

121
755

THESIS

STEAM TURBINE TEST

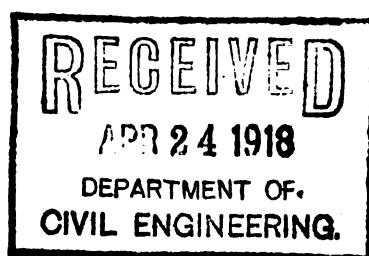
C. B. PECK E. A. TOWNE

1907

This thesis was contributed by

Mr. E. A. Towne

under the date indicated by the department stamp,
to replace the original which was destroyed in
the fire of March 5, 1916.



THE S I S

EFFICIENCY TESTS OF KERR STEAM TURBINE

BY

C. B. PECK

E. A. TOWNE

AGRICULTURAL COLLEGE, MICHIGAN

1907

THESIS

4-51
8)

EFFICIENCY TESTS OF KERR STEAM TURBINE

The purpose of this test is to determine the efficiencies and some of the characteristics of the Kerr ten horse-power steam turbine. Our object has been to determine the efficiencies under different working conditions.

The tests were carried on the testing laboratory of the Mechanical Building. The plant consisted of the turbine, a surface condenser and vacuum pump, weighing barrels and scales.

The machine tested was a twelve inch, six stage Kerr steam turbine with a rating of ten horse-power at four thousand revolutions per minute. The principal dimensions are given on the accompanying blue prints.

The steam admission is controlled by a throttling governor of the centrifugal type with a balanced piston valve, the balance being such that in case the governor should break or become loose while running, the valve would at once close. The governor weights act against a compression spring and the action is very unstable when near the extreme positions. Considerable trouble was experienced with hunting. Steam was supplied to the turbine and vacuum pump from the laboratory main which was fed from the Power House during the eighty pound tests and from the College Road Roller boiler during the one hundred fifteen pound tests.

The power was absorbed by a specially constructed friction brake which was supplied by the makers with the machine. The action of the brake was quite satisfactory considering the very limited amount of surface which was required to radiate all the heat.

The cooling water discharged into a rectangular basin above the pulley and reached the surface of the pulley by means of several small holes through the upper arm. One or two pieces of soap were kept in the basin continuously so that the water discharged against them. The brake shoes and pulley surface were thus kept lubricated, and smooth, steady action resulted.

The surface condenser was supplied with cooling water from the college water system and so required no circulating pump. The condensed exhaust was pumped out of the condenser and the vacuum maintained by a Knowles single acting pump. From the pump the condensation was carried to the weighing platform in the corner of the laboratory where it could be discharged directly into the sewer after being weighed.

To weigh the condensation we used two barrels with quick opening valves, one being placed on the platform of the weighing scales and the other on a platform raised to such a height that it discharged directly into the other and the discharge pipe from the pump emptied into the upper barrel which acted as a reservoir while the lower barrel was being emptied and the

scales balanced. We never had occasion to use the upper barrel in the middle of a test because the lower barrel was in every case large enough to hold the total condensed steam consumed during a half hour.

The speed was determined by a tachometer outfit made up of a small direct current generator, a resistance box and a voltmeter reading to three volts. The generator field consists of permanent magnets housed in a spherical shell mounted on a simple standard and adjustable to any height or angle. The armature had few turns of wire and several coils. The armature shaft was directly connected to the end of the turbine shaft by means of a coil spring acting as a flexible shaft. The generator proper is not more than four inches in diameter. The tachometer was calibrated by means of a counting speed indicator, readings being taken while the turbine was running constant. It was found that with a resistance of five hundred twenty-six ohms in the rheostat, the voltmeter would read one volt for two thousand revolutions per minute, one and one-half volts for three thousand revolutions, and so on. A calibration was made from time to time to see that no change took place. Since the generator has a constant field, the voltage varies directly as the speed.

The calorimeter used was a Peabody Throttling Calorimeter with expansion chambers open to the atmosphere. A small manometer was attached to the expansion chamber which usually read three or four inches of mer-

cury. The calorimeter took the steam through a standard sampler.

The pressures were measured by means of test gauges and mercury manometers, using the gauges on steam pressures and the manometer on vacuums. A gauge reading both pressures and vacuums was used on the stages reading nearest atmosphere.

In all about twenty tests were made, each of thirty minutes duration. Two steam pressures were used, eighty pounds and one hundred fifteen pounds by the gauge. Three different exhaust vacuums were used ranging as high as twenty inches. Owing to the incapacity of the condenser pump, it was impossible to hold the vacuums uniform throughout the tests. In some of the heavier loads only one or two vacuums could be reached.

Tests were run with three different loads, quarter, half and three-quarter loads. It was our intention to run full load tests but it was impossible with the steam pressures and equipment at hand. It might still have been possible had it not been for the limits time placed upon us.

During the thirty minutes the tests were run, readings were taken every five minutes, sums and means of the readings being taken for purposes of computation. When starting a new test with a new set of conditions as load, vacuum and steam pressure, the turbine was brought up to speed and run about fifteen minutes until

conditions got constant before the test was made.

Owing to the lack of constancy of vacuum throughout the tests, difficulty was met with in getting sufficient tests with only two variables for the purpose of plotting such curves as were desired.

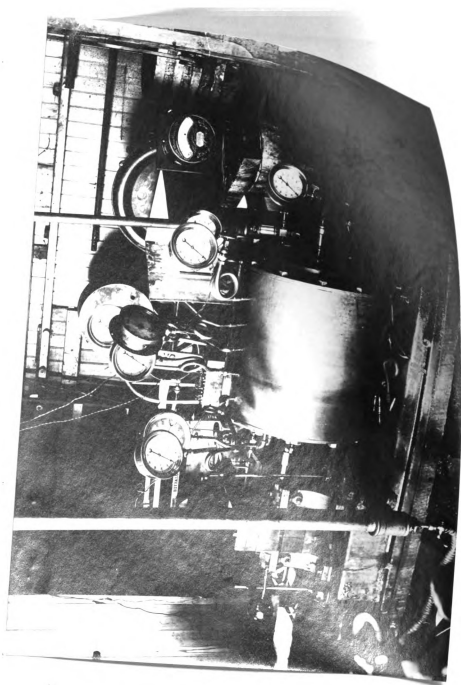
Owing to this fact, but comparatively few of the tests were used for purposes of plotting.

CURVES

For the purpose of comparing the data of the various tests two sets of curves were plotted, the steam consumption load curves having steam consumption in pounds per hour plotted as ordinates and load in horse-power as abscissa for three values of exhaust pressure. The total steam consumption curves were first plotted, only a few points being necessary to determine them, and from these the steam consumption per horse-power hour curves were determined.

Two steam consumption vacuum curves at no load were plotted, one being at one hundred fifteen pounds main pressure, the other at eighty pounds main pressure. These curves show the effect of vacuum on machine losses and give a comparison of machine losses for two values of initial pressure.

Another set of curves shows the expansion line of steam through the turbine, the points plotted being the pressure observed in the various stages. Two other curves are shown on this sheet. One is a double curve, each stage ordinate representing the combined areas of



the nozzles in that stage. The second represents the velocities of the steam in the various stages. Theoretically the velocity should be a constant for each stage and the curve a straight line parallel to the base. The unit taken for this curve was one large cross-section from the base.

RESULTS

NOZZLES

From governor throttle to first stage, one nozzle.
Diam. = .362 in. Area = .000715 sq. ft.

From first stage to second stage, two nozzles.

Diam. = .312 in. Area = .000531 sq.ft.

From second stage to third stage, three nozzles.

Diam. = .305 in. Area = .000507 sq.ft.

From third stage to fourth stage, four nozzles.

Diam. = .314 in. Area = .000538 sq.ft.

From fourth stage to fifth stage, six nozzles.

Diam. = .305 in. Area = .000507 sq.ft.

From fifth stage to sixth stage, eight nozzles.

Diam. = .317 in. Area = .000548 sq.ft.

FORMULAE

$x = \frac{h_1 + C_p(t_s - t) - h}{x}$ for quality of steam before saturation.

$t_s - t = \frac{h_1 + C_p(t_s - t) - h}{C_p}$ for superheat.

Thermodynamic efficiency = $\left(\frac{T - T}{T} \right)$

$$\text{Thermal efficiency} = \left(\frac{A W}{Q} \right).$$

NO. 1
NO LOAD, EXHAUST AT ATMOSPHERE

Duration of test	30 min.
R. P. M.	3550
Temperature of exhaust	
Temperature of room	75° F.
Barometer reading = 29.29 in. =	14.38 lbs.
Pressure on the main	80 lbs.
Pressure on the exhaust	25 "
Boiler temperature at ex- haust pressure	211.75 F.
Moisture in the steam	.5%
Total steam per hour condensed	159 lbs.
Total steam per hour con- densed (Dry).	158.25 lbs.
Total heat supplied per hour	187022 B.T.U.

NO. 1
LOAD = .49 H. P., EXHAUST AT ATMOSPHERE

Duration of test	38 min.
R. P. M.	3660
Temperature of exhaust	131.5°F
Temperature of room	76°F
Barometer reading = 29.32 in. =	14.38 lbs.
Pressure on the main	80.3 "
Pressure on the exhaust	0 "
Boiler temperature at ex- haust pressure	210.9°F

Moisture in steam .7%

Total steam per hour condensed 173.7 lbs.

Total steam per hour condensed (Dry). 172.5 "

Total heat supplied per hour 203600 B.T.U.

B. H. P. .49

Total work done in B.T.U. per hour 1248.2

Steam per B.H.P. hour (Dry) 352 lbs.

Thermodynamic efficiency, $\frac{(T - T_c)}{T} = 13.57\%$

Thermal efficiency, $\frac{(A W)}{Q} = 6\%$

NO. 3

LOAD 1.82 H.P., EXHAUST AT ATMOSPHERE

Duration of test 30 min.

F.P.M. 3600

Temperature of exhaust

Temperature of room 76° F

Barometer reading = 29.32 in. - 14.39 lbs.

Pressure on the main 80 "

Pressure on the exhaust .5 "

Boiler temperature at exhaust pressure 212.51° F

Moisture in the steam 1.2%

Total steam per hour condensed 244 lbs.

Total steam per hour condensed (Dry). 241.1 "

Total heat supplied per hour 285260 B.T.U.

B. H. P. 1.82

Total work done on B.T.U. per hour 4630

Steam per B. H. P. hour (dry)	152.5 lbs.
Thermodynamic efficiency	14.15%
Thermal efficiency	1.6%

NO. 4

LOAD = 4.4 H.P., EXHAUST AT ATMOSPHERE

Duration of test	30 min.
R. P. M.	3550
Temperature of exhaust	
Temperature of room	76° F
Barometer reading = 29.32 in. =	14.37 lbs.
Pressure on the main	80 lbs.
Pressure on the exhaust	1.3 lbs.
Boiler temperature at exhaust pressure	215.3° F
Moisture in steam	1.3%
Total steam per hr. condensed	355 lbs.
Total steam per hour condensed (Dry)	350.4 lbs.
Total heat supplied per hr.	415025 B.T.U.
B. H. P.	4.4
Total work done in B.T.U. per hour	11180
Steam per B.H.P. hr. (Dry)	79.6 lbs.
Thermodynamic efficiency	13.79%
Thermal efficiency	2.7%

NO.5
NO LOAD, 8.75 VACUUM AT EXHAUST

Duration of test	30 min.
R. P. M.	3570
Temperature of exhaust	190°
Temperature of room	76°
Barometer reading=29.41 in. =	14.43 lbs.
Pressure on the main	80 lbs.
Pressure on the exhaust= -8.75 in.=	4.29 lbs.
Boiler temperature at ex- haust pressure	193.88°F
Moisture in the steam	Dry
Total steam per hr.condensed	121.5 lbs.
Total steam per hour con- densed (Dry)	121.5 "
Total heat supplied per hr.	143005.5 B.T.U.

NO.6
LOAD = 3.65 H.P., 7.5 in.VACUUM AT EXHAUST

Duration of test	30 min.
R. P. M.	3725
Temperature of exhaust	193.1° F
Temperature of room	78° F
Barometer reading 29.29 in.	14.38 lbs.
Pressure on the main	80 "
Pressure on exhaust= -3.53 in.=	-3.7 "
Boiler temperature at ex- haust pressure	196.33° F
Moisture in steam	1.3%

Total steam per hr. condensed	249 lbs.
Total steam per hour condensed (Dry)	245.75 lbs.
Total heat supplied per hr.	290728 B.T.U.
B. H. P.	3.65
Total work done in B.T.U. per hour	6745
Steam per B.H.P. hr. (Dry)	92.74 lbs.
Thermodynamic efficiency	16.21%
Thermal efficiency	2.3%

NO. 7

LOAD = 4.91 H.P., 6 in. VACUUM AT EXHAUST

Duration of test	30 min.
R. P. M.	3820
Temperature of exhaust	196° F
Temperature of room	74° F
Barometer reading = 29.36 in.	14.41 lbs.
Pressure on the main	80 "
Pressure on the exhaust = -6 in.	-2.94 "
Boiler temperature at exhaust pressure	199.75° F
Moisture in steam	2.3%
Total steam per hr. condensed	353 lbs.
Total steam per hour condensed (Dry)	344.88 lbs.
Total heat supplied per hr.	409480 B.T.U
B. H. P.	4.91
Total work done in B.T.U. per hour	12495
Steam per B.H.P. hr. (Dry)	70.25 lbs.

Thermodynamic efficiency	15.78%
Thermal efficiency	3.05%

NO. 8

LOAD = 6.63 H.P., 4.14 in. VACUUM AT EXHAUST

Duration of test	30 min.
R. P. M.	3586
Temperature of exhaust	198.5° F
Temperature of the room	76° F
Barometer reading = 29.34 in. =	14.38 lbs.
Pressure on the main	80 "
Pressure on the exhaust = -4.14 in. =	-2.03 "
Boiler temperature at ex- haust pressure	203.35° F
Moisture in steam	2.7%
Total steam per hr. condensed	435.5 lbs.
Total steam per hour con- densed (Dry)	423.6 "
Total heat supplied per hr.	503814 B.T.U.
B. H. P.	6.63
Total work done in B. T. U. per hour	16860
Steam per B.H.P. Hr. (Dry)	63.8 lbs.
Thermodynamic efficiency	14%
Thermal efficiency	3.35%

NO. 9
NO LOAD, 13.5 in.VACUUM AT EXHAUST

Duration of test	30 min.
R. P. M.	3590
Temperature of exhaust	178°F
Temperature of room	76°F
Barometer reading = 29.41 in. =	14.43 lbs.
Pressure on main	80 "
Pressure on the exhaust = -13.5 in. =	6.625 "
Boiler temperature at ex- haust pressure	193.88°F
Moisture in steam	Dry
Total steam per hr. Condensed	106 lbs.
Total steam per hour con- densed (Dry)	106 lbs.
Total heat supplied per hr.	124700 B.T.U.

NO. 10
LOAD = 2.65 H.P., 13.5 in.VACUUM AT EXHAUST

Duration of test	30 min.
R. P. M.	3735
Temperature of exhaust	178°F
Temperature of room	78°F
Barometer reading - 29.8 in =	14.6 lbs.
Pressure on the main	80 "
Pressure on the exhaust = 13.4 in. =	-6.575 lbs.
Boiler temperature at ex- haust pressure	183°F
Moisture in steam	1.25%

Total steam per hr, condensed	221.5 lbs.
Total steam per hour condensed (Dry)	218.5 "
Total heat supplied per hr.	251120 B.T.U.
B. H. P.	2.65
Total work done in B.T.U. per hour	6745
Steam per B.H.P.hr.(Dry)	79.5 lbs.
Thermodynamic efficiency	17.9%
Thermal efficiency	2.7%

NO. 11

LOAD = 4.82 H.P., 12 in.VACUUM AT EXHAUST

Duration of test	30 min.
R. P. M.	3757
Temperature of exhaust	180.6° F
Temperature of room	78° F
Barometer reading=29.26 in.=	14.36 lbs.
Pressure on the main	80 "
Pressure on the exhaust=-12 in.=	-5.89 "
Boiler temperature at exhaust pressure	185.46° F
Moisture in steam	2.5%
Total steam per hr.condensed	329.5 lbs.
Total steam per hour condensed (Dry)	322 lbs.
Total heat supplied per hr.	382437 B.T.U.
B. H. P.	4.82
Total work done in B.T.U. per hour	12263

Steam per B.H.P. hr. (Dry)	66.83 lbs.
Thermodynamic efficiency	17.59%
Thermal efficiency	3.2%

NO. 13
NO LOAD, 18 $\frac{1}{4}$ in. VACUUM AT EXHAUST

Duration of test	30 min.
R. P. M.	3814
Temperature of exhaust	178° F
Temperature of room	76° F
Barometer reading=29.64 in.=	14.54 lbs.
Pressure on main	80 "
Pressure on exhaust= -18.25 in.=	-8.95 "
Boiling temperature at exhaust pressure	196.94° F
Moisture in steam	Dry
Total steam per hr. condensed	82 lbs.
Total steam per hour con- densed per hour (Dry)	82 "
Total steam supplied per hour	96500 B. T. U.

NO. 13
LOAD = 2.68 H.P., 16.9 lbs. VACUUM AT EXHAUST

Duration of test	30 min.
R. P. M.	3750
Temperature of exhaust	167.7° F
Temperature of room	78° F
Barometer reading=29.27 in.=	14.37 lbs.
Pressure on main	80 "
Pressure at exhaust= -16.9 in.=	-8.29 lbs.

Boiling temperature at exhaust pressure	170.68° F
Moisture in steam	0.6%
Total steam per hr. condensed	205.51 lbs.
Total steam per hour condensed (Dry)	204.3 lbs.
Total heat supplied per hr.	241532 B.T.U.
B. H. P.	2.68
Total work done in B.T.U. per hour	6614
Steam per B. H. P. hr. (Dry)	76.31 lbs.
Thermodynamic efficiency	19.48° F
Thermal efficiency	2.6%

NO. 14

LOAD = 6.98 H.P., 6.9 in. VACUUM AT EXHAUST

Duration of test	30 min.
R. P. M.	3757
Temperature of exhaust	193° F
Temperature of room	76° F
Barometer reading = 29.34 in. =	14.76 lbs.
Pressure on the main	80 "
Pressure on the exhaust = -6.9 in. =	-3.38 "
Boiling temperature at Exhaust pressure	199.38° F
Moisture in steam	4.5%
Total steam per hr. condensed	433 lbs.
Total steam per hour condensed (Dry)	413.5 lbs.
Total heat supplied per hr.	487000 B.T.U.

R. H. P.	6.98
Total work done in B.T.U. per hour	17740
Steamper B.H.P. hr. (Dry)	62 lbs.
Thermodynamic efficiency	14.5%
Thermal efficiency	3.67%

NO. 15
HIGH PRESSURE, NO LOAD, EXHAUST AT ATMOSPHERE

Duration of test	30 min.
R. P. H.	3720
Temperature of exhaust	210° F
Temperature of room	79° F.
Barometer reading=29.39 in.	14.42 lbs.
Pressure on the main	115 lbs.
Pressure on the exhaust	.5 "
Boiler temperature at ex- haust pressure	212.75° F
Moisture in steam	.5%
Total steam per hr. condensed	174 lbs.
Total steam per hour con- densed (Dry)	173 "
Total heat supplied per hr.	206100 B.T.U.

NO. 16
NO LOAD, 8.5 in. VACUUM AT EXHAUST

Duration of test	30 min.
R. P. H.	3775
Temperature of exhaust	195.2° F
Temperature of room	78° F
Barometer reading= 29.38 in.	14.42 lbs.

Pressure on the main	115 lbs.
Pressure on the exhaust= -8.5 in.=	-4.17 lbs.
Boiler temperature at ex- haust	194.38° F
Moisture in steam	.36%
Total steam per hr. condensed	134 lbs.
Total steam per hour con- densed (Dry)	133.6 lbs.
Total heat supplied per hr.	158754 B.T.U.

NO. 17
NO LOAD, 19.57 in. VACUUM

Duration of test	30 min.
R. P. M.	3907
Temperature of exhaust	164.4° F
Temperature of room	79° F
Barometer reading=29.36 in.=	14.42 lbs.
Pressure on the main	115 lbs.
Pressure at exhaust= -19.57 in.=	-9.6 lbs.
Boiling temperature at ex- haust pressure	160.67° F
Moisture in steam	1.57%
Total steam per hour con- densed	86 lbs.
Total steam per hour con- densed (Dry)	84.5 lbs.
Total heat supplied per hr.	98892 B.T.U.

NO. 18
LOAD = 4.52 H.P., 10 in. VACUUM AT EXHAUST

Duration of test 30 min.

R. P. M.	3585
Temperature of exhaust	186.3° F
Temperature of room	79° F
Barometer reading=29.52 in.=	14.39 lbs.
Pressure on the main	115 lbs.
Pressure at exhaust= -10 in.=	-4.91 lbs.
Boiling temperature at exhaust pressure	190.69° F
Moisture in steam	1.3%
Total steam per hr. condensed	336 lbs.
Total steam per hour con- densed (Dry)	332 lbs.
Total heat supplied per hr.	395563 B.T.U.
B. H. P.	4.52
Total work done in B. T. U. per hour	11503
Steam per B.H.P. hr. (Dry)	73.32 lbs.
Thermodynamic efficiency	19.35%
Thermal efficiency	2.91%

NO. 19
LOAD = 4.75 H.P., 5 in. VACUUM AT EXHAUST

Duration of test	30 min.
R. P. M.	3700
Temperature of exhaust	197° F
Temperature of room	79° F
Barometer reading=29.31 in.=	14.37 lbs.

Pressure on the main	115 lbs.
Pressure on the exhaust = -5 in. \approx	-2.45 lbs.
Boiler temperature at exhaust pressure	201.68°F
Moisture in steam	3%
Total steam per hr. condensed	395.5 lbs.
Total steam per hour con- densed (Dry)	384.6 lbs.
Total heat supplied per hr.	456800 B.T.U.
B. H. P.	4.75
Total work done in E. T. U. per hr.	12080
Steam per B.H.P. hr. (Dry)	81 lbs.
Thermodynamic efficiency	17%
Thermal efficiency	2.6%

NO. 20
LOAD = 4.82 H.P., EXHAUST AT ATMOSPHERIC

Duration of test	30 min.
R. P. M.	3750
Temperature of exhaust	308°F
Temperature of room	79°F
Barometer reading=29.31 in.=	14.57 lbs.
Pressure on the main	115 "
Pressure on the exhaust	000
Boiling temperature at ex- haust	210.85 F
Moisture in steam	2.2%
Total steam per hr. condensed	411.5 lbs.

Total steam per hour condensed (Dry)	402.5 lbs.
Total heat supplied per hr.	481062 B.T.U.
B. H. P.	4.82
Total work done in B. T. U. per hour	12860
Steam per B. H. P. Hr.(Dry)	83.5 lbs.
Thermodynamic efficiency	16.8%
Thermal efficiency	3.04%

NO. 21
LOAD = 6.9 H.P., EXHAUST AT ATMOSPHERE

Duration of test	30 min.
R. P. M.	3750
Temperature of exhaust	207.5°F
Temperature of room	77°F
Barometer reading=29.43 in.=	14.44 lbs.
Pressure on the main	115 "
Pressure on the exhaust	.68 "
Boiler temperature at exhaust pressure	313.42°F
Moisture in steam	.6%
Total steam per hr. condensed	476 lbs.
Total steam per hour condensed (Dry)	423 "
Total heat supplied per hr.	562994 B.T.U.
B. H. P.	6.9
Total work done in B.T.U. per hour	17684
Steam per B.H.P. hr. (Dry)	68.58 lbs.

Thermodynamic efficiency	13.52%
Thermal efficiency	3.13%

NO.22

LOAD = 6.79 H.P., 6.5 in. VACUUM AT EXHAUST

Duration of test	30 min.
R. P. M.	3690
Temperature of exhaust	191.4°F
Temperature of room	77°F
Barometer reading 29.43 in.	14.44 lbs.
Pressure on the main	115 "
Pressure on the exhaust = -6.5 in. =	-3.2 "
Boiler temperature at ex- haust pressure	198.79°F
Moisture in steam	1.9%
Total steam per hr. condensed	457 lbs.
Total steam per hour con- densed (Dry)	448.25 lbs.
Total heat supplied per hr.	635056 B.T.U.
B. H. P.	6.79
Total work done in B.T.U. per hr.	17273
Steam per B.H.P. hr. (Dry)	66.05
Thermodynamic efficiency	23.04%
Thermal efficiency	5.93%

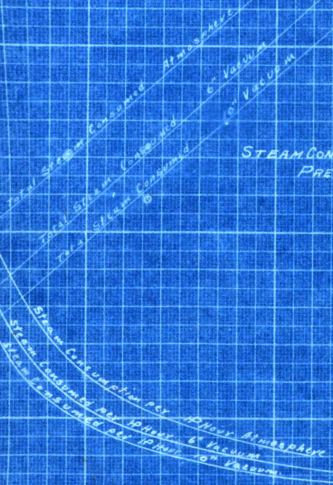
Weight of Steam, lbs. per Hour

400

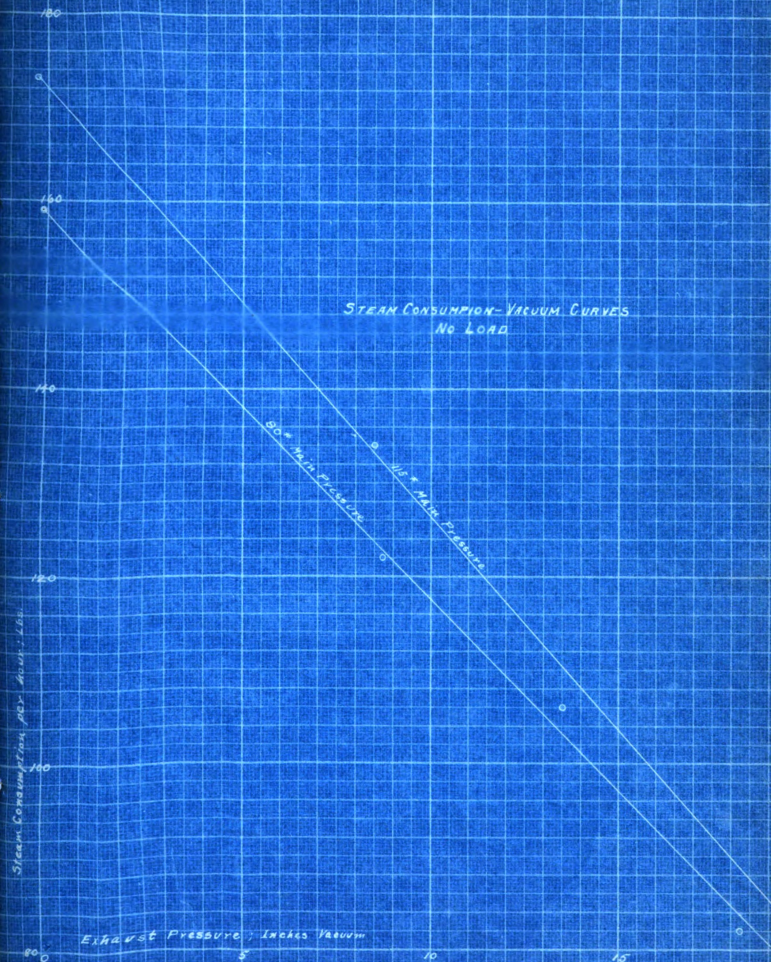
300

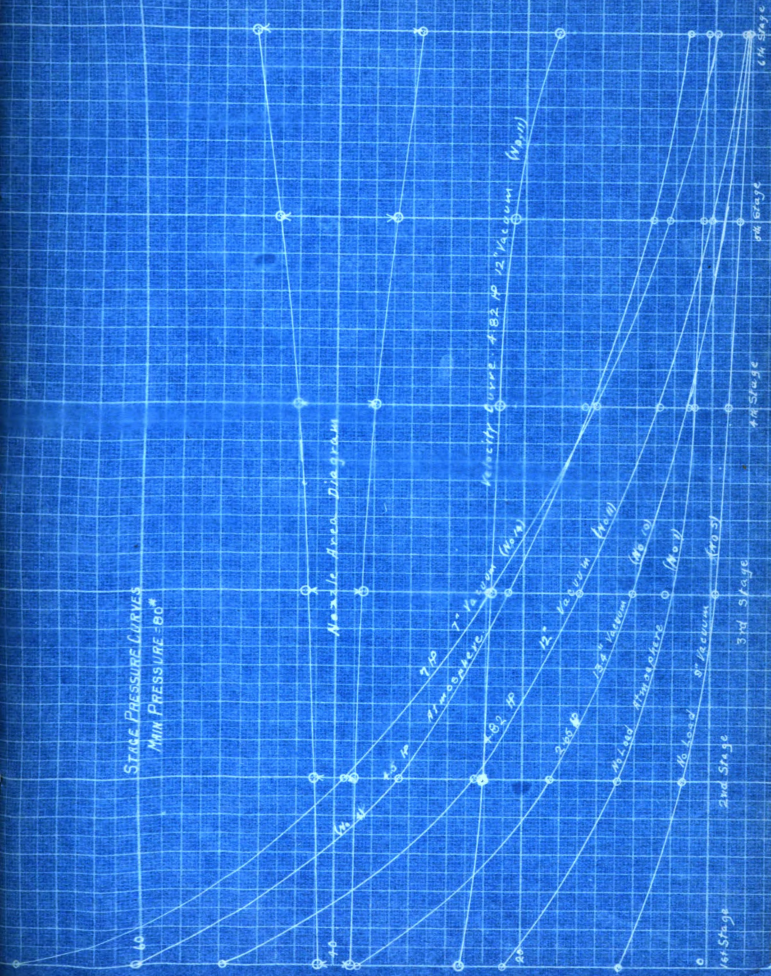
200

STEAM CONSUMPTION - LOAD CURVES
PRESSURE ON MAIN = 80"



Load, Horse Power





No 2 Atmosphere

General Data.	Time	Main	Pressures On Bowls						Exhaust	Speed	Calorimeter		Exhaust	Weight of Brake Gears	Remarks
			Hum.	Temp.	Temp.										
						1	2	3			4	5	6		
Length of Brake Arm = 14.5 ft. Brake Constant = 383# Resistance in Tachometer Circuit = 526 Ohms. Barometer = 29.32" Room Temp. = 76°	11:05	85	27	11.5	7			0	0	3650		266	136	4.3	
	11:10	84	26	12	7			0	0	3650		270	133	4.3	
	11:15	83	26	12	7			0	0	3650		267	131	4.3	
	11:20	85	27	12	7			0	0	3675		264	132	4.3	
	11:25	86	26	12	7			0	0	3675		258	133	4.3	
	11:30	87	26.5	12	7	2.5	1.3	0	0	3650		271	131	4.3	
	11:35	86	27	12	7	2.75	1.3	0	0	3675		270	129	4.3	
	11:40	86	27	12.5	7	3	1.3	0	0	3700		271	130	4.3	
	11:43	86	27	12	7	3	1.3	0	0	3650		220	129.5	4.3	110
	38 min	85.3	26.5	12	7	2.8	1.3	0	0	3660	3.6	266	131.5	4.3	110
No 3 Atmosphere															
Length of Brake Arm, Tachometer Res. were constant for all tests. Brake Constant = 383 Barometer = 29.32" Room Temp = 76°	2:10	80	33	18	12.5					3600	3.8	256	140	5.6	
	2:15	80	40	19	13	6.5	3.2	1.2	.5	3600	3.5	255	140	5.6	
	2:20	80	40	19	13	6.5	3.1	1.2	.5	3600	3.7	255	140	5.6	
	2:25	80	40	19	13	6.5	3.2	1.25	.5	3600	3.6	255	143	5.6	
	2:30	80	41	20	13.5	7	3.25	1.3	.5	3600	3.6	250	143	5.6	
	2:35	80	39	19	13	6.5	3.2	1.2	.5	3600	3.7	258	143	5.6	
	2:40	80	39	19	13	6.5	3.1	1.2	.5	3600	3.7	265	141	5.6	12
	30 min	80	39.6	18.9	13	6.5	3.2	1.2	.5	3600	3.6	256	142.5	5.6	12
No 4 Atmosphere															
Brake Constant = 383 Barometer = 29.32" Room Temp. = 76°	3:25	80	61	33	21	13.5	6.2	2.3	1.25	3550	4	258	155	8.18	
	3:30	80	62	34	21	13.5	6.3	2.3	1.25	3550	4	258	164	8.18	
	3:35	80	60	33	22	13.5	6.2	2.3	1.5	3550	4	257.5	160	8.18	
	3:40	80	60	33	22	13.5	6.2	2.3	1.25	3550	4	258	147	8.18	
	3:45	80	60	33	21	13	6.2	2.25	1.25	3550	4	254	145	8.18	
	3:50	80	61	33	21.5	13.5	6.2	2.3	1.25	3550	4	250	147	8.18	
	3:55	80	61	33	22	13.5	6.25	2.3	1.25	3550	4	252	148	8.18	177
	30 min	80	60.8	33	21.5	13.5	6.2	2.3	1.3	3550	4	253.3	152.3	8.18	177
No 1 Atmosphere															
Barometer = 29.29 Room Temp. = 75°	2:45	80	22	10	6	2	1.2	.5	2.5	3550	3.2	270	127	0	
	2:50	80	22.5	10	6	2	1.2	0	2.5	3550	3.4	262	125	0	
	2:55	80	22	10	6	2	1.05	.5	2.5	3550	3.5	270	127	0	
	3:00	80	22	10	6	2	1.2	.5	2.5	3550	3.5	270	127	0	
	3:05	80	22.5	10	6	2	1.2	.5	2.5	3550	3.6	270	129	0	
	3:10	80	22	10	6	2	1.1	0	2.5	3550	3.5	265	127	0	
	3:15	80	22	10	6	2	1.2	1	2.5	3550	3.5	270	128	0	79
	30 min	80	22	10	6	2	1.2	.43	2.5	3550	3.4	268	127	0	79

No. 5. 8.75" Vacuum

General Data	Time	Main	Pressures							Exhaust	Speed	Calorimeter		Exhaust Temp.	Weight on Brake Scales	Height of Steam
			on Bowls						Rev.			Man.	Temp.			
			1	2	3	4	5	6								
Room Temp. = 76° Barometer = 29.81 Brake Constant = 4.05	4:25	80	9.5	3	7.5	-4.25	-5.5	-8	-8.5	3550	4.2"	275	191	0		
	4:30	80	9.5	3	-5	-4.25	-5.5	-7.5	-8.25	3550	4"	272	191.5	0		
	4:35	79	3.5	2.5	7.5	-5	-6	-8	-8.5	3550	4.3"	272	189.5	0		
	4:40	81	3	2.5	7.5	-4	-6	-8	-8.5	3550	4.1"	275	189	0		
	4:45	80	3.5	3	-2.5	-3.5	-5.25	-7.75	-8.5	3600	4.1"	275	191	0		
	4:50	80	3.5	3	-7.5	-3.25	-5.75	-8	-8.5	3600	4.3"	275	190	0		
	4:55	80	10	3.25	-0	-2.75	-5.25	-7.75	-8.5	3600	4.1"	274	191	0	60.7	
	30 min.	80	3.5	2.87	7.75	-3.85	-5.6	-7.56	-8.75	3570	4.15	274	190	0	60.7	

No. 6. 7.53" Vacuum

Room Temp. = 78° Barometer = 29.29 Brake Constant = 4	2:30	80	36	17	9.5	2	-1.5	-6	-8	3750	3.6"	260	192	6.5		
	2:35	80	37.5	17	8.5	2.4	-1	-5.5	-7.5	3760	3.5"	260	193	6.5		
	2:40	80	38	17	8.5	2.5	-5	-5.5	-7.25	3700	3.6"	255	194	6.5		
	2:45	80	38.5	17.5	8.5	2.5	-5	-5.5	-7.5	3700	3.5"	254	193	6.5		
	2:50	80	37.5	17	8.5	2.5	-5	-5.5	-7.5	3750	3.5"	252	193.5	6.5		
	2:55	80	38.5	17	8.75	2.5	-5	-5.25	-7.5	3725	3.5"	255	194	6.5		
	3:00	80	39	17.5	9	2.5	-7.5	-5.5	-7.5	3900	3.5"	252	192.5	6.5	124.5	
	30 min.	80	37.7	17.1	8.77	2.4	-7	-5.57	-7.53	3720	3.53	255	193.1	6.5	124.5	

No. 7. 6" Vacuum

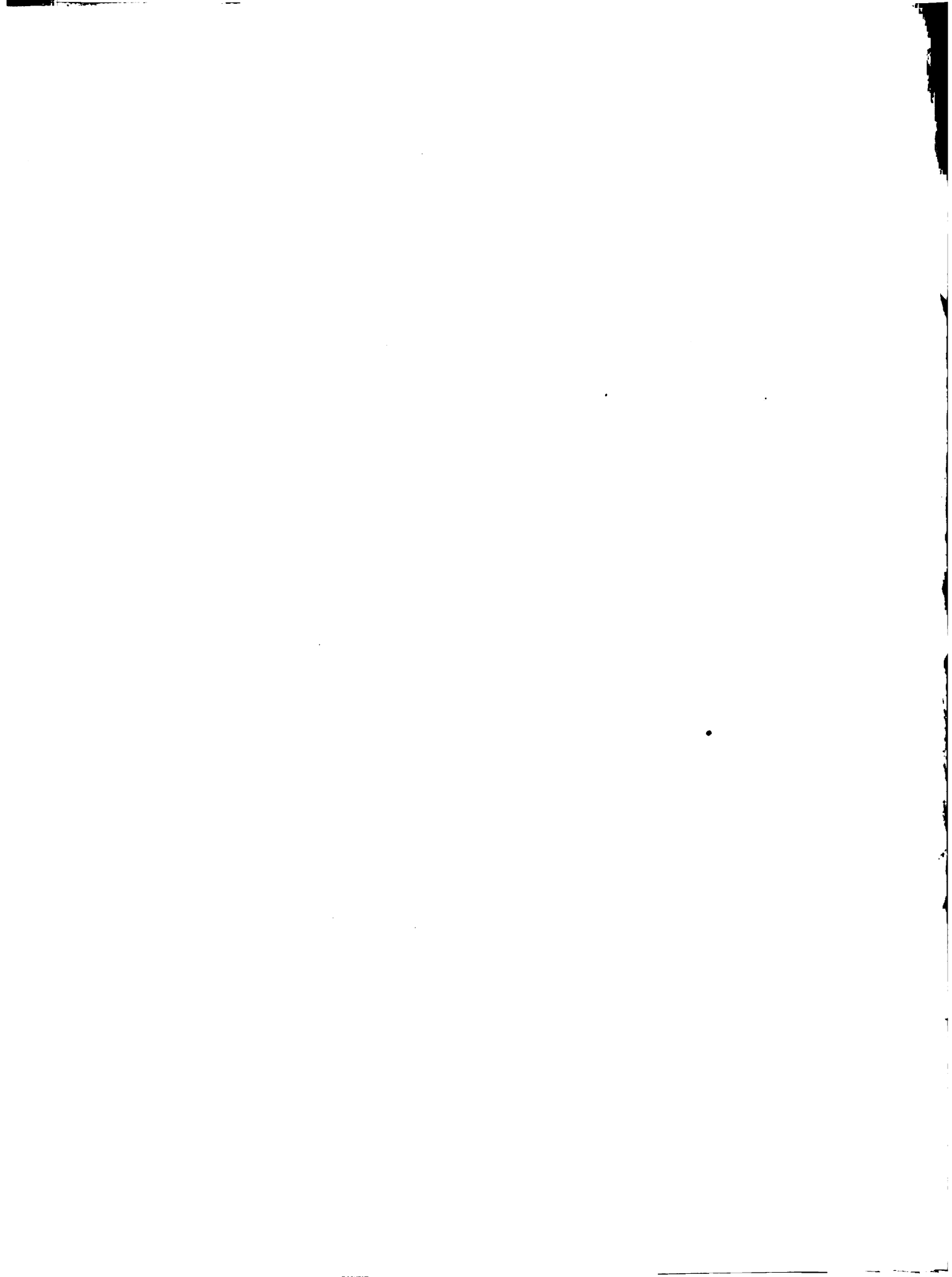
Room Temp. = 74° Barometer = 29.36 Brake Constant = 4	2:00	80	58		15.5	7.2	2	-2.5	-6	3800	3"	225	196	8.5		
	2:05	80	58	28	16.5	7.2	2.5	-2	-5.75	3850	3.2"	224	197	8.5		
	2:10	80	57	28	16.5	7.5	2.5	-2.25	-6	3850	3.5"	235	196	8.5		
	2:15	80	59	29	17	8	2.5	-2	-6	3850	3.5"	250	196	8.5		
	2:20	80	59	29	17.4	8	2.5	-2	-6	3800	3.5"	250	196	8.5		
	2:25	80	60	30	17.8	8	2.75	-1.75	-6	3775	3.5"	245	195	8.5		
	2:30	80	60	30	18	8.4	2.75	-1.75	-6	3800	3.5"	240	195.5	8.5	176.5	
	30 min.	80	58.7	29	16.9	7.8	2.5	-2	-6	3820	3.4	238.4	196	8.5	176.5	

No. 8. 4.14" Vacuum

Room Temp. = 76° Barometer = 29.30 Brake Constant = 4	3:50	80	72.5	39	24.5	12.2	5.5	1	-4"	3450	3.6"	235	199	10.5		
	3:55	80	73	39.5	24.8	12.5	6	1	-4"	3700	3.7"	233	198	10.5		
	4:00	80	72	38.5	23.5	12.4	5.25	1.5	-4.5	3650	3.6"	251	198	10.5		
	4:05	80	72	39	23.8	12	5.25	.5	-4.25	3400	3.6"	251	198.5	10.5		
	4:10	80	72	38.8	24	12	5	1	-4"	3500	3.6"	252	199	10.5		
	4:15	80	73.5	39.5	24.5	12.4	5.5	1	-4"	3700	3.6"	251	199	10.5		
	4:20	80	72.5	39	24.5	12.5	5.5	1	-4.25	3700	3.6"	246	198	10.5	217.7	
	30 min.	80	72.5	39	24.26	12.3	5.47	1	-4.14	3586	3.6"	231	198.5	10.5	217.7	

No. 9 13.5" Vacuum

General Data	Time	Main	Pressures on Bowls								Exhaust	Speed	Calorimetry		Exhaust Temp.	Weight on Brake Scales	We. o Ste
			1	2	3	4	5	6	Hum.	Temp.							
Room Temp = 76° Barometer = 29.41" Brake Constant = 405	5:05	80	5.5	0	-7.5	-9"	-9.5	-13"	-13.5	3600	4.2"	270	180	0			
	5:10	80	6.5	0	-6.5	-6.5	9"	-12.5	-13.5	3600	4.2"	269	179	0			
	5:15	80	5.5	-1"	-7"	-9"	-9.5	-13"	-13.5	3675	4.2"	270	177	0			
	5:20	79	5.5	0	-6"	-9.5	-9.25	-12.5	-13.5	3550	4.2"	270	178	0			
	5:25	80	5	-5"	-7"	-9.5	-9.25	-12.5	-13.5	3600	4.2"	269	178	0			
	5:30	81	6.5	-1"	-7"	-9.5	-9.25	-12.5	-13.5	3600	4.2"	271	178	0			
	5:35	80	5	-1"	-6.5	-10"	-9.25	-12.5	-13.5	3600	4.2"	271	178	0	5		
	30 min	80	5.5	-5"	-6.65	-9"	-9.3	-12.6	-13.5	3590	4.2"	270	178	0	5		
No 10 13.4" Vacuum																	
Room Temp = 78° Barometer = 29.80" Brake Constant = 400	3:30	80	32	13.5	5.2	0	-11"	-13.5"	-13.5	3750	3.5"	252	178	6.5			
	3:35	80	32	13.5	5	-5"	-11.5"	-13.5"	-13.5	3750	3.5"	260	177.5	6.5			
	3:40	80	32	13.5	5	-5"	-11.25"	-13.5"	-13.5	3750	3.5"	265	178	6.5			
	3:45	80	32	13.5	5.2	-5"	-11"	-13.5"	-13.5	3750	3.5"	265	178	6.5			
	3:50	80	33	13.5	5.3	0	-11"	-13"	-13	3750	3.5"	263	179	6.5			
	3:55	80	32	14	5	0	-11"	-13.5"	-13.5	3700	3.5"	257	178.5	6.5			
	3:60	80	32	14	5.4	0	-11"	-13.5"	-13.5	3700	3.5"	256	178	6.5	110		
	30 min	80	32	14	5.14	-2"	-6.5"	-11.11"	-13.4	3735	3.5"	259.7	178	6.5	110		
No 11 12" Vacuum																	
Room Temp = 78° Barometer = 29.26" Brake Constant = 400	5:10	80	50	24	13	4.75	-2.5"	-8"	-12.25	3750	3"	235	180	8.5			
	5:15	80	50	25	14	5.5	+0"	-7.5"	-12"	3750	3"	234	180.5	8.5			
	5:20	80	53	25.5	14.5	5.5	+5"	-7.25"	-12"	3750	3"	236	181	8.5			
	5:25	80	55	25	14	6	+2.5"	-7.5"	-11.75	3750	3"	236	181	8.5			
	5:30	80	52.5	26	14.5	5.5	+5"	-7"	-11.75	3750	3"	237	181	8.5			
	5:35	80	50	25	14	5.75	+2.5"	-7.75"	-12.25	3800	3"	250	180	8.5			
	5:40	80	52	25.5	14	5.5	+2.5"	-7.5"	-12"	3750	3"	249	180.5	8.5	164		
	30 min	80	51.8	25.1	14	5.46	+2.1"	-7.5"	-12"	3757	3"	239.6	180.6	8.5	164		
No 12 18.25" Vacuum																	
Room Temp = 76° Barometer = 29.64" Brake Constant = 405	10:50	80	5	-7"	-12"	-15"	-14"	-15"	-18.6"	3875	3.5"	272	184	0			
	10:55	80	2.5	-7"	-12"	-15"	-13.5"	-18"	-18.5"	3800	3.5"	274	184	0			
	11:00	80	5	-7"	-12"	-15.25"	-13.75"	-17.5"	-18.25"	3825	3.4"	274	184	0			
	11:05	80	5	-7"	-11.5"	-15"	-14"	-17"	-18"	3800	3.3"	271	183	0			
	11:10	80	1	-7"	-11.75"	-14.5"	-13.5"	-17"	-18"	3800	3.6"	271	181	0			
	11:15	80	1	-7.5"	-12"	-16"	-13.75"	-17.75"	-18.25"	3800	3.5"	271	168	0			
	11:20	80	.5	-7"	-12"	-15"	-13.5"	-17.5"	-18.25"	3800	3.5"	271	164	0	41		
	30 min	80	401	-7"	-14.89"	-15.12"	-13.71"	-17.11"	-18.25"	3814	3.47"	272	178	0	41		



No 13. 17" Vacuum

General Data	Time	Main	Pressures						Exhaust	Speed	Calorimeter		Exhaust Temp.	Weight on Brake Scales	Weight of Site
			on Bowls								Man.	Temp.			
			1	2	3	4	5	6							
Room Temp. = 78° Barometer = 29.27 Brake Constant = 4 th	4:20	80	30	12	4	-2"		-13"	-17"	3750	3.5"	268	170	6.5	
	4:25	80	30	12	4	-2"		-13"	-17"	3750	3.5"	268	170.5	6.5	
	4:30	80	29	12	3.8	-2.5"		-13.75"	-16.25"	3750	3.5"	269	168.5	6.5	
	4:35	80	30	12	3.5	-3"		-14"	-16.75"	3750	3.5"	268	167	6.5	
	4:40	80	30	12.2	3.25	-4"		-14.25"	-16.75"	3750	3.5"	264	166	6.5	
	4:45	80	28	11.2	3	-4"	9.5"	-14.5"	-17"	3750	3.5"	264	166	6.5	
	4:50	80	29	12	3.25	-3.1"	9.75"	-14.5"	-17"	3750	3.5"	263	166	6.5	102
	30 min	80	29.4	11.9	3.54	-3.1"	9.6"	-13.9"	-17"	3750	3.5"	266.3	167.7	6.6	102

No 14 6.9" Vacuum

Room Temp = 76° Barometer = 29.34" Brake Constant = 4 th	3:00	80	74	38	23.4	11.2	4.5	-7.5"	-7"	3750	3.5	252	191.5	10.5	
	3:05	80	74	39.5	23.8	11.4	5	-7.75"	-7"	3750	3.5	252	192	10.5	
	3:10	80	74.5	39.5	25	11.8	5	-7.25"	-6.35"	3700	3.5	240	192	10.5	
	3:15	80	74	38.4	24	11.2	4.5	-7.5"	-7"	3800	3.5	238	192	10.5	
	3:20	80	72	37.8	23	11	4.25	-1"	-7.25"	3700	3.5	235	192	10.5	
	3:25	80	73	38.5	24	11	4.5	-7.5"	-7"	3800	3.5	234	192	10.5	
	3:30	80	74	39	24.5	11.4	5	-5"	-6.75"	3800	3.5	235	192	10.5	216
	30 min	80	73.64	38.67	23.98	11.3	4.68	-6.68"	-6.9"	3757	3.5	241	192	10.5	216

HIGH PRESSURE TESTS

No 15 Atmosphere.

Room Temp = 79° Barometer = 29.39" Brake Constant = 4 th	2:45	115	22						.5	3700	7"	281	210	0	
	2:50	115	22						.5	3750	7"	281	210	0	
	2:55	115	22						.5	3750	7"	283	210	0	
	3:00	115	22						.5	3700	7"	285	210	0	
	3:05	115	20						.5	3750	7"	284	210	0	
	3:10	115	21						.5	3700	7"	283	210	0	
	3:15	115	22						.5	3700	7"	285	210	0	87
	30 min	115	21.5						.5	3720	7"	283.1	210	0	87

No 16 8.5" Vacuum.

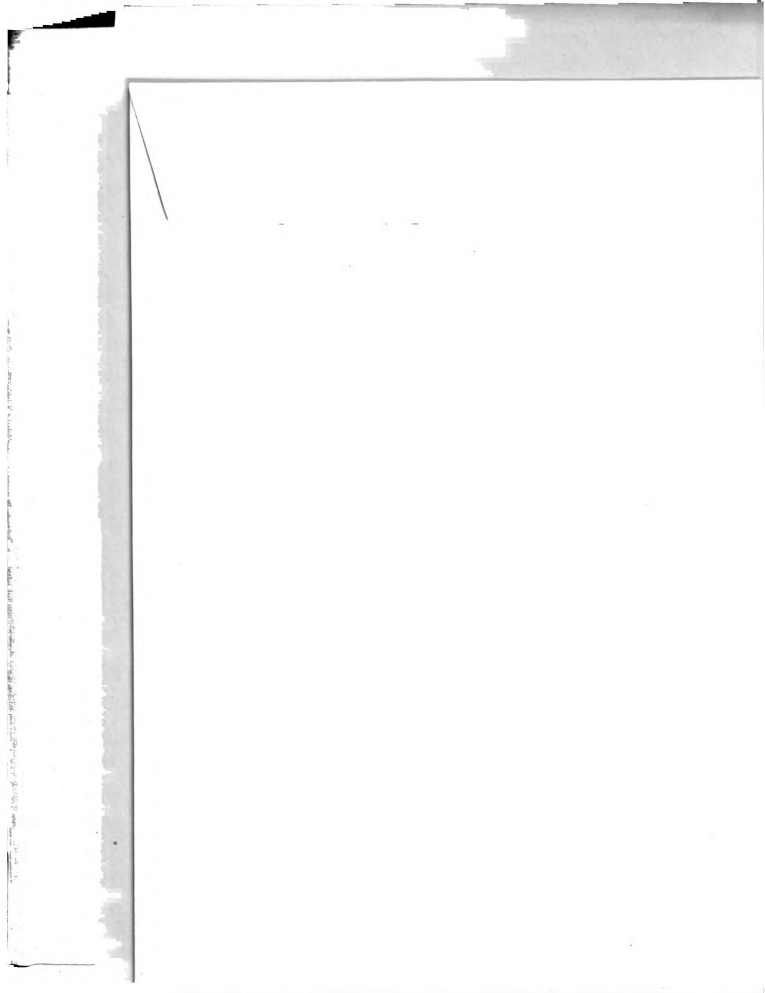
Room Temp. = 79° Barometer = 29.58" Brake Constant = 4 th	3:30	115	12.5						-9"	3750	7.5"	287	198	0	
	3:35	115	12.5						-9"	3750	7.5"	285	198	0	
	3:40	115	12.5						-9.5"	3750	7.5"	286	196	0	
	3:45	115	12.5						-8.5"	3750	7.5"	286	196	0	
	3:50	115	12.5						-8.5"	3750	7.5"	286	196	0	
	3:55	115	12.5						-9.5"	3750	7.5"	285	196.5	0	
	4:00	115	12.5						-9.5"	3700	7.5"	286	191	0	67
	30 min	115	12.5						8.5"	3750	7.5"	286	195.2	0	67

No 17 1951" Vacuum.

General Data	Time	Min	Pressures						Exhaust	Speed	Calorimeter		Exhaust Temp.	Weight on Brake Scales	Weight of Scales
			on Bowls								Max.	Temp			
			1	2	3	4	5	6							
Room Temp = 79° Barometer = 29.38" Brake Constant = 4#	4:20	115	.5						-20"	3775	6.5"	286	168.5	0	
	4:25	115	.5						-20"	3775	7"	285	167	0	
	4:30	115	3.						-19"	4000	7"	285	168	0	
	4:35	115	.5						-20"	4000	7"	287	163	0	
	4:40	115	.5						-20"	3900	7"	288		0	
	4:45	115	3.						-20"	3950	7"	288	161	0	
	4:50	115	3.						-18"	3750	7"	285	163	0	42
	30 min	115	1.57						-18.5"	3907	7"	286	164.4	0	43
No 18 10" Vacuum															
Room Temp = 79° Barometer = 29.32" Brake Constant = 4#	3:00	115	55						-10"	3500	7.5"	276	191	8.5	
	3:05	115	55						-10"	3450	6.5"	283	192	8.5	
	3:10	115	57.5						-9.5"	3450	6.75"	262	191	8.5	
	3:15	115	60						-10"	3450	7"	274	192.5	8.5	
	3:20	115	60						-10"	3700	6"	270	182	8.5	
	3:25	115	55						-10"	3700		265	183	8.5	168
	3:30	115	55						-10"	3700		274	186	8.5	168
	30 min	115	56.8						-10"	3565	6.75"	272	188.2	8.5	168
No. 19 5" Vacuum															
Room Temp = 80° Barometer = 29.31" Brake Constant = 4#	3:45	115	70						-5"	3700	6"	232	198	8.5	
	3:50	115	67.5						-5"	3700	6"	260	198	8.5	
	3:55	115	60						-5"	3700	7"	232	196	8.5	
	4:00	115	62.5						-5"	3700	6.5"	243	197	8.5	
	4:05	115	65						-5"	3700	6"	255	197	8.5	
	4:10	115	65						-5"	3700	6"	232	196	8.5	198
	4:15	115	64						-5"	3700	6"	232	197	8.5	198
	30 min	115	64.7						-5"	3700	6.2"	241	197	8.5	198
No. 20. Atmosphere															
Room Temp = 80° Barometer = 29.31" Brake Constant = 4#	4:30	115	67						0	3750	7.5"	272	208	8.5	
	4:35	115	67						0	3750	7.5"	230	212	8.5	
	4:40	115	70						0	3750	7.5"	272	207	8.5	
	4:45	115	70						0	3750	7.5"	264	206	8.5	
	4:50	115	68						0	3750	7.5"	242	206	8.5	
	4:55	115	70						0	3750	7.5"	230	209	8.5	
	5:00	115	70						0	3750	7.5"	278	206	8.5	20
	30 min	115	69.3						0	3750	7.5"	255	208	8.5	208

No 21. Atmosphere

General Data	Time	H _{air}	Pressures on Boilers						Exhaust	Speed	Calorimeter		Exhaust Temp.	Height on Brake Scale	Height of Steam
			on Boilers								H _{air}	Temp.			
			1	2	3	4	5	6							
Room Temp = 77° Barometer = 29.43 Brake Constant = 4.06	2:45	115	80						0	3750	4.0 ¹	283	204	10.5	
	2:50	115	90						+25	3750	4.0 ¹	282	205	10.5	
	2:55	115	90						5	3750	4.5 ²	283	206	10.5	
	3:00	115	95						1	3750	4.5 ²	283	206	10.5	
	3:05	115	95						1	3750	4.5 ²	284	210	10.5	
	3:10	115	97						1	3750	4.5 ²	280	210	10.5	
	3:15	115	95						1	3750	4.5 ²	277	210	10.5	238
	30 min	115	91.7						.68	3750	4.5 ²	281.7	207.6	10.5	238
									No 22 6.5" Vacuum						
Room Temp. = 77° Barometer = 29.43 Brake Constant = 4.06	3:30	115	85						-6.5 ¹	3700	3.5 ¹	277	190	10.5	
	3:35	115	85						-6.5 ²	3700	3.25 ²	280	191	10.5	
	3:40	115	85						-6.5 ³	3650	3.5 ²	269	191	10.5	
	3:45	115	85						-6.5 ⁴	3700	3.5 ²	240	192	10.5	
	3:50	115	85						-6.5 ⁵	3700	3.5 ²	260	192	10.5	
	3:55	115	85						-6.5 ⁶	3700	3.5 ²	232	193	10.5	
	4:00	115	85						-6.5 ⁷	3650	3.5 ²	269	191	10.5	228
	30 min	115	85						-6.5 ⁸	3650	3.5 ²	258	191.4	10.5	228



MICHIGAN STATE UNIVERSITY LIBRARIES



3 1293 03174 4398