1913

Test of the municipal power plant of the city of Rolla, Missouri

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TEST OF THE MUNICIPAL POWER PLANT OF THE CITY OF ROLLA, MISSOURI.

by

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A

THESIS

submitted to the faculty of the

SCHOOL OF MINES AND METALLURGY OF THE UNIVERSITY OF MISSOURI

in partial fulfillment of the work required for the

DEGREE OF

BACHELOR OF SCIENCE IN MINE ENGINEERING.

Rolla, Mo.

1913

Approved by A L McRae
Professor of Physics

T E S T

of the

M U N I C I P A L P O W E R P L A N T

of the

CITY OF ROLLA, MISSOURI.

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Location.

The power plant is located in Eighth Street between Elm and Oak Streets, in the central part of the city and along the tracks of the St.Louis and San Francisco Railroad.

Equipment.

The plant consists of:-

1- 60"x 16 feet O'Brien horizontal return tubular boiler.

1- 62" x 16 feet Atlas horizontal return tubular boiler.

Both boilers develop steam at 100 pounds/square inch.

1- Cochrane open feed water heater for supplying both boilers.

1- 6" x 4" x 6" Worthington boiler feed water pump.

1- 14" x 21" Hamilton semi-Corliss engine direct coupled to a 100 K.W. 250 volt Westinghouse D.C. compound wound generator, 200 R.P.M. Also connected by a Medart friction clutch to a shaft from which the following machines are belted:-

1- 16" x 9" x 12" Laidlaw-Dunn-Gordon cross compound air compressor 100 R.P.M. to deliver 203 cubic feet of free air per minute against a pressure of 143 pounds/square inch.

2- 4" Worthington centrifugal pumps with two speeds; at the normal speed 900 R.P.M. working against a head of 60 pounds/square inch for ordinary service, and at the high speed capable of working against a head of 125 pounds/ square inch for direct fire pressure.

1- 15" x 15", Brownell high speed automatic engine 240 R.P.M. direct coupled to a 150 K.W. 250 volt Western Electric D.C. compound wound generator. Each engine is equipped with a Cochrane steam separator.

1- Deep well air lift designed by Prof. E.G. Harris, of the Missouri School of Mines and Metallurgy.

1- 2 panel blue Vermont marble switchboards with ammeters, voltmeters, rheostats, switches and lightning arresters.

The water plant has a 40000 gallon concrete tank into which the air lift delivers the water and from which the centrifugal pumps take the water to deliver it into the mains.

There is also a concrete stand pipe 20 feet x 30 feet on the top of a hill half a mile from the well. The top of the stand pipe is 130 feet above the well, which gives ample pressure for commercial water service.

Object of the Test.

The object of the test was to determine the efficiency of the boilers and engines under the actual conditions of every day operation.

Apparatus and Instruments.

Standard Fahrenheit thermometers for measuring the temperature of the air, the feed water and the flue gases.

1- Hot water meter for measuring the water fed to the boilers.

1-Emerson bomb calorimeter for measuring the B.T.U. in the coal.

1- Ellison inclined draft gage for determining the draft in the boiler stack.

1- Fairbanks scale for weighing coal.

1- Oil barrel holding 300 pounds coal, used for weighing same.

1- Hays moisture calorimeter throttling and weight, with manometer and thermometers complete, used for determining the quality of the steam.

1- Peabody calorimeter for same purpose as above.

1- General Electric type T S-2 portable steam flow meter.

1- Mercurial barometer.

1- Techometer.

2- Speed counters.

1- Crosby Steam Engine Indicator with reducing motion.

1- Thompson Steam Engine Indicator. The Hamilton engine was equipped with a lever reducing motion.

1- Bucket used to determine the amount of water discharged from the steam separator on the Brownell engine.

All instruments were carefully tested and calibrated before beginning work.

Water meter reading must be multiplied by 1.08.

Methods of Making Tests.

Boiler.

The test was run as follows:-The ash pit was cleaned and the fire put in good working condition, note being taken of the condition of the fire on the grate and the level of the water in the boilers. These conditions were approximately the same at the finish of the test as at the beginning. The water level in the boiler was marked by placing a narrow strip of paper around the gage glass and it was kept as near this level as possible throughout the test.

The coal was weighed as used in a barrel holding 300 pounds.

The firing was done in the usual manner by the regular fireman.

The quantity and temperature of the feed water was determined by a water meter and thermometer respectively, readings being taken and recorded every 15 minutes.

The draft in the stack was determined in terms of inches of water by means of the Ellison draft gage, readings taken regularly.

The temperature of the flue gases was obtained by means of a thermometer, readings taken regularly.

The steam pressure and the temperature of the feed water was kept as nearly constant as possible throughout the run, as the feed water was heated by means of exhaust steam, the amount of feed water used increased or lowered the temperature; the faster the water was fed to the boilers the lower the temperature would be; the slower, the higher would be its temperature. Accordingly there was some variation in the temperature of the feed water.

<u>Engine and Dynamo</u>.

Indicator cards were taken every fifteen minutes.

An ammeter and voltmeter were used for getting the output of the dynamo. Readings were taken every fifteen minutes and recorded.

The I.H.P. was determined by working out the indicator cards with a planimeter, getting the M.E.P. from this.

The water taken from the steam separator was measured in a bucket, the time and quantity being recorded.

The steam flow meter in the main pipe between the boiler and engine and the moisture calorimeters, one at the boiler and one at the engine, were read every fifteen minutes.

So far as practical auxiliary machines were started up and stopped at the beginning or end of the fifteen minute intervals, so that the load would be uniform during the interval between two readings.

Duration of Tests.

December 31,1912, 3 P.M. to 6 P.M., evaporative tests on boilers.

January 1,1913, 11 A.M. to 1 P.M., friction load of engine measured.

January 6,1913, 7:10 P.M. to 11:40 P.M.

It was intended to make a complete run from 1 P.M. to midnight, with the Brownell engine carrying the load, but the water meter got stopped up and connection to the crank pin of the Brownell engine gave trouble, so the regular readings did not begin until 7 P.M.

January 10,1913, 1:30 P.M. to 8:45 P.M.

A complete run with the Hamilton engine carrying the load was made.

The results of the boiler tests on December 31, 1912.

The O'Brien boiler evaporated 4.63 pounds of water / pound of coal as fired and the ash was 12.5% of the weight of the coal fired.

The Atlas boiler evaporated 4.91 pounds of water / pound of coal as fired and the ash was 12.6% of the weight of the coal.

The temperature of the flue gases varied between 540 and 550 degrees Fahrenheit.

The draft varied from 0.39 to .48 inches of water, with an average of 0.43 inches.

The	amount	of	CO_2 gas	varied	from	2.6 to	6.0%
"	"	"	CO "	"	"	6.8 "	8.2%
"	"	"	O "	"	"	6.0 "	8.0%

The calorimeter showed the coal

12300 B.T.U.

14.2% ash.

The test on January 6,1913, showed that:-

The O'Brien boiler evaporated 4.22 pounds of water per pound of coal as fired and the Atlas boiler evaporated 4.93 pounds of watwr per pound of coal fired. The man washing up allowed some water into the ash under the O'Brien boiler, so that its weight could not be determined. As actually weighed it was 15.4% for the Atlas and 19.6% for the O'Brien boiler.

The calorimeter showed 13.6% ash.

The temperature of the flue gases varied from 440 to 570 degrees Fahrenheit.

The CO_2 from 2.6 to 6.9%; the C O from 3.2 to 19.4% and the O from 2.6 to 6.6%.

The average draft was only 0.2 inches of water.

Test on January 10,1913:

These tests are given in detail and show the method and kind of observations taken. It was not deemed essential to put the detailed readings of previous tests in the report

Boiler Tests. January 10,1913.

Time	#Coal		Water		Steam flow		Steam gage		Stack
	N	S	Meter	Temp.		lb/hr	lbs	Draft	Temp.
1:30	300	300	----	200°	105	2061	83	-----	-----
1:45	300	300	----	180°	120	2355	92	-----	-----
2:00	---	----	181	---	110	2159	86	-----	-----
2:15	---	---	----	160°	118	2316	96	-----	-----
2:30	---	300	----	158°	104	2041	78	.46	530°F
2:33	---	---	----	---	100	1963	84	Therm. broke	
2:37	---	---	----	---	125	2453	89	-----	-----
2:43	---	---	----	---	100	1963	93	-----	-----
2:45	300	---	----	---	108	2120	93	-----	-----
3:00	300	---	736	160°	170	3337	87	-----	-----
3:15	300	---	----	---	152	2983	93	-----	-----
3:17	---	---	----	---	104	2041	93	-----	-----
3:19	---	---	----	----	100	1963	91	-----	-----
3:20	---	---	----	---	135	2650	91	-----	-----
3:30	---	300	----	160°	160	3141	78	.47	-----
3:36	---	---	----	---	158	3101	86.5	-----	-----
3:38	---	---	----	---	120	2356	85.5	----	-----

Time	#Coal		Water		Steam flow		Steam gage	Stack	
	N	S	Meter	Temp.		lb/hr	lbs.	Draft	Temp.
3:45	---	---	----	---	100	1963	93	----	------
4:00	----	---	1299	160°	100	1963	91	.37	-----
4:15	300	300	----	---	100	1963	83	----	-----
4:30	---	---	----	161°	118	2316	83	----	------
4:45	---	---	----	---	120	2355	94	.48	-----
5:00	---	---	-----	176°	126	2512	82	----	-----
5:00	---	---	1684	---	100	1963	83	----	-----
5:15	---	---	----	---	100	1963	93	.38	-----
5:17	---	---	----	---	100	1963	90	----	-----
5:30	300	300	----	142°	105	2061	72	----	-----
5:45	300	---	----	---	120	2355	89	----	-----
6:00	---	300	2196	156°	115	2257	98	.40	-----
6:01	---	---	----	---	120	2355	81	----	-----
6:15	---	---	----	---	125	2453	91	----	-----
6:30	300	300	----	158°	110	2159	72	----	-----
6:45	---	---	----	---	120	2355	86	----	-----
7:00	---	---	2621	194°	110	2159	95	----	-----
7:15	300	300	----	---	108	2120	84	----	-----
7:30	---	---	----	168°	108	2120	84	.37	-----

Time	#Coal		Water		Steam flow		Steam gage		Stack
	N	S	Meter	Temp.		lb/hr.	lbs.	Draft	Temp.
7:45	---	---	----	---	117	2297	92	----	------
8:00	---	---	3100	199	113	2218	91	.44	------
8:15	---	---	----	---	120	2355	86	----	------
8:30	---	29	3322	168	110	2159	90	----	------
8:45	225	---	----	---	112	2198	86	.43	------
8:46	---	---	----	---	150	2952	91	----	------
8:47	---	---	----	---	206	4037	91	----	------
9:00	---	---	----	---	150	2952	91	----	------
9:04	---	---	----	---	155	3040	81	----	------
9:10	---	---	----	---	188	3808	87	----	------
9:11	---	----	----	---	175	3335	92	----	------
9:15	---	---	----	---	175	3335	92	----	------
9:18	---	---	----	---	145	2854	87	----	------
	2775	2729	3322	169		2283	877	.42	530° F

Note: Column 2 and 3 N = North boiler; (Atlas)
S = South boiler. (O'Brien)

Engine Test. January 10,1913.

Time	No. Card	R.P.M.	M.E.P.		H.P.	Calorimeter	
			Head	Crank		Gage	Lower Temp.
1:30	1	200	47.0	32.5	129	---	----
1:45	2	216	45.0	32.5	136.5	---	----
2:00	3	207	47.0	31.1	132	86	214 F
2:15	4	211	47.0	32.2	136	87	219
2:30	5	----	36.0	30.5	114	77	221
2:33	5A	---	36.2	24.3	---	---	----
2:37	--	---	----	----	---	---	----
2:43	--	---	----	----	----	---	----
2:45	6	---	39.4	24.0	----	84	246
3:00	7	---	37.2	24.3	---	85	246
3:15	8	---	39.0	23.0	---	90	250
3:17	--	---	----	----	---	---	----
3:19	--	---	----	----	---	---	----
3:20	--	---	----	----	---	---	----
3:30	9	---	38.5	24.5	108	75	248
3:38	--	---	-----	----	---	---	----
3:38	--	---	-----	----	---	---	----
3:45	10	---	44.0	22.7	---	90	250
4:00	11	----	38.7	24.5	---	87	250

Time	No. Card	R.P.M.	M.E.P. Head	M.E.P. Crank	H.P.	Calorimeter. Gage	Calorimeter. Lower Temp.
4:15	12	---	42.5	21.7	---	85	248
4:30	13	---	42.0	26.7	---	82	248
4.45	14	210	46.5	32.0	---	90	250
5.00	15	208	49.5	36.0	145.1	78	248
5.00	15A	---	29.0	14.5	73.8	--	---
5.15	16	209	34.0	19.5	91.	90	241
5:17	16A	---	36.0	21.0	97.	--	---
5:30	17	211	39.0	26.0	111.5	70	234
5:45	18	213	37.0	24.5	107.	85	230
6:00	19	209	43.0	26.5	119.	75	230
6.01	19A	209	46.0	30.0	130.	--	---
6:15	20	209	42.0	31.0	125.	80	234
6:30	21	209	42.0	30.0	123	80	230
6:45	22	209	42.5	29.5	123	80	234
7:00	23	209	42.0	24.5	110	95	234
7:15	24	210	47.5	35.5	142	75	237
7:30	25	210	47.5	31.0	124	90	236
7:45	26	213	47.0	30.0	134	90	233
8:00	27	212	40.5	20.5	107	90	238
8:15	28	214	43.5	25.0	120	80	232

Time	No. Card	R.P.M.	M.E.P.		H.P.	Calorimeter	
			Head	Crank		Gage	Lower Temp.
8:15	29	214	41.5	21.5	110	90	238
8:45	30	214	37.0	19.0	102	85	231
8:46	--	---	----	----	---	--	----
8:47	1	---	10.0	7.5	---	--	----
9:00	2	---	9.0	6.5	---	--	----
9:04	3	---	9.0	7.0	---	--	---
9:10	16	---	6.5	4.5	---	--	----
9:11	26	---	8.0	6.0	----	--	----
9:15	4	---	8.0	5.5	----	--	-----
9:18	5	---	8.5	6.5	----	--	-----
		209.6					

Dynamo. January 10,1913.

Time	Volts	Amp.	K.W.	Eff.	Remarks.
1:30	219	20	4.4	47 %	
1:45	217	20	4.4	50	
2:00	---	---	4.3	48.5	
2:15	218	18	3.9	50	
2:30	216	22	4.8	40.5	
2:33	---	---	---	----	Started Brownell at 2:33,stopped at 2:37 and started again at 2:43
2:37	---	---	---	----	
2:43	----	---	---	----	
2:45	217	11	3.3	----	
3:00	220	23	5.1	----	
3.15	220	23	4.2	----	
3:17	----	---	---	----	Stopped Brownell at 3.17. Reading just after stopping. Started at 3:20.
3:18	----	---	---	----	
3:20	----	---	---	----	
3:30	218	30	6.5	----	
3:38	----	---	---	----	
3:38	----	---	---	----	Flow meter reading just before and after Brownell stopped at 3:38.
3:45	220	40	8.8	----	

Time	Volts	Amp.	K.W.	Eff.	Remarks.
4.00	219	40	8.8	----	
4:15	220	45	9.5	----	
4:30	219	38	8.3	----	
4:45	220	100	22.0	----	
5:00	215	125	26.9	----	Pumps and compressor shut off and flowmeter reading taken before and after.
5:00	---	---	----	----	
5:15	224	185	41.4	60%	
5:17	---	---	----	56.5	
5:30	216	230	49.7	59.5	First lights go on.
5:45	---	----	53.8	67	
6:00	222	232	51.5	58	
6.01	222	260	57.7	61	Street lights on.
6:15	224	252	56.4	61	
6:30	220	245	53.9	50	
6:45	224	255	57.1	62	
7:00	220	253	55.7	68	
7:15	---	---	56.2	58	
7:30	224	275	61.6	73	
7:45	224	265	59.4	59	
8:00	220	252	55.4	69	
8;15	219	245	53.7	60	Ash in O'Brien boiler 300#
8:30	222	225	50.0	61	" " Atlas " 415#

Time	Volts	Amp.	K.W.	Eff.	Remarks
8:45	222	215	47.7	63	
8:46	---	---	----	--	
8:47	---	---	----	--	
9:00	---	---	----	--	
9:04	---	---	----	--	Corliss stopped. Started with field out at 9 P.M.
9:10	---	---	----	--	
9:11	---	---	----	--	
9:15	---	---	----	--	
9:18	---	---	----	--	Corliss off.
			31.8	60%	

<u>Flue Gases</u>. January 10,1913.

(O'Brien) <u>Small Boiler</u>.

Time	CO_2	O_2	CO
4:00	3.4	14.6	5.
4.45	5.0	14.0	0.8
5:15	2.0	15.8	0.4
6.00	6.2	11.8	0.4
7:30	4.4	13.0	0.4
8;00	7.5	9.6	0.5
8:45	4.2	12.8	0.8

Large Boiler. January 10,1913.

Time	CO_2	O_2	CO
4:00	7.2	11.2	4.4
4:45	2.0	14.6	o.6
5:15	7.0	11.6	0.4
6:00	3.0	15.8	1.0
7.30	8.6	9.2	0.0
8.00	3.6	14.2	0.4
8:45	3.0	15.3	0.7

Conclusions.

Average Pressures.

Steam pressure (gage)-------------------87.7#

Absolute -----------------------------102.0#

Barometric -------------------------- 14.3#

Draft in inches of water ------------ .42 inches.

Average Temperature.

Of external air --------------------- 37° F.

" escaping gases ------------------- 530° F.

" feed water ----------------------- 169° F.

Average moisture in steam ----------- 3%

Water.

Total weight of water pumped into boiler and apparently evaporated into steam
3322 x 1.08 x 8.08 = 28,986 pounds.

Total weight of water actually evaporated corrected for the quality of steam, 28,986 x .97 = 28,116 pounds

Heater.

The feed water heater raises the temperature of the water from about 60 to an average of 169 degrees Fahrenheit, the latter temperature varying with the flow. It ought to raise the temperature steadily to 210 or 212 degrees Fahrenheit. The heater therefore performs 73% of what it ought to do under average conditions.

Boiler.

The O'Brien boiler evaporated 1604 x 1.08 x 8.08 =13995 pounds of water, and burned 2729 pounds of coal, giving an apparent evaporation of 5.13 pounds water per pound of coal. The steam was 3% wet on an average, which reduces the evaporation to 4.98 poumds water per pound of coal.

To evaporate this from water at 168 to steam at 320 degrees Fahrenheit 3% wet requires 13995

(153.6 + .97 x 889.5) = 14,230,000 B.T.U.

The coal fired had

2729 x 12346 = 33,700,000 B.T.U.

Efficiency of boiler $\frac{14230000}{33700000} = 42.2\%$

The Atlas boiler evaporated

1718 x 1.08 = 14991 pounds of water and burned 2775 pounds of coal giving an apparent evaporation of $\frac{14991}{2775} = 5.40$ pounds of water per pound of coal, or corrected for moisture 5.24 pounds of steam per pound of coal.

To evaporate this from water at 168 to steam at 320 degrees Fahrenheit 3% wet requires

14991 (153.6 + 0.97 x 889.5) = 15,230,000 B.T.U.

The coal fired had

2775 x 12346 = 34,270,000 B.T.U.

Efficiency of boiler $\frac{15230000}{34,270,000} = 44.5\%$

The ash under this boiler was 406 pounds

$\frac{406}{2775} = 14.6\%$ water evaporated per pound of combustible from and at 212 degrees

$\frac{1016.4 \times 5.40}{965.8\ (100-13.6)} = 6.58$ lb water

$\frac{12346}{965.8 \times .864} = 14.8$ Efficiency = $\frac{6.58}{14.8} = 44.4\%$

Coal.

The calorimeter test on the coal used on January 10,1913, showed

12346 B.T.U. / pound

ash 13.58%

B.T.U. in a pound of ash 1400 Ash actually obtained under boiler 14.63%. One pound of ash came from $\frac{100}{14.63}$ = 6.83 pounds coal. Therefore $\frac{1400}{6.83}$ = 205 B.T.U. per pound of coal went into the ashes unburned.

(14.63-13.58) 12346 = 130 B.T.U.

Engine.

To find the indicated horse-power (I.H.P.):

Obtain the area of the cards by means of a planimeter in units of the square inch.

The "mean effective pressure"(M.E.P.) is found by dividing the area of the card in square inches by the length of the card in inches, multiplying this quotient by the scale of the spring (used 50 pounds per inch).

Thus I.H.P. = $\frac{PLAN}{33000}$

P= M.E.P. in pounds/square inch
L= length of the stroke in feet
Dynamo A= area of the piston in square inches
N= number of strokes per minute
One H.P. = 33000 foot-pounds

To find the horse-power output

$$H.P. = \frac{\text{volts x amperes}}{746}$$

Note 746 equals the number of watts in one H.P.

Engine and Dynamo.

To find the efficiency of engine and dynamo combined:

$$\text{Efficiency} = \frac{\text{H.P. output of dynamo}}{\text{I.H.P. of engine}}$$

Conclusions.

The friction load of the Hamilton engine was found to be as follows:-

Jan.1,1913 = 20 H.P.

Jan.10,1913 = 19.2 H.P.

The friction load of the Brownell engine was found to be:-

Jan.10.1913, with Field on 30.3 H.P.

Jan.10,1913, with no Field on 24.8 H.P.

It requires 25.2 H.P. for Hamilton engine to run itself and excite the field of its generator.

It requires 63 H.P. for Hamilton engine to run itself, pumps and compressors without load. Hence the friction of pumps and compressors was 37.8 H.P.

On January 10th the engine was driving the dynamo and loaded compressor with pump running idle and developed 145.1 H.P. The friction clutch was thrown out, leaving the engine driving the dynamo alone and the load fell to 73.3 H.P., showing that it required 72.3 H.P. to run loaded compressor and overcome the shaft and pump friction loads. It would require 96.5 H.P. for engine to run loaded compressor with dynamo and pumps idle.

The ratio of the output of the dynamo to the intake of the engine varied from 8.01% at 3:30 in the afternoon, when the compressor and pumps were running, to 73% at 7:30 in the evening, when only the dynamo was being run.

Steam Flow Meter.

At 2:33 P.M. the steam flow meter was reading 100, the Brownell engine was started up and the flow meter read 125. At 2:37, when the Brownell was stopped the flow meter fell back to 100.

At 3.19 P.M. the meter read 100 and on starting the Brownell engine it went to 135.

At 3:38 P.M., with the Brownell running the flow meter read 158. When the Brownell was stopped, it fell to 120.

At 5:00 P.M. the pumps and compressors running the flow meter read 128 and on stopping the pumps and compressors, the reading dropped to 100.

At 5:30 P.M. the reading was 105 and after turning on the house lights, the reading jumped to 120.

At 6:00 P.M. the reading was 115 and after turning on the street lights, the reading was 120.

The average steam flow meter reading was 118.4 x 19.63 x 1 = 2324 pounds per hour. 2324 x $7\frac{1}{4}$ = 16849 pounds steam in $7\frac{1}{4}$ hours as against 2817 pounds of dry saturated steam, as shown by the water meter. The error may possibly be due to the fact that the constant used in the steam flow meter ought to have been 1.5 instead of 1, as supposed. Also a small error arises when taking the average of the readings.

Average for steam flow meter for Jan.6th,1913, when the Brownell engine was carrying the load, was 158.3 x 19.63 = 3107 pounds per hour.

Air Compressor. (These measurements by Thornhill, Mix, Kellogg and Wood, 1908.)

To find the volumetric efficiency:

First find the volume of air displaced per minute by the piston, then volume displaced per second and finally the weight of air displaced per second.

$$\text{Volume displaced per minute} = \frac{\pi d^2}{4} \times L \times N$$

$$= \frac{22 \times 4^2 \times 1 \times 29}{7 \times 3^2 \times 4}$$

$$= 276 \text{ cubic feet}$$

$$\text{Volume displaced per second} = \frac{276}{60} = 4.6 \text{ cubic feet.}$$

Weight of a cubic foot of air at 60°F and under 143 pounds pressure per square inch equals .0745 pounds.

$$\text{Weight of air displaced per second} = 4.6 \times .0745.$$

$$= 3427 \text{ pounds}$$

Compressor intake 58.6 H.P. output, 31.0 H.P.

Now find the weight of air output per second by the formula.

$$\text{Weight per second} = C \times .6299 \times d^2 \times \sqrt{\frac{1}{T}}$$

Take c = .596 obtained by experiment.

Diameter of orifice (d) = 3 inches.

Inches of water (i) = 37

Temperature of air in tank (t) = 207° F = 667° absolute.

Substituting in above formula the values, we have;

Weight in pounds per second = .596 x .6299 x 3^2 x $\frac{37}{667}$.

= .2511 pounds.

$$\text{Volumetric efficiency} = \frac{\text{air output}}{\text{piston displacement}} = \frac{.2511}{.3427} = 73.2\%$$

To find the mechanical efficiency;

The work output = PV log.R

$$R = \frac{153 + 14.3}{143} = 11.7$$

Log R = .2456
P = 14.3
V = 276 x 732% = 202.3 cubic feet.

$$\text{H.P. output} = \frac{\text{PV log R}}{33000} = \frac{14.3 \times 144 \times 202.3 \times 2.456}{33000}$$

= 31.0 H.P.

The work absorbed by the compressor equals the horse-power developed by the engine with air compressor running under its working conditions, minus the horse-power developed by the engine when the compressor was not running, assuming, however, that the electric load is the same in both cases.

H.P. with compressor = 94.40

H.P. with compressor =	94.40
H.P. without compressor =	35.80
Power absorbed by compressor =	58.60

$$\text{Efficiency} = \frac{\text{output}}{\text{input}} = \frac{31.0}{58.6} = \quad 52.9\ \%$$

Air Lift for Deep Well.

The well is 930 feet deep and started at the top with an 8" drill. The water pipe is divided into three sections of approximately equal lengths. The upper section is 6 inches, the middle section is 5 inches and the lower section $4\frac{1}{2}$ inch iron pipe. The bottom of the pipe goes within ten feet of the bottom of the well and the lower end is flared to 6 inches. The air pipe is $1\frac{1}{2}$ inch galvanized iron pipe and goes down inside of the water pipe to within 6 feet of the bottom of the water pipe. The last 6 feet of the air pipe is perforated to facilitate the escape of the compressed air. When the well is not flowing the water stands 181 feet below the surface. When the air lift is in operation it stands at a constant depth of 195 feet below the ground surface. The rate of flow is 290 gallons per minute.

The efficiency of the air lift when using 202.3 cubic feet of air and raising 290 gallons of water per minute is found as follows:

$$\frac{290 \times 181 \times 8.33}{33000} = 13.25 \text{ H.P. required to lift}$$

the water.

H.P. supplied by the compressor to do the work

equals $\frac{PV \log R}{33000}$

$$\frac{PV \log R}{33000} = \frac{143 \times 144 \times 202.3 \times 2.456}{33000} = 31.0 \text{ H.P.}$$

$$\text{Efficiency} = \frac{13.25}{31.0} - 42.7\ \%$$

Boiler Feed Water Pump.

In the test on January 6,1913, the exhaust from the feed pump was condensed in abarrelof water. The condensation amounted to 67 pounds, while 166 gallons or 1340 pounds of water was being delivered to the boiler at 180° Fahrenheit. This shows that one pound of steam used in the pump was required to put 20 pounds of water into the boiler.

Between 7:14 P.M. and 11:40 P.M., January 6,1913, the boilers used 2038 gallons, or 16465 pounds of water. The pump used 823 pounds of steam, or at the rate of 188 pounds per hour.

The feed water pipe is 1½" in diameter, or 1.76 square inches in section. 20 pounds of water at 180° Fahrenheit equals 576 cubic inches. This would be a column 326 inches, or 27.2 feet long. To force this against a pressure of 100 pounds per square inch would require 100 x 1.76 x 27.2 - 4800 feet lb. The heat given to change water at 180 to steam 3% wet at 320° Fahrenheit, is

141.5 + .97 x 889.5 = 1004.3 B.T.U. = 781,000 feet lb.

Efficiency of pump $\frac{4800}{781,000} = 0.6$ %

Cost of Operation for One Month.

Coal	$484.60
Superintendant's salary	110.00
The fireman @ 50............	150.00
Unloading coal	18.60
Oil and waste	18.55
Water	No charge
Interest and depreciation 10% on $50000	416.67
	$1198.42

Annual Income.

Commercial lights 90000 K.W. $9000.00

Street lights assumed to run 10 hours per day, 3600 hours per year, 28 amperes, at 220 volts gives 22176 K.W. hours. Which at the commercial rate would be $2217.60, or the electric light plant will pay for the entire cost of operation of the water and light plant.

Summary.

Efficiency of the O'Brien boiler,........... 42.2%

Efficiency of the Atlas boiler, ... 44.5%

Efficiency of the boiler feed pump,........ 0.6%

Atlas boiler produced... 5.24 lbs dry saturated steam per lb of coal,

O'Brien boiler produced..4.98 lbs dry saturated steam per lb of coal

The steam was about 3% wet.

The Hamilton engine used ..19.9 lb of steam per H.P.-hr.

The Brownell engine used ..22 8 lb of steam per H.P.-hr.

The friction of Brownell engine was 24.8 H.P. without field and 30.3 H.P. with field of generator excited.

The friction of the Hamilton engine was 20.0 H.P. without field and 25.2 H.P. with the field of its generator excited.

In the tests made in 1908 the boilers evaporated 5.34 pounds of dry evaporated steam per pound of coal.