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EFFICIENCY IN THE USE OF OIL FUEL

A HANDBOOK FOR BOILER-PLANT AND LOCOMOTIVE ENGINEERS

BY

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EFFICIENCY IN THE USE OF OIL FUEL; A HANDBOOK FOR BOILER-PLANT AND LOCOMOTIVE ENGINEERS.

By J. M. WADSWORTH.

INTRODUCTION.

This pamphlet is intended as a handbook of information for the man intimately associated with the use of oil fuel. It has been compiled by the Bureau of Mines, from its own investigations and from leading authorities, in cooperation with the United States Fuel Administration. The emergencies of the war have brought before the public with startling directness the need for greater efficiency in the utilization of our mineral resources. As users of fuel oil have shown a lively interest in helping to save fuel, the Bureau of Mines believes that an educational campaign to develop methods for eliminating waste will receive their heartiest support. Such work fostered primarily as a war measure must prove a permanent and lasting benefit to the petroleum industry and to the Nation.

In 1917 there were 160,000,000 barrels of fuel oil burned in the United States. At a conservative estimate 40,000,000 barrels, or one-fourth of the total, might have been saved by more intelligent operation of plants and by proper firing. Therefore all users of oil fuel are urged to take steps immediately to reduce their fuel consumption by carefully observing the principles stated in this pamphlet and by recognizing the value of engineering advice in the design and operation of their plants.

A saving, however small, contributes immediately to higher efficiency and larger profit from a plant, and the aggregate saving at all plants will add tremendously to the effectiveness of the Nation. Production and manufacture will then be kept at a maximum and the value of the fuel oil will be utilized increasingly.

The amount of oil produced in the United States in 1917 and the proportion used and wasted in that year are shown graphically in figure 1.

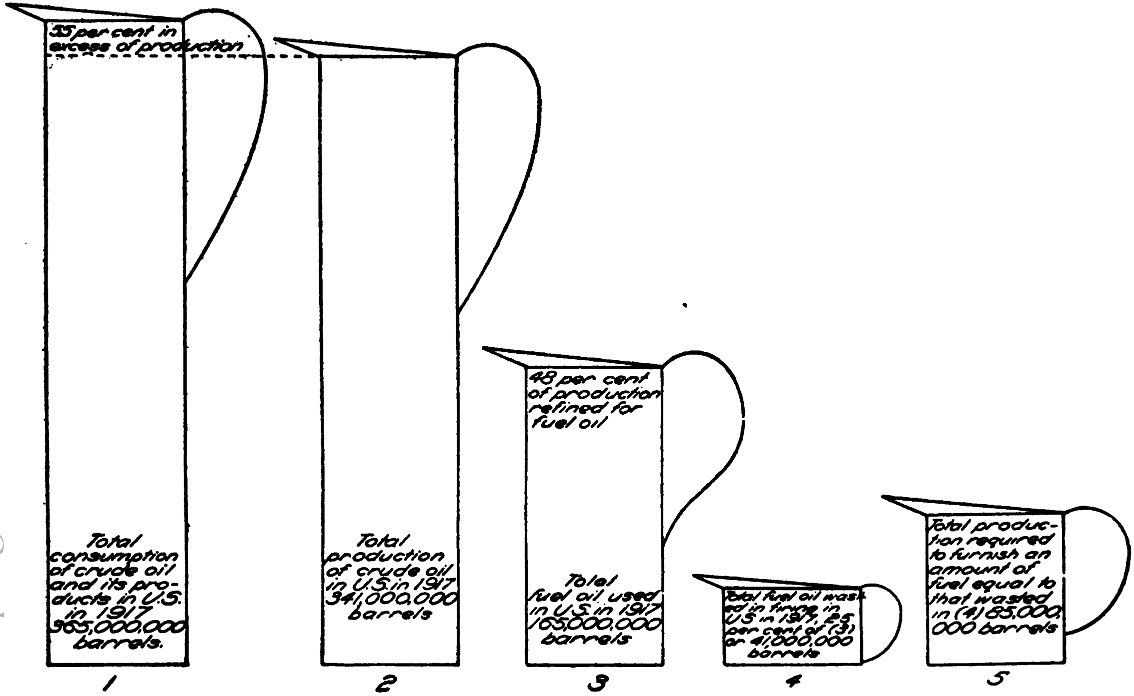

FIGURE 1.—Diagrams showing oil consumption, production, and losses in utilization in United States in 1917.

ACKNOWLEDGMENTS.

In compiling this pamphlet the writer has drawn freely on the results published by leading authorities, including Ernest H. Peabody, Babcock & Wilcox, Lionel S. Marks, and William Kent, as well as Henry Kreisinger and W. T. Ray of the Bureau of Mines. The writer makes grateful acknowledgment to them and believes that they will be glad in thus assisting the work that this pamphlet is intended to start. Acknowledgment is due W. E. Perdew and A. R. Elliott, of the Bureau of Mines, for assistance in preparing the manuscript and illustrations.

Where tables and formulas are presented the method of developing them can be obtained by consulting the authority quoted.

HEAT TRANSMISSION

As the major part of the oil fuel consumed is burned under boilers or stills, a short discussion of the principles of heat transmission and boiler design is presented here. Proper utilization of the fuel value of the oil is not possible without observance of these principles.

Most of the heat produced when oil is burned in a furnace is absorbed immediately by the gaseous products of combustion. The heat contained in these gases is transmitted through the combustion space and the heating surface of the boiler to the boiler water in three ways: The heat is imparted to the heating surface by radiation from the flame and the hot refractory lining of the furnace, and by convection of the hot moving furnace gases; and it reaches the boiler water by conduction through the soot, the metal, and the scale of the heating surface. The heat is imparted to the water almost entirely by convection; the water circulates through the boiler because a unit volume of the water lying against the hot surface becomes lighter, through expansion, than a unit volume of the colder water farther away from this surface. Table 1 (p. 12) shows that the conductivity of water is low.

RADIATION.

Radiant heat passes through space from one body to another without the agency of a third body or other bodies to transmit the heat. In boiler furnaces the heat is radiated from the refractory lining and the luminous flame through the space occupied by gases to the heating surface without heating the gases appreciably. Were these gases not present and the combustion chamber a vacuum, the quantity of heat reaching the heating surface by radiation would be slightly more than that obtained in practice.

CONVECTION.

Transfer of heat by convection implies motion in the fluid or gases receiving or giving up the heat. In a boiler furnace molecules of the moving furnace-gases impinge on the heating surface and impart their heat to it. Convection thus becomes a process of continuous interchange of position between cooled gas molecules, that is, those from the heating surface, and hot gas molecules from the stream of furnace gases. The amount of heat transmitted to the heating surface by convection depends directly on the rate of interchange of the gas molecules. As is shown later, this rate of interchange is increased by increasing the speed at which the gases of combustion move over the heating surface.

CONDUCTION.

In the transfer of heat by conduction the heat flows directly from a hot body to a cold body in contact with it, or from a hotter to a colder part of the same body. The quantity transmitted through a unit area of the heating surface depends on the difference in temperature of the two bodies and their conductivity. Substances differ in their ability to conduct heat, as shown in Tables 1, 2, and 3, following. The metal forming the heating surface has a high conductivity and readily transfers to the boiler water all the heat that can be imparted to it by the convection of the hot gases. In the boiler the heat transmitted to the heating surface is transferred through the soot, metal, and scale to the boiler water solely by conduction. Also, the water has such heat-absorbing capacity that it will take up all the heat conducted to it. The problem, then, of increasing the efficiency or the capacity of a boiler is one of increasing the amount of heat imparted to the dry side of the heating surface.

The thermal conductivity (K) of a substance is the quantity of heat measured in British thermal units (B. t. u.) that flows in one hour through a cube of the substance having 1-foot dimensions and 1° F. difference in temperature between opposite faces.

Tables 1, 2, and 3 show rough average values for the conductivity of various substances:

TABLE 1.—*Thermal conductivities of miscellaneous solid substances.*[a]

Values of K are rough average values for the temperature range indicated.

Substance.	Temperature range, ° F.	K.	Substance.	Temperature range, ° F.	K.
Cardboard		0.120	Glass:		
Cement		0.170	Crown, window		0.6
Cotton wool		0.010	Flint, window		0.48
Ebonite		0.100	Jena, window		0.25–0.5
Felt		0.022	Soda, window		0.3–0.44
Gas carbon		2.400	Fire brick	32–2,400	0.75
Graphite		2.900	Alumina brick	32–1,300	0.5
Marble, white		1.720	Clinker, granular	32–1,300	0.27
Mica		0.440	Pumice stone	70– 150	0.135
Paper		0.075	Carborundum, coarse	70– 212	0.122
Paraffin wax		0.145	Carborundum, fine	70– 212	0.121
Porcelain		0.600	Magnesia, fused	70– 212	0.114
Quartz:			Magnesia, powder		0.04
Parallel to axis		7.250	Magnesia, calcined	70– 212	0.109
Perpendicular to axis		3.900	Coke, powdered	32– 212	0.106
Rubber, Para		0.109	Graphite, powdered	70– 212	0.097
Sand		0.031	Coarse brick dust	32– 212	0.094
Sawdust	70– 275	0.037	Silicate enamel	70– 208	0.097
Silicate cotton		0.046	Fused quartz	70– 212	0.094
Slate		1.140	Infusorial earth	32–1,200	0.092
Blast furnace slag	75– 260	0.064	Serpentine (Cornwall)		1.07
Cork stone (asphalted)	50– 135	0.041	Strawboard		0.80
Lime	70– 212	0.070	Vulcanite		0.21
Fire brick, powdered	70– 212	0.068	Beeswax		0.022
Chalk		0.480	Haircloth		0.01
Charcoal, powdered	32– 212	0.053	Leather (cowhide)		0.10
Wood ashes	32– 212	0.041	Linen		0.05
Lava		0.019	Mill shavings		0.05
Granite		1.300	Hair felt		0.03
Magnesia bricks	32–2,400	1.5	Mineral wool		0.035

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[a] Marks, L. S., Mechanical engineers' handbook, 1916, p. 304. Used with the permission of the publishers, McGraw-Hill Book Co.

TABLE 2.—*Conductivities of insulating materials.*[a]

Material.	Weight per cubic foot (pounds).	Temperatures, ° F.						
		32	100	200	300	400	600	800
Asbestos	36.0	0.087	0.097	0.110	0.117	0.121	0.125	0.130
Burnt infusorial earth for pipe coverings	12.5	0.043	0.046	0.052	0.057	0.062	0.073	0.085
Insulating composition (loose)	25.0	0.040	0.046	0.050	0.053	0.055	......	....
Same mixed with water and dried	42.5	......	......	......	0.067	0.081 (at 428°)	......	....
Cotton	5.0	0.032	0.035	0.039	......	....	......	....
Silk hair	9.1	0.026	0.030	0.034	......	....	......	....
Silk	6.3	0.025	0.028	0.034	......	....	......	....
Wool	8.5	0.022	0.027	0.033	......	....	......	....
Pulverized cork	10.0	0.021	0.026	0.032	......	....	......	....
Infusorial earth (loose)	22.0	0.035	0.039	0.045	0.047	0.050	0.053	....
Same mixed with water and dried	36.0	......	......	......	0.056	....	......	0.083 (at 662°)

[a] Marks, L. S., Mechanical Engineers' Handbook, 1916, p. 305. With permission of the publishers, McGraw-Hill Book Co.

TABLE 3.—*Conductivities of liquids and gases.*[b]

Substance.	Temperature, °F.	K.	Substance.	Temperature, °F.	K.
Alcohol	77	0.104	Ammonia	32.0	0.0111
Aniline	54	0.099	Do	212.0	0.0172
Glycerin	77	0.165	Carbon monoxide	32.0	0.0121
Benzol	41	0.081	Do	44.6	0.0123
Ether	48–59	0.073	Carbon dioxide	32.0	0.0079
Oil, olive	....	0.096	Do	212.0	0.0122
Oil, castor	....	0.103	Ethylene	32.0	0.0096
Oil, paraffin	63	0.085	Helium	32.0	0.0082
Oil, petroleum	55	0.086	Hydrogen	32.0	0.0775
Oil, turpentine	55	0.079	Do	212.0	0.0895
Vaseline	77	0.106	Methane	46.0	0.0156
Water	63	0.032	Nitrogen	45.0	0.0127
Do	52	0.036	Nitrous oxide	32.0	0.0085
Do	77	0.033	Do	212.0	0.0122
Air	32	0.0126	Nitric oxide	46.0	0.0101
Argon	32	0.0094	Oxygen	45.0	0.0136

[b] Marks, L. S., Mechanical Engineers' Handbook, 1916, p. 306. With permission of the publishers, McGraw-Hill Book Co.

The specific heat of a substance is the ratio of the amount of heat, measured in B. t. u., required to raise or lower the temperature of 1 pound of the substance 1° F. to the amount of heat required to raise or lower the temperature of 1 pound of water 1° F. at a specified temperature. Water has a greater heat capacity than any other liquid shown in Table 4.

The British thermal unit (B. t. u.) is $\frac{1}{180}$ part of the heat required to raise the temperature of 1 pound of water from 32° F. to 212° F.

The specific heats of various substances are shown in Table 4.

TABLE 4.—*Specific heats of various substances.*

SOLIDS.

	Temperature,[a] ° F.	Specific heat.		Temperature,[a] ° F.	Specific heat.
Copper	59–460	0.0951	Glass (normal ther. 16^{III})	66–212	0.1988
Gold	32–212	.0316	Lead	59	.0299
Wrought iron	59–212	.1152	Platinum	32–212	.0323
Cast iron	68–212	.1189	Silver	32–212	.0559
Steel (soft)	68–208	.1175	Tin	105–64	.0518
Steel (hard)	68–208	.1165	Ice	....	.5040
Zinc	32–212	.0935	Sulphur (newly fused)	....	.2025
Brass (yellow)	32	.0883			

LIQUIDS.

Water	59	1.0000	Sulphur (melted)	246–297	0.2350
Alcohol	32	.5475	Tin (melted)	....	.637
	176	.7694	Sea water (sp. gr. 1.0043)	64	.980
Mercury	32	.3346	Sea water (sp. gr. 1.0463)	64	.903
Benzol	50	.4066	Oil of turpentine	32	.411
	122	.4502	Petroleum	64–210	.498
Glycerin	59–102	.576	Sulphuric acid	68–133	.3363
Lead (melted)	to 360	.0410			

GASES.

	Temperature,[a] ° F.	Specific heat.			Temperature,[a] ° F.	Specific heat.	
		At constant pressure.	At constant volume.			At constant pressure.	At constant volume.
Air	32–392	0.2375	0.1693	Carbon monoxide	41–208	0.2425	0.1728
Oxygen	55–405	.2175	.1553	Carbon dioxide	52–417	.2169	.1535
Nitrogen	32–392	.2438	.1729	Methane	64–406	.5929	.4505
Hydrogen	54–388	3.4090	2.4141	Blast-furnace gas (approx.)	....	.2277	....
				Flue gas (approx.)	....	.2400	....

[a] When one temperature alone is given the "true" specific heat is given; otherwise the value is the "mean" specific heat for the range of temperature given.

BOILER AND FURNACE DESIGN.

This pamphlet does not discuss the development of steam boilers. Certain essential requirements govern boiler design and each type of boiler has certain advantages, although the water-tube type undoubtedly meets all conditions more fully than the others.

The essential requirements are in general as follows:

(1) The heating surfaces must be arranged in such a way that the gas passages are long and of small cross section so as to give a small hydraulic mean depth, "the hydraulic mean depth being defined as "the quotient of the area of the cross section of the gas stream divided by the perimeter formed by the boiler heating surface touched by the gases." [a] An increase of the ratio of the length of gas path to the hydraulic mean depth of the cross section of the path increases the efficiency of the boiler, because the hot molecules of gas will strike the heating surface oftener and will have to travel smaller distances to reach this surface. The amount of heat given up to this surface by a given volume of gases will therefore be greater, and both boiler and furnace efficiency will be higher.

This ratio can be increased, either by increasing the length of the gas path, or by reducing the hydraulic mean depth. The length of the gas path can be increased by either increasing the length of the boiler or by placing baffles and thus putting parts of the heating surface in series with one another.

(2) The heating surface should "see" as much of the furnace as possible in order to increase the amount of heat imparted to it. This effect should not be so pronounced that the heat will be radiated to the heating surface too rapidly, for the furnace temperature would then be reduced below that required to support combustion.

(3) The combustion space of the furnace must be so constructed that the burning particles of fuel shall be completely consumed before they can touch the relatively cold boiler surface; also this space should enlarge in the direction of the flow of the heated and expanding gases, as the capacity of a furnace for burning oil is limited almost entirely by the furnace volume. The furnace should be lined with refractory brick, which when very hot radiate heat and assist the combustion of the fuel.

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[a] Kreisinger, Henry, and Ray, W. T., The transmission of heat into steam boilers: Bull. 18, Bureau of Mines, 1912, p. 142.

(4) There should be dampers for controlling the air and the flow of the flue gases. The type of burners will determine the best position for admitting the air.

(5) Uptakes and flue passages should be as free from turns as possible, in order not to reduce the available draft from the stack.

(6) Flow of gases countercurrent to the circulation of the water in the boiler is desirable, as it permits the gases to leave the boiler at a temperature approaching that of the feed water as a limit. An economizer in the flue passage accomplishes a similar result.

(7) The boiler should permit uniform and positive circulation of the water, and the steam and water spaces should be large enough to maintain uniform pressures and heating conditions.

(8) The hazards of making steam are reduced if the water is heated in small bodies, and convection transfer is increased if the water circulates through small passages. A water-tube boiler meets these conditions.

(9) Exit of steam should be so controlled as to permit only dry steam to leave the boiler, and the evaporating surface should be of adequate size.

(10) Mud drums, or settling basins for impurities in the water, and means of cleaning them should be provided.

(11) All parts should be easily accessible for repairs.

(12) Possibilities of unequal temperature stresses should be avoided in design, and all parts should be designed with a large safety factor. A countercurrent flow of gases and water establishes more uniform temperature conditions than the ordinary arrangement.

STACK DESIGN.

Stacks for oil-burning equipment differ considerably from those for solid fuels, as relatively slight drafts are required.

Table 5, condensed from one prepared by Weymouth,[a] is based on actual test data. Centrally situated stacks, short flues, average operating efficiencies, and a permissible overload of 50 per cent are assumed.

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[a] Weymouth, C. R., Dimensions of boiler chimneys for crude oil: Trans. Am. Soc. Mech. Eng., vol. 34, 1912, p. 663.

TABLE 5.—*Stack sizes for oil fuel.*

Stack diameter, inches.	Height above boiler-room floor, feet.					
	80	90	100	120	140	160
	Nominal rated boiler horsepower.					
33	161	206	233	270	306	315
36	208	253	295	331	363	387
39	251	303	343	399	488	467
42	295	359	403	474	521	557
48	399	486	551	645	713	760
54	519	634	720	847	933	1,000
60	657	800	913	1,073	1,193	1,280
66	813	993	1,133	1,333	1,480	1,593
72	980	1,206	1,373	1,620	1,807	1,940
84	1,373	1,587	1,933	2,293	2,560	2,767
96	1,833	2,260	2,587	3,087	3,453	3,740
108	2,367	2,920	3,347	4,000	4,483	4,867
120	3,060	3,660	4,207	5,040	5,660	6,160

STEAM AND ITS PROPERTIES.

The temperature of steam in a boiler depends on the pressure under which it is generated; at the atmospheric pressure of 14.7 pounds per square inch its temperature is 212° F. If pressure higher than atmospheric is held in the boiler, the temperature of the water and steam in it is raised to a temperature that corresponds to the increased pressure.

Saturated steam is steam existing at the temperature resulting from this pressure, with no superheat.

Superheated steam is steam that has been heated above the temperature corresponding to its pressure.

Wet steam contains a percentage of moisture in the form of intermingled spray. It has the same temperature as dry saturated steam of the same pressure. The amount of water present is expressed as a percentage and when subtracted from 100 per cent gives the quality of the steam.

The total heat of saturated steam above 32° F. can be computed by the formula

$$H=1{,}150.3+0.3745\ (t-212^\circ)-0.000550\ (t-212^\circ)^2$$

where t is the temperature of the steam in degrees F.

The sensible heat of steam is the amount of heat required to raise the water from 32° F. to the temperature of the steam, or is the heat of the liquid.

The latent heat is the heat required to vaporize the water into steam at any given pressure and is the total heat minus the sensible heat.

The specific volume of saturated steam at any pressure is the volume in cubic feet of 1 pound of steam at that pressure.

Table 6 shows the properties of saturated steam and Table 7 those of superheated steam.

TABLE 6.—*Properties of saturated steam.*[a]

Absolute pressure, pounds.	Temperature, °F.	Specific volume, cubic feet per pound.	Density, pound per cubic foot.	Heat of the liquid, °F.	Latent heat of evaporation, B. t. u.	Heat content of steam, B. t. u.	Internal energy (B. t. u.) of evaporation.	Entropy.	
								Water.	Evaporation.
p	t	v''	$1/v''$	i'	r	i''	l	s'	r/T
1	101.83	333.0	0.00300	69.8	1,034.6	1,104.4	972.9	0.1327	1.8427
2	126.15	173.5	0.00576	94.0	1,021.0	1,115.0	956.7	0.1749	1.7431
3	141.52	118.5	0.00845	109.4	1,012.3	1,121.6	946.4	0.2008	1.6840
4	153.01	90.5	0.01107	120.9	1,005.7	1,126.5	938.6	0.2198	1.6416
5	162.28	73.33	0.01364	130.1	1,000.3	1,130.5	932.4	0.2348	1.6084
6	170.06	61.89	0.01616	137.9	995.8	1,133.7	927.0	0.2471	1.5814
7	176.85	53.56	0.01867	144.7	991.8	1,136.5	922.4	0.2579	1.5582
8	182.86	47.27	0.02115	150.8	988.2	1,139.0	918.2	0.2673	1.5380
9	188.27	42.36	0.02361	156.2	985.0	1,141.1	914.4	0.2756	1.5202
10	193.22	38.38	0.02606	161.1	982.0	1,143.1	910.9	0.2832	1.5042
11	197.75	35.10	0.02849	165.7	979.2	1,144.9	907.8	0.2902	1.4895
12	201.96	32.36	0.03090	169.9	976.6	1,146.5	904.8	0.2967	1.4760
13	205.87	30.03	0.03330	173.8	974.3	1,148.0	902.0	0.3025	1.4639
14	209.55	28.02	0.03569	177.5	971.9	1,149.4	899.3	0.3081	1.4523
14.7	212.00	26.79	0.03732	180.0	970.4	1,150.4	897.6	0.3118	1.4447
15	213.0	26.27	0.03806	181.0	969.7	1,150.7	896.8	0.3133	1.4416
16	216.3	24.79	0.04042	184.4	967.6	1,152.0	894.4	0.3183	1.4311
17	219.4	23.38	0.04277	187.5	965.6	1,153.1	892.1	0.3229	1.4215
18	222.4	22.16	0.04512	190.5	963.7	1,154.2	889.9	0.3273	1.4127
19	225.2	21.07	0.04746	193.4	961.8	1,155.2	887.8	0.3315	1.4045
20	228.0	20.08	0.04980	196.1	960.0	1,156.2	885.8	0.3355	1.3965
21	230.6	19.18	0.05213	198.8	958.3	1,157.1	883.9	0.3393	1.3887
22	233.1	18.37	0.05445	201.3	956.7	1,158.0	882.0	0.3430	1.3811
23	235.5	17.62	0.05676	203.8	955.1	1,158.8	880.2	0.3465	1.3739
24	237.8	16.93	0.05907	206.1	953.5	1,159.6	878.5	0.3499	1.3670
25	240.1	16.30	0.0614	208.4	952.0	1,160.4	876.8	0.3532	1.3604
26	242.2	15.72	0.0636	210.6	950.6	1,161.2	875.1	0.3564	1.3542
27	244.4	15.18	0.0659	212.7	949.2	1,161.9	873.5	0.3594	1.3483
28	246.4	14.67	0.0682	214.8	947.8	1,162.6	872.0	0.3623	1.3425
29	248.4	14.19	0.0705	216.8	946.4	1,163.2	870.5	0.3652	1.3367
30	250.3	13.74	0.0728	218.8	945.1	1,163.9	869.0	0.3680	1.3311
31	252.2	13.32	0.0751	220.7	943.8	1,164.5	867.6	0.3707	1.3257
32	254.1	12.93	0.0773	222.6	942.5	1,165.1	866.2	0.3733	1.3205
33	255.8	12.57	0.0795	224.4	941.3	1,165.7	864.8	0.3759	1.3155
34	257.6	12.22	0.0818	226.2	940.1	1,166.3	863.4	0.3784	1.3107

[a] Condensed from Marks, L. S., and Davis, H. N. Tables and diagrams of the thermal properties of saturated and superheated steam, 1909; by permission of the publishers, Longmans, Green & Co. Marks, L. S., Mechanical engineers' handbook, 1916, p. 324.

TABLE 6.—*Properties of saturated steam*—Continued.

Absolute pressure, pounds.	Temperature, °F.	Specific volume, cubic feet per pound.	Density, pound per cubic foot.	Heat of the liquid, °F.	Latent heat of evaporation, B. t. u.	Heat content of steam, B. t. u.	Internal energy (B. t. u.) of evaporation.	Entropy.	
								Water.	Evaporation.
p	t	v''	$1/v''$	i'	r	i''	l	s'	r/T
35	259.8	11.89	0.0841	227.9	938.9	1,166.8	862.1	0.3808	1.3060
36	261.0	11.58	0.0863	229.6	937.7	1,167.3	860.8	0.3832	1.3014
37	262.6	11.29	0.0886	231.3	936.6	1,167.8	859.5	0.3855	1.2969
38	264.2	11.01	0.0908	232.9	935.5	1,168.4	858.3	0.3877	1.2925
39	265.8	10.74	0.0931	234.5	934.4	1,168.9	857.1	0.3899	1.2882
40	267.3	10.49	0.0953	236.1	933.3	1,169.4	855.9	0.3920	1.2841
41	268.7	10.25	0.0976	237.6	932.2	1,169.8	854.7	0.3941	1.2800
42	270.2	10.02	0.0998	239.1	931.2	1,170.3	853.6	0.3962	1.2759
43	271.7	9.80	0.1020	240.5	930.2	1,170.7	852.4	0.3962	1.2720
44	273.1	9.59	0.1043	242.0	929.2	1,171.2	851.3	0.4002	1.2681
45	274.5	9.39	0.1065	243.4	928.2	1,171.6	850.3	0.4021	1.2644
46	275.8	9.20	0.1087	244.8	927.2	1,172.0	849.2	0.4040	1.2607
47	277.2	9.02	0.1109	246.1	926.3	1,172.4	848.1	0,4059	1.2571
48	278.5	8.84	0.1131	247.5	925.3	1,172.8	847.1	0.4077	1.2536
49	279.8	8.67	0.1153	248.8	924.4	1,173.2	846.1	0 4095	1.2502
50	281.0	8.51	0.1175	250.1	923.5	1,173.6	845.0	0.4113	1.2468
51	282.3	8.35	0.1197	251.4	922.6	1,174.0	844.0	0.4130	1.2435
52	283.5	8.20	0.1219	252.6	921.7	1,174.3	843.1	0.4147	1.2402
53	284.7	8.05	0.1241	253.9	920.8	1,174.7	842.1	0.4164	1.2370
54	285.9	7.91	0.1263	255.1	919.9	1,175.0	841.1	0.4180	1.2339
55	287.1	7.78	0.1285	256.3	919.0	1,175.4	840.2	0.4196	1.2309
56	288.2	7.65	0.1307	257.5	918.2	1,175.7	839.3	0.4212	1.2278
57	289.4	7.52	0.1329	258.7	917.4	1,176.0	838.3	0.4227	1.2248
58	290.5	7.40	0.1350	259.8	916.5	1,176.4	837.4	0.4242	1.2218
59	291.6	7.28	0.1372	261.0	915.7	1,176.7	836.5	0.4257	1.2189
60	292.7	7.17	0.1394	262.1	914.9	1,177.0	835.6	0.4272	1.2160
61	293.8	7.06	0.1416	263.2	914.1	1,177.3	834.8	0.4287	1.2132
62	294.9	6.95	0.1438	264.3	913.3	1,177.6	833.9	0.4302	1.2104
63	295.9	6.85	0.1460	265.4	912.5	1,177.9	833.1	0.4316	1.2077
64	297.0	6.75	0.1482	266.4	911.8	1,178.2	832.2	0.4330	1.2050
65	298.0	6.65	0.1503	267.5	911.0	1,178.5	831.4	0.4344	1.2024
66	299.0	6.56	0.1525	268.5	910.2	1,178.8	830.5	0.4358	1.1998
67	300.0	6.47	0.1547	269.6	909.5	1,179.0	829.7	0.4371	1.1972
68	301.0	6.38	0.1569	270.6	908.7	1,179.3	828.9	0.4385	1.1946
69	302.0	6.29	0.1590	271.6	908.0	1,179.6	828.1	0.4398	1.1921
70	302.9	6.20	0.1612	272.6	907.2	1,179.8	827.3	0.4411	1.1896
71	303.9	6.12	0.1634	273.6	906.5	1,180.1	826.5	0.4424	1.1872
72	304.8	6.04	0.1656	274.5	905.8	1,180.4	825.8	0.4437	1.1848
73	305.8	5.96	0.1678	275.5	905.1	1,180.6	825.0	0.4449	1.1825
74	306.7	5.89	0.1699	276.5	904.4	1,180.9	824.2	0.4462	1.1801
75	307.6	5.81	0.1721	277.4	903.7	1,181.1	823.5	0.4474	1.1778
76	308.5	5.74	0.1743	278.3	903.0	1,181.4	822.7	0.4487	1.1755
77	309.4	5.67	0.1764	279.3	902.3	1,181.6	822.0	0.4499	1.1732
78	310.3	5.60	0.1786	280.2	901.7	1,181.8	821.3	0.4511	1.1710
79	311.2	5.54	0.1808	281.1	901.0	1,182.1	820.6	0.4523	1.1687

TABLE 6.—*Properties of saturated steam*—Continued.

Absolute pressure, pounds.	Temperature, °F.	Specific volume, cubic feet per pound.	Density, pound per cubic foot.	Heat of the liquid, °F.	Latent heat of evaporation, B. t. u.	Heat content of steam, B. t. u.	Internal energy (B. t. u.) of evaporation.	Entropy.	
								Water.	Evaporation.
p	*t*	*v''*	*1/v''*	*i'*	*r*	*i''*	*l*	*s'*	*r/T*
80	312.0	5.47	0.1829	282.0	900.3	1,182.3	819.8	0.4535	1.1665
81	312.9	5.41	0.1851	282.9	899.7	1,182.5	819.1	0.4546	1.1644
82	313.8	5.34	0.1873	283.8	899.0	1,182.8	818.4	0.4557	1.1623
83	314.6	5.28	0.1894	284.6	898.4	1,183.0	817.7	0.4568	1 1602
84	315.4	5.22	0.1915	285.5	897.7	1,183.2	817.0	0.4579	1.1581
85	316.3	5.16	0.1937	286.3	897.1	1,183.4	816.3	0 4590	1.1561
86	317.1	5.10	0.1959	287.2	896.4	1,183.6	815.6	0.4601	1.1540
87	317.9	5.05	0.1980	288.0	895.8	1,183.8	815.0	0.4612	1.1520
88	318.7	5.00	0.2001	288.9	895.2	1,184.0	814.3	0.4623	1.1500
89	319.5	4.94	0.2023	289.7	894.6	1,184.2	813.6	0.4633	1.1481
90	320.3	4.89	0.2044	290.5	893.9	1,184.4	813.0	0.4644	1.1461
91	321.1	4.84	0.2065	291.3	893.3	1,184.6	812.3	0.4654	1.1442
92	321.8	4.79	0.2087	292.1	892.7	1,184.8	811.7	0.4664	1.1423
93	322.6	4.74	0.2109	292.9	892.1	1,184.0	811.0	0.4674	1.1404
94	323.4	4.69	0.2130	293.7	891.5	1,185.2	810.4	0.4684	1.1385
95	324.1	4.65	0.2151	294.5	890.9	1,185.4	809.7	0.4694	1.1367
96	324.9	4.60	0.2172	295.3	890.3	1,185.6	909.1	0.4704	1.1348
97	325.6	4.56	0.2193	296.1	889.7	1,185.8	808.5	0.4714	1.1330
98	326.4	4.51	0.2215	296.8	889.2	1,186.0	807.9	0.4724	1.1312
99	327.1	4.47	0.2237	297.6	888.6	1,186.2	807.2	0.4733	1.1295
100	327.8	4.429	0.2258	298.3	888.0	1,186.3	806.6	0.4743	1.1277
102	329.3	4.347	0.2300	299.8	886.9	1,186.7	805.4	0.4762	1.1242
104	330.7	4.268	0.2343	301.3	885.8	1,187.0	804.2	0.4780	1.1208
106	332.0	4.192	0.2386	302.7	884.7	1,187.4	803.0	0.4798	1.1174
108	333.4	4.118	0.2429	304.1	883.6	1,187.7	801.9	0.4816	1.1141
110	334.8	4.047	0.2472	305.5	882.5	1,188.0	800.7	0.4834	1.1108
112	336.1	3.978	0.2514	306.9	881.4	1,188.4	799.6	0.4852	1.1076
114	337.4	3.912	0.2556	308.3	880.4	1,188.7	798.5	0.4869	1.1045
116	338.7	3.848	0.2599	309.6	879.3	1,189.0	797.4	0.4886	1.1014
118	340.0	3.786	0.2641	311.0	878.3	1,189.3	796.3	0.4903	1.0984
120	341.3	3.726	0.2683	312.3	877.2	1,189.6	795.2	0.4919	1.0954
122	342.5	3.668	0.2726	313.6	876.2	1,189.8	794.2	0.4935	1.0924
124	343.8	3.611	0.2769	314.9	875.2	1,190.1	793.1	0.4951	1.0895
126	345.0	3.556	0.2812	316.2	874.2	1,190.4	792.0	0.4967	1.0865
128	346.2	3.504	0.2854	317.4	873.3	1,190.7	791.0	0.4982	1.0837
130	347.4	3.452	0.2897	318.6	872.3	1,191.0	790.0	0.4998	1.0809
132	348.5	3.402	0.2939	319.9	871.3	1,191.2	789.0	0.5013	1.0782
134	349.7	3.354	0.2981	321.1	870.4	1,191.5	788.0	0.5028	1.0755
136	350.8	3.308	0.3023	322.3	869.4	1,191.7	787.0	0.5043	1.0728
138	352.0	3.263	0.3065	323.4	868.5	1,192.0	876.0	0.5057	1.0702
140	353.1	3.219	0.3107	324.6	867.6	1192.2	785.0	0.5072	1.0675
142	354.2	3.175	0.3150	325.8	866.7	1192.5	784.1	0.5086	1.0649
144	355.3	3.133	0.3192	326.9	865.8	1192.7	783.2	0.5100	1.0624
146	356.3	3.092	0.3234	328.0	864.9	1192.9	782.2	0.5114	1.0599
148	357.4	3.052	0.3276	329.1	864.0	1193.2	781.3	0.5128	1.0574

TABLE 6.—*Properties of saturated steam*—Continued.

Absolute pressure, pounds.	Temperature, °F.	Specific volume, cubic feet per pound.	Density, pound per cubic foot.	Heat of the liquid, °F.	Latent heat of evaporation, B. t. u.	Heat content of steam, B. t. u.	Internal energy (B. t. u.) of evaporation.	Entropy.	
								Water.	Evaporation.
p	t	v''	$1/v''$	i'	r	i''	l	s'	r/T
150	358.5	3.012	0.3320	330.2	863.2	1193.4	780.4	0.5142	1.0550
152	359.5	2.974	0.3362	331.4	862.3	1193.6	779.4	0.5155	1.0525
154	360.5	2.938	0.3404	332.4	861.4	1193.8	778.5	0.5169	1.0501
156	361.6	2.902	0.3446	333.5	860.6	1194.1	777.6	0.5182	1.0477
158	362.6	2.868	0.3488	334.6	859.7	1194.3	776.7	0.5195	1.0454
160	363.6	2.834	0.3529	335.6	858.8	1194.5	775.8	0.5208	1.0431
162	364.6	2.801	0.3570	336.7	858.0	1194.7	775.0	0.5220	1.0409
164	365.6	2.769	0.3612	337.7	857.2	1194.9	774.1	0.5233	1.0387
166	366.5	2.737	0.3654	338.7	856.4	1195.1	773.2	0.5245	1.0365
168	367.5	2.706	0.3696	339.7	855.5	1195.3	772.4	0.5257	1.0343
170	368.5	2.675	0.3738	340.7	854.7	1195.4	771.5	0.5269	1.0321
172	369.4	2.645	0.3780	341.7	853.9	1195.6	770.7	0.5281	1.0300
174	370.4	2.616	0.3822	342.7	853.1	1195.8	769.8	0.5293	1.0278
176	371.3	2.588	0.3864	343.7	852.3	1196.0	769.0	0.5305	1.0257
178	372.2	2.560	0.3906	344.7	851.5	1196.2	768.2	0.5317	1.0235
180	373.1	2.533	0.3948	345.6	850.8	1196.4	767.4	0.5328	1.0215
182	374.0	2.507	0.3989	346.6	850.0	1196.6	766.6	0.5339	1.0195
184	374.9	2.481	0.4031	347.6	849.2	1196.8	765.8	0.5351	1.0174
186	375.8	2.455	0.4073	348.5	848.4	1196.9	765.0	0.5362	1.0154
188	376.7	2.430	0.4115	349.4	847.7	1197.1	764.2	0.5373	1.0134
190	377.6	2.406	0.4157	350.4	846.9	1197.3	763.4	0.5384	1.0114
192	378.5	2.381	0.4199	351.3	846.1	1197.4	762.6	0.5395	1.0095
194	379.3	2.358	0.4241	352.2	845.4	1197.6	761.8	0.5405	1.0076
196	380.2	2.335	0.4283	353.1	844.7	1197.8	761.1	0.5416	1.0056
198	381.0	2.312	0.4325	354.0	843.9	1197.9	760.3	0.5426	1.0038
200	381.9	2.290	0.437	354.9	843.2	1198.1	759.5	0.5437	1.0019
205	384.0	2.237	0.447	357.1	841.4	1198.5	757.6	0.5463	0.9973
210	386.0	2.187	0.457	359.2	839.6	1198.8	755.8	0.5488	0.9928
215	388.0	2.138	0.468	361.4	837.9	1199.2	754.0	0.5513	0.9885
220	389.9	2.091	0.478	363.4	836.2	1199.6	752.3	0.5538	0.9841
225	391.9	2.046	0.489	365.5	834.4	1199.9	750.5	0.5562	0.9799
230	393.8	2.004	0.499	367.5	832.8	1200.2	748.8	0.5586	0.9758
235	395.6	1.964	0.509	369.4	831.1	1200.6	747.0	0.5610	0.9717
240	397.4	1.924	0.520	371.4	829.5	1200.9	745.4	0.5633	0.9676
245	399.3	1.887	0.530	373.3	827.9	1201.2	743.7	0.5655	0.9638
250	401.1	1.850	0.541	375.2	826.3	1201.5	742.0	0.5676	0.9600
260	404.5	1.782	0.561	378.9	823.1	1202.1	738.9	0.5719	0.9525
270	407.9	1.718	0.582	382.5	820.1	1202.6	735.8	0.5760	0.9454
280	411.2	1.658	0.603	386.0	817.1	1203.1	732.7	0.5800	0.9385
290	414.4	1.602	0.624	389.4	814.2	1203.6	729.7	0.5840	0.9316
300	417.5	1.551	0.645	392.7	811.3	1204.1	726.8	0.5878	0.9251
350	431.9	1.334	0.750	408.2	797.8	1206.1	713.3	0.6053	0.8949
400	444.8	1.17	0.86	422.0	786.0	1208.0	701.0	0.621	0.868
450	456.5	1.04	0.96	435.0	774.0	1209.0	690.0	0.635	0.844
500	467.3	0.93	1.08	448.0	762.0	1210.0	678.0	0.648	0.822

NOTATION.

v' =volume in cubic feet of 1 pound of liquid.
v''=volume in cubic feet of 1 pound of saturated vapor, at given temperature.
c' =specific heat of liquid.
c''=specific heat of saturated vapor, at given temperature.
r =latent heat, or heat required to vaporize 1 pound of liquid at given constant pressure and temperature.
$l=r-Ap(v''-v')$=internal latent heat.
$A=\frac{1}{777.7}$=reciprocal of mechanical equivalent of heat.
p=absolute pressure, pounds per square foot.
i', i''=heat content of liquid and saturated vapor, respectively.
u', u''=internal energy of liquid and saturated vapor, respectively.
s' =entropy of the liquid.
s''=entropy of saturated vapor.
T=absolute temperature, °F.

For a unit weight (1 pound) of saturated vapor the following relations exist:

$$i''=i'+r. \qquad u''=u'+l. \qquad s'=\int_{491.6}^{T} c'dT/T. \qquad s''=s'+(r/T).$$

$r/T=A\ dp/dt\ (v''-v')$ (Clapeyron's equation), the derivative dp/dt being determined from the relation $p=f(t)$ between temperature and pressure at saturation.

For a unit weight of mixture of vapor and liquid, quality x, these relations become $i=i''+xr$, $u=u'+xl$, $s=s'+(xr/T)$; also $v=v''+x(v''-v')$.

TABLE 7.—*Properties of superheated steam.*[a]

[*t*—temperature in ° F; *v*—specific volume in cubic feet per pound; *h*—total heat (B. t. u.) from water at 32° F.]

Pressure pounds absolute.		Saturated steam.	Degrees of superheat.							Pressure, pounds absolute.
			50	100	150	200	250	300		
5	*t*	162.3	212.3	262.3	312.3	362.3	412.3	462.3	*t*	5
	v	73.3	79.7	85.7	91.8	97.8	103.8	109.8	*v*	
	h	1,130.5	1,153.5	1,176.4	1,199.5	1,222.5	1,245.6	1,268.7	*h*	
10	*t*	193.2	243.2	293.2	343.2	393.2	443.2	493.2	*t*	10
	v	38.4	41.5	44.6	47.7	50.7	53.7	56.7	*v*	
	h	1,143.1	1,166.3	1,189.5	1,212.7	1,236.0	1,259.3	1,282.5	*h*	
15	*t*	213.0	263.0	313.0	363.0	413.0	463.0	513.0	*t*	15
	v	26.27	28.40	30.46	32.50	34.53	36.56	38.58	*v*	
	h	1,150.7	1,174.2	1,197.6	1,221.0	1,244.4	1,267.7	1,291.1	*h*	
20	*t*	228.0	278.0	328.0	378.0	428.0	478.0	528.0	*t*	20
	v	20.08	21.69	23.25	24.80	26.33	27.85	29.37	*v*	
	h	1,156.2	1,179.9	1,203.5	1,227.1	1,250.6	1,274.1	1,297.6	*h*	
25	*t*	240.1	290.1	340.1	390.1	440.1	490.1	540.1	*t*	25
	v	16.30	17.60	18.86	20.10	21.32	22.55	23.77	*v*	
	h	1,160.4	1,184.4	1,208.2	1,231.9	1,255.6	1,279.2	1,302.8	*h*	
30	*t*	250.4	300.4	350.4	400.4	450.4	500.4	550.4	*t*	30
	v	13.74	14.83	15.89	16.93	17.97	18.99	20.00	*v*	
	h	1,163.9	1,188.1	1,212.1	1,236.0	1,259.7	1,283.4	1,307.1	*h*	
35	*t*	259.3	309.3	359.3	409.3	459.3	509.3	559.3	*t*	35
	v	11.89	12.85	13.75	14.65	15.54	16.42	17.30	*v*	
	h	1,166.8	1,191.3	1,215.4	1,239.4	1,263.3	1,287.1	1,310.8	*h*	
40	*t*	267.3	317.3	367.3	417.3	467.3	517.3	567.3	*t*	40
	v	10.49	11.33	12.13	12.93	13.70	14.48	15.25	*v*	
	h	1,169.4	1,194.0	1,218.4	1,242.4	1,266.4	1,290.3	1,314.1	*h*	
45	*t*	274.5	324.5	374.5	424.5	474.5	524.5	574.5	*t*	45
	v	9.39	10.14	10.86	11.57	12.27	12.96	13.65	*v*	
	h	1,171.6	1,196.6	1,221.0	1,245.2	1,269.3	1,293.2	1,317.0	*h*	
50	*t*	281.0	331.0	381.0	431.0	481.0	531.0	581.0	*t*	50
	v	8.51	9.19	9.84	10.48	11.11	11.74	12.36	*v*	
	h	1,173.6	1,198.8	1,223.4	1,247.7	1,271.8	1,295.8	1,319.7	*h*	
55	*t*	287.1	337.1	387.1	437.1	487.1	537.1	587.1	*t*	55
	v	7.78	8.40	9.00	9.59	10.16	10.73	11.30	*v*	
	h	1,175.4	1,200.8	1,225.6	1,250.0	1,274.2	1,298.1	1,322.0	*h*	
60	*t*	292.7	342.7	392.7	442.7	492.7	542.7	592.7	*t*	60
	v	7.17	7.75	8.30	8.84	9.36	9.89	10.41	*v*	
	h	1,177.0	1,202.6	1,227.6	1,252.1	1,276.4	1,300.4	1,324.3	*h*	

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[a] Reproduced from Marks, L. S., and Davis, H. N., Tables and diagrams of the thermal properties of saturated and superheated steam, 1909, by permission of the publishers, Longmans, Green & Co.; Marks, L. S., Mechanical engineers' handbook, 1916, pp. 324-327.

TABLE 7.—*Properties of superheated steam*—Continued.

Pressure pounds absolute.		Saturated steam.	Degrees of superheat.							Pressure, pounds absolute.
			50	100	150	200	250	300		
65	*t*	298.0	348.0	398.0	448.0	498.0	548.0	598.0	*t*	65
	v	6.65	7.20	7.70	8.20	8.69	9.17	9.65	*v*	
	h	1,178.5	1,204.4	1,229.5	1,254.0	1,278.4	1,302.4	1,326.4	*h*	
70	*t*	302.9	352.9	402.9	452.9	502.9	552.9	602.9	*t*	70
	v	6.20	6.71	7.18	7.65	8.11	8.56	9.01	*v*	
	h	1,179.8	1,205.9	1,231.2	1,255.8	1,280.2	1,304.3	1,328.3	*h*	
75	*t*	307.6	357.6	407.6	457.6	507.6	557.6	607.6	*t*	75
	v	5.81	6.28	6.73	7.17	7.60	8.02	8.44	*v*	
	h	1,181.1	1,207.5	1,232.8	1,257.5	1,282.0	1,306.1	1,330.1	*h*	
80	*t*	312.0	362.0	412.0	462.0	512.0	562.0	612.0	*t*	80
	v	5.47	5.92	6.34	6.75	7.17	7.56	7.95	*v*	
	h	1,182.3	1,208.8	1,234.3	1,259.0	1,283.6	1,307.8	1,331.9	*h*	
85	*t*	316.3	366.3	416.3	466.3	516.3	566.3	616.3	*t*	85
	v	5.16	5.59	6.99	6.38	6.76	7.14	7.51	*v*	
	h	1,183.4	1,210.2	1,235.8	1,260.6	1,285.2	1,309.4	1,333.5	*h*	
90	*t*	320.3	370.3	420.3	470.3	520.3	570.3	620.3	*t*	90
	v	4.89	5.29	5.67	6.04	6.40	6.76	7.11	*v*	
	h	1,184.4	1,211.4	1,237.2	1,262.0	1,286.6	1,310.8	1,334.9	*h*	
95	*t*	324.1	374.1	424.1	474.1	524.1	574.1	624.1	*t*	95
	v	4.65	5.03	5.39	5.74	6.09	6.43	6.76	*v*	
	h	1,185.4	1,212.6	1,238.4	1,263.4	1,288.1	1,312.3	1,336.4	*h*	
100	*t*	327.8	377.8	427.8	477.8	527.8	577.8	627.8	*t*	100
	v	4.43	4.79	5.14	5.47	5.80	6.12	6.44	*v*	
	h	1,186.3	1,213.8	1,239.7	1,264.7	1,289.4	1,313.6	1,337.8	*h*	
105	*t*	331.4	381.4	431.4	481.4	531.4	581.4	631.4	*t*	105
	v	4.23	4.58	4.91	5.23	5.54	5.85	6.15	*v*	
	h	1,187.2	1,214.9	1,240.8	1,265.9	1,290.6	1,314.9	1,339.1	*h*	
110	*t*	334.8	384.8	434.8	484.8	534.8	584.8	634.8	*t*	110
	v	4.05	4.38	4.70	5.01	5.31	5.61	5.90	*v*	
	h	1,188.0	1,215.9	1,242.0	1,267.1	1,291.9	1,316.2	1,340.4	*h*	
115	*t*	338.1	388.1	438.1	488.1	538.1	588.1	638.1	*t*	115
	v	3.88	4.20	4.51	4.81	5.09	5.38	5.66	*v*	
	h	1,188.8	1,216.9	1,243.1	1,268.2	1,293.0	1,370.3	1,341.5	*h*	
120	*t*	341.3	391.3	441.3	491.3	541.3	591.3	641.3	*t*	120
	v	3.73	4.04	4.33	4.62	4.89	5.17	5.44	*v*	
	h	1,189.6	1,217.9	1,244.1	1,269.3	1,294.1	1,318.4	1,342.7	*h*	
125	*t*	344.4	394.4	444.4	494.4	544.4	594.4	644.4	*t*	125
	v	3.58	3.88	4.17	4.45	4.71	4.97	5.23	*v*	
	h	1,190.3	1,218.8	1,245.1	1,270.4	1,295.2	1,319.5	1,343.8	*h*	
130	*t*	347.4	397.4	447.4	497.4	547.4	597.4	647.4	*t*	130
	v	3.45	3.74	4.02	4.28	4.54	4.80	5.05	*v*	
	h	1,191.0	1,219.7	1,246.1	1,271.4	1,296.2	1,320.6	1,344.9	*h*	

TABLE 7.—*Properties of superheated steam*—Continued.

Pressure pounds absolute.		Saturated steam.	Degrees of superheat.							Pressure, pounds absolute.
			50	100	150	200	250	300		
135	*t*	350.3	400.3	450.3	500.3	550.3	600.3	650.3	*t*	135
	v	3.33	3.61	3.88	4.14	4.38	4.63	4.87	*v*	
	h	1,191.6	1,220.6	1,247.4	1,272.3	1,297.2	1,321.6	1,345.9	*h*	
140	*t*	353.1	403.1	453.1	503.1	553.1	603.1	653.1	*t*	140
	v	3.22	3.49	3.75	4.00	4.27	4.48	4.71	*v*	
	h	1,192.2	1,221.4	1,248.0	1,273.3	1,298.2	1,322.6	1,346.9	*h*	
145	*t*	355.8	405.8	455.8	505.8	555.8	605.8	655.8	*t*	145
	v	3.12	3.38	3.63	3.87	4.10	4.33	4.56	*v*	
	h	1,192.8	1,222.2	1,248.8	1,274.2	1,299.1	1,323.6	1,347.9	*h*	
150	*t*	358.5	408.5	458.5	508.5	558.5	608.5	658.5	*t*	150
	v	3.01	3.27	3.51	3.75	3.97	4.19	4.41	*v*	
	h	1,193.4	1,223.0	1,249.6	1,275.1	1,300.0	1,324.5	1,348.8	*h*	
155	*t*	361.0	411.0	461.0	511.0	561.0	611.0	661.0	*t*	155
	v	2.92	3.17	3.41	3.63	3.85	4.06	4.28	*v*	
	h	1,194.0	1,223.6	1,250.5	1,276.0	1,300.8	1,325.3	1,349.7	*h*	
160	*t*	363.6	413.6	463.6	513.6	563.6	613.6	663.6	*t*	160
	v	2.83	3.07	3.30	3.53	3.74	3.95	4.15	*v*	
	h	1,194.5	1,224.5	1,251.3	1,276.8	1,301.7	1,326.2	1,350.6	*h*	
165	*t*	366.0	416.0	466.0	516.0	566.0	616.0	666.0	*t*	165
	v	2.75	2.99	3.21	3.43	3.64	3.84	4.04	*v*	
	h	1,195.0	1,225.2	1,252.0	1,277.6	1,302.5	1,327.1	1,351.5	*h*	
170	*t*	368.5	418.5	468.5	518.5	568.5	618.5	668.5	*t*	170
	v	2.68	2.91	3.12	3.34	3.54	3.73	3.92	*v*	
	h	1,195.4	1,225.9	1,252.8	1,278.4	1,303.3	1,327.9	1,352.3	*h*	
175	*t*	370.8	420.8	470.8	520.8	570.8	620.8	670.8	*t*	175
	v	2.60	2.83	3.04	3.24	3.44	3.63	3.82	*v*	
	h	1,195.9	1,226.6	1,253.6	1,279.1	1,304.1	1,328.7	1,353.2	*h*	
180	*t*	373.1	423.1	473.1	523.1	573.1	623.1	673.1	*t*	180
	v	2.53	2.75	2.96	3.16	3.35	3.54	3.72	*v*	
	h	1,196.4	1,227.2	1,254.3	1,279.9	1,304.8	1,329.5	1,353.9	*h*	
185	*t*	375.4	425.4	475.4	525.4	575.4	625.4	675.4	*t*	185
	v	2.47	2.68	2.89	3.08	3.27	3.45	3.63	*v*	
	h	1,196.8	1,227.9	1,255.0	1,280.6	1,305.6	1,330.2	1,354.7	*h*	
190	*t*	377.6	427.6	477.6	527.6	577.6	627.6	677.6	*t*	190
	v	2.41	2.62	2.81	3.00	3.19	3.37	3.55	*v*	
	h	1,197.3	1,228.6	1,255.7	1,281.3	1,306.3	1,330.9	1,355.5	*h*	
195	*t*	379.8	429.8	479.8	529.8	579.8	629.8	679.8	*t*	195
	v	2.35	2.55	2.75	2.93	3.11	3.29	3.46	*v*	
	h	1,197.7	1,229.2	1,256.4	1,282.0	1,307.0	1,331.6	1,356.2	*h*	
200	*t*	381.9	431.9	481.9	531.9	581.9	631.9	681.9	*t*	200
	v	2.29	2.49	2.68	2.86	3.04	3.21	3.38	*v*	
	h	1,198.1	1,229.8	1,257.1	1,282.6	1,307.7	1,332.4	1,357.0	*h*	

TABLE 7.—*Properties of superheated steam*—Continued.

Pressure pounds absolute.		Saturated steam.	Degrees of superheat.							Pressure, pounds obsolute.
			50	100	150	200	250	300		
205	*t*	384.0	434.0	484.0	534.0	584.0	634.0	684.0	*t*	205
	v	2.24	2.44	2.62	2.80	2.97	3.14	3.30	*v*	
	h	1,198.5	1,230.4	1,257.7	1,283.3	1,308.3	1,333.0	1,357.7	*h*	
210	*t*	386.0	436.0	486.0	536.0	586.0	636.0	686.0	*t*	210
	v	2.19	2.38	2.56	2.74	2.91	3.07	3.23	*v*	
	h	1,198.8	1,231.0	1,258.4	1,284.0	1,309.0	1,333.7	1,358.4	*h*	
215	*t*	388.0	438.0	488.0	538.0	588.0	638.0	688.0	*t*	215
	v	2.14	2.33	2.51	2.68	2.84	3.00	3.16	*v*	
	h	1,199.2	1,231.6	1,259.0	1,284.6	1,309.7	1,334.4	1,359.1	*h*	
220	*t*	389.9	439.9	489.9	539.9	589.9	639.9	689.9	*t*	220
	v	2.09	2.28	2.45	2.62	2.78	2.94	3.10	*v*	
	h	1,199.6	1,232.2	1,259.6	1,285.2	1,310.3	1,335.1	1,359.8	*h*	
225	*t*	391.9	441.9	491.9	541.9	591.9	641.9	691.9	*t*	225
	v	2.05	2.23	2.40	2.57	2.72	2.88	3.03	*v*	
	h	1,199.9	1,232.7	1,260.2	1,285.9	1,310.9	1,335.7	1,360.3	*h*	
230	*t*	393.8	443.8	493.8	543.8	593.8	643.8	693.8	*t*	230
	v	2.00	2.18	2.35	2.51	2.67	2.82	2.97	*v*	
	h	1,200.2	1,233.2	1,260.7	1,286.5	1,311.6	1,336.3	1,361.0	*h*	
235	*t*	395.6	445.6	495.6	545.6	595.6	645.6	695.6	*t*	235
	v	1.96	2.14	2.30	2.46	2.62	2.77	2.91	*v*	
	h	1,200.6	1,233.8	1,261.4	1,287.1	1,312.2	1,337.0	1,361.7	*h*	
240	*t*	397.4	447.4	497.4	547.4	597.4	647.4	697.4	*t*	240
	v	1.92	2.09	2.26	2.42	2.57	2.71	2.85	*v*	
	h	1,200.9	1,234.3	1,261.9	1,287.6	1,312.8	1,337.6	1,362.3	*h*	
245	*t*	399.3	449.3	499.3	549.3	599.3	649.3	699.3	*t*	245
	v	1.89	2.05	2.22	2.37	2.52	2.66	2.80	*v*	
	h	1,201.2	1,234.8	1,262.5	1,288.2	1,313.3	1,338.2	1,362.9	*h*	
250	*t*	401.0	451.0	501.0	551.0	601.0	651.0	701.0	*t*	250
	v	1.85	2.02	2.17	2.33	2.47	2.61	2.75	*v*	
	h	1,201.5	1,235.4	1,263.0	1,288.8	1,313.9	1,338.8	1,363.5	*h*	

OIL FUEL AND ITS PROPERTIES.

The greater proportion of the oil fuel now burned is known as reduced crude or residuum. Formerly crude petroleum was burned but as this has a low flash point and is unsafe to handle, because of its containing the more volatile hydrocarbons, and as it contains considerable water, its use has been largely abandoned. The present practice is to remove the lighter hydrocarbons and the water by partial distillation, thus raising the flash point, recovering the valuable light products, and reducing the water content to an allowable percentage. In addition to oil fuel derived as residuum from topping heavy crude oils—largely from California, Texas, and parts of Oklahoma—the mid-Continent and the eastern fields supply an oil fuel derived from more complete refining operations which has very different characteristics from oil fuel from residuum. It comprises the pressure tar from cracking stills—gas oil—and certain fractions from lubricating and cylinder stocks. In general it is of such viscosity as to require little or no heating for proper burning.

Fuel oil in this country is purchased by volume and not by weight. Table 9 shows that a barrel of reduced crude has a higher calorific value than a barrel of lighter crude. This fact should be remembered by users of oil fuel because in buying fuel calorific value is sought. The table can be used for making approximate calculations of the relative amount of heat to be had from coal, oil, and gas.

The calorific value of a fuel oil is determined in the laboratory by means of a calorimeter. In this apparatus a weighed quantity of fuel is burned in a steel bomb in the presence of oxygen under about 25-atmosphere pressure or with chemically pure sodium peroxide. The heat is absorbed by a known quantity of water surrounding the bomb and the rise in temperature of the water is, with certain corrections, a measure of the amount of heat generated.

The flash point of an oil is the temperature at which it begins to give off appreciable quantities of inflammable vapors. It is determined by heating the oil in a suitable device and testing with a lighted taper or spark. There are two types of flash testers—the open-cup and the closed-cup—and various makes of both types are on the market. Among the open-cup may be mentioned the Tagliabue and the Clevland. The most common closed-cup testers are the New York State, the Pensky-Martens, and the Abel.

The closed-cup testers give more reliable results because they permit better control of conditions, such as rate of heating, uniformity of mixing, and exclusion of drafts. Results obtained with closed-cup testers are always lower than those with open cups because the vapors are concentrated.

The instrument illustrated in figure 2 is the Pensky-Martens closed-cup tester.

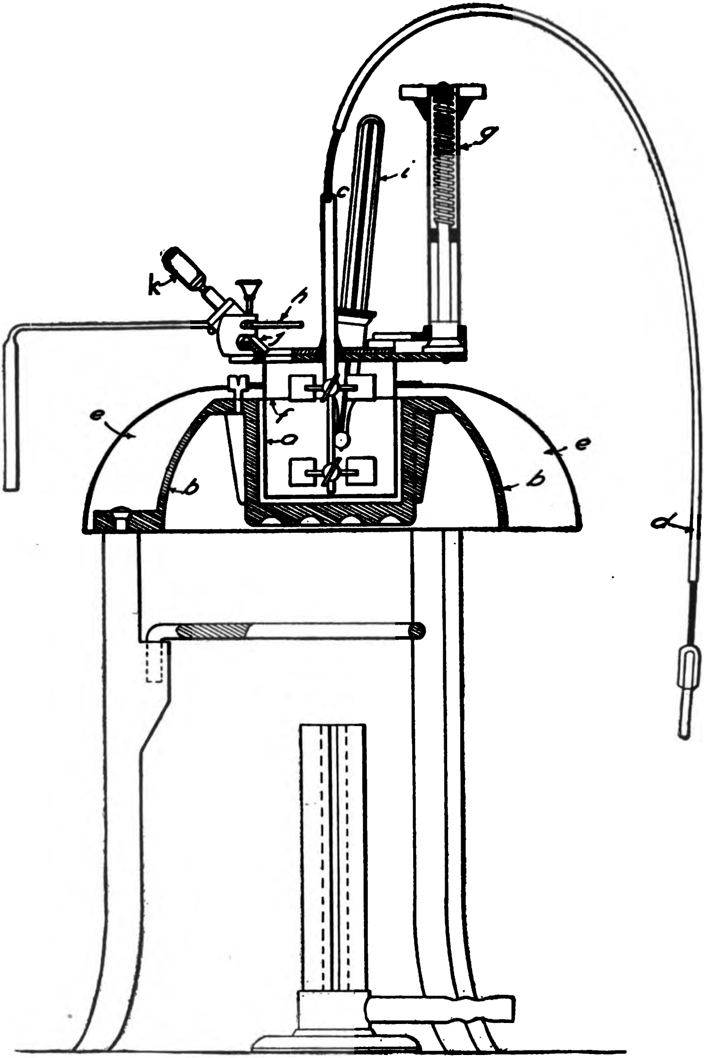

FIGURE 2.—Pensky-Martens closed-cup tester. *a*, oil cup; *b*, air jacket; *c*, stirrer shaft *d*, stirrer; *e*, brass mantle; *f*, graduation mark; *g*, shutter control; *h*, pilot light; *i*, thermometer; *j*, flash flame; *k*, flame adjuster.

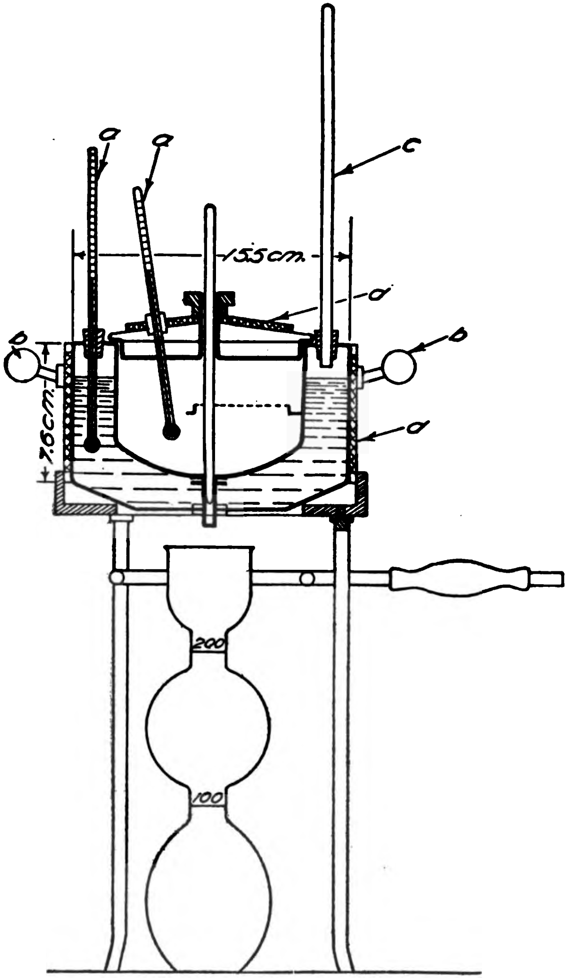

Figure 3.—An Engler viscosimeter. *a, a,* thermometers; *b, b,* wooden handles; *c* condenser; *d, d,* asbestos.

The fire point is the temperature at which the vapors given off are sufficient in volume to remain ignited after flashing; it is determined with the open-cup flash-point apparatus.

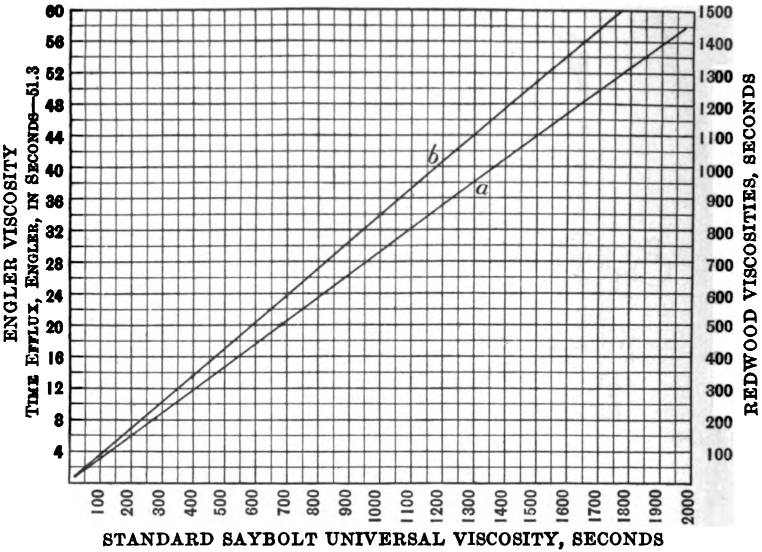

FIGURE 4.—Viscosity curves for converting Saybolt to Engler values, and Saybolt to Redwood values, at any constant temperature. *a*, Saybolt-Engler; *b*, Saybolt-Redwood. Based on Tables 9 and 10, Technologic Paper 110, U. S. Bureau of Standards.

Viscosity of an oil is the measure of the internal friction of the liquid or its resistance to flow. It is generally stated as the time in seconds required for a given quantity of the oil in question to flow through a small orifice, at stated temperature or a ratio of the time of flow of the oil in question to the time of flow of water or some oil as standard at stated temperature. The instrument illustrated in figure 3 is the Engler viscosimeter. With this instrument the time of outflow is taken in seconds by a stop watch and the viscosity is reported as the quotient of the number of seconds required for 200 c. c. of the liquid to be discharged at the given temperature, divided by the number of seconds required for 200 c. c. of water to be discharged at 20° C. The viscosity of water at 60° F. on the Engler scale is 1.0.

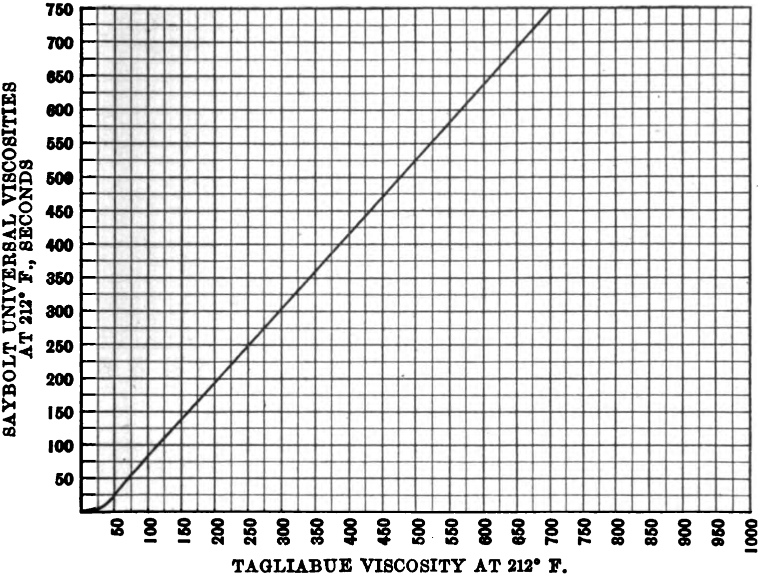

FIGURE 5.—Viscosity curve for converting Saybolt values at 212° F. to Tagliabue viscosities at 212° F. Calculated from formula given in S. A. E. data sheets, vol. 2, 1918, p. 18.

Other common types of instruments are the Redwood, Saybolt, and Tagliabue, so that in stating viscosity the name of the instrument used must be given.

The curves shown in figures 4, 5, and 6 give the relation between viscosities taken by these methods for convenience in converting from one to another. This conversion is not strictly accurate, because of conditions being different with each instrument, but for practical purposes it is of value.

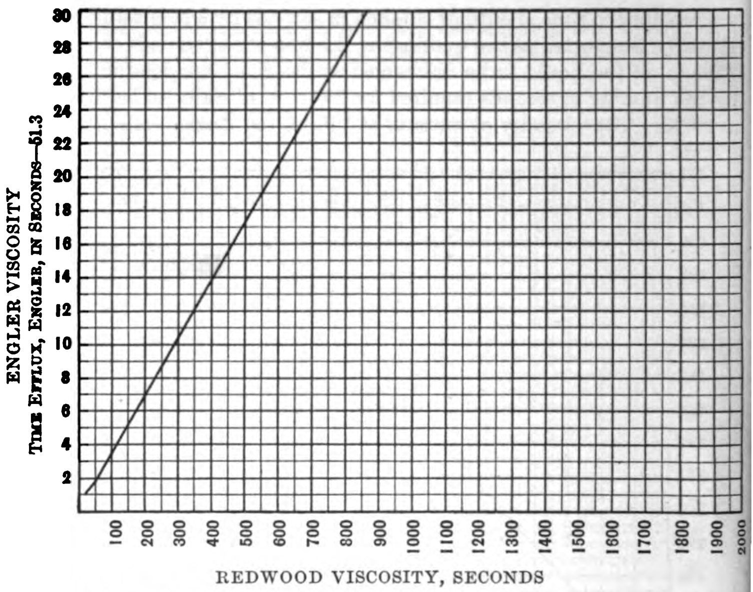

FIGURE 6.—Viscosity curve for converting Redwood to Engler values, at any constant temperature. Computed from Tables 9 and 10, Technologic Paper 112, U. S. Bureau of Standards.

TABLE 8.—*Comparative heat values of coal, oil, and gas.*[a]

Calorific value of coal.	Quantity of coal equal to 1 barrel of oil.	Quantity of oil equal to 1 short ton of coal.	Quantity of coal equal to 1,000 cubic feet gas.	Quantity of gas equal to 1 short ton of coal.
B.t.u. per lb.	*Pounds.*	*Barrels.*	*Pounds.*	*Thousands of feet*
10,000	620	3.23	100	20
11,000	564	3.55	91	22
12,000	517	3.87	83	24
13,000	477	4.19	77	26
14,000	443	4.52	71	28
15,000	443	4.84	67	30

[a] Gebhardt, G. F., Steam power plant engineering, 1913.

The table is based on the assumption that 1 barrel of oil has a heating value of 6,200,000 B. t. u., and that 1,000 cubic feet of gas has a heating value of 1,000,000 B. t. u.

TABLE 9.—*Approximate calorific values of California crude oils.*[a]

° Baumé.	Specific gravity.	Weight per barrel, pounds.	B. t. u. per pound.	B. t. u. per barrel.
10	1.0000	350	18,380	6,442,006
11	.9929	347	18,440	6,417,868
12	.9859	345	18,500	6,393,970
13	.9790	342	18,560	6,370,035
14	.9722	341	18,620	6,345,324
15	.9655	338	18,680	6,323,180
16	.9589	336	18,740	6,301,512
17	.9524	333	18,800	6,279,576
18	.9459	331	18,860	6,257,371
19	.9396	329	18,920	6,234,708
20	.9333	326	18,980	6,212,534
21	.9272	324	19,040	6,192,950
22	.9211	322	19,100	6,173,500
23	.9150	320	19,160	6,153,426
24	.9091	318	19,220	6,133,486
25	.9032	316	19,280	6,113,495
26	.8974	314	19,340	6,093,260
27	.8917	312	19,400	6,072,006
28	.8861	310	19,460	6,051,282
29	.8805	308	19,520	6,030,118
30	.8750	306	19,580	6,008,319
31	.8696	304	19,640	5,990,200
32	.8642	302	19,700	5,972,646
33	.8589	301	19,760	5,954,083
34	.8537	299	19,820	5,935,297
35	.8485	297	19,880	5,917,083
36	.8434	295	19,940	5,900,645
37	.8383	293	20,000	5,884,800
38	.8333	291	20,050	5,865,026
39	.8284	290	20,100	5,846,487
40	.8235	288	20,150	5,827,179
41	.8187	286	20,200	5,808,308
42	.8140	285	20,250	5,789,475
43	.8092	283	20,300	5,770,275
44	.8046	282	20,350	5,750,910
45	.8000	280	20,400	5,732,196

[a] Table from Western Engineering.

DENSITY OF OIL.

The density of an oil is the mass of a unit volume of the oil and is usually expressed in terms of pounds per cubic foot.

The specific gravity of an oil is the relative mass of a given volume of the oil as compared with the mass of the same volume of water at a definitely stated temperature. In tables of specific gravity it is usual to show the temperatures, thus specific gravity at $\frac{60^\circ}{60^\circ}$ F. indicates that the specific gravity of the oil at 60° F. is referred to water at 60° F. as unity.

The Baumé hydrometer is generally used in the United States to measure the "gravity," really the density, of an oil, as described in a circular of the Bureau of Standards as follows:[a]

"It was first proposed and used by Antoine Baumé, a French chemist, in 1768, and from this beginning have come the different Baumé scales that have been prepared since that time. Baumé's directions for setting up his scale state that for the hydrometer scale for liquids heavier than water he used a solution of sodium chloride (common table salt) containing 15 parts of salt and 85 parts of water by weight. He described the salt as being very pure and dry and states that the experiments were conducted in a cellar in which the temperature was 54.5° F.

The point to which the hydrometer sank in the 15 per cent salt solution was marked 15°, and the point to which it sank in distilled water at the same temperature was marked 0°. The space between these two points was divided into 15 equal parts and divisions of the same length were extended beyond the 15° point.

For the hydrometer for liquids lighter than water he used a 10 per cent salt solution for fixing the zero and distilled water for the 10° point. The distance between these points was divided into 10 equal parts, and these divisions extended above the 10° point.

Other makers of Baumé hydrometers soon began to deviate from the procedure outlined by Baumé, partly no doubt through accident and partly through intent, and in the course of time many different Baumé scales came into use.

This condition led to great confusion in the use of the scale.

From a consideration of the variations that occurred it was soon evident that some means of defining and reproducing the scale more exactly than could be done by the simple rules given by Baumé should, if possible, be found. This means was readily provided by assuming that a fixed relation should exist between the Baumé scale and the specific-gravity scale at the

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[a] United States Bureau of Standards, United States standard Baumé hydrometer scales: Circular 59, Apr. 5, 1916, pp. 5-6.

same temperature, and in terms of some definite unit. When this relation is expressed in mathematical terms in the form of an equation, the Baumé scale is fixed beyond all question of doubt. At the present time all Baumé scales in use are based on some such an assumed relation, and the differences existing between them arise from differences in the assumed relation or 'modulus' on which the various scales are based, and the standard temperature at which the instruments are intended to be read.''

The readings on the Tagilabue hydrometer, which is much used in the oil trade, may be converted to the corresponding figures for specific gravity by the following formula:

$$\text{Specific gravity} = \frac{141.5}{131.5} + {}^\circ\ \text{B}.$$

The "modulus" of 141.5 was proposed by the manufacturer when he discovered that his Baumé hydrometers were not graduated in accordance with the American standard Baumé scale in general use, which is based on the "modulus" 140.

The United States Bureau of Standards as a result of its investigations has expressed the relation between the Baumé gravity and the specific gravity for liquids lighter than water by the formula:

$$\text{Specific gravity at } 60^\circ/60^\circ\ \text{F.} = \frac{140}{130 + {}^\circ\ \text{B}}$$

For liquids heavier than water,

$$\text{Specific gravity at } 60^\circ/60^\circ\ \text{F.} = \frac{145}{145 - {}^\circ\ \text{B}}$$

Table 10 gives the gravity (° B.) with the corresponding weight per gallon and specific gravity of oil. Tables 11 to 14 are furnished by the Bureau of Standards supplementary to Circular 57, "United States Standard Tables for Petroleum Oils."

Table 10.—*Degrees Baumé and corresponding specific gravities of oil, pounds per gallon, and gallons per pound.*[a]

Degrees Baumé (modulus 140).	Specific gravity at 60°/60° F.	Pounds per gallon.	Gallons per pound.	Degrees Baumé (modulus 140).	Specific gravity at 60°/60° F.	Pounds per gallon.	Gallons per pound.
10.0	1.0000	8.328	0.1201	30.5	0.8723	7.264	0.1377
10.5	.9964	8.299	.1205	31.0	.8696	7.241	.1381
11.0	.9929	8.269	.1209	31.5	.8669	7.218	.1385
11.5	.9894	8.240	.1214	32.0	.8642	7.196	.1390
12.0	.9859	8.211	.1218	32.5	.8615	7.173	.1394
12.5	.9825	8.182	.1222	33.0	.8589	7.152	.1398
13.0	.9790	8.153	.1227	33.5	.8563	7.130	.1403
13.5	.9756	8.125	.1231	34.0	.8537	7.108	.1407
14.0	.9722	8.096	.1235	34.5	.8511	7.087	.1411
14.5	.9688	8.069	.1239	35.0	.8485	7.065	.1415
15.0	.9655	8.041	.1244	35.5	.8459	7.044	.1420
15.5	.9622	8.013	.1248	36.0	.8434	7.022	.1424
16.0	.9589	7.986	.1252	36.5	.8408	7.001	.1428
16.5	.9556	7.959	.1256	37.0	.8383	6.980	.1433
17.0	.9524	7.931	.1261	37.5	.8358	6.960	.1437
17.5	.9492	7.904	.1265	38.0	.8333	6.939	.1441
18.0	.9459	7.877	.1270	38.5	.8309	6.918	.1446
18.5	.9428	7.851	.1274	39.0	.8284	6.898	.1450
19.0	.9696	7.825	.1278	39.5	.8260	6.877	.1454
19.5	.9365	7.799	.1282	40.0	.8235	6.857	.1459
20.0	.9333	7.772	.1287	40.5	.8211	6.837	.1463
20.5	.9302	7.747	.1291	41.0	.8187	6.817	.1467
21.0	.9272	7.721	.1295	41.5	.8163	6.797	.1471
21.5	.9241	7.696	.1299	42.0	.8140	6.777	.1476
22.0	.9211	7.670	.1304	42.5	.8116	6.758	.1480
22.5	.9180	7.645	.1308	43.0	.8092	6.738	.1484
23.0	.9150	7.620	.1313	43.5	.8069	6.718	.1489
23.5	.9121	7.595	.1317	44.0	.8046	6.699	.1493
24.0	.9091	7.570	.1321	44.5	.8023	6.680	.1497
24.5	.9061	7.546	.1325	45.0	.8800	6.661	.1501
25.0	.9032	7.522	.1330	45.5	.7977	6.642	.1506
25.5	.9003	7.497	.1334	46.0	.7955	6.623	.1510
26.0	.8974	7.473	.1338	46.5	.7932	6.604	.1514
26.5	.8946	7.449	.1342	47.0	.7910	6.586	.1518
27.0	.8917	7.425	.1347	47.5	.7887	6.567	.1523
27.5	.8889	7.402	.1351	48.0	.7865	6.548	.1527
28.0	.8861	7.378	.1355	48.5	.7843	6.530	.1531
28.5	.8833	7.355	.1360	49.0	.7821	6.511	.1536
29.0	.8805	7.332	.1364	49.5	.7799	6.494	.1540
29.5	.8777	7.309	.1368	50.0	.7778	6.476	.1544
30.0	.8750	7.286	.1373	50.5	.7756	6.458	.1548

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[a] United States Bureau of Standards, United States standard tables for petroleum oils. Circular 57, Jan. 29, 1916, p. 57.

TABLE 11.—*Temperature corrections to readings of specific gravity hydrometers in American petroleum oils at various temperatures.*[a]

[Standard at 60°/60° F.]

Observed temperature, °F.	Observed specific gravity.						
	0.650	0.700	0.750	0.800	0.850	0.900	0.950
	Subtract from observed specific gravity						
30	0.016	0.015	0.014	0.012	0.011	0.011	0.011
32	.015	.014	.013	.012	.011	.010	.010
34	.014	.013	.012	.011	.010	.010	.010
36	.013	.012	.011	.010	.009	.009	.009
38	.012	.011	.010	.009	.008	.008	.008
40	.0105	.0095	.0090	.0080	.0075	.0070	.0070
42	.0095	.0085	.0080	.0070	.0065	.0065	.0065
44	.0085	.0075	.0070	.0065	.0060	.0060	.0055
46	.0075	.0065	.0060	.0055	.0050	.0050	.0050
48	.0065	.0060	.0055	.0050	.0045	.0045	.0040
50	.0050	.0050	.0045	.0040	.0035	.0035	.0035
52	.0040	.0040	.0035	.0030	.0030	.0030	.0030
54	.0030	.0030	.0025	.0025	.0020	.0020	.0020
56	.0020	.0020	.0020	.0015	.0015	.0015	.0015
58	.0010	.0010	.0010	.0005	.0005	.0005	.0005
	Add to observed specific gravity.						
60	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
62	.0010	.0010	.0010	.0005	.0005	.0005	
64	.0020	.0020	.0015	.0015	.0015	.0015	
66	.0030	.0030	.0025	.0025	.0020	.0020	
68	.0040	.0040	.0035	.0030	.0030	.0030	
70	.0050	.0050	.0045	.0040	.0040	.0035	
72	.0060	.0055	.0050	.0045	.0045	.0040	
74	.0070	.0065	.0060	.0055	.0050	.0050	
76	.0080	.0075	.0070	.0065	.0060	.0055	
78	.0090	.0085	.0080	.0070	.0065	.0065	
80	.010	.009	.008	.008	.007	.007	
82	.011	.010	.009	.008	.008	.007	
84	.012	.011	.010	.009	.009	.008	
86	.013	.012	.011	.010	.009	.009	
88	.014	.013	.012	.011	.010	.010	
90	.015	.014	.013	.012	.011	.010	
92	.016	.015	.013	.012	.011	.011	
94	.017	.016	.014	.013	.012	.012	
96	.018	.016	.015	.014	.013	.013	
98	.019	.017	.016	.015	.014	.013	

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[a] This table is calculated from the same data as Table 1, Circular 57, Bureau of Standards.

TABLE 11.—*Temperature corrections to readings of specific gravity hydrometers in American petroleum oils at various temperatures*—Continued.

Observed temperature, °F.	Observed specific gravity.						
	0.650	0.700	0.750	0.800	0.850	0.900	0.950
	Add to observed specific gravity.						
100	0.020	0.018	0.017	0.015	0.014	0.014	
102	.021	.019	.018	.016	.015	.015	
104	.022	.020	.018	.017	.016	.015	
106	.023	.021	.019	.017	.016	.016	
108	.024	.022	.020	.018	.017	.017	
110	.025	.023	.021	.019	.018	.017	
112	.026	.024	.022	.020	.019	.018	
114	.027	.025	.022	.020	.019	.019	
116	.028	.026	.023	.021	.020	.019	
118	.029	.026	.024	.022	.021	.020	
120	.030	.027	.025	.023	.022	.021	

TABLE 12.—*Temperature corrections to readings of Baumé hydrometers in American petroleum oils at various temperatures.*[a]

[Standard at 60° F.; modulus 140.]

Observed temperature, °F.	Observed degrees Baumé.							
	20.0	30.0	40.0	50.0	60.0	70.0	80.0	90.0
	Add to observed degrees Baumé.							
30	1.7	2.0	2.4	3.0	3.7	4.3	5.0	5.7
32	1.6	1.9	2.3	2.8	3.4	4.0	4.7	5.3
34	1.5	1.8	2.1	2.6	3.1	3.7	4.3	4.9
36	1.4	1.6	2.0	2.4	2.9	3.4	4.0	4.6
38	1.3	1.5	1.8	2.2	2.6	3.1	3.6	4.2
40	1.2	1.4	1.6	2.0	2.4	2.8	3.2	3.8
42	1.1	1.2	1.5	1.8	2.2	2.5	2.9	3.4
44	.9	1.1	1.3	1.6	2.0	2.2	2.6	3.0
46	.8	.9	1.1	1.4	1.7	1.9	2.3	2.7
48	.7	.8	.9	1.2	1.4	1.6	2.0	2.3
50	.6	.7	.8	1.0	1.2	1.4	1.6	1.9
52	.5	.6	.7	.8	1.0	1.1	1.3	1.5
54	.3	.4	.5	.6	.8	.9	1.0	1.1
56	.2	.3	.3	.4	.5	.6	.6	.7
58	.1	.1	.1	.2	.3	.3	.3	.4

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[a] This table is calculated from the same data as Table 2, Circular 57, Bureau of Standards.

TABLE 12.—*Temperature corrections to readings of Baumé hydrometers in American petroleum oils at various temperatures*—Continued.

Observed temperature, °F.	Observed degrees Baumé.							
	20.0	30.0	40.0	50.0	60.0	70.0	80.0	90.0
	Subtract from observed degrees Baumé.							
60	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
62	.1	.1	.1	.2	.2	.3	.3	.4
64	.2	.3	.3	.4	.4	.6	.6	.7
66	.3	.4	.5	.6	.7	.8	.9	1.0
68	.5	.6	.6	.7	.9	1.1	1.3	1.4
70	.6	.7	.8	.9	1.1	1.4	1.6	1.7
72	.7	.8	.9	1.1	1.3	1.6	1.9	2.1
74	.8	.9	1.1	1.3	1.6	1.8	2.2	2.5
76	.9	1.1	1.3	1.5	1.8	2.1	2.5	2.8
78	1.0	1.2	1.4	1.7	2.0	2.4	2.8	3.1
80	1.1	1.3	1.5	1.8	2.2	2.6	3.1	3.5
82	1.2	1.4	1.7	2.0	2.5	2.9	3.4	3.9
84	1.3	1.5	1.8	2.2	2.7	3.2	3.7	4.3
86	1.4	1.7	2.0	2.4	2.9	3.4	4.0	4.6
88	1.6	1.8	2.1	2.6	3.1	3.7	4.2	4.9
90	1.7	2.0	2.3	2.7	3.3	3.9	4.5	5.2
92	1.8	2.1	2.4	2.9	3.5	4.2	4.8	5.6
94	1.9	2.2	2.6	3.1	3.8	4.4	5.1	5.9
96	2.0	2.3	2.7	3.3	4.0	4.6	5.4	6.3
98	2.1	2.4	2.9	3.4	4.2	4.9	5.7	6.6
100	2.2	2.6	3.0	3.6	4.4	5.1	6.0	6.9
102	2.3	2.7	3.2	3.8	4.6	5.4	6.3	7.2
104	2.4	2.9	3.3	4.0	4.8	5.7	6.6	7.5
106	2.5	3.0	3.5	4.2	5.0	5.9	6.9	7.9
108	2.7	3.1	3.6	4.3	5.2	6.2	7.2	8.2
110	2.8	3.2	3.7	4.4	5.4	6.4	7.5	8.5
112	2.9	3.3	3.9	4.6	5.6	6.7	7.7	8.8
114	3.0	3.4	4.0	4.7	5.8	6.9	7.9	9.1
116	3.1	3.6	4.1	4.9	6.0	7.1	8.2	9.4
118	3.2	3.7	4.3	5.1	6.2	7.3	8.5	9.8
120	3.3	3.8	4.4	5.3	6.4	7.5	8.8	10.1

TABLE 13.—*Temperature corrections to apparent specific gravities of petroleum oils.*[a]

[This table gives the correction to be added to apparent specific gravities of heavy petroleum oils (fuel oils, lubricating oils, etc.), at temperatures of 60° to 210° F. to give the true specific gravity of the oil at 60°/60° F. It is assumed that the hydrometer or picnometer used is of glass having a coefficient of cubical expansion of 0.000023 per degree centigrade, and is correct at 60° F.]

Observed temperature, ° F.	Observed specific gravity.											
	0.850	0.860	0.870	0.880	0.890	0.900	0.910	0.920	0.930	0.940	0.950	0.960
	Add to observed specific gravity to give true specific gravity at 60°/60° F.											
60	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
62	.001	.001	.001	.001	.001	.001	.001	.001	.001	.001	.001	.001
64	.002	.002	.002	.002	.002	.002	.002	.002	.002	.002	.002	.002
66	.002	.002	.002	.002	.002	.002	.002	.002	.002	.002	.002	.002
68	.003	.003	.003	.003	.003	.003	.003	.003	.003	.003	.003	.003
70	.004	.004	.004	.004	.004	.004	.004	.004	.004	.004	.004	.004
72	.004	.004	.004	.004	.004	.004	.004	.004	.004	.004	.004	.004
74	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005
76	.006	.006	.006	.006	.006	.006	.006	.006	.006	.006	.006	.006
78	.006	.006	.006	.006	.006	.006	.006	.006	.006	.006	.006	.006
80	.007	.007	.007	.007	.007	.007	.007	.007	.007	.007	.007	.007
82	.008	.008	.008	.008	.008	.007	.007	.007	.007	.007	.007	.007
84	.009	.008	.008	.008	.008	.008	.008	.008	.008	.008	.008	.008
86	.009	.009	.009	.009	.009	.009	.009	.009	.009	.009	.009	.009
88	.010	.010	.010	.010	.010	.010	.010	.010	.010	.010	.010	.010
90	.011	.011	.011	.011	.010	.010	.010	.010	.010	.010	.010	.010
92	.011	.011	.011	.011	.011	.011	.011	.011	.011	.011	.011	.011
94	.012	.012	.012	.012	.012	.012	.012	.012	.012	.012	.012	.012
96	.013	.013	.013	.013	.013	.013	.012	.012	.012	.012	.012	.012
98	.014	.013	.013	.013	.013	.013	.013	.013	.013	.013	.013	.013
100	.014	.014	.014	.014	.014	.014	.014	.014	.014	.014	.014	.014
105	.016	.016	.016	.016	.016	.016	.016	.016	.016	.016	.016	.016
110	.018	.018	.018	.018	.017	.017	.017	.017	.017	.017	.017	.017
115	.020	.020	.020	.020	.019	.019	.019	.019	.019	.019	.019	.019
120	.022	.021	.021	.021	.021	.021	.021	.021	.021	.021	.021	.021
125	.023	.023	.023	.023	.023	.023	.023	.023	.023	.022	.022	......
130	.025	.025	.025	.025	.025	.024	.024	.024	.024	.024	.024	......
135	.027	.027	.026	.026	.026	.026	.026	.026	.026	.026	.026	......
140	028	.028	.028	.028	.028	.028	.028	.028	.028	.027	.027	......
145	.030	.030	.030	.030	.030	.030	.029	.029	.029	.029	.029	......
150	.032	.032	.032	.031	.031	.031	.031	.031	.031	.031	.031	......
155	.034	.033	.033	.033	.033	.033	.033	.033	.033	.033	......	......
160	.035	.035	.035	.035	.035	.035	.034	.034	.034	.034	......	......
165	.037	.037	.037	.037	.036	.036	.036	.036	.036	.036	......	......
170	.039	.039	.038	.038	.038	.038	.038	.038	.038	.037	......	......
175	.040	.040	.040	.040	.040	.040	.039	.039	.039	.039	......	......
180	.042	.042	.042	.041	.041	.041	.041	.041	.041	.041	......	......
185	.044	.044	.043	.043	.043	.043	.043	.013	.042	......	......	......
190	.045	.045	.045	.045	.045	.044	.044	.044	.044	......	......	......
195	.047	.047	.047	.047	.046	.046	.046	.046	.046	......	......	......
200	.049	.049	.048	.048	.048	.048	.048	.048	.047	......	......	......
205	.051	.050	.050	.050	.050	.050	.049	.049	.049	......	......	......
210	.052	.052	.052	.051	.051	.051	.051	.051	.051	......	......	......

[a] For more complete oil tables, see Circular 57, Bureau of Standards.

TABLE 14.—*Temperature corrections to apparent degrees Baumé of petroleum oils.*[a]

[This table gives the corrections to be subtracted from the apparent degrees Baumé of heavy petroleum oils (fuel oils, lubricating oils, etc.) at temperatures from 60° to 210° F. to give the true degrees Baumé at 60° F. (modulus, 140). It is assumed that the hydrometer is of glass having a coefficient of cubical expansion of 0.000023 per degree centigrade, and is correct at 60° F.]

Observed temperature, °F.	Observed degrees Baumé.											
	14	16	18	20	22	24	26	28	30	32	34	36
	Subtract from observed degrees Baumé to obtain true degrees Baumé at 60° F.											
60	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
62	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1
64	.2	.2	.2	.2	.2	.2	.3	.3	.3	.3	.3	.3
66	.3	.3	.3	.3	.3	.3	.4	.4	.4	.4	.4	.4
68	.4	.4	.4	.5	.5	.5	.5	.5	.6	.6	.6	.6
70	.5	.5	.5	.6	.6	.6	.6	.6	.7	.7	.8	.8
72	.6	.6	.6	.7	.7	.7	.7	.7	.8	.8	.9	.9
74	.7	.7	.7	.8	.8	.8	.9	.9	.9	.9	1.0	1.1
76	.8	.8	.8	.9	.9	.9	1.0	1.0	1.1	1.1	1.2	1.2
78	.9	.9	.9	1.0	1.1	1.1	1.1	1.2	1.2	1.2	1.3	1.4
80	1.0	1.0	1.1	1.1	1.2	1.2	1.2	1.3	1.3	1.3	1.4	1.5
82	....	1.1	1.2	1.2	1.3	1.3	1.3	1.4	1.4	1.5	1.5	1.6
84	....	1.3	1.3	1.3	1.4	1.4	1.5	1.5	1.5	1.6	1.7	1.8
86	....	1.4	1.4	1.4	1.5	1.5	1.6	1.6	1.7	1.8	1.8	1.9
88	....	1.5	1.5	1.6	1.6	1.7	1.7	1.8	1.8	1.9	2.0	2.0
90	....	1.6	1.6	1.7	1.7	1.8	1.8	1.9	2.0	2.0	2.1	2.1
92	....	1.7	1.7	1.8	1.8	1.9	1.9	2.0	2.1	2.1	2.2	2.3
94	....	1.8	1.8	1.9	1.9	2.0	2.0	2.1	2.2	2.2	2.3	2.4
96	....	1.9	1.9	2.0	2.0	2.1	2.2	2.3	2.3	2.4	2.5	2.5
98	....	2.0	2.0	2.1	2.2	2.2	2.3	2.4	2.4	2.5	2.6	2.7
100	....	2.1	2.2	2.2	2.3	2.3	2.4	2.5	2.6	2.7	2.7	2.8
105	....	2.4	2.4	2.5	2.6	2.6	2.7	2.8	2.9	3.0	3.1	3.2
110	....	2.6	2.7	2.8	2.8	2.9	3.0	3.1	3.2	3.3	3.4	3.5
115	....	2.9	2.9	3.0	3.1	3.2	3.3	3.4	3.5	3.6	3.8	3.9
120	....	3.1	3.2	3.3	3.4	3.5	3.6	3.7	3.8	3.9	4.0	4.2
125	....	....	3.4	3.5	3.6	3.7	3.8	4.0	4.1	4.2	4.3	4.5
130	....	....	3.7	3.8	3.9	4.0	4.1	4.3	4.4	4.5	4.7	4.8
135	....	....	3.9	4.1	4.2	4.3	4.4	4.6	4.7	4.8	5.0	5.2
140	....	....	4.2	4.3	4.4	4.6	4.7	4.8	5.0	5.1	5.3	5.5
145	....	....	4.4	4.6	4.7	4.8	5.0	5.1	5.3	5.4	5.6	5.8
150	....	....	4.7	4.8	5.0	5.1	5.2	5.4	5.6	5.7	5.9	6.1
155	....	....	4.9	5.1	5.2	5.4	5.5	5.7	5.9	6.0	6.2	6.4
160	....	....	....	5.3	5.5	5.6	5.8	6.0	6.2	6.3	6.5	6.7
165	....	....	....	5.6	5.7	5.9	6.1	6.3	6.5	6.6	6.8	7.0
170	....	....	....	5.8	6.0	6.2	6.3	6.5	6.7	6.9	7.1	7.3
175	....	....	....	6.0	6.2	6.4	6.6	6.8	7.0	7.2	7.4	7.6
180	....	....	....	6.3	6.5	6.6	6.8	7.1	7.3	7.5	7.7	8.0
185	....	....	....	6.5	6.7	6.9	7.1	7.3	7.6	7.8	8.0	8.3
190	....	....	....	6.8	7.0	7.2	7.4	7.6	7.8	8.1	8.3	8.6
195	....	....	....	7.0	7.2	7.4	7.6	7.9	8.1	8.4	8.6	8.9
200	....	....	....	....	7.5	7.7	7.9	8.1	8.4	8.6	8.9	9.2
205	....	....	....	....	7.7	7.9	8.2	8.4	8.7	8.9	9.2	9.5
210	....	....	....	....	8.0	8.2	8.4	8.7	8.9	9.2	9.5	9.8

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[a] For more complete oil tables see Circular 57, Bureau of Standards.

AVERAGE SPECIFIC HEAT.

All fuel oils are mixtures of many hydrocarbon compounds, each with its own specific heat. When the heat capacity of an oil is desired it is the practice to accept the average specific heat of a similar oil as determined by experiment. Table 15 gives average values for different petroleums.

TABLE 15.—*Specific heat capacities.*[a]

	Specific gravity.	Specific heat capacity.
Petroleum ether at −190° C		0.452
Petroleum ether at −100° C		0.445
Petroleum ether at 0° C		0.419
Kerosene, 21–58° C		0.511
Kerosene, 18–99° C		0.498
Paraffin solid, −20° to 3°		0.377
Paraffin solid, −19° to 20°		0.525
Paraffin solid, 25° to 30°		0.589
Paraffin solid, 35° to 40°		0.622
Paraffin liquid, 52.4° to 55°		0.700
Crude oils:		
Japan	0.862	0.453
Pennsylvania	0.810	0.500
Russia	0.908	0.435
California	0.960	0.398
Bustenari	0.842	0.462
Campina, 0.8 per cent paraffin	0.869	0.467
Campina, 3.2 per cent paraffin	0.854	0.467

Mabery and Goldstein[b] give the following formula for calculating specific heats:

$$\frac{\text{Specific heat} \times \text{molecular weight}}{\text{Number of atoms in molecule}} = K$$

For the hydrocarbons of the paraffin series, C_nH_{2n+2}, the value of K is 2.28.

---

[a] Holde, David, The examination of hydrocarbon oils, 1915, pp. 13 and 17.

[b] Mabery, C. F., and Goldstein, A. H., On the specific heats and heat of vaporization of the paraffin and methylene hydrocarbons: Am. Chem. Jour., 1902, vol. 28, pp. 66–78.

LATENT HEAT OF VAPORIZATION.

The latent heat of vaporization is the amount of heat required to change the oil from a liquid to a vapor; it is called latent because any of the present methods of measuring temperatures will not indicate its presence. The latent heat of vaporization of oil is expressed in B. t. u. per pound of oil and is the experimental average for the hydrocarbon compounds comprising the oil in question. The latent heat of vaporization of commercial gasoline has been given as 130 B. t. u. per pound and that of gas oil as approximately 100 B. t. u. per pound.

COEFFICIENT OF EXPANSION OF OIL.

As oil is sold in the United States by volumetric measurement the temperature at which it is to be measured must be given. The standard temperature is 60° F. With a rise in temperature the oil expands and its volume increases. An average measure of this expansion for California oils is 0.0004 for each increase of 1° F.

Therefore, for measuring oils at a temperature above 60° F. where

Q=actual quantity.
Q_1=measured quantity.
C=coefficient of expansion (variable for different oils) and
T=temperature of Q, in ° F.

$$Q=\frac{Q_1}{1+C(T-60)}$$

For oils measured at a temperature below 60° F. the corrected amount is

$$Q=\frac{Q_1}{1-C(T-60)}$$

Tables of coefficients of expansion of oil have been published in United States Bureau of Standards Circular 57 and Technologic Paper 77.

The interrelation of these various properties of oil will be made evident in the following discussion of burners and proper atomization of the oil for firing.

ATOMIZATION AND BURNERS.

The function of any burner is to atomize or finely divide the oil so t the oil particles will present the maximum of surface for contact with air required for combustion. Usually this air is admitted around burner, provision being made at other points in the furnace for admitt more as needed.

The proper position of air ports and the method of admitting the are of prime importance, slight changes often having a startling effect the fire. In general, the cooling effect of a large volume of air should avoided as much as possible. Preheating the air is decidedly benefi and various furnaces have air flues in the walls for this purpose. It m not be assumed that the heat absorbed by this air would be otherw wasted, as the cooling effect of the air increases the flow of heat through furnace walls.

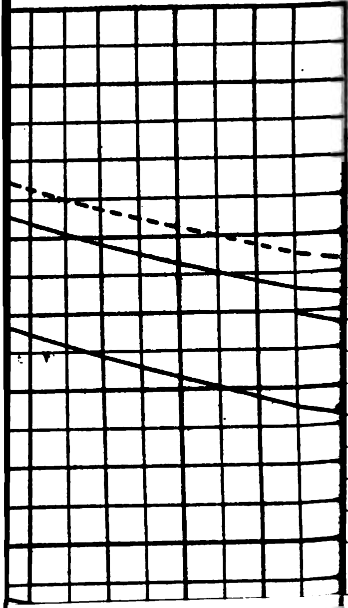
HEATING THE OIL—VISCOSITY AND FLASH POINT.

For effective atomization of heavy fuel oil the viscosity must be redu by heating. The proper viscosity can be determined experimentally; ranges from 8° to 15° Engler. Certain oils now marketed have to be hea above their flash point in order to attain this viscosity, consequently hazard in handling them is increased. Inflammable vapors driven fr the oil at or above the flash point are a continual menace, and such heat should be avoided if possible. The purchaser should specify in contract for a supply of fuel oil that the oil will attain proper viscosity at a tempe ture below the flash point. (See Hyland curves for oil, Plate I.)

In practice there is often a tendency to overheat the oil. Hence att tion is called to the capacity-temperature curve shown in figure 7. T capacity of the burner increases as the oil is heated to a certain tempe ture, determined by the viscosity and the expansion relation, but w further increase of temperature the capacity steadily decreases. T operator should always know the temperature to which the oil is be heated and govern the conditions according to the oil.

HEATERS.

The oil is usually heated by steam, and preferably by exhaust stea which has a heat content that is nearly as great as live steam and at m plants would be wasted otherwise. The immense amount of heat lat



N.

	Gravity.		Flash point, ° F.
	Specific.	° B.	
	1.000	10.0	374
	.988	11.7	220
	.986	12.0	124
	.980	12.9	280
	.980	12.9	285
	.964	13.4	202
	.978	13.2	262
	.952	17.3	126
	.952	17.3	164
nia	.953	17.1	230

in exhaust steam is so rarely utilized that the advantage of utilization needs to be emphasized repeatedly.

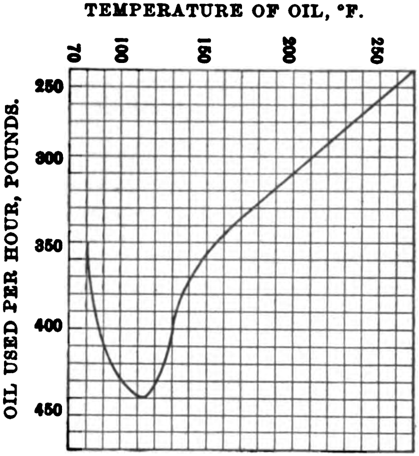


FIGURE 7.—Temperature-capacity curve for mechanical oil burner. Texas crude oil (gravity, 18° B., flash point, 240° F.) used in a Peabody burner producing a round flame at 200-pound pressure.

Many types of heaters are in use. The one shown in figure 8 is illustrated because it incorporates correct engineering principles in its design, as has been stated under the notes on heat transmission, and in practice has shown excellent rates of heat transfer. Many other makes of heaters are giving good service.

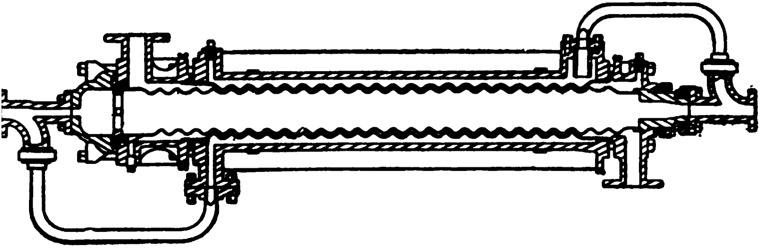


FIGURE 8.—Heater for heating oil fuel by steam.

BURNERS.

Three types of burners have been developed for burning fuel oil, each being better adapted to some conditions than others. No attempt is made in this paper to describe the many burners on the market. For such descriptions the reader is referred to "The Science of Burning Fuel Oil," by W. N. Best, and "Oil Fuel," by E. H. Peabody. However, the various types are defined and their adaptability to different purposes is explained in this paper. The burners illustrated are not selected because of their being more efficient or having greater capacity than others of similar type, but merely to show the principles involved.

STEAM ATOMIZING BURNERS.

Steam atomizing burners are of two types—the outside mixing and the inside mixing. In the outside type, the steam and oil leave the burners from separate nozzles and are mixed directly in the combustion chamber. The burner shown in figure 9 is used rather widely on locomotives. The steam jet is directed across the oil jet and creates a suction effect that aids the atomization.

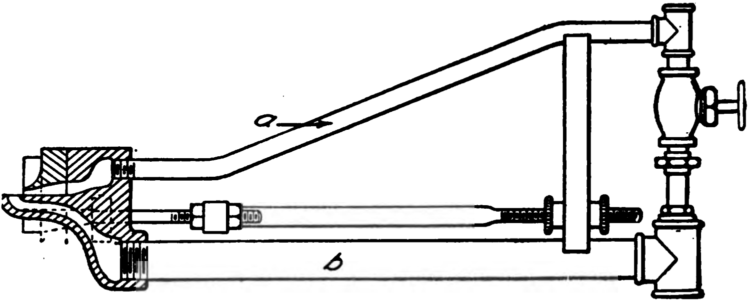


FIGURE 9.—Section of locomotive type of steam-jet burner. *a*, Steam; *b*, oil.

Figure 10 shows a burner of the inside type. The steam enters the mixing chamber through a central nozzle and thus induces the flow of oil. Air is also drawn into the chamber through a small central passage; this air hastens combustion and the central passage facilitates the cleaning of the burner. The outside ring of steam jets is for inducing a sufficient supply of air and directing this where needed.

The steam atomizing burner is in general use for stationary and locomotive practice and excels in effectiveness of atomization. Opinions differ in regard to the efficiency of a boiler and furnace equipped with steam burners as compared with the efficiency with air or pressure jet burners, but authoritative tests with all types have shown that the steam type can give as economical results as any. Its principal advantages are the simplicity of the necessary equipment compared with that required for air or pressure jet burners, and the relatively longer and less intense flame in the furnace. Among the many objections to it are the following: (1) In a boiler furnace quantity rather than intensity of heat is desired, and steam reduces intensity but also reduces available quantity, for its heat capacity is high and it carries a large amount of heat with it up the stack, thus lowering the temperature possible in the furnace; (2) the quantity of steam required makes the supply of additional water an item to be considered anywhere and one that is prohibitive in marine practice; (3) priming in the boiler immediately affects the flame, causing it to fluctuate and sometimes extinguishing it; (4) the burner is not as susceptible to nice control as is always desirable; (5) the steam displaces an equal volume of air in the combustion chamber.

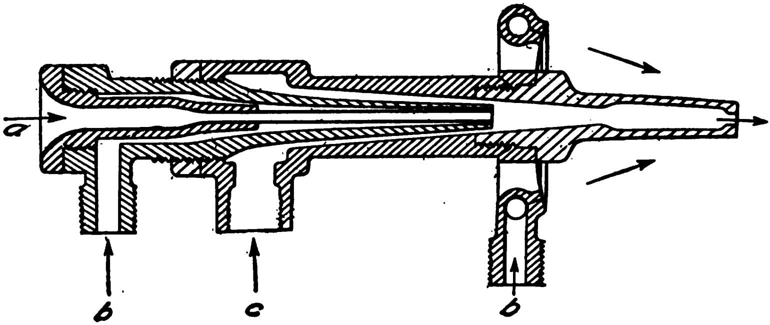


FIGURE 10.—Diagram of intermixing steam-jet burner. *a*, Air; *b b*, steam; *c*, liquid fuel.

AIR-JET BURNERS.

Air-jet burners are used somewhat in marine work and very largely in metallurgical work where intense heat is desired. The effect of an air-jet

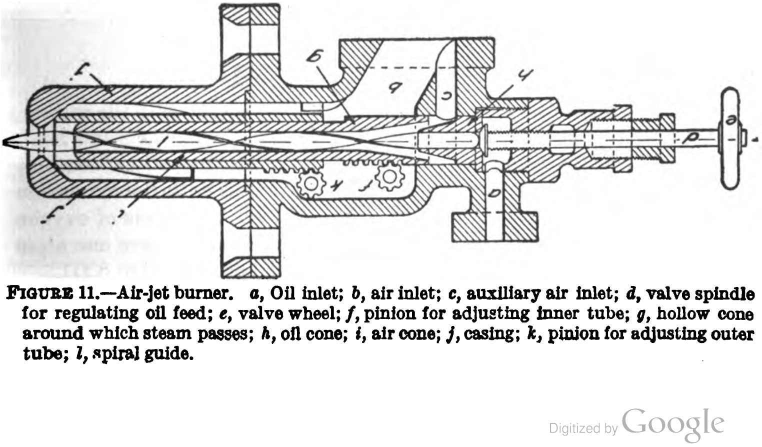


FIGURE 11.—Air-jet burner. *a*, Oil inlet; *b*, air inlet; *c*, auxiliary air inlet; *d*, valve spindle for regulating oil feed; *e*, valve wheel; *f*, pinion for adjusting inner tube; *g*, hollow cone around which steam passes; *h*, oil cone; *i*, air cone; *j*, casing; *k*, pinion for adjusting outer tube; *l*, spiral guide.

burner is an exceedingly short intense flame which has a damaging action on ordinary furnace brickwork. A burner of this type is illustrated in figure 11. The oil enters by pressure at *a* and is regulated by the spindle valve *d*. The supply of compressed air previously heated enters at *b* and *c*, that entering at *c* mixing with the oil spray controlled by *e*. The air can be regulated at two points: One by the pinion *f* which moves the internal tube over the oil nozzle, and the other by the second pinion *k* which adjusts the opening of the outer tube or sleeve against the casing *j*. The air-jet burners are also difficult to regulate quickly and to control uniformly and the equipment necessary is rather elaborate, including an air compressor.

MECHANICAL BURNERS.

A mechanical burner accomplishes atomization by mechanical means, usually by giving the oil a centrifugal throw through small slots tangentially placed in the burner, and the parts are so arranged that the air currents assist in breaking up the oil.

With the mechanical burner illustrated in Plate II it is possible to regulate the fire very closely by means of the adjusting rod.

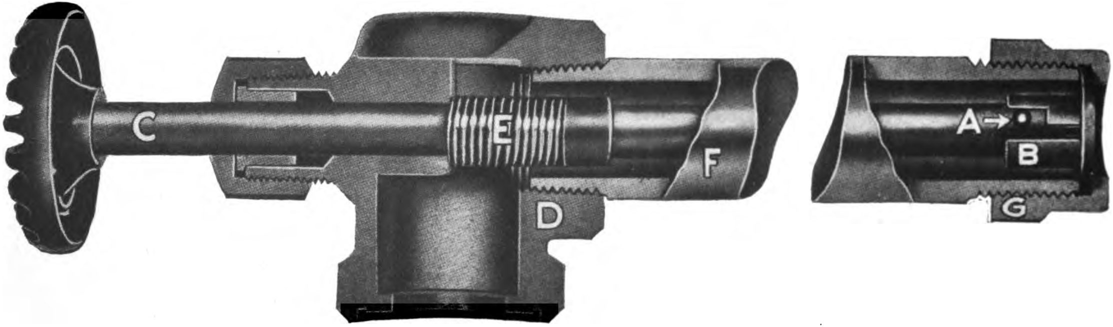
A mechanical burner has the prime advantage of permitting the return as feed water to the boiler of all the steam used by the pumps and heaters; in addition it requires considerably less steam for operating than other burners. These considerations have made its use in marine work quite general; and stationary plants in which feed water is an item are gradually adopting it. Additional advantages are a wide range of capacity and simplicity of equipment and operation.

The objection to burners of this type, as compared with the steam-atomization type, is the equipment required. Also, the general conical shape of the flame and the tendency toward blast action frequently requires change in the furnace to insure successful use.

COMBUSTION OF THE FUEL.

Combustion is the rapid chemical combination of oxygen with the carbon, hydrogen, and sulphur in the fuel, with the production of light and heat. The principal combustibles in the oil are carbon and hydrogen, and combustion is complete when each atom of the carbon unites with the maximum quantity of oxygen, that is, when it combines with two atoms of oxygen to form carbon dioxide (CO_2). Combustion is incomplete when one atom of carbon combines with one of oxygen to form carbon monoxide (CO).

Hydrogen unites with oxygen to form water vapor (H_2O), which passes up the stack as superheated steam. Sulphur unites with oxygen to form



ADJUSTABLE-TIP MECHANICAL OIL BURNER: *A*, PIN; *B*, BURNER TIP; *C*, ADJUSTING ROD; *D*, BURNER VALVE; *E*, BURNER SPRING; *F*, BURNER TUBE; *G*, BURNER CAP.

SO_2, principally, and this forms sulphurous acid when in solution in water. Sulphur is generally undesirable in a fuel oil. Nitrogen in the fuel and in the air required for combusion passes through the furnace unchanged, taking heat up the stack. A certain temperature known as the kindling or ignition temperature is necessary for combustion, hence no cooling action should be allowed in the furnace.

A definite quantity of oxygen is required for the complete combustion of each combustible element shown in Table 17. About one-fifth of the air by volume is oxygen and the exact amount of air required to furnish oxygen enough for complete combusion of the fuel can be computed from an anlysis of the fuel, as follows:

$$\text{Pounds of air per pound of fuel} = 11.52\ C + 34.56\left(H - \frac{O}{8}\right) + 4.32\ S.$$

Where C, H, O, and S are the percentages by weight of the carbon, hydrogen, oxygen, and sulphur in the fuel.

For practical purposes, the quantity required theoretically averages about 14 pounds of air to the pound of fuel oil.

In practice it is not possible to burn oil with only this exact quantity of air, 100 to 200 per cent excess being sometimes used with a resulting great loss of heat. With good design 25 per cent excess should be the maximum. No evidence of heat loss from excessive air supply can be had by watching the stack, for there will be no smoke if the carbon fully combines with oxygen to form CO_2, and the excess air is invisible. Smoke is caused by unburned carbon particles escaping from the cumbustion chamber and cooling below the ignition point in the tubes and uptake. Also, partly decomposed hydrocarbons may escape unburned and be evidenced by smoke. A stack gas just hazy, although it indicates slightly incomplete combustion, is the safest check on operation except the definite knowledge gained by an analysis of the stack gases.

The amount of air required by any furnace depends on the completeness of the atomization obtained with the burners in use, the method of admitting the air, the design of the furnace, and the operating conditions.

Figure 12 shows the heat losses due to excess air in burning fuel. The conditions of operation on which these curves are based are stated beneath the figure.

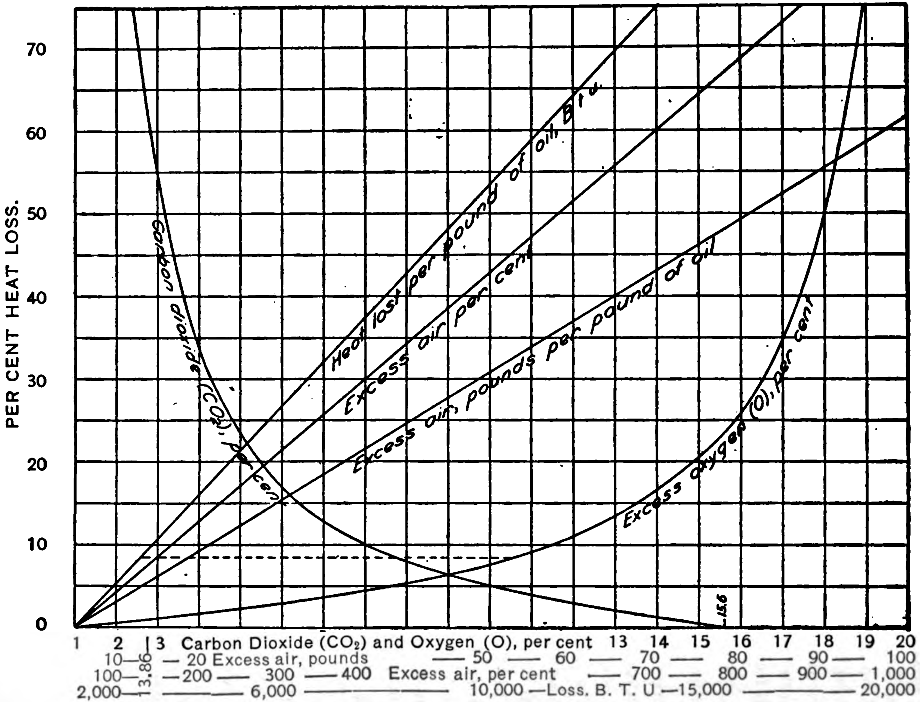


FIGURE 12.—Curves showing heat losses due to excess air. Calculated on following conditions: Oil as fired—18,633 B. t. u., 84.73 per cent carbon, 11.74 per cent hydrogen, 1.06 per cent sulphur, 5 per cent nitrogen, 0.87 per cent oxygen, 0.7 per cent moisture, and 0.4 per cent sediment; atmospheric temperature, 55° F.; [illegible] stack temperature, 500° F.; Kern oil, 15° B.

FLUE-GAS ANALYSIS.

Flue gas is analyzed to determine the conditions of combustion of the fuel and to procure data for apportioning the heat losses. The relative pro-

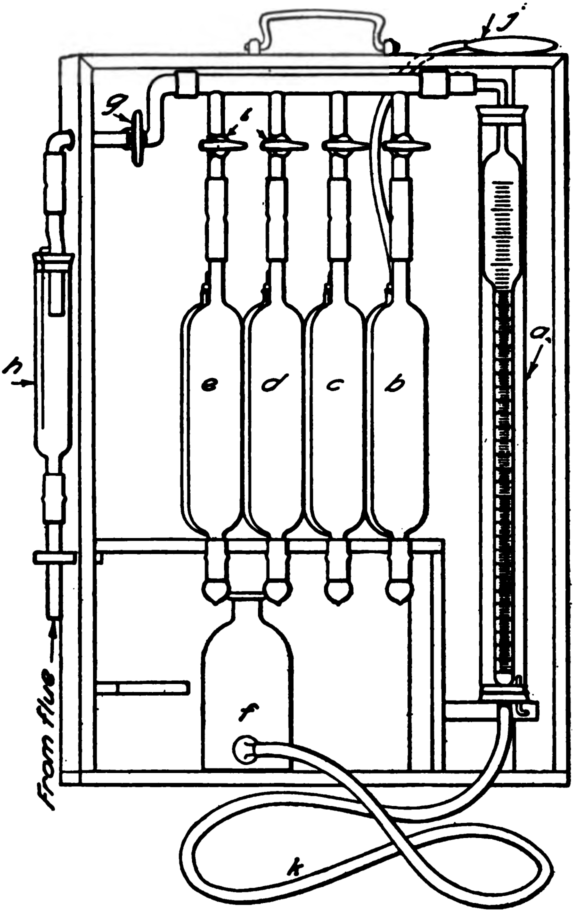


FIGURE 13.—Orsat apparatus for testing flue gases. *a*, Burette; *b*, caustic potash pipette; *c*, alkaline pyrogallol pipette; *d*, *e*, cuprous chloride pipettes; *f*, levelling bottle; *g*, 3-way cock; *h*, U-tube; *i*, cock; *j*, rubber bag; *k*, tube.

portions by volume of carbon dioxide (CO_2), oxygen (O), and carbon monoxide (CO) are determined by the analysis in the order named.

The Orsat apparatus for testing flue gases is simple and is in general use where a portable outfit is desired. It is illustrated in figure 13 and the following is a general description of the method of using it.

The burette *a* is graduated in cubic centimeters up to 100, and is surrounded by a water jacket to prevent any change in temperature from affecting the volume of the gas during analysis.

For accurate work it is advisable to use four pipettes, *b*, *c*, *d*, *e*, the first containing a solution of caustic potash for absorbing carbon dioxide, the second an alkaline solution of pyrogallol for absorbing oxygen, and the remaining two an acid solution of cuprous chloride for absorbing carbon monoxide. Each pipette contains a number of glass tubes, to which some of the solution clings, thus facilitating absorption. In pipettes *d* and *e* these tubes contain copper wire to strengthen the cuprous chloride solution as its absorbent power becomes weakened. The rear half of each pipette is fitted with a rubber bag, one of which is shown at *j*, to protect the solution from the action of the air. The solution in each pipette should be drawn up to the mark on the capillary tube.

The gas is drawn into the burette through the U tube *h*, which is filled with spun glass, or similar material, to clean the gas. To discharge any air or gas in the apparatus, the cock *g* is opened to the air and the bottle *f* is raised until the water in the burette reaches the 100-cubic centimeter mark. The cock *g* is then turned so as to close the air opening and allow gas to be drawn through *h*, the bottle *f* being lowered for this purpose. The gas is drawn into the burette to a point below the zero mark, the cock *g* then being opened to the air and the excess gas expelled until the level of the water in *f* and in *a* are at the zero mark. This procedure is necessary in order to obtain the zero reading at atmospheric pressure.

The apparatus as well as all connections leading thereto should be carefully tested for leakage. Simple tests can be made. For example, if after the cock *g* is closed the bottle *f* is placed on top of the frame for a short time and again brought to the zero mark, the level of the water in *a* is above the zero mark, a leak is indicated.

Before taking a final sample for analysis, the burette *a* should be filled with gas and emptied once or twice, to make sure that all the apparatus is filled with the new gas. The cock *g* is then closed, the cock *i* opened, and the gas driven over into *b* by raising *f*. The gas is drawn back into *a* by lowering *f* and when the solution in *b* has reached the mark in the capillary tube, the cock *i* is closed and a reading is taken on the burette, the level of the water in the bottle *f* being brought to the same level as the water in *a*. The operation is repeated until a constant reading is obtained, the decrease in volume, in cubic centimeters, being the percentage of CO_2 in the flue gases.

The gas is then driven over into the pipette *c* and the apparatus manipulated in a similar manner. The difference between the resulting reading and the carbon dioxide reading gives the percentage of oxygen in the flue gases.

The next operation is to drive the gas into the pipette *d*, the gas being given a final wash in *e*, and then passed into the pipette *c* to absorb any hydrochloric acid fumes that may have been given off by the cuprous chloride solution, if old; such fumes would increase the volume of the gases and make the reading on the burette less than the true amount.

The sum of the percentages by volume of CO_2, O, and CO is subtracted from 100 and for practical purposes this difference is taken as the percentage by volume of N.

The gas must be passed through the burettes in the order named, as the pyrogallol solution will absorb carbon dioxide and the cuprous chloride solution will absorb oxygen.

As the gases in the flue are under less than atmospheric pressure, they will not of themselves flow through the pipe connecting the flue to the apparatus. The gas may be drawn into the pipe in the way already described, but this is tedious. A rubber bulb aspirator connected to the air outlet of the cock *g* will quickly draw a new supply of gas into the pipe. Another form of aspirator draws the gas from the flue in a constant stream, thus insuring a fresh supply for each sample.

The analysis made by the Orsat apparatus is volumetric; if the analysis by weight is required, it can be found from the volumetric analysis as follows:

Multiply the percentages by volume by the molecular weight of each gas, and divide the products by the sum of all the products; the quotients will be the percentages by weight. For most work the use of the even values of the molecular weights insures sufficient accuracy.

The even values of the molecular weights of the gases that appear in an analysis by an Orsat are:

Carbon dioxide (CO_2)	44
Carbon monoxide (CO)	28
Oxygen (O_2)	32
Nitrogen (N_2)	28

Table 16 indicates the method of converting a volumetric flue-gas analysis into an analysis by weight.

TABLE 16.—*Conversion of a flue-gas analysis by volume to one by weight.*

Gas.	Analysis by volume (per cent).	Molecular weight.	Volume times molecular weight.	Analysis by weight (per cent).
Carbon dioxide CO_2	12.2	12+(2×16)	536.8	$\frac{536.8}{3022.8}=17.7$
Carbon monoxide CO	.4	12+16	11.2	$\frac{11.2}{3022.8}=.4$
Oxygen (O_2)	6.9	2×16	220.8	$\frac{220.8}{3022.8}=7.3$
Nitrogen (N_2)	80.5	2×14	2254.0	$\frac{2254.0}{3022.8}=74.6$
Total	100.0	....	3022.8	100.0

From the flue gas analysis the weight of air actually used for combustion can be computed from this formula provided the percentage by weight of C in the fuel is known:

$$\text{Weight of air}=3.036\left(\frac{N}{CO_2+CO}\right)\times C$$

Where N, CO_2, and CO are percentages by volume in the flue gas and C is the percentage by weight of carbon in the fuel.

The quantity of heat (B. t. u.) lost in the flue gases per pound of fuel is $L=0.24\ W(T-t)$ (See figure 14).

Where W=weight in pounds of flue gases per pound of dry fuel.
T=temperature of flue gases, °F.
t=temperature of atmosphere, °F.
0.24=specific heat of flue gases.

The weight W of the flue gases per pound of dry fuel is computed from the analysis by the formula:

$$C\left(\frac{11\ CO_2+8\ O+7\ (CO+N)}{3(CO_2+CO)}\right)$$

where CO_2, O, CO, and N are the percentages by volume, by analyses of the flue gas. C is the percentage by weight of the carbon in the dry fuel.

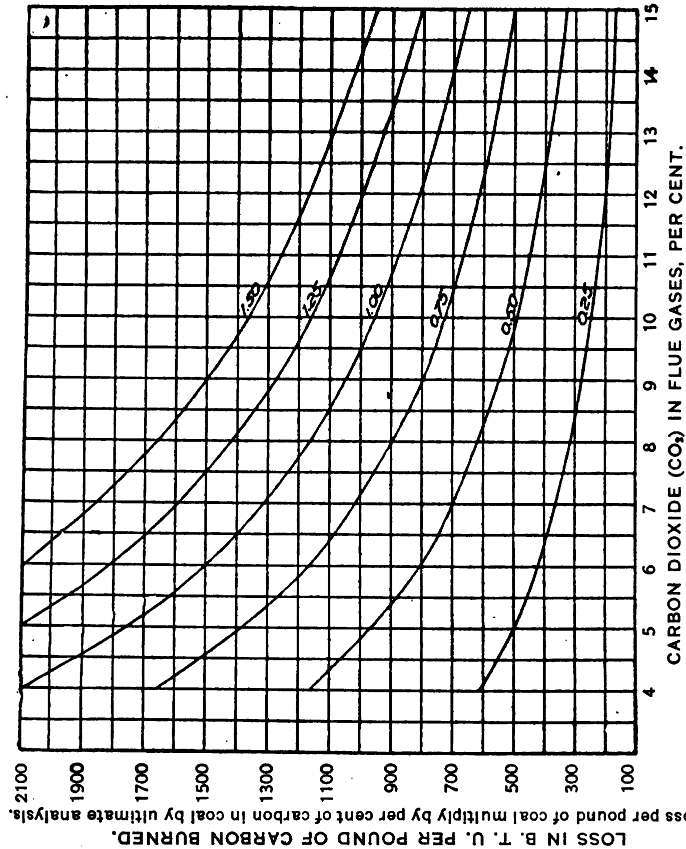


FIGURE 14.—Curves showing heat losses in flue gases per pound of fuel burned. Figures on curves show percentage of carbon monoxide (CO) in the flue gases.

The quantity heat (B. t. u.) lost per pound of fuel oil burned through incomplete combustion of carbon and the presence of CO in the flue gas is in B. t. u. (see figure 14[a]) obtained by using the formula:

$$L=10{,}150\times\left(\frac{CO}{CO+CO_2}\right)C$$

where CO and CO_2 are the percentages of the gases by volume in the flue gases and C is the percentage of C by weight in the fuel.

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[a] From Marks, L. S., Mechanical engineers' handbook, 1916, p. 892, with the permission of the publishers, McGraw-Hill Book Co.

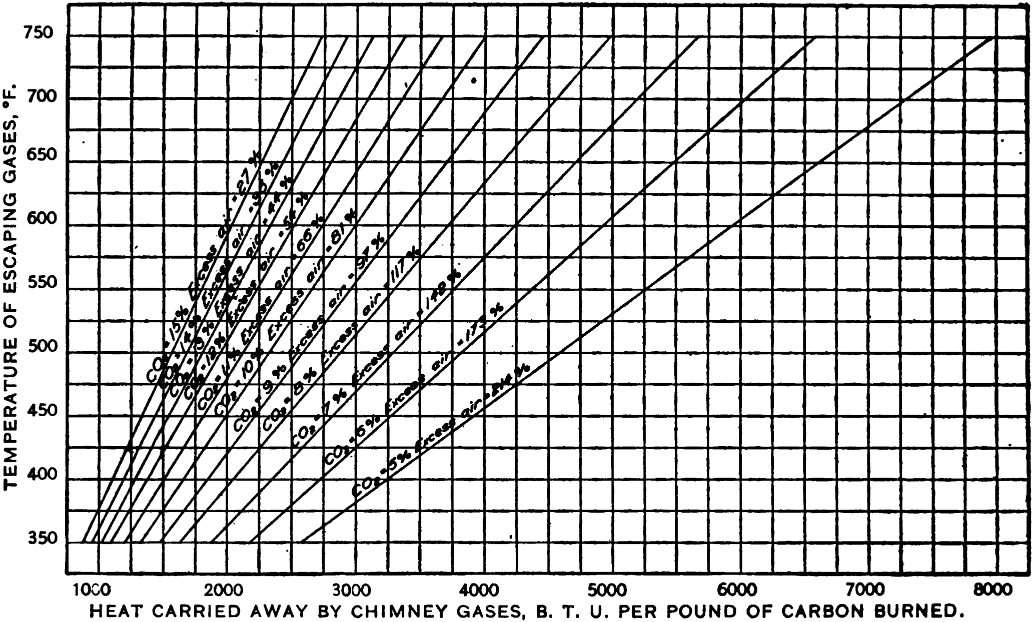

FIGURE 15.—Curves showing relation of heat losses in chimney gases to temperature of gases.

Loss of heat due to the utilization of a portion of the heat of the fuel in evaporating the moisture contained in it after raising it from atmospheric temperature to 212° F, and superheating it to the temperature of the flue gases, in B. t. u. per pound of combustible may be calculated from the formula:

$$(\text{Loss}= W[(212-t)\ t\ 970.4+0.47\ (T-212)]$$

where:

W=moisture per pound of combustible, in pounds.
t=temperature of boiler room in °F.
T=temperature of flue gases in °F.

The loss of heat through the superheating of moisture in the air, the loss being expressed as B. t. u. per pound of combustible equals

$$0.47\ M(T-\text{t})$$

where M=weight of moisture introduced with the air.
t=atmospheric temperature.
T=stack temperature.

The loss due to hydrogen in the fuel, the loss being expressed as B. t. u. per pound of combustible, equals:

$$9\ H(\ (212-\text{t})+970.4+.47\ (T-212)\ )$$

where H=weight of hydrogen per pound of combustible.
T=stack temperature °F.
t=atmospheric temperature °F.

From the above formulas it is possible to compute the distribution and amount of the heat losses. The heat used, absorbed by the boiler, can be computed from a knowledge of the amount of water evaporated and the conditions under which this is done. The steam tables and short explanation accompanying them on pages 17 to 26 will be of assistance in doing this.

Various recording CO_2 meters are in use and if occasionally checked by an Orsat apparatus are invaluable in the proper operation of a plant. CO_2 readings alone are not sufficient without these supplementary readings.

Many plants, upon the installation of meters, have begun the bonus system of firing contingent upon a minimum CO_2 reading for proper operating conditions. The flat rate is paid upon this and a bonus is awarded for any saving obtained in operation by the fireman.

Table 17, showing the composition and calorific value of various oils, is included for reference in connection with the various formulas. As the table shows, the percentage of carbon and hydrogen in the oils varies over a narrow range. For average calculations the analysis of an oil similar to the one under consideration will suffice.

TABLE 17.—*Composition and calorific value of various oils.*[a]

[C=carbon; H=hydrogen; S=sulphur; O=oxygen; M=moisture.]

Kind of oil.	C.	H.	S.	O.	Specific gravity.	Flash point.	M.	B. t. u. per pound.	Authority.
	Per ct.	*Per ct.*	*Per ct.*	*Per ct.*		° *F.*	*Per ct.*		
California, Kern	85.6	11.89	1.09	1.42	0.9589			18,840	
California, Coalinga					.927	134		17,117	Babcock & Wilcox.
California, Bakersfield					.975			17,600	Wade.
Do			1.30		.992			18,257	Do.
California, Kern					.950	140		18,845	Babcock & Wilcox.
California, Los Angeles			2.56					18,328	Do.
Do					.977		[c] .40	18,280	Do.
Do					.957	196		18,855	Do.
California, Monte Christo					.966	205		18,875	Do.
California, Whittier			.98		.944		1.06	18,507	Wade.
Do			.72		.936		1.06	18,240	Do.
California	85.04	11.52	2.45	[b] .99			1.40	17,871	Babcock & Wilcox.
Do	81.52	11.51	.55	[b] 6.92		230		18,667	U. S. Naval Fuel Board.
Do			.87				.95	18,533	Blasdale.
Do					.891	257		18,655	Babcock & Wilcox.
Do			2.45		.973		[c] 1.50	17,976	O'Neill.
Do			2.46		.975		1.32	18,104	Shepherd.
Texas, Beaumont	84.6	10.9	1.63	2.87	.924	180		19,060	U. S. Naval Fuel Board.
Do	83.3	12.4	.50	3.83	.926	216		19,481	Do.
Do	85.0	12.3	1.75	[b] .92				19,060	Denton.
Do	86.1	12.3	1.60		.942			20,152	Sparkes.
Do					.903	222		19,349	Babcock & Wilcox.
Texas, Sabine					.937	143		18,662	Do.
Texas	87.15	12.33	.32		.908	370		19,338	U. S. Navy.
Do	87.29	12.32	.43		.910	375		19,659	Do.
Ohio	83.4	14.7	.60	1.3				19,580	
Pennsylvania	84.9	13.7		1.4	.886			19,210	Booth.
West Virginia	84.3	14.1		1.6	.841			21,240	
Mexico					.921	162		18,840	Babcock & Wilcox.
Russia, Baku	86.7	12.9			.884			20,691	Booth.
Russia, Novorossick	84.9	11.6		3.46				19,452	Do.
Russia, Caucasus	86.6	12.3		1.10	.938			20,138	
Java	87.1	12.0		.9	.923			21,163	
Austria, Galacia	82.2	12.1	5.7		.870			18,416	
Italy, Parma	84.0	13.4	1.8		.786				
Borneo	85.7	11.0		3.31				19,240	Orde.

[a] Table from Babcock & Wilcox Co.'s Handbook on steam. [b] Includes nitrogen. [c] Includes silt.

RECORDING INSTRUMENTS AND THEIR USE.

The chimney on an oil furnace has two functions—it carries away the waste gases and creates a draft, or difference of pressure, sufficient to force the required amount of air into the furnace, the column of hot air within the stack being more than balanced by an equal column of cold air outside. This pressure difference is measured by an instrument called a draft gage, the one illustrated in figure 16 being representative. The instrument records the pressure difference or "draft" in inches of water.

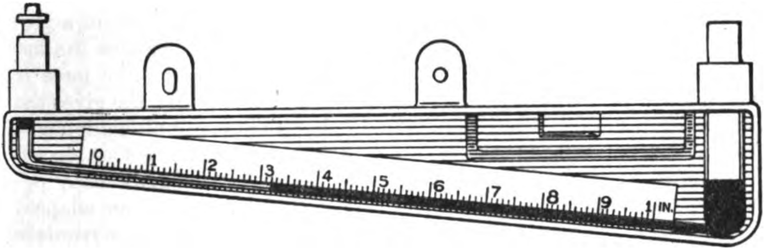

FIGURE 16.—Draft-pressure gage.

One inch of water at 62° F.=0.0360 pound pressure per square inch.

One ounce pressure per square inch at 62° F.=1.732 inches of water.

In oil firing the only resistance this draft is required to overcome is that of the boiler tube and uptake passages, hence it is easy to understand that only a slight draft is necessary for ordinary conditions. Indeed, even when a boiler is forced considerably beyond its rated capacity the present stack sizes are probably adequate to furnish sufficient natural draft.

The use of the draft gage is essential to a true knowledge of furnace operation. The Orsat flue-gas analysis apparatus has been described; it should supplement some type of CO_2 recorder. In this way a constant record may be obtained of plant operations. As oil fuel is easily measured the relation between the quantity fired and the CO_2 readings will immediately be manifest.

RECORDING PYROMETER.

In connection with the flue-gas analysis and computation of heat losses it is advantageous to know the temperature in the furnace and at the base of the stack. Thermoelectric pyrometers are accurate over a wide range of temperatures and are extensively used. They are constructed as follows:

The ends of two wires of different metals, for instance, platinum and platinum-rhodium, are welded together, this union being called the hot junction; and their other ends are connected to a galvanometer of high resistance, by which a needle is deflected over an indicator dial calibrated accurately for different temperatures. The wires are inclosed in a protecting tube and when the end of this tube, which contains the hot junction, is exposed to increased temperature an electromotive force is set up through the galvanometer which deflects the needle and gives the temperature reading directly on the dial. Many thermocouple equipments have also a clock dial and recording pencil for making a continuous record.

In addition to pyrometers equipped with temperature dials many pyrometers have dials reading in millivolts. Such instruments are adapted for use with any calibrated thermocouple and thus have the advantage of interchangeability of elements as well as adaptability to reading temperatures indicated by several differently located thermocouples.

These instruments are all essential to economy of operation and there are few plants at which their installation would not show immediately the substantial savings possible.

BOILER EFFICIENCY, CAPACITY AND RATING.

EFFICIENCY.

It is practically impossible to state the heat absorbing efficiency of a boiler alone, because some losses of the heat from the fuel burned in the furnace can not be proportioned separately to boiler and furnace. As ordinarily stated, therefore, the boiler efficiency is usually the over-all efficiency of both boiler and furnace and is equal to the heat absorbed by water per pound of fuel ÷ by heat value of pound of fuel.

Kreisenger and Ray[a] proposed a formula for true boiler efficiency which is

$$\frac{\text{Heat absorbed by boiler per pound of fuel}}{\text{Heat available for absorption by boiler per pound of fuel}}$$

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[a] Kreisenger, Henry, and Ray, W. T. The transmission of heat into steam boilers: Bull. 18, Bureau of Mines, 1912, pp. 21–22.

This formula recognizes the fact that heat below the temperature of the boiler is not available for absorption by the boiler and is wasted up the stack. Also any factor tending to reduce the temperature of furnace gases is charged to the furnace and not to the boiler.

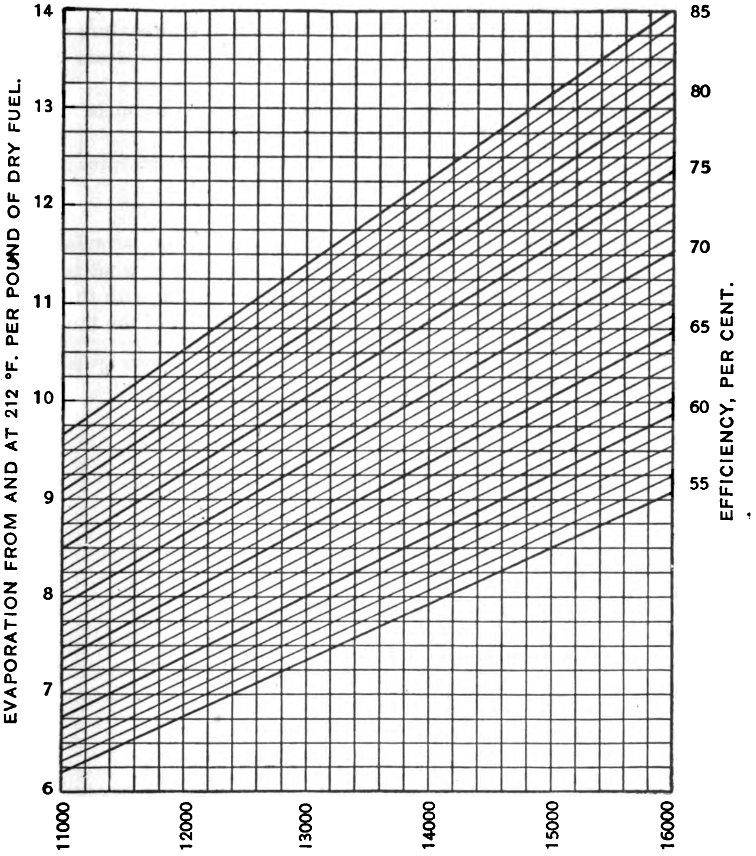

FIGURE 17.—Curves for determining efficiency of steam boilers.

The chart shown in figure 17[a] is a graphic representation of the ordinary over-all boiler furnace efficiency for different evaporative rates.

The difference between the boiler efficiency and 100 per cent efficiency includes the avoidable and unavoidable losses that occur in practice.

These losses are as follows:

(1) Loss due to making steam and superheating to temperature of stack gases the moisture in the fuel and in the air, and also the steam used in atomizing.

(2) Loss due to water formed from burning the hydrogen in the fuel, which must be converted into superheated steam as in (1).

(3) Loss due to heating dry flue gases to their exit temperature.

(4) Loss due to incomplete combustion of fuel.

(5) Loss due to radiation of heat from setting.

These losses, except item 5, can be computed from the formulas given under "flue-gas analysis" and are generally summarized in what is known as a heat balance, in which the total B. t. u. losses, together with the B. t. u. absorbed by the boiler water, equal the B. t. u. content of the fuel.

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[a] From Marks, L. S., Mechanical engineers' handbook, 1916, p. 897, with the permission of the publishers, McGraw-Hill Book Co.

TABLE 18.—*Data and results of evaporation tests to determine efficiency of boilers in burning oil.*[a]

[Tests were conducted by the Standard Oil Co. of California to determine efficiency of boilers fired with "Coen system" of mechanical oil burning.]

Item.	Dimensions, proportions, etc.		Computation. Recorded data marked* Numbers in parentheses () refer to items.	Test No. 2.
3	Kind and number of boilers, 66 inches by 16 feet, return tubular boilers, 2-inch tubes.	Number	*	3
4	Kind of furnace, front firing	Drawing No.	*	B—
5	Kind of burners, mechanical fuel-oil burners	Make	*	Coen.
6	Kind of fuel, oil, and gravity	° B	*	Kern, 16°.
7	Water heating surface	Square feet	*	4,472
8	Date of test		*	6-21-13
9	Duration of test	Hours	*	7
	Average pressures, temperatures, etc.			
10	Steam pressure by gage in main line near boilers	Pounds per sq. inch	*	90.7
11	Steam pressure by gage at oil-heater inlet	do	*	82.0
12	Fuel oil pressure by gage in burner line near pump	do	*	190.2
13	Temperature of steam in main line near boilers	° F	From steam table	331.6
14	Temperature of fuel oil before entering heater	° F	*	102
15	Temperature of fuel oil leaving heater	° F	*	258
16	Temperature of feed water entering boilers	° F	*	162.5
17	Temperature of flue gases leaving boilers	° F	*	411
18	Temperature of boiler room	° F	*	109
19	Temperature of condensed steam leaving heater	° F	*	305
20	Force of draft in chimney near boilers	Inches of water	*	0.125
21	Percentage of moisture in steam (main line)	Per cent	Throttling calorimeter	2.25
22	Percentage of moisture in steam (at oil heater)	do	do	3.3
23	Percentage of moisture and sediment in fuel oil	do	*	0.7 0.4
	Total quantities.			
24	Total weight of oil as fired	Pounds	*	6,023
25	Total weight of dry oil consumed	do	$\frac{100-(23)\times(24)}{100}$	5,956.7

[a] Furnished by Coen Mechanical Atomizing Burner Co.

TABLE 18.—*Data and results of evaporation tests to determine efficiency of boilers in burning oil*—Con.

Item.	Dimensions, proportions, etc.		Computation. Recorded data marked* Numbers in parentheses () refer to items.	Test No. 2.
26	Total weight of water fed to boilers	Pounds	*	87,110
27	Total weight of water evaporated, corrected for moisture in steam.	do		85,392
28	Factor of evaporation based on temperature of feed water.	Factor		1.0889
29	Total equivalent evaporation from and at 212° F.	Pounds	(28)×(27)	92,983
30	Total steam used by fuel-oil pump	do	*	729
31	Total steam used by fuel-oil heater	do	*	581
	Hourly quantities and rates.			
32	Dry oil consumed per hour	Pounds	(25)÷(9)	850.9
33	Equivalent evaporation per hour from and at 212° F	do	(29)÷(9)	13,283
35	Steam used by fuel-oil pump per hour	do	(30)÷(9)	104.1
36	Steam used by fuel-oil heater per hour	do	(31)÷(9)	83.0
	Calorific value and analysis of dry fuel oil.			
37	Calorific value of 1 pound of oil by calorimeter	B. t. u		18,840
A	Analysis: C, 85.6; H, 11.89; O, 0.9; N, 0.52; S, 1.09			
	Capacity.			
38	Evaporation per hour from and at 212° F	Pounds	Same as (33)	13,283
39	Boiler horsepower developed	Brake horsepower	(38)÷34.5	385
40	Rated boiler horsepower	do	(7)÷(10)	447
41	Percentage of rated capacity developed	Per cent	(39)÷(40)	86.1
	Economy results.			
42	Equivalent evaporation from and at 212° F. per pound of oil fired.	Pounds	(29)÷(24)	15.44
43	Equivalent evaporation from and at 212° F. per pound of dry oil.	do	(33)÷(32)	15.61
44	Steam used by fuel-oil pump per pound of oil fired	do	(30)÷(24)	0.1210
45	Steam used by fuel-oil heater per pound of oil fired	do	(31)÷(24)	0.0964

46	Steam used for heating and pumping fuel oil per pound of oil fired.	....do....	(44)+(45)....		0.2174
47	Per cent of total water fed to boilers used for heating and pumping fuel oil.	Per cent....	100×[(30)+(31)]+(26).		1.504
	Efficiency.				
48	Efficiency of boilers....	Per cent....	[(43)×970.4]+(37)....		80.4
	Analysis of dry chimney gases by volumes.		Orsat analysis.		
50	Carbon dioxide (CO_2)....	Per cent....	*		11
51	Oxygen (O)....	....do....	*		6.4
52	Carbon monoxide (CO)....	....do....	*		0.0
53	Nitrogen by difference (N)....	....do....	*		82.6
54	Theoretical weight of air required for combustion per pound of oil.	Pounds....	Computed from analysis of fuel oil.		14.03
55	Excess air for combustion....	Per cent....	From CO_2 curve for analyzed oil.		39
	Heat balance based on oil as fired.			*B.t.u.*	*Per cent.*
56	Heat absorbed by boilers....	....	(42)×970.4....	14,983	80.4
57	Loss due to evaporation of moisture in oil....	....	....	7	0.04
58	Loss due to heat carried away by steam formed by the burning of hydrogen.	....	....	1,251	6.72
59	Loss due to heat carried away in dry chimney gases.	....	....	1,406	7.55
60	Loss due to carbon monoxide....	....	....	....	....
61	Loss due to heating moisture in air, humidity 30 per cent.	....	....	39	0.21
62	Loss due to radiation—losses unaccounted for....	....	....	947	5.08
63	Total calorific value of 1 pound of oil as fired..	....	....	18,633	100.00

CAPACITY.

The method of stating the capacity of a boiler is misleading and somewhat unsatisfactory. The unit expression for work done is the horsepower—defined as the work done in raising 33,000 pounds 1 foot in 1 minute, or its equivalent. The present method of rating boilers developed from an attempt to express boiler capacity in terms of the engine horsepower their steam would develop.

The committee of judges of boiler trials at the Centennial Exposition, 1876, in Philadelphia, determined from tests that the average requirements then for approved types of steam engines in use required 30 pounds of steam per horsepower-hour developed. In an attempt to state boiler capacity in terms of engine requirements, they recommended that the evaporation of 30 pounds of water an hour from 100° F. feed water to steam at 70 pounds be considered as one boiler horsepower. Expressed in terms of equivalent evaporation from and at 212° F. this relation becomes

$$30 \text{ pounds} \times 1.1494 = 34.482 \text{ pounds},$$

and a boiler horsepower is now accepted as the evaporation from and at 212° F. of 34.482 pounds of water per hour.

The factor 1.1494 is known as the factor of evaporation and is calculated by dividing the total heat above 32° F. in one pound of steam at the given pressure minus the total heat in one pound of the feed water above 32° F. by the latent heat of evaporation of 1 pound of steam at 212° F., which is 970.4 B. t. u. See Table 19, evaporation factors.

Expressed as a formula where H equals the total heat of 1 pound of steam above 32° F. (from steam tables) and h equals the sensible heat of feed water above 32° F. (from Table 20)

$$\text{the factor of evaporation} = \frac{H-h}{970.4}.$$

Table 20 is inserted to furnish the heat units contained in feed water of different temperatures above 32° F. It is of assistance in the above formula.

Boilermakers are accustomed to express boiler capacity in terms of heating surface, allowing 10 square feet to a boiler horsepower as the normal rated capacity. In practice with proper operation it is possible to operate a boiler at double this capacity, or better, without injury to it and with little loss in efficiency. Indeed, the possibilities of getting increased capacity from boilers by proper flow of the furnace gases are receiving constantly increasing attention by engineers.

TABLE 19.—*Factors of evaporation.*[a]

Feed-water temperature, ° F.	Steam pressure, by gage.										
	50	60	70	80	90	100	110	12C	130	140	150
32	1.2143	1.2170	1.2194	1.2215	1.2233	1.2251	1.2265	1.2280	1.2292	1.2304	1.2314
40	1.2060	1.2087	1.2111	1.2131	1.2150	1.2168	1.2181	1.2196	1.2209	1.2221	1.2231
50	1.1957	1.1984	1.2008	1.2028	1.2047	1.2065	1.2079	1.2093	1.2106	1.2117	1.2128
60	1.1854	1.1881	1.1905	1.1925	1.1944	1.1961	1.1976	1.1990	1.2003	1.2014	1.2025
70	1.1751	1.1778	1.1802	1.1822	1.1841	1.1859	1.1873	1.1887	1.1900	1.1911	1.1922
80	1.1649	1.1675	1.1699	1.1720	1.1738	1.1756	1.1770	1.1785	1.1797	1.1809	1.1819
90	1.1545	1.1572	1.1596	1.1617	1.1636	1.1653	1.1668	1.1682	1.1695	1.1706	1.1717
100	1.1443	1.1470	1.1493	1.1514	1.1533	1.1550	1.1565	1.1579	1.1592	1.1603	1.1614
110	1.1340	1.1367	1.1391	1.1411	1.1430	1.1448	1.1462	1.1477	1.1489	1.1500	1.1511
120	1.1237	1.1264	1.1288	1.1309	1.1327	1.1345	1.1359	1.1374	1.1386	1.1398	1.1408
130	1.1134	1.1161	1.1185	1.1206	1.1225	1.1242	1.1257	1.1271	1.1284	1.1295	1.1305
140	1.1031	1.1058	1.1082	1.1103	1.1122	1.1139	1.1154	1.1168	1.1181	1.1192	1.1203
150	1.0928	1.0955	1.0979	1.1000	1.1019	1.1036	1.1051	1.1065	1.1078	1.1089	1.1099
160	1.0825	1.0852	1.0876	1.0897	1.0916	1.0933	1.0948	1.0962	1.0975	1.0986	1.0997
170	1.0722	1.0749	1.0773	1.0794	1.0813	1.0830	1.0845	1.0859	1.0872	1.0883	1.0893
180	1.0619	1.0646	1.0670	1.0691	1.0709	1.0727	1.0741	1.0756	1.0768	1.0780	1.0790
190	1.0516	1.0543	1.0567	1.0587	1.0606	1.0624	1.0638	1.0653	1.0665	1.0676	1.0687
200	1.0412	1.0439	1.0463	1.0484	1.0503	1.0520	1.0535	1.0549	1.0562	1.0573	1.0584
210	1.0309	1.0336	1.0360	1.0380	1.0399	1.0417	1.0432	1.0446	1.0458	1.0469	1.0480

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[a] Table from Handbook on steam, issued by Babcock & Wilcox Co., is based on Marks and Davis steam tables.

TABLE 19.—*Factors of evaporation*—Continued.

Feed-water temperature, ° F.	Steam pressure, by gage.									
	160	170	180	190	200	210	220	230	240	250
32	1.2323	1.2333	1.2342	1.2350	1.2357	1.2364	1.2372	1.2378	1.2384	1.2390
40	1.2241	1.2250	1.2259	1.2267	1.2274	1.2282	1.2289	1.2295	1.2301	1.2307
50	1.2137	1.2147	1.2156	1.2164	1.2171	1.2178	1.2186	1.2192	1.2198	1.2204
60	1.2034	1.2044	1.2053	1.2061	1.2068	1.2075	1.2083	1.2089	1.2095	1.2101
70	1.1931	1.1941	1.1950	1.1958	1.1965	1.1972	1.1980	1.1986	1.1992	1.1998
80	1.1828	1.1838	1.1847	1.1855	1.1863	1.1869	1.1877	1.1883	1.1889	1.1895
90	1.1725	1.1735	1.1744	1.1752	1.1760	1.1766	1.1774	1.1780	1.1786	1.1792
100	1.1623	1.1633	1.1642	1.1650	1.1657	1.1664	1.1671	1.1678	1.1684	1.1690
110	1.1520	1.1530	1.1539	1.1547	1.1554	1.1562	1.1569	1.1575	1.1581	1.1587
120	1.1418	1.1427	1.1436	1.1444	1.1452	1.1459	1.1466	1.1472	1.1478	1.1484
130	1.1315	1.1324	1.1333	1.1341	1.1349	1.1356	1.1363	1.1369	1.1375	1.1381
140	1.1212	1.1221	1.1230	1.1239	1.1246	1.1253	1.1260	1.1266	1.1272	1.1278
150	1.1109	1.1118	1.1127	1.1136	1.1143	1.1150	1.1157	1.1163	1.1169	1.1176
160	1.1006	1.1015	1.1024	1.1033	1.1040	1.1047	1.1054	1.1060	1.1066	1.1073
170	1.0903	1.0912	1.0921	1.0930	1.0937	1.0944	1.0951	1.0957	1.0963	1.0969
180	1.0800	1.0809	1.0818	1.0826	1.0834	1.0841	1.0848	1.0854	1.0860	1.0866
190	1.0696	1.0706	1.0715	1.0723	1.0730	1.0737	1.0745	1.0751	1.0757	1.0763
200	1.0593	1.0602	1.0611	1.0620	1.0627	1.0634	1.0641	1.0647	1.0653	1.0660
210	1.0489	1.0499	1.0508	1.0516	1.0523	1.0531	1.0538	1.0544	1.0550	1.0556

TABLE 20.—*B. t. u. per pound and weight per cubic foot of water between 32° and 340° F.*[a]

Temperature.	Heat units per pound.	Weight per cubic foot.	Temperature.	Heat units per pound.	Weight per cubic foot.	Temperature.	Heat units per pound.	Weight per cubic foot.	Temperature.	Heat units per pound.	Weight per cubic foot.	Temperature.	Heat units per pound.	Weight per cubic foot.	Temperature.	Heat units per pound.	Weight per cubic foot.
° *F.*	*B.t.u.*	*Lbs.*	° *F.*	*B.t.u.*	*Lbs.*	° *F.*	*B.t.u*	*Lbs.*	° *F.*	*B.t.u.*	*Lbs.*	° *F.*	*B.t.u.*	*Lbs.*	° *F.*	*B.t.u.*	*Lbs.*
32	0.00	62.42	61	29.08	62.36	90	58.00	62.12	119	86.91	61.72	148	115.86	61.24	177	144.88	60.65
33	1.01	62.42	62	30.08	63.36	91	59.00	62.11	120	87.91	61.71	149	116.86	61.22	178	145.88	60.62
34	2.01	62.42	63	31.07	62.35	92	60.00	62.09	121	88.91	61.69	150	117.86	61.20	179	146.88	60.60
35	3.02	62.43	64	32.07	62.35	93	60.99	62.08	122	89.91	61.68	151	118.86	61.18	180	147.88	60.58
36	4.03	62.43	65	33.07	62.34	94	61.99	62.07	123	90.90	61.66	152	119.86	61.16	181	148.88	60.56
37	5.04	62.43	66	34.07	62.33	95	62.99	62.06	124	91.90	61.65	153	120.86	61.14	182	149.89	60.53
38	6.04	62.43	67	35.07	62.33	96	63.98	62.05	125	92.90	61.63	154	121.86	61.12	183	150.89	60.51
39	7.05	62.43	68	36.07	62.32	97	64.98	62.04	126	93.90	61.61	155	122.86	61.10	184	151.89	60.49
40	8.05	62.43	69	37.06	62.31	98	65.98	62.03	127	94.89	61.59	156	123.86	61.08	185	152.89	60.47
41	9.05	62.43	70	38.06	62.30	99	66.97	62.02	128	95.89	61.58	157	124.86	61.06	186	153.89	60.45
42	10.06	62.43	71	39.06	62.30	100	67.97	62.00	129	96.89	61.56	158	125.86	61.04	187	154.90	60.42
43	11.06	62.43	72	40.05	62.29	101	68.97	61.99	130	97.89	61.55	159	126.86	61.02	188	155.90	60.40
44	12.06	62.43	73	41.05	62.28	102	69.96	61.98	131	98.89	61.53	160	127.86	61.00	189	156.90	60.38
45	13.07	62.42	74	42.05	62.27	103	70.96	61.97	132	99.88	61.52	161	128.86	60.98	190	157.91	60.36
46	14.07	62.42	75	43.05	62.26	104	71.96	61.95	133	100.88	61.50	162	129.86	60.96	191	158.91	60.33
47	15.07	62.42	76	44.04	62.26	105	72.95	61.94	134	101.88	61.49	163	130.86	60.94	192	159.91	60.31
48	16.07	62.42	77	45.04	62.25	106	73.95	61.93	135	102.88	61.47	164	131.86	60.92	193	160.91	60.29
49	17.08	62.42	78	46.04	62.24	107	74.95	61.91	136	103.88	61.45	165	132.86	60.90	194	161.92	60.27
50	18.08	62.42	79	47.04	62.23	108	75.95	61.90	137	104.87	61.43	166	133.86	60.88	195	162.92	60.24
51	19.08	62.41	80	48.03	62.22	109	76.94	61.88	138	105.87	61.41	167	134.86	60.86	196	163.92	60.22
52	20.08	62.41	81	49.03	62.21	110	77.94	61.86	139	106.87	61.40	168	135.86	60.84	197	164.93	60.19
53	21.08	62.41	82	50.03	62.20	111	78.94	61.85	140	107.87	61.38	169	136.86	60.82	198	165.93	60.17
54	22.08	62.40	83	51.02	62.19	112	79.93	61.83	141	108.87	61.36	170	137.87	60.80	199	166.94	60.15
55	23.08	62.40	84	52.02	62.18	113	80.93	61.82	142	109.87	61.34	171	138.87	60.78	200	167.94	60.12
56	24.08	62.39	85	53.02	62.17	114	81.93	61.80	143	110.87	61.33	172	139.87	60.76	201	168.94	60.10
57	25.08	62.39	86	54.01	62.16	115	82.92	61.79	144	111.87	61.31	173	140.87	60.73	202	169.95	60.07
58	26.08	62.38	87	55.01	62.15	116	83.92	61.77	145	112.86	61.29	174	141.87	60.71	203	170.95	60.05
59	27.08	62.37	88	56.01	62.14	117	84.92	61.75	146	113.86	61.27	175	142.87	60.69	204	171.96	60.02
60	28.08	62.37	89	57.00	62.13	118	85.92	61.74	147	114.86	61.25	176	143.87	60.67	205	172.96	60.00

[a] Table prepared from Handbook on steam, issued by Babcock & Wilcox Co., is based on Marks and Davis's steam tables.

TABLE 20.—*B. t. u. per pound and weight per cubic foot of water between 32° and 340° F.*—Continued.

Temperature.	Heat units per pound.	Weight per cubic foot.	Temperature.	Heat units per pound.	Weight per cubic foot.	Temperature.	Heat units per pound.	Weight per cubic foot.	Temperature.	Heat units per pound.	Weight per cubic foot.	Temperature.	Heat units per pound.	Weight per cubic foot.	Temperature.	Heat units per pound.	Weight per cubic foot.
° *F.*	*B.t.u.*	*Lbs.*	° *F.*	*B.t.u.*	*Lbs.*	° *F.*	*B.t.u.*	*Lbs.*	° *F.*	*B.t.u.*	*Lbs.*	° *F.*	*B.t.u.*	*Lbs.*	° *F.*	*B.t.u.*	*Lbs.*
206	173.97	59.98	215	183.0	59.75	224	192.1	59.53	233	201.2	59.29	242	210.3	59.05	260	228.6	58.55
207	174.97	59.95	216	184.0	59.73	225	193.1	59.50	234	202.2	59.27	243	211.4	59.03	270	238.8	58.26
208	175.98	59.93	217	185.0	59.70	226	194.1	59.48	235	203.2	59.24	244	212.4	59.00	280	249.0	57.96
209	176.98	59.90	218	186.1	59.68	227	195.2	59.45	236	204.2	59.21	245	213.4	58.97	290	259.3	57.65
210	177.99	59.88	219	187.1	59.65	228	196.2	59.42	237	205.3	59.19	246	214.4	58.94	300	269.6	57.33
211	178.99	59.85	220	188.1	59.63	229	197.2	59.40	238	206.3	59.16	247	215.4	58.91	310	279.9	57.00
212	180.00	59.83	221	189.1	59.60	230	198.2	59.37	239	207.3	59.14	248	216.4	58.89	320	290.2	56.66
213	181.0	59.80	222	190.1	59.58	231	199.2	59.34	240	208.3	59.11	249	217.4	58.86	330	300.6	56.30
214	182.0	59.78	223	191.1	59.55	232	200.2	59.32	241	209.3	59.08	250	218.5	58.83	340	311.0	55.94

AUXILIARY APPARATUS AS AN AID TO FUEL SAVING.

Apart from the actual firing of the fuel, many other considerations enter into the economic operation of a boiler plant.

FEED-WATER SOFTENERS AND TREATERS.

All natural water, except rain water, contains chemicals in solution or suspension which may appear as solids under boiler conditions. When by analysis such solid-forming compounds are determined in water they may be removed or rendered harmless by some method of treatment.

Against the cost of this treatment is balanced the decreased capacity and efficiency of the boiler when fired through scaly tubes, the depreciation of the tubes, and also the frequency of cleaning and repairs with the necessary shutdowns.

Scale is formed by the deposit of these compounds on the heating surface, through their concentration in the process of evaporation, the lower power of the water to hold them in solution at high temperatures, and the chemical reactions produced by concentration and temperature. It may also be formed by mud and sediment being cemented with other impurities on the surface.

Table 21 classifies many scale-forming impurities and the various methods of overcoming their effect.

TABLE 21.—*Approximate classification of impurities found in feed waters, their effect, and ordinary methods of relief.*[a]

Impurity.	Nature of difficulty.	Ordinary method of overcoming or relieving.
Sediment, mud, etc	Incrustation	Settling tanks, filtration, blowing down.
Readily soluble salts	do	Blowing down.
Bicarbonates of lime, magnesia, etc.	do	Heating feed. Treatment by addition of lime, or lime and soda. Barium carbonate.
Sulphate of lime	do	Treatment by addition of barium carbonate.
Chloride and sulphate of magnesia.	Corrosion	Treatment by addition of carbonate of soda.
Acid	do	Alkali.
Dissolved carbonic acid and oxygen.	do	Heating feed. Keeping air from feed Addition of caustic soda or slacked lime.
Grease	do	Filter. Iron alum as coagulant. Neutralization by carbonate of soda. Use of best hydrocarbon oils.
Organic matter	do	Filter. Use of coagulant.
Organic matter (sewage)	Priming	Settling tanks. Filter in connection with coagulant.
Carbonate of soda in large quantities.	do	Barium carbonate. New feed supply. If from treatment, change.

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[a] From Marks, L. S., Mechanical engineers' handbook, 1916, p. 907; with the permission of the publishers, McGraw-Hill Book Co.

In general one can say that it always pays to treat a poor feed water and, further, the treatment should be outside the boiler. Boiler compounds should be used only when treatment plants are not feasible. Treatment plants use different chemical reagents for precipitating the scale-forming substance in water—soda and lime being the most common. Tannins or other chemicals forming colloidal solutions are sometimes used.

The losses from firing through scale, and from foaming and priming caused by impurities, although difficult to express in precise terms, are nevertheless actual and quite evident upon careful observation.

FEED WATER HEATERS.

The fuel saving possible from heating feed water may be computed from the formula:

$$\text{Percentage of fuel saving} = \frac{100(t - t^1)}{H + 32 - t^1}$$

where t equals the feed water temperature after heating, t^1 the temperature of feed water before heating, and H is the heat content above 32° F. per pound of steam at boiler pressure.

Table 22 following gives the percentage of fuel that can be saved by heating feed water.

TABLE 22.—*Data for feed-water heaters.*[a]

Initial temperature of feed water, °F.	Steam pressure in boiler, pounds per square inch above atmosphere.										
	0	20	40	60	80	100	120	140	160	180	200
32	0.0872	0.0861	0.0855	0.0851	0.0847	0.0844	0.0841	0.0839	0.0837	0.0835	0.0833
40	.0878	.0867	.0861	.0856	.0853	.0850	.0847	.0845	.0843	.0841	.0839
50	.0886	.0875	.0868	.0864	.0860	.0857	.0854	.0852	.0850	.0848	.0846
60	.0894	.0883	.0876	.0872	.0867	.0864	.0862	.0859	.0856	.0855	.0853
70	.0902	.0890	.0884	.0879	.0875	.0872	.0869	.0867	.0864	.0862	.0860
80	.0910	.0898	.0891	.0887	.0883	.0879	.0877	.0874	.0872	.0870	.0868
90	.0919	.0907	.0900	.0895	.0888	.0887	.0884	.0883	.0879	.0877	.0875
100	.0927	.0915	.0908	.0903	.0899	.0895	.0892	.0890	.0887	.0885	.0883
110	.0936	.0923	.0916	.0911	.0907	.0903	.0900	.0898	.0895	.0893	.0891
120	.0945	.0932	.0925	.0919	.0915	.0911	.0908	.0906	.0903	.0901	.0899
130	.0954	.0941	.0934	.0928	.0924	.0920	.0917	.0914	.0912	.0909	.0907
140	.0963	.0950	.0943	.0937	.0932	.0929	.0925	.0923	.0920	.0918	.0916

[a] Table from Kent, William, Mechanical engineer's handbook 1916, p. 907.

TABLE 22.—*Data for feed-water heaters*—Continued.

Initial temperature of feed water, °F.	Steam pressure in boiler, pounds per square inch above atmosphere.										
	0	20	40	60	80	100	120	140	160	180	200
150	.0973	.0959	.0951	.0946	.0941	.0937	.0934	.0931	.0929	.0926	.0924
160	.0982	.0968	.0961	.0955	.0950	.0946	.0943	.0940	.0937	.0935	.0933
170	.0992	.0978	.0970	.0964	.0959	.0955	.0952	.0949	.0946	.0944	.0941
180	.1002	.0988	.0981	.0973	.0969	.0965	.0961	.0958	.0955	.0953	.0951
190	.1012	.0998	.0989	.0983	.0978	.0974	.0971	.0968	.0964	.0962	.0960
200	.1022	.1008	.0999	.0993	.0988	.0984	.0980	.0977	.0974	.0972	.0969
210	.1033	.1018	.1009	.1003	.0998	.0994	.0990	.0987	.0984	.0981	.0979
220	....	.1029	.1019	.1013	.1008	.1004	.1000	.0997	.0994	.0991	.0989
230	....	.1039	.1031	.1024	.1018	.1012	.1010	.1007	.1003	.1001	.0999
240	....	.1050	.1041	.1034	.1029	.1024	.1020	.1017	.1014	.1011	.1009
250	....	.1062	.1052	.1045	.1040	.1035	.1031	.1027	.1025	.1022	.1019

An approximate rule for the conditions of ordinary practice is that a saving of 1 per cent is made by each increase of 11° F. in the temperature of the feed-water. This corresponds to 0.0909 per cent per degree of temperature rise.

The calculation of saving is made as follows: Boiler-pressure, 100 pounds gage; total heat in steam above 32°=1,185 B.t.u. Feed-water, original temperature, 60°; final temperature, 209° F. Increase in heat-units, 150. Heat-units above 32° in feed-water of original temperature=28. Heating units in steam above that in cold feed-water, 1,185—28=1,157. Saving by the feed-water heater=150/1,157=12.96 per cent. The same result is obtained by the use of the table. Increase in temperature 150° × tabular figure 0.0864=12.96 per cent.

Exhaust steam from the main or auxiliary machinery is usually used in both the open and closed types of heater for heating the feed water. Economizers are sometimes used in the flue passages from a boiler for preheating the feed water, and are generally constructed as a continuous coil or are improvised from a discarded tubular boiler. Where a boiler is not abstracting the proper proportion of heat from the combustion gases an economizer has a proper field. Otherwise, with the good efficiencies of 75 to 80 per cent possible with oil fuel, there is small opportunity for much gain from installing economizers. The selection of a feed-water heater should be intrusted to an engineer who has made a study of the conditions at the particular plant.

Plate III, *A* and *B*, shows graphically the results accomplished with feed-water heater installations on locomotives. The distribution and recovery of heat is shown proportionately by the width of the colored bands; it will be noted that the recovery in the feed water is about 12.5 per cent.

The writer is indebted to Mr. C. A. Averill, of the Locomotive Feed Water Heater Co., for the compilation of these graphic charts.

SUPERHEATERS.

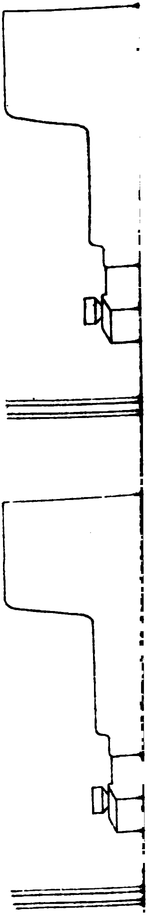
In the transportation of saturated steam to the main engines all radiation of heat from the piping has its equivalent in condensation within the line, whereas with superheat the radiation simply causes a loss of superheat but no condensation. In addition the conductibility of superheated steam is less than that of saturated and the radiation losses are lower.

Within the engine cylinder, entering steam is required immediately to supply heat to the relatively cool cylinder walls. The result with saturated steam is a condensation loss of 20 to 30 per cent. Assume that a certain cylinder requires 1 pound of steam at a pressure of 150 pounds to fill it to the point of cut-off. As the volume of 1 pound of steam at that pressure is about 170 times as great as the volume of 1 pound of water, the space occupied by the condensed water is slight as compared with that of the steam, and an additional volume of steam practically equal to that condensed will have to be supplied, or practically 1.25 pounds of steam will be required.

On the contrary, if the degree of superheat is sufficient, superheated steam gives no condensation in the cylinder and every pound of steam from the boiler does useful work in the cylinder. It is the practice to govern the amount of superheat so as to obviate most of the condensation and at the same time to avoid the difficulty of lubrication and the new or special engine valves, steam lines, and fittings made necessary by excessively high temperatures. In general the fuel saving from a superheater placed properly will practically equal the percentage of steam saved.

The curves shown in figure 17 are graphic representations of the observed results of a series of runs of oil-burning locomotives, with and without superheaters, hauling equal train loads. It will be noted that the fuel consumption of engines with superheaters is 30 to 40 per cent less than the fuel consumption with saturated steam.

BUREAU



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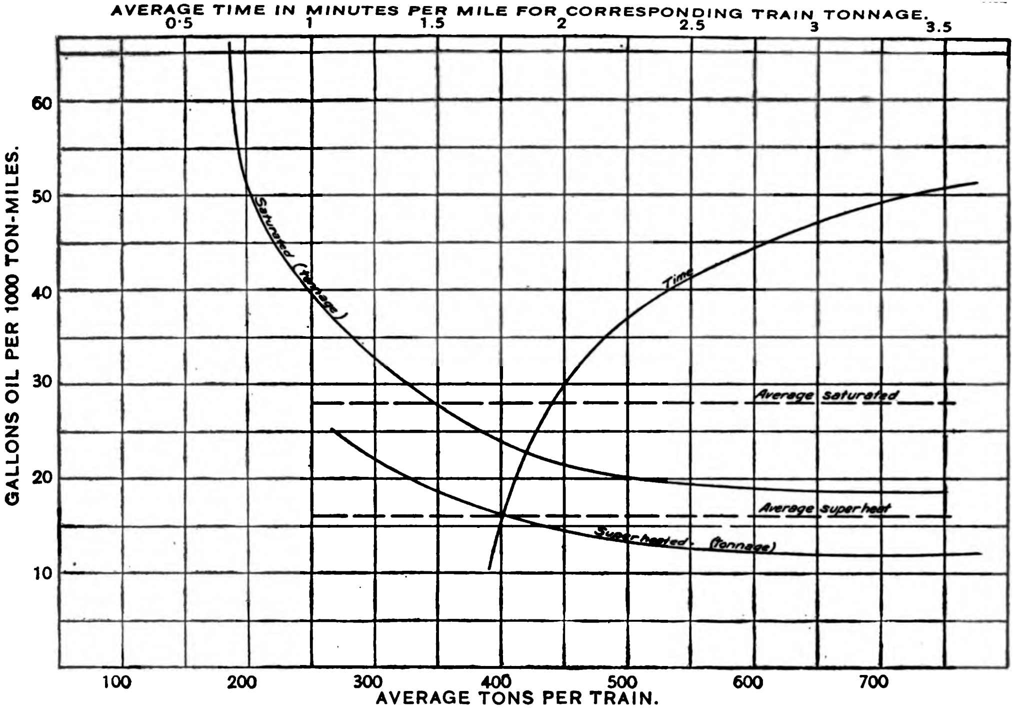

FIGURE 18.—Curves showing fuel-oil consumption for various train loads with "superheated" and "saturated" oil-burning engines.

THE MAIN MACHINERY.

The selection of main machinery will not be treated in this pamphlet. It is sufficient to say that steam turbogenerator units from which the power is transmitted to the individual motors of each machine are generally recognized as more economical than long steam lines to the various machines. The transportation of the electrical power entails losses, but these are much less than the condensation losses with steam. The turbines are usually arranged to exhaust in a partial vacuum, by means of condensers, in order to reduce the back pressure on the engine and thus increase the power. With direct short lines to the condensers, the efficiency of any steam engine can be increased by condensing the exhaust, and, further, the condensate can be returned for boiler feed.

With existing plants the engineer can effect considerable economies by reducing friction from improper alignment of shafts and poor or inefficient lubrication.

Lubricants should be chosen with regard to their particular duty, and if intended for use under high temperatures should be selected with that in view. The viscosity should be the viscosity desired at that temperature, and the other specifications should be considered with regard to the temperature condition.

Many opportunities exist for the recovery of lubricating oil which only requires filtering to become suitable for use again. The recovery of lubricants should be carefully watched in the industries, for frequently inexpensive adjustments will effect substantial savings.

NOTES ON SPECIFICATIONS FOR THE PURCHASE OF FUEL OIL.

1. In the purchase of fuel oil by large users, all buying should be done under competitive bids. In determining the award of a contract consideration should be given to the quality of the fuel offered by the bidders, as well as the price, and should it appear to the best interest of the purchaser to award a contract at a higher price than that named in the bid or bids received the contract should be so awarded.

2. Each bidder should be required to submit an accurate statement regarding the fuel oil he proposes to furnish. This statement should show:

(*a*) The commercial name of the oil.

(*b*) The name or designation of the field from which the oil is obtained.

(*c*) Whether the oil is a crude oil, a refinery residuum, a distillate, or a blend.

(*d*) The name and location of the refinery, if the oil has been refined at all.

3. The fuel oil should be delivered f. o. b. cars, vessels, tanks, or tank wagons, according to the manner of shipment or delivery at such places, at such times, and in such quantities as may be required during the fiscal year ending ....

3a. Minimum and maximum weekly or monthly deliveries should be specified.

4. Should the contractor, for any reason, fail to comply with the written order to make delivery, the purchaser is to be at liberty to buy oil in the open market and charge against the contractor any excessive price, above the contract price, of the fuel oil so purchased.

5. It should be understood that the fuel oil delivered during the term of the contract shall be of the quality specified. The frequent or continued failure of the contractor to deliver oil of the specified quality should be considered sufficient cause for the cancellation of the contract.

ESSENTIAL PROPERTIES OF THE OIL.

6. **Viscosity.**—Fuel oil, as regards viscosity, may be divided into two general classes, namely:

Class 1. Asphaltic base crudes, residuums, or other oils which require heating facilities to reduce the viscosity in order that the oil may be handled by the storage and burning equipment.

Class 2. Oils of a sufficiently low viscosity to make heating equipment unnecessary.

It is imperative that oils of class 2 be heated to a temperature at which they have a viscosity of 12° Engler or lower before they reach the burner, in order to obtain proper atomization. It is desirable that this viscosity be obtained at a temperature below the flash point of the oil, in order to minimize fire hazards and to insure uniform feed to the burner.

For an oil of Class 2, 12° Engler at 60° F. is the approximate maximum viscosity permissible.

Method of determination: Viscosity should be determined with a standard Engler instrument according to the recognized method of manipulating this viscosimeter. Other standard viscosimeters may be used in special cases and their readings converted to Engler degrees by means of recognized tables or formulas.

7. **Flash point.**—In general it is desirable that the flash point of Class 1 oils should not be below 140° F., and that of Class 2 oils not below 120° F. It should be noted that for Class 1 oils, specifications for flash point are contingent upon viscosity requirements as well as upon general considerations for safety requirements and evaporation losses.

Method of determination: Pensky-Martens closed-cup tester manipulated according to standard procedure.

8. **Specific gravity.**—Specifications for specific gravity are superfluous. In case oil is purchased by weight and measured by volume an accurate determination of its specific gravity is essential.

Method of determination: By specific gravity balance, pycnometer, or hydrometer. If conversion of Baumé readings to specific gravity is necessary it is essential that the Baumé hydrometer be accurate and that the proper modulus for this instrument be used. Specific gravities should be reported at 60° F. compared to water at 60° F. If they are determined at other temperatures the temperature corrections given in Bureau of Standards Circular 57 should be used.

9. **Impurities.**—The oil should not contain more than 2 per cent by volume of moisture and sediment. Proper deductions should be made from all oil deliveries for the impurities contained therein so that the oil purchased shall be pure oil.

Method of determination: A definite volume of the oil sample should be thoroughly shaken or "cut" with an equal volume of gasoline of a specific gravity not greater than 0.74, and centrifuged. An appropriate tube that goes with a special machine is commonly used for this purpose. Centrifuging should be continued until there is a clear line of demarcation between the water and sediment and oil in the bottom of the tube, and until a constant reading of water and sediment is obtained. From this reading the percentage by volume of water and sediment is computed. If the oil under consideration has a specific gravity greater than 0.96, one volume of oil to three volumes of gasoline should be used rather than equal volumes. When there is a question that the gasoline used for thinning the oil in making this determination renders insoluble certain of its fuel constituents, then mixtures of gasoline and carbon disulphide, or of gasoline and benzol may be used for "cutting," providing the specific gravity of such mixtures is not greater than 0.74. If, after continued centrifuging, a clear line of demarcation between the impurities and the oil is not obtainable, the uppermost line should be read. If this procedure proves unsatisfactory, 100 c. c. of the sample may be distilled with an excess of hydrocarbons saturated with water and having boiling points slightly above and below that of water. Distillation is continued until all of the water has been distilled over into a graduated tube. The water in the oil is thus distilled over and readily collects at the bottom of this tube, where the percentage may be read off. The percentage of sediment in the oil may then be determined on the sample remaining in the distilling flask by "cutting" it with gasoline and centrifuging. The percentage of water obtained in the tube added to the percentage of sediment gives a total percentage to be deducted for moisture and impurities.

10. **Sulphur content.**—Appreciable sulphur content in a fuel oil is objectionable. However, a content of 4 per cent or less is not sufficiently objectionable to cause the rejection of a fuel oil for general purposes. (In general, experiments in burning fuel oils of various sulphur content have shown that the corrosive effects on the boiler tubes or heating surfaces are negligible. However, with steel stacks and low stack-gas temperatures, considerable corrosion in the stack has been noted. In handling these oils, prior to burning, the corrosive action of the sulphur on steel storage tanks, piping, etc., is quite apparent and should be considered. If the oil is to be used for special metallurgical or other purposes where sulphur

fumes are decidedly objectionable, it is necessary to specifiy a limiting figure for the sulphur content of the oil.)

Method of determination: Complete combustion in a bomb by means of oxygen or sodium peroxide, the sulphur being weighed as barium sulphate.

11. **Calorific value.**—A standard of 18,500 B. t. u to the pound of pure fuel oil is a good figure to be taken as the basis, if the fuel oil is to be purchased on calorific determinations. A bonus may be paid for calorific value in excess of this figure and deductions made if the heating value of the fuel is below 18,500 B. t. u. per pound.

Method of determination: Any bomb calorimeter of recognized accuracy.

12. **Methods of sampling.**—The accuracy of these different tests depends upon the care with which an average representative sample of the fuel oil delivery has been taken, and the importance of obtaining such a sample can not be overestimated. Top, middle, and bottom samples should be taken with a standard "car thief" and these samples should be combined and thoroughly mixed to form one sample for car deliveries. Where oil is received in tanks or reservoirs the swing pipe should first be locked at a position well above the level of the water and sediment usually found in the bottom of such tanks. Tanks should be sampled every foot for the first 5 feet above the bottom of the swing pipe, and at 5-foot intervals from there to the surface of the oil. This sampling should be done with a standard tank thief, the samples "cut" individually, and deductions for impurities made on the separate volumes which these samples represent. If the tank is a large one, it should be sampled through at least two hatches. In receiving large deliveries of the more viscous oils it is necessary to take many samples in order to insure fair and average impurity (W. and B. S.) deductions. This is because water and sediment do not readily settle out of such oils.

13. **General specifications can not be drawn to advantage for fuel oils.**—Individual conditions and requirements at the points of consumption influence to a large degree the specifications for viscosity, flash point, and sulphur content. Definite specifications can be drawn for a fuel oil which will meet practically all requirements, but it can readily be seen that such specifications will exclude much of the fuel oil now available, and for most purposes the requirements need not be severe. Hence, it is advised that in purchasing fuel oil the individual requirements be studied, and that as lenient specifications as possible be written which will insure an oil that will be satisfactory for the conditions for which it is intended.

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