# BOILER TEST
# of
# THE UNIVERSITY OF TENNESSEE POWER PLANT

A THESIS

SUBMITTED BY

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FOR

THE DEGREE OF BACHELOR OF SCIENCE

MECHANICAL ENGINEERING COURSE

UNDER

PROFESSOR W.R.WOOLRICH

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ACKNOWLEDGEMENTS

Due consideration and acknowledgement is hereby given to Professors Woolrich and Switzer and their classes in Steam Engineering - 6a and Hydraulics - 6 for their assitance in running the test. Professor Woolrich's classes ran the test and Professor Switzer's classes calibrated the V-Notch Meter. Without the assistance of these two professors and their classes the performance of this test and the calibration of the V-Notch Meter would have been extremely difficult and impossible without hired help. To all of these I express my thanks and appreciation.

Everett D. Phillips

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# INTRODUCTION

A boiler test as a thesis involves about an equal amount of mental and manual labor. The mental part requires much study of the code itself in order to make a proper application, and also, a study of the history of the development of the code. The manual part involves a calibration of the various instruments, of which the V-notch meter is by far the most difficult. The actual test involves only the boilers of the University of Tennessee Power Plant, and is the latest development in boiler tests up to the present time.

The boiler test was selected for this thesis first, because it involved both mental and manual labor; second, it enabled the engineer to make a direct application of much information obtained from his studies of Thermo-Dynamics and Steam Engineering; and third, it offered a certain amount of actual experience in boiler testing which will be of great value in specializing in Power Plant Engineering. This test differs from a regular class test in accuracy and thoroughness. Furthermore, since the engineer had charge of the test, he became familiar with every phase of it, and it was under his direct supervision and observation during the whole period of twenty-four hours. On the other hand, in tests conducted by the regular class, the students performing the same become familiar with only one phase.

# CHAPTER I - CONCLUSIONS

The results of this test prove that:

1. Excellent combustion is obtained.
2. Very little heat goes to waste in dry chimney gases.
3. The boilers are capable of producing a high efficiency even though operating under their rated capacities.
4. Had the boilers been operated at their rated capacity, the evaporation per pound of coal would have been higher.

The average $CO_2$ results, a percentage of twelve per cent (12%), indicate good combustion. The flue gas temperature in this experiment is entirely too low, but it does not cast any reflection on the boiler's ability to transfer heat. It does show that there was supplied considerable amount of excess air, a direct result of the irregularities in the governor on the fan engine. An overall efficiency of sixty per cent (60%) for the grates and boilers was obtained at a sixty-nine per cent (69%) rating. This result is good, but had the rating been higher, the efficiency would have been proportionally higher. Results in power plant tests show that maximum efficiency is obtained when water tube boilers operate between one hundred and sixty (160) and two hundred per cent (200%) rating. The evaporation of only eight (8) pounds of water to the pound of coal is only another indication that the boiler's load was too light, and that one boiler should have done the work of both.

## CHAPTER II - GENERAL SURVEY OF THE FIELD

1. The boiler, like other new inventions and discoveries, in its evolutionary stage of development had a very crude beginning. Even then, man was curious to learn how well a boiler would perform and how much work one might expect it to do. The methods for measuring its capacity or power (rate of doing work) must necessarily have been crude since the boiler was a new invention and little was known about its characteristics of operation and the laws governing its performance. Then, too, the unit for measuring the boiler's usefulness had to be a unit easily understood and applied. This unit, which was called the horse power, was obtained from the device, frequently seen in farm yards in those days, by which the power of a horse was utilized for driving the threshing machine or other machinery. Since the boiler and steam engine were substituted for doing the work of the horse, their output and capacity were measured in horse power. James Watt established this unit and sold his engines by telling his customers how many horses they would replace. He estimated that a strong London draught horse was capable of performing 550 foot pounds of work in one second, 33,000 foot pounds in a minute, or 1,980,000 foot pounds in an hour. This was then accepted as an arbitrary value for this unit and has come down to this day as such.

2. In America the practice has been to rate the capacity of boilers in terms of boiler horse power. Custom has brought this about even though it frequently leads to a misunderstanding.

However, there is a logical tendency to abandon the use of horse power as a measure of boiler capacity. But, this practice is now so universal and well established that it will require a long time to abandon it and substitute a more rational basis for measuring boiler capacity. In a strictly rational sense horse power is a unit of work for general use among prime movers, such as steam engines, water wheels, etc. As defined and used in mechanics, "work is overcoming resistance through space" and "power is the rate of doing work per unit of time." Since the boiler, while in service, implies no motion, it cannot produce any power in the true sense of the applied term in mechanics. In actual operation the boiler acts only as a medium. It conveys the energy of the fuel (heat energy) to a prime mover which converts that energy into energy of motion or work, and power is thereby developed.

A committee of judges in charge of the boiler trials at the Centennial Exposition at Philadelphia in 1876 sought to eliminate the indefiniteness of the term "boiler horse power". They ascertained that a good engine of the type prevailing at that time required approximately thirty (30) pounds of steam per indicated horse power developed. To establish the relation between the engine power and a boiler to supply that power, they recommended that an eveporation of thirty (30) pounds of water from an initial temperature of 100 degrees Fahrenheit to steam at 70 pounds pressure per square inch gage be considered as one boiler horse power. In 1889 the American Society of Mechanical Engineers standardized this recommendation which has been, until recently, the standard accepted by American

Engineers. Whenever boiler horse power is used in America in connection with stationary boilers, it is understood to have this meaning. It is customary, however, to consider the standard boiler horse power as recommended by the Centennial Exposition Committee in terms of equivalent evaporation from and at 212 degrees Fahrenheit. This means that thirty (30) pounds of water evaporated must be multiplied by a factor of evaporation. This factor, which is obtained from a 70 pound pressure per square inch gage and 100 degrees Fahrenheit feed-water temperature, has a value of 1.194. This means that the boiler horse power is a measure of evaporation and not of power. Therefore, its equivalent value would be 30# X 1.194 = 34.482# or approximately 34.5# per horse power.

In present day practice boiler builders rate their boiler horse power upon heating surface. Usually ten (10) square feet of boiler heating surface is allowed to the horse power. This is what is commonly known as the normal or builder's rating. This rating does not bear any significance or meaning whatever to boiler operation. It only means that there are so many square feet of heating surface to the horse power. The builders determined their rating from early operation by the fact that they considered one square foot heating surface would evaporate from 2.5 to 3 pounds of water per hour. The evaporation has increased from time to time as the art of boiler making and operation has progressed, until to-day one square foot of boiler heating surface evaporates from 4.5 to 6 pounds of water per hour. Therefore the normal rating is purely an arbitrary value and does not in any way alter the definition of boiler horse power as given in the preceding paragraph.

Despite the fact that there is a growing dissatisfaction caused by the indefiniteness of the terms capacity and boiler horse power, custom has so well established these terms that no other proposed methods, offering a more definite and rational basis for rating capacity, have ever been universally accepted. The most logical to rate boilers is on size only, (expressed in so many square feet of boiler heating surface), since the ultimate amount of evaporation is dependent upon the quantity of fuel fired. The American Society of Mechanical Engineers Committee on "Definitions and Values" of the Power Test Codes has recommended this basis of rating boilers. The same committee has recommended that boiler output, instead of being given in terms of boiler horse power, be expressed:

(A) "By the heat output in steam delivered by the unit per hour, as represented by the difference between the total heat in steam delivered and in the feed-water as fed to the unit;

(B) "By the actual evaporation in pounds of steam per hour at the reported steam pressure and quality or temperature of steam, and the reported feed water temperature; and

(C) "To do away with the objection resulting from (A) to the use of large numbers, that the total heat output be expressed in 'units of output', such units being determined by the total heat output, (A), divided by 1,000."

Supplementary definitions - See Appendix A

3. The necessities and possibilities of boiler tests are best illustrated by a narrative of an actual boiler operation*. The moral of that story is summarized in the last sentence. Even in the most modernly designed plant,which would represent the last word in power plant engineering,and under ideal operating conditions, a proper and sufficient number of instruments must be supplied and performance tests run. These are absolute essentials that the power plant engineer may know how well he is operating the plant. He may be operating it the very best he can, but without tests and necessary apparatus, he will not know how well that is.

*See Appendix B

# CHAPTER III - STATEMENT OF PURPOSE

The primary purpose of this thesis was to determine the overall efficiency of the grates, boilers, and feed water heater under actual operating conditions. The ulterior purpose for choosing this test as a thesis was the experience to be gained in running tests on power plants. Then, too, this test combined admirably the mental and manual labor which made it a creditable subject for a thesis. The secondary purpose was to write a brief, concise, intelligible, and interesting history of the development of boiler tests. The last purpose was to give a short, terse, and pointed statement or summary of the results and possibilities.

# CHAPTER IV - GENERAL THEORY

The boiler efficiency is the ratio of the amount of heat absorbed by the boiler in B.T.U.'s to the amount supplied in B.T.U.'s. Under actual operating conditions all the combustible supplied to the grates in the form of coal is not burned. Therefore, the waste heat in the unburned combustible cannot be charged against the boiler. So far there is no absolutely dependable method for determining the amount of heat lost due to unburned combustible, and moreover, there is no reason for separating the boiler and the grates in calculating the efficiency. Thus, the efficiency is determined for the boiler and grates jointly.

For power plant tests the one general and recognized code is that drafted by the Power Test Code Committee of the American Society of Mechanical Engineers. There is a code for each particular class of power plants, such as solid fuel burning, gaseous fuel burning, etc. The code must apply properly to the plant under test.

# CHAPTER V - PERFORMANCE OF TEST

1. This test was conducted under the directions of the A.S.M.E.Code, because this code is most generally accepted, and universally employed for performing power plant tests.

2. In this test no detailed theoretical considerations were involved. Everything was detailed and all calculations were indicated in the code. The code stated the instructions for making the test very thoroughly, and all that was necessary was to follow carefully these instructions, record all test data, substitute this data in a code log, and make all indicated calculations.

3. The greatest hindrance encountered in running this test was the adjustment and calibration of the V-notch weir (meter). The installation of the feed water heater was the chief cause of this impediment. The proximity to the wall made the approach chamber rather dark, a condition which rendered work most difficult. It is necessary to determine the zero level of the V-notch weir in order to adjust the meter. This level is obtained by adjusting the water surface of the approach chamber until it is exactly level with the apex of the weir. For this purpose the weir is manufactured with two lugs, one on either side and exactly in line with the weir's apex. The lugs, which extend one-fourth ($\frac{1}{4}$) of an inch from the weir, eliminate the possibility of any error that might be caused by capillary attraction. The water surface is then adjusted until it barely coincides with the faces of the notches. The accuracy of the adjustment of the water surface is raised

to a higher degree by the use of a magnifying mirror.

In installing the feed water heater it was leveled from some external place, and not by the weir. Consequently one lug appeared below the surface of the water, and the other above. Also, in all probability the weir was not leveled in a vertical position. Under these conditions it was impossible to determine the zero level with any degree of accuracy. Since this condition could not be remedied, the zero level was got as well as possible by approximation, but this was not any better than a good guess. The meter was then calibrated and its readings showed an error of 13.9%* low. This error is mostly, if not wholly, due to the installation of the feed water heater.

4. The possibilities of error in this test were confined mostly to the human element. The $CO_2$ recorder presented another possibility of error in that on the day of the test it registered from five (5) to seventeen (17) per cent $CO_2$. Very likely this was a correct reading because the instrument was checked and adjusted with the Orsat apparatus only two days before the test. However, this apparatus was not an accurate instrument for checking the $CO_2$ recorder, because it was later found that the liquids were slightly mixed, and air leaks appeared in the tubing. An attempt was made to analyze the fluegas with the Orsat apparatus, but because of the facts just mentioned, the results of these analyses were disregarded and only the $CO_2$ readings were accepted.

5. To reduce all eroors to a minimum, proper log charts were compiled, students were assisted and instructed in their

* See Appendix Fig. 4a and 4b

particular parts, the work of one shift was co-ordinated with that of another, and the entire test was conducted under personal observation.

6. The average $CO_2$ percentage may not be considered unique, but it is extraordinary. Most power plant engineers would seriously question this value on the ground that values for $CO_2$ results from six (6) to nine (9) per cent are good for best equipped plants operating under fairly ideal conditions. There are even some engineers who are skeptical of automatic devices for producing dependable and reliable results. Automatic devices cannot be relied upon too much for reliable results, though they are capable of furnishing fairly accurate records when the engineer understands their operation and cares for them properly. In running tests, these records should be checked and supplemented by other apparatus for that purpose. Excess air, which varied from a small to a large per cent, and the Hay's recorder, which fluctuated between five (5) and seventeen (17) per cent may be interpreted to indicate that the recorder is a reliable indicating device and that the results in this test are approximately correct. Furthermore, while no smoke observations were recorded, smoke from the chimney was conspicuous by its absence; and this also indicates that fairly complete combustion took place, and that the $CO_2$ results are fairly reliable. Also these results are possible because the official tests on the famous Hell Gate Station show $CO_2$ percentage 11.69% and 12.01%.

Fluegas temperature might be considered another extraordinary feature of this test. A comparison of the $CO_2$ results in this test with Table B* of the Thirty-sixth Edition of Steam shows that percentages of excess air varied from ten (10) to one hundred and fifty (150) per cent. Thus, this was the chief cause of $CO_2$ percentage varying from low to high per cents. The chief cause for excess air was the irregularities of the action of the governor on the fan engine. At times the fan raced at high speed and at others it ran at decidedly low speeds. This condition,coupled with the operation of the boiler under rated capacity, served to reduce the temperature of the fluegas outlet.

*See Appendix C

TEMPERATURE OBSERVATIONS, DEGREES FAH

TIME INTERVALS — MINUTES

| TIME INTERVALS — HOURS | | CALORIMETER 0 | 15 | 30 | 45 | FEEDWATER-HEATER 0 | 15 | 30 | 45 | DRY GASES-CHIMNEY 0 | 15 | 30 | 45 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A.M. | 1 | 259 | 260 | 260 | 258 | 176 | 176 | 175 | 175 | 347 | 372 | 362 | 357 |
| | 2 | 258 | 264 | 259 | 256 | 174 | 172 | 168 | 166 | 372 | 347 | 347 | 347 |
| | 3 | 258 | 254 | 260 | 251 | 167 | 167 | 167 | 168 | 362 | 357 | 347 | 352. |
| | 4 | 254 | 260 | 262 | 258 | 168 | 168 | 169 | 170 | 362 | 362 | 342 | 342 |
| | 5 | 250 | 261 | 257 | 261 | 171 | 170 | 170 | 169 | 342 | 337 | 342 | 337 |
| | 6 | 255 | 250 | 270 | 262 | 170 | 159 | 155 | 153 | 427 | 392 | 462 | 402 |
| | 7 | 254 | 262 | 255 | 265 | 163 | 180 | 189 | 192 | 392 | 442 | 392 | 382 |
| | 8 | 264 | 242 | 254 | 270 | 196 | 199 | 201 | 202 | 442 | 392 | 382 | 427 |
| | 9 | 265 | 250 | 248 | 252 | 202 | 202 | 203 | 203 | 442 | 482 | 372 | 367 |
| | 10 | 270 | 262 | 230 | 264 | 203 | 203 | 203 | 198 | 442 | 372 | 382 | 422 |
| | 11 | 272 | 268 | 250 | 254 | 183 | 189 | 194 | 192 | 447 | 442 | 372 | 377 |
| | 12 | 278 | 250 | 258 | 260 | 194 | 198 | 198 | 199 | 442 | 362 | 392 | 362 |
| P.M. | 1 | 261 | 261 | 260 | 259 | 200 | 201 | 201 | 201 | 362 | 362 | 362 | 362 |
| | 2 | 260 | 260 | 261 | 260 | 202 | 202 | 202 | 202 | 360 | 352 | 352 | 382 |
| | 3 | 261 | 261 | 260 | 260 | 202 | 202 | 202 | 203 | 342 | 342 | 342 | 332 |
| | 4 | 260 | 261 | 259 | 258 | 203 | 203 | 203 | 203 | 332 | 342 | 342 | 357 |
| | 5 | 259 | 263 | 259 | 260 | 203 | 203 | 203 | 202 | 382 | 352 | 342 | 402 |
| | 6 | 260 | 266 | 268 | 266 | 203 | 203 | 204 | 203 | 347 | 342 | 352 | 342 |
| | 7 | 258 | 267 | 254 | 260 | 204 | 204 | 204 | 204 | 342 | 342 | 377 | 347 |
| | 8 | 266 | 265 | 260 | 266 | 204 | 204 | 204 | 204 | 342 | 397 | 402 | 352 |
| | 9 | 257 | 264 | 264 | 264 | 204 | 202 | 203 | 204 | 387 | 362 | 347 | 352 |
| | 10 | 260 | 262 | 256 | 258 | 204 | 202 | 203 | 202 | 362 | 342 | 357 | 342 |
| | 11 | 248 | 261 | 265 | 248 | 200 | 195 | 188 | 182 | 382 | 407 | 352 | 397 |
| | 12 | 258 | 260 | 259 | 259 | 174 | 179 | 176 | 176 | 307 | 347 | 347 | 342 |
| | | AVERAGE 259 | | | | AVERAGE — 190 | | | | AVERAGE — 371 | | | |

FIGURE — 1

| TIME INTERVALS — HOURS | | TEMPERATURE OBSERVATIONS DEGREES FAH. TIME — MINUTES AIR | | | | WATER USED LBS. PER HOUR FACTORS: INTEG. = 250 ERROR = 1.139* COLUMN 1 = #LBS. OF WATER COLUMN 2 = #LBS. OF WATER (corrected) DIFF. X 250 = COLUMN 1 COLUMN 1 X 1.139 = COLUMN 2 | | | | | COAL USED #LBS. PER HOUR | #LBS. ASHES IN 24 HOURS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 0 | 15 | 30 | 45 | 2nd meter R. | 1st meter R. | Diff. | COL. 1 | COL. 2 | | |
| A. M. | 1 | 69 | 70 | 69 | 69 | 6764265 | 6763901 | 36.4 | 9100 | 10365 | 973 | — |
| | 2 | 69 | 69 | 68 | 67 | 6764589 | 6764265 | 32.4 | 8100 | 9226 | 1815 | — |
| | 3 | 68 | 70 | 71 | 72 | 6764879 | 6764589 | 29.0 | 7250 | 8258 | 1949 | — |
| | 4 | 72 | 70 | 71 | 71 | 6765160 | 6764879 | 28.1 | 7025 | 8001 | 2028 | — |
| | 5 | 72 | 76 | 77 | 77 | 6765455 | 6765160 | 29.5 | 7380 | 8400 | 1894 | — |
| | 6 | 71 | 68 | 68 | 73 | 6765703 | 6765455 | 24.8 | 6200 | 7062 | 1478 | — |
| | 7 | 76 | 78 | 78 | 80 | 6766570 | 6765703 | 86.7 | 21675 | 24688 | 3378 | — |
| | 8 | 79 | 82 | 84 | 83 | 6767183 | 6766570 | 61.3 | 15325 | 17455 | 1898 | — |
| | 9 | 82 | 83 | 84 | 85 | 6767882 | 6767183 | 69.9 | 17475 | 19904 | 1972 | — |
| | 10 | 86 | 86 | 87 | 89 | 6768469 | 6767882 | 58.7 | 14675 | 16715 | 3108 | — |
| | 11 | 89 | 89 | 89 | 89 | 6769082 | 6768469 | 61.3 | 15325 | 17455 | 3162 | — |
| | 12 | 89 | 89 | 91 | 92 | 6769654 | 6769082 | 57.2 | 14300 | 16288 | 2068 | — |
| P. M. | 1 | 91 | 91 | 93 | 93 | 6770210 | 6769654 | 55.6 | 13900 | 15832 | 2997 | — |
| | 2 | 92 | 93 | 93 | 93 | 6770834 | 6770210 | 62.4 | 15600 | 17768 | 2119 | — |
| | 3 | 92 | 94 | 92 | 92 | 6771344 | 6770834 | 51.0 | 12750 | 14522 | 1071 | — |
| | 4 | 94 | 93 | 93 | 93 | 6771857 | 6771344 | 51.3 | 12825 | 14608 | 1052 | — |
| | 5 | 93 | 93 | 92 | 92 | 6772363 | 6771857 | 50.6 | 12650 | 14408 | 2180 | — |
| | 6 | 92 | 91 | 91 | 91 | 6772910 | 6772363 | 54.7 | 13675 | 15576 | 2083 | — |
| | 7 | 89 | 87 | 88 | 86 | 6773425 | 6772910 | 51.5 | 12875 | 14665 | 3951 | — |
| | 8 | 84 | 85 | 83 | 83 | 6773930 | 6773425 | 50.5 | 12625 | 14380 | 1754 | — |
| | 9 | 82 | 82 | 81 | 80 | 6774434 | 6773930 | 50.4 | 12600 | 14351 | — | — |
| | 10 | 80 | 79 | 78 | 78 | 6775950 | 6774434 | 151.6 | 38900 | 43168 | 1047 | — |
| | 11 | 78 | 78 | 78 | 78 | 6776420 | 6775950 | 47.0 | 11750 | 13383 | 1041 | — |
| | 12 | 71 | 71 | 71 | 71 | 6776670 | 6776420 | 25.0 | 6250 | 1119 | — | — |
| | AVERAGE 82 | | | | | | TOTAL | | | 363455 | 45018 | 4506 |

*See Appendix — Figure 4b

FIGURE - 2

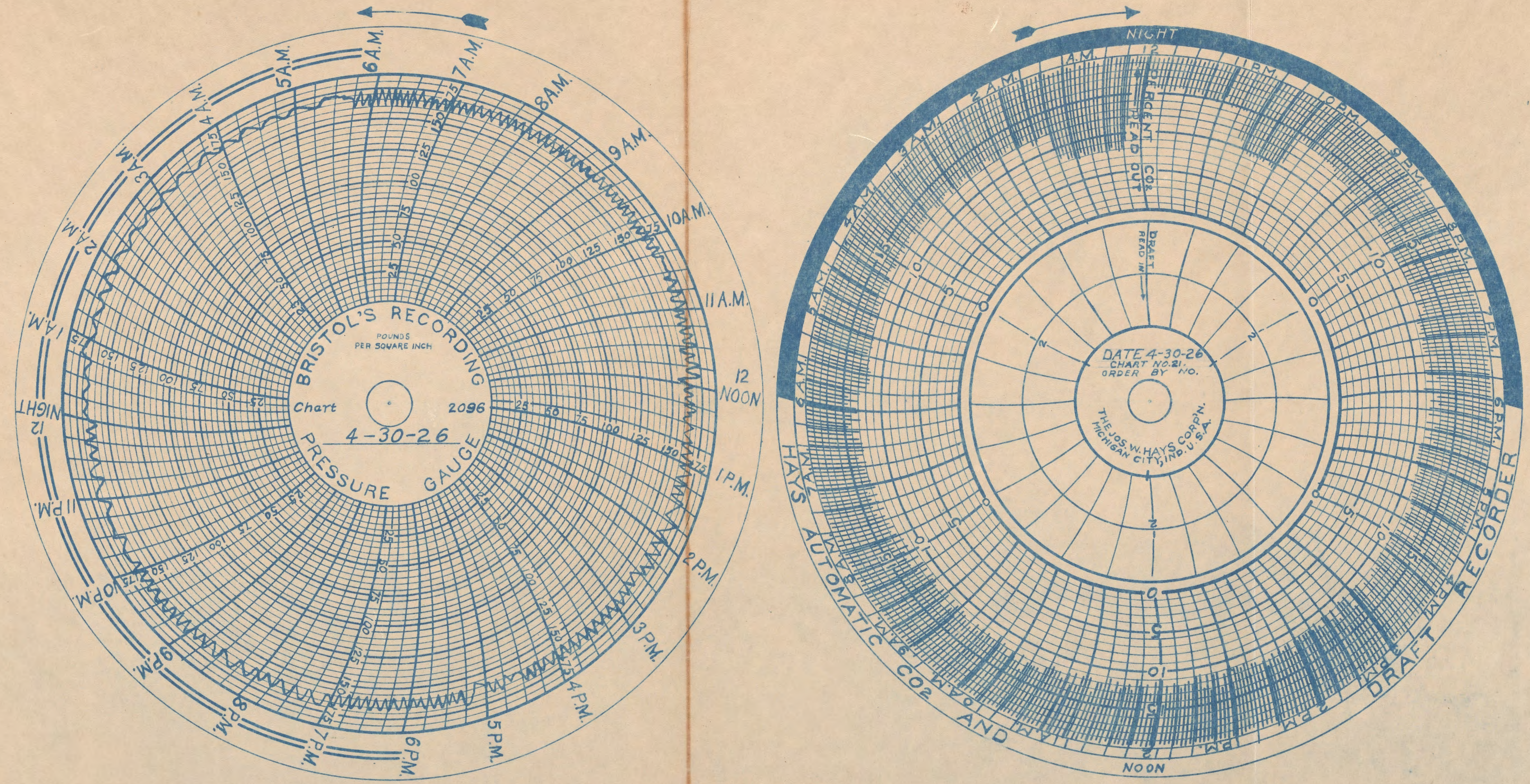
BRISTOL'S RECORDING
POUNDS PER SQUARE INCH
Chart 2096
4-30-26
PRESSURE GAUGE
12 NIGHT
1 A.M.
2 A.M.
3 A.M.
4 A.M.
5 A.M.
6 A.M.
7 A.M.
8 A.M.
9 A.M.
10 A.M.
11 A.M.
12 NOON
1 P.M.
2 P.M.
3 P.M.
4 P.M.
5 P.M.
6 P.M.
7 P.M.
8 P.M.
9 P.M.
10 P.M.
11 P.M.
NIGHT
NOON
PERCENT CO2 READ OUT
DRAFT READ IN
DATE 4-30-26
CHART NO. 21
ORDER BY NO.
THE JOS. W. HAYS CORP'N.
MICHIGAN CITY, IND. U.S.A.
HAYS AUTOMATIC CO2 AND DRAFT RECORDER

FIGURE-3

# CHAPTER VI - DATA AND CALCULATIONS

## I

General Information

1. Date of test . . . . . . . 4/30/26
2. Location . . . . Knoxville, Tennessee
3. Owner . . . . . University of Tennessee
4. Maker of boiler . . . Walsh & Wiedner Boiler Co., Chattanooga, Tennessee
5. Type of boiler . . . . Two-Water Tube Boiler
6. Maker and type of fuel burning equipment . . Two-Taylor Underfeed Stokers
7. Test conducted by . . . Everett Dee Phillips
8. Object of test . . . .To determine the overall working efficeincy

## II

Descriptions, Dimensions, etc.

9.(a) Boiler heating surface . (per boiler) . 3270 sq.ft.
  (b) " " " . (total) . 6740 "
10.(a) Grate surface . (per grate) . . . 66 "
  (b) " " . (total) . . . 132 "
11. Draft . . . . . Forced and chimney draft
12. Fuel . . . . . Bituminous, nut, and slack Fields .. LaFollete and Jellico
13.(a) Volume of combustible space . (per boiler).. . 597 cu.ft.
  (b) " " " " . (total) . 1194 "
14. Furnace, center of grate to nearest heating surface . 9 ft.
15. Furnace volume per square foot boiler heating surface. . 0.177 cu.ft.

## III

Fuel and Gas Analyses and Data

A. Fuel approximate analysis

16. Volatile matter . . . . . . . . 32.81%
17. Fixed carbon . . . . . . . . 57.11%
18. Ash . . . . . . . . . . 8.79%
19. Moisture . (as fired). . . . . . . 1.29%
20. Heating value per pound . (as fired). . 13,347 B.T.U.
21. Size of coal . (as fired) . . . nut and slack

B. Fuel, ultimate analysis . (Sulphur, ash, moisture free)

22. Carbon . . . . . . . . . . 83.75%
23. Hydrogen . . . . . . . . . 5.29%
24. Nitrogen . . . . . . . . . 1.66%
25. Oxygen . . . . . . . . . 9.30%

C. Gas

26. Fluegas analysis, boiler outlet
  (a) $CO_2$ . . . . . . . . . 12.00%
  (b) $O_2$ . . . . . . . . . 8.00%

(c) CO . . . . . . . . 1.00%
(d) $N_2$ . . . . . . . . 79.00%
27. Dry gas per pound of fuel, boiler outlet. . 15.08 lb.
28. " " " " " " , theoretical . . 11.73 lb.
29. Air supplied per pound of fuel, furnace .
(as fired) . . 15.44 lb.

IV

Pressures
30. Moisture in air . . 0.0049764 # per lb. of air
31. Steam pressure by gage, boiler . . . .
166 lb. pressure per sq. in.

V

Temperatures
32. Steam pressure . (by calorimeter) 259 deg.Fah.
33. Moisture in steam . . . . . 2.91%
34. Temperature in boiler room . (avg.) . 82 deg. Fah.
35. Temperature gases leaving boiler . . 371 " "
36. Temperature of feedwater entering boiler. 190 " "

VI

Hourly Quantities
37. Duration of test . . . . . 24 hrs.
38. Fuel as fired per hour . . . . 1876 lb.
39. Fuel as fired per sq. ft. of grate per hour 14.21 lb.
40. Fuel as fired retort per hour . . . 234 lb.
41. Combustion space per pound of coal per hour
(as fired). . 0.637 cu.ft.
42. Refuse per hour . . . . . 188 lb.
43. Actual water per hour . . . . 15,150 lb.
44. Factor of evaporation . . . . 1.046 lb.
45. Equivalent evaporations per hour . . 15,847 lb.
46. (a) Units of evaporation . . . . 153,779 U.E.
(b) Boiler horse power . (avg.) . . 459.3 Hp.

VII

Refuse
47. Refuse per cent of fuel . (as fired) . . 10.00%
48. Percentage of combustible in refuse . . 18.00%
49. Carbon burned per pound of fuel . (as fired). 0.8195 lb.

VIII

Evaporation
50. Actual evaporation per pound of fuel . (as fired)
8.076 lb.
51. Equivalent evaporation per pound of fuel .
(as fired) . 8.045 lb.
52. Equivalent evaporation per sq.ft. heating surface
per hour . 2.35 lb.
53. Units of evaporation absorbed per sq.ft. of

boiler heating surface per hour.... 12.8 U.E.

54. Percentage rating . . . . . 66.29%

IX

Efficiency

55. Efficiency of boiler, furnace, grate . . 61.43%
56. Efficiency . (overall, including feedwater heater) . . . 70.99%

X

| Heat Balance | B.T.U. | Per cent |
|---|---|---|
| 1. Heat absorbed by water and steam in boiler | 8,190 | 61.30 |
| 2. Heat loss due to moisture in coal | 15 | 0.12 |
| 3. Heat loss due to water from combustion of hydrogen | 561 | 4.20 |
| 4. Heat loss due to moisture in air | 10 | 0.10 |
| 5. Heat loss due to chimney gases | 1,101 | 8.26 |
| 6. Heat loss due to imcomplete combustion of carbon | 640 | 4.79 |
| 7. Heat loss due to unconsumed combustible in refuse | 1,345 | 10.08 |
| 8. Heat loss due to unconsumed hydrogens, hydro-carbons, radiations, and unaccounted for | 1,485 | 11.12 |
| Total | 13,347 | 99.97 |

# BIBLIOGRAPHY

Steam

Gebhart's "Steam Engineering"

Biggs and Woolrich "Handbook"

Kent's Mechanical Engineers' Handbook

Encyclopedia Brittanica

A.S.M.E. Boiler Test Code

# APPENDIX

A.*Supplementary Definitions:

1. The measure of the efficiency of a boiler is the number of pounds of water evaporated per pound of combustible (coal less moisture and ash), the evaporation being reduced to the standard of from and at 212 degrees Fah.

2. The capacity of a boiler is the amount of boiler "horse power" developed. A horse power for this purpose is defined as the evaporation of 34.5 pounds of water per hour "from and at 212 degrees Fah."

3. The relative rapidity of steaming of boilers is the number of pounds of water evaporated "from and at 212 degrees Fah." per hour per square foot of heating surface.

4. The relative rapidity of combustion of fuel in boiler furnaces is the number of pounds burned per hour per square foot of heating surface.

B.** A manager of a large industrial corporation in Chicago was showing me, with a great deal of justifiable pride, the intricate and comprehensive system of cost accounting adopted by his organization. Every phase of manufacture from selection of raw material to merchandizing of the finished product was covered with records of material used, time studies, labor costs, power requirements, and overhead charges. Thousands of

*From Kent's Handbook

**From Boiler Room Operation by G.F.Gebhart dollars were invested in testing machines, counters and other labor saving devices and a small army of clerks was employed to take care of the records. All together it was the last word in scientific management and accounting -- for the factory. The power plant, and particularly the boiler room, was apparently not included in the magic circle, because no attempt was made to record other than the electrical output, cost of labor and supplies; and boiler room instruments were conspicuous by their absence.

When asked why he did not apply efficiency methods to the power plant as well as to the factory, he said, "Why install instruments that only increase the plant overhead and maintenance charges, and why collect a bunch of records that only conjest the files? In my old plant I dolled up the boilers with every contrivance that the engineer called for and I got a lot of charts -- pressures, temperatures, drafts, steam flow, $CO_2$, and the like, but the coal bill was just the same as the year before the instruments were installed. The weather conditions both years were about the same and there was no increase in the electrical output. On the other hand the records in the factory mean something. They tell us just exactly what each department is doing and where the trouble lies in case the output is not what it should be. No sir! Not for me! I know when I am well off! I still have my old engineer because he knows how to keep my factory running, and he is operating it satisfactorily without a lot of expensive power plant ornaments."

"But," I replied, "how do you know that your power plant is operating at its best commercial efficiency, and how did you arrive at the power and steam costs for your factory records? And, furthermore, are you sure that the use of the boiler room instruments in the old plant did not better the economy of operation?"

"Well," he said, "we are getting all the power and steam that we need at practically the same costs as the old plant and we have added considerably to the equipment -- that answers your first question. We took the total boiler and power plant operating costs and prorated them to the best of our knowledge among the various departments -- that answers your second question. As for the old plant, I have already told you that the yearly cost of operation with instruments showed no improvement over the preceding year when we operated without them, and heating and power loads were approximately the same."

The chief engineer, who had been called into the office and who had been listening to the discussion, remarked at this point, "Mr.Manager, as I have told you before, I am positive that I made good use of the instruments inasmuch as I raised the average rate of evaporation from 6 lb. per lb. of coal, the day the instruments were put into service, to 7.2 lb. the day we abandoned the old plant. You did not want me to overhaul the steam appliances in the process rooms and heating system because of the building of the new plant, and I feel sure in view of the run-down condition of the equipment, that we generated considerably more steam than we did the year before even if the weather and electrical load conditions were about the same. We had no steam-flow records for the earlier years and so were unable to make comparisons. I am doing my best with the new plant,but how good that is, I don't know, and I never will know without some sort of check."

C. Variation of $CO_2$ with Different Percentages of Excess Air

| Excess Air Per Cent | -- | $CO_2$ Per Cent |
|---|---|---|
| 0 | | 18.43 |
| 20 | | 15.29 |
| 40 | | 13.06 |
| 60 | | 11.40 |
| 80 | | 10.11 |
| 100 | | 9.09 |

APPENDIX — FIG. 4a

CALIBRATION OF V-NOTCH METER

METER READINGS

2ND 643602

1ST 643431

DIFF. 000171

MULT. "METER DIFF." X 250 TO OBTAIN # WATER

171 X 250 = 42750 # WATER

FIRST RUN — MONDAY

WEIGHTS OF TANKS OF WATER IN POUNDS

| TANK — A | | | TANK — B | | | |
|---|---|---|---|---|---|---|
| INI. WT. | FIN. WT. | DIFF. | INI. WT. | FIN. WT. | DIFF. | TOTAL |
| 231 | 1276 | 1045 | 240 | 1376 | 1136 | 2181 |
| 325 | 1180 | 855 | 270 | 1293 | 1023 | 1878 |
| 325 | 1208 | 883 | 321 | 1421 | 1100 | 1983 |
| 372 | 1273 | 901 | 292 | 1403 | 1111 | 2012 |
| 319 | 1251 | 932 | 320 | 1332 | 1012 | 1944 |
| 322 | 1166 | 844 | 305 | 1404 | 1099 | 1943 |
| 360 | 1066 | 706 | 301 | 1357 | 1056 | 1762 |
| 314 | 1072 | 758 | 299 | 1365 | 1066 | 1824 |
| 309 | 1299 | 990 | 302 | 1369 | 1066 | 2056 |
| 301 | 1383 | 1082 | 317 | 1358 | 1041 | 2123 |
| 278 | 1205 | 927 | 294 | 1415 | 1121 | 2048 |
| 296 | 1164 | 868 | 297 | 1296 | 999 | 1867 |
| 282 | 1358 | 1076 | 322 | 1340 | 1018 | 2094 |
| 275 | 1355 | 1080 | 286 | 1289 | 1003 | 2083 |
| 263 | 1334 | 1071 | 275 | 1367 | 1092 | 2163 |
| 277 | 1289 | 1012 | 278 | 1397 | 1119 | 2131 |
| 296 | 1262 | 966 | 315 | 1331 | 1016 | 1982 |
| 300 | 1200 | 900 | 303 | 1384 | 1081 | 1981 |
| 293 | 1253 | 960 | 286 | 1410 | 1124 | 2084 |
| 313 | 1265 | 952 | 302 | 1412 | 1110 | 2062 |
| 300 | 1200 | 900 | 313 | 1410 | 1097 | 1997 |
| 318 | 1211 | 893 | 319 | 1420 | 1101 | 1994 |
| 493 | 1280 | 787 | 360 | 1436 | 1076 | 1863 |
| 309 | 885 | 576 | 357 | 1401 | 1045 | 1681 |
| | | | 320 | 1439 | 1119 | 1119 |
| | | | SUM TOTAL | | | 48795 |

WATER USED BY WEIGHING = 48795 #

" REG. " METER = 42750 #

DIFFERENCE = 06045 #

PER CENT ERROR = 6045 ÷ 42750 X 100 = 14.14

## APPENDIX—FIG. 4b

SAME AS FIG. 4a

METER READINGS

| | |
|---|---|
| 2nd | 640582 |
| 1st | 640462 |
| DIFF. | 000120 |

120X250 = 30000 # WATER

SECOND RUN — TUESDAY

WEIGHTS OF TANKS WATER IN POUNDS

| TANK—A | | | TANK—B | | | |
|---|---|---|---|---|---|---|
| INI.WT. | FIN.WT. | DIFF. | INI.WT. | FIN.WT. | DIFF. | TOTAL |
| 156 | 1100 | 944 | 100 | 1134 | 1034 | 1978 |
| 227 | 1240 | 1013 | 282 | 1285 | 1004 | 2017 |
| 239 | 1306 | 1067 | 309 | 1420 | 1110 | 2177 |
| 260 | 1343 | 1083 | 274 | 1434 | 1161 | 2244 |
| 271 | 1309 | 1038 | 291 | 1172 | 881 | 1919 |
| 295 | 1276 | 981 | 302 | 1177 | 874 | 1855 |
| 288 | 1241 | 953 | 298 | 1139 | 841 | 1794 |
| 289 | 1201 | 912 | 289 | 1188 | 899 | 1811 |
| 290 | 1224 | 934 | 250 | 1318 | 1069 | 2001 |
| 271 | 1298 | 1027 | 265 | 1234 | 969 | 1996 |
| 293 | 1362 | 1069 | 332 | 1324 | 992 | 2061 |
| 288 | 1366 | 1078 | 350 | 1350 | 1000 | 2078 |
| 276 | 1334 | 1058 | 308 | 1325 | 1017 | 2074 |
| 289 | 1350 | 1061 | 346 | 1344 | 998 | 2059 |
| 284 | 1336 | 1052 | 347 | 1395 | 1048 | 2100 |
| 288 | 1221 | 933 | 342 | 1349 | 1006 | 1939 |
| 296 | 1294 | 998 | 356 | 1349 | 993 | 1991 |
| | | | | SUM TOTAL | | 34097 |

WATER USED BY WEIGHT = 34097

" REG. " METER = 30000

DIFFERENCE = 04097

PER CENT ERROR = 4097 ÷ 30000 X 100 = 13.66

MEAN PERCENT ERROR = 14.14 + 13.66 ÷ 2 = 13.9

ATMOSPHERIC CONDITIONS—U.S. BUREAU 4-30-26

| | BAR. | VAP. PRES. | REL. HUM. | DRY B. | WET B. |
|---|---|---|---|---|---|
| 7 A.M. | 30.17 | 0.237 | 57% | 53.8°F. | 46.3°F. |
| 12 NOON | ——— | 0.211 | 21 " | 76.4 " | 54.7 " |
| 7 P.M. | 30.04 | 0.195 | 23 " | 76.0 " | 55.2 " |
| AV'GE | 30.10 | 0.221 | 33 " | 68.7 " | 52.1 " |

## APPROVAL

The foregoing thesis is hereby approved as a creditable study of an engineering subject, carried out and presented in a manner sufficiently satisfactory to warrant its acceptance as a prerequisite to the degree for which it has been submitted. It is to be understood that by this approval the undersigned does not necessarily endorse or approve and statement made, opinions expressed, or conclusions drawn therein, but approves the thesis only for the purpose for which it is submitted.

Name W. R. Woolrich

Title Prof. Mech. Eng.

Aug 24, 1926.