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DIESEL ELECTRIC POWER PLANT FOR  
SUMMER OPERATION AT  
MICHIGAN STATE COLLEGE

Thesis for the Degree of M. S.  
MICHIGAN STATE COLLEGE  
Douglas E. Lee  
1951



This is to certify that the

thesis entitled

Diesel Electric Power Plant for Summer Operation at

Michigan State College

presented by

Douglas E. Lee

has been accepted towards fulfillment  
of the requirements for

Master's degree in Mechanical Engineering

Major professor

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DIESEL ELECTRIC POWER PLANT FOR SUMMER OPERATION AT  
MICHIGAN STATE COLLEGE

By

Douglas E. Lee

A THESIS

Submitted to the School of Graduate Studies of Michigan  
State College of Agriculture and Applied Science  
in partial fulfillment of the requirements  
for the degree of

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1951



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## INTRODUCTION

This thesis deals with the operation of the Michigan State College Power Plant which is located on the College Campus in East Lansing, Michigan.

The present plant is maintained under the direction of college officials. The power is produced by two large steam turbine units and one small unit. These are located in the Plant on the North Campus. Boilers number five and six are located in this building. The new plant has two boilers installed in 1948.

Steam is now generated principally in this new plant located east of the stadium on the South Campus a distance of approximately 2000 feet from the plant on the North Campus. During the winter months all boilers are in use, but during the summer months of June, July, August and September it is necessary to operate only one or two boilers to produce enough steam for campus usage. The primary purpose of the power plant is the production of steam for heating and cooking; the production of electricity being a secondary issue.

It is the objective of the author to put forth in this paper the advantages and disadvantages of installing a Diesel system to take care of the summer electrical load for the college in part or in full. Investigations were made and are set forth in this paper of the relative merits of such combinations as a Diesel system combining with a turbine for the production of power and steam and as a Diesel system with a

package boiler. The Diesels supplying the electrical loads and the package boiler taking care of the steam requirements.

It is not sought here to report on the replacement of the turbines by Diesels for year-around use, but only for the summer months. It has been noted, however, that many towns and colleges, including the University of Michigan, have found it desirable to purchase Diesels to replace the steam engines and turbines. It is assumed that such towns and colleges are relying on package boiler units to produce the required steam for heating, cooking, etc.

## PROCEDURE

The following steps were taken in the investigation which led to the conclusions stated herein. First, it was seen that the amount of steam used by the college aside from the production of electricity must be determined. At first it was considered necessary to measure the amount of condensate lost at the trailer camp where a large portion of the steam used does not return to the receiver tanks. However, further analysis showed that this method was in a measure unnecessary since there is a meter showing the amount of makeup used which over a period of time would amount to the same answer. A study of a diagram of the steam piping showed that all condensate return from the South Campus came through two pumping stations. One of these is located in the Women's Gym on the west side of the Campus just north of the Red Cedar River and the other is located in the southeast corner of Farm Lane Bridge.

A method was devised whereby the amount of condensate passing through these two stations could be determined and recorded over any desired period of time. The method used was as follows: each of the pumps has fastened adjacent to its discharge a tank in which there is a float switch. When the water level in the tank drops to a certain set point an electric switch clicks on and starts a motor which drives a centrifugal pump to refill the tank to a certain predetermined level where the switch cuts off the motor. A connection was made to the mechanical rise and fall of the float lever so that at the point where

the motor starts an electrical contact was made to a magnetizing coil. This moves a pin on a chart to form a mark perpendicular to the line of travel of the pin on the chart as the chart revolved under the action of a clock. This gave 24 hour readings with a record of the number of times the motor started up. The charts were changed every day at the same hour.

A glass gauge was installed on the tanks whereby the difference between high point and low point of water levels could be determined. Knowing these values it was only necessary to determine the volume of the tank in order to determine the quantity of water or condensate passing through the line for any desired length of time. See included sketch showing process steam metering system.

An insufficient number of meters are installed about the campus to give the necessary readings for determining the amount of process steam used on the campus. By process steam it is meant the steam used for purposes other than the direct production of electricity with a turbine or any of the accessories used to produce the steam which are operated by steam or in which steam is used. For instance, blowdown is not to be included in the process steam. The steam used for heating and for cooking or various other things around the campus is the process steam.

Steam Flow Meters are located on the instrument board of the boiler-room. This gives the total amount of steam which leaves the boiler and enters the turbines. We shall refer to this value which is the combined



total of all boilers in use as  $M_1$ . In the turbine steam is extracted at 100 pounds per square inch and at five pounds per square inch for use as process steam. This steam travels to all the buildings on the campus for such purposes as mentioned before. The condensate which does not return to the flow circuit is replaced by makeup. As shown on diagram No. 6. This makeup water enters the surge tank after it has been properly treated. From the surge tank the condensate is pumped to the condensate receivers located in the hold in the northeast corner of the large basement of the powerhouse on the North Campus. A meter is located in the makeup line and through the cooperation of the power plant employees a flow meter was installed for  $M_2$  shown on the diagram. This thereby measures the condensate which has passed through the condenser.

The method used for determining a value for  $M_4$  was a long process and necessarily a tedious one. The method used was as follows: to the gauge glass on one end of a receiver tank was fastened a three foot rule. A scale with a weighing tank was obtained from the Power Lab and moved down in the hold and placed under the petcock under the gauge glass. The scales were set to read a definite amount and then the petcock was opened noting and marking beforehand the level of the water in the gauge glass. When the amount of water for which the scales were set drained out of the receiver tank, the petcock was shut off and the water level in the gauge glass marked. The water in the tank on the scales was then drained out and the process repeated until there were

a sufficient number of marks on the gauge glass to permit the running of a test.

The purpose of the test was to determine a value for  $M_4$  as shown on the diagram. The time required to fill the receiver tank with a certain number of pounds of water gives a value for  $M_4$ , which is accurate when taken with simultaneous readings of  $M_1$ ,  $M_2$ , and  $M_3$ . Care was taken to insure that the best possible result would be obtained. Since the return main does not enter the top of the receiver tank care was taken to make sure that readings taken were not influenced by this fact. In other words the range of operations for the performance of the tests was taken at points on the gauge glass below the level of the return main.

Results of these tests are given in the form of data sheet material. The results should check closely with a calculated value for  $M_4$  in order for the diagram to be correct. There is a slight discrepancy between the results obtained from the test and the calculated value. The possible cause of this slight discrepancy is that some of the steam is used to heat the makeup water and is returned to the circuit bypassing  $M_2$  and  $M_3$ .

#### Determination of the Amount of Electricity Bought and Sold

The Michigan State College Power Plant is tied in with the city of Lansing Power Plant so that when the College Station is not producing enough power to maintain campus activities the Lansing station automatically cuts in to provide this extra needed power. Also, if the

College Station produces more steam than is necessary for heating and producing the required electric load the turbine may be made to use a greater amount of steam thus running at a greater load and operating more efficiently. This excess power is then sold to the Lansing station at reduced rates.

The average price for buying power from Lansing is 6 cents for the first 50 kwhrs and 2.5¢ for each additional kwhr. The college can sell its power for .2¢ per kwhr. As can be seen from these figures it is not economical to overproduce or underproduce power because of the very low price for which it is sold and the high price for which it is bought.

The Diesel installation would greatly reduce this exchange of power because it could be regulated more closely. In other words, if the generation of steam were a separate item then its generation would have no effect on the power production. Even with the possible operation of one turbine along with the Diesels, the variable power demand could be taken care of by the Diesels.

An accurate record of the amount of electricity bought and sold is kept in the record book of Power Plant Operations. Each month a bill is sent to the college showing the amount and the cost.

It was not the desire of the author to have the bills, but rather the record of the amount bought and sold for the period of summer operation from June 10th to September 15th of each year. Since the period covers three months, the first 150 kwhrs for the period was figured at 6¢ per kwhr and the remaining at 2.5¢ per kwhr to determine the cost of

power bought. The return from power sold was figured at .2¢ per kwhr. The results show for the period 1945-1950 an increasing amount of power bought along with an increasing amount of power sold. The overall cost of this exchange is rising with each year and for the year 1950 it reached the value of \$3755.

The advantages of a tie-up with Lansing should not however be overlooked. In case of a complete breakdown of the College Plant the tie-up with Lansing would prove its worth. There would be no need for shutdown of things on the campus because the needed power would be there.

#### Determination of the Load Duration Curve

A load duration curve is a curve with kilowatts as the ordinate and the number of hours total that the plant is operated at each kilowatt value as the abscissa. In order to determine the points through which to draw this curve the record books of the power produced and how much is bought and sold for each day over the period of investigation. Some days there would be two or three turbines in operation (usually not over two during the summer). By adding the hourly readings of the turbines which shows the kw load at the time of the reading and which may be assumed to be a good average value over the hour of that day, we get the total output of the turbines.

From the total output as obtained above the amount bought from Lansing must be added or the amount sold must be subtracted to obtain the amount of power consumed on the Campus. The amount sold is listed as "out" in the Power Plant Record Book and the amount bought is listed as "in".

The method for determining the total number of hours that a certain number of kilowatts were used during the period is as follows:

A graph is made with the kilowatt reading as the ordinate and the number of hours operated as the abscissa. The record books are checked for the number of hours the plant is operated at a certain kilowatt reading and this point is plotted on the graph. A succession of these points over the period gives the load duration curve for the period.

From this curve it can be determined what percent of the time a certain kw generator would take care of the load, how large a generator would be required to meet the maximum demands and what the duration of any load in the range is.

#### The Field for Diesel Engine Power

The Diesel engine is an excellent prime mover for electrical generation in capacities of from 100 hp to 5000 hp. Since the spread of the utility business in towns and cities is, at present, an acquisition of municipal plants, the ability of the Diesel to generate energy in a small plant about as cheaply as it can be supplied by a larger organization has not brought the Diesel into exceptionally good repute with utility system men. The utility use of Diesels, at present, is the operation of such plants as they have purchased from municipalities and installation of plants in communities to which the cost of carrying a transmission line would be expensive. To a limited extent the Diesel is used for standby service.

The Diesel can convert more energy of each heat unit into work than any other engine in the world. For that reason it becomes an attractive prime mover wherever first cost is written off slowly enough so that initial costs are influential. Central station service in which the college station may be classed is of that type. The Diesel can be brought up to speed, paralled and loaded up to full load in a few minutes. When the Diesel is running idle it has no loss such as the hydraulic turbine gate leakage or steam boiler banking fuel. Small sizes are about as economical to operate as large sizes. Steam rates of turbines are often twice as great in small units as in large units. Also, a condensing turbine cannot be located where a scarcity of water exists. The Diesel uses but a fraction of the water required for condensing, and can use that over and over again.

Some advantages of the Diesel are low fuel cost, no long warm-up period, no standby losses, uniformly high efficiency of all sizes, simple plant layout and no large water supply is needed.

An objection to the Diesel is the exhaust noise, a sort of galloping, thumping, or booming, which is chiefly noticeable at night when most other noises are stilled. Proper installation of exhaust silencers will minimize this fault.

\*The exhaust system requires the attention of the designing engineer, because although the engine manufacturer will provide an exhaust manifold

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\* Power Plant Engineering and Design. F. T. Morse.

for the engine, the plant designer must arrange for connection of the manifold to a suitable exhaust system which will convey the exhaust gases to the atmosphere with proper provision for the following:

1. Silencing of the exhaust noise to the required degree.
2. Discharge of the exhaust sufficiently high above ground level for the prevailing conditions.
3. High temperature of the exhaust gas, which necessitate water-cooled exhaust lines or special high-temperature material.
4. Expansion and contraction due to changes in temperature between the extremes of full load and no load or cold.
5. Possible by-product heat utilization. Where the exhaust is to be employed for building heating, or other source of heat, such conditions necessarily modify the exhaust system.
6. Arrangement of the exhaust system to minimize the back pressure created by the exhaust itself (Header pressure ought not to be over two or three pounds gauge pressure).
7. Isolation of engine vibration from building and muffler system by use of a flexible section of exhaust pipe.

The exhaust system must carry approximately eight cubic feet a second of gases per horsepower developed, this volume being at the average exhaust temperature.

#### Fuel Storage

Manufacturers generally design their engines to run on a certain grade of Diesel fuel. The volume of fuel oil to be stored should be

sufficient so that the maximum rate of fuel consumption in the plant will not empty the storage during the maximum expected period between oil deliveries to the storage tank.

The location of the plant and its accessibility to a supply line are important in the amount of storage that must be made. If fuel oil is delivered once a month, then the storage capacity should be enough to run the plant for the full month with ample fuel left over in case of a late delivery.

Whether the tank should be located above ground or below is a matter of local conditions, including the method of oil delivery, local ordinances, building location, etc. The National Board of Fire Underwriters has provided regulations covering construction of fuel oil storage tanks.

\*The advantages of storage above ground are; the cost of excavation is avoided, leakage is readily detected, maintenance is easier and water and sediment are easily drained. Advantages of below ground storage are; oil can be delivered to the tank by gravity, fire hazard is reduced to a minimum, and the grounds about the plant can be landscaped.

A filter should be located between the storage tank and the engine so as to remove all impurities which are in the fuel. If the fuel is of a particularly high viscosity as most Diesel fuels are, heating coils

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\* From Power Plant Engineering & Design, F. T. Morse.



are required in the tank to keep the oil warm enough to flow. Only a slight rise in temperature is required to produce a tremendous change in the flow characteristics of most fuels.

When motors are used with pumps for oil transfers, the motors should be of a type approved by the Fire Underwriters for this particular service.

The average Diesel will generate a kwh on approximately .10 gallon of fuel. Thus three 1800 kw engines operating 24 hours a day and operating on a plant capacity factor of 55%, which is average, will use  $3 \times 1800 \times .1 \times .55 \times 30 = 214,000$  gal of fuel per month. Enough storage capacity to last over two periods would call for approximately a 400,000 gal fuel tank.

If possible the main storage tank should be divided into two tanks. Fuel tanks need to be cleaned very infrequently but when this cleaning time does come around the procedure need not interrupt operations if there are two tanks. If the fuel is high in water or sediment, or in both, and requires cleaning by centrifuge one tank can serve for incoming fuel before purification, the other for clean oil after purification.

Diesel fuels must be kept at a certain temperature to flow through the injection systems. Following are the Pour Point and Saybolt viscosity of some Diesel fuels.

| *Sample Number              | B-1 | B-2 | B-3 | B-4 | B-5 | B-7 | B-8 | B-9 |
|-----------------------------|-----|-----|-----|-----|-----|-----|-----|-----|
| Pour Point F°               | -25 | -30 | -10 | +5  | +5  | +5  | -20 | +15 |
| Viscos., Sec., SU at 100°F. | 34  | 33  | 36  | 39  | 40  | 37  | 34  | 44  |

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\* The Development of Testing Fuels by Theodore Brinton Hetzel p. 56.

#### Characteristic of Sun No. 11 Oil

|                                    |        |
|------------------------------------|--------|
| Gross Heat Value BTU/lb.           | 18,969 |
| Net Heat Value BTU/lb.             | 17,905 |
| API Gravity 60°F.                  | 17.7   |
| Specific Gravity                   | 0.9484 |
| Flash Point °F.                    | 200    |
| Saybolt Universal Viscosity 150°F. | 207    |
| Sulphur Percent                    | 0.68   |
| Conradson Carbon, Percent          |        |
| 1st Run                            | 6.03   |
| 2nd Run                            | 6.11   |
| Ash, Percent                       | 0.15   |

Contrary to a commonly held belief, oils of themselves, do not tend to thin out, but rather tend to thicken. However in service, most oils show a lower viscosity after use than in the new condition. The answer is dilution. Fuel is the commonest diluent, and therefore viscosity may be used as a measure of engine condition.

The storage tanks should be of a good grade of metal able to withstand heat changes without buckling enough to cause leaks at a joint. However, most tanks are now welded. The tank should have an opening at its top so that a measuring stick can be used. The day tank should be fitted with a gauge glass.

Viscosity of a fuel determines its fluidity. It is a fair indication of how readily the oil will atomize and how it will affect the injection pump. A very viscous oil may prove troublesome to handle without heating. Viscosity is stated in terms of seconds Saybolt, Universal, at some specified temperature, usually 100° F. It is the number of seconds required for 60 cc of the oil to flow through a certain size orifice at this temperature.

A hand pump may be used between the large tank and the day tank. This is not, however, compulsory. Fuel lines should be of copper or brass.

#### Efficiency and Economy

Power can be and is being generated by Diesels at a cost of from 5 to 8 mils per kilowatt-hour. Including fixed charges of interest, depreciation, insurance and taxes, a Diesel engine will deliver a kilowatt-hour at a cost of from 7 to 20 mils depending upon the load and the operating schedule. Often there is no extra labor charge since an existing employee takes on the added duties.

Important factors in the cost per unit output are the kilowatt hours generated per year for each kilowatt of installed capacity and the engine load when running in terms of the percent of engine rating. This is termed the Running Capacity Factor. If an 1800 kw Diesel operated at an average load of 1000 kw for 5000 hours a year, the Running Capacity factor would be  $\frac{1000 \times 5000}{1800 \times 8760} = 31\%$ . \*The 8760 is the number of hours in a year. In the usual lighting plant, either municipally or privately owned, the Running Capacity Factor averages around 55%.

The large items in the cost of a Diesel plant are lubrication oil, engine repairs, labor costs, fixed charges and total operating costs. When considering engine repairs it should be understood that this item includes the cost of the repairs and the extra labor needed over and

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\* Diesel Engineering Handbook 1946 - 47ed.

above the operating force to make the replacements. \*A good average figure as computed for 158 plant years for the cost of engine repairs and reported in the Reports of the Oil Engine Power Cost Sub-Committee of the American Society of Mechanical Engineers is 0.52 mils per kilowatt hour. This survey included utility, industrial, and municipal ownership of the plants.

Labor costs are an exceedingly variable item in power production. Reports show that the better plants employ as a rule but one man per shift for plants up to 1500 kw in size. Over this a second man may be needed. The labor cost must be established for the particular locality of the plant.

The total of the two items, engine repairs and other repairs and supplies ranges from 0.5 to 1.0 mils per kilowatt hour. The enclosed chart is based on a 50 cent per gallon lubricating oil and on 4 cents per gallon fuel oil. This seems to be a fair average for the cost of the oils, however, the cost depends to a very great extent upon transportation of the oil.

The total cost of generating a kilowatt hour of electricity, including all repairs, supplies, lubrication and fuel ranges between 6 and 4.3 mils depending upon the output per kilowatt of plant capacity and the above mentioned factors. Every plant should be designed to produce over 1000 kilowatt-hours per kilowatt capacity every year.

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\* Diesel Engineer's Handbook - 1946 - 47ed.

\* Fixed charges include the cost of the engine, building, foundations, etc. Of course the individual plant may set any length of time they choose within which to wipe out the plant investment, but the usually accepted period is 12 years. An average Diesel plant can be installed for \$100 per kw., including everything except real estate.

When comparing the cost of Diesel power with the cost of purchased power, it is much better to calculate interest and tax charges and determine what the yearly saving over purchased power will be. If the saving will pay for the Diesel plant in a reasonable time, it is a good investment.

If the plant cost is to be retired by a yearly refunding, the average interest rate is one-half the yearly interest rate calculated on the entire investment. If the interest rate is 6 percent, the average based on the entire first cost is 3 percent.

Plants with an output ratio of over 4000 are considered to be three-shift plants with a \$4000 operator on each shift. Plants under 4000 are considered one shift plants. With the extra operators on there is an increase in cost per kilowatt-hour for the plant. Below is a table of total generating costs, based on fuel oil at 4 cents per gallon.

| TOTAL GENERATING COSTS, INCLUDING INTEREST, TAXES AND OPERATING CHARGES |                                                                        |      |      |                    |      |      |
|-------------------------------------------------------------------------|------------------------------------------------------------------------|------|------|--------------------|------|------|
| Plant Capacity                                                          | Cost in Mills per Kwhr When the Yearly Output Per Kilowatt Capacity Is |      |      |                    |      |      |
| KW                                                                      | 2000                                                                   | 3000 | 4000 | 5000               | 6000 | 7000 |
| 250                                                                     | 11.44                                                                  | 8.96 | 7.81 | 10.87              | 9.89 | 9.26 |
| 1000                                                                    | 8.08                                                                   | 6.71 | 6.13 | 6.82               | 6.51 | 6.37 |
| 1500                                                                    | 9.20                                                                   | 7.46 | 6.70 | 8.17               | 7.64 | 7.34 |
| 2000                                                                    | 7.46                                                                   | 6.33 | 5.85 | 6.14               | 5.95 | 5.89 |
|                                                                         | One-shift plants                                                       |      |      | Three-shift plants |      |      |

\* Diesel Engineering Handbook, 1946-47

\* An Example: Costs of Running 10 Diesels for 4 Years

On five 6-12 $\frac{1}{2}$  x 13-T turbocharged Diesel engines designed to develop 810 bhp each at 600 rpm and five 6-12 $\frac{1}{2}$  -13 Diesel engines delivering 540 bhp each at 600 rpm a review of the cost of operation was made. The plants are located in South America and the records were compiled by the engineers in charge of operations.

The total number of working hours was 86,361 for the first five engines or an average of 4318 operating hours per year for the period 1942 to 1945 inclusive. The total cost of all plant repairs averaged 1.75 mills per kilowatt hour. Of this figure approximately one-third is chargeable against the total cost of repair parts for the Diesel engine. Roughly 0.6 mills per kwhr was expended for replacement parts, some of which were still included in the inventory, but which were already charged off to maintenance cost in the 0.6 mills.

Maintenance for all purchased parts comes to only \$1.13 per rated horsepower per year. This plant's maintenance cost was roughly one-half the average recorded inside the United States.

The lubricating oil economy of this plant averaged 2000 horsepower hours per gallon of lube oil. Leakage and other usage of lube oil are included in this figure since no attempt was made to reclaim used oil.

The fuel oil consumption of the five engines averaged 12.75 kwhr per gal at an average plant running capacity factor of 70 percent.

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\* Power Generation, March 1948.

This includes all leakage and cleaning oil used. Load conditions called for operation at less than half load for 50 percent of the time, and at full load the other half of the period.

In the second five Diesel engines referred to in the first paragraph bearing replacement was very high. After the first two years of operation, a different type of lubricating oil was used and bearing replacements declined materially. The maintenance cost for this plant over the five year period from 1941-1945 inclusive, averaged 0.809 mills per kilowatt hour. This is roughly 40 percent of the average maintenance cost per kwhr for ten plants of approximately the same size as tabulated in the ASME "Report on Oil Engine Power Cost" for 1943.

The total operating cost of the first five engines including fixed charges, fuel, lube oil, maintenance, attendance, and all other charges, amounts to 1.75 cents per kwhr. On a twenty year amortization plan, this final total cost would run approximately 0.9 to 1.0 cents per kwhr.

#### SOME FACTS AND FIGURES OF THE ABOVE DESCRIBED PLANTS

Author's Note: Since costs are those of South America they are not to be included.

|                                         | 1942      | 1943       | 1944      | 1945      |
|-----------------------------------------|-----------|------------|-----------|-----------|
| Total engine hours operated             | 21,896    | 29,427     | 17,956    | 17,082    |
| Total kwhr Generated                    | 7,606,100 | 10,515,660 | 6,404,800 | 6,209,000 |
| Total fuel oil consumption<br>(gallons) | 568,925   | 822,538    | 509,949   | 483,048   |
| Total lubricating oil consumption (gal) | 6,351     | 6,546      | 4,763     | 4,534     |
| Kwhr output per gallon of<br>fuel oil   | 12.92     | 12.784     | 12.56     | 12.646    |
| Kwhr output per gallon of<br>lube oil   | 1198      | 1606       | 1345      | 1347      |
| Station running capacity factor         |           | 71%        | 71.3%     | 69.4%     |

(Continued next page)

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Running-engine-capacity factor=  $\frac{\text{Engine output in gross kwhr} \times 100}{\text{Kw rating} \times \text{number of hrs operated}}$

Running-plant-capacity factor, percent=  $\frac{\text{Plant output in gross kwhr} \times 100}{\text{Total rated kwhr of individual units}}$

Annual-plant-load factor, percent=  $\frac{\text{Plant output in gross kwhr} \times 100}{\text{Peak load in kw} \times \text{number of hrs in period}}$

Plant-service factor, percent=  $\frac{\text{Total rated kwhr of individual units} \times 100}{\text{Total installed kw} \times \text{number of hrs in period}}$

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#### Purchased Power Held Under Control Aids Process Plant

If the power plant is on a tie-up so that part of the electrical load can be generated and the rest of it bought when needed there is one principal shortcoming. The turbine is sometimes used instead of a reducing valve as is the case with Michigan State College Plant to bring boiler pressure down to required process level. The principal shortcoming is that plant demands for process steam and for power seldom vary concurrently. As a result costly peak demands on purchased power occur that seriously affect the over-all savings.

\*One company met this situation by installing a turbine that is provided with an automatic governor control, responsive to both purchased or primary power and plant demands for process steam.

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\* Power, Nov. 1948, pp. 82-



The savings by this company indicated a complete return of investment in less than three years after deducting interest, depreciation and taxes, despite operating only ten hours per day, five days a week. The unit operates in parallel with the purchased source of power. The automatic governor-control varies the output of the unit within the range from no load to full-load setting of the regular governor, but not in excess of this setting. Thus all the features of the standard governor are in control.

The automatic governor control provides for the following conditions: (1) Limits maximum demands on the primary purchased source to a predetermined top level regardless of plant process steam demands. (2) Limits minimum demands at a fixed level so as to prevent returnflow of power to primary source when plant steam demands may be high and electric-power demands low. (2) With the minimum demand set at a fixed point, the maximum demands are automatically varied in the range from the fixed top position to the minimum one, depending on steam demands.

The control is provided with means to alter easily and accurately the maximum top fixed-limit while the unit is in operation, thus advantage can be taken of power rates that permit higher peaks without penalty during certain periods.

The standard design of control uses one wattmeter element relay with the pressure element a counterpart of the unit. The turbine used was equipped with a back pressure regulator built into the governor. The control, therefore, has two wattmeter element relays, one set for maximum, the other for minimum.

The relays have contacts which are set for a predetermined maximum and minimum purchased-power demand. When the incoming power is less than the predetermined minimum, the lower contacts close and the upper contacts close when the incoming power is greater than the predetermined maximum. Within a certain range of incoming power load the exhaust-pressure regulator is permitted to function through its full range of control.

The servomotor can take over at any time regardless of the exhaust pressure regulator thus permitting the all-important "peak demand" to supersede other factors. If excess exhaust pressure develops beyond the desired limit, steam is vented to the atmosphere.

When power demands are so low that available exhaust steam proves insufficient to meet plant demands the usual makeup reducing valves bypasses the turbine.

When an incoming power failure occurs, the turbine is thrown automatically into position to assume its full power generating capacity.

The standard element includes the pressure element. In limited steam-generating capacity or scarcity of product fuel when boiler pressure becomes the criterion, the pressure element is used with reverse action.

#### How To Save Fuel In Any Particular Plant

1. Maintain a high feedwater temperature. Recover exhaust steam that might be otherwise wasted by utilizing it in a direct contact open or deaerating feedwater heater. Do not allow any steam to escape to the atmosphere that can possibly be used in the plant.

2. Recover the heat in Boiler Blowoff Water. The steam flashed in flash tanks can be used in the feedwater heater or process lines. Heat exchangers recover the remaining heat in the blowoff water before discharging it to the sewer.

3. Return all Condensate to the Boiler. If oil contaminated remove the oil from the exhaust with a steam purifier or pass the condensate through an oil remover filter. To run condensate to the sewer is sheer waste of heat and water. Enter trap discharges and heating system returns to the open feedwater heater. Avoid loss of flash steam in open receivers and hotwells. Return high temperature condensate from corrugators, dryers, process kettles, etc., directly to the boiler by the use of a condensate return system.

4. Reduce moisture content of steam. Steam purifiers can reduce the moisture from 5 percent more down to less than 1 percent, resulting in dryer, hotter steam.

5. Check Boiler Water Treatment. Accumulations of scale on any heating surface seriously restricts the transfer of heat and such are a major cause of boiler troubles in addition to waste in fuel. Corrosion is both dangerous and costly.

6. Keep on the watch for steam and hot water leaks. A 1/8 in. diameter steam leak in a 100 psi line will cause the loss of over 50,000 pounds of steam in a month. Make sure that all valves in steam line close tightly.

7. Insulation or lagging. Keep all piping and steam using equipment properly insulated to cut down heat losses.

8. Practice Preventive Maintenance. Don't wait until trouble catches up with you. Be on the lookout for it. Keep a reasonable supply of replacement parts on hand as they are often difficult to secure when you have a breakdown. Make use of all available instruments, and regularly check the efficiency of your equipment with them. Avoid overloading boilers above their efficient operating rate. Keep furnace baffles tight and use soot blowers regularly.

#### Requirements Of A Good Foundation

\*(1) A foundation is required to maintain the machinery and structures rigid and keep all parts in true adjustment.

(2) A foundation is required to transmit the dead weight of the machinery and structures to the ground and distribute it in such a manner that the safe bearing pressure of the ground is not exceeded. This dead load always acts vertically downward.

(3) A foundation may be required to transmit the live loads of the machinery and structures to the ground. The direction in which the forces act due to the live loads will depend upon the type of machinery and structures used.

(4) A foundation is required to absorb as far as possible vibrations set up by machinery and transmit as little as possible of this vibration to the surrounding ground. The machinery foundations should be isolated from the building foundations to reduce the transmission

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\* Electric Power Stations by Carr, p: 12.

of vibration forces to a minimum and obviate troubles due to settlement. A foundation should be heavy enough to take care of any accidental out-of-balance forces which may arise during normal working of the machinery. The design and types of foundations will depend primarily on the sub-soil obtaining on the site.

#### Waste Heat Boilers and Water Heaters

Four type of heating surfaces are available for waste heat recovery. They are cast iron, extended surface, armored tubes and bare tubes.

Thermal efficiency of a water heater is represented by the ratio of the gas temperature drop to the difference between the entering gas temperature and the saturated steam temperature in the case of a boiler, or the entering water temperature in the case of a water heater.

The amount of heat that can be recovered in the form of steam generated, or water heated, depends upon the amount of exhaust gas and its temperature. Engine efficiencies and conditions vary with different types and different manufacturers. Therefore, the exact operating performance of any engine should be obtained from the manufacturer in order to make a detailed survey of heat recovery possibilities.

Below are some average values for rough approximations:

| Engine Type    | Gas wt. lbs. per hr.<br>per rate 1 hp. | Exhaust<br>Deg. Fahr. | Gas Temp.<br>Full load |
|----------------|----------------------------------------|-----------------------|------------------------|
| 4 Cycle Diesel | 12.0                                   |                       | 750                    |
| 2 Cycle Diesel | 20.0                                   |                       | 550                    |

Waste heat boilers must handle a large volume of gas with only a low

draft loss so as to impose the minimum back pressure on the engine. The available temperature difference between the gas and the boiler water is smaller than in a direct fired boiler, and thus more heating surface is required for a desired weight of steam. As the steam pressure is increased, the saturation temperature approaches the gas temperature, and this consideration limits the maximum practical steam pressure.

There is practically no limit to the diversity of uses for steam and hot water made available through recovery from engine exhaust.

Steam may be generated for power purposes. Each engine is equipped with a waste heat boiler of novel design incorporating economizer and steam superheater sections. The engine normally operates at an exhaust gas temperature of 1175°F. Each boiler generates approximately 11,400 pounds of steam per hour at a pressure of 150 pounds gage, superheated to a final steam temperature of 580°F. for power uses. Exhaust gases are discharged from the economizer section at a temperature of 360°F, with feedwater of 180°F. This represents a thermal efficiency of 82 percent for the waste heat recovery equipment.

\*In 98 percent of our Diesel installations this available heat from the exhaust is thrown away. If the specific fuel consumption of an engine is 0.38 pounds per brake horsepower and the potential heat value of the fuel is 18,000 BTU per pound, then the efficiency of the

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\* Diesel Power, Dec. 1947, p. 50.

engine is  $\frac{2545}{.38 \times 18000} = 34.6$  (approximately). This is a good efficiency for an internal combustion engine, but where a certain amount of steam is needed this waste heat may be recovered to a certain extent.

When from the above engine 1000 BTU of the exhaust waste is retained for the production of steam, the overall efficiency of the system is increased to  $\frac{3545}{.38 \times 18000} = 48.6$  (approximately).

The basic operation of an exhaust boiler hook-up is as follows: When the steam demand is using the full steam capacity of the unit, the output of the boiler is directly proportional to the load on the engine and the water level in the unit is kept to the proper height by a Bristol liquid level indication gauge.

When the water level drops below the set position due to evaporation the gauge operates to admit air to the top of the diaphragm of the waste heat boiler feed valve opening the valve. When steam demand is less than the full output of the boiler, excess pressure is built up in the boiler which actuates the pressure controller which in turn throttles the feed water, and if enough excess pressure is built up, closes the feed valve entirely, and opens the dump valve to the accumulator tank.

The pressure in the boiler will force the water to the accumulator tank, lowering the water level until a level is reached which will generate steam at a rate just sufficient to meet the steam demand at which point the dump valve will close and the water level will be maintained at this point by the pressure actuated feed valve.

Should the steam demand fall off entirely, all the water will be drained from the boiler and the unit will operate dry as a silencer and spark arrester.

With the average Diesel engine and correct design of heat recovery unit, a pound of steam per bhp can be developed at about full load. If the steam from these heat recovery silencers can not be used at maximum capacity, then a superheater can be installed in the exhaust and 600 pounds of steam per hour at 500°F furnished to a turbine and exhausted at 1psi absolute. With 70 percent Rankine efficiency at these conditions, a 525 hp turbine could be operated representing almost a 10 percent increase in the total power output at no extra cost for the fuel.

Amount Of Heat That May Be Recovered From The Diesels To Heat Steam  
BTU/lb of fuel 18000 BTU

It may be assumed with fair accuracy that 1000 BTU/lb of fuel may be retained for the production of steam from the average Diesel.

Number of gallons of fuel used during the summer 437,000

Pounds of fuel = 437,000 x 8.33 x .825 (Grade 1) 3,000,000

Available BTU's 3 million x 1000 =  $3 \times 10^9$  BTU

Assume raw water temperature of 60°F.

Condition of steam wanted 100 psi and 5 psi.

Heat required to change water to steam

at 100 psi -  $(327.81 - 60) + 888.8 = 1151$  BTU/lb

$\frac{3 \times 10^9}{1151} = 2,600,000$  lb of 100 psi steam could be generated

or



at 5 psi (182.24 - 60) + 1001 = 1103 BTU/lb

$\frac{3 \times 109}{1103} = 2,720,000$  lb of 5 psi steam could be generated

Average daily process steam consumption =

$37000 \times 24 = 888,000$  lb/day

$\frac{2,600,000}{888,000} = 2.92$  days ←- This would be impractical but the

heat may be utilized to heat feedwater.

#### Heat Recovery in Diesel Engines

\*From the pressure volume diagram the kinetic energy of the exhaust gases may be determined. (Refer to diagram) The area ABCDEFA represents the energy obtainable from the exhaust, where A is the point of exhaust valve opening and EF indicates the back pressure. The expansion line AB is assumed to be adiabatic.

The amount of exhaust heat that may be recovered is reduced to 60 or 70 percent of the total, mainly by the necessity of maintaining a final exhaust temperature of at least 250°F. to avoid precipitation of water in the system and resulting acid formation and rapid corrosion, which would occur if the exhaust gas were to be cooled below the dew point.

#### Burning Oil In The Furnace

In addition to proportioning fuel and air, and mixing them, oil burners must prepare the fuel for combustion. There are two ways of

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\* Trans. ASME OGP-53-1

doing this, with many variations of each: (1) The oil may be vaporized or gasified by heating within the burner, or (2) it may be atomized by the burner so vaporization can occur in the combustion space.

If oil is to be vaporized in the combustion space in the instant of time available, it must be broken up into many small particles to expose as much surface as possible to the heat. This atomization may be effected in three ways by (1) using steam or air under pressure to break the oil into droplets (2) forcing oil under pressure through a suitable nozzle, and (3) tearing an oil film into drops by centrifugal force. In addition to this turbulence must be provided to provide motion between oil droplets and air, so vapor "coats" are stripped off as fast as they form and fresh surfaces exposed.

#### Blowdown

Water always contains impurities and no matter what treatment method is used a portion at least will reach the boiler. When the water in the boiler evaporates, these impurities are left behind to concentrate in the boiler with the result that the boiler water becomes dirty. As the boiler continues to evaporate water, the impurities settling in the boiler continue to increase. Soon this accumulation of sledge and soluble impurities will cause the boiler to foam and carry boiler water with its impurities over into the superheater, steam lines, and prime movers. The purpose of blowdown is to regulate the concentration of solids in the boiler water so as to prevent carryover in the steam.

Continuous blowdown is the name applied to a system through which the amount of water discharged from the boiler drum is regulated by a valve placed in the blowdown line. The flow is continuous and the energy carried away in the discharge from the boiler is usually recovered by conducting it through a heat exchanger in which it is utilized to increase the temperature of the feedwater.

In an arrangement for continuous blowdown a connection is made to the boiler drum at a point just below the minimum permissible water level, thus preventing the draining of the boiler in the event of an accident to the blowdown system.

#### Some Regulations of the National Board of Fire Underwriters

The regulations of the National Board of Fire Underwriters require oil storage tanks to be constructed of steel, wrought iron, or concrete, the latter not being permitted for oils lighter than 35° Baume. When the storage tanks are located above ground and are liable, in case of breakage to overflow, to endanger surrounding property, each tank should be protected by a continuous embankment or dike. Inside storage is much more hazardous than outside, and should be considered only when there is no possibility of outside storage. Then the tanks should not be located above the lowest story or basement of the building and should also be located below the level of any piping to which they may be connected.

The Underwriter's rules state that the normal gross capacity of such tanks shall not exceed 5000 gal in ordinary buildings nor 15,000

gal in fire resistive buildings. However, under special conditions and where the oil is stored in a specially constructed room, 50,000 gal. may be stored.

#### Procedure for Determining the Proper Size of Engine to Use

After the duration curve for the entire summer period for previous years was plotted from the information obtained from the record books of the power plant it was noted that the maximum load was around 4600 kw. It has been suggested by highly authorized personnel that a figure of 80% of the maximum load be taken as a basis of the minimum size of plant to be chosen. Of course this would cause an overload on the engine in the neighborhood of 25% for short intervals of time. Since the overload would be, however, of a very short duration it is not considered dangerous and in case the load did become of a greater duration, the Lansing Company could be relied upon to provide the overload needed.

With a maximum load of 4600 kw., 80% would be 3680 kw. This is not giving any outlook to future expansion of the plant which will surely come within a few years. The population of the college was more than doubled during the years from 1940 to 1950 and is very likely to continue to grow in the years to come. It is with this in mind that the author has chosen the following engines.

The Cooper-Bessemer LSV-16 Engine rated at 3770 hp at 327 rpm. Two of these Engines were chosen so as to allow for the future expansion of the college and since one engine was insufficient to carry the load at present.

The LSV-16 is supercharged with one Exhaust Turbine driving an integral Centrifugal blower. The engines are Gas-Diesel and are equipped with a complete Diesel Fuel System and also with gas fuel admission equipment. This permits operation entirely on Diesel fuel or on proportions of oil and gas fuel up to 96% gas and 4% Diesel Pilot oil. At any time while the engine is running, the fuel mixture may be changed to the proportions desired. Gas is taken into the cylinder with the charge of intake air where it is ignited by the Diesel Pilot oil. A governor controls the quantity of the two fuels to meet engine demands.

These engines are shipped as a completely assembled, factory tested unit. The branch office closest to Lansing is the Chicago office. The net weight of each engine is 75 tons and the shipping weight is 90 tons. The engines may be shipped by railroad car.

Enclosed is a rating curve for the LSV-16 Diesel and Gas-Diesel engine.

#### SUMMER SCHOOL ENROLLMENT AT MICHIGAN STATE COLLEGE

| Year | First Six Weeks | Second Six Weeks | Full Quarter | Total 3 & 6 Week Sessions |
|------|-----------------|------------------|--------------|---------------------------|
| 1946 | --              | --               | 4814         | --                        |
| 1947 | --              | --               | 3828         | 1089                      |
| 1948 | --              | --               | 3466         | 1304                      |
| 1949 | 4828            | 1405             | --           | --                        |
| 1950 | 4659            | 2100             | --           | --                        |

## Cooling of an Engine

The quantity of heat generated in an engine cylinder varies from about 7,000 to 12,000 BTU per hphr. From 25 to 35 percent of this heat finds its way into the cylinder walls and must be carried away.

The methods of cooling may be divided into two main groups (1) direct, or air cooling; and (2) indirect, or liquid cooling.

\*Permitting the water temperature to rise above the boiling temperature to about 220°F. to 250°F. gives very important and far reaching advantages. (1) It eliminates the condensation of the water vapor contained in the products of combustion which in turn (a) prevents, or at least reduces materially the washing off of the lubricating-oil film from the cylinder and piston-ring surfaces and prevents the formation of sulfuric acid from  $\text{SO}_2$ , which is very often obtained in the products of combustion; these two factors reduce the wear of the cylinders, piston rings, and valves considerably, under certain conditions, down to one-eighth of the usual amount; and (b) eliminates crankcase condensation and sludging of the lubricating oil.

(2) The higher temperature lowers the viscosity of the cylinder-lubricating oil, thus raising the mechanical efficiency of the engine and lowering the specific fuel rate as much as 10 percent, at full load.

(3) Also, it reduces considerably the amount of water which must be circulated, since the cooling effect of each pound of water evaporated

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\* Heat Power Fundamentals - Leonard S. Haleer

is about 970 BTU per pound, instead of 10 to 20 BTU per pound, absorbed by the water due to temperature difference only; this increases the fuel saving.

(4) Again, it increases the temperature difference between the cooling water and air to which the heat is rejected and, if a radiator is used, requires a smaller radiator surface and fan, which again saves fuel. Quite naturally, with an increase of the jacket temperatures, the heat absorbed by the jacket from the gases in the cylinder decreases because of a smaller temperature difference. The heat not transferred to the jacket water is absorbed by the exhaust gases, which raises their temperature.

# MICHIGAN STATE COLLEGE

## PLANT OPERATION DATA FOR FIVE YEARS ENDING WITH 1949-1950 FISCAL YEAR

|                              | 49-50           | 48-49           | 47-48           | 46-47           | 45-46           |
|------------------------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| Average Temperature          | 46.3°F.         | 49°F.           | 46.2°F.         | 45.6°F.         | 45.8°F.         |
| Cooling Water Temp. Range    | 33°-89°F.       |                 |                 |                 |                 |
| Coal Consumed                | 53,283 tons     | 49,879 tons     | 51,542 tons     | 43,132 tons     | 29,495 tons     |
| Gross Steam Generated        | 985,317,182 lbs | 900,495,111 lbs | 876,290,250 lbs | 723,325,025 lbs | 504,971,072 lbs |
| #1 Boiler Generated          | 397,466,925     | 359,376,937     | 87,648,380      | 0               | 0               |
| #2 Boiler Generated          | 324,460,000     | 397,200,375     | 0               | 0               | 0               |
| #5 Boiler Generated          | 97,411,474      | 20,285,160      | 192,197,040     | 149,488,560     | 153,121,462     |
| #6 Boiler Generated          | 163,978,783     | 118,541,603     | 231,473,023     | 215,408,025     | 159,262,743     |
| #7 Boiler Generated          | 0               | 5,085,036       | 364,971,807     | 358,428,440     | 192,586,868     |
| System Steam Peak            | 219,000 lbs     | 195,000 lbs     |                 |                 |                 |
| #1 Boiler Peak               | 122,000 lbs     | 115,000         | 103,000         |                 |                 |
| #2 Boiler Peak               | 118,000         | 122,000         | 0               |                 |                 |
| #5 Boiler Peak               | 49,000          | 37,000          | 67,000          | 63,000          | 50,000 lbs      |
| #6 Boiler Peak               | 85,000          | 61,000          | 85,000          | 80,000          | 65,000          |
| #7 Boiler Peak               | 0               | 50,000          | 78,000          | 94,000          | 87,000          |
| Gross Electrical Generated   | 30,542,500 kw   | 27,624,100 kw   | 18,706,460      | 14,282,300      | 10,895,400      |
| #1 Turbine Generated         | 175,500         | 278,300         | 1,135,400       | 539,000         | 12,200          |
| #2 Turbine Generated         | 799,000         | 1,115,800       | 1,647,060       | 670,100         | 58,200          |
| #3 Turbine Generated         | 13,609,000      | 15,103,000      | 16,924,900      | 13,073,000      | 10,735,000      |
| #4 Turbine Generated         | 15,959,000      | 11,126,000      |                 |                 |                 |
| System Electrical Peak       | 6,800           | 6,300           | 5,030           | 3,380           | 2,550           |
| Total Electrical Used        | 27,669,500      | 24,461,000      | 21,013,460      | 13,257,200      | 9,193,400       |
| % increase over previous yr. | 12.5%           | 14.3%           | 54%             | 44%             | 12.5%           |
| Electricity Bought           | 376,000         | 709,000         | 2,202,000       | 461,000         | 154,000         |
| Electricity Sold             | 3,249,000       | 2,872,000       | 895,000         | 1,506,000       | 1,795,000       |
| Boiler Room cu.ft./kw.       | 125             | 125             | 64              | 64              | 64              |
| Turbine Room cu.ft./kw.      | 20.3            | 20.3            | 35.5            | 35.5            | 35.5            |
| Office Space cu.ft./kw.      | .985            | .985            | 1.3             | 1.3             | 1.3             |
| Coal Storage Tons/kw.        | 3.57            | 3.57            | 3.5             | 3.5             | 3.5             |



# MICHIGAN STATE COLLEGE POWER PLANT

## ANALYSIS OF STEAM USED DURING THE CALENDAR YEAR OF 1949

| (1)<br>Month | (2)<br>Million lbs<br>of Steam | (3)<br>Percent of<br>Years Total | (4)<br>Percent of<br>Years Total<br>To Turbines | (5)<br>Percent of<br>Years Total<br>To Extract. | (6)<br>Percent of<br>Years Total<br>to Condens. | (7)<br>Percent of Years<br>Total to Auxil-<br>Heat Steam Passing<br>thru red. vol. in-<br>stead of steam<br>turbine |
|--------------|--------------------------------|----------------------------------|-------------------------------------------------|-------------------------------------------------|-------------------------------------------------|---------------------------------------------------------------------------------------------------------------------|
| Jan.         | 106.9                          | 11.2                             | 10.6                                            | 8.75                                            | 1.94                                            | 0.56                                                                                                                |
| Feb.         | 101.9                          | 10.7                             | 10.19                                           | 8.35                                            | 1.84                                            | 0.53                                                                                                                |
| Mar.         | 102.2                          | 10.7                             | 10.21                                           | 8.37                                            | 1.84                                            | 0.54                                                                                                                |
| April        | 80.9                           | 8.5                              | 8.09                                            | 6.61                                            | 1.48                                            | 0.43                                                                                                                |
| May          | 62.9                           | 6.6                              | 6.29                                            | 5.14                                            | 1.15                                            | 0.33                                                                                                                |
| June         | 49.9                           | 5.2                              | 4.98                                            | 4.08                                            | 0.90                                            | 0.26                                                                                                                |
| July         | 47.4                           | 5.0                              | 4.72                                            | 3.88                                            | 0.85                                            | 0.25                                                                                                                |
| Aug.         | 44.8                           | 4.7                              | 4.47                                            | 3.66                                            | 0.80                                            | 0.23                                                                                                                |
| Sept.        | 63.3                           | 6.7                              | 6.32                                            | 5.18                                            | 1.14                                            | 0.32                                                                                                                |
| Oct.         | 82.9                           | 8.8                              | 8.28                                            | 6.78                                            | 1.49                                            | 0.43                                                                                                                |
| Nov.         | 103.6                          | 10.9                             | 10.35                                           | 8.48                                            | 1.87                                            | 0.53                                                                                                                |
| Dec.         | 104.7                          | 11.0                             | 10.47                                           | 8.57                                            | 1.90                                            | 0.54                                                                                                                |

Note: For the months of July and August the maximum steam pressure was 160 PSI

Column (4) plus column (7) equals 100%

Column (5) plus column (6) equals the values shown in column (4).

ELECTRICITY BOUGHT AND SOLD TO LANSING BY THE MICHIGAN STATE  
COLLEGE POWER PLANT

Observers: Micheal Delich  
Douglas Lee

Date: January 30, 1951

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| Period June 10 - September 15, 1945-50 |               |             |           |       |                 |
|----------------------------------------|---------------|-------------|-----------|-------|-----------------|
| Year                                   | KWH<br>Bought | KWH<br>Sold | Liability | Asset | Overall<br>Cost |
| 1945                                   | 49,000        | 269,000     | \$1231    | \$536 | \$693           |
| 1946                                   | 41,000        | 297,000     | 1031      | 594   | 437             |
| 1947                                   | 149,000       | 293,000     | 3731      | 586   | 3145            |
| 1948                                   | 175,000       | 398,000     | 4381      | 796   | 3585            |
| 1949                                   | 161,000       | 392,000     | 4031      | 784   | 3247            |
| 1950                                   | 161,000       | 388,000     | 4531      | 776   | 3755            |

Selling price = .2¢/kwhr  
 Buying price = 6¢/kwhr and 2.5¢/kwhr  
 for additional power based on each  
 months usage.

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KWHR COST OF PRESENT POWER GENERATED  
(Figures for 1950 Calendar Year)  
Based on 20 year life of equipment

**EQUIPMENT COST DATA:**

|                                                      |              |             |
|------------------------------------------------------|--------------|-------------|
| No. 3 Turbo-generator                                | \$83,300.    |             |
| No. 3 Condenser                                      | 11,305.      |             |
| Diver Pump House (Condenser Circulating Water)       |              |             |
| Traveling Water Screen                               | \$3745.      |             |
| Building                                             | 7000.        |             |
| Pumps                                                | <u>3000.</u> | 13,811.     |
| No. 4 Turbo-generator                                |              | 91,800.     |
| No. 4 Condenser                                      |              | 14,500.     |
| Switchgear, original installation                    | 80,167.      | \$14,744.15 |
| No information is available on subsequent additions. |              |             |

**GENERATING COSTS:**

|                                        |                   |          |
|----------------------------------------|-------------------|----------|
| Superintendence                        | 2,310.            | 2,310.   |
| Boiler labor (none)                    |                   |          |
| Engine and Turbine labor - 4 operators | 13,200.           | 13,200.  |
| Elec. Labor 50% of \$3500.             | 1,750.            | 1,750.   |
| Maintenance                            |                   |          |
| Station building                       | 200.              |          |
| Steam Equipment                        | 1500.             |          |
| Electrical Equipment                   | 400.              |          |
| Misc. Power Equipment                  | 800.              |          |
| Misc. Labor                            | <u>600.</u>       | 3,500.   |
| Fuel Costs                             |                   |          |
| 100% Steam                             | 8,250.            |          |
| 5% Steam                               | 42,300.           |          |
| Condensing op.                         | 60,000.           |          |
| Water expense                          | 3,750.            |          |
| (5% Growth)                            | <u>\$114,300.</u> | 114,300. |
| Cooling water for condenser            | 21,549.           | 21,549.  |
| Lubricants                             | 100.              | 100.     |
| Production supplies                    | 600.              | 600.     |
| Station expense                        | 300.              | 300.     |

**BUILDING COSTS:**

|                                               |                     |                     |
|-----------------------------------------------|---------------------|---------------------|
| New Plant (620,460 cu. ft.) 1948              | \$506,000.          |                     |
| Old Plant (514,300 cu. ft.) 1921              | 409,000.            |                     |
| Additions & alterations (310,200 cu.ft.) 1940 | 500,000.            | 50,300.             |
|                                               | <u>\$1,415,000.</u> |                     |
| 3% of \$1,415,000                             |                     | 42,450.             |
|                                               |                     | <u>\$265,103.15</u> |
| Total kwhr generated 31,271,400               |                     | 31,271,400          |
| Cost per kwhr                                 |                     | \$.0085             |



# COST OF DIESEL\*

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|         |                                |  |           |
|---------|--------------------------------|--|-----------|
| Fuel -- | 437,000 gallons at 10¢         |  |           |
|         | 5,600,000 kwhr. 12.8 kwhr./gal |  | \$43,700. |

## Installation

|                                  |           |         |
|----------------------------------|-----------|---------|
| Approximately \$100 per rated kw |           |         |
| 2 - 3700 hp - 2760 kw            | \$552,000 |         |
| 20 years to pay plus 6% interest |           |         |
| 3% x \$552,000 =                 |           | 16,560. |
| Total                            | 552,000   | 27,600. |

|                                         |        |        |
|-----------------------------------------|--------|--------|
| Additional Building at \$.80 per cu.ft. |        |        |
| 20 x 60 x 60 = 72,000 cu. ft.           | 57,600 |        |
| 20 year rate plus 6% interest           |        |        |
| 3% x \$57,600 =                         |        | 1,729. |
| Total                                   | 57,600 | 2,880. |

|                                        |  |        |
|----------------------------------------|--|--------|
| Foundation - concrete at \$.50/100 yd. |  |        |
| Allow 20 yds.                          |  | 1,000. |

|                                             |  |        |
|---------------------------------------------|--|--------|
| Labor - 2 operators (3 shifts for 3 months) |  |        |
| \$3300.                                     |  | 6,600. |

|                                   |  |        |
|-----------------------------------|--|--------|
| Lubrication - 4070 gallons at 50¢ |  |        |
| Average 1374 kwhr/gal             |  | 2,035. |

|                           |  |        |
|---------------------------|--|--------|
| Repairs and Supplies      |  |        |
| 1 mill per kwhr generated |  | 5,600. |

|                                      |  |        |
|--------------------------------------|--|--------|
| Storage tanks - 3 - 25,000 gal tanks |  |        |
| at \$2200 each                       |  | 6,600. |

|                        |           |            |
|------------------------|-----------|------------|
| Overhead Crane (5 ton) |           | 2,000.     |
| Total                  |           | \$116,303. |
| Total kwhr production  | 5,600,000 |            |
| One kwhr cost          |           | \$0.0207   |

---

\* This cost is based on three months of operation per year.



## CONCLUSIONS

It has been shown by the calculations that the possibility of making a profit from Diesel installation at the Michigan State College for summer operation only is small. The present cost of generating electricity is only 6 mills per kwhr. This cost includes equipment costs with an amortization plan over 20 years. It also included operating costs, building costs, labor costs and fuel cost.

With a Diesel fuel cost of 4 cents per gallon which is a low figure for this since the fuel would have to be trucked in from several miles and other cost figures shown in the chart, a Diesel would cost approximately 18 mills per kwhr. This figure is based on the 1950 load duration curve and the average figure of 12.8 kwhr per gallon of fuel. It has been found that Diesel plants could be installed at a cost of \$100 per rated kw. This has been used and an interest rate of 6 percent has been charged over the period which gives an average rate of 3 percent.

The chief costs are fuel costs, installation costs and storage tank costs. The author was informed by Mr. Bunting of the Bunting Company of Lansing that fuel storage tanks of 25,000 gallon capacity could be obtained for \$2200 each. Tanks of a capacity over 25,000 gallons have to be specially built by the factory. The cost of these oversized tanks is not a straight line function, but drops off with a larger size tank. However, the cost of these oversize tanks is not readily available.

Additional building to house the Diesels would cost, by the 1948 price level, an average of 80 cents per cubic foot. This is the cost of the building on South Campus which houses boilers.

The foundation concrete may be assumed to be \$50 a cubic yard. The weight of the foundation should be enough to keep down vibrations.

The operation would require 2 operators on each shift for 8 hours a shift. The average salary of these operators is \$3300 a year. Repairs and supplies may be taken as one mill per kwhr for an average figure as determined by past reports.

Lubrication costs based on a lubricating fuel cost of 50¢ per gallon gives a cost of \$2035 for the 3-month period of operation. An average figure of 1374 kwhr per gallon may be taken as a basis for the calculation of lubricating oil costs.

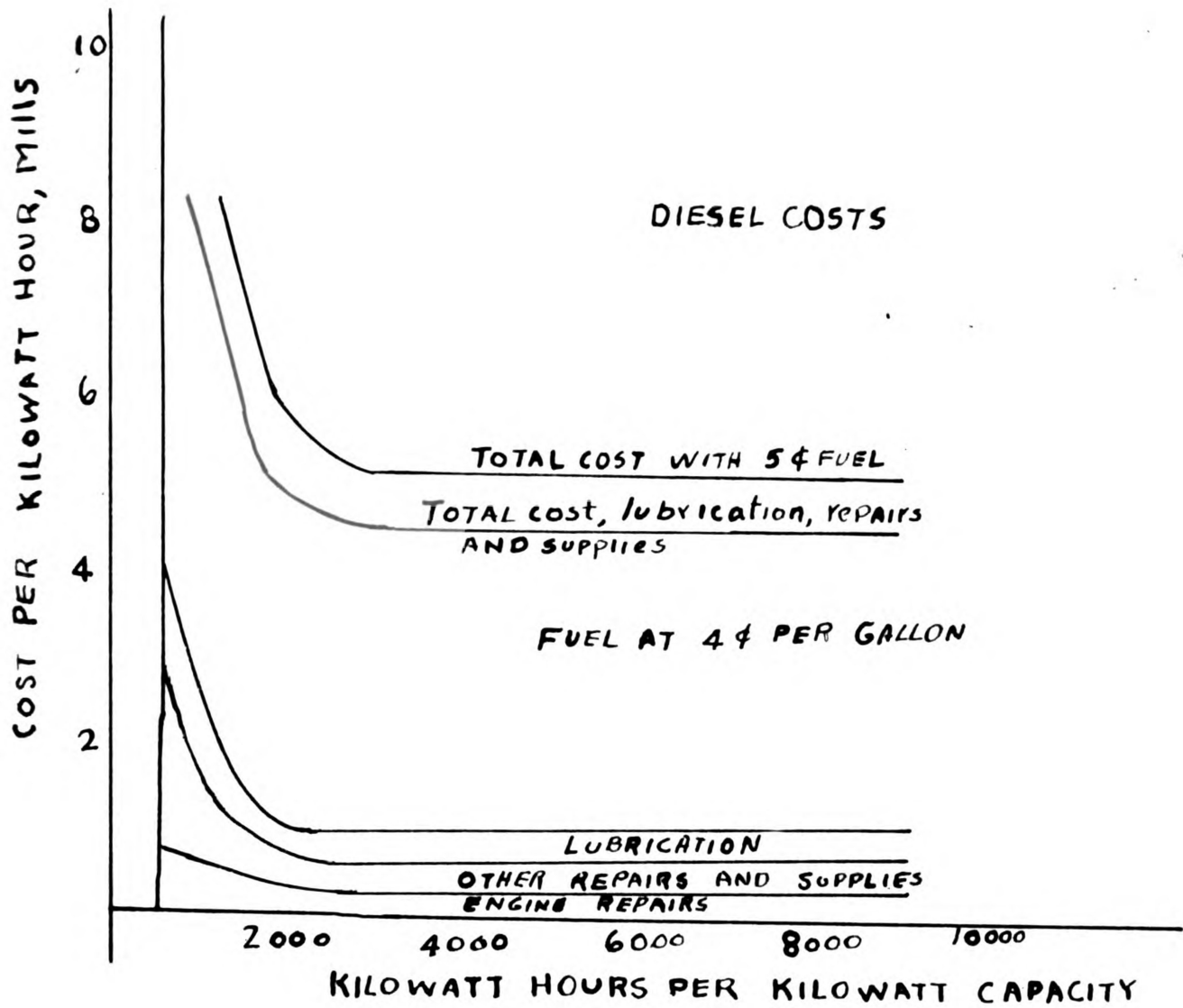
Thus it is seen that the present set-up is less expensive than a Diesel would be. However, the probability of the Diesel being cheaper if operated for the full year was investigated by the author. If a 55% plant capacity factor is used the output for a full year would be 24,395,250 kwhrs. This would reduce the kwhr cost to less than 6 mills. Therefore this should not be overlooked.

The amount of steam used during the summer months is shown on an enclosed graph. The exhaust of the Diesel could be used to raise the temperature of the feedwater. If it were to be used for the production of 100 psi and 5 psi steam about 10% of the total steam consumed during the summer could be generated in this manner.

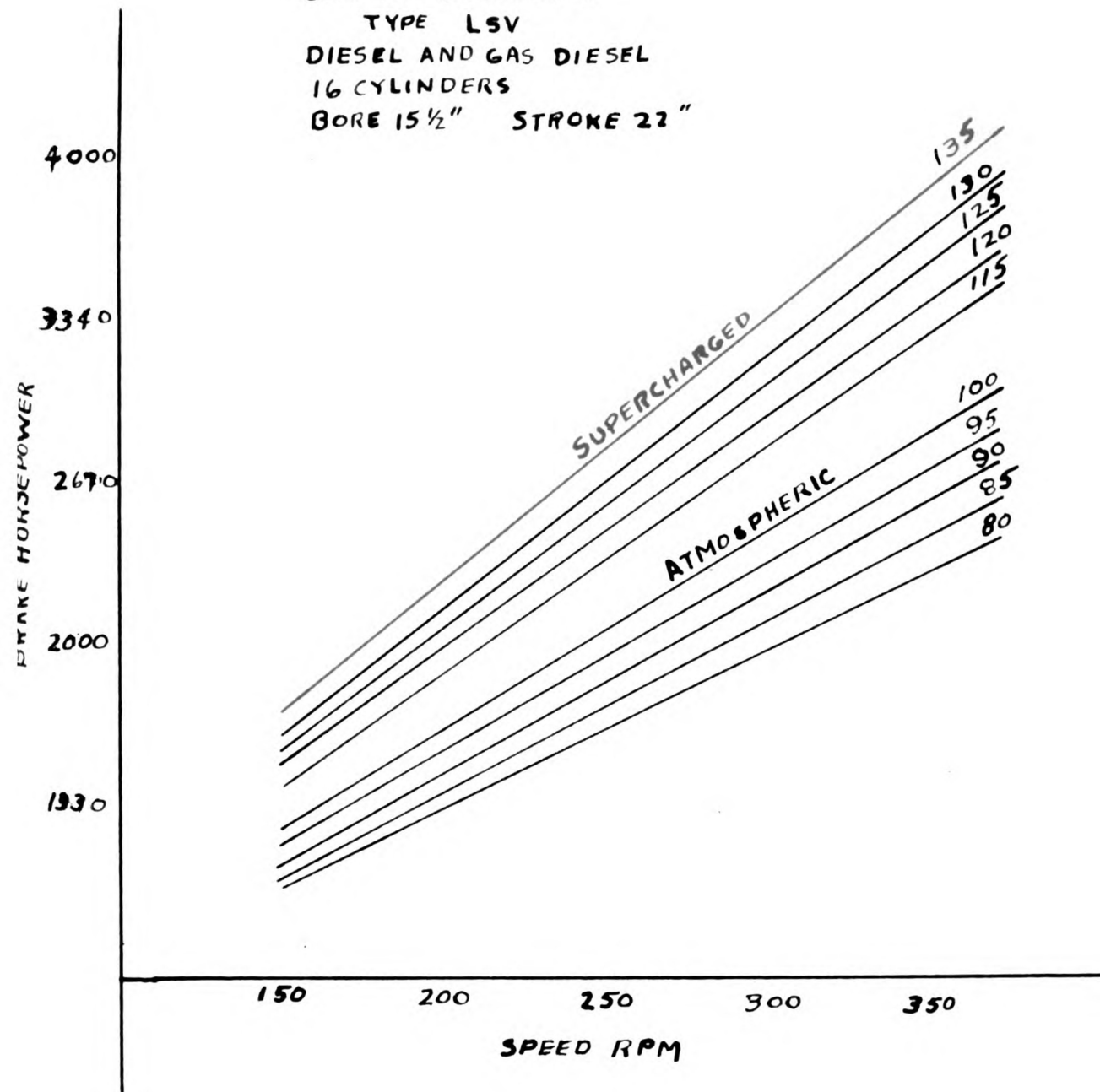


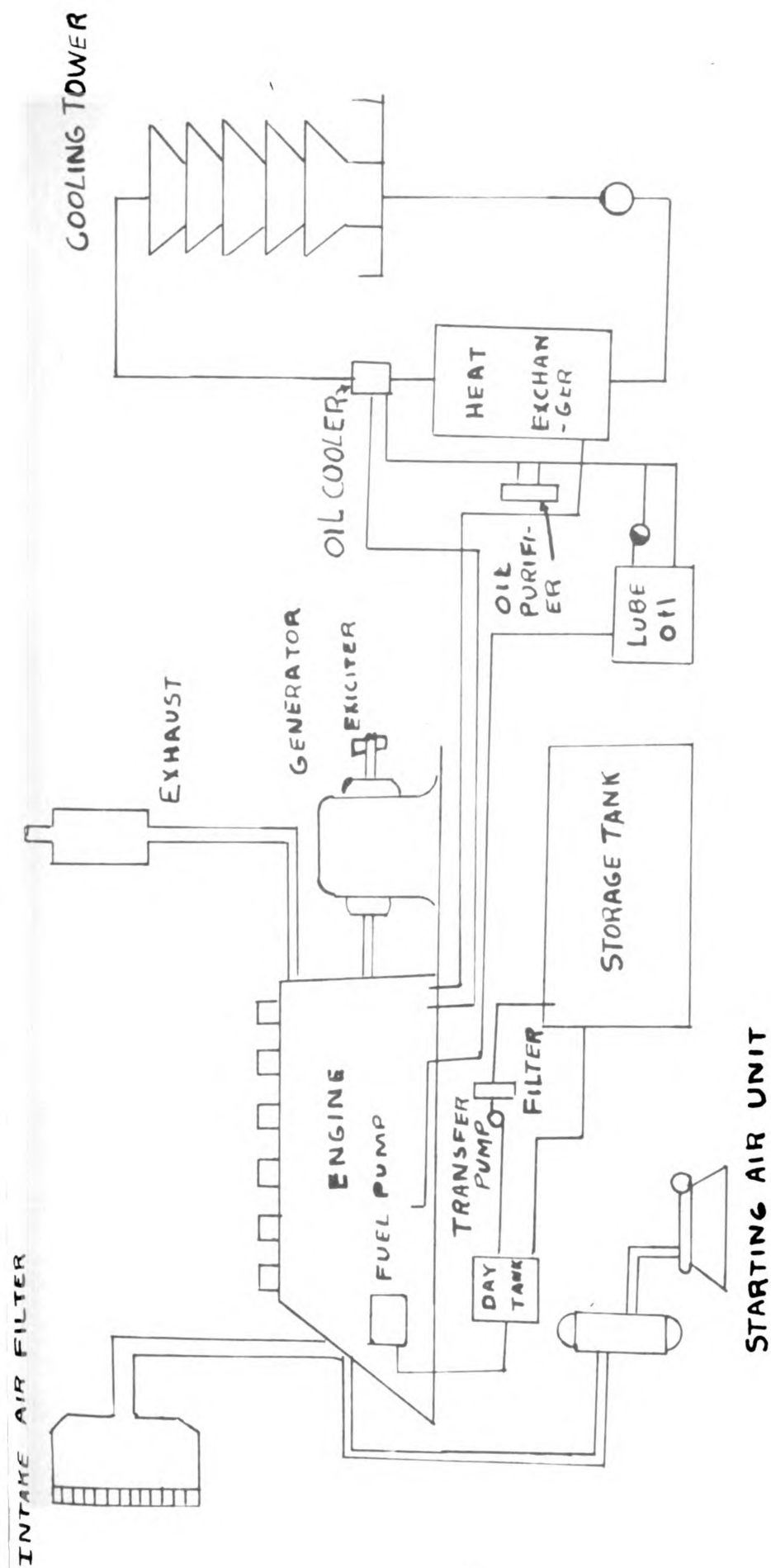
## REFERENCES

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- Hetzl, Theodore Brinton, The Development of Testing Fuel, p. 56.
- Leonard and Maleev, Heat Power Fundamentals, Pittman Publishing Corporation, p. 523.
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- Power Generation, Technical Publishing Company, Vol. 52, No. 3, March 1948, p. 100.
- Williamson, W. R., Diesel Power, Diesel Publications, Inc., Vol. 25, No. 12, December 1947, p. 50.

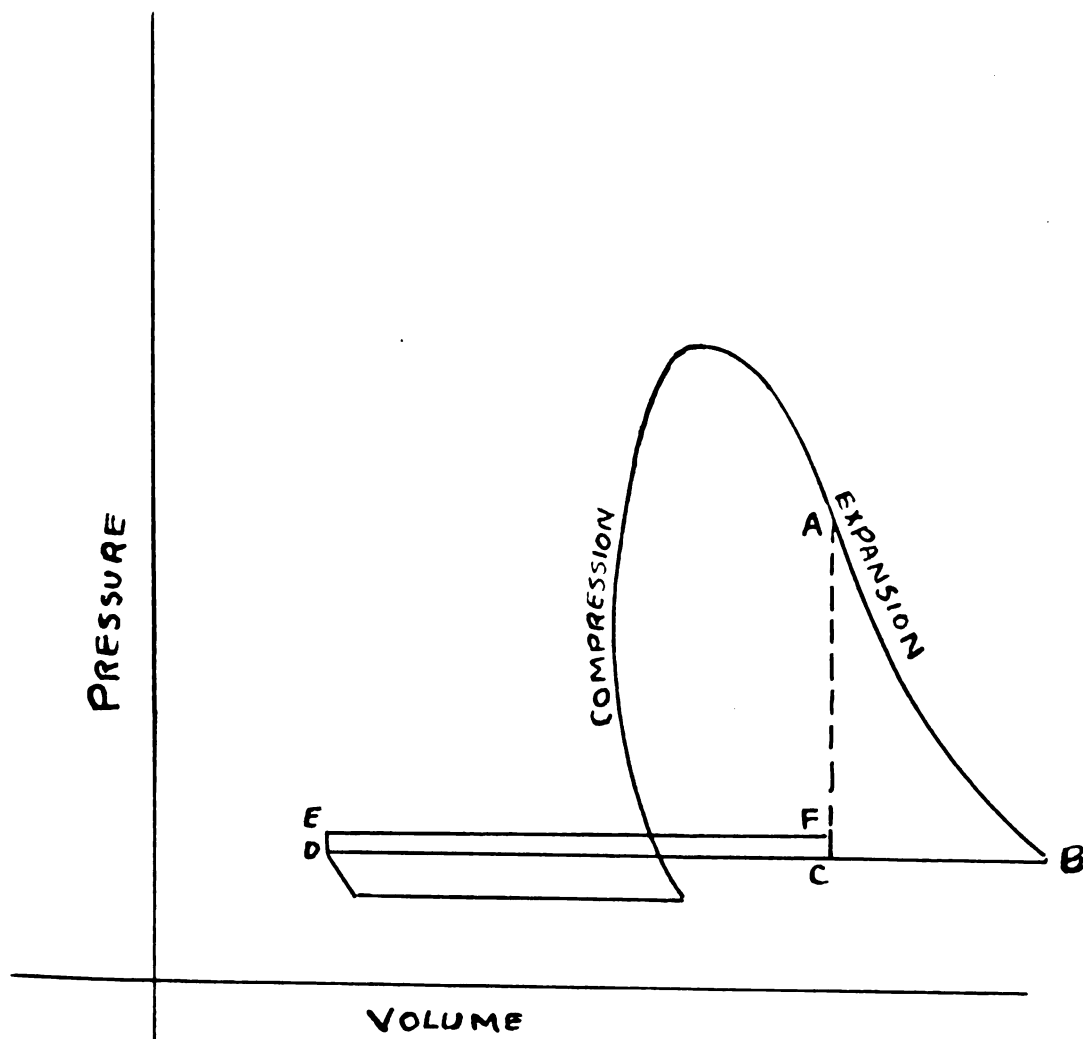


RATING CURVE FOR  
 COOPER-BESSEMER  
 TYPE LSV  
 DIESEL AND GAS DIESEL  
 16 CYLINDERS  
 BORE 15 1/2" STROKE 22"

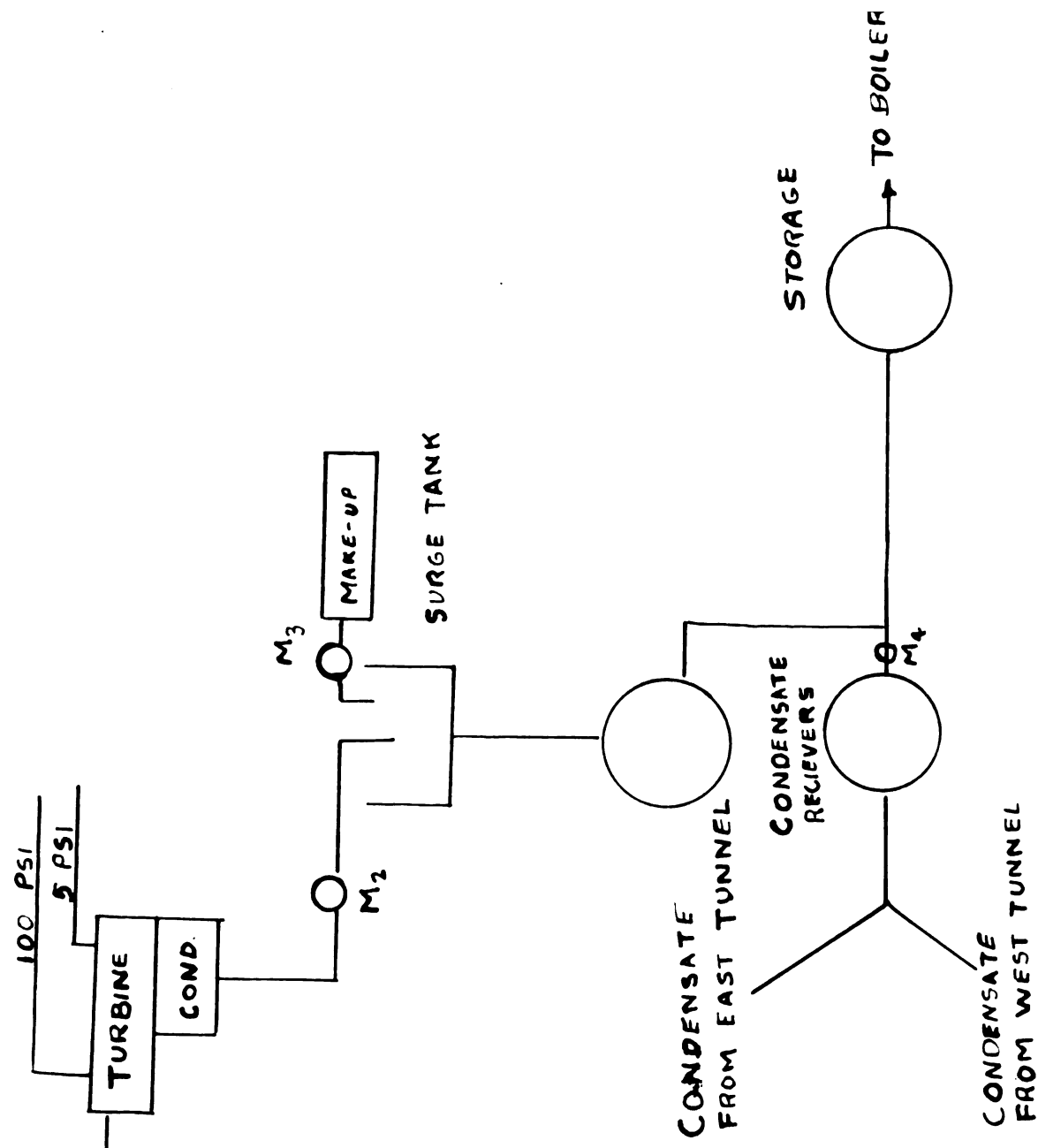




TYPICAL LAYOUT OF DIESEL  
POWER PLANT



REPRESENTING THE ENERGY OBTAINABLE  
FROM EXHAUST GAS. AREA ABCDEFA.



### EQUATIONS

$$M_1 = M_2 + M_3 + M_4$$

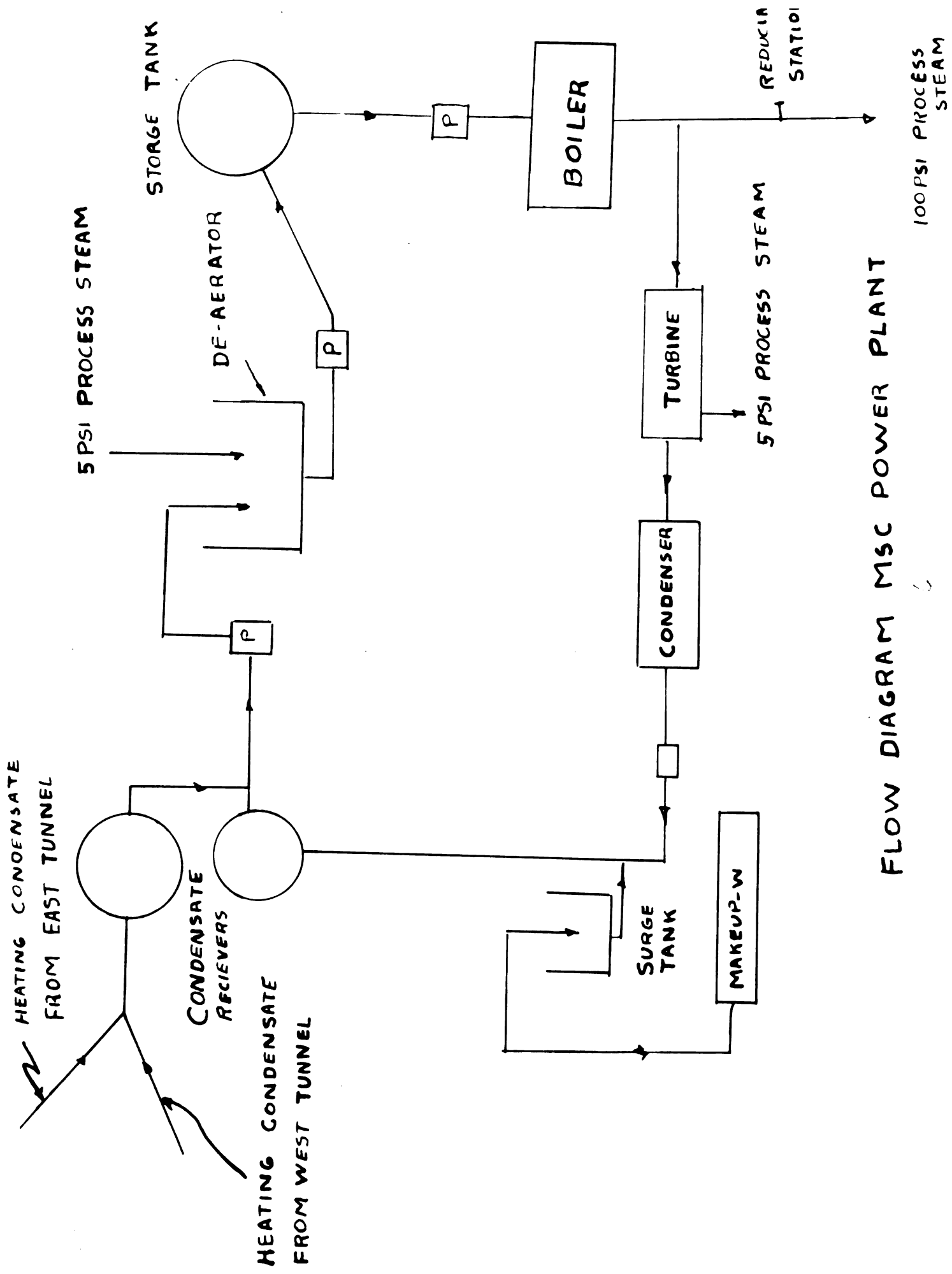
$$M_1 = \text{TOTAL STEAM}$$

$$M_2 = \text{TURBINE CONDENSATE}$$

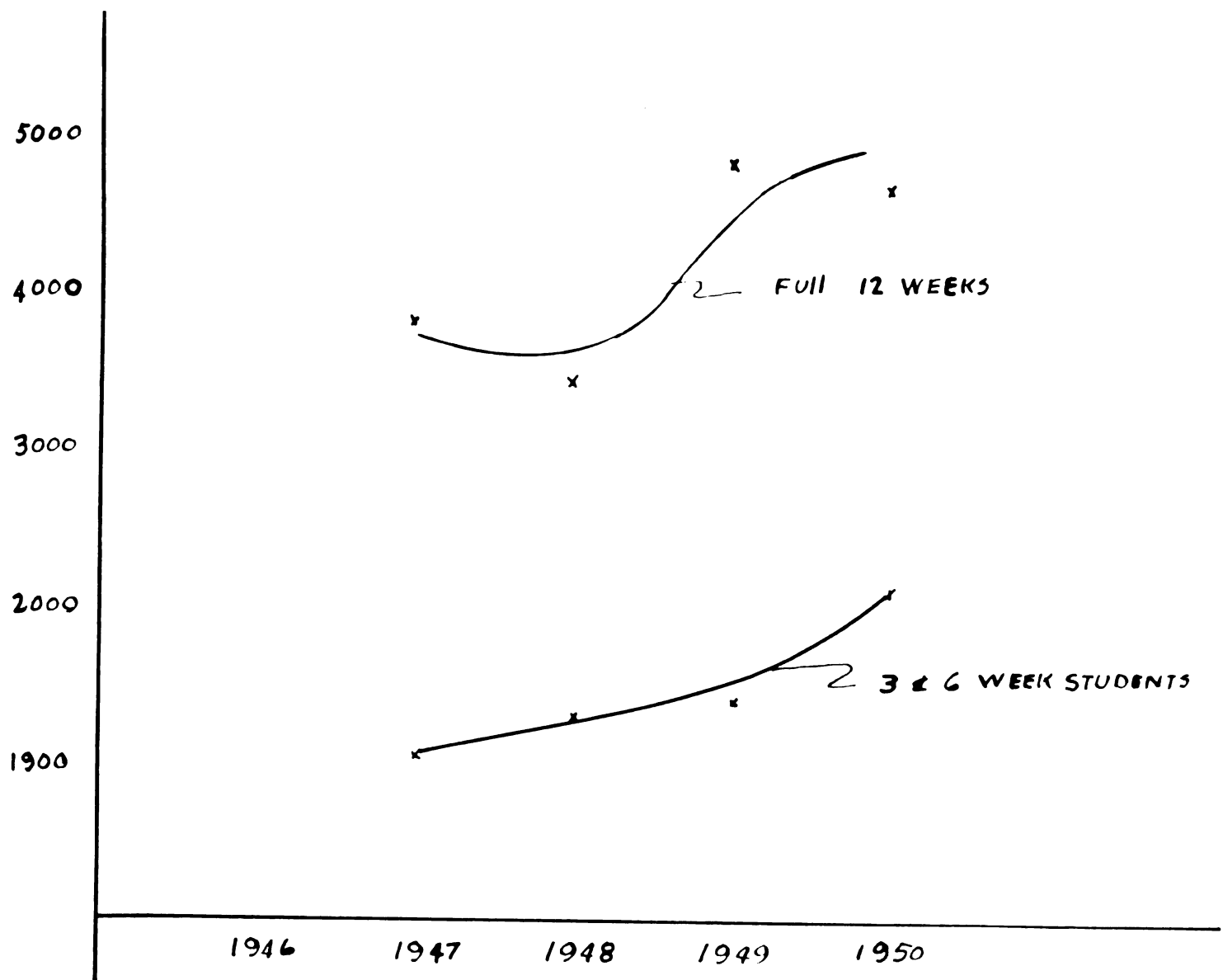
$$M_3 = \text{MAKEUP WATER}$$

$$M_4 = \text{PROCESS RETURN}$$

METERING SYSTEM FOR  
DETERMINING THE PROCESS STEAM USED ON CAMPUS



FLOW DIAGRAM MSC POWER PLANT

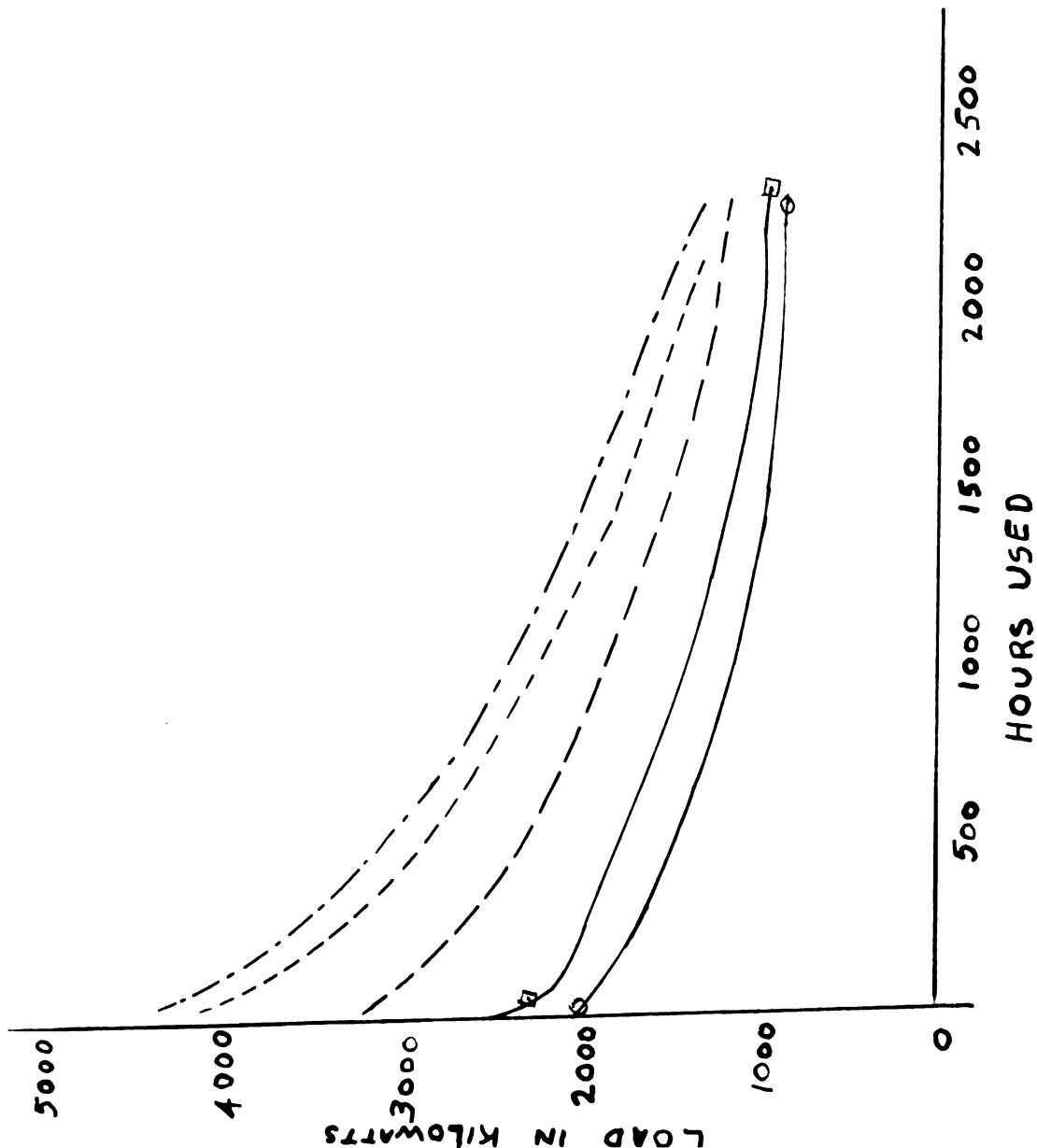


SUMMER SCHOOL  
ENROLLMENT FIGURES

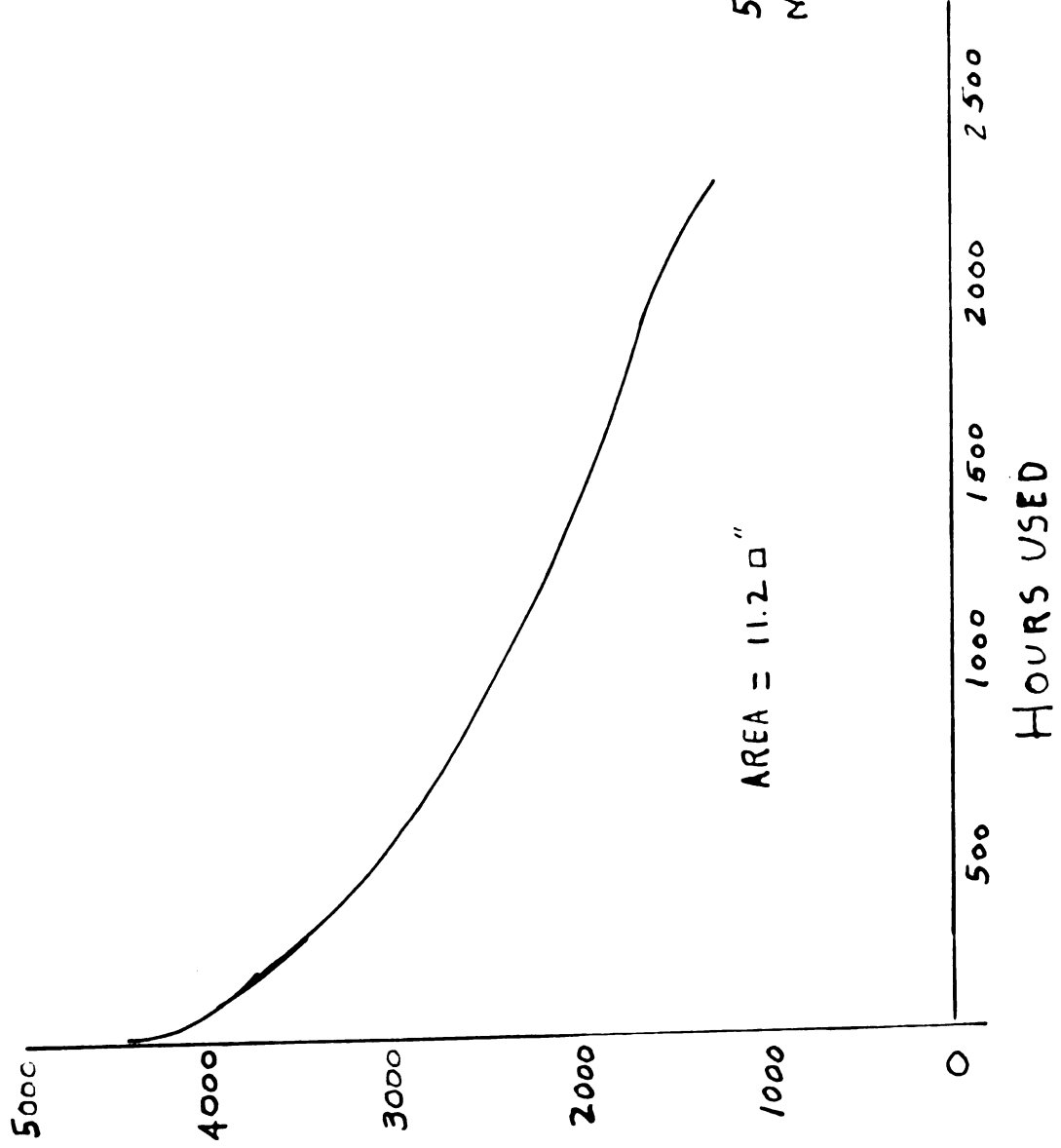


MSC POWER PLANT  
LOAD DURATION CURVES  
for June 10th - Sept 15th

- 1949  
- 1948  
□ 1947  
○ 1946  
-- 1950

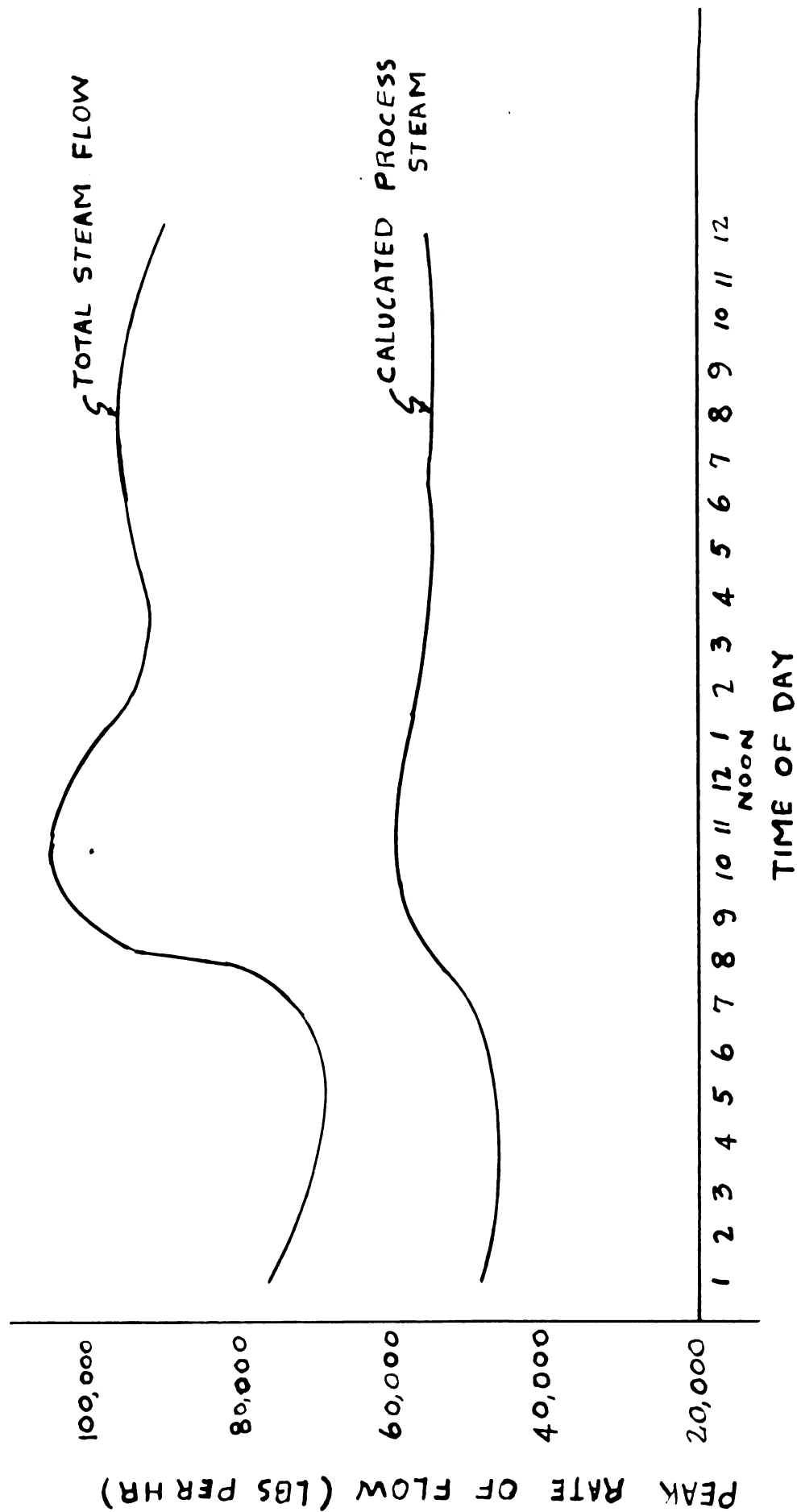


MSC POWER PLANT  
LOAD DURATION CURVE  
for June 10th - Sept 15th 1950



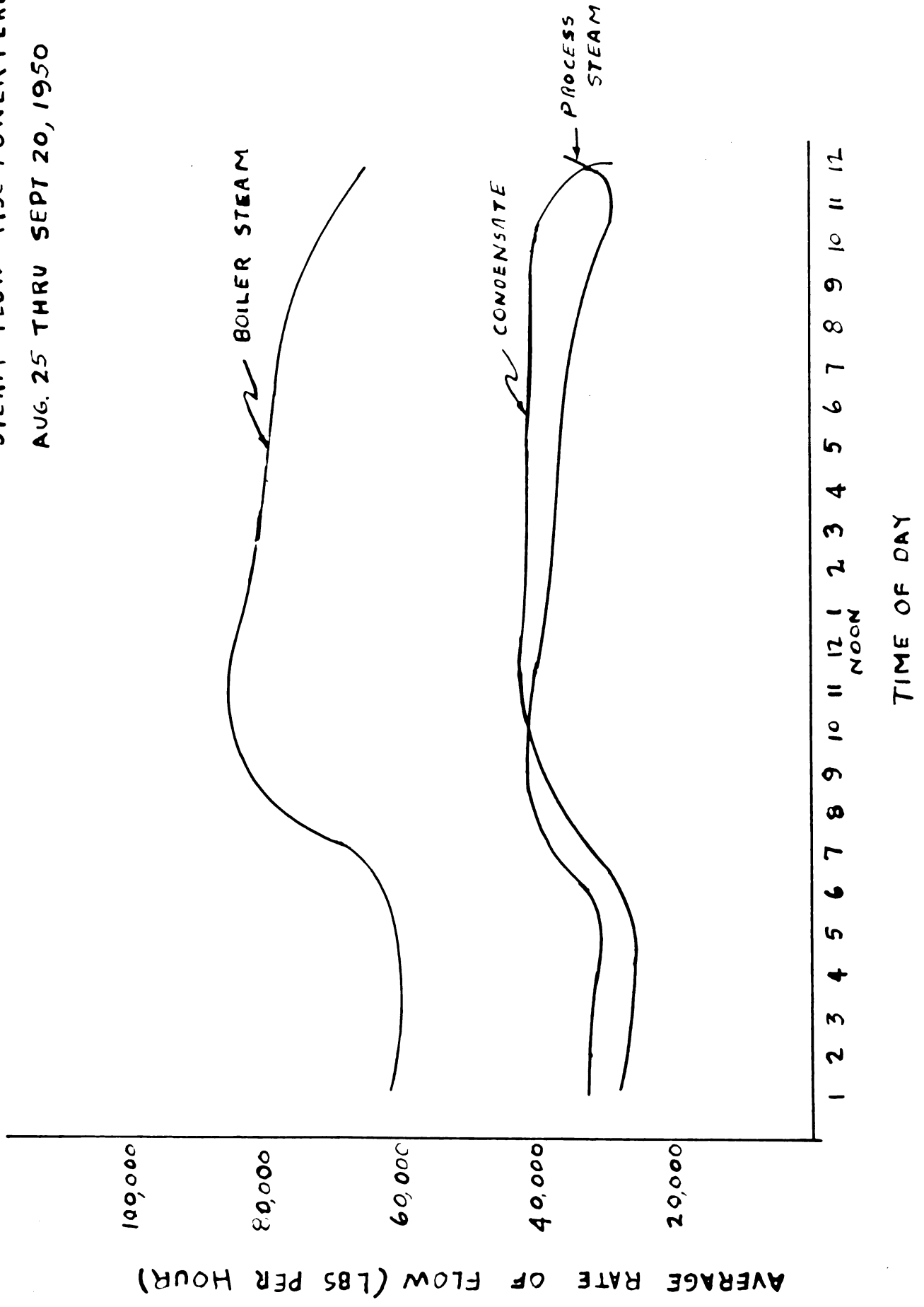
5,600,000 kWhrs. Generated  
NOTE: THIS FIGURE WAS USED IN  
DETERMINING COSTS

STEAM FLOW MSC POWER PLANT  
AUG 25 thru SEPT 20, 1950

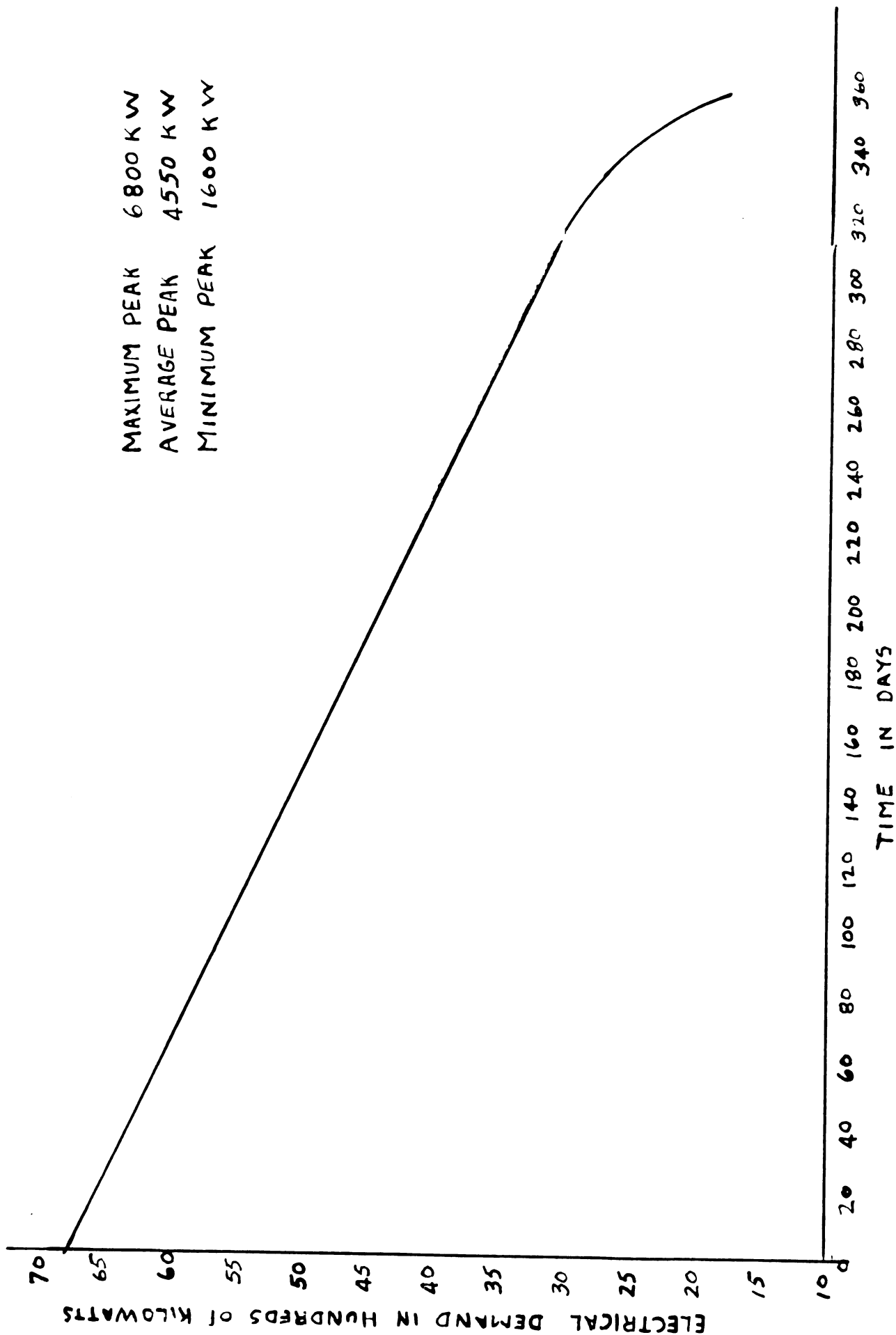


18

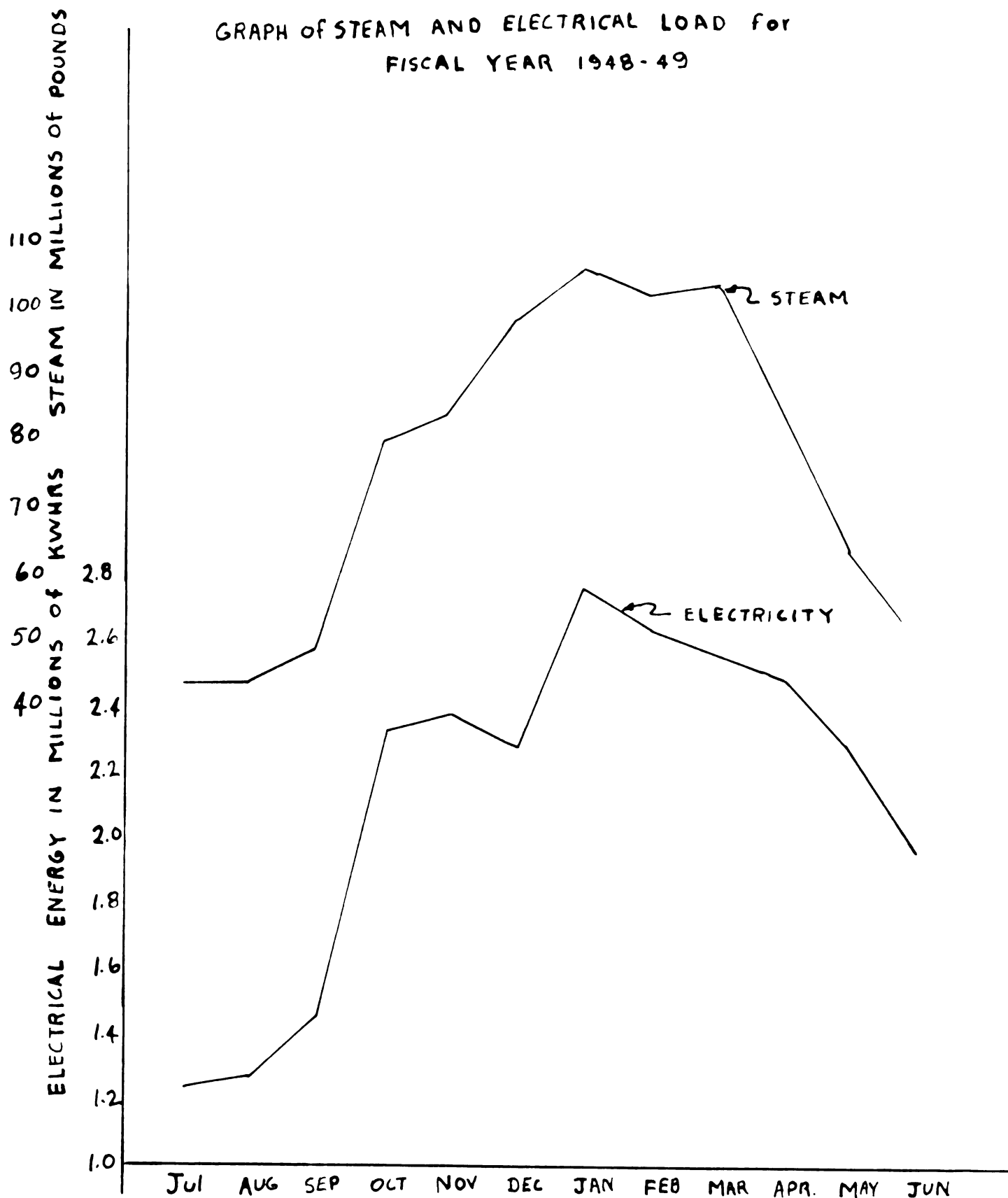
# STEAM FLOW MSC POWER PLANT AUG. 25 THRU SEPT 20, 1950



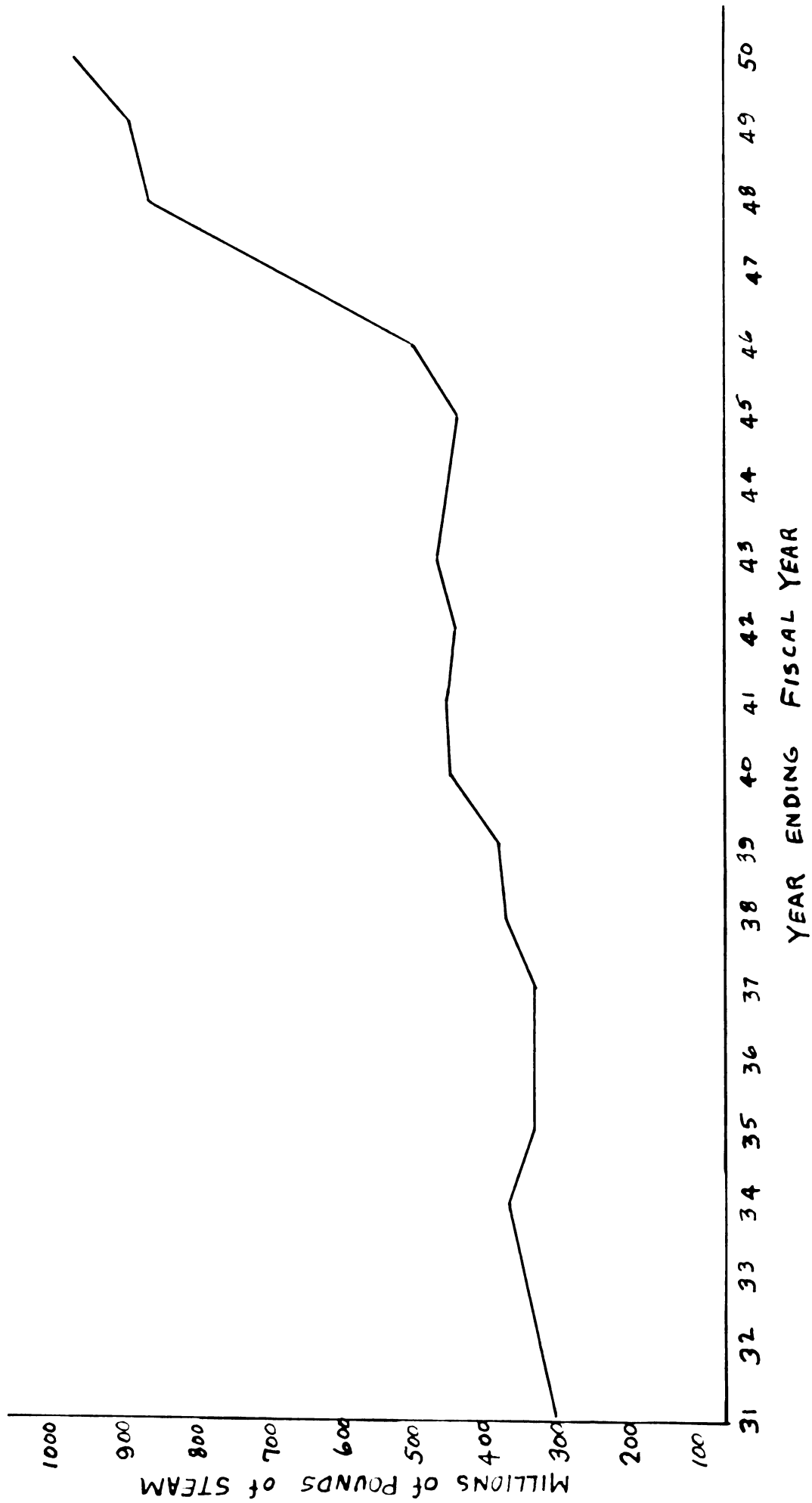
# DISTRIBUTION CURVE of DAILY PEAK ELECTRICAL DEMAND for 1949-50



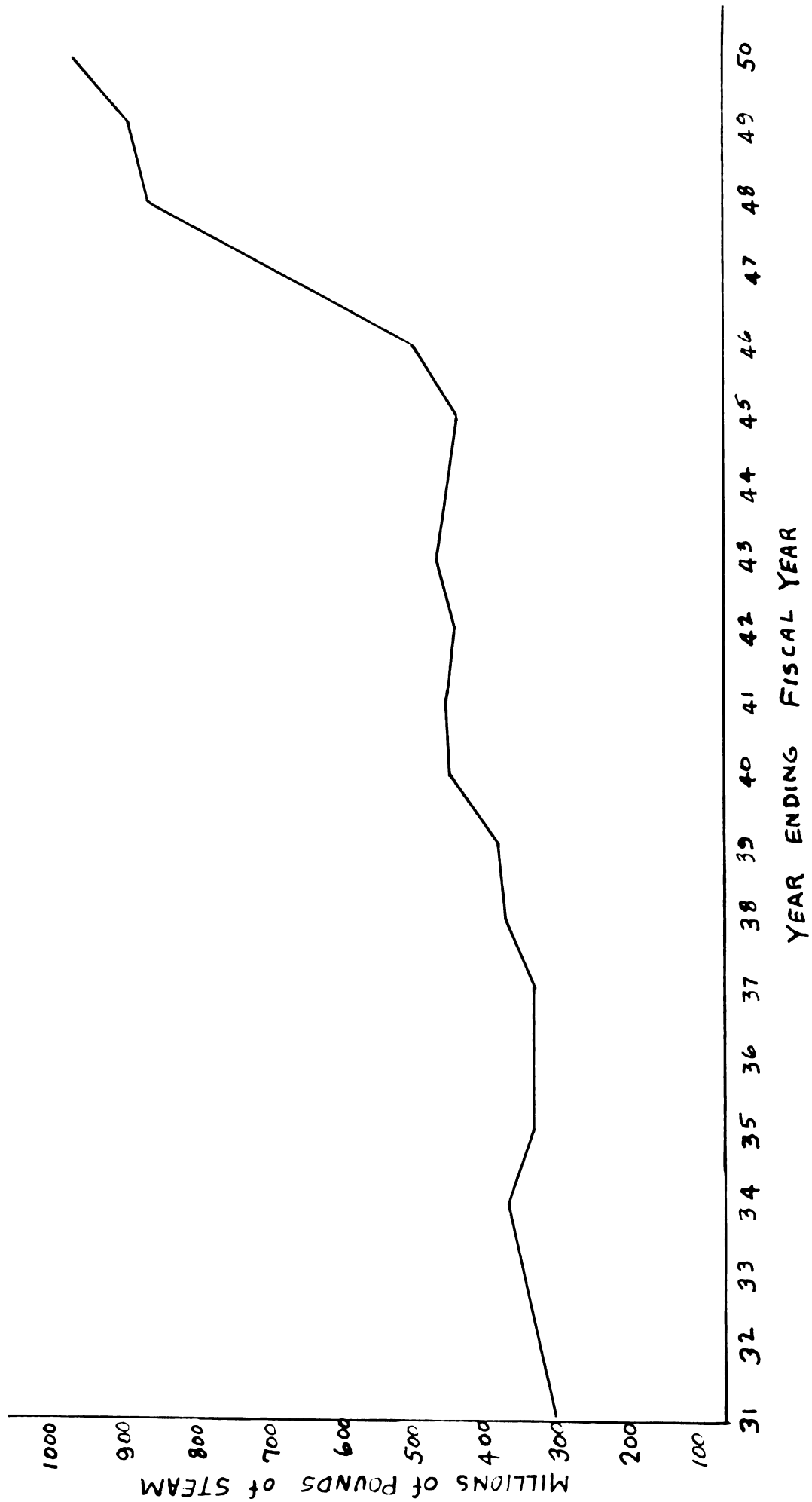
GRAPH OF STEAM AND ELECTRICAL LOAD for  
FISCAL YEAR 1948-49



GRAPH SHOWING YEARLY STEAM GENERATION 1930-1950

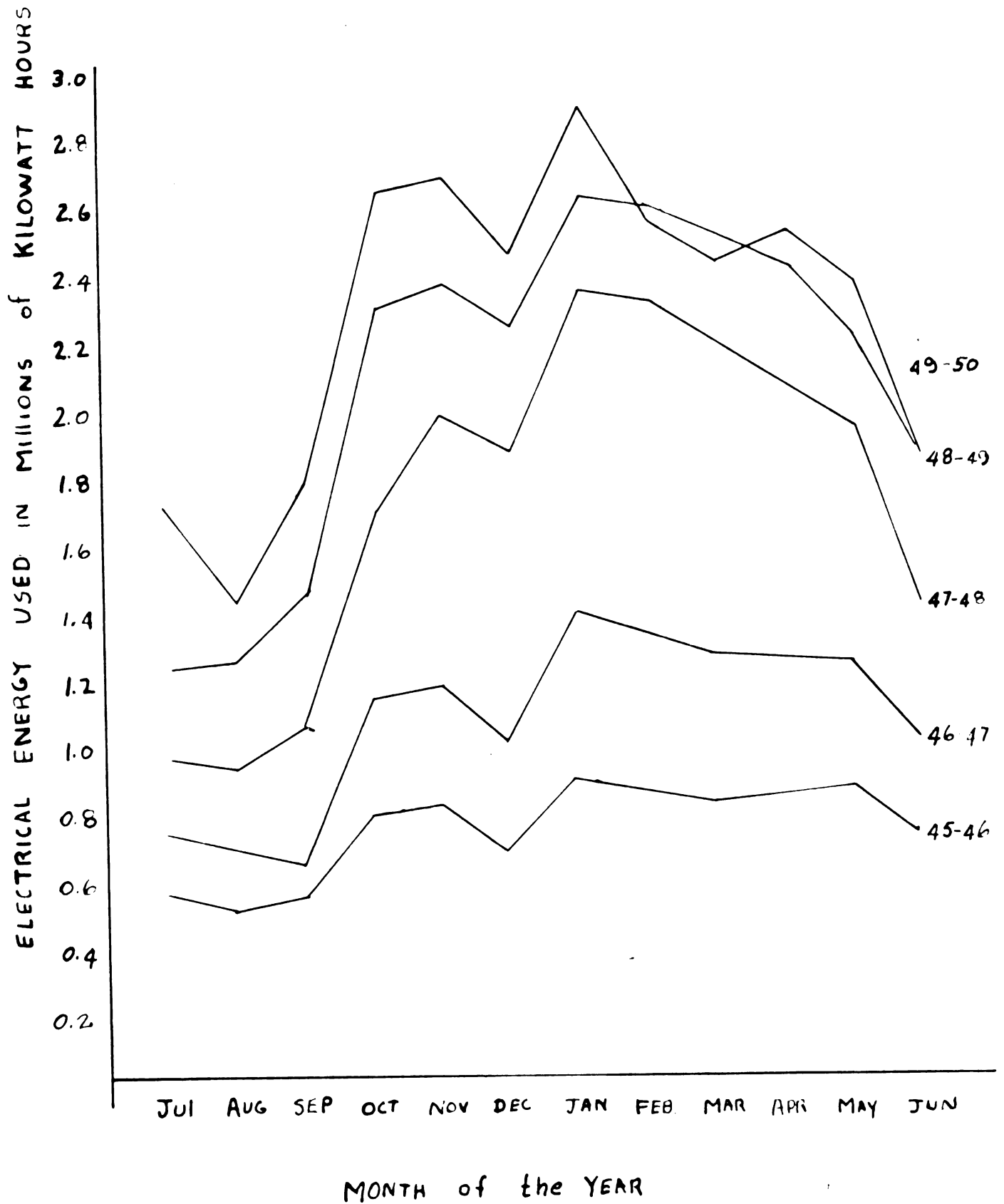


GRAPH SHOWING YEARLY STEAM GENERATION 1930-1950



12



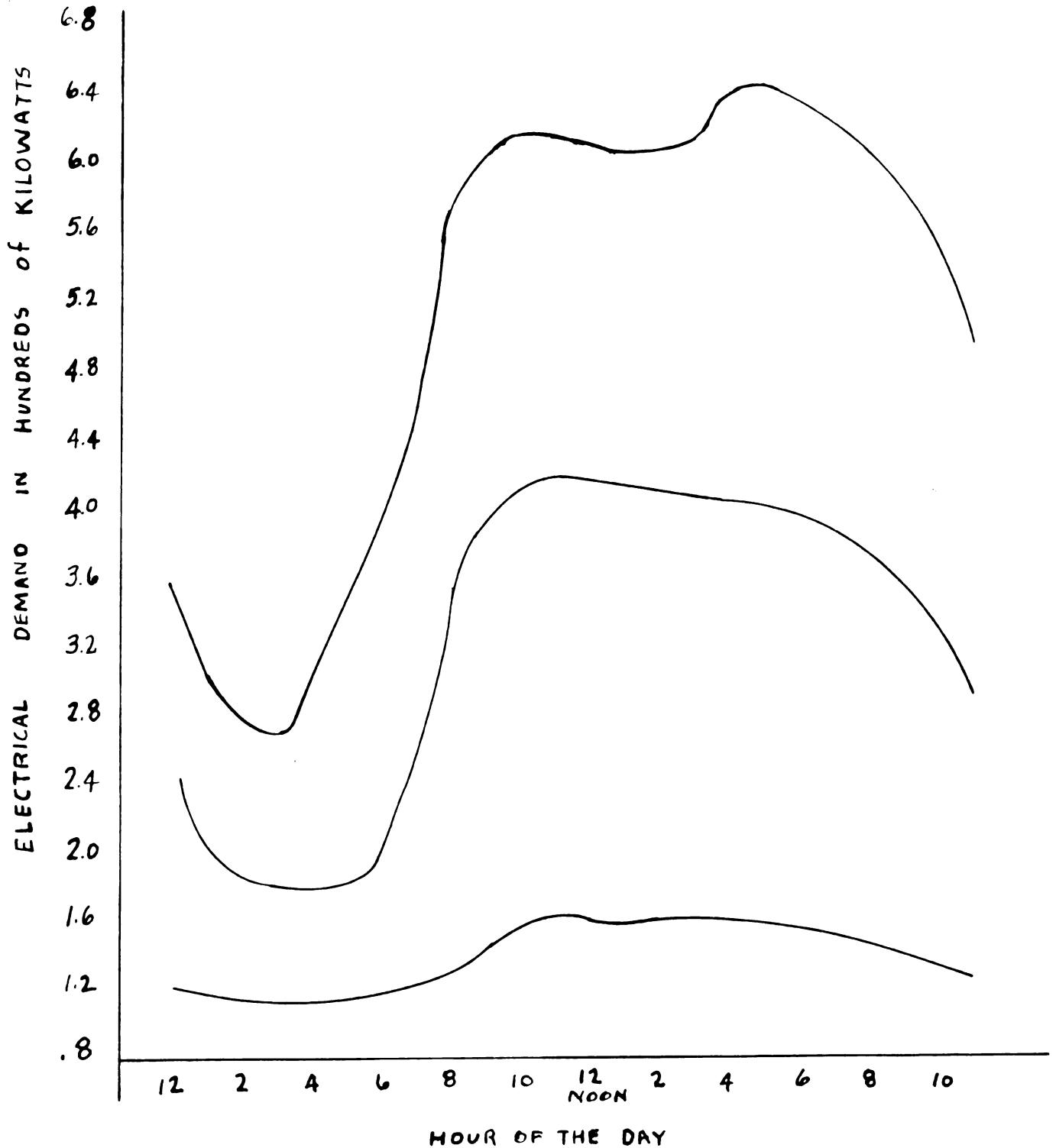


# MICHIGAN STATE COLLEGE POWER PLANT

IN AVERAGING OVER A 24 HR PERIOD:

AVERAGE CURVE RUNS 35% BELOW MAX.

MINIMUM CURVE RUNS 74% BELOW MAX.



ROOM USE ONLY

ROOM USE ONLY



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