Test Of

72,000,000 Gallon Pumping Engine

Of Boston

(Main Drainage Pumping Station)

A Thesis

by

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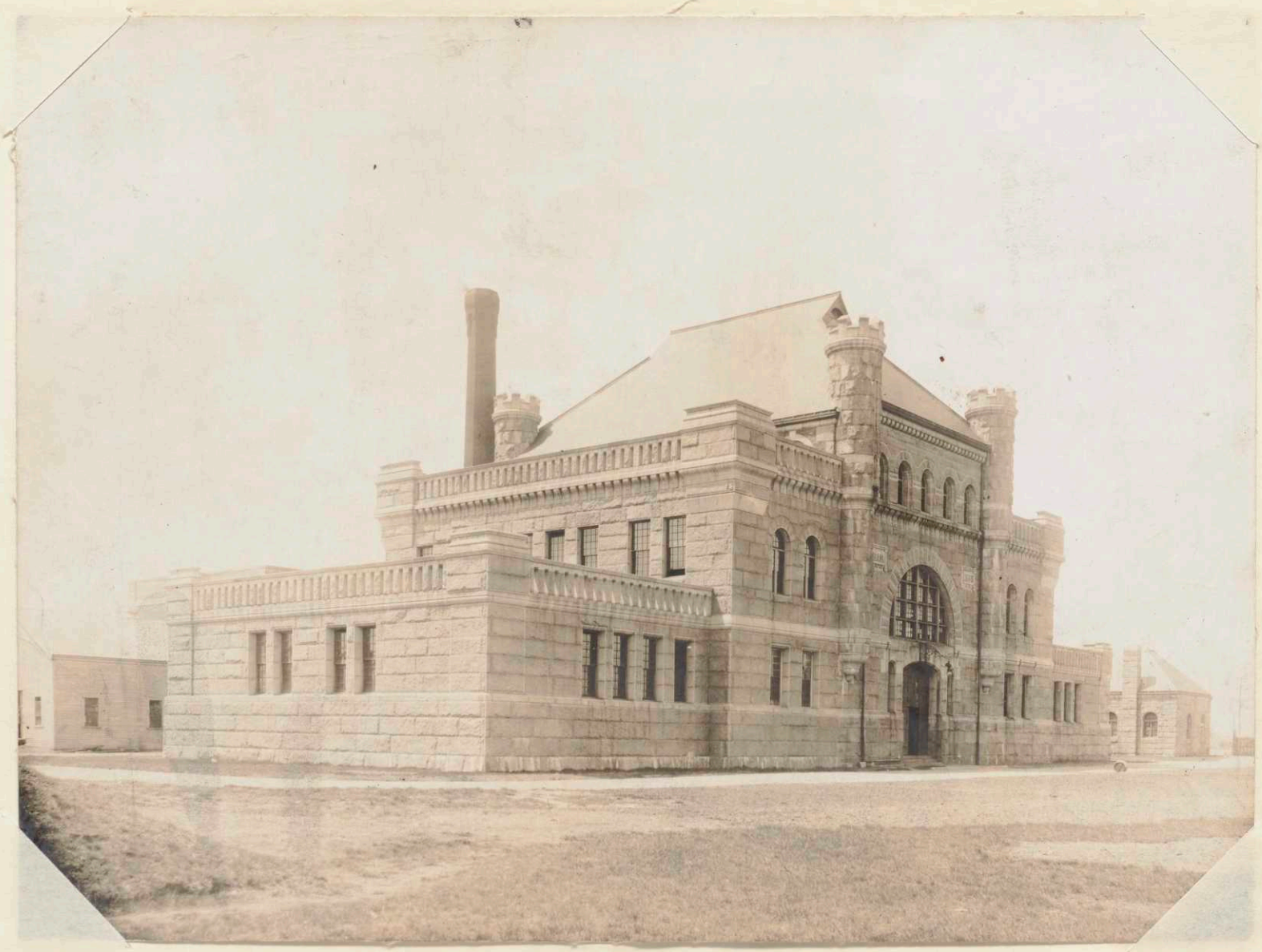
Massachusetts Institute of Technology

1907



Duty Test on the Seventy-Two Million Gallon Leavitt Pumping Engine at the Boston Main Drainage Pumping Station.

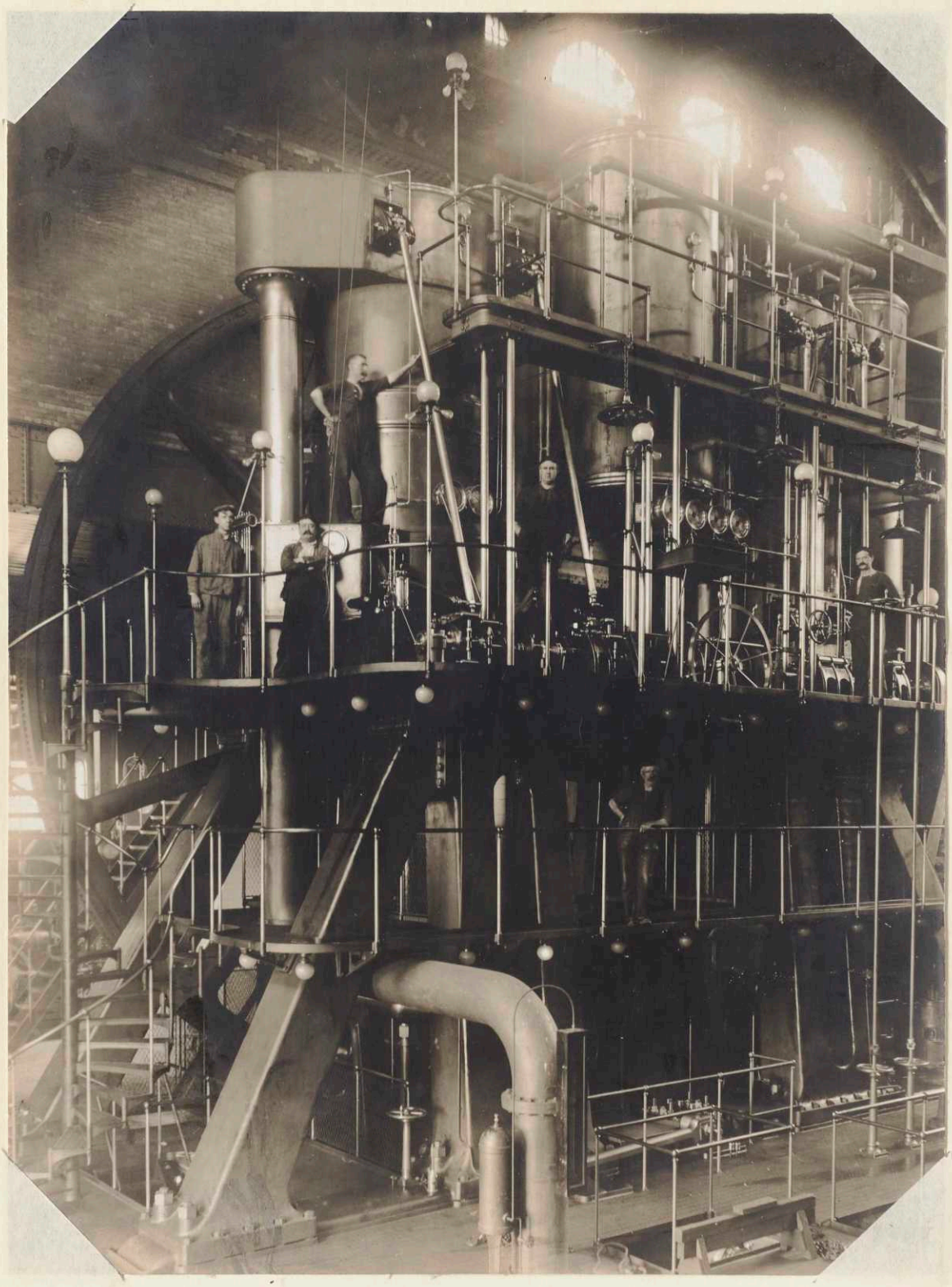
The test was made on the new Leavitt Pumping Engine at the Boston Main Drainage Pumping Station, on March 23, 1907, and was the first test of the engine of which there is any record. The engine was built in 1902, and has been running regularly since 1904. The following description of engine and boilers is taken from the contract specifications:-

"There will be one triple-expansion beam and fly wheel engine of the Leavitt type, which will operate two single-acting pumps.

The steam cylinders will be vertical and inverted; the pistons of the high-pressure and intermediate cylinders being connected to one end of the beam and that of the low-pressure cylinder to the other end of the same.

The pumps will be hung underneath the engine bed-plate, and additionally supported by adjusting screws which will bear on girders built into the foundations.

The two plungers will be rigidly connected by rods to the two steam cross heads.



The high-pressure and intermediate pistons with their attached plunger will make their upward stroke at the same time that the low-pressure piston and its attached plunger are making their downward stroke, and vice versa..

The pumps will hang in a well from which they will take direct suction..

The delivery chambers of the two pumps will be connected together, and two discharge mains will lead in opposite directions; one from each pump..

Each pump will consist of twelve principal castings, viz:

Four suction boxes, to which the suction valve seats will be bolted..

Four suction tubes leading to the suction boxes..

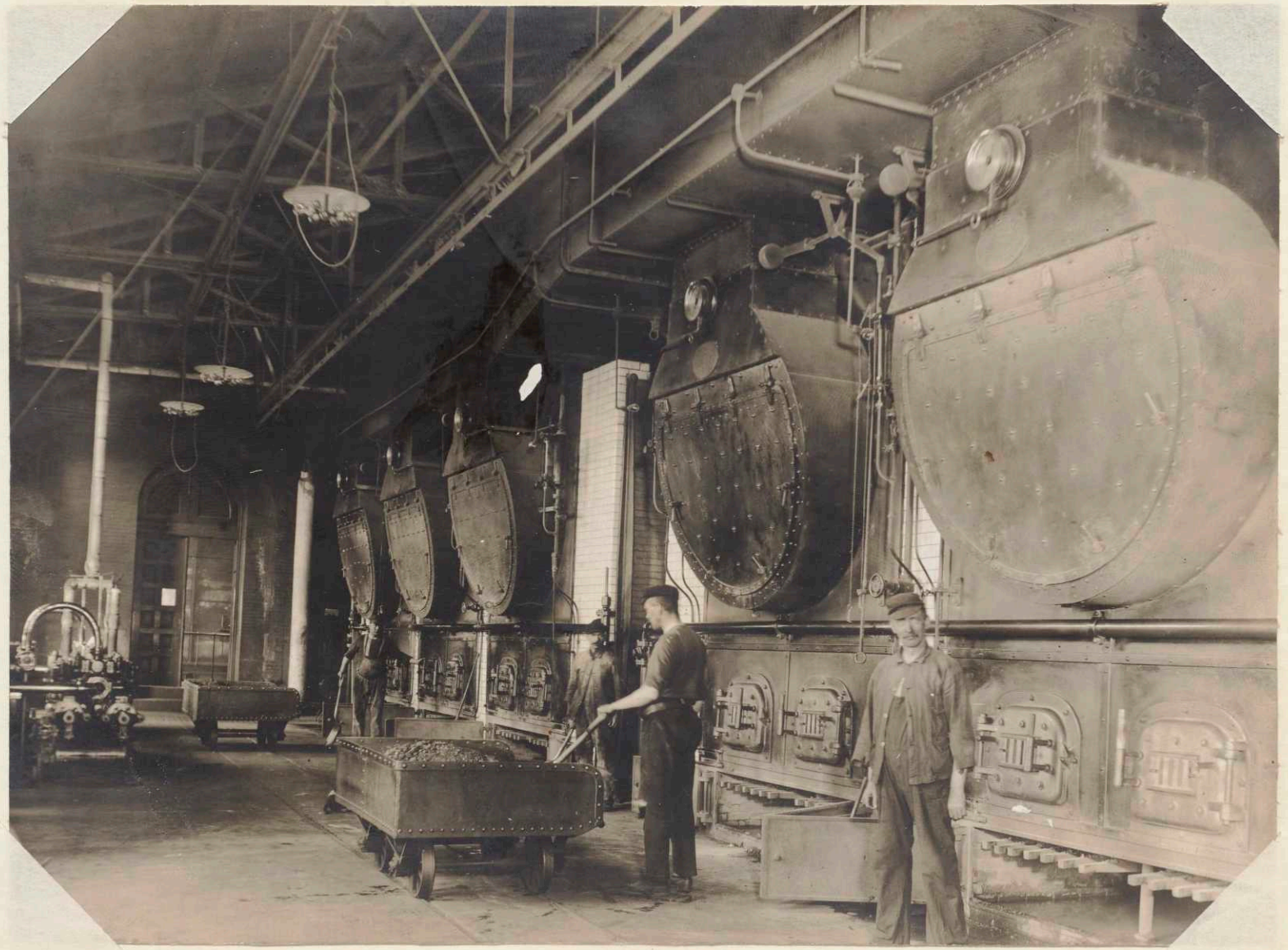
One suction chamber, to which the suction boxes will be bolted..

A delivery seating, next above the suction chamber, to which the delivery valve seats will be bolted..

A delivery chamber made in two castings, forming also an air [illegible].

The pump valves will be rubber flaps with composition backing plates loaded with lead, and with composition washer plates.

The valve seats will be composition, with inclined faces, valve guards of composition will be bolted to the seats..



The plunger of each pump will work in a long composition-lined sleeve, with an outside stuffing-box.

The pedestals for the main beam-pin will rest upon a central transverse bed plate, and will be bolted to longitudinal bed plates which will carry the engine columns.

The cylinders, valve gear, and main crank-shaft bearings will be carried on a massive entablature which will be supported by four columns with diagonal braces.

There will be an outboard bearing for the crank-shaft, carried on an independent foundation pier.

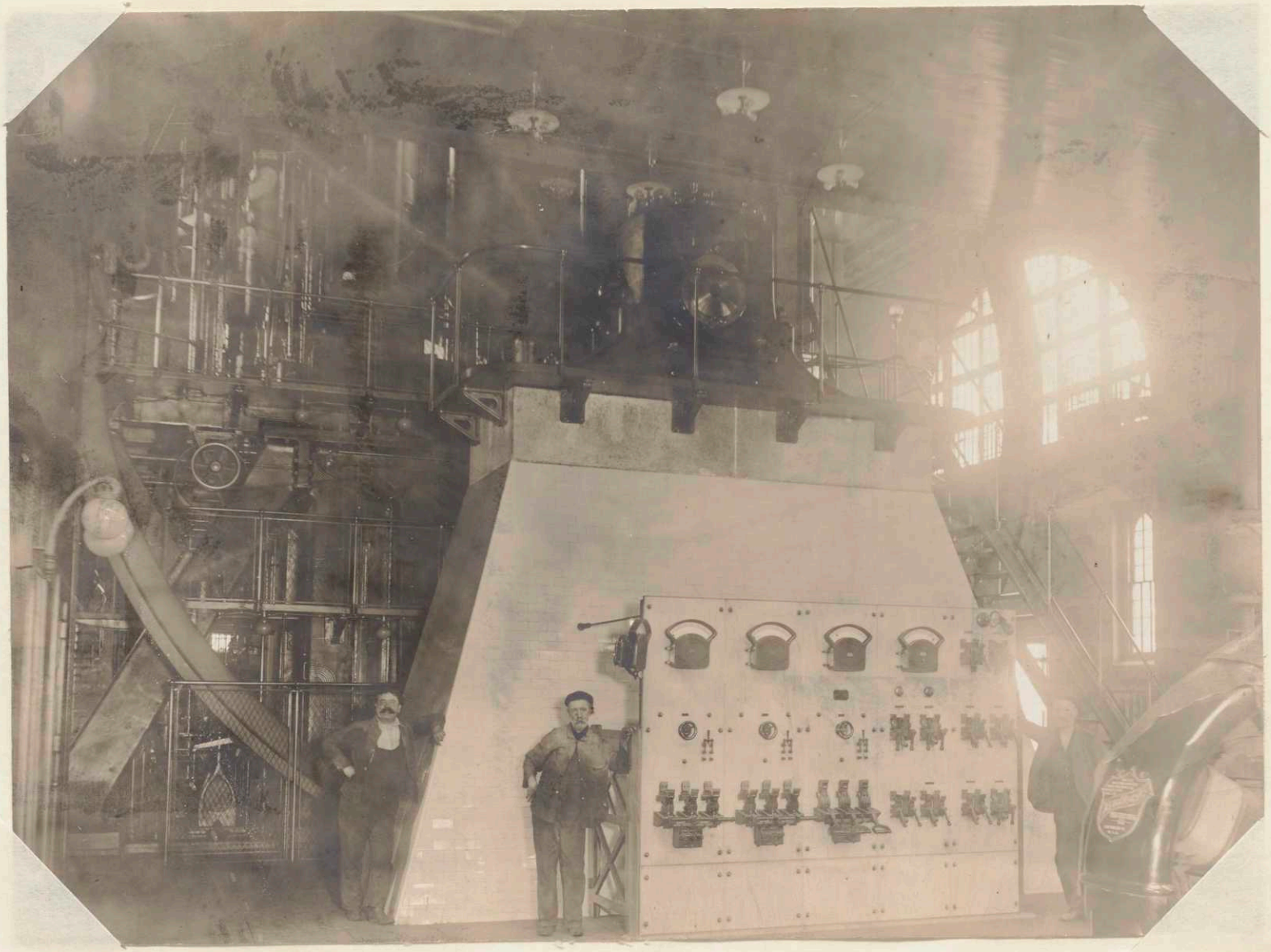
The cylinders will be thoroughly steam jacketed all over, on heads and barrels.

Tubular reheaters will reheat the steam on its way from the high-pressure to the intermediate cylinder, and from the intermediate to the low-pressure cylinder.

All hot surfaces will be thoroughly protected from radiation by non-conducting covering, with a cast-iron and sheet-steel lagging handsomely finished.

The steam valves will be of the gridiron type, operated by cam valve gear. The cam shafts will be driven from the crank shaft by a drag link, lay shaft, and mitre gearing.

There will be a jet-condenser with a vertical single-acting bucket air-pump, driven by links and a rocker shaft from the main beam centre.



The condensing apparatus will be hung from girders which will span the pit adjoining the main pump-well..

Cast-iron galleries,, with suitable stairs and hand rails,, will be provided for reaching all parts of the engine and pumps..

Screens will be provided in the pump-wells,,to catch solid material which may pass the sewer screens..

The working steam pressure will be 185 lbs..per square inch above the atmosphere..

The static head on pumps, from the suction-well to the deposit-sewer, will ordinarily be about 37 feet, but may at times be as high as 43 feet. The dynamic head will be slightly greater.

The normal speed of the engine will be about 17 revolutions per minute, at which speed the pumping capacity by plunger displacement will be about 72,000 U. S. gallons in 24 hours..

The leading dimensions are as follows:-

Steam cylinders, 18-1/2,, 33, and 52-3/4 inches diameter,, and 120 inches stroke..

Steam plungers (two single-acting), each 60 inches diameter,, and 120 inches stroke..

High pressure piston rod, 4-1/2 inches diameter..

Intermediate piston rod,,4-1/2 inches diameter..

Low pressure piston rod 5-1/2 inches diameter.

Pump rods, 6 inches diameter.

Fly wheel: Diameter, 35 feet, Rim, 15 inches face; 15 inches depth: Hub 30 inches long. Weight, about 55 net tons..

Delivery mains; two, 48 inches diameter..

Suction chambers; 5 feet 5-1/2 inches X 6 feet 5-1/2 inches oval at bottom, 8 feet 2 inches X 9 feet 2 inches oval at top; outside dimensions."

The boilers tested were two horizontal multi-tubular boilers, designed by E. D. Leavitt, and built by I. P. Morris Co.. of Philadelphia, Pa.. They were built for 185 pounds working pressure..

The following dimensions were taken from the drawings:-

Grate area	35	sq. ft.
Total Heating Surface	2144.21	" "
Ratio $\frac{HS}{GS}$ =	61.26	
Inside area through tubes	6.27	" "
$\frac{\text{Grate Surface}}{\text{Area thro' tubes.}}$	5.58	
Area through smoke box	6.62	

Arrangements made for the Test..

The feed water for the boilers tested ordinarily passed through heater before going to the feed pump, but during the test it was found necessary to break this connection, and take the water directly from the city mains to a tank where it was weighed, and then allowed to pass into a second tank, from which it was sucked by the feed pump.. The level of the wa-

ter in the second tank was found at the beginning of the test, and at the end it was brought up to the same level.

The drip from the high pressure jackets and first receiver was caught in a barrel partly filled with water, the steam entering under the water and condensing. The barrel was weighed before and after the drip was caught, and so the amount of drip determined. The barrel filled several times during the test, and was emptied by bailing, the condensed steam being shut off during this process.

The drips from the intermediate and low pressure jackets, second receiver, and oil pump were all caught in one barrel, as before. This barrel did not fill up during the test; it was weighed before and after the test and the total drip obtained.

The height of water in the suction well was obtained by means of a float which gave the height of the sewage in the well above mean low water. The delivery pressure was found by means of a water column which led directly from the delivery mains, and the head of water was obtained directly from a scale placed aside of the water column.

The amount of steam used by the calorimeter was obtained by means of Napier's formula; the steam was allowed to run through the calorimeter for 6-1/2 minutes.

The flue gas samples were taken from the uptake over one of the boilers.

A small sample of coal was taken from each carload, and put into a barrel. After the test ~~is~~ this coal was spread out out and quartered, and a sample taken. The heat of combustion was determined by a Mahler bomb.

The sewage from the suction well is raised about 37 feet by the pump and then flows by gravity, through a large tunnel, to Moon Island, where it discharges into four large reservoirs. These reservoirs are emptied twice daily, on the o outgoing tide, and the sewage is carried out to sea by the strong current flowing past the island.

The height of sewage in each reservoir was obtained by means of a float calebrated to read directly in feet above mean low water. Reading of these gages were obtained at the beginning of the engine test, and the amount of water in each calculated from tables compiled by the Boston Civil Engineering department. The height of sewage at the end of the test was found in the same way, the amount of sewage in the reservoirs calculated, and the total amount pumped obtained by the difference between the two calculations.

Starting and Ending the Test.

The test on the boilers was originally intended to be started at 6:00 P. M. Mar. 22, 1907, and the test on the engine at 10:00 P. M., and all arrangements had been completed for the start, when the feed pump for the boilers gave trouble,

and could not be started.. It was necessary to take the pump apart, put in new packing, and change the piping before the pump would take water, and so the boiler test was not started until 2:35 A. M. March 23, 1907..

The engine test had to be so timed as to start when the reservoirs at Moon Island were empty or nearly empty, which would be about two hours after high tide.. It was expected that by starting at about 10:00 P. M. the engine to be tested could hold the entire load on the station during the night, which would give a nine or ten hour test, but owing to trouble with the boiler feed pump the test was not started until 3:00 A..M., and then, due to trouble with one of the floats at the reservoirs, the water pumped only passed into three reservoirs, and so the test had to be discontinued after about two hours. As the test was for so short a time the results were not used in calculating the duty of the pump..

A second test on the engines was started at 11:00 A. M.. March 23, 1907, and continued until 4:00 P. M. of the same day, when it had to be stopped, owing to high water in the main sewer, as more pumps had to be started to reduce the height of the water. During the test the drips were caught as explained previously, cards were taken on both ends of each cylinder every fifteen minutes, and readings of the count-counter, boiler pressure, pressure in first and second re-

celvers, vacuum in condenser, feet in well and on hill were taken every fifteen minutes. Everything on this test was satisfactory and the results obtained should be very accurate.

The boiler test was started at 2:35 A. M., March 23, 1907. The fires were cleaned at 12:30 A. M. The height and condition of the fires at the beginning of the test were noted, and also the level of the water in the boilers. The fires were cleaned again about two hours before the end of the test, and the level of the water in the boilers, and the height and condition of the fires made the same as at the beginning of the test.

During the test the coal was weighed in cars just befdre going to the boiler room, and a sample of coal taken from each car. The quality of steam was determined every hour by means of a calorimeter. An analysis of flue gas was made every hour. Readings were taken every fifteen minutes of the boiler pressures, room temperature, feed water temperature, and temperature of flue gas.

All the gages used during the test were tested and the average readings corrected. The thermometers used had been previously calibrated, and the necessary corrections were applied to the average reading.

Boiler Test Data.

(1)	Duration of Test	24 hours
(2)	Barometer 30.14 inches	14.80 lbs.
(3)	Boiler pressure absolute	193.3 lbs.
(4)	Temp. of inside air	83°.8 F
(5)	Temp of feed water	39°.9 F
(6)	Quality of steam, dry steam unity.	.968
(7)	Kinds of coal used	New River
(8)	Moisture in coal, by drying test	1.06%
(9)	Total water fed to boilers	148,653 lbs.
(10)	Coal fired in 24 hours	23,930 lbs.
(11)	Ash and Clinker	4,167 lbs.
(12)	Dry Coal burned	23,650 lbs
(13)	Dry Combustible	19,483 lbs.
(14)	Heating surface	4288.42 sq. ft
(15)	Grate Surface	70 sq. ft.
(16)	Flue hgas Analysis CO_2 6.97; O_2 13.44; CO .04	
(17)	Heat of combustion of dry coal	13,270 B.T.U. per lb
(18)	Total ash and clinker in percent dry coal	17.6%

Boiler Test Results

(19)	Heat taken up per punnd of water	1162.47 BTU
(20)	Heat of Combustion of Dry Coal	13,270 BTU
(21)	Total equivalent evaporation from and at 212°F	178,925 lbs
	Equivalent evaporation from and at 212°F per lb. dry coal	7,56 lbs

Equivalent evaporation from and at 212°F per lb. combustible 9.18 lbs.

Equivalent evaporation from and at 212°F per sq. ft. of H. S. per hr 1.74 lbs.

Coal burned per sq. ft. of grate surface " " 14.23 "

Boiler Horse Power developed, A.S.M.E. rating 216.1 H.P.

Maximum assumed possible error of test 2.34%

Thermal efficiency of boiler plant 54.5%

Engine Test Data.

(30)	Duration of Test		5 hours
(31)	Revolutions per minute		16.103
(32)	Barometer	29.887 in.	14.67 lbs.
(33)	Steam used in cylinder, jacket, etc.		30,950 lbs.
(34)	Boiler pressure (absolute)		187.07 lbs.
(35)	High pressure drip		779 lbs.
(36)	Low pressure drip		265 lbs.
(37)	Vacuum	27.98 in.	13.67 lbs.
(38)	Total steam through cylinder		29,672 lbs
(39)	Steam used by calorimeter		234 lbs.
(4)	Pressure 1st receiver (gauge)		27.88 lbs.
(41)	Prsssure 2nd receiver (gauge)		3.87 lbs.
(42)	Discharge head		27.27 ft.
(43)	USuction head		13.06 ft.
(44)	Weight 1 cu. ft. sewage		62.6 lbs

(45) Steam Cards

M.E.P.			
High, H. E.	55.57	High C. E.	60.47
Int. H. E.	15.39	Int. C. E.	15.15
Low. H. E.	7.750	Low C. E.	8.803

Results of Engine Test.

(31)	Revolutions per minute	16.103
(46)	Total I. H. P. of engine	449.35
(47)	Total head	39.33 ft..
(48)	Total steam to engine, jackets, etc.	30950 lbs
(49)	Total drip in five hours	1044 lbs..
(50)	Total steam through cylinder	28672 lbs..
(51)	Steam per I.H.P. per hour as weighed in tank	13.78 lbs
(52)	Steam per I.H.P. per hour through cylinder	13.21 "
(53)	Gallons of water pumped in 5 hours	13,282,500
(54)	Gallons of water through cylinder, by piston displacement ~~department~~	14,190,300
	Slip of pump	6.4 %
(55)	Work done by pump per min.	14,573,130 ft lbs
	B. T. U. per H. P. hour	14,920
	Duty	

Calculations for Boiler Test

Total equivalent evaporation from and at 212°F
$(0.968 r_{193.3} + q_{193.3} - q_{39°.9}) = .968 \times 845.9 + 351.6 - 7.96 = 1162.47$ BTU

$$\frac{(19) \times (9)}{r_{212°}} = \frac{1162.47 \times 148,653}{965.8} = 178,925 \text{ lbs}$$

Equivalent evaporation from and at 212°F per lb. dry coal

$$\frac{(21)}{(12)} = \frac{178,925}{23,650} = 7.56 \text{ lbs}$$

Equivalent evaporation from and at 212°F per lb. combustible

$$\frac{(21)}{(13)} = \frac{178,925}{19,483} = 9.18 \text{ lbs}$$

Equivalent evaporation from and at wlw°F per sq.ft. H.S. per hr.

$$\frac{(21)}{(1) \times (14)} = \frac{178,925}{2 \times 24 \times 2144.2} = 1.74$$

Coal burned per sq. ft. grate surface per hour

$$\frac{28,903}{2 \times 24 \times 35} = 14.23 \text{ lbs.} = \frac{(10)}{(1) \times (15)}$$

Boiler H.P. developed $\frac{1162.47 \times 148,653}{24 \times 33,320} = 216.1$ H.P. $= \frac{(19) \times (9)}{(1) \times 33,320}$

Maximum assumed possible error;- It is assumed that an error of 1" might be made in the height of the fire and that the errors are accumulative:= 48 x 70 x 1/6 = 560 lbs..

$$\frac{560}{23,903} = 2.34\%$$

Thermal Efficiency: $\frac{1162.47 \times 148,653}{23,903 \times 13,270} = 54.5\%$

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Calculations of Engine Test

Water pumped in 5 hours:

By piston displacement

$1 \times \frac{d^2}{4} = 10 \times \frac{25}{4} = 196.35$ cu. ft per stroke

196.35 x 7.48 = 1468.7 gals per stroke
1468.7 x 2 x 16.103 = 47,301 gals per minute
47,301 x 300 = 14,190,300 gals per 5 hours

By measurement at Moon Island

1st	Basin	3,484,500
2nd	"	3,445,000
3rd	"	3,982,000
4th	"	2,371,000
	Total =	13,282,500

$$\% \text{ slip } \frac{(54) - (53)}{54} = \frac{14,190,300 - 13,282,500}{14,190,300} = \frac{907,800}{14,190,300} ; 6.4\%$$

Work done by pump:--

$$\frac{(53) \times (44) \times (47)}{(3) \text{ in minute} \times 7.48 \times 33,000} = \frac{13,382,500 \times 62.6 \times 39.33}{5 \times 60 \times 7.48 \times 33,000} = 447.61 \text{ HP}$$

Steam per I H P per hour as weighed in tank

$$\frac{(48)}{(30) \times (46)} = \frac{30950}{5 \times 449.35} = 13.78$$

Steam per I H P per hour through cylinder

$$\frac{(38)}{(30) \times (46)} = \frac{29672}{5 \times 449.35} = 13.21$$

B T U per H. P. per hour

$$= \frac{5,934.4(x p_{187.07} + q_{187.07} - q_{1.0}) + 155.8(x p_{187.07}) + 53(x p_{187.07} + q - q)}{449.35}$$

$$= 1492.0$$

Duty (Ft. lbs per 1,000,000 B T U)

$$= \frac{(55) \times 1,000,000}{\text{Heat given up by steam per min.}}$$

$$= \frac{(55) \times 1,000,000}{\frac{(48)}{60 \times (30)} (x p_{187.07} + q_{187.07} - q_{1.0})}$$

$$= \frac{14,573,130 \times 1,000,000}{103.2(.968 \times 847.9 + 348.7 - 70)}$$

$$= 128,430,000$$

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Indicated Horse Power of Cylinders

$$\text{I. H. P.} = \frac{P \, L \, A \, N}{33000}$| Cylinder	Mean E.Flue Pres=P	Length of Stroke=L	Area of Piston=A	Number of Strokes=N	I. H.P.
Low Crank	8.803	10'	2161.6	16.103	92.85
Low Head	7,750	10'	2185.4	16.103	82.65
Int. Crank	15.16	10'	839.4	16.103	62.097
Int. Head	15.39	10'	855.3	16.103	64.233
Hign Crank	60.47	10'	252.9	16.103	74.626
High Head	55.57	10'	268.8	16.103	72.890

Total L. H. P. 449.352

Head End.

Crank End.

High Pressure Cylinder.

Head End.

Crank End.

Intermediate Cylinder.

LH
80

Head End.

LC
14

Crank End

Low Pressure Cylinder.

Boiler Test Data

Time	Water	Flue	Room	Boiler Pressure No. 1	Boiler Pressure No 2
2.35	5.0°C	477°F	29.0°C	180	180
2.45	5.0	496	25.0	180	180
3.00	7.0	474	25.0	176	180
.15	5.0	442	24.0	178	180
.30	6.0	435	25.0	177	180
.45	5.0	455	25.0	175	178
4.00	5.0	442	25.0	173	175
.15	4.0	445	26.0	180	180
.30	5.0	440	26.0	175	177
.45	5.0	440	25.0	180	180
5.00	5.0	470	24.0	180	182
.15	4.0	440	26.0	180	180
.30	4.0	474	25.0	180	182
.45	4.0	470	25.0	177	179
6.00	4.0	465	27.0	177	180
.15	4.0	481	26.0	179	180
.15	4.0	481	26.0	179	180
.30	4.0	486	26.0	175	178
.45	4.0	480	26.0	180	182
7.00	4.0	459	26.0	180	180
.15	4.0	480	27.0	180	180
.30	4.0	472	26.0	175	177
.45	4.0	400	27.0	170	169
8.00	4.0	425	27.0	175	177
.15	4.0	462	27.0	175	177
.30	4.0	489	27.0	176	175
.45	4.0	472	30.0	170	176
9.00	4.0	490	30.0	175	176
.15	4.0	473	33.0	175	175
.30	4.0	480	31.0	180	183
.45	4.0	495	31.2	175	178
10.00	4.0	490	32.1	175	178
.15	4.0	480	30.0	176	179
.30	4.0	472	30.0	176	180
.45	4.0	484	31.8	175	179
11.00	4.0	475	33.0	176	179
.15	4.0	448	33.2	177	180
.30	3.8	485	33.5	176	180
.45	4.0	475	32.6	177	180
12.00	4.0	425	32.6	180	181

Boiler Test Data, Contd..

Time	Water	Flue	Room	Boiler Pressure No.. 1	Boiler Pressure No.. 2
12.15	4.0°C	430°F	32.7°C	176	180
.30	4.0	403	32.5	178	180
.45	4.0	445	33.0	177	180
1.00	4.0	420	31.6	178	180
.15	4.0	440	30.0	177	180
.30	4.0	415	29.2	177	179
.45	4.0	455	30.2	176	179
2.00	4.5	455	31.4	180	182
.15	4.0	440	28.0	178	180
.30	4.0	425	25.5	190	182
.45	4.0	452	30.0	178	180
3.00	4.0	440	30.5	180	182
.15	4.0	405	29.0	178	180
.30	4.0	395	30.0	178	180
.45	4.0	430	28.5	177	180
4.00	4.0	480	27.5	177	180
.15	4.0	458	28.0	180	179
.30	4.0	455	28.0	180	179
.45	4.0	460	30.0	176	178
5.00	4.0	460	30.0	176	178
.15	4.5	466	30.5	178	180
.30	4.5	452	30.5	180	182
.45	4.5	460	31.0	175	176
6.00	4.5	460	31.0	179	180
.15	4.5	465	31.0	176	175
.30	5.0	465	31.0	177	176
.45	5.0	465	31.0	178	178
7.00	5.0	468	29.5	180	178
.15	4.5	465	28.5	180	180
.30	5.0	460	30.0	180	180
.45	4.5	460	29.8	180	180
8.00	4.5	465	30.0	180	180
.15	4.5	475	30.0	177	179
.30	4.5	470	29.5	178	180
.45	4.75	465	30.5	178	179
9.00	4.5	460	30.0	178	179
.15	4.2	465	28.0	177	180
.30	4.0	465	31.0	177	180
.45	4.0	460	29.0	177	180

Boiler Test Data

Time	Water	Flue	Room	Boiler Pressure No. 1	Boiler Pressure No. 2
10.15	4.0	465	30.0	178	180
.15	4.0	475	26.5	180	182
.30	4.0	470	29.0	180	182
.45	4.2	470	28.0	180	180
11.00	4.3	460	25.0	178	180
.15	4.3	450	28.0	180	181
.30	4.3	455	29.0	180	181
.45	4.3	450	29.5	179	181
12.00	4.2	465	29.0	177	178
.15	4.2	465	28.0	176	178
.30	4.3	478	28.0	180	181
.45	4.2	490	29.0	175	180
1.00	4.2	465	28.5	175	178
.15	4.3	498	28.0	178	175
.30	4.3	500	26.5	175	180
.45	4.3	475	27.0	180	180
2.00	4.3	475	28.0	180	180
.15	4.3	502	28.0	180	180
.35	4.2	475	28.5	180	180
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Sum	415.95	44731	2789.1	17229	17387
Ave	4.39	461.1	28.75	177.77	179.3
Corr	34.39°F	461.1	28.75	177.7	179.3
	39.9°F	461.1	83.8°F		

Ave 178.5

Weight Empty	Weight Full	Weight Water
340	1593	1253
377	1530	1153
369	1569	1200
388	1557	1169
321	1579	1258
346	1572	1226
303	1616	1313
295	1605	1310
385	1579	1184
337	1590	1253
338	1607	1269
300	1615	1315
335	1595	1260
304	1575	1271
312	1610	1298
313	1594	1281
338	1610	1272
310	1590	1280
285	1582	1297
305	1597	1292
310	1592	1282
320	1580	1260
308	1585	1277
308	1598	1280
306	1584	1278
317	1588	1271
321	1617	1296
302	1584	1282
340	1585	1245
334	1566	1232
313	1555	1242
331	1550	1219
296	1568	1272
347	1570	1223
360	1570	1210
332	1585	1253
344	1574	1230
340	1595	1255
320	1600	1280
320	1610	1290

Weight Empty	Weight Full	Weight Water
315	1600	1285
302	1652	1350
311	1608	1287
310	1600	1290
312	1598	1286
303	1545	1242
303	1582	1280
295	1600	1305
292	1608	1316
290	1596	1306
287	1646	1359
286	1675	1389
276	1652	1376
296	1507	1211
373	1495	1117
357	1523	1166
288	1524	1236
291	1528	1237
300	1542	1242
292	1561	1269
295	1516	1221
287	1546	1259
265	1618	1353
373	1618	1345
296	1533	1237
282	1562	1280
292	1523	1231
309	1515	1206
295	1580	1285
330	1585	1255
330	1570	1240
285	1615	1330
300	1605	1305
385	1590	1205
345	1570	1225
285	1595	1310
310	1575	1265
337	1580	1233
350	1517	1161
300	1580	1280

Feed Water

Weight Empty	Weight Full	Weight Water
350	1570	1220
285	1630	1345
290	1670	1380
264	1670	1406
261	1675	1414
269	1670	1401
270	1675	1405
263	1672	1409
259	1673	1414
363	1674	1311
301	1506	1205
282	1665	1383
298	1626	1328
290	1515	1225
296	1576	1280
292	1513	1221
272	1394	1222
289	1575	1286
277	1570	1293
286	1583	1297
300	1675	1375
250	1675	1425
265	1670	1405
302	1675	1373
273	1675	1402
291	1525	1237
276	1543	1267
293	1540	1246
305	1610	1305
255	1675	1420
257	1650	1393
280	1675	1395
280	1675	1395
280	1645	1365
872	1670	798
	Total	148,653

Coal Fired

Weight of Car & Coal	Weight of Car	Weight of Coal
1976	586	1290
1976	586	1300
1972	672	1300
1858	684	1174
1972	672	1300
1962	662	1300
1970	660	1310
1960	660	1300
1962	662	1300
1962	662	1300
2000	670	1330
2048	662	1386
2144	664	1480
1944	662	1282
1970	668	1302
1976	676	1300
1970	1776	194
2125	670	1455
	Total Coal Fired	23.903

Ashes

Weight of Car & Ash	Weight of Car	Weight of Ash
1290	526	664
1220	530	696
1056	538	518
1248	534	714
1130	532	598
1069	530	539
974	536	438
	Total Ash	4167

Analysis of Flue Gas

Time	% CO_2	% O	% CO
2.45 A.M.	6.0	1.10	.3
3.45	7.7	11.7	.2
4.45	9.2	11.0	.1
5.45	6.8	12.2	.0
6.45	6.8	13.5	.0
7.45	6.8	12.4	.0
8.45	6.8	17.2	.1
9.45	8.0	11.6	.0
10.45	7.8	13.2	.1
11.45	5.3	14.7	.0
12.45 P.M.	6.9	14.3	.0
1.45	7.2	13.2	.0
2.45	5.6	14.0	.1
3.45	7.0	13.1	.0
4.45	3.4	17.2	.0
5.45	6.9	13.8	.0
6.45	7.0	14.3	.0
7.45	7.4	13.0	.0
8.45	9.0	14.0	.0
9.45	7.3	13.4	.0
10.45	7.2	13.5	.0
11.45	7.4	13.5	.0
12.45 A.M.	7.7	13.8	.0
1.45	7.0	13.0	.0
	167.4	322.6	.9
	6.97	13.44	.04

Calorimeter Readings

Time	Steam Gage	Cal. Temp	Cal. Press	Time	Steam Gage	Cal Temp.	Cal. Press
2.45A	176	134.2	24.2	8.45A	171	138.1	24.2
		134.6	24.0			137.0	24.5
		134.0	24.0			137.0	24.0
		134.4	24.5			137.2	24.3
Sum	176	537.2	96.7	Sum	171	549.3	97.0
Ave	176	134.3	24.18	Ave	171	137.33	24.25
3.45A	179	133.0	27.5	9.45A	180	132.0	25.0
		135.5	27.5			132.0	25.0
		135.0	27.0			132.5	25.0
		135.7	27.5			133.0	25.0
Sum	179	539.2	109.5	Sum	180	529.5	100.0
Ave	179	134.8	27.38	Ave	180	132.37	25.0
4.45A	180	138.5	25.5	10.45A	180	133.0	24.5
		139.2	25.5			133.0	24.7
		138.0	25.0			133.0	24.5
		139.0	26.0			133.0	24.3
Sum	180	554.7	102.0	Sum	180	532.0	98.0
Ave	180	138.68	25.5	Ave	180	133.0	24.5
5.45A	180	140.0	26.5	11.45A	177	133.8	24.0
		140.3	26.7			134.0	24.1
		140.5	26.7			134.0	24.3
		140.1	26.5			134.0	24.0
Sum	180	560.8	106.4	Sum	177	535.8	96.4
Ave	180	140.23	26.6	Ave	177	133.95	24.1
6.45A	173	137.3	24.5	12.45A	176	134.0	24.0
		138.0	29.5			134.8	23.8
		138.0	24.0			135.0	24.0
		139.0	24.5			135.0	24.0
Sum	173	552.3	97.5	Sum	176	538.8	95.8
Ave	173	138.1	24.38	Ave	176	134.7	23.95
7.45A	177	140.8	28.0	1.45P	177	132.0	24.5
		141.3	27.5			132.5	24.2
		140.8	27.5			133.0	24.5
		140.3	27.5			133.5	24.5
Sum	177	563.2	110.5	Sum	177	531.0	97.7
Ave	177	140.8	27.63	Ave	177	132.75	24.43

Calorimeter Readings Cont..

Time	Steam Gage	Temp Temp	Cal.. Press	Time	Steam Gage	Cal.. Temp.	Cal.. Press
2.45P	178	130.1	24.2	8.45P	179	132.0	23.5
		130.3	24.3			132.0	23.5
		131.0	24.4			133.0	23.2
		131.0	24.0			132.8	23.2
Sum	178	522.4	96.9	Sum	179	529.8	93.4
Ave	178	130.6	24.23	Ave	179	132.45	23.35
3.45P	181	132.4	23.8	9.45P	181	137.0	25.0
		132.5	23.5			137.8	25.0
		132.3	23.5			139.0	25.3
		132.3	23.7			139.0	25.2
Sum	181	529.5	94.5	Sum	181	552.8	100.5
Ave	181	132.4	23.63	Ave	181	138.2	25.13
4.45P	178	133.5	24.5	10.45P	181	138.0	25.0
		132.3	24.3			138.0	25.2
		133.8	24.5			138.0	24.8
		135.1	25.0			138.5	25.0
Sum	178	535.2	98.3	Sum	181	552.5	100.0
Ave	178	133.8	24.57	Ave	181	138.13	25.0
5.45P	176	134.1	22.8	11.45P	180	138.5	23.0
		134.6	23.0			138.2	23.0
		134.2	23.0			138.2	23.0
		134.5	23.7			138.5	22.8
Sum	176	337.4	29.25	Sum	180	553.4	91.8
Ave	176	134.25	23.13	Ave	180	138.35	22.95
6.45P	178	135.0	23.8				
		135.0	23.5	12.45P	180	139.0	24.8
		135.2	24.0			139.2	24.3
		135.5	24.0			139.0	25.0
Sum	178	540.7	95.3			138.5	25.2
Ave	178	135.18	23.83	Sum	180	555.7	99.3
				Ave	180	138.93	24.83
7.45P	178	136.0	25.7				
		136.2	25.8	1.45A	180	135.0	22.5
		136.0	25.5			135.0	22.3
		137.0	25.5			136.0	22.4
Sum	178	545.2	102.5			136.0	22.5
Ave	178	136.3	25.6	Sum	180	542.0	89.7
				Ave	180	135.5	22.43

Calorimeter Readings (Summary)

Time	Steam Gage	Calorimeter Temp. C.	Calorimeter Pressure
2.45AM	176	134.30	24.18
3.45	179	134.80	27.38
4.45	177	138.68	25.50
5.45	180	140.23	26.60
6.45	180	138.10	24.38
7.45	173	140.80	27.63
8.45	171	137.33	24.25
9.45	180	132.37	25.00
10.45	180	133.00	24.50
11.45	177	133.95	24.10
12.45 PM	176	134.70	23.95
1.45	177	132.75	24.43
2.45	178	130.60	24.23
3.45	181	132.40	23.63
4.45	178	133.80	24.57
5.45	176	134.25	23.13
6.45	178	135.18	23.83
7.45	178	136.30	25.63
8.45	179	132.45	23.35
9.45	181	138.20	25.13
10.45	181	138.13	25.00
11.45	180	138.35	22.95
12.45AM	180	138.93	24.88
1.45	180	135.50	22.43
Sum	427.6	3255.10	590.61
Ave	178.2	135.63°C	24.61
Corr	172.2	136.93°C	21.81
	186.0 Abs	278.47°Far	36.65Abs.

Per cent primary in steam

$$x = \frac{\lambda_{36.65} + 48(t_s - t_1)) - q_{186.0}}{r_{186.0}}$$

$$= \frac{1161.8 + 48(278.47 - 261.90)) - 348.2}{848.3}$$

$$= .968$$

Engine Test Readings

Time	Counter	Rev's	Pressures: Boiler	1st Rec.	2nd Rec.	Vac. in Cond.	Water Levels: Well	Hill
11.AM	321964	242	176	28.0	2.0	29.2	13.1	27.3
11.15	322206	243	180	28.0	2.0	28.9	13.0	27.3
11.30	322449	241	178	27.8	1.8	28.8	13.1	27.25
11.45	322690	242	177	28.0	2.0	28.7	13.2	27.25
12. M	322932	243	181	27.9	1.8	28.8	13.2	27.3
12.15	323175	240	176	27.8	2.0	29.0	13.3	27.3
12.30	323415	240	179	27.9	2.1	29.0	13.4	27.3
12.45	323655	245	178	26.0	2.0	29.0	13.2	27.25
1.	323900	242	180	27.8	2.0	29.0	13.3	27.3
1.15	324142	245	179	27.7	2.1	29.1	13.2	27.3
1.30	324386	241	179	27.8	2.0	29.1	13.4	27.25
1.45	324627	240	175	27.5	2.0	29.0	12.9	27.25
2..	324867	238	180	27.6	1.8	29.0	12.9	27.25
2.15	325105	242	180	29.0	1.5	29.2	12.9	27.3
2.30	325347	243	177	27.8	1.6	29.2	13.0	27.25
2.45	325590	243	176	27.3	1.6	29.3	13.3	27.3
3.	325833	238	179	28.5	1.4	29.3	12.6	27.2
3.15	326071	242	181	27.1	1.0	29.3	13.2	27.2
3.30	326313	242	179	27.9	0.9	29.4	12.9	27.3
3.45	326555	240	177	29.0	0.8	29.2	12.7	27.3
4.	326795		179	29.0	0.6	29.3	12.1	27.3
Sum		4831	3746	585.4	35.0	611.0	274.3	572.75
Ave		241.55	178.4	27.88	1.67	29.09	13.06	27.27
Cor			172.4	27.88	3.87	2789	13.06	27.27

Drip in 5 hours High Press 779'

Low Press. 265'

Length of Cards

	Low Crank	Low Head	Int. Crank	Int. Head	High Crank	High Head
1	4.46	4.34	4.40	4.23	3.99	4.34
2	4.43	4.36	4.40	4.19	4.12	4.32
3	4.44	4.35	4.38	4.15	4.12	4.34
4	4.42	4.34	4.40	4.14	4.09	4.36
5	4.43	4.37	4.36	4.16	4.11	4.44
Sum	22.18	21.76	21.34	20.87	20.43	2180
Ave	4.436	4.352	4.388	4.174	4.086	4.360

Mean Effective Pressures

$$M.E.P. = \frac{\text{Area}}{\text{Length}} \times \text{Spring}$$

Cylinder	Area	Length	Spring	M. E. P.
Low Crank	3.905	4.436	10	8.803
Low Head	3.377	4.352	10	7.750
Int. Crank	3.327	4.388	20	15.16
Int. Head	3.213	4.174	20	15.39
High Crank	3.471	4.086	100	60.47
High Head	3.423	4.360	100	55.57

Areas of Cards

	Low Crank	Low Head	Int. Crank	Int. Head	High Crank	High Head
1	3.78	3.23	3.34	3.29	2.40	2.45
	3.87	3.26	3.30	3.28	2.50	2.19
3	3.82	3.32	3.37	3.35	2.47	2.44
4	3.91	3.24	3.40	3.30	2.40	2.35
5	3.81	3.38	3.36	3.49	---	2.41
6	3.79	3.27	3.31	3.37	---	2.50
7	3.72	3.35	3.36	3.32	---	2.55
8	3.37	3.23	3.34	3.24	---	2.57
9	3.81	3.17	3.35	3.19	2.50	2.45
10	3.80	3.33	3.28	3.25	2.60	2.37
11	3.80	3.31	3.32	3.17	2.52	2.52
12	3.79	3.35	3.35	3.19	2.57	2.55
13	3.92	3.39	3.35	3.21	2.60	2.51
14	3.93	3.41	3.44	3.24	2.43	2.53
15	3.86	3.43	3.41	3.22	2.46	2.35
16	3.99	3.40	3.23	3.14	2.46	2.32
17	4.12	3.52	3.37	3.32	2.49	2.48
18	4.15	3.52	3.10	2.87	2.37	2.38
19	3.95	3.52	3.14	2.95	2.39	2.28
20	4.21	3.67	3.18	2.93	2.49	2.43
21	4.10	3.68	3.47	3.04	2.33	2.25
Sum	82.10	70.92	69.86	67.46	42.03	50.88
Ave	3.905	3.377	3.327	3.213	2.471	2.423

Water Pumped to Basin #1

Time	VLevel in Basin	Contents	Diff.
11.00 AM	12.070 ft.	2173000	504500
.30	12.750	2677500	431700
12.00M	13.330	3109200	435900
12.30PM	13.915	3545100	465500
1.00	14.540	4010600	394900
.30	15.070	4405500	409500
2.30	15,620	4815000	295000
2.30	16.015	5110000	178500
3.00	16,255	5288500	182500
.30	16.500	5471000	186500
4.00	16.750	5657500	
		Total - - -	-3484500

Water Pumped to Basin #2

11.00AM	21.135	2554000	455000
.30	12.663	3009000	397500
12.00M	13.125	3506500	417100
.30PM	13.610	3823600	431100
1.00	14.110	4254700	397300
.30	14.570	4652000	389200
2.00	15.020	5041200	276800
.30	15.340	5318000	211000
3.00	15.585	5529000	229000
.30	15.850	5758000	241000
4.00	16.130	5999000	
		Total--	3445000

Water Pumped to Bason #3.

10.00 AM	11,250 ft.	1756000	425500
.30	11,750	2181500	340500
12.00 M	12.150	2522000	349000
.30PM	12.560	2871000	358000
1.00	12.980	3229000	362200
.30	13.405	3591200	405800
2.00	13.880	3996000	435500
.30	14.390	4431500	486500
3.00	14.960	4918000	452500
.30	14.490	5370500	367500
4.00	15.920	5738000	
		Total - -	3982000

Water Pumped to Basin #4

Time	Level in Basin	Contents	Diff.
11.00 AM	11.655 ft	1988000	127000
.30	11.960	2215000	195600
12.00 M.	12.170	2410600	101400
.30 PM	12.295	2512000	137000
1.00	12.465	2649000	113000
.30	12.605	2762000	181000
2.0	12.830	2943000	267500
.30	13.160	3210500	343500
3.00	13.585	3554000	416000
.30	14.100	3970000	384000
4.00	14.580	4359000	
		Total - - -	2371000

Water pumped to Basin #1	3484500
" " " " #2	3445000
" " " " #3	3982000
" " " " #4	2371000
Total water pumped	13282500

W a t e r p u m p e d t o

Time	Basin #1	Basin #2	Basin #3	Basin #4	Total
11.00AM					
.30	504500	455000	425500	127000	1512000
12.00 M.	431700	397500	340500	195600	1365300
.30 PM	435900	417100	349000	101400	1303400
1.00	465500	431100	358000	137000	1391600
.30	394900	397300	362200	113000	1267400
2.00	409500	389200	405800	181000	1385500
.30	295000	276800	435500	267500	1274800
3.00	178500	211000	486500	343500	1219500
.30	182500	229000	452500	416000	1280000
4.00	186500	241000	367500	384000	1183000
Total	3484500	3445000	3982000	2371000	13282500