

THESIS

REPORT OF A BOILER AND ENGINE TRIAL

by

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under

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The test was made at the Tennessee Producer's Marble Mills, April 24 & 25, 1903. The power plant of this company consisted of three horizontal fire tubes boilers and a 250 H. P. engine built by Charles Brown. There is ~~is~~ also run in connection with these a double cylinder steam pump which is used for pumping water for the boiler and other purposes.

Commencing with the boilers I will say that they were in fairly good condition. They were cleaned out the Sunday before the test was made and were free from all incrustation. The feed water was good being clear and containing very little solid matter. The shell of the boilers was completely covered over the top by a double layer of brick and cement, which serves as a good non-conductor of heat. All the steam pipes were bare, there being forty feet about equally divided between 4 and 7 inch pipe. There were no satisfactory calorimeter tests made because of the difficulty in getting a fair sample of the steam. The details of the boilers as to dimensions and proportions will be found in the log of the test.

The engine was old having been in use for many years but its work now shows that it has been well cared for and is still good for several years.

The chief objection to the this engine is small steam and exhaust port area, the maximum pressure in the cylinder being only 81 % of the boiler pressure. It would also be a great advantage if the back pressure could be re-

duced to atmospheric pressure. The admission and cut-off in this engine are very good and are not far surpassed by the Cobliss.

The engine ran continuously throughout the entire test and the load was kept very nearly constant. The average H. P. developed was about 70 % of the rated H. P. The results given below are not the best that can be had from the engine for the load was not heavy enough for the valves to cut off at the most economical point. The water consumption of the engine was gotten by weighing the feed water of the boiler and deducting the weight of steam used by the steam pump. All the small water as drip from the injector in the steam pipe were charged to the engine, no deduction being made from the water rate of the engine for these small items. The steam pump was used to pump water from a creek into two large tanks fifty feet above the surface. The capacity of the pump if in good order would be about four thousand gallons per hour, but the pump was old, looking almost like a complete wreck in every particular. The valves in the water cylinder were out of adjustment and besides this they had a great deal of lost motion. The results given below show this pump to be a very deficient machine but all must not be charged to the pump alone. The pump is placed 250 feet from the boilers and is fed by a 1 1/2 inch steam pipe which runs all the way a few inches from and parallel to a cold water-feed pipe. There was no chance to make a calorimeter test at the pump but the per cent of moisture in the pump must have been very high.

An attempt was first made to measure the water pumped by finding the velocity of the delivery pipe by means of Pilot's Tube but the test proved very unsatisfactory on account of the sudden variation of the height of the water in the tube, the flow in the pipe being very irregular, we tried other means. We next made a well 6" long cut from brass and beveled the edges as directed by Frances and other authorities and all our results proved very satisfactory.

Taking in consideration the whole plant, there are somethings as good as could be expected while there are others not so good. The steam is much more economically generated than it is used.

The ideal conditions as to water supply have not been considered deeply by the engineer consequently he does not realize the advantage of his situation. Neither has he once thought that he is using 24 H. P. of steam to pull a 3 H. P. pump, or that it takes 86.60 % of the power developed by his engine to overcome frictional resistance of his machinery.

After this short description there will be given the log of the average of readings taken every ten and fifteen minutes throughout the test. After the log will be considered the proper means of diminishing the excessive losses, calculating the gain in economy of steam and the saving in dollars and cents by the introduction of same.

The accompanying shows the men responsible for the different results given opposite their names. All the

results given in this log were figured carefully and accurately, all the water and coal were weighed except the water pumped which was allowed to flow over a weir.

The instruments used in this test were calibrated very accurately after the test and the errors properly tabulated. The results are wholly reliable as our testing apparatus was good and responsible men made the readings.

Log of Test

1. Date of Trial April 24 & 25, 1903.
2. Duration of Trial 23 hours.

DIMENSIONS AND PROPORTIONS

Grate surface of 1st boiler	5 X 5	25 sq. ft.
" " 2nd "	5 X 6	30 " "
" " 3rd "	5 X 6	30 " "
3. Total grate surface		85 sq. ft.

Water heating surface of 1st boiler	936 sq. ft.
" " " 2nd "	1048 " "
" " " 3rd "	1048 " "
Total water heating surface	3022 " "
5. " superheating surface	260 " "
6. Ratio of water heating surface to grate area--	35.6 : 1

AVERAGE PRESSURES

7. Steam pressure in boiler by gauge 83.3 #

- Absolute pressure in boiler by gauge 98.0 #
9. Atmospheric pressure per barometer 28.95 inches
10. Force of draught in inches of water 27.00 inches

Average of Temperatures

11. Of external air 57.5 degrees F.
12. " fire room 68.8 " "
13. " escaping gases 427.2 " "
14. " feed waters 59.2 " "

Fuel

15. Total amount of coal consumed 22837 lbs.
16. Moisture in coal (1st lot--17669 #) 5.71 %
17. " " (2nd " 3932) 7.64 %
18. Total refuse dry 18.35 %

29. " combustible

- 19a'. Dry coal consumed 17501

20. Dry coal consumed per hour 932 lbs.

21. Combustible consumed per hour 761 "

Water

22. Total weight of water pumped into boiler
and apparently evaporated 162675 lbs.

23. Total amount pumped per hour 7073 "

24. Water actually evaporated corrected
for quality of steam 157795 "

25. Equivalent water evaporated 182516

26. Equivalent total heat delivered from fuel in B. T. U.

161344144

27. Equivalent amount of water evaporated into dry
steam from and at 212 per 7963 lbs.

Economic Evaporation

28. Water actually evaporated per pound of dry coal from
actual pressure and temperature 7.36 lbs.

29. Equivalent water evaporated per pound of dry coal
from and at 212 degrees F. 8.62 lbs.

30. Equivalent water evaporation per pound
of combustible from and at 212 degrees F. 10.42 lbs.

Commercial Evaporation

Or Coal actually burned per sq. ft.

31. Equivalent water evaporated per pound of dry coal.
with 16 2/3% of refuse, at
70 lbs. guage pressure, from Tem. of
100 degrees F. 8.32 lbs.

Rate of Combustion

32. Or Coal actually burned per Sq. Ft.
of grate surface per hour. 10.96 lbs.
Consumption of dry coal per hour,) per sq. ft.
coal being 18.35 per cent refuse) of grate surface 8.95#

33.) per sq. ft. of water
) heating surface 252#
 per sq. ft. less area of draught, 7.53#

34. On basis of 30# of water per hour
evaporated from temp. of 100 degrees F.
into steam of 70# guage pressure 253.1 H.P.

35. Horse power, Builders' rating at 280 "

36. Per cent developed below rating	9.8%
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Flue Gas Analysis.

37. Area of grate sq. ft.	85 sq. ft.
38. " " chimney "	12 "
39. Height of chimney in feet	60 ft.
40. Length of heated flue	16 "
41. Inside perimeter of chimney	11.2 " 3
42. Number of boilers	
43. Fire Tube boilers, no mechanical blower	

Log.

44. Reading of draught gauge, water	.27 in.
45. Temp. of flue	427.2 deg. F.
46. " of boiler room	69.8 "
47. " of outside air	57.5 "
48. Weight of coal burned per second	.259 lbs.
49. CO per cent of volume	4.41 %
50. CO ₂ plus CO per cent of volume	19.39 "
51. O free " " " "	14.98 %
52. CO " " " "	47.00 "
53. N per cent of volume	80.14 "
54. Dilution Coefficient	3.41 "
55. Proportional weight	2964.2 "
56. Per cent free O by weight	8.1 "
57. " total O "	21.2 "
58. " carbon "	1.97 "
59. Weight of air per cent of carbon	39.9 "
60. Heat units lost per pound of carbon in flue	3482 B. T. U.

61. Efficiency, per cent	70.9 %
62. Max. Temp. possible in furnace	1467 deg. F.
63. Per cent heat lost in flue	24.0 %
64. Volume of air per pound of coal at 32 degrees F.	500 cu. ft.
65. Velocity of gases in chimney	19.3 ft. per sec.
66. Head to produce draft from calculated velocity	58 feet
67. Head to produce draft from draft guage reading	30.6 ft.
68. Required height of chimney	90 feet

Engine Test.

250 H.P., Brown

69. Duration of Test	23 hours	
70. Revolutions per minute	56.7	
71. Steam used per minute	105.8 lbs.	
	Crank End	Head End
72. Piston displacement	12.34	12.57
73. Clearance per cent of piston displacement	3 %	3 %
74. Cut-off per cent of stroke	22.59	22.83
75. Pressure at cut-off	67.9	66.7
76. Comparison per cent of stroke	9.1 %	8.7 %
77. Pressure at beginning of comparison	15:7# Av.	15:6# Av.
78. Pressure at release	17.8# "	17.4# "
79. Mean effective pressure	29.21#	27.14#

	Crank End	Head End
80. Average horse power	88.3 H.P.	84.25 H.P.
81. Average M.E.P. of both ends	28.17# per sq. in.	
82. " indicated H.P. developed	173.5 H.P.	
83. Weight of water pumped into boiler per hour for engine	6357#	
84. Weight of water used per hour as calculated from indicator card	4620# per hour	
85. Weight of water per horse power per hour actual	35.5 lbs.	
86. Weight of water per H.P. per hour as calculated from indicator card	26.6	

Pump Test		
	of steam cylinder	6"
Number	" "	2"
Lenght	of stroke	10"
Quan.	of steam pipe	1 1/2"
"	" exhaust "	1 1/2"
No.	strokes per minute (Approx.)	60
Diam.	of suction pipe	3/12"
Horizontal	length of suction pipe	154 feet
Vertical	height " " "	17.5 "
Diam.	of discharge pipe	3.5 "
Vertical	height of discharge pipe	10 "
Total	lift of pump	49.8 "
Total	amount of steam used for pump	16420 lbs.
Amount	of steam consumed per hour	714 "
(Assuming 30 lbs. of steam equal to 1 H.p. per hour)		

Power expended in pumping	23.8 H.P.
Amount of water pumped.	
Average height of water on weir	2 61/64 in.
Length of weir	6 in.
Q equal the amount of water pumped per minute.	
According to Frances Q	3.33 $1 \frac{h^3}{2}$ 12.01 cu.ft.
" " Smith Q	3.29 $(1 \frac{h}{t}) \frac{h^3}{2}$ 11.53 "
" " Bazin Q	MLH 2gh 13.25 "
Average of these results	12.25 "
As given in tables in Victor Turbine	
Catalogue	Q 12.247
Average number of gallons pumped per minute	144
Loss of head due to friction in the pipe	4.2 ft.
Total lift of pump(including friction head)	5.4 "
Total weight of water lifted per minute	765.6 lbs.
No. foot pounds per minute	41342.4
41342.4 ft. pounds is equivalent to	1.253 H.P.
H.P. expended in driving pump	23.8 "
Efficiency of operation	5 27/100