0	kPa	QL 20-21=	0.0	KJ/Kg
M17=	22.0	Kg/sec	TRB #2 Stg Grp #1 eff=	0.50	(-)	PL 23-24=	0.0	kPa	QL 23-24=	0.0	KJ/Kg
P18=	8.0	kPa	TRB #2 Stg Grp #2 eff=	0.50	(-)	PL 25-26=	0.0	kPa	QL 25-26=	0.0	KJ/Kg
M18=	2.0	Kg/sec	TRB #2 Stg Grp #3 eff=	0.50	(-)	PL 27-28=	0.0	kPa	QL 27-28=	0.0	KJ/Kg
P20=	6.0	kPa	TRB #2 Stg Grp #4 eff=	0.50	(-)	PL 29-30=	0.0	kPa	QL 29-30=	0.0	KJ/Kg
P22=	4.0	kPa	TRB #2 Stg Grp #5 eff=	0.50	(-)	PL 1-2=	0.0	kPa	QL 1-2=	0.0	KJ/Kg
M22=	2.0	Kg/sec	Pmp #1 eff=	0.50	(-)	PL 3-4=	0.0	kPa	QL 3-4=	0.0	KJ/Kg
P23=	3.0	kPa	Pmp #2 eff=	0.50	(-)	PL 5-6=	0.0	kPa	QL 5-6=	0.0	KJ/Kg
P25=	2.0	kPa	Pmp #3 eff=	0.50	(-)	PL 7-8=	0.0	kPa	QL 7-8=	0.0	KJ/Kg
P27=	1.5	kPa	Pmp #4 eff=	0.50	(-)	PL 9-10=	0.0	kPa	QL 9-10=	0.0	KJ/Kg
P29=	1.0	kPa	T dead=	298.15	Kelvin	PL 11-12=	0.0	kPa	QL 11-12=	0.0	KJ/Kg
T32=	267.64	Deg C	P dead=	0.101	kPa	PL 13-14=	0.0	kPa	QL 13-14=	0.0	KJ/Kg
T34=	267.64	Deg C	h dead=	105.7	KJ/Kg	PL 15-16=	0.0	kPa	QL 15-16=	0.0	KJ/Kg
			S dead=	0.367	KJ/Kg-K	PL 22-23=	0.0	kPa	QL 22-23=	0.0	KJ/Kg
			T high=	773.15	Kelvin	PL 34-35=	0.0	kPa	QL 34-35=	0.0	KJ/Kg
			T low=	298.15	Kelvin	PL 19-31=	0.0	kPa	QL 19-31=	0.0	KJ/Kg
						PL 32-36=	0.0	kPa	QL 32-36=	0.0	KJ/Kg
						Boiler PL=	0.0	kPa			

Node	Temperature (Deg C)	Pressure (MPa)	Fluid Phase (-)	Quality (-)	Entropy (KJ/Kg-K)	Enthalpy (KJ/Kg)	Spec Vol (m^3/Kg)	Mass flow rate (Kg/sec)	Avail (KJ/Kg)	Actual Work (KW)	Rev Work (KW)	Irrev (KW)	Heat X-Fer (KW)
1	379.87	1.0000	4	0.00	2.1367	762.23	1.13E-03	19.8440	129.50	0.00	15869.73	15869.73	-45316.93
2	379.87	1.0000	4	0.00	2.1367	762.23	1.13E-03	19.8440	129.50	0.00	0.00	0.00	0.00
3s	XXXXXXXXXX	1.5000	XXXXXXXXXXXXXXXX	XXXXXXXXXX	2.1367	763.56	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX
3	180.42	1.5000	1	-1.00	2.1396	764.89	1.12E-03	19.8440	131.30	-52.80	-35.58	17.23	0.00
4	180.42	1.5000	1	-1.00	2.1396	764.89	1.12E-03	19.8440	131.30	0.00	0.00	0.00	0.00
5	198.28	1.5000	4	0.00	2.3127	844.32	1.15E-03	20.5434	159.10	0.00	42.53	42.53	0.00
6	198.28	1.5000	4	0.00	2.3127	844.32	1.15E-03	20.5434	159.10	0.00	0.00	0.00	0.00
7s	XXXXXXXXXX	2.0000	XXXXXXXXXXXXXXXX	XXXXXXXXXX	2.3127	846.22	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX
7	199.08	2.0000	1	-1.00	2.3167	848.13	1.15E-03	20.5434	161.72	-78.31	-53.79	24.52	0.00
8	199.08	2.0000	1	-1.00	2.3167	848.13	1.15E-03	20.5434	161.72	0.00	0.00	0.00	0.00
9	212.37	2.0000	4	0.00	2.4450	908.29	1.18E-03	21.0980	183.63	0.00	39.95	39.95	0.00
10	212.37	2.0000	4	0.00	2.4450	908.29	1.18E-03	21.0980	183.63	0.00	0.00	0.00	0.00
11s	XXXXXXXXXX	3.0000	XXXXXXXXXXXXXXXX	XXXXXXXXXX	2.4450	911.51	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX
11	213.70	3.0000	1	-1.00	2.4516	914.73	1.18E-03	21.0980	188.12	-135.84	-94.66	41.18	0.00
12	213.70	3.0000	1	-1.00	2.4516	914.73	1.18E-03	21.0980	188.12	0.00	0.00	0.00	0.00
13	233.85	3.0000	4	0.00	2.6437	1008.11	1.22E-03	22.0000	224.22	0.00	73.57	73.57	0.00
14	233.85	3.0000	4	0.00	2.6437	1008.11	1.22E-03	22.0000	224.22	0.00	0.00	0.00	0.00
15s	XXXXXXXXXX	10.0000	XXXXXXXXXXXXXXXX	XXXXXXXXXX	2.6437	1020.69	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX
15	238.95	10.0000	1	-1.00	2.6678	1033.26	1.23E-03	22.0000	242.17	-553.30	-394.74	158.56	0.00
16	238.95	10.0000	1	-1.00	2.6678	1033.26	1.23E-03	22.0000	242.17	0.00	0.00	0.00	0.00
17	500.00	10.0000	3	-1.00	6.5984	3374.66	3.27E-02	22.0000	1411.67	0.00	15345.26	15345.26	51510.71
18	500.00	10.0000	3	-1.00	6.5984	3374.66	3.27E-02	22.0000	1411.67	0.00	0.00	0.00	0.00
19s	XXXXXXXXXX	8.0000	XXXXXXXXXXXXXXXX	XXXXXXXXXX	6.5984	3303.33	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX
19	475.93	8.0000	3	-1.00	6.6465	3339.00	4.00E-02	22.0000	1361.67	784.56	1099.87	315.31	0.00
20s	XXXXXXXXXX	6.0000	XXXXXXXXXXXXXXXX	XXXXXXXXXX	6.6465	3249.74	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX
20	446.67	6.0000	3	-1.00	6.7093	3294.37	5.18E-02	20.0000	1298.32	892.60	1267.10	374.50	0.00
21	446.67	6.0000	3	-1.00	6.7093	3294.37	5.18E-02	20.0000	1298.32	0.00	0.00	0.00	0.00
22s	XXXXXXXXXX	4.0000	XXXXXXXXXXXXXXXX	XXXXXXXXXX	6.7093	3173.77	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX
22	408.49	4.0000	3	-1.00	6.7994	3234.07	7.46E-02	2.0000	1211.14	1205.97	1743.52	537.55	0.00
23s	XXXXXXXXXX	3.0000	XXXXXXXXXXXXXXXX	XXXXXXXXXX	6.7994	3150.97	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX
23	383.10	3.0000	3	-1.00	6.8636	3192.52	9.64E-02	0.9020	1150.45	747.89	1092.44	344.56	0.00
24	383.10	3.0000	3	-1.00	6.8636	3192.52	9.64E-02	0.9020	1150.45	0.00	0.00	0.00	0.00
25s	XXXXXXXXXX	2.0000	XXXXXXXXXXXXXXXX	XXXXXXXXXX	6.8636	3080.40	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX
25	349.59	2.0000	3	-1.00	6.9555	3136.46	1.39E-01	0.5547	1067.00	958.52	1426.84	468.32	0.00
26	349.59	2.0000	3	-1.00	6.9555	3136.46	1.39E-01	0.5547	1067.00	0.00	0.00	0.00	0.00
27s	XXXXXXXXXX	1.5000	XXXXXXXXXXXXXXXX	XXXXXXXXXX	6.9555	3059.30	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX
27	327.26	1.5000	3	-1.00	7.0207	3097.88	1.79E-01	0.5994	1008.97	638.26	959.94	321.68	0.00

Benchmark Case #3 (Cont'd)

Node	Temperature (Deg C)	Pressure (MPa)	Fluid Phase (-)	Quality (-)	Entropy (KJ/Kg/K)	Enthalpy (KJ/Kg)	Spec Vol (m^3/Kg)	Mass flow rate (Kg/sec)	Aval (KJ/Kg)	Actual Work (KW)	Rev Work (KW)	Irrev (KW)	Heat X-Fer (KW)
28	327.26	1.6000	3	-1.00	7.0207	3097.88	1.79E-01	0.6994	1006.97	0.00	0.00	0.00	0.00
28a	XXXXXXXXXX	1.6000	XXXXXXXXXXXXXXXXXX	XXXXXXXXXX	7.0207	2993.90	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX
29	297.54	1.0000	3	-1.00	7.1138	3045.89	2.57E-01	15.8440	929.23	823.71	1263.43	439.72	0.00
30	297.54	1.0000	3	-1.00	7.1138	3045.89	2.57E-01	15.8440	929.23	0.00	0.00	0.00	0.00
31	475.83	8.0000	3	-1.00	6.8465	3339.00	4.00E-02	2.0000	1361.67	0.00	0.00	0.00	0.00
32	297.54	1.0000	3	-1.00	7.1139	3045.90	2.57E-01	2.0000	929.22	0.00	864.91	864.91	-586.20
33	498.49	4.0000	3	-1.00	6.7994	3234.07	7.46E-02	2.0000	1211.14	0.00	0.00	0.00	0.00
34	297.54	1.0000	3	-1.00	7.1138	3045.90	2.57E-01	2.0000	929.22	0.00	563.84	563.84	-376.34
35	297.54	1.0000	3	-1.00	7.1138	3045.90	2.57E-01	2.0000	929.22	0.00	0.00	0.00	0.00
36	297.54	1.0000	3	-1.00	7.1139	3045.90	2.57E-01	2.0000	929.22	0.00	0.00	0.00	0.00

Boiler heat=	51510.71	KW
Heat load #1 heat =	-586.20	KW
Heat load #2 heat =	-376.34	KW
Condenser heat=	-45316.93	KW
Trb #1 Stg Grp #1 wk=	784.56	KW
Trb #1 Stg Grp #2 wk=	892.60	KW
Trb #2 Stg Grp #1 wk=	1205.97	KW
Trb #2 Stg Grp #2 wk=	747.89	KW
Trb #2 Stg Grp #3 wk=	958.52	KW
Trb #2 Stg Grp #4 wk=	638.26	KW
Trb #2 Stg Grp #5 wk=	823.71	KW
Actual turbine work=	6051.50565	KW
Pump #1 work=	-52.80	KW
Pump #2 work=	-78.31	KW
Pump #3 work=	-135.84	KW
Pump #4 work=	-553.30	KW
Total net work=	5231.2476	KW
1st law eff=	10.1556	Percent
Carnot cycle eff=	61.4370	Percent
adj boiler heat=	51546.6251	KW
Aval Prod by system=	5145.6264	KW
Aval Supp to system=	3716.8708	KW
2nd law eff=	30.9452	Percent
2nd law effect=	18.5302	Percent

Benchmark Case #4

P17=	10.0	MPa	Trb #1 Stg Grp #1 eff=	0.75	(-)	PL 17-18=	0.0	MPa	OL 17-18= 0.0 KJ/Kg
H17=	3099.1	KJ/Kg	Trb #1 Stg Grp #2 eff=	0.75	(-)	PL 20-21=	0.0	MPa	OL 20-21= 0.0 KJ/Kg
M17=	45.0	Kg/sec	Trb #2 Stg Grp #1 eff=	0.75	(-)	PL 23-24=	0.0	MPa	OL 23-24= 0.0 KJ/Kg
P18=	8.0	MPa	Trb #2 Stg Grp #2 eff=	0.75	(-)	PL 25-26=	0.0	MPa	OL 25-26= 0.0 KJ/Kg
M18=	2.0	KG/sec	Trb #3 Stg Grp #1 eff=	0.75	(-)	PL 28-29=	0.0	MPa	OL 28-29= 0.0 KJ/Kg
P20=	6.0	MPa	Trb #3 Stg Grp #2 eff=	0.75	(-)	PL 30-31=	0.0	MPa	OL 30-31= 0.0 KJ/Kg
P22=	4.0	MPa	Trb #3 Stg Grp #3 eff=	0.75	(-)	PL 32-33=	0.0	MPa	OL 32-33= 0.0 KJ/Kg
M22=	2.0	Kg/sec	Trb #3 Stg Grp #4 eff=	0.75	(-)	PL 34-35=	0.0	MPa	OL 34-35= 0.0 KJ/Kg
P23=	3.0	MPa	Trb #3 Stg Grp #5 eff=	0.75	(-)	PL 1-2=	0.0	MPa	OL 1-2= 0.0 KJ/Kg
T25=	400.0	Deg C	Pmp #1 eff=	0.75	(-)	PL 3-4=	0.0	MPa	OL 3-4= 0.0 KJ/Kg
P27=	2.0	MPa	Pmp #2 eff=	0.75	(-)	PL 5-6=	0.0	MPa	OL 5-6= 0.0 KJ/Kg
M27=	2.0	Kg/sec	Pmp #3 eff=	0.75	(-)	PL 7-8=	0.0	MPa	OL 7-8= 0.0 KJ/Kg
P28=	1.0	MPa	Pmp #4 eff=	0.75	(-)	PL 9-10=	0.0	MPa	OL 9-10= 0.0 KJ/Kg
P30=	0.5	MPa	T dead=	298.15	Kelvin	PL 11-12=	0.0	MPa	OL 11-12= 0.0 KJ/Kg
P32=	0.25	MPa	P dead=	0.101	MPa	PL 13-14=	0.0	MPa	OL 13-14= 0.0 KJ/Kg
P34=	0.05	MPa	h dead=	105.1	KJ/Kg	PL 15-16=	0.0	MPa	OL 15-16= 0.0 KJ/Kg
H37=	2580.28	KJ/Kg	s dead=	3.67E-01	KJ/Kg-K	PL 19-42=	0.0	MPa	OL 19-42= 0.0 KJ/Kg
H40=	2580.28	KJ/Kg	T high=	673.15	Kelvin	PL 43-44=	0.0	MPa	OL 43-44= 0.0 KJ/Kg
H43=	2580.28	KJ/Kg	T low=	298.15	Kelvin	PL 22-41=	0.0	MPa	OL 22-41= 0.0 KJ/Kg
						PL 39-40=	0.0	MPa	OL 39-40= 0.0 KJ/Kg
						PL 27-36=	0.0	MPa	OL 27-36= 0.0 KJ/Kg
						PL 37-38=	0.0	MPa	OL 37-38= 0.0 KJ/Kg
						Boiler PL=	0.0	MPa	
						Reheat leg PL=	0.0	MPa	

Node	Temperature (Deg C)	Pressure (MPa)	Fluid Phase (-)	Quality (-)	Entropy (KJ/Kg/K)	Enthalphy (KJ/Kg)	Spec Vol (m^3/kg)	Mass Flow Rate (Kg/sec)	Aval (Kg/Kg)	Actual Work (KW)	Rev Work (KW)	Irrev (KW)	Heat X-Fer (KW)
1	81.35	0.05	4	0	1.0903	340.37	1.03E-03	37.5634	19.82	0.00	13374.67	13374.67	-84138.73
2	81.35	0.05	4	0	1.0903	340.37	1.03E-03	37.5634	19.82	0.00	0.00	0.00	0.00
3a	XXXXXXXXXX	0.25	XXXXXXXXXXXXXXXXXXXX	XXXXXXXXX	1.0903	340.61	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX
3	81.39	0.25	1	-1	1.0905	340.68	1.03E-03	37.5634	19.87	-11.77	-9.41	2.36	0.00
4	81.39	0.25	1	-1	1.0905	340.68	1.03E-03	37.5634	19.87	0.00	0.00	0.00	0.00
5	127.43	0.25	4	0	1.6065	535.09	1.07E-03	40.8093	60.43	0.00	350.21	350.21	0.00
6	127.43	0.25	4	0	1.6065	535.09	1.07E-03	40.8093	60.43	0.00	0.00	0.00	0.00
7a	XXXXXXXXXX	0.50	XXXXXXXXXXXXXXXXXXXX	XXXXXXXXX	1.6065	535.52	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX
7	127.52	0.5	1	-1	1.6069	535.66	1.61E-03	40.8093	60.90	-23.34	-19.13	4.21	0.00
8	127.52	0.5	1	-1	1.6069	535.66	1.61E-03	40.8093	60.90	0.00	0.00	0.00	0.00
9	151.84	0.5	4	0	1.8595	639.79	1.09E-03	42.6969	89.71	0.00	105.17	105.17	0.00
10	151.84	0.5	4	0	1.8595	639.79	1.09E-03	42.6969	89.71	0.00	0.00	0.00	0.00
11a	XXXXXXXXXX	1.0	XXXXXXXXXXXXXXXXXXXX	XXXXXXXXX	1.8595	640.68	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX
11	152.05	1.0	1	-1	1.8602	640.98	1.85E-03	42.6969	90.69	-50.71	-41.70	9.01	0.00
12	152.05	1.0	1	-1	1.8602	640.98	1.85E-03	42.6969	90.69	0.00	0.00	0.00	0.00
13	179.87	1.0	4	0	2.1367	762.23	1.13E-03	45.0000	129.50	0.00	146.05	146.05	0.00
14	179.87	1.0	4	0	2.1367	762.23	1.13E-03	45.0000	129.50	0.00	0.00	0.00	0.00
15a	XXXXXXXXXX	10.0	XXXXXXXXXXXXXXXXXXXX	XXXXXXXXX	2.1367	774.06	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX
15	182.43	10.0	1	-1	2.1453	778.01	1.13E-03	45.0000	142.70	-709.88	-594.04	115.84	0.00
16	182.43	10.0	1	-1	2.1453	778.01	1.13E-03	45.0000	142.70	0.00	0.00	0.00	0.00
17	400.00	10.0	3	-1	6.2158	3099.05	2.64E-02	45.0000	1250.12	0.00	18855.94	18855.94	104447.00
18	400.00	10.0	3	-1	6.2158	3099.05	2.64E-02	45.0000	1250.12	0.00	0.00	0.00	0.00
19a	XXXXXXXXXX	8.0	XXXXXXXXXXXXXXXXXXXX	XXXXXXXXX	6.2158	3041.48	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX
19	371.03	8.0	3	-1	6.2382	3055.87	3.19E-02	2.0000	1200.26	1942.95	2243.72	300.76	0.00
20a	XXXXXXXXXX	6.0	XXXXXXXXXXXXXXXXXXXX	XXXXXXXXX	6.2382	2984.70	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX
20	335.76	6.0	3	-1	6.2676	3002.49	4.07E-02	43.0000	1138.13	2295.43	2671.86	376.42	0.00
21	335.76	6.0	3	-1	6.2676	3002.49	4.07E-02	43.0000	1138.13	0.00	0.00	0.00	0.00
22a	XXXXXXXXXX	4.0	XXXXXXXXXXXXXXXXXXXX	XXXXXXXXX	6.2676	2907.84	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX
22	289.76	4.0	3	-1	6.3099	2931.50	5.72E-02	2.0000	1054.52	3052.46	3595.15	542.69	0.00
23a	XXXXXXXXXX	3.0	XXXXXXXXXXXXXXXXXXXX	XXXXXXXXX	6.3099	2867.76	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX
23	259.48	3.0	3	-1	6.3400	2883.69	7.28E-02	41.0000	997.74	1960.24	2327.84	367.60	0.00
24	259.48	3.0	3	-1	6.3400	2883.69	7.28E-02	41.0000	997.74	0.00	0.00	0.00	0.00

Benchmark Case #4 (Cont'd)

Node	Temperature (Deg C)	Pressure (MPa)	Fluid Phase (-)	Quality (-)	Entropy (KJ/Kg/K)	Enthalphy (KJ/Kg)	Spec Vol (m^3/kg)	Mass Flow Rate (Kg/sec)	Aval (Kg/Kg)	Actual Work (KW)	Rev Work (KW)	Irrev (KW)	Heat X-Fer (KW)
25	400.00	3.0	3	-1	6.9215	3230.96	9.94E-02	41.0000	1171.65	0.00	1810.06	1810.06	14238.07
26	400.00	3.0	3	-1	6.9215	3230.96	9.94E-02	41.0000	1171.65	0.00	0.00	0.00	0.00
27a	XXXXXXXXXX	2.0	XXXXXXXXXXXXXXXXXX	XXXXXXXXX	6.9215	3115.42	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX
27	353.22	2.0	3	-1	6.9681	3144.31	1.39E-01	2.0000	1071.10	3552.82	4122.45	569.62	0.00
28a	XXXXXXXXXX	1.0	XXXXXXXXXXXXXXXXXX	XXXXXXXXX	6.9681	2965.48	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX
28	280.89	1.0	3	-1	7.0503	3010.18	2.49E-01	2.3031	912.46	5230.89	6187.12	956.23	0.00
29	280.89	1.0	3	-1	7.0503	3010.18	2.49E-01	2.3031	912.46	0.00	0.00	0.00	0.00
30a	XXXXXXXXXX	0.5	XXXXXXXXXXXXXXXXXX	XXXXXXXXX	7.0503	2851.07	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX
30	216.57	0.5	3	-1	7.1331	2890.85	4.42E-01	1.8876	768.43	4378.12	5285.21	906.09	0.00
31	216.57	0.5	3	-1	7.1331	2890.85	4.42E-01	1.8876	768.43	0.00	0.00	0.00	0.00
32a	XXXXXXXXXX	0.25	XXXXXXXXXXXXXXXXXX	XXXXXXXXX	7.1331	2749.65	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX
32	153.45	0.25	3	-1	7.2183	2784.95	7.83E-01	3.2458	637.72	3686.26	4549.88	863.62	0.00
33	153.45	0.25	3	-1	7.2183	2784.95	7.83E-01	3.2458	637.72	0.00	0.00	0.00	0.00
34a	XXXXXXXXXX	0.05	XXXXXXXXXXXXXXXXXX	XXXXXXXXX	7.2183	2512.06	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXX
34	81.35	0.05	2	0.9715	7.4088	2580.28	3.15E+00	31.5634	375.67	6460.17	8271.24	1811.08	0.00
35	81.35	0.05	2	0.9715	7.4088	2580.28	3.15E+00	31.5634	375.67	0.00	0.00	0.00	0.00
36	353.22	2.0	3	-1	6.9681	3144.31	1.39E-01	2.0000	1071.10	0.00	0.00	0.00	0.00
37	81.35	0.05	2	0.9715	7.4088	2580.28	3.15E+00	2.0000	375.67	0.00	1390.86	1390.86	-1128.06
38	81.35	0.05	2	0.9715	7.4088	2580.28	3.15E+00	2.0000	375.67	0.00	0.00	0.00	0.00
39	81.35	0.05	2	0.9715	7.4088	2580.28	3.15E+00	2.0000	375.67	0.00	0.00	0.00	0.00
40	81.35	0.05	2	0.9715	7.4088	2580.28	3.15E+00	2.0000	375.67	0.00	1357.69	1357.69	-702.45
41	289.76	4.0	3	-1	6.3099	2931.50	5.72E-02	2.0000	1054.52	0.00	0.00	0.00	0.00
42	371.03	8.0	3	-1	6.2382	3055.87	3.19E-02	2.0000	1200.26	0.00	0.00	0.00	0.00
43	81.35	0.05	2	0.9715	7.4088	2580.28	3.15E+00	2.0000	375.67	0.00	1649.18	1649.18	-951.18
44	81.35	0.05	2	0.9715	7.4088	2580.28	3.15E+00	2.0000	375.67	0.00	0.00	0.00	0.00

Total boiler heat=	118685.07	KW
Total condenser heat=	-84138.73	KW
Heat load #1 heat =	-951.19	KW
Heat load #2 heat =	-702.45	KW
Heat load #3 heat =	-1128.06	KW
Trb #1 Stg Grp #1 work=	1942.95	KW
Trb #1 Stg Grp #2 work=	2295.43	KW
Trb #2 Stg Grp #1 work=	3052.46	KW
Trb #2 Stg Grp #2 work=	1960.24	KW
Trb #3 Stg Grp #1 work=	3552.82	KW
Trb #3 Stg Grp #2 work=	5230.89	KW
Trb #3 Stg Grp #3 work=	4379.12	KW
Trb #3 Stg Grp #4 work=	3686.26	KW
Trb #3 Stg Grp #5 work=	6460.17	KW
Actual turbine work=	32569.3	KW
Pump #1 work=	-11.77	KW
Pump #2 work=	-23.34	KW
Pump #3 work=	-50.71	KW
Pump #4 work=	-709.88	KW
Total net work=	31764.8	KW
1st law thermal eff=	26.7638	Percent
Carnot cycle eff=	55.7082	Percent
adj boiler heat=	68117.4	KW
Aval produced by system=	6851.8	KW
Aval supplied to system=	2254.0	KW
2nd law eff=	56.6919	Percent
2nd law effectiveness=	48.0428	Percent

Benchmark Case #5

P17=	20.0	MPa	TRB #1 Stg Grp #1 eff=	0.75	(-)	PL 17-18=	0.0 MPa
T17=	600.0	Deg C	TRB #1 Stg Grp #2 eff=	0.75	(-)	PL 20-21=	0.0 MPa
M17=	50.0	Kg/sec	TRB #2 Stg Grp #1 eff=	0.75	(-)	PL 22-23=	0.0 MPa
P18=	15.0	MPa	TRB #2 Stg Grp #2 eff=	0.75	(-)	PL 25-26=	0.0 MPa
M18=	1.0	Kg/sec	TRB #3 Stg Grp #1 eff=	0.75	(-)	PL 27-28=	0.0 MPa
P20=	10.0	MPa	TRB #3 Stg Grp #2 eff=	0.75	(-)	PL 30-31=	0.0 MPa
T22=	600.0	Deg C	TRB #3 Stg Grp #3 eff=	0.75	(-)	PL 32-33=	0.0 MPa
P24=	7.5	MPa	TRB #3 Stg Grp #4 eff=	0.75	(-)	PL 34-35=	0.0 MPa
M24=	50.0	Kg/sec	TRB #3 Stg Grp #5 eff=	0.75	(-)	PL 36-37=	0.0 MPa
P25=	5.0	MPa	Pump #1 eff=	0.75	(-)	PL 1-2=	0.0 MPa
T27=	600.0	Deg C	Pump #2 eff=	0.75	(-)	PL 3-4=	0.0 MPa
P29=	2.5	MPa	Pump #3 eff=	0.75	(-)	PL 5-6=	0.0 MPa
M29=	5.0	Kg/sec	Pump #4 eff=	0.75	(-)	PL 7-8=	0.0 MPa
P30=	1.0	MPa	T dead=	298.15	Kelvin	PL 9-10=	0.0 MPa
P32=	0.5	MPa	P dead=	0.101	MPa	PL 11-12=	0.0 MPa
P34=	0.25	MPa	h dead=	105.1	KJ/Kg	PL 13-14=	0.0 MPa
P36=	0.1	MPa	S dead=	3.67E-01	KJ/Kg/K	PL 15-16=	0.0 MPa
T39=	175.7	Deg C	T low=	298.15	Kelvin	PL 19-38=	0.0 MPa
T41=	175.7	Deg C	T high=	873.15	Kelvin	PL 38-44=	0.0 MPa
T43=	175.7	Deg C				PL 24-40=	0.0 MPa
						PL 41-45=	0.0 MPa
						PL 29-42=	0.0 MPa
						PL 43-46=	0.0 MPa
						Saher PL=	0.0 MPa
						Reheat leg #1 PL=	0.0 MPa
						Reheat leg #2 PL=	0.0 MPa

OL 17-18=	0.0	KJ/Kg										
OL 20-21=	0.0	KJ/Kg										
OL 22-23=	0.0	KJ/Kg										
OL 25-26=	0.0	KJ/Kg										
OL 27-28=	0.0	KJ/Kg										
OL 30-31=	0.0	KJ/Kg										
OL 32-33=	0.0	KJ/Kg										
OL 34-35=	0.0	KJ/Kg										
OL 36-37=	0.0	KJ/Kg										
OL 1-2=	0.0	KJ/Kg										
OL 3-4=	0.0	KJ/Kg										
OL 5-6=	0.0	KJ/Kg										
OL 7-8=	0.0	KJ/Kg										
OL 9-10=	0.0	KJ/Kg										
OL 11-12=	0.0	KJ/Kg										
OL 13-14=	0.0	KJ/Kg										
OL 15-16=	0.0	KJ/Kg										
OL 19-38=	0.0	KJ/Kg										
OL 39-44=	0.0	KJ/Kg										
OL 24-40=	0.0	KJ/Kg										
OL 41-45=	0.0	KJ/Kg										
OL 29-42=	0.0	KJ/Kg										
OL 43-46=	0.0	KJ/Kg										

Node	Temperature (Deg C)	Pressure (MPa)	Fluid Phase (-)	Quality (-)	Entropy (KJ/Kg/K)	Enthalpy (KJ/Kg)	Specific Volume (m^3/kg)	Mass flow rate (Kg/sec)	Aval (KJ/Kg)	Actual Work (KW)	Rev Work (KW)	Irrev (KW)	Heat X-Fer (KW)
1	99.83	0.10	4	0.00	1.3020	417.31	1.04E-03	43.6477	33.4476723	0.00	21536.97		-105200.30
2	99.83	0.10	4	0.00	1.3020	417.31	1.04E-03	43.6477	33.4476723	0.00	0.00	0.00	0.00
3a	XXXXXXXXXXX	0.25	XXXXXXXXXXXXXXXXX	XXXXXXXXXX	1.3020	417.52	XXXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX
3	99.88	0.25	1	-1.00	1.3022	417.60	1.04E-03	43.6477	33.6752571	-12.64	-9.93	2.71	0.00
4	99.88	0.25	1	-1.00	1.3022	417.60	1.04E-03	43.6477	33.6752571	0.00	0.00	0.00	0.00
5	127.43	0.25	4	0.00	1.6065	535.09	1.07E-03	45.7484	60.4276231	0.00	196.35	196.35	0.00
6	127.43	0.25	4	0.00	1.6065	535.09	1.07E-03	45.7484	60.4276231	0.00	0.00	0.00	0.00
7a	XXXXXXXXXXX	0.50	XXXXXXXXXXXXXXXXX	XXXXXXXXXX	1.6065	535.52	XXXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX
7	127.52	0.50	1	-1.00	1.6069	535.66	1.07E-03	45.7484	60.8963299	-26.16	-21.44	4.72	0.00
8	127.52	0.50	1	-1.00	1.6069	535.66	1.07E-03	45.7484	60.8963299	0.00	0.00	0.00	0.00
9	151.84	0.50	4	0.00	1.8595	639.79	1.09E-03	47.6792	89.7135325	0.00	178.98	178.98	0.00
10	151.84	0.50	4	0.00	1.8595	639.79	1.09E-03	47.6792	89.7135325	0.00	0.00	0.00	0.00
11a	XXXXXXXXXXX	1.00	XXXXXXXXXXXXXXXXX	XXXXXXXXXX	1.8595	640.68	XXXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX
11	152.05	1.00	1	-1.00	1.8602	640.98	1.09E-03	47.6792	90.6901756	-58.63	-46.57	10.06	0.00
12	152.05	1.00	1	-1.00	1.8602	640.98	1.09E-03	47.6792	90.6901756	0.00	0.00	0.00	0.00
13	179.87	1.00	4	0.00	2.1367	762.23	1.13E-03	50.0000	129.502297	0.00	255.04	255.04	0.00
14	179.87	1.00	4	0.00	2.1367	762.23	1.13E-03	50.0000	129.502297	0.00	0.00	0.00	0.00
15a	XXXXXXXXXXX	20.00	XXXXXXXXXXXXXXXXX	XXXXXXXXXX	2.1367	786.36	XXXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX
15	185.00	20.00	1	-1.00	2.1542	794.40	1.13E-03	50.0000	156.437553	-1608.30	-1346.76	261.54	0.00
16	185.00	20.00	1	-1.00	2.1542	794.40	1.13E-03	50.0000	156.437553	0.00	0.00	0.00	0.00
17	600.00	20.00	3	-1.00	6.5052	3536.61	1.81E-02	50.0000	1601.41749	0.00	52840.50	52840.50	137110.62
18	600.00	20.00	3	-1.00	6.5052	3536.61	1.81E-02	50.0000	1601.41749	0.00	0.00	0.00	0.00
19s	XXXXXXXXXXX	15.00	XXXXXXXXXXXXXXXXX	XXXXXXXXXX	6.5052	3435.76	XXXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX
19	554.33	15.00	3	-1.00	6.5358	3460.98	2.30E-02	1.0000	1516.64604	3781.69	4238.57	456.89	0.00
20s	XXXXXXXXXXX	10.00	XXXXXXXXXXXXXXXXX	XXXXXXXXXX	6.5358	3326.85	XXXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX
20	494.42	10.00	3	-1.00	6.5799	3360.38	3.24E-02	49.0000	1402.91891	4928.96	5572.63	643.67	0.00
21	494.42	10.00	3	-1.00	6.5799	3360.38	3.24E-02	49.0000	1402.91891	0.00	0.00	0.00	0.00
22	500.00	10.00	3	-1.00	6.8991	3621.73	3.83E-02	49.0000	1569.09921	0.00	850.43	850.43	12806.04
23	500.00	10.00	3	-1.00	6.8991	3621.73	3.83E-02	49.0000	1569.09921	0.00	0.00	0.00	0.00
24s	XXXXXXXXXXX	7.50	XXXXXXXXXXXXXXXXX	XXXXXXXXXX	6.8991	3514.96	XXXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX

Benchmark Case #5 (Cont'd)

Node	Temperature (Deg C)	Pressure (MPa)	Fluid Phase (-)	Quality (-)	Entropy (KJ/Kg/K)	Enthalpy (KJ/Kg)	Specific Volume (m^3/kg)	Mass flow rate (Kg/sec)	Avail (KJ/Kg)	Actual Work (KW)	Rev Work (KW)	Irrev (KW)	Heat X-Fer (KW)
24	557.45	7.50	3	-1.00	6.9314	3541.65	4.88E-02	5.0000	1479.36862	3924.05	4396.80	472.74	0.00
25a	XXXXXXXXXX	5.00	XXXXXXXXXXXXXXXXXX	XXXXXXXXXX	6.9314	3399.64	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX
25	501.09	5.00	3	-1.00	6.9777	3435.14	6.86E-02	44.0000	1359.05136	4686.37	5293.96	607.59	0.00
26	501.09	5.00	3	-1.00	6.9777	3435.14	6.86E-02	44.0000	1359.05136	0.00	0.00	0.00	0.00
27	600.00	5.00	3	-1.00	7.2540	3662.39	7.86E-02	44.0000	1503.94286	0.00	613.12	613.12	9998.83
28	600.00	5.00	3	-1.00	7.2540	3662.39	7.86E-02	44.0000	1503.94286	0.00	0.00	0.00	0.00
29a	XXXXXXXXXX	2.50	XXXXXXXXXXXXXXXXXX	XXXXXXXXXX	7.2540	3409.27	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX
29	395.43	2.50	3	-1.00	7.3367	3472.55	1.41E-01	5.0000	1289.42126	8352.93	9438.95	1086.02	0.00
30a	XXXXXXXXXX	1.00	XXXXXXXXXXXXXXXXXX	XXXXXXXXXX	7.3367	3180.34	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX
30	395.43	1.00	3	-1.00	7.4490	3253.39	3.04E-01	2.3208	1036.78231	8547.08	9852.92	1305.84	0.00
31	395.43	1.00	3	-1.00	7.4490	3253.39	3.04E-01	2.3208	1036.78231	0.00	0.00	0.00	0.00
32a	XXXXXXXXXX	0.50	XXXXXXXXXXXXXXXXXX	XXXXXXXXXX	7.4490	3057.92	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX
32	320.88	0.50	3	-1.00	7.5329	3106.79	5.43E-01	1.9309	865.175785	5377.38	6284.40	917.02	0.00
33	320.88	0.50	3	-1.00	7.5329	3106.79	5.43E-01	1.9309	865.175785	0.00	0.00	0.00	0.00
34a	XXXXXXXXXX	0.25	XXXXXXXXXXXXXXXXXX	XXXXXXXXXX	7.5329	2933.03	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX
34	253.69	0.25	3	-1.00	7.6171	2976.47	9.65E-01	2.1007	709.764827	4528.32	5400.28	871.97	0.00
35	253.69	0.25	3	-1.00	7.6171	2976.47	9.65E-01	2.1007	709.764827	0.00	0.00	0.00	0.00
36a	XXXXXXXXXX	0.10	XXXXXXXXXXXXXXXXXX	XXXXXXXXXX	7.6171	2777.86	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX
36	175.86	0.10	3	-1.00	7.7309	2827.51	2.06E+00	32.6477	526.865775	4863.20	5971.23	1108.03	0.00
37	175.86	0.10	3	-1.00	7.7309	2827.51	2.06E+00	32.6477	526.865775	0.00	0.00	0.00	0.00
38	554.33	15.00	3	-1.00	6.5358	3460.98	2.30E-02	1.0000	1518.64604	0.00	0.00	0.00	0.00
39	175.70	0.10	3	-1.00	7.7309	2827.55	2.06E+00	1.0000	526.906495	0.00	989.74	989.74	-633.43
40	557.45	7.50	3	-1.00	6.9314	3541.65	4.88E-02	5.0000	1479.36862	0.00	0.00	0.00	0.00
41	175.70	0.10	3	-1.00	7.7309	2827.55	2.06E+00	5.0000	526.901495	0.00	4762.34	4762.34	-3570.52
42	505.87	2.50	3	-1.00	7.3367	3472.55	1.41E-01	5.0000	1289.42126	0.00	0.00	0.00	0.00
43	175.70	0.10	3	-1.00	7.7309	2827.55	2.06E+00	5.0000	526.901495	0.00	3812.60	3812.60	-3225.01
44	175.70	0.10	3	-1.00	7.7309	2827.55	2.06E+00	1.0000	526.906495	0.00	0.00	0.00	0.00
45	175.70	0.10	3	-1.00	7.7309	2827.55	2.06E+00	5.0000	526.901495	0.00	0.00	0.00	0.00
46	175.70	0.10	3	-1.00	7.7309	2827.55	2.06E+00	5.0000	526.901495	0.00	0.00	0.00	0.00

Total boiler heat=	159915.49	KW
Total condenser heat=	-105200.30	KW
Heat load #1 heat =	-633.43	KW
Heat load #2 heat =	-3570.52	KW
Heat load #3 heat =	-3225.01	KW
Trb #1 Stg Grp #1 wk=	3781.69	KW
Trb #1 Stg Grp #2 wk=	4928.95	KW
Trb #2 Stg Grp #1 wk=	3924.05	KW
Trb #2 Stg Grp #2 wk=	4686.37	KW
Trb #3 Stg Grp #1 wk=	8352.93	KW
Trb #3 Stg Grp #2 wk=	8547.08	KW
Trb #3 Stg Grp #3 wk=	5377.38	KW
Trb #3 Stg Grp #4 wk=	4528.32	KW
Trb #3 Stg Grp #5 wk=	4863.20	KW
Actual turbine work=	48989.97	KW
Pump #1 work=	-12.64	KW
Pump #2 work=	-26.16	KW
Pump #3 work=	-56.63	KW
Pump #4 work=	-1608.30	KW
Total net work=	47286.23	KW
1st law eff=	29.5695	Percent
Carnot cycle eff=	65.8535	Percent
adj boiler heat=	105310.0	KW
Avail prod by system=	15360.5	KW
Avail supp to system=	5795.9	KW
2nd law eff=	57.0435	Percent
2nd law effectiveness=	44.9020	Percent

Appendix E:

RANKINE 3.0 input files for benchmark case #1 through case #5

```
TITLE LINE
  BENCHMARK CASE #1
  END TITLE

NUMBER OF NODES IS 4
HIGH TEMPERATURE RESERVOIR: 600.0 DEG C
LOW TEMPERATURE RESERVOIR: 25.0 DEG C
DEAD STATE TEMPERATURE: 25.0 DEG C
DEAD STATE PRESSURE: 101 KPA
GENERATOR MECHANICAL LOSS IS 0.0 MW
GENERATOR ELECTRICAL LOSS IS 0.0 MW

DEVICE #1:  SIMPLE TURBINE
  INLET NODE NUMBER IS 3
  EXTRACTION #1 NODE NUMBER IS 4
  STAGE GROUP #1 EFFICIENCY IS 75
PERCENT
  EXTRACTION #1 PRESSURE IS 0.1 MPA
  END DEVICE

DEVICE #2: SIMPLE CONDENSER
  EXIT NODE NUMBER IS 1
  INLET #1 NODE NUMBER IS 4
  END DEVICE

DEVICE #3:  SIMPLE PUMP
  SUCTION NODE NUMBER IS 1
  DISCHARGE NODE NUMBER IS 2
  PUMP EFFICIENCY IS 75 PERCENT
  END DEVICE

DEVICE #4: SIMPLE BOILER
  BOILER INLET NODE NUMBER IS 2
  BOILER EXIT NODE NUMBER IS 3
  BOILER EXIT PRESSURE IS 20.0 MPA
  BOILER EXIT TEMPERATURE IS 600 DEG C
  BOILER EXIT MASS FLOW RATE IS 50
KG/SEC
  BOILER PRESSURE LOSS IS 0.0 MPA
  END DEVICE
```

```
TITLE LINE
  BENCHMARK CASE #2
  END TITLE

NUMBER OF NODES IS 21
HIGH TEMPERATURE RESERVOIR: 500.0 DEG C
LOW TEMPERATURE RESERVOIR: 25.0 DEG C
DEAD STATE TEMPERATURE: 25.0 DEG C
DEAD STATE PRESSURE:101 KPA
GENERATOR MECHANICAL LOSS: 0.0 MW
GENERATOR ELECTRICAL LOSS: 0.0 MW

DEVICE #1:  SIMPLE TURBINE
  INLET NODE NUMBER IS 10
  EXTRACTION #1 NODE NUMBER IS 11
  EXTRACTION #2 NODE NUMBER IS 12
  EXTRACTION #3 NODE NUMBER IS 14
  STAGE GROUP #1 EFFICIENCY IS 75
PERCENT
  STAGE GROUP #2 EFFICIENCY IS 75
PERCENT
  STAGE GROUP #3 EFFICIENCY IS 75
PERCENT
  EXTRACTION #1 PRESSURE IS 8.0 MPA
  EXTRACTION #1 MASS FLOW RATE IS 5.0
KG/SEC
  EXTRACTION #2 PRESSURE IS 6.0 MPA
  EXTRACTION #3 PRESSURE IS 4.0 MPA
  END DEVICE

DEVICE #2:  SIMPLE PUMP
  SUCTION NODE NUMBER IS 2
  DISCHARGE NODE NUMBER IS 3
  PUMP EFFICIENCY IS 75 PERCENT
  END DEVICE

DEVICE #3: SIMPLE PUMP
  SUCTION NODE NUMBER IS 6
  DISCHARGE NODE NUMBER IS 7
  PUMP EFFICIENCY IS 75 PERCENT
  END DEVICE

DEVICE #4: SIMPLE PIPE
  INLET NODE NUMBER IS 14
  EXIT NODE NUMBER IS 15
  PIPE PRESSURE LOSS IS 0.0 MPA
  PIPE ENTHALPY LOSS IS 0.0 KJ/KG
  END DEVICE

DEVICE #5: SIMPLE PIPE
  INLET NODE NUMBER IS 12
  EXIT NODE NUMBER IS 13
  PIPE PRESSURE LOSS IS 0.0 MPA
  PIPE ENTHALPY LOSS IS 0.0 KJ/KG
  END DEVICE

DEVICE #6: SIMPLE PIPE
  INLET NODE NUMBER IS 1
  EXIT NODE NUMBER IS 2
  PIPE PRESSURE LOSS IS 0.0 MPA
  PIPE ENTHALPY LOSS IS 0.0 KJ/KG
  END DEVICE

DEVICE #7: SIMPLE PIPE
  INLET NODE NUMBER IS 3
  EXIT NODE NUMBER IS 4
  PIPE PRESSURE LOSS IS 0.0 MPA
  PIPE ENTHALPY LOSS IS 0.0 KJ/KG
  END DEVICE

DEVICE #8: SIMPLE PIPE
  INLET NODE NUMBER IS 5
  EXIT NODE NUMBER IS 6
  PIPE PRESSURE LOSS IS 0.0 MPA
  PIPE ENTHALPY LOSS IS 0.0 KJ/KG
  END DEVICE

DEVICE #9: SIMPLE PIPE
  INLET NODE NUMBER IS 7
  EXIT NODE NUMBER IS 8
  PIPE PRESSURE LOSS IS 0.0 MPA
  PIPE ENTHALPY LOSS IS 0.0 KJ/KG
  END DEVICE

DEVICE #10: SIMPLE PIPE
  INLET NODE NUMBER IS 9
  EXIT NODE NUMBER IS 16
  PIPE PERCENTAGE PRESSURE LOSS 0.0
PERCENT
  PIPE PERCENTAGE ENTHALPY LOSS 0.0
PERCENT
  END DEVICE

DEVICE #11: SIMPLE PIPE
  INLET NODE NUMBER IS 11
  EXIT NODE NUMBER IS 19
  PIPE PRESSURE LOSS IS 0.0 MPA
  PIPE ENTHALPY LOSS IS 0.0 KJ/KG
  END DEVICE

DEVICE #12: SIMPLE PIPE
  INLET NODE NUMBER IS 20
  EXIT NODE NUMBER IS 21
  PIPE PRESSURE LOSS IS 0.0 MPA
  PIPE ENTHALPY LOSS IS 0.0 KJ/KG
  END DEVICE

DEVICE #13: SIMPLE PIPE
  INLET NODE NUMBER IS 18
  EXIT NODE NUMBER IS 10
  PIPE PRESSURE LOSS IS 0.0 MPA
  PIPE ENTHALPY LOSS IS 0.0 KJ/KG
  END DEVICE

DEVICE #14: SIMPLE JUNCTION
  INLET #1 NODE NUMBER IS 16
  EXIT #1 NODE NUMBER IS 17
  EXIT #2 NODE NUMBER IS 18
  EXIT #1 MASS FLOW RATE IS 0.0 KG/SEC
  END DEVICE

DEVICE #15: SIMPLE CONDENSER
  EXIT NODE NUMBER IS 1
  INLET #1 NODE NUMBER IS 15
  INLET #2 NODE NUMBER IS 21
  END DEVICE
```

```
  END DEVICE

DEVICE #16: SIMPLE HEAT LOAD
  INLET NODE NUMBER IS 19
  EXIT NODE NUMBER IS 20
  EXIT TEMPERATURE IS 380.21 DEG C
  END DEVICE

DEVICE #17: SIMPLE OFW HEATER
  FEED WATER EXIT NODE NUMBER IS 5
  EXTRACTION INLET NODE NUMBER IS 13
  FEED WATER INLET NODE NUMBER IS 4

DEVICE #18: SIMPLE BOILER
  BOILER INLET NODE NUMBER IS 8
  BOILER EXIT NODE NUMBER IS 9
  BOILER EXIT PRESSURE IS 10 MPA
  BOILER EXIT TEMPERATURE IS 500 DEG C
  BOILER EXIT MASS FLOW RATE IS 25
KG/SEC
  BOILER PRESSURE LOSS IS 0.0 MPA
  END DEVICE
```

```
TITLE LINE
  BENCHMARK CASE #3
  END TITLE LINE

NUMBER OF NODES IS 36
HIGH TEMPERATURE RESERVOIR: 500 DEG C
LOW TEMPERATURE RESERVOIR: 25.0 DEG C
DEAD STATE TEMPERATURE: 25.0 DEG C
DEAD STATE PRESSURE: 101 KPA
GENERATOR MECHANICAL LOSS: 0.0 MW
GENERATOR ELECTRICAL LOSS: 0.0 MW

DEVICE #1: SIMPLE BOILER
  BOILER INLET NODE NUMBER IS 16
  BOILER EXIT NODE NUMBER IS 17
  BOILER EXIT TEMPERATURE IS 500 DEG C
  BOILER EXIT PRESSURE IS 10.0 MPA
  BOILER EXIT MASS FLOW RATE IS 22.0
KG/SEC
  BOILER PRESSURE LOSS IS 0.0 MPA
  END DEVICE

DEVICE #2: SIMPLE PIPE
  INLET NODE NUMBER IS 17
  EXIT NODE NUMBER IS 18
  PIPE PRESSURE LOSS 0.0 MPA
  PIPE ENTHALPY LOSS 0.0 KJ/KG
  END DEVICE

DEVICE #3: SIMPLE TURBINE
  INLET NODE NUMBER IS 18
  EXTRACTION #1 NODE NUMBER IS 19
  EXTRACTION #2 NODE NUMBER IS 20
  EXTRACTION #1 PRESSURE IS 8.0 MPA
  EXTRACTION #2 PRESSURE IS 6.0 MPA
  EXTRACTION #1 MASS FLOW RATE IS 2.0
KG/SEC
  STAGE GROUP #1 EFFICIENCY IS 50%
  STAGE GROUP #2 EFFICIENCY IS 50%
  END DEVICE

DEVICE #4: SIMPLE PIPE
  INLET NODE NUMBER IS 20
  EXIT NODE NUMBER IS 21
  PIPE PRESSURE LOSS 0.0 MPA
  PIPE ENTHALPY LOSS 0.0 KJ/KG
  END DEVICE

DEVICE #5: SIMPLE TURBINE
  INLET NODE NUMBER IS 21
  EXTRACTION #1 NODE NUMBER IS 22
  EXTRACTION #2 NODE NUMBER IS 23
  EXTRACTION #3 NODE NUMBER IS 25
  EXTRACTION #4 NODE NUMBER IS 27
  EXTRACTION #5 NODE NUMBER IS 29
  EXTRACTION #1 PRESSURE IS 4.0 MPA
  EXTRACTION #2 PRESSURE IS 3.0 MPA
  EXTRACTION #3 PRESSURE IS 2.0 MPA
  EXTRACTION #4 PRESSURE IS 1.5 MPA
  EXTRACTION #5 PRESSURE IS 1.0 MPA
  EXTRACTION #1 MASS FLOW RATE IS 2.0
KG/SEC
  STAGE GROUP #1 EFFICIENCY IS 50%
  STAGE GROUP #2 EFFICIENCY IS 50%
  STAGE GROUP #3 EFFICIENCY IS 50%
  STAGE GROUP #4 EFFICIENCY IS 50%
  STAGE GROUP #5 EFFICIENCY IS 50%
  END DEVICE

DEVICE #6: SIMPLE PIPE
  INLET NODE NUMBER IS 23
  EXIT NODE NUMBER IS 24
  PIPE PRESSURE LOSS 0.0 MPA
  PIPE ENTHALPY LOSS 0.0 KJ/KG
  END DEVICE

DEVICE #7: SIMPLE PIPE
  INLET NODE NUMBER IS 25
  EXIT NODE NUMBER IS 26
  PIPE PRESSURE LOSS 0.0 MPA
  PIPE ENTHALPY LOSS 0.0 KJ/KG
  END DEVICE

DEVICE #8: SIMPLE PIPE
  INLET NODE NUMBER IS 27
  EXIT NODE NUMBER IS 28
  PIPE PRESSURE LOSS 0.0 MPA
  PIPE ENTHALPY LOSS 0.0 KJ/KG
  END DEVICE

DEVICE #9: SIMPLE PIPE
  INLET NODE NUMBER IS 29
  EXIT NODE NUMBER IS 30
  PIPE PRESSURE LOSS 0.0 MPA
  PIPE ENTHALPY LOSS 0.0 KJ/KG
  END DEVICE

DEVICE #10: SIMPLE CONDENSER
  EXIT NODE NUMBER IS 1
  INLET #1 NODE NUMBER IS 30
  INLET #2 NODE NUMBER IS 35
  INLET #3 NODE NUMBER IS 36
  END DEVICE

DEVICE #11: SIMPLE PIPE
  INLET NODE NUMBER IS 1
  EXIT NODE NUMBER IS 2
  PIPE PRESSURE LOSS 0.0 MPA
  PIPE ENTHALPY LOSS 0.0 KJ/KG
  END DEVICE

DEVICE #12: SIMPLE PUMP
  SUCTION NODE NUMBER IS 2
  DISCHARGE NODE NUMBER IS 3
  PUMP EFFICIENCY IS 50%
  END DEVICE

DEVICE #13: SIMPLE PIPE
  INLET NODE NUMBER IS 3
  EXIT NODE NUMBER IS 4
  PIPE PRESSURE LOSS 0.0 MPA
  PIPE ENTHALPY LOSS 0.0 KJ/KG
  END DEVICE

DEVICE #14: SIMPLE OFW HEATER
  FEED WATER EXIT NODE NUMBER IS 5
```

EXTRACTION INLET NODE NUMBER IS 28
FEED WATER INLET NODE NUMBER IS 4
END DEVICE

DEVICE #15: SIMPLE PIPE
INLET NODE NUMBER IS 5
EXIT NODE NUMBER IS 6
PIPE PRESSURE LOSS 0.0 MPA
PIPE ENTHALPY LOSS 0.0 KJ/KG
END DEVICE

DEVICE #16: SIMPLE PUMP
SUCTION NODE NUMBER IS 6
DISCHARGE NODE NUMBER IS 7
PUMP EFFICIENCY IS 50%
END DEVICE

DEVICE #17: SIMPLE PIPE
INLET NODE NUMBER IS 7
EXIT NODE NUMBER IS 8
PIPE PRESSURE LOSS 0.0 MPA
PIPE ENTHALPY LOSS 0.0 KJ/KG
END DEVICE

DEVICE #18: SIMPLE OFW HEATER
FEED WATER EXIT NODE NUMBER IS 9
EXTRACTION INLET NODE NUMBER IS 26
FEED WATER INLET NODE NUMBER IS 8
END DEVICE

DEVICE #19: SIMPLE PIPE
INLET NODE NUMBER IS 9
EXIT NODE NUMBER IS 10
PIPE PRESSURE LOSS 0.0 MPA
PIPE ENTHALPY LOSS 0.0 KJ/KG
END DEVICE

DEVICE #20: SIMPLE PUMP
SUCTION NODE NUMBER IS 10
DISCHARGE NODE NUMBER IS 11
PUMP EFFICIENCY IS 50%
END DEVICE

DEVICE #21: SIMPLE PIPE
INLET NODE NUMBER IS 11
EXIT NODE NUMBER IS 12
PIPE PRESSURE LOSS 0.0 MPA
PIPE ENTHALPY LOSS 0.0 KJ/KG
END DEVICE

DEVICE #22: SIMPLE OFW HEATER
FEED WATER EXIT NODE NUMBER IS 13
EXTRACTION INLET NODE NUMBER IS 24
FEED WATER INLET NODE NUMBER IS 12
END DEVICE

DEVICE #23: SIMPLE PIPE
INLET NODE NUMBER IS 13
EXIT NODE NUMBER IS 14
PIPE PRESSURE LOSS 0.0 MPA
PIPE ENTHALPY LOSS 0.0 KJ/KG
END DEVICE

DEVICE #24: SIMPLE PUMP
SUCTION NODE NUMBER IS 14
DISCHARGE NODE NUMBER IS 15
PUMP EFFICIENCY IS 50 %
END DEVICE

DEVICE #25: SIMPLE PIPE
INLET NODE NUMBER IS 15
EXIT NODE NUMBER IS 16
PIPE PRESSURE LOSS 0.0 MPA
PIPE ENTHALPY LOSS 0.0 KJ/KG
END DEVICE

DEVICE #26: SIMPLE PIPE
INLET NODE NUMBER IS 22
EXIT NODE NUMBER IS 33
PIPE PRESSURE LOSS 0.0 MPA
PIPE ENTHALPY LOSS 0.0 KJ/KG
END DEVICE

DEVICE #27: SIMPLE HEAT LOAD
INLET NODE NUMBER IS 33
EXIT NODE NUMBER IS 34
EXIT TEMPERATURE IS 297.54 DEG C
END DEVICE

DEVICE #28: SIMPLE PIPE
INLET NODE NUMBER IS 34
EXIT NODE NUMBER IS 35
PIPE PRESSURE LOSS 0.0 MPA
PIPE ENTHALPY LOSS 0.0 KJ/KG
END DEVICE

DEVICE #29: SIMPLE PIPE
INLET NODE NUMBER IS 19
EXIT NODE NUMBER IS 31
PIPE PRESSURE LOSS 0.0 MPA
PIPE ENTHALPY LOSS 0.0 KJ/KG
END DEVICE

DEVICE #30: SIMPLE HEAT LOAD
INLET NODE NUMBER IS 31
EXIT NODE NUMBER IS 32
EXIT TEMPERATURE IS 297.54 DEG C
END DEVICE

DEVICE #31: SIMPLE PIPE
INLET NODE NUMBER IS 32
EXIT NODE NUMBER IS 36
PIPE PRESSURE LOSS 0.0 MPA
PIPE ENTHALPY LOSS 0.0 KJ/KG
END DEVICE

TITLE LINE
BENCHMARK CASE #4
END TITLE LINE

NUMBER OF NODES IS 44
HIGH TEMPERATURE RESERVOIR: 400 DEG C
LOW TEMPERATURE RESERVOIR: 25.0 DEG C
DEAD STATE TEMPERATURE: 25.0 DEG C
DEAD STATE PRESSURE: 101 KPA
GENERATOR MECHANICAL LOSS: 0.0 MW
GENERATOR ELECTRICAL LOSS: 0.0 MW

DEVICE #1: SIMPLE BOILER
BOILER INLET NODE NUMBER IS 16
BOILER EXIT NODE NUMBER IS 17
BOILER REHEAT LEG #1 INLET NODE NUMBER IS 24
BOILER REHEAT LEG #1 EXIT NODE NUMBER IS 25
BOILER EXIT ENTHALPY IS 3099.05 KJ/KG
BOILER EXIT PRESSURE IS 10.0 MPA
BOILER EXIT MASS FLOW RATE IS 45.0 KG/SEC
BOILER REHEAT LEG #1 EXIT TEMPERATURE IS 400.0 DEG C
BOILER PRESSURE LOSS IS 0.0 MPA
BOILER REHEAT LEG #1 PRESSURE LOSS IS 0.0 MPA
END DEVICE

DEVICE #2: SIMPLE PIPE
INLET NODE NUMBER IS 17
EXIT NODE NUMBER IS 18
PIPE PRESSURE LOSS IS 0.0 MPA
PIPE ENTHALPY LOSS IS 0.0 KJ/KG
END DEVICE

DEVICE #3: SIMPLE TURBINE
INLET NODE NUMBER IS 18
EXTRACTION #1 NODE NUMBER IS 19
EXTRACTION #2 NODE NUMBER IS 20
STAGE GROUP #1 EFFICIENCY IS 75%
STAGE GROUP #2 EFFICIENCY IS 75%
EXTRACTION #1 PRESSURE IS 8.0 MPA
EXTRACTION #2 PRESSURE IS 6.0 MPA
EXTRACTION #1 MASS FLOW RATE IS 2.0 KG/SEC
END DEVICE

DEVICE #4: SIMPLE PIPE
INLET NODE NUMBER IS 20
EXIT NODE NUMBER IS 21
PIPE PRESSURE LOSS IS 0.0 MPA
PIPE ENTHALPY LOSS IS 0.0 KJ/KG
END DEVICE

DEVICE #5: SIMPLE PIPE
INLET NODE NUMBER IS 23
EXIT NODE NUMBER IS 24
PIPE PRESSURE LOSS IS 0.0 MPA
PIPE ENTHALPY LOSS IS 0.0 KJ/KG
END DEVICE

DEVICE #6: SIMPLE PIPE
INLET NODE NUMBER IS 25
EXIT NODE NUMBER IS 26
PIPE PRESSURE LOSS IS 0.0 MPA
PIPE ENTHALPY LOSS IS 0.0 KJ/KG
END DEVICE

DEVICE #7: SIMPLE TURBINE
INLET NODE NUMBER IS 26
EXTRACTION #1 NODE NUMBER IS 27
EXTRACTION #2 NODE NUMBER IS 28
EXTRACTION #3 NODE NUMBER IS 30
EXTRACTION #4 NODE NUMBER IS 32
EXTRACTION #5 NODE NUMBER IS 34
STAGE GROUP #1 EFFICIENCY IS 75%
STAGE GROUP #2 EFFICIENCY IS 75%
STAGE GROUP #3 EFFICIENCY IS 75%
STAGE GROUP #4 EFFICIENCY IS 75%
STAGE GROUP #5 EFFICIENCY IS 75%
EXTRACTION #1 PRESSURE IS 2.0 MPA
EXTRACTION #2 PRESSURE IS 1.0 MPA
EXTRACTION #3 PRESSURE IS 0.5 MPA
EXTRACTION #4 PRESSURE IS 0.25 MPA
EXTRACTION #5 PRESSURE IS 0.05 MPA
EXTRACTION #1 MASS FLOW RATE IS 2.0 KG/SEC
END DEVICE

DEVICE #8: SIMPLE PIPE
INLET NODE NUMBER IS 28
EXIT NODE NUMBER IS 29
PIPE PRESSURE LOSS IS 0.0 MPA
PIPE ENTHALPY LOSS IS 0.0 KJ/KG
END DEVICE

DEVICE #9: SIMPLE PIPE
INLET NODE NUMBER IS 30
EXIT NODE NUMBER IS 31
PIPE PRESSURE LOSS IS 0.0 MPA
PIPE ENTHALPY LOSS IS 0.0 KJ/KG
END DEVICE

DEVICE #10: SIMPLE PIPE
INLET NODE NUMBER IS 32
EXIT NODE NUMBER IS 33
PIPE PRESSURE LOSS IS 0.0 MPA
PIPE ENTHALPY LOSS IS 0.0 KJ/KG
END DEVICE

DEVICE #11: SIMPLE PIPE
INLET NODE NUMBER IS 34
EXIT NODE NUMBER IS 35
PIPE PRESSURE LOSS IS 0.0 MPA
PIPE ENTHALPY LOSS IS 0.0 KJ/KG
END DEVICE

DEVICE #12: SIMPLE CONDENSER
EXIT NODE NUMBER IS 1
INLET #1 NODE NUMBER IS 35
INLET #2 NODE NUMBER IS 38
INLET #3 NODE NUMBER IS 39
INLET #4 NODE NUMBER IS 44
END DEVICE

DEVICE #13: SIMPLE PIPE
INLET NODE NUMBER IS 1
EXIT NODE NUMBER IS 2
PIPE PRESSURE LOSS IS 0.0 MPA
PIPE ENTHALPY LOSS IS 0.0 KJ/KG
END DEVICE

DEVICE #14: SIMPLE PUMP
SUCTION NODE NUMBER IS 2
DISCHARGE NODE NUMBER IS 3
PUMP EFFICIENCY IS 75%
END DEVICE

DEVICE #15: SIMPLE PIPE
INLET NODE NUMBER IS 3
EXIT NODE NUMBER IS 4
PIPE PRESSURE LOSS IS 0.0 MPA
PIPE ENTHALPY LOSS IS 0.0 KJ/KG
END DEVICE

DEVICE #16: SIMPLE OFW HEATER
FEED WATER EXIT NODE NUMBER IS 5
EXTRACTION INLET NODE NUMBER IS 33
FEED WATER INLET NODE NUMBER IS 4
END DEVICE

DEVICE #17: SIMPLE PIPE
INLET NODE NUMBER IS 5
EXIT NODE NUMBER IS 6
PIPE PRESSURE LOSS IS 0.0 MPA
PIPE ENTHALPY LOSS IS 0.0 KJ/KG
END DEVICE

DEVICE #18: SIMPLE PUMP
SUCTION NODE NUMBER IS 6
DISCHARGE NODE NUMBER IS 7
PUMP EFFICIENCY IS 75%
END DEVICE

DEVICE #19: SIMPLE PIPE
INLET NODE NUMBER IS 7
EXIT NODE NUMBER IS 8
PIPE PRESSURE LOSS IS 0.0 MPA
PIPE ENTHALPY LOSS IS 0.0 KJ/KG
END DEVICE

DEVICE #20: SIMPLE OFW HEATER
FEED WATER EXIT NODE NUMBER IS 9
EXTRACTION INLET NODE NUMBER IS 31
FEED WATER INLET NODE NUMBER IS 8
END DEVICE

DEVICE #21: SIMPLE PIPE
INLET NODE NUMBER IS 9
EXIT NODE NUMBER IS 10
PIPE PRESSURE LOSS IS 0.0 MPA
PIPE ENTHALPY LOSS IS 0.0 KJ/KG
END DEVICE

DEVICE #22: SIMPLE PUMP
SUCTION NODE NUMBER IS 10
DISCHARGE NODE NUMBER IS 11
PUMP EFFICIENCY IS 75%
END DEVICE

DEVICE #23: SIMPLE PIPE
INLET NODE NUMBER IS 11
EXIT NODE NUMBER IS 12
PIPE PRESSURE LOSS IS 0.0 MPA
PIPE ENTHALPY LOSS IS 0.0 KJ/KG
END DEVICE

DEVICE #24: SIMPLE OFW HEATER
FEED WATER EXIT NODE NUMBER IS 13
EXTRACTION INLET NODE NUMBER IS 29
FEED WATER INLET NODE NUMBER IS 12
END DEVICE

DEVICE #25: SIMPLE PIPE
INLET NODE NUMBER IS 13
EXIT NODE NUMBER IS 14
PIPE PRESSURE LOSS IS 0.0 MPA
PIPE ENTHALPY LOSS IS 0.0 KJ/KG
END DEVICE

DEVICE #26: SIMPLE PUMP
SUCTION NODE NUMBER IS 14
DISCHARGE NODE NUMBER IS 15
PUMP EFFICIENCY IS 75%
END DEVICE

DEVICE #27: SIMPLE PIPE
INLET NODE NUMBER IS 15
EXIT NODE NUMBER IS 16
PIPE PRESSURE LOSS IS 0.0 MPA
PIPE ENTHALPY LOSS IS 0.0 KJ/KG
END DEVICE

DEVICE #28: SIMPLE PIPE
INLET NODE NUMBER IS 19
EXIT NODE NUMBER IS 42
PIPE PRESSURE LOSS IS 0.0 MPA
PIPE ENTHALPY LOSS IS 0.0 KJ/KG
END DEVICE

DEVICE #29: SIMPLE HEAT LOAD
INLET NODE NUMBER IS 42
EXIT NODE NUMBER IS 43
EXIT ENTHALPY IS 2580.28 KJ/KG/K
END DEVICE

DEVICE #30: SIMPLE PIPE
INLET NODE NUMBER IS 43
EXIT NODE NUMBER IS 44
PIPE PRESSURE LOSS IS 0.0 MPA
PIPE ENTHALPY LOSS IS 0.0 KJ/KG
END DEVICE

DEVICE #31: SIMPLE PIPE
INLET NODE NUMBER IS 22
EXIT NODE NUMBER IS 41
PIPE PRESSURE LOSS IS 0.0 MPA
PIPE ENTHALPY LOSS IS 0.0 KJ/KG
END DEVICE

DEVICE #32: SIMPLE HEAT LOAD
INLET NODE NUMBER IS 41

```
  EXIT NODE NUMBER IS 40
  EXIT ENTHALPY IS 2580.28 KJ/KG/K
  END DEVICE

DEVICE #33: SIMPLE PIPE
  INLET NODE NUMBER IS 40
  EXIT NODE NUMBER IS 39
  PIPE PRESSURE LOSS IS 0.0 MPA
  PIPE ENTHALPY LOSS IS 0.0 KJ/KG
  END DEVICE

DEVICE #34: SIMPLE PIPE
  INLET NODE NUMBER IS 27
  EXIT NODE NUMBER IS 36
  PIPE PRESSURE LOSS IS 0.0 MPA
  PIPE ENTHALPY LOSS IS 0.0 KJ/KG
  END DEVICE

DEVICE #35: SIMPLE HEAT LOAD
  INLET NODE NUMBER IS 36
  EXIT NODE NUMBER IS 37
  EXIT ENTHALPY IS 2580.28 KJ/KG/K
  END DEVICE

DEVICE #36: SIMPLE PIPE
  INLET NODE NUMBER IS 37
  EXIT NODE NUMBER IS 38
  PIPE PRESSURE LOSS IS 0.0 MPA
  PIPE ENTHALPY LOSS IS 0.0 KJ/KG
  END DEVICE

DEVICE #37: SIMPLE TURBINE
  INLET NODE NUMBER IS 21
  EXTRACTION #1 NODE NUMBER IS 22
  EXTRACTION #2 NODE NUMBER IS 23
  STAGE GROUP #1 EFFICIENCY IS 75%
  STAGE GROUP #2 EFFICIENCY IS 75%
  EXTRACTION #1 PRESSURE IS 4.0 MPA
  EXTRACTION #2 PRESSURE IS 3.0 MPA
  EXTRACTION #1 MASS FLOW RATE IS 2.0
KG/SEC
  END DEVICE
```

```
TITLE LINE
  BENCHMARK CASE #5
  END TITLE LINE

NUMBER OF NODES IS 46
HIGH TEMPERATURE RESERVOIR: 600.0 DEG C
LOW TEMPERATURE RESERVOIR: 25.0 DEG C
DEAD STATE TEMPERATURE: 25.0 DEG C
DEAD STATE PRESSURE: 101 KPA
GENERATOR MECHANICAL LOSS: 0.0 MW
GENERATOR ELECTRICAL LOSS: 0.0 MW

DEVICE #1: SIMPLE BOILER
    BOILER INLET NODE NUMBER IS 16
    BOILER EXIT NODE NUMBER IS 17
    BOILER REHEAT LEG #1 INLET NODE NUMBER IS 21
    BOILER REHEAT LEG #1 EXIT NODE NUMBER IS 22
    BOILER REHEAT LEG #2 INLET NODE NUMBER IS 26
    BOILER REHEAT LEG #2 EXIT NODE NUMBER IS 27
    BOILER EXIT TEMPERATURE IS 600.0 DEG C
    BOILER EXIT PRESSURE IS 20 MPA
    BOILER EXIT MASS FLOW RATE IS 50.0 KG/SEC
    BOILER REHEAT LEG #1 EXIT TEMPERATURE IS 600.0 DEG C
    BOILER REHEAT LEG #2 EXIT TEMPERATURE IS 600.0 DEG C
    BOILER PERCENTAGE PRESSURE LOSS IS 0.0 PERCENT
    REHEAT LEG #1 PERCENTAGE PRESSURE LOSS IS 0.0 PERCENT
    REHEAT LEG #2 PERCENTAGE PRESSURE LOSS IS 0.0 PERCENT
    END DEVICE

DEVICE #2: SIMPLE PIPE
  INLET NODE NUMBER IS 17
  EXIT NODE NUMBER IS 18
  PIPE PRESSURE LOSS IS 0.0 MPA
  PIPE ENTHALPY LOSS IS 0.0 KJ/KG
  END DEVICE

DEVICE #3: SIMPLE TURBINE
  INLET NODE NUMBER IS 18
  EXTRACTION #1 NODE NUMBER IS 19
  EXTRACTION #2 NODE NUMBER IS 20
  STAGE GROUP #1 EFFICIENCY IS 75%
  STAGE GROUP #2 EFFICIENCY IS 75%
  EXTRACTION #1 PRESSURE IS 15.0 MPA
  EXTRACTION #2 PRESSURE IS 10.0 MPA
 EXTRACTION #1 MASS FLOW RATE IS 1.0 KG/SEC
  END DEVICE

DEVICE #4: SIMPLE PIPE
  INLET NODE NUMBER IS 20
  EXIT NODE NUMBER IS 21
  PIPE PERCENTAGE PRESSURE LOSS IS 0.0 PERCENT
  PIPE PERCENTAGE ENTHALPY LOSS IS 0.0 PERCENT
  END DEVICE

DEVICE #5: SIMPLE PIPE
  INLET NODE NUMBER IS 22
  EXIT NODE NUMBER IS 23
  PIPE PRESSURE LOSS IS 0.0 MPA
  PIPE ENTHALPY LOSS IS 0.0 KJ/KG
  END DEVICE

DEVICE #6: SIMPLE TURBINE
  INLET NODE NUMBER IS 23
```

EXTRACTION #1 NODE NUMBER IS 24
EXTRACTION #2 NODE NUMBER IS 25
STAGE GROUP #1 EFFICIENCY IS 75%
STAGE GROUP #2 EFFICIENCY IS 75%
EXTRACTION #1 PRESSURE IS 7.5 MPA
EXTRACTION #2 PRESSURE IS 5.0 MPA
EXTRACTION #1 MASS FLOW RATE IS 5.0 KG/SEC
END DEVICE

DEVICE #7: SIMPLE PIPE
INLET NODE NUMBER IS 25
EXIT NODE NUMBER IS 26
PIPE PRESSURE LOSS IS 0.0 MPA
PIPE ENTHALPY LOSS IS 0.0 KJ/KG
END DEVICE

DEVICE #8: SIMPLE PIPE
INLET NODE NUMBER IS 27
EXIT NODE NUMBER IS 28
PIPE PRESSURE LOSS IS 0.0 MPA
PIPE ENTHALPY LOSS IS 0.0 KJ/KG
END DEVICE

DEVICE #9: SIMPLE TURBINE
INLET NODE NUMBER IS 28
EXTRACTION #1 NODE NUMBER IS 29
EXTRACTION #2 NODE NUMBER IS 30
EXTRACTION #3 NODE NUMBER IS 32
EXTRACTION #4 NODE NUMBER IS 34
EXTRACTION #5 NODE NUMBER IS 36
STAGE GROUP #1 EFFICIENCY IS 75%
STAGE GROUP #2 EFFICIENCY IS 75%
STAGE GROUP #3 EFFICIENCY IS 75%
STAGE GROUP #4 EFFICIENCY IS 75%
STAGE GROUP #5 EFFICIENCY IS 75%
EXTRACTION #1 PRESSURE IS 2.5 MPA
EXTRACTION #2 PRESSURE IS 1.0 MPA
EXTRACTION #3 PRESSURE IS 0.5 MPA
EXTRACTION #4 PRESSURE IS 0.25 MPA
EXTRACTION #5 PRESSURE IS 0.10 MPA
EXTRACTION #1 MASS FLOW RATE IS 5.0 KG/SEC
END DEVICE

DEVICE #10: SIMPLE PIPE
INLET NODE NUMBER IS 30
EXIT NODE NUMBER IS 31
PIPE PRESSURE LOSS IS 0.0 MPA
PIPE ENTHALPY LOSS IS 0.0 KJ/KG
END DEVICE

DEVICE #11: SIMPLE PIPE
INLET NODE NUMBER IS 32
EXIT NODE NUMBER IS 33
PIPE PRESSURE LOSS IS 0.0 MPA
PIPE ENTHALPY LOSS IS 0.0 KJ/KG
END DEVICE

DEVICE #12: SIMPLE PIPE
INLET NODE NUMBER IS 34
EXIT NODE NUMBER IS 35
PIPE PRESSURE LOSS IS 0.0 MPA
PIPE ENTHALPY LOSS IS 0.0 KJ/KG
END DEVICE

```
DEVICE #13: SIMPLE PIPE
  INLET NODE NUMBER IS 36
  EXIT NODE NUMBER IS 37
  PIPE PRESSURE LOSS IS 0.0 MPA
  PIPE ENTHALPY LOSS IS 0.0 KJ/KG
  END DEVICE
DEVICE #14: SIMPLE CONDENSER
  EXIT NODE NUMBER IS 1
  INLET #1 NODE NUMBER IS 37
  INLET #2 NODE NUMBER IS 44
  INLET #3 NODE NUMBER IS 45
  INLET #4 NODE NUMBER IS 46
  END DEVICE

DEVICE #15: SIMPLE PIPE
  INLET NODE NUMBER IS 1
  EXIT NODE NUMBER IS 2
  PIPE PRESSURE LOSS IS 0.0 MPA
  PIPE ENTHALPY LOSS IS 0.0 KJ/KG
  END DEVICE

DEVICE #16: SIMPLE PUMP
  SUCTION NODE NUMBER IS 2
  DISCHARGE NODE NUMBER IS 3
  PUMP EFFICIENCY IS 75%
  END DEVICE

DEVICE #17: SIMPLE PIPE
  INLET NODE NUMBER IS 3
  EXIT NODE NUMBER IS 4
  PIPE PRESSURE LOSS IS 0.0 MPA
  PIPE ENTHALPY LOSS IS 0.0 KJ/KG
  END DEVICE

DEVICE #18: SIMPLE OFW HEATER
  FEED WATER INLET NODE NUMBER IS 4
  FEED WATER EXIT NODE NUMBER IS 5
  EXTRACTION INLET NODE NUMBER IS 35
  END DEVICE

DEVICE #19: SIMPLE PIPE
  INLET NODE NUMBER IS 5
  EXIT NODE NUMBER IS 6
  PIPE PRESSURE LOSS IS 0.0 MPA
  PIPE ENTHALPY LOSS IS 0.0 KJ/KG
  END DEVICE

DEVICE #20: SIMPLE PUMP
  SUCTION NODE NUMBER IS 6
  DISCHARGE NODE NUMBER IS 7
  PUMP EFFICIENCY IS 75%
  END DEVICE

DEVICE #21: SIMPLE PIPE
  INLET NODE NUMBER IS 7
  EXIT NODE NUMBER IS 8
  PIPE PRESSURE LOSS IS 0.0 MPA
  PIPE ENTHALPY LOSS IS 0.0 KJ/KG
  END DEVICE

DEVICE #22: SIMPLE OFW HEATER
  FEED WATER INLET INLET NODE NUMBER IS 8
  FEED WATER EXIT NODE NUMBER IS 9
  EXTRACTION INLET NODE NUMBER IS 33
```

END DEVICE

DEVICE #23: SIMPLE PIPE
INLET NODE NUMBER IS 9
EXIT NODE NUMBER IS 10
PIPE PRESSURE LOSS IS 0.0 MPA
PIPE ENTHALPY LOSS IS 0.0 KJ/KG
END DEVICE

DEVICE #24: SIMPLE PUMP
SUCTION NODE NUMBER IS 10
DISCHARGE NODE NUMBER IS 11
PUMP EFFICIENCY IS 75%
END DEVICE

DEVICE #25: SIMPLE PIPE
INLET NODE NUMBER IS 11
EXIT NODE NUMBER IS 12
PIPE PRESSURE LOSS IS 0.0 MPA
PIPE ENTHALPY LOSS IS 0.0 KJ/KG
END DEVICE

DEVICE #26: SIMPLE OFW HEATER
FEED WATER EXIT NODE NUMBER IS 13
FEED WATER INLET NODE NUMBER IS 12
EXTRACTION INLET NODE NUMBER IS 31
END DEVICE

DEVICE #27: SIMPLE PIPE
INLET NODE NUMBER IS 13
EXIT NODE NUMBER IS 14
PIPE PRESSURE LOSS IS 0.0 MPA
PIPE ENTHALPY LOSS IS 0.0 KJ/KG
END DEVICE

DEVICE #28: SIMPLE PUMP
SUCTION NODE NUMBER IS 14
DISCHARGE NODE NUMBER IS 15
PUMP EFFICIENCY IS 75%
END DEVICE

DEVICE #29: SIMPLE PIPE
INLET NODE NUMBER IS 15
EXIT NODE NUMBER IS 16
PIPE PRESSURE LOSS IS 0.0 MPA
PIPE ENTHALPY LOSS IS 0.0 KJ/KG
END DEVICE

DEVICE #30: SIMPLE PIPE
INLET NODE NUMBER IS 19
EXIT NODE NUMBER IS 38
PIPE PRESSURE LOSS IS 0.0 MPA
PIPE ENTHALPY LOSS IS 0.0 KJ/KG
END DEVICE

DEVICE #31: SIMPLE HEAT LOAD
INLET NODE NUMBER IS 38
EXIT NODE NUMBER IS 39
EXIT TEMPERATURE IS 175.7 DEG C
END DEVICE

DEVICE #32: SIMPLE PIPE
INLET NODE NUMBER IS 39
EXIT NODE NUMBER IS 44

PIPE PRESSURE LOSS IS 0.0 MPA
PIPE ENTHALPY LOSS IS 0.0 KJ/KG
END DEVICE

DEVICE #33: SIMPLE PIPE
INLET NODE NUMBER IS 24
EXIT NODE NUMBER IS 40
PIPE PRESSURE LOSS IS 0.0 MPA
PIPE ENTHALPY LOSS IS 0.0 KJ/KG
END DEVICE

DEVICE #34: SIMPLE HEAT LOAD
INLET NODE NUMBER IS 40
EXIT NODE NUMBER IS 41
EXIT TEMPERATURE IS 175.7 DEG C
END DEVICE

DEVICE #35: SIMPLE PIPE
INLET NODE NUMBER IS 41
EXIT NODE NUMBER IS 45
PIPE PRESSURE LOSS IS 0.0 MPA
PIPE ENTHALPY LOSS IS 0.0 KJ/KG
END DEVICE

DEVICE #36: SIMPLE PIPE
INLET NODE NUMBER IS 29
EXIT NODE NUMBER IS 42
PIPE PRESSURE LOSS IS 0.0 MPA
PIPE ENTHALPY LOSS IS 0.0 KJ/KG
END DEVICE

DEVICE #37: SIMPLE HEAT LOAD
INLET NODE NUMBER IS 42
EXIT NODE NUMBER IS 43
EXIT TEMPERATURE IS 175.7 DEG C
END DEVICE

DEVICE #38: SIMPLE PIPE
INLET NODE NUMBER IS 43
EXIT NODE NUMBER IS 46
PIPE PRESSURE LOSS IS 0.0 MPA
PIPE ENTHALPY LOSS IS 0.0 KJ/KG
END DEVICE

Appendix F:

RANKINE 3.0 output files for benchmark case #1 through case #5

RANKINE 3.0: A steam power plant computer simulation

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W.A. Thelen, C.W. Somerton

********** TITLE **********

BENCHMARK CASE #1

********** NODE DATA **********

NODE	T(C)	P(MPa)	L	Q	S(KJ/KG/K)	H(KJ/KG)	V(M^3/KG)	M(KG/S)	A(KJ/KG)
1	99.63	.1000	4	*****	1.3020	417.31	.00104	50.0000	33.47
2	103.52	20.0000	1	*****	1.3228	448.50	.00105	50.0000	58.45
3	600.00	20.0000	3	*****	6.5052	3536.61	.01808	50.0000	1601.44
4	99.63	.1000	2	.990	7.2962	2651.90	1.67621	50.0000	480.88

********** DEVICE DATA (DEVICE BEFORE NODE) **********

NODE	REV. WRK (KW)	ACT. WRK (KW)	IRREV (KW)	HEAT X-FER (KW)	MASS ERROR (KG/S)	ENERGY ERROR (KW)
1	22370.37	.00	22370.37	-111729.90	.000	-.008
2	-1249.04	-1559.60	310.56	.00	.000	.000
3	71843.58	.00	71843.58	154405.60	.000	.000
4	56028.13	44235.28	11792.86	.00	.000	.000

********** SYSTEM DATA **********

TOTAL MASS FLOW RATE EXITING SYSTEM:	.0000	KG/SEC
TOTAL MASS FLOW RATE ENTERING SYSTEM:	.0000	KG/SEC
TOTAL ENTHALPY FLOW RATE EXITING SYSTEM:	.0000	KW
TOTAL ENTHALPY FLOW RATE ENTERING SYSTEM:	.0000	KW
TOTAL HEAT AND WORK ENTERING SYSTEM:	-.0039	KW
BOILER HEAT (DEVICE # 4):	154405.6000	KW
TOTAL BOILER HEAT:	154405.6000	KW
TOTAL HEAT LOAD HEAT:	.0000	KW
CONDENSER HEAT (DEVICE # 2):	-111729.9000	KW
TOTAL PIPE ENERGY LOSSES:	.0000	KW
TURBINE WORK (DEVICE # 1):	44235.2800	KW
NET WORK TO GENERATORS:	44235.2800	KW
PUMP WORK (DEVICE # 3):	-1559.6010	KW
TOTAL PUMP WORK:	-1559.6010	KW
GENERATOR MECHANICAL LOSSES:	.0000	KW
GENERATOR ELECTRICAL LOSSES:	.0000	KW
NET ELECTRICAL POWER:	42675.6800	KW
SYSTEM HEAT RATE:	12345.0200	BTU/KW*HR
CARNOT CYCLE EFFICIENCY:	65.8535	PERCENT
1ST LAW EFFICIENCY:	27.6387	PERCENT
2ND LAW EFFICIENCY:	42.8466	PERCENT
2ND LAW EFFECTIVENESS:	41.9699	PERCENT

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********** TITLE **********

BENCHMARK CASE #2

********** NODE DATA **********

NODE	T(C)	P(MPa)	L	Q	S(KJ/KG/K)	H(KJ/KG)	V(M^3/KG)	M(KG/S)	A(KJ/KG)
1	250.34	4.0000	4	*****	2.7947	1087.16	.00125	23.6636	258.27
2	250.34	4.0000	4	*****	2.7947	1087.16	.00125	23.6636	258.27
3	252.58	6.0000	1	*****	2.7997	1098.06	.00126	23.6636	267.66
4	252.58	6.0000	1	*****	2.7997	1098.06	.00126	23.6636	267.66
5	275.56	6.0000	4	*****	3.0251	1213.37	.00132	25.0000	315.78
6	275.56	6.0000	4	*****	3.0251	1213.37	.00132	25.0000	315.78
7	280.24	10.0000	1	*****	3.0345	1235.51	.00133	25.0000	335.10
8	280.24	10.0000	1	*****	3.0345	1235.51	.00133	25.0000	335.10
9	500.00	10.0000	3	*****	6.5984	3374.66	.03275	25.0000	1411.69
10	500.00	10.0000	3	*****	6.5984	3374.66	.03275	25.0000	1411.69
11	468.79	8.0000	3	*****	6.6225	3321.17	.03951	5.0000	1351.00
12	430.55	6.0000	3	*****	6.6540	3255.07	.05032	1.3364	1275.50
13	430.55	6.0000	3	*****	6.6540	3255.07	.05032	1.3364	1275.50
14	380.21	4.0000	3	*****	6.6993	3167.23	.07073	18.6636	1174.18
15	380.21	4.0000	3	*****	6.6993	3167.23	.07073	18.6636	1174.18
16	500.00	10.0000	3	*****	6.5984	3374.66	.03275	25.0000	1411.69
17	500.00	10.0000	3	*****	6.5984	3374.66	.03275	.0000	1411.69
18	500.00	10.0000	3	*****	6.5984	3374.66	.03275	25.0000	1411.69
19	468.79	8.0000	3	*****	6.6225	3321.17	.03951	5.0000	1351.00
20	380.21	4.0000	3	*****	6.6993	3167.23	.07073	5.0000	1174.18
21	380.21	4.0000	3	*****	6.6993	3167.23	.07073	5.0000	1174.18

********** DEVICE DATA (DEVICE BEFORE NODE) **********

NODE	REV. WRK (KW)	ACT. WRK (KW)	IRREV (KW)	HEAT X-FER (KW)	MASS ERROR (KG/S)	ENERGY ERROR (KW)
1	21673.79	.00	21673.79	-49221.96	.000	.000
2	.00	.00	.00	.00	.000	.000
3	-222.35	-257.97	35.62	.00	.000	.000
4	.00	.00	.00	.00	.000	.000
5	143.95	.00	143.95	.00	.000	.001
6	.00	.00	.00	.00	.000	.001
7	-483.05	-553.59	70.55	.00	.000	.001
8	.00	.00	.00	.00	.000	.001
9	15406.16	.00	15406.16	53478.70	.000	.000
10	.00	.00	.00	.00	.000	-.002
11	1517.32	1337.32	179.99	.00	.000	.000
12	1509.85	1321.96	187.89	.00	.000	.000
13	.00	.00	.00	.00	.000	.000
14	1891.02	1639.32	251.69	.00	.000	.000
15	.00	.00	.00	.00	.000	.000
16	.00	.00	.00	.00	.000	-.002
17	.00	.00	.00	.00	.000	-.002
18	.00	.00	.00	.00	.000	.000
19	.00	.00	.00	.00	.000	.000
20	884.08	.00	884.08	-769.69	.000	.000
21	.00	.00	.00	.00	.000	.000

********** SYSTEM DATA **********

TOTAL MASS FLOW RATE EXITING SYSTEM:	.0000	KG/SEC
TOTAL MASS FLOW RATE ENTERING SYSTEM:	.0000	KG/SEC
TOTAL ENTHALPY FLOW RATE EXITING SYSTEM:	.0000	KW
TOTAL ENTHALPY FLOW RATE ENTERING SYSTEM:	.0000	KW
TOTAL HEAT AND WORK ENTERING SYSTEM:	.0042	KW
BOILER HEAT (DEVICE # 18):	53478.7000	KW
TOTAL BOILER HEAT:	53478.7000	KW
HEAT LOAD HEAT (DEVICE # 16):	-769.6887	KW
TOTAL HEAT LOAD HEAT:	-769.6887	KW
CONDENSER HEAT (DEVICE # 15):	-49221.9600	KW
TOTAL PIPE ENERGY LOSSES:	.0000	KW
TURBINE WORK (DEVICE # 1):	4298.6090	KW
NET WORK TO GENERATORS:	4298.6090	KW
PUMP WORK (DEVICE # 2):	-257.9682	KW
PUMP WORK (DEVICE # 3):	-553.5919	KW
TOTAL PUMP WORK:	-811.5601	KW
GENERATOR MECHANICAL LOSSES:	.0000	KW
GENERATOR ELECTRICAL LOSSES:	.0000	KW
NET ELECTRICAL POWER:	3487.0490	KW
SYSTEM HEAT RATE:	52327.7200	BTU/KW*HR
CARNOT CYCLE EFFICIENCY:	61.4370	PERCENT
1ST LAW EFFICIENCY:	6.5204	PERCENT
2ND LAW EFFICIENCY:	27.9568	PERCENT
2ND LAW EFFECTIVENESS:	10.6132	PERCENT

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********** TITLE **********

BENCHMARK CASE #3

********** NODE DATA **********

NODE	T(C)	P(MPa)	L	Q	S(KJ/KG/K)	H(KJ/KG)	V(M^3/KG)	M(KG/S)	A(KJ/KG)
1	179.87	1.0000	4	*****	2.1367	762.23	.00113	19.8440	129.52
2	179.87	1.0000	4	*****	2.1367	762.23	.00113	19.8440	129.52
3	180.43	1.5000	1	*****	2.1396	764.89	.00113	19.8440	131.31
4	180.43	1.5000	1	*****	2.1396	764.89	.00113	19.8440	131.31
5	198.28	1.5000	4	*****	2.3127	844.32	.00115	20.5434	159.12
6	198.28	1.5000	4	*****	2.3127	844.32	.00115	20.5434	159.12
7	199.08	2.0000	1	*****	2.3167	848.13	.00115	20.5434	161.74
8	199.08	2.0000	1	*****	2.3167	848.13	.00115	20.5434	161.74
9	212.37	2.0000	4	*****	2.4450	908.29	.00118	21.0980	183.65
10	212.37	2.0000	4	*****	2.4450	908.29	.00118	21.0980	183.65
11	213.70	3.0000	1	*****	2.4516	914.73	.00118	21.0980	188.14
12	213.70	3.0000	1	*****	2.4516	914.73	.00118	21.0980	188.14
13	233.84	3.0000	4	*****	2.6437	1008.11	.00122	22.0000	224.25
14	233.84	3.0000	4	*****	2.6437	1008.11	.00122	22.0000	224.25
15	238.95	10.0000	1	*****	2.6678	1033.26	.00123	22.0000	242.19
16	238.95	10.0000	1	*****	2.6678	1033.26	.00123	22.0000	242.19
17	500.00	10.0000	3	*****	6.5984	3374.66	.03275	22.0000	1411.69
18	500.00	10.0000	3	*****	6.5984	3374.66	.03275	22.0000	1411.69
19	475.93	8.0000	3	*****	6.6465	3339.00	.04002	2.0000	1361.70
20	446.67	6.0000	3	*****	6.7093	3294.36	.05182	20.0000	1298.34
21	446.67	6.0000	3	*****	6.7093	3294.36	.05182	20.0000	1298.34
22	408.49	4.0000	3	*****	6.7994	3234.06	.07455	2.0000	1211.16
23	383.09	3.0000	3	*****	6.8636	3192.52	.09644	.9020	1150.47
24	383.09	3.0000	3	*****	6.8636	3192.52	.09644	.9020	1150.47
25	349.69	2.0000	3	*****	6.9555	3136.46	.13854	.5547	1067.02
26	349.69	2.0000	3	*****	6.9555	3136.46	.13854	.5547	1067.02
27	327.25	1.5000	3	*****	7.0207	3097.87	.17902	.6994	1008.99
28	327.25	1.5000	3	*****	7.0207	3097.87	.17902	.6994	1008.99
29	297.54	1.0000	3	*****	7.1138	3045.89	.25684	15.8440	929.25
30	297.54	1.0000	3	*****	7.1138	3045.89	.25684	15.8440	929.25
31	475.93	8.0000	3	*****	6.6465	3339.00	.04002	2.0000	1361.70
32	297.54	1.0000	3	*****	7.1138	3045.90	.25685	2.0000	929.25
33	408.49	4.0000	3	*****	6.7994	3234.06	.07455	2.0000	1211.16
34	297.54	1.0000	3	*****	7.1138	3045.90	.25685	2.0000	929.25
35	297.54	1.0000	3	*****	7.1138	3045.90	.25685	2.0000	929.25
36	297.54	1.0000	3	*****	7.1138	3045.90	.25685	2.0000	929.25

********** DEVICE DATA (DEVICE BEFORE NODE) **********

NODE	REV. WRK (KW)	ACT. WRK (KW)	IRREV (KW)	HEAT X-FER (KW)	MASS ERROR (KG/S)	ENERGY ERROR (KW)
1	15869.79	.00	15869.79	-45316.91	.000	-.004
2	.00	.00	.00	.00	.000	.000
3	-35.56	-52.81	17.26	.00	.000	.001
4	.00	.00	.00	.00	.000	.000
5	42.51	.00	42.51	.00	.000	-.001
6	.00	.00	.00	.00	.000	.001
7	-53.80	-78.31	24.51	.00	.000	.001
8	.00	.00	.00	.00	.000	.001
9	39.97	.00	39.97	.00	.000	.001

10	.00	.00	.00	.00	.000	-.001
11	-94.71	-135.85	41.14	.00	.000	-.001
12	.00	.00	.00	.00	.000	.000
13	73.62	.00	73.62	.00	.000	.001
14	.00	.00	.00	.00	.000	-.001
15	-394.70	-553.28	158.58	.00	.000	-.001
16	.00	.00	.00	.00	.000	-.001
17	15345.20	.00	15345.20	51510.73	.000	.000
18	.00	.00	.00	.00	.000	.004
19	1099.83	784.57	315.27	.00	.000	.000
20	1267.15	892.64	374.51	.00	.000	.000
21	.00	.00	.00	.00	.000	.001
22	1743.64	1205.98	537.65	.00	.000	.000
23	1092.44	747.89	344.55	.00	.000	.000
24	.00	.00	.00	.00	.000	.000
25	1426.84	958.52	468.32	.00	.000	.000
26	.00	.00	.00	.00	.000	.000
27	959.94	638.26	321.68	.00	.000	.000
28	.00	.00	.00	.00	.000	.000
29	1263.42	823.70	439.72	.00	.000	.000
30	.00	.00	.00	.00	.000	-.001
31	.00	.00	.00	.00	.000	.000
32	864.89	.00	864.89	-586.20	.000	.000
33	.00	.00	.00	.00	.000	.000
34	563.81	.00	563.81	-376.34	.000	.000
35	.00	.00	.00	.00	.000	.000
36	.00	.00	.00	.00	.000	.000

********** SYSTEM DATA **********

TOTAL MASS FLOW RATE EXITING SYSTEM:	.0000	KG/SEC
TOTAL MASS FLOW RATE ENTERING SYSTEM:	.0000	KG/SEC
TOTAL ENTHALPY FLOW RATE EXITING SYSTEM:	.0000	KW
TOTAL ENTHALPY FLOW RATE ENTERING SYSTEM:	.0000	KW
TOTAL HEAT AND WORK ENTERING SYSTEM:	-.0010	KW
BOILER HEAT (DEVICE # 1):	51510.7300	KW
TOTAL BOILER HEAT:	51510.7300	KW
HEAT LOAD HEAT (DEVICE # 27):	-376.3354	KW
HEAT LOAD HEAT (DEVICE # 30):	-586.1978	KW
TOTAL HEAT LOAD HEAT:	-962.5332	KW
CONDENSER HEAT (DEVICE # 10):	-45316.9100	KW
TOTAL PIPE ENERGY LOSSES:	.0000	KW
TURBINE WORK (DEVICE # 3):	1677.2080	KW
TURBINE WORK (DEVICE # 5):	4374.3420	KW
NET WORK TO GENERATORS:	6051.5500	KW
PUMP WORK (DEVICE # 12):	-52.8148	KW
PUMP WORK (DEVICE # 16):	-78.3066	KW
PUMP WORK (DEVICE # 20):	-135.8547	KW
PUMP WORK (DEVICE # 24):	-553.2777	KW
TOTAL PUMP WORK:	-820.2538	KW
GENERATOR MECHANICAL LOSSES:	.0000	KW
GENERATOR ELECTRICAL LOSSES:	.0000	KW
NET ELECTRICAL POWER:	5231.2960	KW
SYSTEM HEAT RATE:	33596.7700	BTU/KW*HR
CARNOT CYCLE EFFICIENCY:	61.4370	PERCENT
1ST LAW EFFICIENCY:	10.1557	PERCENT
2ND LAW EFFICIENCY:	30.9454	PERCENT
2ND LAW EFFECTIVENESS:	16.5303	PERCENT

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********** TITLE **********

BENCHMARK CASE #4

********** NODE DATA **********

NODE	T(C)	P(MPa)	L	Q	S(KJ/KG/K)	H(KJ/KG)	V(M^3/KG)	M(KG/S)	A(KJ/KG)
1	81.35	.0500	4	*****	1.0903	340.37	.00103	37.5634	19.64
2	81.35	.0500	4	*****	1.0903	340.37	.00103	37.5634	19.64
3	81.39	.2500	1	*****	1.0905	340.68	.00103	37.5634	19.88
4	81.39	.2500	1	*****	1.0905	340.68	.00103	37.5634	19.88
5	127.43	.2500	4	*****	1.6065	535.09	.00107	40.8093	60.45
6	127.43	.2500	4	*****	1.6065	535.09	.00107	40.8093	60.45
7	127.52	.5000	1	*****	1.6069	535.66	.00107	40.8093	60.91
8	127.52	.5000	1	*****	1.6069	535.66	.00107	40.8093	60.91
9	151.84	.5000	4	*****	1.8595	639.79	.00109	42.6969	89.73
10	151.84	.5000	4	*****	1.8595	639.79	.00109	42.6969	89.73
11	152.05	1.0000	1	*****	1.8601	640.98	.00109	42.6969	90.71
12	152.05	1.0000	1	*****	1.8601	640.98	.00109	42.6969	90.71
13	179.87	1.0000	4	*****	2.1367	762.23	.00113	45.0000	129.52
14	179.87	1.0000	4	*****	2.1367	762.23	.00113	45.0000	129.52
15	182.43	10.0000	1	*****	2.1453	778.01	.00113	45.0000	142.73
16	182.43	10.0000	1	*****	2.1453	778.01	.00113	45.0000	142.73
17	400.00	10.0000	3	*****	6.2158	3099.05	.02643	45.0000	1250.14
18	400.00	10.0000	3	*****	6.2158	3099.05	.02643	45.0000	1250.14
19	371.03	8.0000	3	*****	6.2382	3055.87	.03190	2.0000	1200.28
20	335.76	6.0000	3	*****	6.2676	3002.49	.04065	43.0000	1138.15
21	335.76	6.0000	3	*****	6.2676	3002.49	.04065	43.0000	1138.15
22	289.76	4.0000	3	*****	6.3099	2931.51	.05718	2.0000	1054.54
23	259.48	3.0000	3	*****	6.3400	2883.70	.07277	41.0000	997.76
24	259.48	3.0000	3	*****	6.3400	2883.70	.07277	41.0000	997.76
25	400.00	3.0000	3	*****	6.9215	3230.96	.09936	41.0000	1171.67
26	400.00	3.0000	3	*****	6.9215	3230.96	.09936	41.0000	1171.67
27	353.22	2.0000	3	*****	6.9681	3144.31	.13945	2.0000	1071.12
28	280.89	1.0000	3	*****	7.0503	3010.18	.24854	2.3031	912.47
29	280.89	1.0000	3	*****	7.0503	3010.18	.24854	2.3031	912.47
30	216.57	.5000	3	*****	7.1331	2890.85	.44173	1.8876	768.45
31	216.57	.5000	3	*****	7.1331	2890.85	.44173	1.8876	768.45
32	159.46	.2500	3	*****	7.2163	2784.95	.78322	3.2458	637.74
33	159.46	.2500	3	*****	7.2163	2784.95	.78322	3.2458	637.74
34	81.35	.0500	2	.972	7.4088	2580.28	3.14808	31.5634	375.69
35	81.35	.0500	2	.972	7.4088	2580.28	3.14808	31.5634	375.69
36	353.22	2.0000	3	*****	6.9681	3144.31	.13945	2.0000	1071.12
37	81.35	.0500	2	.972	7.4088	2580.28	3.14808	2.0000	375.69
38	81.35	.0500	2	.972	7.4088	2580.28	3.14808	2.0000	375.69
39	81.35	.0500	2	.972	7.4088	2580.28	3.14808	2.0000	375.69
40	81.35	.0500	2	.972	7.4088	2580.28	3.14808	2.0000	375.69
41	289.76	4.0000	3	*****	6.3099	2931.51	.05718	2.0000	1054.54
42	371.03	8.0000	3	*****	6.2382	3055.87	.03190	2.0000	1200.28
43	81.35	.0500	2	.972	7.4088	2580.28	3.14808	2.0000	375.69
44	81.35	.0500	2	.972	7.4088	2580.28	3.14808	2.0000	375.69

********** DEVICE DATA (DEVICE BEFORE NODE) **********

NODE	REV. WRK (KW)	ACT. WRK (KW)	IRREV (KW)	HEAT X-FER (KW)	MASS ERROR (KG/S)	ENERGY ERROR (KW)
1	13374.69	.00	13374.69	-84138.79	.000	.008

2	.00	.00	.00	.00	.000	.000
3	-9.31	-11.79	2.48	.00	.000	.002
4	.00	.00	.00	.00	.000	.000
5	350.10	.00	350.10	.00	.000	-.001
6	.00	.00	.00	.00	.000	.001
7	-19.00	-23.34	4.34	.00	.000	.001
8	.00	.00	.00	.00	.000	.001
9	105.04	.00	105.04	.00	.000	.000
10	.00	.00	.00	.00	.000	.000
11	-41.84	-50.72	8.87	.00	.000	.000
12	.00	.00	.00	.00	.000	.000
13	146.20	.00	146.20	.00	.000	-.002
14	.00	.00	.00	.00	.000	-.002
15	-594.18	-709.90	115.71	.00	.000	-.002
16	.00	.00	.00	.00	.000	.002
17	18856.23	.00	18856.23	104447.00	.000	.000
18	.00	.00	.00	.00	.000	-.002
19	2243.78	1942.94	300.83	.00	.000	.000
20	2671.75	2295.33	376.42	.00	.000	.000
21	.00	.00	.00	.00	.000	.000
22	3595.13	3052.43	542.70	.00	.000	.000
23	2327.83	1960.23	367.60	.00	.000	.001
24	.00	.00	.00	.00	.000	-.001
25	1810.01	.00	1810.01	14237.95	.000	.000
26	.01	.00	.01	.00	.000	.001
27	4122.44	3552.83	569.61	.00	.000	.000
28	6187.20	5230.97	956.23	.00	.000	.000
29	.00	.00	.00	.00	.000	.000
30	5285.17	4379.08	906.09	.00	.000	.000
31	.00	.00	.00	.00	.000	.000
32	4549.93	3686.26	863.67	.00	.000	.000
33	.00	.00	.00	.00	.000	.000
34	8271.18	6460.11	1811.07	.00	.000	.006
35	.00	.00	.00	.00	.000	.000
36	.00	.00	.00	.00	.000	.000
37	1390.86	.00	1390.86	-1128.06	.000	.000
38	.00	.00	.00	.00	.000	.000
39	.00	.00	.00	.00	.000	.000
40	1357.70	.00	1357.70	-702.45	.000	.000
41	.00	.00	.00	.00	.000	.000
42	.00	.00	.00	.00	.000	.000
43	1649.18	.00	1649.18	-951.19	.000	.000
44	.00	.00	.00	.00	.000	.000

********** SYSTEM DATA **********

TOTAL MASS FLOW RATE EXITING SYSTEM: .0000 KG/SEC
TOTAL MASS FLOW RATE ENTERING SYSTEM: .0000 KG/SEC
TOTAL ENTHALPY FLOW RATE EXITING SYSTEM: .0000 KW
TOTAL ENTHALPY FLOW RATE ENTERING SYSTEM: .0000 KW
TOTAL HEAT AND WORK ENTERING SYSTEM: -.0039 KW

BOILER HEAT (DEVICE # 1): 118684.9000 KW
TOTAL BOILER HEAT: 118684.9000 KW
HEAT LOAD HEAT (DEVICE # 29): -951.1870 KW
HEAT LOAD HEAT (DEVICE # 32): -702.4536 KW
HEAT LOAD HEAT (DEVICE # 35): -1128.0580 KW
TOTAL HEAT LOAD HEAT: -2781.6990 KW
CONDENSER HEAT (DEVICE # 12): -84138.7900 KW
TOTAL PIPE ENERGY LOSSES: .0000 KW

TURBINE WORK (DEVICE # 3): 4238.2780 KW
TURBINE WORK (DEVICE # 7): 23309.2500 KW
TURBINE WORK (DEVICE # 37): 5012.6660 KW

NET WORK TO GENERATORS:	32560.1900	KW
PUMP WORK (DEVICE # 14):	-11.7890	KW
PUMP WORK (DEVICE # 18):	-23.3438	KW
PUMP WORK (DEVICE # 22):	-50.7156	KW
PUMP WORK (DEVICE # 26):	-709.8953	KW
TOTAL PUMP WORK:	-795.7437	KW
GENERATOR MECHANICAL LOSSES:	.0000	KW
GENERATOR ELECTRICAL LOSSES:	.0000	KW
NET ELECTRICAL POWER:	31764.4500	KW
SYSTEM HEAT RATE:	12748.6200	BTU/KW*HR
CARNOT CYCLE EFFICIENCY:	55.7082	PERCENT
1ST LAW EFFICIENCY:	26.7637	PERCENT
2ND LAW EFFICIENCY:	56.6917	PERCENT
2ND LAW EFFECTIVENESS:	48.0426	PERCENT

RANKINE 3.0: A steam power plant computer simulation

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********** TITLE **********

BENCHMARK CASE #5

********** NODE DATA **********

NODE	T(C)	P(MPa)	L	Q	S(KJ/KG/K)	H(KJ/KG)	V(M^3/KG)	M(KG/S)	A(KJ/KG)
1	99.63	.1000	4	*****	1.3020	417.31	.00104	43.6475	33.47
2	99.63	.1000	4	*****	1.3020	417.31	.00104	43.6475	33.47
3	99.68	.2500	1	*****	1.3022	417.59	.00104	43.6475	33.70
4	99.68	.2500	1	*****	1.3022	417.59	.00104	43.6475	33.70
5	127.43	.2500	4	*****	1.6065	535.09	.00107	45.7481	60.45
6	127.43	.2500	4	*****	1.6065	535.09	.00107	45.7481	60.45
7	127.52	.5000	1	*****	1.6069	535.66	.00107	45.7481	60.91
8	127.52	.5000	1	*****	1.6069	535.66	.00107	45.7481	60.91
9	151.84	.5000	4	*****	1.8595	639.79	.00109	47.6790	89.73
10	151.84	.5000	4	*****	1.8595	639.79	.00109	47.6790	89.73
11	152.05	1.0000	1	*****	1.8601	640.98	.00109	47.6790	90.71
12	152.05	1.0000	1	*****	1.8601	640.98	.00109	47.6790	90.71
13	179.87	1.0000	4	*****	2.1367	762.23	.00113	50.0000	129.52
14	179.87	1.0000	4	*****	2.1367	762.23	.00113	50.0000	129.52
15	185.00	20.0000	1	*****	2.1542	794.40	.00113	50.0000	156.46
16	185.00	20.0000	1	*****	2.1542	794.40	.00113	50.0000	156.46
17	600.00	20.0000	3	*****	6.5052	3536.61	.01808	50.0000	1601.44
18	600.00	20.0000	3	*****	6.5052	3536.61	.01808	50.0000	1601.44
19	554.33	15.0000	3	*****	6.5358	3460.98	.02304	1.0000	1516.67
20	494.41	10.0000	3	*****	6.5799	3360.38	.03242	49.0000	1402.94
21	494.41	10.0000	3	*****	6.5799	3360.38	.03242	49.0000	1402.94
22	600.00	10.0000	3	*****	6.8991	3621.73	.03828	49.0000	1569.12
23	600.00	10.0000	3	*****	6.8991	3621.73	.03828	49.0000	1569.12
24	557.45	7.5000	3	*****	6.9314	3541.65	.04878	5.0000	1479.39
25	501.09	5.0000	3	*****	6.9777	3435.14	.06862	44.0000	1359.07
26	501.09	5.0000	3	*****	6.9777	3435.14	.06862	44.0000	1359.07
27	600.00	5.0000	3	*****	7.2540	3662.39	.07860	44.0000	1503.96
28	600.00	5.0000	3	*****	7.2540	3662.39	.07860	44.0000	1503.96
29	505.66	2.5000	3	*****	7.3367	3472.55	.14102	5.0000	1289.44
30	395.43	1.0000	3	*****	7.4490	3253.16	.30442	2.3210	1036.57
31	395.43	1.0000	3	*****	7.4490	3253.16	.30442	2.3210	1036.57
32	320.86	.5000	3	*****	7.5329	3106.73	.54259	1.9309	865.14
33	320.86	.5000	3	*****	7.5329	3106.73	.54259	1.9309	865.14
34	253.64	.2500	3	*****	7.6171	2976.46	.96451	2.1007	709.77
35	253.64	.2500	3	*****	7.6171	2976.46	.96451	2.1007	709.77
36	175.68	.1000	3	*****	7.7309	2827.51	2.05840	32.6475	526.88
37	175.68	.1000	3	*****	7.7309	2827.51	2.05840	32.6475	526.88
38	554.33	15.0000	3	*****	6.5358	3460.98	.02304	1.0000	1516.67
39	175.70	.1000	3	*****	7.7310	2827.54	2.05849	1.0000	526.90
40	557.45	7.5000	3	*****	6.9314	3541.65	.04878	5.0000	1479.39
41	175.70	.1000	3	*****	7.7310	2827.54	2.05849	5.0000	526.90
42	505.66	2.5000	3	*****	7.3367	3472.55	.14102	5.0000	1289.44
43	175.70	.1000	3	*****	7.7310	2827.54	2.05849	5.0000	526.90
44	175.70	.1000	3	*****	7.7310	2827.54	2.05849	1.0000	526.90
45	175.70	.1000	3	*****	7.7310	2827.54	2.05849	5.0000	526.90
46	175.70	.1000	3	*****	7.7310	2827.54	2.05849	5.0000	526.90

********** DEVICE DATA (DEVICE BEFORE NODE) **********

NODE	REV. WRK (KW)	ACT. WRK (KW)	IRREV (KW)	HEAT X-FER (KW)	MASS ERROR (KG/S)	ENERGY ERROR (KW)
1	21536.46	.00	21536.46	-105199.70	.000	.016
2	.00	.00	.00	.00	.000	.000
3	-10.11	-12.63	2.53	.00	.000	.000
4	.00	.00	.00	.00	.000	.001
5	196.52	.00	196.52	.00	.000	.000
6	.00	.00	.00	.00	.000	.000
7	-21.30	-26.17	4.87	.00	.000	.000
8	.00	.00	.00	.00	.000	.001
9	178.76	.00	178.76	.00	.000	.000
10	.00	.00	.00	.00	.000	.000
11	-46.72	-56.63	9.91	.00	.000	.000
12	.00	.00	.00	.00	.000	.000
13	254.86	.00	254.86	.00	.000	.002
14	.00	.00	.00	.00	.000	.002
15	-1346.88	-1608.31	261.43	.00	.000	.002
16	.00	.00	.00	.00	.000	.000
17	52840.78	.00	52840.78	137110.60	.000	.000
18	.00	.00	.00	.00	.000	.000
19	4238.50	3781.70	456.80	.00	.000	.000
20	5572.79	4929.13	643.66	.00	.000	.005
21	.00	.00	.00	.00	.000	-.006
22	850.56	.00	850.56	12806.20	.000	-.006
23	.01	.00	.01	.00	.000	-.005
24	4396.73	3924.03	472.70	.00	.000	.000
25	5294.03	4686.43	607.60	.00	.000	-.007
26	.00	.00	.00	.00	.000	.001
27	613.13	.00	613.13	9998.87	.000	.001
28	.01	.00	.01	.00	.000	.005
29	9438.87	8352.90	1085.97	.00	.000	.000
30	9861.99	8556.09	1305.90	.00	.000	.000
31	.00	.00	.00	.00	.000	.000
32	6287.99	5370.97	917.02	.00	.000	.000
33	.00	.00	.00	.00	.000	.000
34	5398.73	4526.77	871.96	.00	.000	.000
35	.00	.00	.00	.00	.000	.000
36	5970.83	4862.75	1108.08	.00	.000	.000
37	.00	.00	.00	.00	.000	.002
38	.00	.00	.00	.00	.000	.000
39	989.77	.00	989.77	-633.43	.000	.000
40	.00	.00	.00	.00	.000	.000
41	4762.47	.00	4762.47	-3570.52	.000	.000
42	.00	.00	.00	.00	.000	.000
43	3812.74	.00	3812.74	-3225.02	.000	.000
44	.00	.00	.00	.00	.000	.000
45	.00	.00	.00	.00	.000	.000
46	.00	.00	.00	.00	.000	.000

********** SYSTEM DATA **********

TOTAL MASS FLOW RATE EXITING SYSTEM: .0000 KG/SEC
TOTAL MASS FLOW RATE ENTERING SYSTEM: .0000 KG/SEC
TOTAL ENTHALPY FLOW RATE EXITING SYSTEM: .0000 KW
TOTAL ENTHALPY FLOW RATE ENTERING SYSTEM: .0000 KW
TOTAL HEAT AND WORK ENTERING SYSTEM: -.0039 KW

BOILER HEAT (DEVICE # 1): 159915.7000 KW
TOTAL BOILER HEAT: 159915.7000 KW
HEAT LOAD HEAT (DEVICE # 31): -633.4307 KW
HEAT LOAD HEAT (DEVICE # 34): -3570.5250 KW

HEAT LOAD HEAT (DEVICE # 37):	-3225.0180	KW
TOTAL HEAT LOAD HEAT:	-7428.9740	KW
CONDENSER HEAT (DEVICE # 14):	-105199.7000	KW
TOTAL PIPE ENERGY LOSSES:	.0000	KW
TURBINE WORK (DEVICE # 3):	8710.8320	KW
TURBINE WORK (DEVICE # 6):	8610.4610	KW
TURBINE WORK (DEVICE # 9):	31669.4800	KW
NET WORK TO GENERATORS:	48990.7800	KW
PUMP WORK (DEVICE # 16):	-12.6342	KW
PUMP WORK (DEVICE # 20):	-26.1689	KW
PUMP WORK (DEVICE # 24):	-56.6334	KW
PUMP WORK (DEVICE # 28):	-1608.3100	KW
TOTAL PUMP WORK:	-1703.7460	KW
GENERATOR MECHANICAL LOSSES:	.0000	KW
GENERATOR ELECTRICAL LOSSES:	.0000	KW
NET ELECTRICAL POWER:	47287.0400	KW
SYSTEM HEAT RATE:	11538.7300	BTU/KW*HR
CARNOT CYCLE EFFICIENCY:	65.8535	PERCENT
1ST LAW EFFICIENCY:	29.5700	PERCENT
2ND LAW EFFICIENCY:	57.0444	PERCENT
2ND LAW EFFECTIVENESS:	44.9027	PERCENT

Appendix G:

Hand calculations for benchmark case #6

Benchmark Case #6

Input data in english units

T1=	543.4	Deg F
P1=	990.0	psia
M1=	15913429.0	lbm/hr
P4=	431.3	psia
P10=	293.0	psia
P11=	182.0	psia
M22=	198275.0	lbm/hr
P23=	89.4	psia
P24=	41.3	psia
P25=	17.1	psia
P26=	10.7	psia
P27=	6.0	psia
M27=	158865.0	lbm/hr
P28=	1.7	psia
P35=	540.0	psia
O56=	0.0	Percent
L56=	4	(-)
Flow frac @2=	84.75997	Percent
Flow frac @6=	92.34106	Percent

HPT #1 stg grp #1 eff=	81.0	Percent
HPT #2 stg grp #1 eff=	84.0	Percent
HPT #2 stg grp #2 eff=	83.0	Percent
LPT stg grp #1 eff=	91.5	Percent
LPT stg grp #2 eff=	91.0	Percent
LPT stg grp #3 eff=	91.0	Percent
LPT stg grp #4 eff=	87.8	Percent
LPT stg grp #5 eff=	86.7	Percent
LPT stg grp #6 eff=	70.0	Percent
FPT stg grp #1 eff=	78.0	Percent
Pump #1 eff=	95.0	Percent
Pump #2 eff=	95.0	Percent
Pump #3 eff=	65.0	Percent
CFW #1 Terminal TD=	5.0	Deg F
CFW #2 Terminal TD=	5.0	Deg F
CFW #3 Terminal TD=	5.0	Deg F
CFW #5 Terminal TD=	5.0	Deg F
CFW #6 Terminal TD=	5.0	Deg F
CFW #7 Terminal TD=	5.0	Deg F
CFW #1 Approach TD=	10.0	Deg F
CFW #2 Approach TD=	10.0	Deg F
CFW #3 Approach TD=	10.0	Deg F
CFW #4 Approach TD=	10.0	Deg F
CFW #5 Approach TD=	39.593	Deg F
CFW #6 Approach TD=	10.0	Deg F
CFW #7 Approach TD=	10.0	Deg F
Low temp reheater TTD=	25.0	Deg F
High temp reheater TTD=	25.0	Deg F
Generator Mech. losses=	8725.0	KW
Generator Elect. Losses=	15150.0	KW
T dead=	75.0	Deg F
P dead=	14.7	psia
h dead=	43.09	Btu/lbm
s dead=	0.083975	Btu/lbm/R
T high=	543.4	Deg F
T low=	55.0	Deg F

PL 9-62=	12.0	psid
PL 10-57=	9.0	psid
PL 12-53=	5.4	psid
PL 19-20=	0.0	psid
PL 22-09=	0.0	psid
PL 23-46=	2.7	psid
PL 24-43=	1.3	psid
PL 25-40=	0.5	psid
PL 27-36=	0.2	psid
PL 28-31=	0.0	psid
PL 30-32=	0.0	psid
PL 63-65=	0.0	psid
PL 5-7=	1.0	psid
PL 49-50=	0.0	psid

Steam Generator PL=	138.2	psid
Moisture seperator PL=	5.4	psid
Low temp cycle stm PL=	2.6	psid
Low temp reheat stm PL=	4.3	psid
High temp cycle stm PL=	2.6	psid
High temp reheat stm PL=	10.0	psid
CFW #1 extraction PL=	0.0	psid
CFW #2 extraction PL=	0.0	psid
CFW #3 extraction PL=	0.0	psid
CFW #4 extraction PL=	0.0	psid
CFW #5 extraction PL=	0.0	psid
CFW #6 extraction PL=	0.0	psid
CFW #7 extraction PL=	0.0	psid
CFW #1 feed water PL=	0.0	psid
CFW #2 feed water PL=	0.0	psid
CFW #3 feed water PL=	0.0	psid
CFW #4 feed water PL=	0.0	psid
CFW #5 feed water PL=	0.0	psid
CFW #6 feed water PL=	0.0	psid
CFW #7 feed water PL=	0.0	psid

QI 9-62=	0.00	Btu/lbm
QL 10-57=	0.00	Btu/lbm
QL 12-53=	0.00	Btu/lbm
QL 19-20=	0.00	Btu/lbm
QL 22-29=	0.00	Btu/lbm
QL 23-46=	0.00	Btu/lbm
QL 24-43=	0.00	Btu/lbm
QL 25-40=	0.00	Btu/lbm
QL 27-36=	0.00	Btu/lbm
QL 28-31=	0.00	Btu/lbm
QL 30-32=	0.00	Btu/lbm
QL 63-65=	0.0	Btu/lbm
QL 5-7=	0.0	Btu/lbm
QL 49-50=	0.0	Btu/lbm

QL 16-54=	0.00	Btu/lbm
QL 18-61=	0.00	Btu/lbm
QL 26-37=	0.00	Btu/lbm
QL 39-33=	0.00	Btu/lbm
QL 64-66=	0.00	Btu/lbm
QL 59-67=	0.00	Btu/lbm
QL 48-68=	0.00	Btu/lbm
QL 45-69=	0.00	Btu/lbm
QL 42-70=	0.00	Btu/lbm
QL 58-71=	0.00	Btu/lbm

Input data converted to SI units

T1=	284.11	Deg C
P1=	6.82580	MPa
M1=	2005.09	Kg/sec
P4=	2.97371	MPa
P10=	2.02018	MPa
P11=	1.25484	MPa
M22=	24.98	Kg/sec
P23=	0.61639	MPa
P24=	0.28475	MPa
P25=	0.11790	MPa
P26=	0.07377	MPa
P27=	0.04137	MPa
M27=	20.02	Kg/sec
P28=	0.01172	MPa
P35=	3.72317	MPa
O56=	0.00	(-)
L56=	4	(-)
Flow frac @2=	0.8476997	(-)
Flow frac @6=	0.9234106	(-)

HPT #1 stg grp #1 eff=	0.810	(-)
HPT #2 stg grp #1 eff=	0.840	(-)
HPT #2 stg grp #2 eff=	0.830	(-)
LPT stg grp #1 eff=	0.915	(-)
LPT stg grp #2 eff=	0.910	(-)
LPT stg grp #3 eff=	0.910	(-)
LPT stg grp #4 eff=	0.878	(-)
LPT stg grp #5 eff=	0.867	(-)
LPT stg grp #6 eff=	0.700	(-)
FPT stg grp #1 eff=	0.780	(-)
Pump #1 eff=	0.950	(-)
Pump #2 eff=	0.950	(-)
Pump #3 eff=	0.650	(-)
CFW #1 Terminal TD=	2.78	Deg C
CFW #2 Terminal TD=	2.78	Deg C
CFW #3 Terminal TD=	2.78	Deg C
CFW #5 Terminal TD=	2.78	Deg C
CFW #6 Terminal TD=	2.78	Deg C
CFW #7 Terminal TD=	2.78	Deg C
CFW #1 Approach TD=	5.56	Deg C

PL 9-62=	0.0827	MPa
PL 10-57=	0.0621	MPa
PL 12-53=	0.0372	MPa
PL 19-20=	0.0000	MPa
PL 22-09=	0.0000	MPa
PL 23-46=	0.0186	MPa
PL 24-43=	0.0090	MPa
PL 25-40=	0.0034	MPa
PL 27-36=	0.0014	MPa
PL 28-31=	0.0000	MPa
PL 30-32=	0.0000	MPa
PL 63-65=	0.0000	MPa
PL 5-7=	0.0069	MPa
PL 49-50=	0.0000	MPa

Steam Generator PL=	0.9529	MPa
Moisture seperator PL=	0.0372	MPa
Low temp cycle stm PL=	0.0179	MPa
Low temp reheat stm PL=	0.0296	MPa
High temp cycle stm PL=	0.0179	MPa

QI 9-62=	0.0000	KJ/kg
QL 10-57=	0.0000	KJ/kg
QL 12-53=	0.0000	KJ/kg
QL 19-20=	0.0000	KJ/kg
QL 22-29=	0.0000	KJ/kg
QL 23-46=	0.0000	KJ/kg
QL 24-43=	0.0000	KJ/kg
QL 25-40=	0.0000	KJ/kg
QL 27-36=	0.0000	KJ/kg
QL 28-31=	0.0000	KJ/kg
QL 30-32=	0.0000	KJ/kg
QL 63-65=	0.0000	KJ/kg
QL 5-7=	0.0000	KJ/kg
QL 49-50=	0.0000	KJ/kg

QL 16-54=	0.0000	KJ/kg
QL 18-61=	0.0000	KJ/kg
QL 26-37=	0.0000	KJ/kg
QL 39-33=	0.0000	KJ/kg
QL 64-66=	0.0000	KJ/kg

Benchmark Case #6 (cont'd)

CFW #2 Approach TD=	5.56 Deg C
CFW #3 Approach TD=	5.56 Deg C
CFW #6 Approach TD=	5.56 Deg C
CFW #5 Approach TD=	22.00 Deg C
CFW #8 Approach TD=	5.56 Deg C
CFW #7 Approach TD=	5.56 Deg C
Low temp reheater TTD=	13.89 Deg C
High temp reheater TTD=	13.89 Deg C
Generator Mech. losses=	5725.0 KW
Generator Elect. Losses=	15150.0 KW
T dead=	297.04 Kelvin
P dead=	0.101 MPa
h dead=	100.5 KJ/Kg
s dead=	0.3516 KJ/Kg/K
T high=	557.26 Kelvin
T low=	285.93 Kelvin

high temp reheat stm PL=	0.0689 MPa
CFW #1 extraction PL=	0.0000 MPa
CFW #2 extraction PL=	0.0000 MPa
CFW #3 extraction PL=	0.0000 MPa
CFW #4 extraction PL=	0.0000 MPa
CFW #5 extraction PL=	0.0000 MPa
CFW #6 extraction PL=	0.0000 MPa
CFW #7 extraction PL=	0.0000 MPa
CFW #1 feed water PL=	0.0000 MPa
CFW #2 feed water PL=	0.0000 MPa
CFW #3 feed water PL=	0.0000 MPa
CFW #4 feed water PL=	0.0000 MPa
CFW #5 feed water PL=	0.0000 MPa
CFW #6 feed water PL=	0.0000 MPa
CFW #7 feed water PL=	0.0000 MPa

OL 59-67=	0.0000 KJ/kg
OL 46-58=	0.0000 KJ/kg
OL 45-59=	0.0000 KJ/kg
OL 42-70=	0.0000 KJ/kg
OL 56-71=	0.0000 KJ/kg

Node	Temperature (Deg C)	Pressure (MPa)	Fluid Phase (-)	Quality (-)	Entropy (KJ/Kg/K)	Enthalpy (KJ/Kg)	Specific Volume (m^3/kg)	Mass flow rate (Kg/sec)	Aval (KJ/Kg)	Actual Work (KW)	Rev Work (KW)	Irrev (KW)	Heat X-Fer (KW)
1	284.111	6.82580	3	-1.000	5.8269	2774.96	2.82E-02	2005.0921	1048.05	0.00	39074.79	39074.79	3587169.04
2	284.111	6.82580	3	-1.000	5.8269	2774.96	2.82E-02	1900.2251	1048.05	0.00	0.00	0.00	0.00
3	284.111	6.82580	3	-1.000	5.8269	2774.96	2.82E-02	104.8669	1048.05	0.00	0.00	0.00	0.00
3 (T sat)	284.102	6.82580	XXXXXXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX
4s	XXXXXXXXXX	2.97371	XXXXXXXXXXXXXX	XXXXXXXXXX	5.8269	2819.98	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX
4	233.353	2.97371	2	0.915	5.8851	2649.43	6.17E-02	1900.2251	905.24	238542.48	271369.79	32827.31	0.00
5	233.353	2.97371	2	0.915	5.8851	2649.43	6.17E-02	145.5371	905.24	0.00	0.00	0.00	0.00
6	233.353	2.97371	2	0.915	5.8851	2649.43	6.17E-02	1754.6880	905.24	0.00	0.00	0.00	0.00
7	233.225	2.96881	2	0.915	5.8859	2649.43	6.18E-02	145.5371	904.99	0.00	36.75	36.75	0.00
8	233.225	2.96881	2	0.915	5.8859	2649.43	6.18E-02	85.0085	904.99	0.00	0.00	0.00	0.00
8 (T sat)	233.225	2.96881	XXXXXXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX
9	233.225	2.96881	2	0.915	5.8859	2649.43	6.18E-02	80.5286	904.99	0.00	0.00	0.00	0.00
10s	XXXXXXXXXX	2.02016	XXXXXXXXXXXXXX	XXXXXXXXXX	5.8851	2579.60	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX
10	212.876	2.02016	2	0.891	5.9081	2590.77	8.80E-02	103.2105	839.76	102918.01	114904.29	11986.28	0.00
11s	XXXXXXXXXX	1.25484	XXXXXXXXXXXXXX	XXXXXXXXXX	5.9081	2508.44	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX
11	189.980	1.25484	2	0.868	5.9383	2522.44	1.36E-01	1651.4776	762.45	112850.57	127677.54	14826.97	0.00
12	189.980	1.25484	2	0.868	5.9383	2522.44	1.36E-01	88.3296	762.45	0.00	0.00	0.00	0.00
13	189.980	1.25484	2	0.868	5.9383	2522.44	1.36E-01	1563.1479	762.45	0.00	0.00	0.00	0.00
14	188.612	1.21761	4	0.000	2.2207	801.00	1.14E-03	205.6886	145.28	0.00	0.00	0.00	0.00
15	188.612	1.21761	5	1.000	6.5144	2783.28	1.61E-01	1357.4593	852.18	0.00	5134.95	5134.95	0.00
16	232.570	2.93716	4	0.000	2.6329	1002.59	1.21E-03	65.0085	224.43	0.00	6213.14	6213.14	-107058.58
16 (T sat)	232.570	2.93716	XXXXXXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX
17	218.826	1.19969	3	-1.000	6.6859	2862.15	1.78E-01	1357.4593	880.10	0.00	10792.55	10792.55	107058.58
18	283.420	6.75686	4	0.000	3.0974	1254.43	1.34E-03	104.8669	338.30	0.00	11381.57	11381.57	-159453.40
18 (T sat)	283.420	6.75686	XXXXXXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX
19	269.477	1.18176	3	-1.000	6.9200	2979.61	2.04E-01	1357.4593	928.04	0.00	17486.24	17486.24	159453.40
20	269.477	1.18176	3	-1.000	6.9200	2979.61	2.04E-01	1357.4593	928.04	0.00	0.00	0.00	0.00
21	269.477	1.18176	3	-1.000	6.9200	2979.61	2.04E-01	1332.4767	928.04	0.00	0.00	0.00	0.00
22	269.477	1.18176	3	-1.000	6.9200	2979.61	2.04E-01	24.9827	928.04	0.00	0.00	0.00	0.00
23s	XXXXXXXXXX	0.61639	XXXXXXXXXXXXXX	XXXXXXXXXX	6.9200	2833.83	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX
23	198.578	0.61639	2	0.946	6.9464	2846.22	3.41E-01	1332.4767	786.80	177739.12	188197.27	10458.15	0.00
24s	XXXXXXXXXX	0.28475	XXXXXXXXXXXXXX	XXXXXXXXXX	6.9464	2697.41	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX
24	131.767	0.28475	2	0.995	6.9794	2710.80	6.32E-01	65.3897	641.55	170905.30	183304.87	12398.57	0.00
25s	XXXXXXXXXX	0.11790	XXXXXXXXXXXXXX	XXXXXXXXXX	6.9794	2560.20	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX
25	104.301	0.11790	2	0.952	7.0154	2573.76	1.38E+00	62.9007	493.84	163992.60	176756.11	12763.51	0.00
26s	XXXXXXXXXX	0.07377	XXXXXXXXXXXXXX	XXXXXXXXXX	7.0154	2499.46	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX
26	91.347	0.07377	2	0.933	7.0402	2508.53	2.10E+00	31.0598	421.23	73954.11	82327.13	8373.02	0.00
27s	XXXXXXXXXX	0.04137	XXXXXXXXXXXXXX	XXXXXXXXXX	7.0402	2421.85	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX
27	76.698	0.04137	2	0.912	7.0732	2433.38	3.53E+00	20.0170	336.29	82868.38	93660.84	10792.46	0.00
28s	XXXXXXXXXX	0.01172	XXXXXXXXXXXXXX	XXXXXXXXXX	7.0732	2261.26	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX
28	48.977	0.01172	2	0.884	7.2335	2312.90	1.12E+01	1082.6685	168.20	130439.24	181984.43	51545.19	0.00
29	269.477	1.18176	3	-1.000	6.9200	2979.61	2.04E-01	24.9827	928.04	0.00	0.00	0.00	0.00

Benchmark Case #6 (cont'd)

Node	Temperature (Deg C)	Pressure (MPa)	Fluid Phase (-)	Quality (-)	Entropy (KJ/Kg/K)	Enthalpy (KJ/Kg)	Specific Volume (m^3/kg)	Mass flow rate (Kg/sec)	Axial (KJ/Kg)	Actual Work (KW)	Rev Work (KW)	Irrev (KW)	Heat X-Fer (KW)
30s	XXXXXXXXXX	0.01172	XXXXXXXXXXXXXX	XXXXXXXXXX	9.9200	2210.90	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX
30	48.977	0.01172	2	0.812	7.4418	2380.02	1.15E+01	24.9827	173.43	14979.47	18852.01	3872.54	0.00
31	48.977	0.01172	2	0.884	7.2335	2312.90	1.12E+01	1082.6685	168.20	0.00	0.00	0.00	0.00
32	48.977	0.01172	2	0.865	7.4418	2380.02	1.15E+01	24.9827	173.43	0.00	0.00	0.00	0.00
33	48.977	0.01172	2	0.810	0.7563	229.52	1.32E-01	249.8082	5.82	0.00	60.62	60.62	0.00
34	48.977	0.01172	4	0.000	0.6898	204.86	1.01E-03	1357.4593	3.89	0.00	263412.14	263412.14	-2342802.80
35s	XXXXXXXXXX	3.72317	XXXXXXXXXXXXXX	XXXXXXXXXX	0.6898	209.30	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX
35	49.319	3.72317	1	-1.000	0.6905	209.53	1.01E-03	1357.4593	8.34	-6338.82	-6034.55	304.07	0.00
36	75.881	0.03999	2	0.912	7.0873	2433.38	3.64E+00	20.0170	332.08	0.00	84.25	84.25	0.00
36 (Tset)	75.881	0.03999	XXXXXXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX
37	75.881	0.03999	2	0.845	7.3026	2508.53	3.77E+00	20.0598	343.28	0.00	2421.12	2421.12	0.00
38	73.103	3.72317	1	-1.000	0.9877	308.76	1.02E-03	1357.4593	19.30	0.00	6093.14	6093.14	-134693.26
39	54.875	0.03999	1	-1.000	0.7655	229.52	1.01E-03	249.8082	6.06	0.00	5017.03	5017.03	-134693.26
40	103.449	0.11445	2	0.952	7.9282	2573.76	1.42E+00	62.9007	490.03	0.00	239.70	239.70	0.00
40 (Tset)	103.449	0.11445	XXXXXXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX
41	100.671	3.72317	1	-1.000	1.3094	424.39	1.04E-03	1357.4593	39.37	0.00	7493.33	7493.33	156962.89
42	78.659	0.11445	1	-1.000	1.0582	329.12	1.03E-03	198.7314	18.71	0.00	6209.48	6209.48	-156962.89
43	130.692	0.27579	2	0.995	6.9937	2710.80	8.52E-01	65.3897	637.33	0.00	276.41	276.41	0.00
43 (Tset)	130.692	0.27579	XXXXXXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX
44	127.914	3.72317	1	-1.000	1.6069	539.53	1.07E-03	1357.4593	66.13	0.00	6812.30	6812.30	156301.94
45	105.227	0.27579	1	-1.000	1.3757	445.25	1.05E-03	135.8307	40.55	0.00	5912.12	5912.12	-156301.94
46	198.114	0.59777	3	-1.000	6.9401	2846.22	3.52E-01	70.4410	782.73	0.00	286.28	286.28	0.00
46 (T set)	158.683	0.59777	XXXXXXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX
47	155.535	3.72317	1	-1.000	1.8924	658.11	1.10E-03	1357.4593	99.90	0.00	6401.35	6401.35	160988.20
48	133.469	0.59777	1	-1.000	1.6695	561.07	1.07E-01	70.4410	69.09	0.00	6337.55	6337.55	-160968.20
49	189.311	3.72317	1	-1.000	2.2212	805.26	1.14E-03	647.6327	149.40	0.00	0.00	0.00	0.00
50	189.311	3.72317	1	-1.000	2.2212	805.26	1.14E-03	647.6327	149.40	-2759.33	-2670.46	88.88	0.00
50s	XXXXXXXXXX	3.72317	XXXXXXXXXXXXXX	XXXXXXXXXX	2.2207	805.05	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX
51	188.612	1.21761	4	0.000	2.2207	801.60	1.14E-03	647.6327	145.28	0.00	1.44	1.44	0.00
52	186.614	3.72317	1	-1.000	2.0015	705.64	1.11E-03	2005.0921	115.03	0.00	1721.18	1721.18	0.00
53	188.610	1.21761	1	0.858	5.9494	2522.44	1.40E-01	88.3296	759.16	0.00	290.37	290.37	0.00
53 (Tset)	188.610	1.21761	XXXXXXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX
54	188.610	1.21761	2	0.102	2.6574	1002.59	1.74E-02	65.0085	217.17	0.00	472.05	472.05	0.00
55	185.633	3.72317	1	-1.000	2.1879	789.84	1.14E-03	2005.0921	143.87	0.00	3738.44	3738.44	168831.16
56	188.610	1.21761	4	0.000	2.2207	801.00	1.14E-03	441.9441	145.28	0.00	4499.90	4499.90	-168831.16
57	211.301	1.95811	2	0.891	5.9195	2590.77	9.98E-02	103.2105	836.37	0.00	349.68	349.68	0.00
57 (T set)	211.301	1.95811	XXXXXXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX
58	208.523	3.72317	1	-1.000	2.4021	891.41	1.17E-03	2005.0921	181.82	0.00	4388.70	4388.70	209555.19
59	191.388	1.95811	1	-1.000	2.2440	813.72	1.14E-03	288.6060	151.09	0.00	5060.37	5060.37	-203655.19
60s	XXXXXXXXXX	7.77866	XXXXXXXXXXXXXX	XXXXXXXXXX	2.4021	896.51	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX
60	209.938	7.77866	1	-1.000	2.4077	899.25	1.17E-03	2005.0921	187.99	-15726.09	-12372.32	3353.77	0.00
61	231.665	2.88407	2	0.142	3.1321	1254.43	1.09E-02	104.8669	328.00	0.00	1080.52	1080.52	0.00
61 (T set)	231.665	2.88407	XXXXXXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX
62	231.665	2.88407	2	0.915	5.8963	2649.43	6.37E-02	80.5286	901.91	0.00	247.93	247.93	0.00
63	228.888	7.77866	1	-1.000	2.5816	985.93	1.21E-03	2005.0921	223.02	0.00	2185.12	2185.12	173797.21
64	215.493	2.88407	1	-1.000	2.4684	922.92	1.18E-03	185.3955	193.52	0.00	3550.87	3550.87	-173797.21
65	228.887	7.77866	1	-1.000	2.5816	985.93	1.21E-03	2005.0921	223.02	0.00	0.00	0.00	0.00
66	211.301	1.95811	2	0.010	2.4754	922.92	2.21E-03	185.3955	191.56	0.00	380.53	380.53	0.00
67	188.610	1.21761	2	0.206	2.2463	813.72	2.17E-03	288.6060	149.81	0.00	368.88	368.88	0.00
68	130.692	0.27579	2	0.006	1.6709	561.07	4.70E-03	70.4410	68.66	0.00	29.90	29.90	0.00
69	103.450	0.11445	2	0.005	1.3763	445.25	8.90E-03	135.8307	40.36	0.00	25.98	25.98	0.00
70	75.881	0.03999	2	0.005	1.0586	329.12	2.11E-03	198.7314	18.60	0.00	20.48	20.48	0.00
71	188.612	1.21761	4	0.000	2.2207	801.00	1.14E-03	441.9441	145.28	0.00	0.00	0.00	0.00

Benchmark Case #6 (cont'd)

Total boiler heat=	3587169.04	KW
Total condenser heat=	-2342802.8	KW
HPT #1 stg grp #1 work=	238542.48	KW
HPT #2 stg grp #1 work=	102918.01	KW
HPT #2 stg grp #2 work=	112850.57	KW
LPT stg grp #1 work=	177739.12	KW
LPT stg grp #2 work=	170906.30	KW
LPT stg grp #3 work=	163992.60	KW
LPT stg grp #4 work=	73954.11	KW
LPT stg grp #5 work=	82868.38	KW
LPT stg grp #6 work=	130439.24	KW
FPT stg grp #1 work=	14979.47	KW
Actual turbine work=	1269190.28	KW
Pump #1 work=	-6338.62	KW
Pump #2 work=	-2759.33	KW
Pump #3 work=	-15726.09	KW
Total net work=	1223491.24	KW
1st law thermal eff=	34.1074	Percent
Carnot cycle eff=	48.6905	Percent
Adj boiler heat=	1675087.48	KW
Aval produced by system=	0.00	KW
Aval supplied to system=	0.00	KW
2nd law eff=	74.6821	Percent
2nd law effectiveness=	70.0494	Percent

Appendix H:

RANKINE 3.0 input file for benchmark case #6

```
TITLE LINE
  BENCHMARK CASE #6
  END TITLE LINE

NUMBER OF NODES IS 71
HIGH TEMPERATURE RESERVOIR:543.4 DEG F
LOW TEMPERATURE RESERVOIR: 55.0 DEG F
DEAD STATE TEMPERATURE:75.0 DEG F
DEAD STATE PRESSURE: 14.7 PSIA
GENERATOR MECHANICAL LOSS : 5725 KW
GENERATOR ELECTRICAL LOSS : 15150 KW

DEVICE #1: SIMPLE BOILER
  BOILER INLET NODE NUMBER IS 65
  BOILER EXIT NODE NUMBER IS 1
  BOILER EXIT TEMPERATURE IS 543.4 DEG F
  BOILER EXIT PRESSURE IS 990 PSIA
  BOILER EXIT MASS FLOW RATE IS 15913429
LBM/HR
  BOILER PRESSURE LOSS IS 138.2 PSID
  END DEVICE

DEVICE #2: SIMPLE JUNCTION
  INLET #1 NODE NUMBER IS 1
  EXIT #1 NODE NUMBER IS 2
  EXIT #2 NODE NUMBER IS 3
  EXIT #1 FLOW FRACTION IS 94 PERCENT
  END DEVICE

DEVICE #3:  SIMPLE TURBINE
  INLET NODE NUMBER IS 2
  EXTRACTION #1 NODE NUMBER IS 4
  EXTRACTION #1 PRESSURE IS 431.3 PSIA
  STAGE GROUP #1 EFFICIENCY IS 81
PERCENT
  END DEVICE

DEVICE #4: SIMPLE JUNCTION
  INLET #1 NODE NUMBER IS 4
  EXIT #1 NODE NUMBER IS 6
  EXIT #2 NODE NUMBER IS 5
  EXIT #1 FLOW FRACTION IS 91 PERCENT
  END DEVICE

DEVICE #5:  SIMPLE TURBINE
  INLET NODE NUMBER IS 6
  EXTRACTION #1 NODE NUMBER IS 10
  EXTRACTION #2 NODE NUMBER IS 11
  STAGE GROUP #1 EFFICIENCY IS 84
PERCENT
  STAGE GROUP #2 EFFICIENCY IS 83
PERCENT
  EXTRACTION #1 PRESSURE IS 293 PSIA
  EXTRACTION #2 PRESSURE IS 182 PSIA
  END DEVICE

DEVICE #6: SIMPLE JUNCTION
  INLET #1 NODE NUMBER IS 11
  EXIT #1 NODE NUMBER IS 12
  EXIT #2 NODE NUMBER IS 13
  END DEVICE

DEVICE #7: SIMPLE MOISTURE SEPARATOR
  SEPARATOR INLET NODE NUMBER IS 13
  SEPARATOR VAPOR EXIT NODE NUMBER IS
15
  SEPARATOR CONDENSATE EXIT NODE
NUMBER IS 14
  SEPARATOR PRESSURE LOSS IS 5.4 PSID
  END DEVICE

DEVICE #8: SIMPLE JUNCTION
  INLET #1 NODE NUMBER IS 7
  EXIT #1 NODE NUMBER IS 9
  EXIT #2 NODE NUMBER IS 8
  END DEVICE

DEVICE #9: SIMPLE PIPE
  INLET NODE NUMBER IS 9
  EXIT NODE NUMBER IS 62
  PIPE PRESSURE LOSS IS 12.0 PSID
  PIPE ENTHALPY LOSS IS 0.0 BTU/LBM
  END DEVICE

DEVICE #10: SIMPLE REHEATER
  CYCLE STEAM INLET NODE NUMBER IS 15
  CYCLE STEAM EXIT NODE NUMBER IS 17
  REHEAT STEAM INLET NODE NUMBER IS 8
  REHEAT STEAM EXIT NODE NUMBER IS 16
  FLOW FRACTION CONTROLED BY
JUNCTION DEVICE NUMBER 4
  TERMINAL TEMPERATURE DIFFERENCE IS
25.0 DEG F
  CYCLE STEAM PRESSURE LOSS IS 2.6 PSID
  REHEAT STEAM PRESSURE LOSS IS 4.3 PSID
  END DEVICE

DEVICE #11: SIMPLE REHEATER
  CYCLE STEAM INLET NODE NUMBER IS 17
  CYCLE STEAM EXIT NODE NUMBER IS 19
  REHEAT STEAM INLET NODE NUMBER IS 3
  REHEAT STEAM EXIT NODE NUMBER IS 18
  FLOW FRACTION CONTROLED BY
JUNCTION DEVICE NUMBER 2
  TERMINAL TEMPERATURE DIFFERENCE IS
25.0 DEG F
  CYCLE STEAM PRESSURE LOSS IS 2.6 PSID
  REHEAT STEAM PRESSURE LOSS IS 10.0
PSID
  END DEVICE

DEVICE #12: SIMPLE PIPE
  INLET NODE NUMBER IS 10
  EXIT NODE NUMBER IS 57
  PIPE PRESSURE LOSS IS 9.0 PSID
  PIPE ENTHALPY LOSS IS 0.0 BTU/LBM
  END DEVICE

DEVICE #13: SIMPLE PIPE
  INLET NODE NUMBER IS 12
  EXIT NODE NUMBER IS 53
  PIPE PRESSURE LOSS IS 5.4 PSID
  PIPE ENTHALPY LOSS IS 0.0 BTU/LBM
  END DEVICE

DEVICE #14: SIMPLE PIPE
  INLET NODE NUMBER IS 16
  EXIT NODE NUMBER IS 54
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PIPE ENTHALPY LOSS IS 0.0 BTU/LBM
END DEVICE

DEVICE #15: SIMPLE PIPE
INLET NODE NUMBER IS 18
EXIT NODE NUMBER IS 61
PIPE ENTHALPY LOSS IS 0.0 BTU/LBM
END DEVICE

DEVICE #16: SIMPLE PIPE
INLET NODE NUMBER IS 19
EXIT NODE NUMBER IS 20
PIPE PRESSURE LOSS IS 0.0 PSID
PIPE ENTHALPY LOSS IS 0.0 BTU/LBM
END DEVICE

DEVICE #17: SIMPLE JUNCTION
INLET #1 NODE NUMBER IS 20
EXIT #1 NODE NUMBER IS 21
EXIT #2 NODE NUMBER IS 22
EXIT #2 MASS FLOW RATE IS 198275 LBM/HR
END DEVICE

DEVICE #18: SIMPLE TURBINE
INLET NODE NUMBER IS 21
EXTRACTION #1 NODE NUMBER IS 23
EXTRACTION #2 NODE NUMBER IS 24
EXTRACTION #3 NODE NUMBER IS 25
EXTRACTION #4 NODE NUMBER IS 26
EXTRACTION #5 NODE NUMBER IS 27
EXTRACTION #6 NODE NUMBER IS 28
STAGE GROUP #1 EFFICIENCY IS 91.5 PERCENT
STAGE GROUP #2 EFFICIENCY IS 91.0 PERCENT
STAGE GROUP #3 EFFICIENCY IS 91.0 PERCENT
STAGE GROUP #4 EFFICIENCY IS 87.8 PERCENT
STAGE GROUP #5 EFFICIENCY IS 86.7 PERCENT
STAGE GROUP #6 EFFICIENCY IS 70.0 PERCENT
EXTRACTION #1 PRESSURE IS 89.4 PSIA
EXTRACTION #2 PRESSURE IS 41.3 PSIA
EXTRACTION #3 PRESSURE IS 17.1 PSIA
EXTRACTION #4 PRESSURE IS 10.7 PSIA
EXTRACTION #5 PRESSURE IS 6.0 PSIA
EXTRACTION #5 MASS FLOW RATE IS 158865 LBM/HR
EXTRACTION #6 PRESSURE IS 1.7 PSIA
END DEVICE

DEVICE #19: SIMPLE PIPE
INLET NODE NUMBER IS 22
EXIT NODE NUMBER IS 29
PIPE PRESSURE LOSS IS 0.0 PSID
PIPE ENTHALPY LOSS IS 0.0 BTU/LBM
END DEVICE

DEVICE #20: SIMPLE TURBINE
INLET NODE NUMBER IS 29
EXTRACTION #1 NODE NUMBER IS 30
STAGE GROUP #1 EFFICIENCY IS 78.0 PERCENT
END DEVICE

DEVICE #21: SIMPLE PIPE
INLET NODE NUMBER IS 23
EXIT NODE NUMBER IS 46
PIPE PRESSURE LOSS IS 2.7 PSID
PIPE ENTHALPY LOSS IS 0.0 BTU/LBM
END DEVICE

DEVICE #22: SIMPLE PIPE
INLET NODE NUMBER IS 24
EXIT NODE NUMBER IS 43
PIPE PRESSURE LOSS IS 1.3 PSID
PIPE ENTHALPY LOSS IS 0.0 BTU/LBM
END DEVICE

DEVICE #23: SIMPLE PIPE
INLET NODE NUMBER IS 25
EXIT NODE NUMBER IS 40
PIPE PRESSURE LOSS IS 0.5 PSID
PIPE ENTHALPY LOSS IS 0.0 BTU/LBM
END DEVICE

DEVICE #24: SIMPLE PIPE
INLET NODE NUMBER IS 26
EXIT NODE NUMBER IS 37
PIPE ENTHALPY LOSS IS 0.0 BTU/LBM
END DEVICE

DEVICE #25: SIMPLE PIPE
INLET NODE NUMBER IS 27
EXIT NODE NUMBER IS 36
PIPE PRESSURE LOSS IS 0.2 PSID
PIPE ENTHALPY LOSS IS 0.0 BTU/LBM
END DEVICE

DEVICE #26: SIMPLE PIPE
INLET NODE NUMBER IS 28
EXIT NODE NUMBER IS 31
PIPE PRESSURE LOSS IS 0.0 PSID
PIPE ENTHALPY LOSS IS 0.0 BTU/LBM
END DEVICE

DEVICE #27: SIMPLE PIPE
INLET NODE NUMBER IS 30
EXIT NODE NUMBER IS 32
PIPE PRESSURE LOSS IS 0.0 PSID
PIPE ENTHALPY LOSS IS 0.0 BTU/LBM
END DEVICE

DEVICE #28: SIMPLE CONDENSER
EXIT NODE NUMBER IS 34
INLET #1 NODE NUMBER IS 31
INLET #2 NODE NUMBER IS 32
INLET #3 NODE NUMBER IS 33
END DEVICE

DEVICE #29: SIMPLE PUMP
SUCTION NODE NUMBER IS 34
DISCHARGE NODE NUMBER IS 35
DISCHARGE PRESSURE IS 540 PSIA
PUMP EFFICIENCY IS 95.0 PERCENT

END DEVICE

DEVICE #30: SIMPLE PIPE
INLET NODE NUMBER IS 39
EXIT NODE NUMBER IS 33
PIPE ENTHALPY LOSS IS 0.0 BTU/LBM
END DEVICE

DEVICE #31: SIMPLE STEAM TRAP CFW
FEED WATER INLET NODE NUMBER IS 35
FEED WATER EXIT NODE NUMBER IS 38
EXTRACTION INLET NODE NUMBER IS 36
DRAIN INLET #1 NODE NUMBER IS 37
DRAIN INLET #2 NODE NUMBER IS 70
DRAIN EXIT NODE NUMBER IS 39
EXTRACTION PRESSURE LOSS IS 0.0 PSID
FEED WATER PRESSURE LOSS IS 0.0 PSID
TERMINAL TEMPERATURE DIFFERENCE IS 5.0 DEG F
APPROACH TEMPERATURE DIFFERENCE IS 10.0 DEG F
END DEVICE

DEVICE #32: SIMPLE STEAM TRAP CFW
FEED WATER INLET NODE NUMBER IS 38
FEED WATER EXIT NODE NUMBER IS 41
EXTRACTION INLET NODE NUMBER IS 40
DRAIN INLET #1 NODE NUMBER IS 69
DRAIN EXIT NODE NUMBER IS 42
EXTRACTION PRESSURE LOSS IS 0.0 PSID
FEED WATER PRESSURE LOSS IS 0.0 PSID
TERMINAL TEMPERATURE DIFFERENCE IS 5.0 DEG F
APPROACH TEMPERATURE DIFFERENCE IS 10.0 DEG F
END DEVICE

DEVICE #33: SIMPLE STEAM TRAP CFW
FEED WATER INLET NODE NUMBER IS 41
FEED WATER EXIT NODE NUMBER IS 44
EXTRACTION INLET NODE NUMBER IS 43
DRAIN INLET #1 NODE NUMBER IS 68
DRAIN EXIT NODE NUMBER IS 45
EXTRACTION PRESSURE LOSS IS 0.0 PSID
FEED WATER PRESSURE LOSS IS 0.0 PSID
TERMINAL TEMPERATURE DIFFERENCE IS 5.0 DEG F
APPROACH TEMPERATURE DIFFERENCE IS 10.0 DEG F
END DEVICE

DEVICE #34: SIMPLE STEAM TRAP CFW
FEED WATER INLET NODE NUMBER IS 44
FEED WATER EXIT NODE NUMBER IS 47
EXTRACTION INLET NODE NUMBER IS 46
DRAIN EXIT NODE NUMBER IS 48
EXTRACTION PRESSURE LOSS IS 0.0 PSID
FEED WATER PRESSURE LOSS IS 0.0 PSID
APPROACH TEMPERATURE DIFFERENCE IS 10.0 DEG F
END DEVICE

DEVICE #35: SIMPLE OFW HEATER
FEED WATER EXIT NODE NUMBER IS 52
EXTRACTION INLET NODE NUMBER IS 49
FEED WATER INLET NODE NUMBER IS 47
FEED WATER EXIT IS NOT SATURATED
END DEVICE

DEVICE #36: SIMPLE PUMP
SUCTION NODE NUMBER IS 51
DISCHARGE NODE NUMBER IS 50
PUMP EFFICIENCY IS 95.0 PERCENT
END DEVICE

DEVICE #37: SIMPLE OFW HEATER
FEED WATER EXIT NODE NUMBER IS 51
EXTRACTION INLET NODE NUMBER IS 71
FEED WATER INLET NODE NUMBER IS 14
FEED WATER EXIT IS NOT SATURATED
END DEVICE

DEVICE #38: SIMPLE STEAM TRAP CFW
FEED WATER INLET NODE NUMBER IS 52
FEED WATER EXIT NODE NUMBER IS 55
EXTRACTION INLET NODE NUMBER IS 53
DRAIN INLET #1 NODE NUMBER IS 54
DRAIN INLET #2 NODE NUMBER IS 67
DRAIN EXIT NODE NUMBER IS 56
DRAIN EXIT FLUID PHASE IS A SATURATED LIQUID
DRAIN EXIT QUALITY IS 0.0 PERCENT
EXTRACTION PRESSURE LOSS IS 0.0 PSID
FEED WATER PRESSURE LOSS IS 0.0 PSID
TERMINAL TEMPERATURE DIFFERENCE IS 5.0 DEG F
APPROACH TEMPERATURE DIFFERENCE IS 39.593 DEG F
END DEVICE

DEVICE #39: SIMPLE STEAM TRAP CFW
FEED WATER INLET NODE NUMBER IS 55
FEED WATER EXIT NODE NUMBER IS 58
EXTRACTION INLET NODE NUMBER IS 57
DRAIN INLET #1 NODE NUMBER IS 66
DRAIN EXIT NODE NUMBER IS 59
EXTRACTION PRESSURE LOSS IS 0.0 PSID
FEED WATER PRESSURE LOSS IS 0.0 PSID
TERMINAL TEMPERATURE DIFFERENCE IS 5.0 DEG F
APPROACH TEMPERATURE DIFFERENCE IS 10.0 DEG F
END DEVICE

DEVICE #40: SIMPLE PUMP
SUCTION NODE NUMBER IS 58
DISCHARGE NODE NUMBER IS 60
PUMP EFFICIENCY IS 65.0 PERCENT
END DEVICE

DEVICE #41: SIMPLE STEAM TRAP CFW
FEED WATER INLET NODE NUMBER IS 60
FEED WATER EXIT NODE NUMBER IS 63
EXTRACTION INLET NODE NUMBER IS 61
DRAIN INLET #1 NODE NUMBER IS 62
DRAIN EXIT NODE NUMBER IS 64
EXTRACTION PRESSURE LOSS IS 0.0 PSID
FEED WATER PRESSURE LOSS IS 0.0 PSID

TERMINAL TEMPERATURE DIFFERENCE IS
5.0 DEG F
APPROACH TEMPERATURE DIFFERENCE IS
10.0 DEG F
END DEVICE

DEVICE #42: SIMPLE PIPE
INLET NODE NUMBER IS 63
EXIT NODE NUMBER IS 65
PIPE PRESSURE LOSS IS 0.0 PSID
PIPE ENTHALPY LOSS IS 0.0 BTU/LBM
END DEVICE

DEVICE #43: SIMPLE PIPE
INLET NODE NUMBER IS 5
EXIT NODE NUMBER IS 7
PIPE PRESSURE LOSS IS 1.0 PSID
PIPE ENTHALPY LOSS IS 0.0 BTU/LBM
END DEVICE

DEVICE #44: SIMPLE PIPE
INLET NODE NUMBER IS 64
EXIT NODE NUMBER IS 66
PIPE ENTHALPY LOSS IS 0.0 BTU/LBM
END DEVICE

DEVICE #45: SIMPLE PIPE
INLET NODE NUMBER IS 59
EXIT NODE NUMBER IS 67
PIPE ENTHALPY LOSS IS 0.0 BTU/LBM
END DEVICE

DEVICE #46: SIMPLE PIPE
INLET NODE NUMBER IS 50
EXIT NODE NUMBER IS 49
PIPE PRESSURE LOSS IS 0.0 PSID
PIPE ENTHALPY LOSS IS 0.0 BTU/LBM
END DEVICE

DEVICE #47: SIMPLE PIPE
INLET NODE NUMBER IS 48
EXIT NODE NUMBER IS 68
PIPE ENTHALPY LOSS IS 0.0 BTU/LBM
END DEVICE

DEVICE #48: SIMPLE PIPE
INLET NODE NUMBER IS 45
EXIT NODE NUMBER IS 69
PIPE ENTHALPY LOSS IS 0.0 BTU/LBM
END DEVICE

DEVICE #49: SIMPLE PIPE
INLET NODE NUMBER IS 42
EXIT NODE NUMBER IS 70
PIPE ENTHALPY LOSS IS 0.0 BTU/LBM
END DEVICE

DEVICE #50: SIMPLE PIPE
INLET NODE NUMBER IS 56
EXIT NODE NUMBER IS 71
PIPE ENTHALPY LOSS IS 0.0 BTU/LBM
END DEVICE

Appendix I:

RANKINE 3.0 output file for benchmark case #6

RANKINE 3.0: A steam power plant computer simulation

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********** TITLE **********

BENCHMARK CASE #6

********** NODE DATA **********

NODE	T(C)	P(MPa)	L	Q	S(KJ/KG/K)	H(KJ/KG)	V(M^3/KG)	M(KG/S)	A(KJ/KG)
1	284.11	6.8258	3	*****	5.8269	2774.96	.02818	2005.0920	1048.06
2	284.11	6.8258	3	*****	5.8269	2774.96	.02818	1900.2050	1048.06
3	284.11	6.8258	3	*****	5.8269	2774.96	.02818	104.8874	1048.06
4	233.35	2.9737	2	.915	5.8851	2649.43	.06170	1900.2050	905.25
5	233.35	2.9737	2	.915	5.8851	2649.43	.06170	145.5357	905.25
6	233.35	2.9737	2	.915	5.8851	2649.43	.06170	1754.6690	905.25
7	233.22	2.9668	2	.915	5.8859	2649.43	.06184	145.5357	905.00
8	233.22	2.9668	2	.915	5.8859	2649.43	.06184	65.0102	905.00
9	233.22	2.9668	2	.915	5.8859	2649.43	.06184	80.5255	905.00
10	212.88	2.0202	2	.891	5.9081	2590.77	.08803	103.1886	839.76
11	189.98	1.2548	2	.868	5.9383	2522.44	.13594	1651.4800	762.45
12	189.98	1.2548	2	.868	5.9383	2522.44	.13594	88.3536	762.45
13	189.98	1.2548	2	.868	5.9383	2522.44	.13594	1563.1270	762.45
14	188.61	1.2176	4	*****	2.2207	801.00	.00114	205.6862	145.28
15	188.61	1.2176	5	*****	6.5144	2783.28	.16110	1357.4410	852.18
16	232.67	2.9372	4	*****	2.6329	1002.59	.00121	65.0102	224.43
17	218.83	1.1997	3	*****	6.6859	2862.15	.17840	1357.4410	880.10
18	283.42	6.7568	4	*****	3.0974	1254.43	.00134	104.8874	338.30
19	269.49	1.1818	3	*****	6.9200	2979.64	.20420	1357.4410	928.05
20	269.49	1.1818	3	*****	6.9200	2979.64	.20420	1357.4410	928.05
21	269.49	1.1818	3	*****	6.9200	2979.64	.20420	1332.4580	928.05
22	269.49	1.1818	3	*****	6.9200	2979.64	.20420	24.9826	928.05
23	198.59	.6164	3	*****	6.9464	2846.25	.34131	70.4334	786.81
24	131.77	.2848	2	.995	6.9795	2710.82	.63268	65.3857	641.56
25	104.30	.1179	2	.952	7.0154	2573.78	1.38167	62.9030	493.85
26	91.35	.0738	2	.933	7.0403	2508.55	2.09972	31.0590	421.24
27	76.70	.0414	2	.912	7.0732	2433.39	3.52771	20.0170	336.29
28	48.98	.0117	2	.884	7.2335	2312.92	11.16561	1082.6600	168.21
29	269.49	1.1818	3	*****	6.9200	2979.64	.20420	24.9826	928.05
30	48.98	.0117	2	.912	7.4443	2380.83	11.52524	24.9826	173.51
31	48.98	.0117	2	.884	7.2335	2312.92	11.16561	1082.6600	168.21
32	48.98	.0117	2	.912	7.4443	2380.83	11.52524	24.9826	173.51
33	48.98	.0117	2	.010	.7663	229.52	.13157	249.7981	5.82
34	48.98	.0117	4	*****	.6898	204.87	.00101	1357.4410	3.89
35	49.32	3.7232	1	*****	.6905	209.53	.00101	1357.4410	8.34
36	75.88	.0400	2	.912	7.0874	2433.39	3.64422	20.0170	332.09
37	75.88	.0400	2	.945	7.3027	2508.55	3.77363	31.0590	343.28
38	73.10	3.7232	1	*****	.9877	308.76	.00102	1357.4410	19.30
39	54.87	.0400	1	*****	.7654	229.52	.00101	249.7981	6.08
40	103.45	.1145	2	.952	7.0282	2573.78	1.42151	62.9030	490.04
41	100.67	3.7232	1	*****	1.3094	424.39	.00104	1357.4410	39.38
42	78.66	.1145	1	*****	1.0582	329.12	.00103	198.7221	18.71
43	130.69	.2758	2	.995	6.9937	2710.82	.65238	65.3857	637.33
44	127.91	3.7232	1	*****	1.6069	539.53	.00107	1357.4410	66.13
45	106.23	.2758	1	*****	1.3757	445.26	.00105	135.8191	40.55
46	198.13	.5978	3	*****	6.9601	2846.25	.35194	70.4334	782.74
47	155.63	3.7232	1	*****	1.8924	658.10	.00110	1357.4410	99.90
48	133.47	.5978	1	*****	1.6695	561.07	.00107	70.4334	69.09
49	189.31	3.7232	1	*****	2.2212	805.27	.00114	647.6515	149.42
50	189.31	3.7232	1	*****	2.2212	805.27	.00114	647.6515	149.42
51	188.61	1.2176	4	*****	2.2207	801.00	.00114	647.6515	145.28

52	166.61	3.7232	1	*****	2.0015	705.64	.00111	2005.0920	115.03
53	188.61	1.2176	2	.868	5.9494	2522.44	.14005	88.3536	759.16
54	188.61	1.2176	2	.102	2.6574	1002.59	.01741	65.0102	217.17
55	185.83	3.7232	1	*****	2.1879	789.86	.00114	2005.0920	143.87
56	188.61	1.2176	4	*****	2.2207	801.00	.00114	441.9653	145.28
57	211.30	1.9581	2	.891	5.9195	2590.77	.09082	103.1886	836.37
58	208.52	3.7232	1	*****	2.4021	891.41	.00117	2005.0920	181.82
59	191.39	1.9581	1	*****	2.2439	813.69	.00114	288.6014	151.08
60	209.94	7.7786	1	*****	2.4077	899.25	.00117	2005.0920	187.99
61	231.67	2.8841	2	.142	3.1321	1254.43	.01091	104.8874	328.00
62	231.67	2.8841	2	.915	5.8963	2649.43	.06364	80.5255	901.92
63	228.89	7.7786	1	*****	2.5816	985.93	.00121	2005.0920	223.03
64	215.49	2.8841	1	*****	2.4684	922.92	.00118	185.4129	193.62
65	228.89	7.7786	1	*****	2.5816	985.93	.00121	2005.0920	223.03
66	211.30	1.9581	2	.010	2.4754	922.92	.00221	185.4129	191.56
67	188.61	1.2176	2	.006	2.2482	813.69	.00216	288.6014	149.80
68	130.69	.2758	2	.006	1.6709	561.07	.00470	70.4334	68.66
69	103.45	.1145	2	.005	1.3764	445.26	.00891	135.8191	40.33
70	75.88	.0400	2	.005	1.0586	329.12	.02115	198.7221	18.60
71	188.61	1.2176	4	*****	2.2207	801.00	.00114	441.9653	145.28

********** DEVICE DATA (DEVICE BEFORE NODE) **********

NODE	REV. WRK (KW)	ACT. WRK (KW)	IRREV (KW)	HEAT X-FER (KW)	MASS ERROR (KG/S)	ENERGY ERROR (KW)
1	39073.68	.00	39073.68	3587170.00	.000	.000
2	.00	.00	.00	.00	.000	.022
3	.00	.00	.00	.00	.000	.000
4	271364.90	238541.50	32823.39	.00	.000	.109
5	.00	.00	.00	.00	.000	.000
6	.00	.00	.00	.00	.000	.112
7	36.71	.00	36.71	.00	.000	-.013
8	.00	.00	.00	.00	.000	.000
9	.00	.00	.00	.00	.000	-.020
10	114907.50	102921.40	11986.09	.00	.000	.000
11	127678.00	112850.60	14827.36	.00	.000	.219
12	.00	.00	.00	.00	.000	.177
13	.00	.00	.00	.00	.000	.000
14	.00	.00	.00	.00	.000	.000
15	5138.71	.00	5138.71	.00	.000	-.198
16	6213.08	.00	6213.08	-107061.50	.000	-.008
17	10790.37	.00	10790.37	107061.50	.000	.063
18	11382.03	.00	11382.03	-159484.80	.000	.000
19	17484.69	.00	17484.69	159484.70	.000	.078
20	.00	.00	.00	.00	.000	-.113
21	.00	.00	.00	.00	.000	-.064
22	.00	.00	.00	.00	.000	.000
23	188197.70	177739.30	10458.38	.00	.000	.000
24	183304.60	170906.30	12398.25	.00	.000	.000
25	176759.10	163995.60	12763.52	.00	.000	.000
26	82320.40	73947.20	8373.20	.00	.000	.000
27	93674.75	82880.06	10794.69	.00	.000	.000
28	181965.40	130425.60	51539.79	.00	.000	-.219
29	.00	.00	.00	.00	.000	-.001
30	18850.46	14959.90	3890.56	.00	.000	-.001
31	.00	.00	.00	.00	.000	-.087
32	.00	.00	.00	.00	.000	-.001
33	65.34	.00	65.34	.00	.000	-.001
34	263424.80	.00	263424.80	-2342823.00	.000	-.250
35	-6035.67	-6327.46	291.79	.00	.000	-.012
36	84.08	.00	84.08	.00	.000	.000
37	2421.21	.00	2421.21	.00	.000	-.002
38	6095.37	.00	6095.37	134691.70	.000	.000

39	5012.34	.00	5012.34	-134691.70	.000	.000
40	239.35	.00	239.35	.00	.000	.001
41	7493.96	.00	7493.96	156968.90	.000	.000
42	6205.63	.00	6205.63	-156968.90	.000	.016
43	276.63	.00	276.63	.00	.000	-.004
44	6811.39	.00	6811.39	156292.90	.000	-.016
45	5911.38	.00	5911.38	-156292.90	.000	-.016
46	286.20	.00	286.20	.00	.000	-.002
47	6401.92	.00	6401.92	160952.70	.000	.000
48	6337.50	.00	6337.50	-160952.70	.000	.000
49	.00	.00	.00	.00	.000	.002
50	-2680.83	-2769.12	88.29	.00	.000	-.002
51	.00	.00	.00	.00	.000	.029
52	1729.77	.00	1729.77	.00	.000	.020
53	290.46	.00	290.46	.00	.000	-.004
54	472.40	.00	472.40	.00	.000	.000
55	3752.41	.00	3752.41	168862.50	.000	.016
56	4500.66	.00	4500.66	-168862.50	.000	-.016
57	349.84	.00	349.84	.00	.000	-.014
58	4371.07	.00	4371.07	203627.80	.000	-.031
59	5058.86	.00	5058.86	-203627.80	.000	-.016
60	-12370.51	-15724.26	3353.75	.00	.000	.002
61	1080.70	.00	1080.70	.00	.000	-.006
62	247.92	.00	247.92	.00	.000	.007
63	2183.92	.00	2183.92	173798.70	.000	.000
64	3551.05	.00	3551.05	-173798.70	.000	-.016
65	.00	.00	.00	.00	.000	-.053
66	380.60	.00	380.60	.00	.000	-.006
67	368.90	.00	368.90	.00	.000	.004
68	29.95	.00	29.95	.00	.000	.000
69	29.64	.00	29.64	.00	.000	.000
70	21.05	.00	21.05	.00	.000	.001
71	.00	.00	.00	.00	.000	-.004

********** SYSTEM DATA **********

TOTAL MASS FLOW RATE EXITING SYSTEM:	.0000	KG/SEC
TOTAL MASS FLOW RATE ENTERING SYSTEM:	.0000	KG/SEC
TOTAL ENTHALPY FLOW RATE EXITING SYSTEM:	.0000	KW
TOTAL ENTHALPY FLOW RATE ENTERING SYSTEM:	.0000	KW
TOTAL HEAT AND WORK ENTERING SYSTEM:	-.1250	KW
BOILER HEAT (DEVICE # 1):	3587170.0000	KW
TOTAL BOILER HEAT:	3587170.0000	KW
TOTAL HEAT LOAD HEAT:	.0000	KW
CONDENSER HEAT (DEVICE # 28):	-2342823.0000	KW
TOTAL PIPE ENERGY LOSSES:	.0000	KW
TURBINE WORK (DEVICE # 3):	238541.5000	KW
TURBINE WORK (DEVICE # 5):	215772.1000	KW
TURBINE WORK (DEVICE # 18):	799894.2000	KW
TURBINE WORK (DEVICE # 20):	14959.9000	KW
NET WORK TO GENERATORS:	1269168.0000	KW
PUMP WORK (DEVICE # 29):	-6327.4590	KW
PUMP WORK (DEVICE # 36):	-2769.1210	KW
PUMP WORK (DEVICE # 40):	-15724.2600	KW
TOTAL PUMP WORK:	-24820.8400	KW
GENERATOR MECHANICAL LOSSES:	5725.0000	KW
GENERATOR ELECTRICAL LOSSES:	15150.0000	KW
NET ELECTRICAL POWER:	1223472.0000	KW
SYSTEM HEAT RATE:	10003.8400	BTU/KW*HR
CARNOT CYCLE EFFICIENCY:	48.6905	PERCENT

1ST LAW EFFICIENCY:	34.1069 PERCENT
2ND LAW EFFICIENCY:	74.6609 PERCENT
2ND LAW EFFECTIVENESS:	70.0483 PERCENT

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