CANADA
DEPARTMENT OF MINES
HON. W. A. GORDON, MINISTER — CHARLES CAMSELL, DEPUTY MINISTER

MINES BRANCH
JOHN MCLEISH, *Director*

DIVISION OF FUELS AND FUEL TESTING
B. F. HAANEL, *Chief of Division*

Wood Fuel Burning Tests

BY

E. S. Malloch and C. E. Baltzer

(A report on tests conducted at the Fuel Research Laboratories, Department of Mines, in co-operation with the Forest Products Laboratories of Canada, Department of the Interior.)

OTTAWA
J. O. PATENAUDE, I.S.O.
PRINTER TO THE KING'S MOST EXCELLENT MAJESTY
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Price, 10 cents

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INTRODUCTORY

Although wood is the lowest grade fuel being utilized in Canada to-day, it is in constant demand in many parts of the Dominion, chiefly in the more sparsely-settled districts of the eastern provinces, including Ontario, and in British Columbia. The annual consumption of wood fuel in Canada is in the neighbourhood of ten million cords, and according to the figures of the Quebec Forest Products Commission, 100,000 tons of coal were replaced by wood in 1932. Consequently, it deserves more attention by the general public than has been accorded it in the past.

In order to supplement the meagre information at the disposal of the public regarding the relative heating values of wood and the efficiency of domestic heating plants burning wood, and at the request of the Director of Forestry, Forest Service Department of the Interior of Canada, it was decided to conduct a series of burning tests on wood fuel. The investigation was made by the staff of the Mechanical Engineering Section operating under the direction of E. S. Malloch, the test work and preparation of results being in charge of C. E. Baltzer, assisted by J. R. Kirkconnell, H. P. Hudson, P. B. Seely, and W. H. Harper.

The staff of the Forest Products Laboratories of Canada co-operated by selecting and supplying the samples of wood to be tested, namely, green hardwood, dry hardwood, green softwood slabs, and dry softwood slabs; and by measuring the volume, weight, average density, and average moisture content of each cord before it was delivered to the Fuel Research Laboratories' test floor. In addition, they secured a representative sample of the sawdust resulting from the cutting of the cordwood into suitable lengths for burning. Immediately on receipt, the sawdust samples were turned over to the Solid Fuels Analysis Section of the Fuel Research Laboratories, where proximate and ultimate analyses were made, as well as calorific value determinations, etc. Further information on this aspect of the work will be found in the report published by the Forest Products Laboratories on "Heating Value of Wood Fuels," by J. D. Hale.

In order to make the investigation as comprehensive as possible, and at the same time have the conditions of the tests approach those appertaining in the average house which uses wood as its furnace fuel, it was considered best to conduct two tests on each sample of wood, one when firing the fuel on the ordinary coal grate, with which the furnace was equipped, and the second when this coal grate was covered with a perforated plate. This scheme, however, was not fully adhered to: the tests on green hardwood and green softwood, with the perforated plate over the ordinary grate, were not run, as it was found that similar tests on air-dried hardwood and softwood differed so little from those run when using the coal grate, that the expenditure of the necessary time and money was not warranted. At the special request of the Superintendent of the Forest Products Laboratories, the investigation was extended to include a test of air-dried hardwood in the furnace after the coal grate was removed and when the fire was made up on a solid firebrick bed in the ash-pit.

DESCRIPTION OF APPARATUS

The apparatus employed for these tests was similar in all respects to that used for the burning tests conducted at the Fuel Research Laboratories in the years 1923-1925 inclusive, and reported in Mines Branch publications Nos. 671-2 and 705. A brief description of the apparatus is as follows:—

The heating plant employed for these tests consisted of a round hot-water boiler; a radiation tank and cooling-water system; the usual equipment of scales for weighing fuel and refuse; thermometers; pyrometers; draught gauges; gas sampling and analysing apparatus; and water meter.

Figure 1 shows the general arrangement of the equipment, piping, etc., and Plate I illustrates the furnace and auxiliary test apparatus located on the main floor. The round hot-water boiler used was of the design, similar in all respects to such as are installed in an average size house of eight or nine rooms, having a nominal grate diameter of 25 inches, a grate area of 3·4 square feet, and a heating surface of 32·4 square feet. The radiation tank was an insulated box, 6½ feet by 3 feet by 2½ feet, containing 81 square feet of wall type radiation connected to the circulating water system of the furnace. The heat was carried away from the boiler by means of the circulating water, which in turn gave up its heat to the cooling water which flowed through the radiation tank, and the product of the weight of the cooling water and the increase of its temperature in passing through the radiation tank gave the useful heat output of the boiler or furnace. The weight of the cooling water was measured by means of an accurately calibrated water meter and the increase in temperature was determined by carefully calibrated thermometers placed in the inlet and outlet sides of the cooling-water system. The fuel was weighed, and knowing its calorific value, this gave the heat input, and then the thermal efficiency could be calculated. Further details and particulars with regard to the method of conducting the tests may be had from either of the above-mentioned reports, viz., Mines Branch publications Nos. 671-2 and 705, there being but one difference, viz., that only one furnace was set up for this series of tests, as it was thought that duplicate tests would not add materially to their accuracy.

DESCRIPTION OF TESTS

The duration of each test was 120 hours, with the exception of the test on green softwood, which was only 117 hours, owing to a shortage of fuel. In most respects the tests were conducted along similar lines to those reported in Mines Branch publications Nos. 671-2 and 705 previously mentioned, the only marked difference needing further comment being in the method employed to ignite and quench the fuel at the start and end of the test, respectively. The wood-burning tests were started in the following manner:—

A preliminary fire was built in the furnace the evening prior to the start of the test, in order to heat up the furnace and water in the system to ordinary operating temperatures. At the end of this period—(approximately at 9.00 a.m. the next morning)—the fire was drawn, the ash-pit and furnace thoroughly cleaned, and a fresh charge of fuel placed on the bare grate and ignited by means of a gas (wheel-type) burner connected with the city gas main, the gas having an approximate calorific value of 500 B.T.U. per cubic foot. Careful note was made of the quantities of gas consumed during the ignition period and of the fuel charged during the whole test, and these factors were taken into account when reckoning the quantity of fuel burned during the test. At the end of the test the system was brought to approximately the same temperatures as prevailed at the start; the fire was then dumped, drawn, and quenched with dry carbon dioxide gas. The heat value of the quenched residual fire was then determined and subtracted from that of the fuel burned during the test.

Table II, which is the basis of this report, gives the detailed data and results of seven tests made in co-operation with the Forest Products Laboratories of Canada. It is compiled under thirty-eight headings and is made up of eighty-three items with three footnotes. Those interested in a detailed analysis of the results of the various tests, will find that a careful study of this table will bring out the many points of interest much better than the written description can.

However, in order to facilitate the comparison of one test with another, and of wood with peat fuel and with American anthracite, a short condensed table has been prepared. This table is made up of five items, comprising the chief points needed for summary comparison of each of the seven tests and also of those on peat and anthracite. Peat has been chosen on account of being a slightly higher grade fuel, and anthracite has been chosen because it has been used as the basis of comparison for all the domestic furnace burning tests conducted at the Fuel Research Laboratories. The numbers in the first column on the left correspond with the item numbers in the large table appended. Of the five items, the third, 14 (e), Fuel Fired per Therm (100,000 B.T.U.) delivered to the cooling water, is the most important from an economic standpoint, since when the cost of the fuel is known it may at once be translated into the tangible expression "Heat delivered per dollar". Items 6 (a), 8 (a), and 31 (b) are all factors in determining the value of item 14 (e), viz., the fuel per therm, as well as being interesting points of comparison in themselves. Item 16 (e), Total refuse recovered, per cent of fuel fired, is not an economic factor for the ordinary house-heating furnace, but for heating large buildings it may assume important dimensions where ash removal must be done by paid labour.

TABLE I

Item	Fuel	Hardwood				Softwood			Average American anthracite*	Air-dried machine peat**
		Air-dried			Green	Air-dried		Green		
	Kind of grate used	Coal grate	Perforated plate on coal grate	Fire-brick on ash-pit floor	Coal grate	Coal grate	Perforated plate on coal grate	Coal grate	Coal grate	Coal grate
	Trial No.	DS-30	DS-31	DS-36	DS-32	DS-34	DS-35	DS-33	See Footnote	
6 (a)	Moisture in fuel as fired.....per cent.	18·7	18·7	16·5	27·0	10·5	9·7	44·7	3·1	25·1
8 (a)	Calorific value of fuel as fired, gross B.T.U.	6890	6980	7039	6410	8100	8080	5000	13230	7350
14 (e)	Fuel fired per therm delivered to the cooling water..lb.	25·3	23·9	27·8	30·8	25·0	23·8	47·0	11·3	25·0
31 (b)	Overall thermal efficiency, per cent	57·3	59·9	51·2	50·6	49·4	52·0	42·5	66·6	54·4
16 (e)	Total refuse recovered per cent o ffuel fired.............	1·0	1·0	1·0	1·2	0·2	0·2	0·3	17·0	4·0

*Average results of three tests recently conducted at the Fuel Research Laboratories, Ottawa, viz., Tests Nos. DS-49, DS-50, and DS-51, full results not yet reported.

**Results of Test G-83-A conducted at the Fuel Research Laboratories, Ottawa, and reported in Mines Branch publications Nos. 671-2 and 705.

COMPARISON OF THE FUELS

This comparison of the wood fuels, one with another and with peat and American anthracite, as well as a description of the fuels, can best be accomplished by reference to the large table appended.

Hardwood—or Average Maple Firewood. Four tests in all were conducted on this fuel—three on air-dried wood seasoned for two years and one on green wood seasoned for three months. For the three tests made on the air-dried fuel, a different arrangement of grates was used for each test: the first with the ordinary coal grate, the second with a plate having ¼-inch perforations laid over the ordinary grate, and the third with the ordinary coal grate removed and the fire set on a firebrick hearth built in the ash-pit. The results of the tests indicated that this fuel, viz., air-dried hardwood, when charged on a perforated plate, was more efficiently burned than was the case with the other arrangements of fuel and grate, with the exception of American anthracite. From the economic side, however, it will be seen that this hardwood differed little from the air-dried softwood when burned on a perforated plate. This combination, however, was better than the other arrangements, with the exception of American anthracite. In small houses, item 16 (c), Total refuse recovered per cent of fuel fired, is not worth considering. The results of the fourth test, made on green hardwood which had been seasoned for three months, appeared to be at a disadvantage when compared with those of the other tests, with the exception of green softwood; the efficiency, however, is not very low, although lower than for the other tests on hardwood.

Softwood—or Soft Pine Slabs and Edgings. Three tests were conducted, two on the air-dried fuel, seasoned for two years, and one on that seasoned for five weeks only. Of the two tests on the air-dried wood, one was made on the coal grate and the other on a perforated plate. It was found that the latter combination of fuel and grate was the most economic arrangement of all in this series of wood-burning tests. On the other hand, the thermal efficiency for this test was low in comparison with those found in the tests on air-dried hardwood, but higher than that obtained with the other arrangements of softwood and grate.

GENERAL CONCLUSIONS

Wood fuel, as tested at the Fuel Research Laboratories, cannot be called a substitute for American anthracite, except under special circumstances, but is almost the equal of air-dried machine peat, when considered from an economic standpoint. The addition of a perforated plate placed over the coal grate resulted in a decided saving in fuel per therm of heat delivered to the cooling water. (*See* item 14 (e) for trials Nos. DS-31 and DS-30 for air-dried hardwood and also DS-35 and DS-34 for air-dried softwood.) The same improvement will be noted when examining item 31 (b); the thermal efficiencies ranged from 59·9 per cent when air-dried hardwood was burned on a perforated grate, to 42·5 per cent when green softwood was burned on the coal grate.

Domestic furnace and auxiliary test apparatus. (Water meter; and radiation, expansion, and water service tanks not shown.) **A.** Domestic hot-water boiler. **B.** Ordinary ash-pit. **C.** False ash-pit into which fuel is dumped for quenching. **D_1, D_2.** Flow and return headers. **E_1, E_2.** Thermometers in flow and return headers. **F.** Thermograph recording flow and return water temperatures. **G.** Flue-pipe entering chimney. **H_1, H_2.** Draught adjustments on butterfly and flap dampers in flue-pipe. **I.** Draught recorder measuring over-fire draught. **J_1, J_2.** Draught gauges measuring over-fire and flue-pipe draughts. **K.** Flue gas sampling and analysing equipment. **L.** Recording pyrometer measuring flue gas temperatures. **M.** Fire tool rack. **N.** Wheel-type gas burner for igniting fuels. **O.** Gas meter measuring gas supplied for ignition. **P.** Hygrograph recording indoor humidity. **Q.** Thermograph recording indoor and outdoor temperatures.

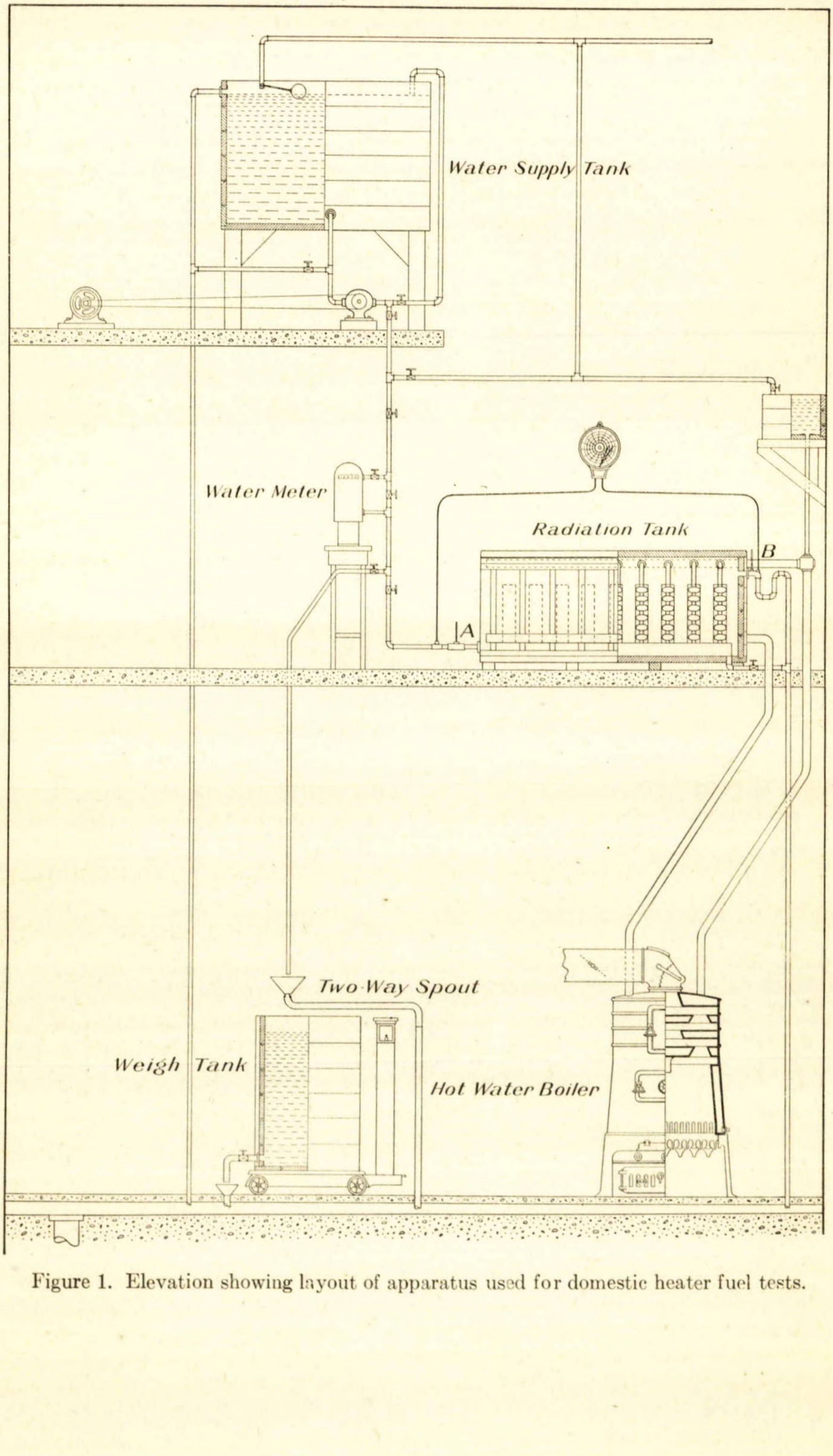

Figure 1. Elevation showing layout of apparatus used for domestic heater fuel tests.

TABLE II

Detailed Data and Results of Wood Fuel Burning Tests Made in Co-operation with The Forest Products Laboratories of Canada

Item	Wood — Species	Hardwood Average Maple Firewood				Softwood Soft Pine Slabs and Edgings		
	Moisture Conditions	Air-dried (Seasoned two years)			Green (Seasoned three months)	Air-dried (Seasoned two years)		Green (Sawed May, 1933)
	Kind of Grate Used	Coal grate	Perforated plate on coal grate	Firebrick on ash-pit floor	Coal grate	Coal grate	Perforated plate on coal grate	Coal grate
	Column No.	1	2	3	4	5	6	7
1. Trial number		DS–30	DS–31	DS–36	DS–32	DS–34	DS–35	DS–33
2. Date of trial		29/5/33	5/6/33	17/7/33	12/6/33	26/6/33	3/7/33	19/6/33
3. Duration of trial	hr.	120	120	120	120	120	120	117
4. Interval between firings	hr.	2	2	2	2	1	1	1
5. Furnace: (a) average rating, feet of water radiation	sq. ft.	880	880	880	880	880	880	880
(b) nominal grate area	sq. ft.	3·4	3·4	5·8	3·4	3·4	3·4	3·4
(c) area of heating surface	sq. ft.	32·4	32·4	32·4	32·4	32·4	32·4	32·4
(d) volume, grate to top of firepot	cu. ft.	5·4	5·4	10·5	5·4	5·4	5·4	5·4
Raw Fuel as Fired								
6. Proximate analysis:								
(a) Moisture	per cent	18·7	18·7	16·5	27·0	10·5	9·7	44·7
(b) Ash	"	0·8	1·1	1·3	1·2	0·7	0·8	0·9
(c) Volatile matter	"	66·5	65·2	66·5	59·0	73·8	73·8	42·8
(d) Fixed carbon (by difference)	"	14·0	15·0	15·7	12·8	15·0	15·7	11·6
7. Ultimate analysis:								
(a) Carbon	"	40·6	41·2	41·9	36·6	47· 6	47·3	29·8
(b) Hydrogen	"	7·1	7·0	6·9	7·4	6·8	6·9	8·3
(c) Ash	"	0·8	1·1	1·3	1·2	0·7	0·8	0·9
(d) Sulphur	"	Trace	Trace	0·3	Trace	Trace	Trace	Trace
(e) Nitrogen	"	0·2	0·2	0·2	0·1	0·1	0·1	0·2
(f) Oxygen (by difference)	"	51·3	50·5	49·4	54·7	44·8	44·9	60·8
8. Calorific value:								
(a) as fired, gross value	B.T.U. per lb.	6,890	6,980	7,039	6,410	8,100	8,080	5,000
(b) dry, gross value	"	8,470	8,580	8,430	8,780	9,050	8,950	9,040
9. Fuel ratio, fixed carbon/volatile matter		0·2	0·2	0·2	0·2	0·2	0·2	0·3
10. Carbon-hydrogen ratio		5·7	5·9	6·1	4·9	7·0	6·9	3·6
11. Bulk density[1]—weight per solid cubic foot	per lb.	45·2	45·3	45·3	53·6	24·5	24·5	38·0
12. Solid cubic feet per cord[2]—(assumed)	cu. ft.	90	90	90	90	90	90	90
13. Weight per cord of 90 solid cubic feet	lb.	4,068	4,077	4,077	4,824	2,205	2,205	3,420
14. Weight fired:								
(a) total for trial—(corrected)	lb.	2,598·3	2,414·4	2,785·4	3,116·4	2,553·7	2,460·3	4,677·5
(b) average per fire-period	"	43·3	40·2	46·4	51·9	21·3	20·5	40·0
(c) average per hour	"	21·7	20·1	23·2	26·0	21·3	20·5	40·0
(d) per square foot grate surface per hour	"	6·4	5·9	4·0	7·6	6·3	6·0	11·8
(e) per therm[3] delivered to cooling water	"	25·3	23·9	27·8	30·8	25·0	23·8	47·0
15. Solid volume fired:								
(a) total for trial (corrected)	cu. ft.	57·48	53·30	61·48	58·14	104·23	100·42	123·09
(b) average per fire-period	"	0·96	0·89	1·03	0·97	0·87	0·84	1·05
(c) average per hour	"	0·48	0·44	0·51	00·48	0·87	0·84	1·05
(d) per square foot grate surface per hour	"	0·14	0·13	0·09	0·14	0·26	0·25	0·31
(e) per therm delivered to cooling water	"	0·56	0·53	0·61	0·57	1·02	0·97	1·24
Refuse, Ash, Combustible, and Carbon								
16. Refuse:								
(a) total recovered (dry)	lb.	27·0	24·3	27·3	37·3	5·8	6·0	16·0
(b) recovered per cord of fuel fired	"	42·3	41·0	40·0	57·7	5·0	5·4	11·7
(c) recovered as a percentage of the fuel fired	per cent	1·0	1·0	1·0	1·2	0·2	0·2	0·3
(d) analysis dry basis (1) ash	"	100·0	100·0	100·0	100·0	100·0	100·0	100·0
(2) combustible	"	Trace	Trace	Trace	Trace	Trace	Trace	Trace
17. Ash:								
(a) quantity fired based on proximate analysis	lb.	20·8	26·6	36·2	37·4	17·9	19·7	42·1
(b) total recovered based on refuse analysis	"	27·0	24·3	27·3	37·3	5·8	6·0	16·0
(c) ratio, ash fired/ash recovered		0·770	1·095	1·326	1·003	3·086	3·283	2·631
18. Combustible:								
(a) total ash and moisture-free fuel fired	lb.	2,091·6	1,936·3	2,289·6	2,237·6	2,267·7	2,201·9	2,544·6
(b) ash and moisture-free fuel removed in refuse	"	Trace	Trace	Trace	Trace	Trace	Trace	Trace
(c) unconsumed (estimated)	"	Trace	Trace	Trace	Trace	Trace	Trace	Trace
(d) consumed	"	2,091·6	1,936·3	2,289·6	2,237·6	2,267·7	2,201·9	2,544·6
19. Carbon consumed per lb. of fuel fired	"	0·406	0·412	0·419	0·366	0·476	0·473	0·298
Average Temperatures and Pressures								
20. Temperature:								
(a) circulating water (1) flow	°F	151	153	166	157	162	165	159
(2) return	"	121	125	137	128	134	137	130
(b) cooling water (1) inlet	"	60·1	64·7	73·9	66·2	71·6	72·8	66·5
(2) outlet	"	130·7	134·3	143·5	136·8	142·4	143·7	137·1
(3) rise	"	70·6	69·6	69·6	70·6	70·8	70·9	70·6
(c) flue gases	"	439	472	483	494	541	544	573
(d) outdoor	"	62	74	71	57	77	71	68
(e) indoor	"	70	77	75	66	80	75	73
21. Barometric pressure	in. Hg.	29·785	29·694	29·845	29·793	29·758	29·969	29·773
22. Relative humidity indoor	per cent	63	65	63	63	68	57	56
23. Draught:								
(a) in flue	in. W.G.	0·012	0·012	0·142	0·014	0·035	0·078	0·067
(b) over fire	"	0·006	0·005	0·008	0·007	0·000	0·003	0·007
Air and Products of Combustion								
24. Volumetric analysis of flue gases at boiler outlet:								
(a) CO_2	per cent	12·4	12·2	9·5	11·9	12·8	13·2	10·6
(b) O_2	"	7·3	7·7	10·5	8·3	6·4	6·0	8·9
(c) CO	"	0·2	0·2	0·2	0·2	0·5	0·6	0·3
(d) N_2 (by difference)	"	80·1	79·9	79·8	79·6	80·3	80·2	80·2
25. Dry flue gases per lb. of fuel as fired	lb.	8·1	8·4	10·8	7·6	9·0	8·7	6·8
26. Excess air	"	52·2	56·9	98·0	64·5	42·8	39·2	71·7
Rates, Capacities, and Efficiencies								
27. Total cooling water used during trial (corrected)	lb.	145,303	144,999	144,094	143,282	144,347	145,706	140,832
28. Heat transmitted to cooling water:								
(a) total for trial	B.T.U.	10,258,392	10,091,930	10,028,942	10,115,709	10,219,768	10,330,555	9,942,739
(b) per hour	"	85,487	84,099	83,575	84,298	85,165	86,088	84,981
(c) per lb. of fuel fired	"	3,948	4,180	3,601	3,246	4,002	4,199	2,126
(d) per solid cubic foot fuel fired	"	178,469	189,342	163,072	173,989	98,050	102,873	80,776
29. Rated capacity of boiler	B.T.U./hr.	132,000	132,000	132,000	132,000	132,000	132,000	132,000
30. Percentage of rated capacity developed	per cent	64·8	63·7	63·3	63·9	64·5	65·2	64·4
31. Efficiency:								
(a) grate	"	100·0	100·0	100·0	100·0	100·0	100·0	100·0
(b) overall thermal	"	57·3	59·9	51·2	50·6	49·4	52·0	42·5
Heat Account per lb. of Fuel as Fired		B.T.U. =%	B.T.U. =%	B.T.U. =%	B.T.U. =%	B.T.U. =%	B.T.U. =%	B.T.U. =%
32. Total heat value of 1 lb. of fuel as fired, gross value		6,890=100·0	6,980=100·0	7,039=100·0	6,410=100·0	8,100=100·0	8,080=100·0	5,000=100·0
33. Heat transmitted to cooling water		3,948= 57·3	4,180= 59·9	3,601= 51·2	3,246= 50·6	4,002= 49·4	4,199= 52·0	2,126= 42·5
34. Loss due to total heat of steam formed from moisture in fuel and that formed by combustion of hydrogen in dry fuel		780= 11·3	775= 11·1	768= 10·9	834=13·0	771= 9·5	787= 9·7	958= 19·2
35. Loss due to heat carried away in dry flue gases		717= 10·4	796= 11·4	1,058= 15·0	781=12·2	996= 12·3	979= 12·1	816= 16·3
36. Loss due to unburned ash moisture-free fuel in refuse		Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible
37. Loss due to unburned carbon monoxide		65= 1·0	67= 1·0	88= 1·2	61= 1·0	182= 2·3	209= 2·6	83= 1·7
38. Balance of heat account, errors of observation, radiation loss, and unaccounted for		1,380= 20·0	1,162= 16·6	1,524= 21·7	1,488= 23·2	2,149= 26·5	1,906= 23·6	1,018= 20·3

[1]The bulk density figures reported herein were furnished by the Forest Products Laboratories.

[2]The commercial "Cord" is customarily taken to be a pile of wood 4 feet wide by 4 feet deep by 8 feet long—(128 piled cubic feet). It is an arbitrary standard which varies greatly in respect to net weight of substance even for wood of the same species, kind, and condition, and as such is dependent as to both weight and solid volume on the local practice employed in piling and measuring as well as on shape and size of piece, etc. The term "Cord" as used herein is taken to mean 90 solid cubic feet of wood substance which has been found by experiment to closely approximate 128 piled cubic feet of maple firewood.

[3]Therm=100.000 B.T.U.