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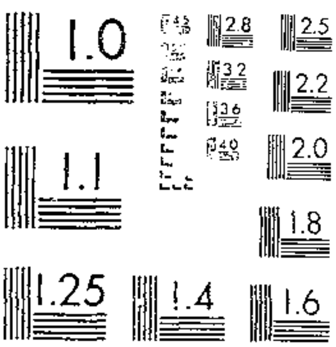

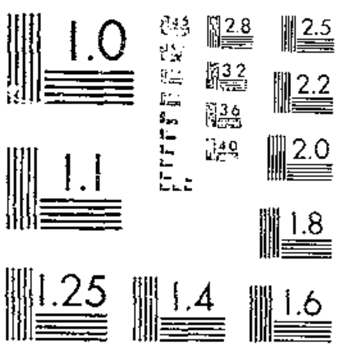

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A STUDY OF THE OIL BURNER AS APPLIED TO DOMESTIC HEATING

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INTRODUCTION

To meet the demand of prospective purchasers of the domestic oil burner for reliable information, the United States Department of Agriculture has tested a number of oil burners of different design and has issued a circular based on the results of the tests.[1] That circular was designed to give the information necessary for the home owner to make his own selection of an oil burner. This bulletin deals with the more technical phases of the investigation.[2]

The tests conducted by the Department, supplemented by a study of many domestic installations, have indicated the performance that may be expected of the several types of burners, boilers, and accessories, the adaptability of existing heating plants to oil burning, and the cost of operating such plants. The conclusions presented herein are not to be regarded as final since the industry is changing rapidly.

[1] Senner, A. H. Oil burners for home heating. U. S. Dept. Agr. Cir. 406, 27 pp., illus. 1936.

[2] Acknowledgment is made of the cooperation of the Johns Hopkins School of Engineering which made available the laboratories in which this work was conducted.

OIL FUELS

Crude petroleum, from which oil fuels are derived, consists principally of hydrocarbons, together with smaller percentages of sulphur, nitrogen, and oxygen.

Crude oils fall into three classes: those with a paraffin base, those with an asphalt base, and those with a mixed base. The paraffin-base crude is so named because on distillation it yields a residue that is principally paraffin wax. The asphalt-base crude on distillation yields a residue of asphalt. The mixed-base crude yields both asphalt and paraffin. The paraffin oils vary in color from a dark green to a light amber and are found principally in the Appalachian and midcontinent fields. The asphaltic types are the heavier oils and are found in California and in the Gulf coast regions. They are darker in color than the paraffin oils and vary from a red brown to black.

The petroleum pools of the United States may be grouped into seven major producing fields or districts as follows: (1) The Appalachian district, (2) the Lima-Indiana district, (3) the Illinois district, (4) the midcontinent district (including Kansas-Oklahoma and Texas-Louisiana), (5) the Gulf coast district, (6) the Rocky Mountain district, and (7) the California district. Table 1 gives analyses of various crude petroleums.

TABLE 1.—*Analyses of crude petroleums*

Source	Carbon	Hydrogen	Oxygen and nitrogen	Sulphur	Gravity (Baumé)
	Percent	*Percent*	*Percent*	*Percent*	*Degrees*
Texas (Beaumont)	84.60	10.90	2.87	1.63	22
California (Bakersfield)	81.50	10.60	6.90	.55	15
Pennsylvania	84.90	13.70	1.40	....	28
West Virginia	83.50	13.30	3.20	....	30
Ohio	84.20	13.10	2.70	....	28
Mexican	82.80	12.19	2.15	2.83	24
Union of Soviet Socialist Republics (Baku)	86.60	12.30	1.10	....	17

FUELS FOR THE DOMESTIC OIL BURNER

Oil fuels are now commercially known as domestic fuel oils, No. 1, No. 2, and No. 3; and industrial fuel oils, No. 4, No. 5, and No. 6. Sometimes the fuels are referred to as light, medium, and heavy domestic oils; and light, medium, and heavy industrial oils. For most of the domestic burners of the present day, the manufacturers recommend fuel oil No. 3, while some burn either No. 1 or No. 2 fuel only. The oils identified by successively higher numbers have correspondingly higher flash points, contain more water and solid matter, and are less volatile and more viscous. The industrial fuel oils are generally too viscous for use in domestic burners. Such oils are generally heated before being fed to the burner, so that they will be more readily atomized. Preheating is not provided for in the usual domestic oil-burner installations.

The heating values of the different grades of oil fuels differ somewhat. A light oil is usually thought to have a greater heating value than a heavy oil, and this is true on a pound basis. Fuels, however, are customarily sold by the gallon, and the heavier oils contain a greater number of heat units per gallon than the lighter oils. They also are generally cheaper. Table 2 shows approximate average heat values of various oil fuels for domestic use.

TABLE 2.—*Heat content of certain oil fuels*

Oil	Heat units	
	Per pound	Per gallon
	B. t. u.[1]	*B. t. u.*[1]
Kerosene	20,000	136,000
No. 1 fuel oil	19,850	137,000
No. 2 fuel oil	19,700	140,000
No. 3 fuel oil	19,500	141,000

[1] A British thermal unit (B. t. u.) for practical purposes may be defined as the amount of heat necessary to raise 1 pound of water through 1° F.

OIL-FUEL SPECIFICATIONS

The Bureau of Standards, in cooperation with refiners and other interested groups and individuals, has established specifications for domestic oil-burner fuels and has issued a publication on the subject.[3]

FLASH AND FIRE POINTS

The flash point of an oil fuel is the temperature at which the liquid, on being slowly heated under definite, specified conditions, begins to give off vapor in such quantities that when a torch is applied it will ignite momentarily, causing a flash. A flash point of 150° to 180° F. is considered to be within safe limits for fuels used in domestic furnaces. If heated further the vapor will be given off in larger quantities, and the temperature at which it will ignite and continue burning (for a period of at least 5 seconds) is called the fire point which for an oil fuel should be low enough for the atomized oil to ignite fairly easily when a torch is applied.

Crankcase oils, from the crankcases of automobiles, trucks, and tractors, generally contain more or less gasoline and consequently may have low flash and fire points. The use of this oil as a fuel for oil burners, without refining, may thus be a dangerous practice.

VISCOSITY

The viscosity of an oil fuel is that property which resists any force tending to make it flow and is usually measured by the time required for a definite quantity of the oil to pass through an orifice of definite size under known conditions of temperature and pressure head. For oils suitable for domestic-burner usage, the viscosity should be low enough that the oil will flow readily in cold weather.

WATER

Water is only slightly soluble in the oil fuels, and when present it will be found mostly in the bottom of the container; however, in the heavy oil fuels some may be found in mechanical suspension.

[3] NATIONAL BUREAU OF STANDARDS. FUEL OILS COMMERCIAL STANDARDS, Bur. Standards C S 12–35, ed. 3, 14 pp. 1935. Revised edition in preparation.

Some ready means of detecting the presence of water in tanks should be available. Where water is stratified in an oil tank it may be detected by means of a water detector. This is merely a metallic rule weighted at the bottom and drilled at the top so that it may be lowered into a tank through the fill or other opening. Clipped on this rule is a strip of paper covered with a substance impervious to oil but readily soluble in water. Any substance having these properties is suitable. Iron ammonium citrate, a double salt of citric acid, rich purple in color when solid and giving a coating like varnish when applied to paper, is commonly used. For determining the presence of water the detector is lowered into the tank. Water, if present, dissolves the coating and leaves the paper almost white, while the portion of the paper in contact with the oil remains unaltered in color.

SOLID MATTER

The solid-matter content as ordinarily found in light oil fuels suitable for domestic use is negligible. As a precautionary measure, however, it is advisable that all oils be strained before they are put into the consumer's storage tanks.

SULPHUR

The presence of sulphur in appreciable quantities in oil fuels is very undesirable. The sulphur compound formed during combustion has an objectionable odor and may corrode the metal parts of the furnace.

HEATING VALUES

The energy involved in the reactions of the various elements of a fuel is heat. The most important reaction with oil is the combination of the carbon and hydrogen of the fuel, with the oxygen supplied for combustion. To estimate efficiencies, flame temperatures, etc., knowledge of these heats of reaction is necessary.

The following are heat values of the elemental combustibles and of various gases.

Heat values in B. t. u. per pound

Carbon burned to CO_2	14,600.
Carbon burned to CO	4,400.
Sulphur burned to SO_2	4,000.
Hydrogen burned to H_2O	62,000, higher. 52,500, lower.

Heat values in B. t. u. per standard cubic foot

[14.7 pounds per square inch and 32° F.]

	Higher	Lower
Carbon monoxide, CO	342	
Hydrogen (H_2)	346	294
Methane (CH_4)	1,065	955
Ethylene (C_2H_4)	1,680	1,560
Benzol (C_6H_6)	4,000	3,830

Heating values of fuels may be determined either by calculation from the results of a chemical analysis or by burning a sample in a calorimeter. Oil fuel is sold by volume, not by weight, and in considering heating values it is well to bear this fact in mind. A general idea of the heating value of an oil can be had from the specific gravity. In figure 1 the approximate heating value of the various oil fuels are plotted as a function of the Baumé gravity of the oil. These values are only approximate, and when greater precision is desired the calorimeter test is required. The effect of estimating heat content per unit of volume, instead of per unit of weight, is shown by the two lines. While the lighter oils have a higher heat content per pound than do the heavier oils, they have a lower heat content per gallon.

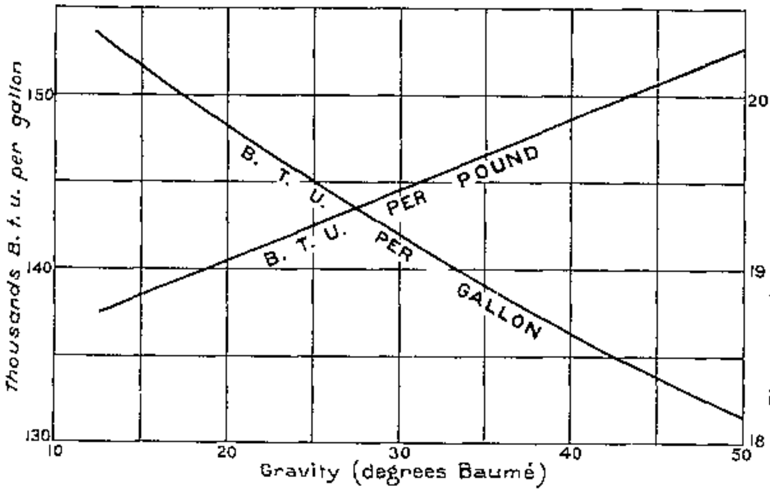

FIGURE 1.—Heat values per pound and per gallon of oil fuels of various gravities.

HIGHER AND LOWER HEATING VALUES

In the combustion of fuels containing hydrogen, water is formed. This water—produced in a region of high temperature—is in the form of superheated steam, and in ordinary practice this steam never is condensed within the heating passages of the boiler but passes up the chimney, carrying with it an appreciable number of heat units. The heat units thus lost, through noncondensation, diminish the calorific value of the fuel as represented by the ultimate analysis, and this diminished value is known as the "lower heating value," while the "higher heating value" is the gross heat which is liberated by the combination of the elements of the fuel with oxygen.

The determination of the heating value of a fuel in the laboratory gives the higher heating value, because the water vapor that is generated is condensed and gives up its latent heat. Also, when hydrogen is burned to water vapor and the products cooled to the initial temperature, the heat liberated is the higher heating value. This is the value obtained by the use of the ordinary calorimeter. The lower heating value assumes the products cooled to the initial temperature but the water not condensed. The difference between the higher and the lower heating values, then, is equivalent to the heat of vaporization of water at the initial temperature. Assuming the initial temperature, or room temperature, to be 60° F., the difference between the higher and lower heating values of 1 pound of hydrogen shows the following values for various temperatures of escaping steam:

Temperature of escaping steam	Difference in heating values
° F.	B.t.u.
60	9,450
300	10,430
500	11,240
700	12,060
1,000	13,280
1,500	15,320

These differences are too large to be negligible, and it must be decided which heating value is to be used. The difference is not great with fuels of low hydrogen content but with oils containing roughly 0.14 pound of hydrogen per pound of oil, the discrepancy is appreciable. The lower heating value cannot easily be determined experimentally and is not so definite, so the higher heating value is commonly used.

VOLATILITY

The volatility of a fuel is of particular importance when it is burned in the ordinary vaporizing-type burner. The No. 1 or No. 2 oils are generally supplied to burners of this type. Those fuels which are more volatile require only a relatively low temperature to cause them to vaporize and become mixed with the air for combustion; thus the tendency to "crack" is reduced.

To determine the relative volatilities of various fuels supplied to the vaporizing type of burner, a number of samples of these oils were collected from the open market and subjected to the distillation test. This test is so contrived as to determine the temperatures at which the various fractions of the oil are distilled off.

Table 3 gives complete analyses of the various oils designated as A, B, C, and D, and table 4 contains corresponding distillation data for these oils. Figure 2 represents the typical distillation curves as plotted from table 4.

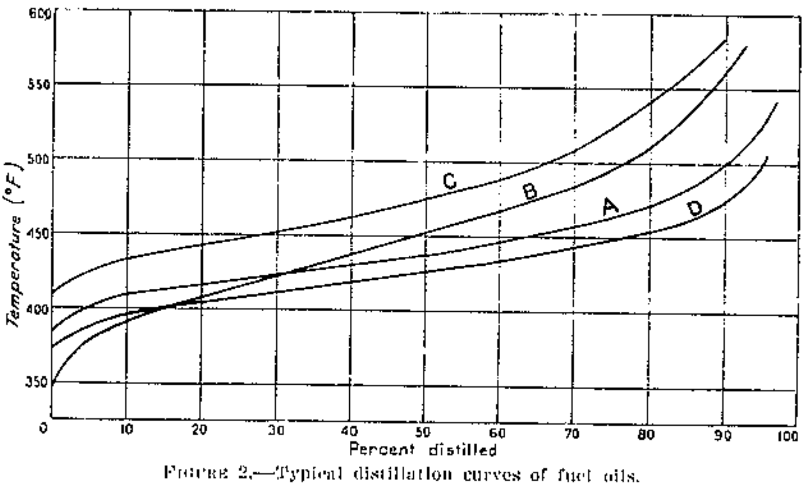

FIGURE 2.—Typical distillation curves of fuel oils.

TABLE 3.—*Analyses of fuel oils*[1]

Property determined	Oil samples			
	A	B	C	D
Gravity designation under which oil was sold	38 to 40	38 to 40	38 to 40	38 to 40
Specific gravity at 60/60° F	0.843	0.823	0.818	0.845
Degrees Baumé	36.07	40.11	40.94	35.68
Flash point (Pensky-Martin's closed cup) ° F	155	130	165	155
Flash point (Cleveland open cup) do	170	135	175	155
Fire point (Cleveland open cup) do	190	160	205	175
Viscosity (Saybolt universal viscosimeter) at:				
70° F	42	43		42
100° F	41.5	41.5		41
120° F	40	40.5		40
Water percent	None	None	None	None
Color of oil	Straw	Straw	Colorless	Straw
Gross B. t. u., per pound	19,471	19,991	20,572	19,959
Gross B. t. u., per gallon	136,686	137,138	140,095	140,511
Proximate analyses:				
Volatile matter percent	99.988	99.86	99.995	99.984
Fixed carbon do	.012	.14	.005	.016
Ultimate analyses:				
Carbon do	84.51	84.09	84.56	86.16
Hydrogen do	12.43	12.17	13.69	12.64
Sulphur do	.63	.47	.55	.19
Oxygen and nitrogen do	2.43	3.27	1.20	1.01

[1] Oils tested at U. S. Naval Engineering Experiment Station at Annapolis, Md.

TABLE 4.—*Results of distillation tests on four fuel oils*[1]

Progress of distillation	Oil samples				Progress of distillation	Oil samples			
	A	B	C	D		A	B	C	D
	° F.	° F.	° F.	° F.	First drop—Continued	° F.	° F.	° F.	° F.
First drop	384	344	408	372	50 cc	470	507	540	452
5 cc	402	380	421	389	90 cc	496	568	583	472
10 cc	408	392	433	395	95 cc	523		593	500
20 cc	416	408	442	404	End point	542	578	606	506
30 cc	421	422	447	410		cc	cc	cc	cc
40 cc	431	436	462	418	Total recovered	97	93	98½	98
50 cc	438	451	474	425					
60 cc	446	468	487	432					
70 cc	456	482	505	441					

[1] Oils tested at U. S. Naval Engineering Experiment Station at Annapolis, Md.

METHODS OF HEAT TRANSFER

A clear conception of the methods of heat transfer is necessary for a complete understanding of boiler and furnace problems. There are three methods of heat transfer—conduction, convection, and radiation.

Conduction is the intermolecular transfer of heat within a body. For instance, if one end of a copper bar is placed in a flame an increase in molecular activity takes place in the end subjected to the flame, and this activity is transferred from molecule to molecule until the whole bar is very hot. Now, if one end is maintained at a low temperature, heat will continue to flow along the bar from the hot end to the cold. Heat is transferred through metal-boiler heating surfaces in this manner.

Convection refers to the mass transfer of heat. For example, a volume of gas is heated by contact with a hot surface or by combustion, and rises owing to decreased density. Later, the gas comes in contact with a cold body to which it gives up its heat. The greater part of the heat is delivered to the indirect heating passages of a boiler by means of convection.

Radiant energy is a form of activity in the ether, similar to light and electricity. One standing near an open fire is conscious not only of the light coming from it, but also of a sensation of warmth. This sensation is lost when an opaque screen is interposed but returns as quickly as does the light when the screen is withdrawn. This phenomenon is shown also by the fact that after a solar eclipse the warming effect of the radiation from the sun appears simultaneously with the light itself. This radiant effect can even be felt through a thin sheet of ice. Since both surfaces of the ice are at the same temperature (32° F., the temperature of melting ice) no heat can be transferred by ordinary conduction. Radiant energy must therefore be transmitted by a very different process. This is also indicated by the fact that it readily passes through a vacuum.

Heat radiation is wave action and differs from light and electricity only in wave length. The molecules of a hot body are in a state of vibration. These molecules set up in the ether radiant-energy vibrations which travel at enormous speeds in straight lines in all directions from the hot body. When such radiant-energy waves impinge on a colder body some of whose molecules can vibrate in tune with them, then the waves are absorbed by the colder body and its temperature rises due to this absorption. If the cold body is such that it does not absorb these vibrations, then the latter either pass through it or are reflected. The character of the body has a marked effect on its absorbing and radiating possibilities. A dull black body has the greatest property of absorption and radiation. Any other body, under similar conditions of temperature, will emit and absorb only a fraction of the energy that a black body will.

In furnace operation we are concerned not only with the radiating properties of solids but also those of certain gases. It has been shown that the net radiation exchange between a gaseous flame and a colder solid body is largely due to the CO_2 and H_2O molecules which are good radiators and absorbers. All other molecules in the gaseous mixture apparently act as nearly perfect reflectors. Hence, heat radiation from the gases plays an important part in the performance of a furnace.

The Stefan-Boltzmann law of radiant-heat transfer states that for an ideal black body the amount of heat transferred varies as the difference between the fourth powers[4] of the absolute temperatures of the hot and cold bodies.

This is expressed by the relation

$$H=K\ (T_h^4-T_c^4),$$

where H is the heat transferred in unit time,

K is a constant depending on the nature of the hot and cold substances,

[4] The exponent 4 holds only for the black body; for gases it is very different because only certain bands of the spectrum appear and the total heat emission can be determined only by direct tests.

T_h and T_c are the absolute temperatures of the hot and cold substances, respectively.[6]

COMBUSTION

Combustion, or burning, is any chemical combination in which heat is evolved. In engineering, the kind of combustion in which we are particularly interested is the combination of various fuels with oxygen. In this sense the word combustible may apply to any substance that is capable of combining rapidly with oxygen to produce heat.

Ignition temperature is the temperature necessary to start local combustion at such a rate that the adjacent portions of the air-fuel mixture will be brought to combustion temperature. The most rapid ignition and combustion are desired in order to attain high furnace temperatures and thus realize highest radiation efficiencies. It is generally considered that the small atomized oil droplets entering the furnace must first be vaporized and then gasified and raised to ignition temperature, before they will burn in the presence of the oxygen supplied for combustion. This process is endothermic or heat absorbing, and the furnace walls or flame must provide the heat necessary. The air supplied for combustion—particularly the primary air—must also be heated before combustion will ensue. Air is a poor absorber of radiant heat and may have increased in temperature comparatively little by the time the oil droplet has been gasified to considerable extent. The air is heated largely by convection from the high-temperature portions of the flame. Ultimately the air-fuel mixture reaches ignition temperature and combustion commences. It is apparent, however, that before combustion is complete the oil droplet may have gone some distance into the furnace. Early ignition and rapid burning are conducive to high flame temperatures and reduced flame travel.

The speed of combustion is greatly dependent upon the rate of mixing fuel and air. As the droplets of oil are gasified and burned in passing through the furnace, each droplet is surrounded by its products of combustion and the process of further combining is somewhat hindered thereby. Thus a certain amount of turbulence is desirable. The degree of atomization also affects the speed of combustion.

The importance of combustion speed is seen clearly when it is considered that higher combustion speed means higher flame temperatures and higher accompanying heat emission by radiation. Moreover, high combustion speed results in shorter flame travel and the required combustion space, for a given heat energy emission, is then at a minimum.

There are certain vital problems to be considered when fuels are burned, as for instance, how much heat will be developed through a given reaction; will the combustion be complete if sufficient time is allowed; how much fuel will be consumed in a given time under certain conditions? Obviously these questions are of importance to the designer, and they are best solved by recourse to the laws of chemistry. The more important combustion reactions, together with

[6] For data on radiation from CO_2 and H_2O, and referring to radiation from gas layers in furnaces, see the following: SCHACK, A. [EFFECT OF GAS RADIATION ON HEAT TRANSMISSION.] Iron and Steel Inst., Düsseldorf, Heat Research Bur. Bull. 55. [Abstract by B. N. Broido in Amer. Soc. Mech. Engin. Trans. (1925) 47: 1143–1147, illus. 1926.]

the heats of reaction, have been presented in the section dealing with heating values (p. 4).

Chemical combinations or reactions always take place in definite weight relations that are characteristic of the elements acting, and in definite volume changes that are dependent upon the number of gaseous molecules reacting and the number produced. Following are the weights of the substances concerned in the combustion of the oils used in the tests made by the Department of Agriculture.

Substance	Atomic weight	Molecular weight
Carbon	C=12.01	
Sulphur	S=32.07	
Oxygen	O=16.00	O_2=32.00
Nitrogen	N=14.04	N_2=28.08
Hydrogen	H=1.008	H_2=2.015
Carbon dioxide		CO_2=44.01
Carbon monoxide		CO=28.01
Water		H_2O=18.02
Sulphur dioxide		SO_2=64.07

When sufficient air is supplied, and other conditions satisfied, carbon will combine with oxygen in the following manner:

$$C+O_2=CO_2$$

and this relation when expressed by the weights entering is,

$$12+32=44$$

$$1+2.67=3.67$$

that is, 2.67 pounds of O_2 are required per pound of C. Similarly,

$$2H_2+O_2=2H_2O$$

$$4+32=36$$

$$1+8=9$$

that is, 8 pounds of O_2 are required per pound of H_2. And finally,

$$S+O_2=SO_2$$

$$32+32=64$$

$$1+1=2$$

that is, 1 pound of O_2 is required per pound of S. In the above relations the approximate atomic weights have been used.

From each of the three reactions expressed above, the quantities of O_2 required to combine with C, H_2, and S have been determined. From a knowledge of the proportion of oxygen in the air, these calculations may be extended in order to ascertain the quantity of air entering into these reactions. By weight, air is composed of approximately 23.15 percent of O_2 and 76.85 percent of N_2; it follows, then, that 1 pound of O_2 is represented in $1 \div .2315 = 4.32$ pounds of air.

The combustion calculations shown in table 5 are for 1 pound of a fuel-oil distillate such as is supplied to domestic oil burners.

TABLE 5.—*Air required for and products resulting from complete combustion of oil with no excess air*

Element	Weight per pound of fuel	Required quantity		Products of combustion				
		O_2	Air	CO_2	O_2	N_2	H_2O	SO_2
	Pounds	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*
C	0.8451	2.256	9.746	3.101		7.490		
H_2	.1298	1.035	4.484			3.446	1.168	
O_2	.0099	—.010	—.043			[1] —.033		
N_2	.0099					.010		
S	.0053	.005	.022			.017		0.010
Total	1.0000	3.280	14.209	3.101	0.000	10.930	1.168	.010

[1] N_2 equivalent of O_2 in fuel.

However, in an Orsat apparatus the SO_2 is absorbed with CO_2, thus:

CO_2	O_2	N_2	H_2O
3.101	0	10.930	1.168
.010			
3.111	0	10.930	1.168

The total weight of the products of combustion, then, is 3.111+10.930+1.168 pounds=15.209 pounds.

Therefore the pounds of air theoretically required per pound of fuel is equal to 15.209 minus 1 (weight of fuel) = 14.209, which agrees with the total required air as determined above.

Table 6 gives the weights of products of combustion with varied air-fuel ratios (percentages of excess air), per pound of fuel.

For an Orsat analysis the H_2O is not determined; thus the percentages of dry products of combustion with varied air-fuel ratios, are as given in table 7. Reduced to percentages by volume, the dry products of combustion are as given in table 8.

TABLE 6.—*Wet and dry products resulting from combustion of oil per pound of fuel with varying percentages of excess air*

	No excess	20 percent	40 percent	60 percent	80 percent	100 percent	150 percent	200 percent	250 percent	300 percent
	Pounds	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*
CO_2	3.111	3.111	3.111	3.111	3.111	3.111	3.111	3.111	3.111	3.111
O_2	0	.658	1.316	1.974	2.632	3.290	4.935	6.580	8.225	9.870
N_2	10.930	13.114	15.298	17.482	19.666	21.850	27.309	32.769	38.229	43.689
H_2O	1.168	1.168	1.168	1.168	1.168	1.168	1.168	1.168	1.168	1.168
Wet products	15.209	18.051	20.893	23.735	26.577	29.419	36.523	43.628	50.733	57.838
Dry products	14.041	16.883	19.725	22.567	25.409	28.251	35.355	42.460	49.565	56.670

TABLE 7.—*Relative weights of the dry products of combustion with varying percentages of excess air*

	No excess	20 percent	40 percent	60 percent	80 percent	100 percent	150 percent	200 percent	250 percent	300 percent
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
CO_2	22.16	18.43	15.77	13.78	12.24	11.01	8.80	7.32	6.27	5.49
O_2	.00	3.90	6.67	8.75	10.35	11.64	13.95	15.49	16.59	17.41
N_2	77.84	77.67	77.56	77.47	77.41	77.35	77.25	77.19	77.14	77.10

TABLE 8.—*Relative volumes of the dry products of combustion with varying percentages of excess air*

	No excess	20 percent	40 percent	60 percent	80 percent	100 percent	150 percent	200 percent	250 percent	300 percent
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
CO_2	15.3	12.6	10.7	9.3	8.3	7.4	5.9	4.9	4.2	3.6
O_2	.00	3.7	6.2	8.2	9.6	10.8	12.8	14.2	15.2	15.9
N_2	84.7	83.7	83.1	82.5	82.1	81.8	81.3	80.9	80.6	80.5

In figure 3 are five graphs that show the characteristics of the products of combustion of a representative distillate fuel, when burned with various percentages of excess air. The curves are characteristic for the distillate assumed in the foregoing computations, but since the range of fuels used in practice is relatively narrow the curves should hold substantially for any of the fuels used by domestic burners, at the time of writing.

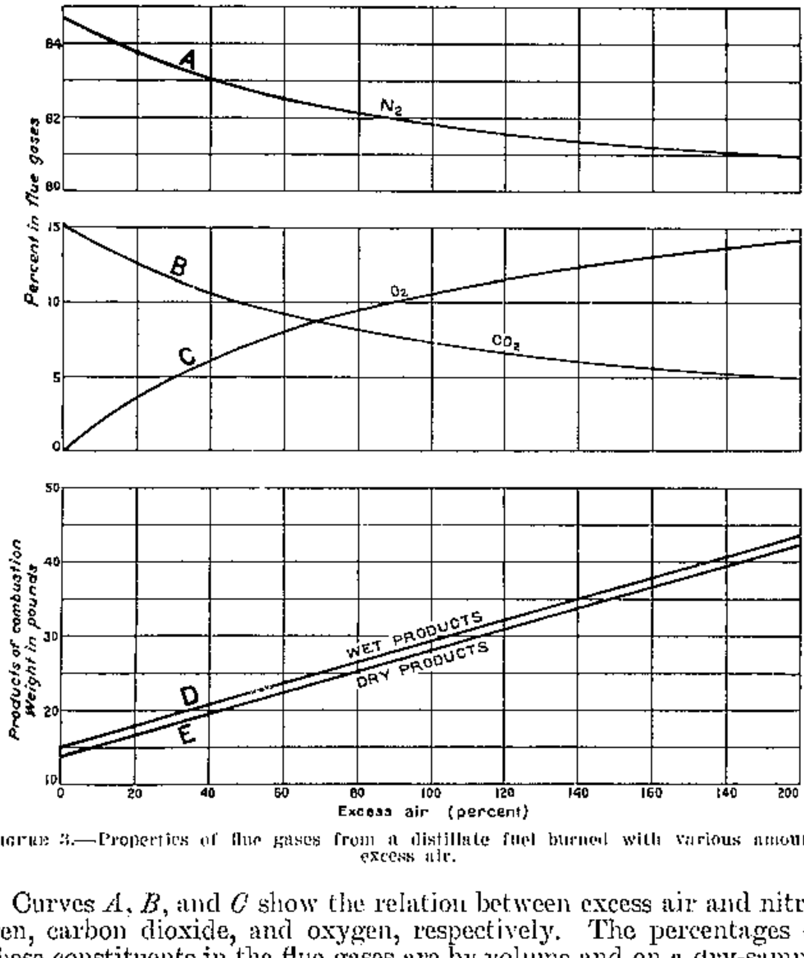

FIGURE 3.—Properties of flue gases from a distillate fuel burned with various amounts excess air.

Curves *A*, *B*, and *C* show the relation between excess air and nitrogen, carbon dioxide, and oxygen, respectively. The percentages of these constituents in the flue gases are by volume and on a dry-sample basis—that is, they are the percentages as determined from an Orsat analysis. Curves *D* and *E* show the relations between the percentage of excess air and the weights of the dry and wet products of combustion.

Curve *A* shows that the percentage of nitrogen in the flue gases diminishes as the excess air is increased. This curve is slightly concave upward.

Curve *B* is the function which is most frequently referred to and shows the variation in CO_2 content as the air-fuel ratio is altered. For the oil under consideration, this has a maximum value of 15.3 percent and decreases as the excess air is increased.

Curve *C*—showing the relation between excess air and O_2—passes through the origin of coordinates and is concave downward. As the excess air is increased, the O_2 content of the flue gases also increases. It is of some value to note that curves *B* and *C* afford a good check on the operation of the Orsat apparatus, as to leaks and completeness of absorption and errors in technique. To illustrate this, assume that the operator in analyzing a flue-gas sample has determined that the percentage of CO_2 is 10. By referring to curves *B* and *C* it is found that the corresponding O_2 content should be approximately 7. Similarly, a check can be made all along the range of excess air provided, of course, complete combustion exists. If the incompleteness of combustion is slight the curves will still be applicable.

Curves *D* and *E*, which show respectively the weights of the products of combustion with and without water vapor, are straight lines whose vertical distance apart is equal to the constant weight of water in the flue gases. The weights of the products are given in terms of pounds per pound of fuel burned. The difference in the ordinates of the two curves due to the formation of water vapor is, on this basis, 1.168 pounds. This is constant throughout the entire range of excess air, as is brought out in the foregoing computations. These two curves are of importance in estimating the quantity of heat that passes up the stack, which quantity depends in part upon the weight of products of combustion.

It should be remembered that, in combustion, it is desirable to operate with the minimum of excess air; this means operation at a point as far as possible to the left on the graphs in figure 3. The conditions then, will be those of relatively high CO_2 and N_2 percentages, and a low percentage of O_2. Moreover, the weight of the products of combustion will be low under these conditions. The principal limiting factor in this connection is the margin of precaution against soot and smoke production; therefore most manufacturers recommend that 20 to 40 percent excess air be admitted.

Figure 4, the Ostwald diagram,[6] shows an interesting way of presenting the flue-gas data which ordinarily is shown as in figure 3. In this graph the abscissa is percent O_2 in the flue gases while the ordinate is percent CO_2 in the same. If from the computations we plot these values for various percentages of excess air, the locus of such points will be a straight line. The points indicated on this line are the percentages of excess air. The graph provides a compact scheme for plotting the corresponding percentages of the two com-

[6] OSTWALD, W. BEITRÄGE ZUR GRAPHISCHEN FEUERUNGS-TECHNIK. Monog. zur Feuerungstechnik Heft. 2. Leipzig. 1920.

ponents of the flue gas at various percentages of excess air, and is attractive because of the simple straight-line function.

Frequently it is desired to know how much free air will be drawn into the furnace in order to burn a certain quantity of fuel, at a given

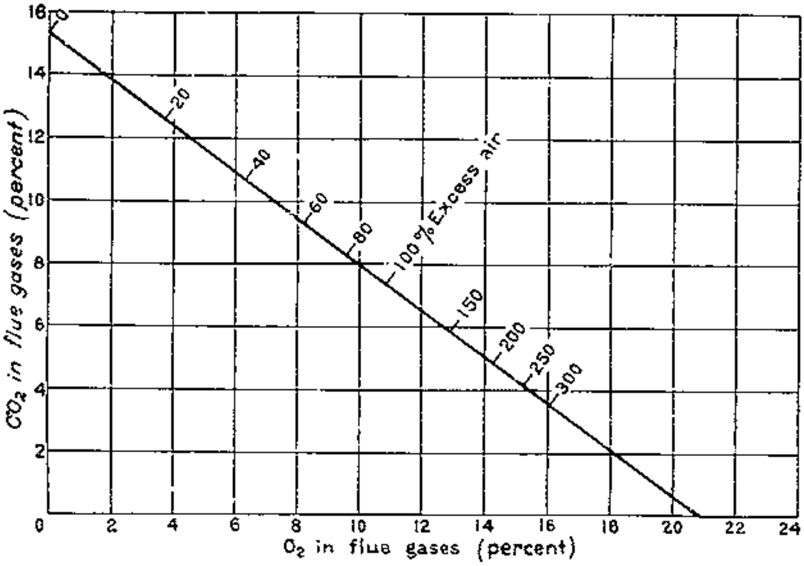

FIGURE 4.—Oxygen—CO_2 relation in flue gases when various percentages of excess air are used.

air-fuel ratio. To answer this question figure 5 has been prepared. In this case the horizontal coordinate is the number of cubic feet of free air required for combustion, per gallon of oil. The vertical coordinate is the percentage of CO_2 in the flue gas. Let it be required, for example, to determine the number of cubic feet of air which will be consumed in 1 hour, when the burner is consuming 2 gallons of oil per hour and the CO_2 content is 10 percent. From the curve, for a condition of 10 percent of CO_2, it is seen that 1 gallon of oil would require about 2,030 cubic feet of free air for combustion; therefore, if we are burning at the rate of 2 gallons per hour the requirement will be 4,060 cubic feet of free air. Free air is here to be understood as air at 70° F. and at atmospheric pressure. Thus it is seen that a burner—even a relatively small one—can displace the air content of a 20- by

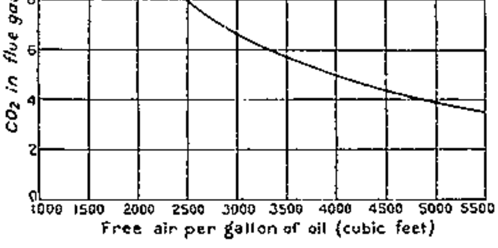

FIGURE 5.—Volume of air required for the combustion of oil.

20- by 10-foot room once every hour that it operates, merely to supply air for combustion. The importance of this fact, from practical considerations, is evident.

FURNACE ENERGY RELATIONS

The energy relations of the furnace and fuel may be stated as follows:

$$HF = P + L$$

HF represents the rate of energy liberation by the burning fuel, where H represents the British thermal units liberated per pound of fuel, and F the pounds of fuel consumed per hour. P represents the rate at which the liberated heat is absorbed by the products of combustion. It results from the addition of heat at constant pressure to the various components of the products of combustion. In the case of the fuels generally supplied to the domestic oil burners these products of combustion are, with complete combustion, CO_2, O_2, N_2, H_2O, and SO_2. This may be represented as follows:

$$P = w_1h_1 + w_2h_2 + w_3h_3 + w_4h_4 + w_5h_5$$

In this summation w_1, w_2, etc., represents the weights, in pounds per hour, of the constituents CO_2, O_2, etc., formed by combustion, and h_1, h_2, etc., represent their respective heat capacities at constant pressure between the initial temperature and the flame temperature.

The last term of the original equation, L, represents the rate of heat energy lost by the products of combustion during their travel through the furnace. This will be the sum of the heat energy lost by radiation and that lost by convection. By the Stefan-Boltzmann law, the heat lost by radiation will be

$$K(T_f^n - T_c^n)$$

where T_f is the absolute flame temperature,
T_c is the absolute temperature of the absorbing cold surface,
K is a constant depending on many factors.

The loss by convection (C) may be represented by the relation

$$C = \Sigma Se\Delta t$$

where S is the furnace-wall surface,
e is the heat transfer coefficient in B.t.u per hour, per degree temperature difference, per unit of area.
Δt is the mean temperature difference between the furnace wall and the layer of moving gas immediately in front of the surface.

The last term of the original equation, L, may then be expressed as follows:

$$L = K(T_f^n - T_c^n) + \Sigma Se\Delta t$$

Thus

$$HF = \Sigma wh + K(T_f^n - T_c^n) + \Sigma Se\Delta t$$

FLAME TEMPERATURE

With a knowledge of the amount of available heat in the fuel and of amounts and specific heats of the products of combustion, the theoretical flame temperature can be determined. Specific heats are not constant but increase with temperature; thus integration must be resorted to in order to determine their true values. Such a flame-temperature determination as the one thus referred to is theoretical in that it is assumed that there is no loss of heat to surrounding surfaces during the interval required for combustion—or what is equivalent, that no time is required for combustion. Actually, of course, such is not the case. A finite, appreciable time is required for completion of combustion, and the surrounding surfaces of the furnace are excellent absorbers of radiant energy so that the actual temperature which the products of combustion attain is considerably less than the theoretical temperature. The energy relations for the actual conditions are given in the section next above.

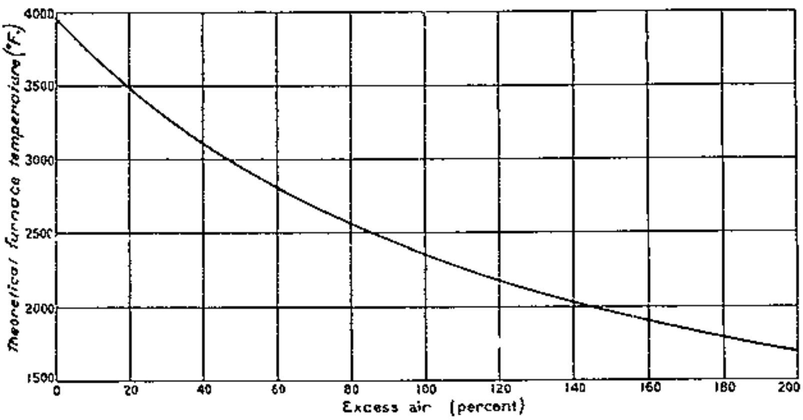

FIGURE 6.—Theoretical furnace temperatures as obtained with various percentages of excess air.

It is obvious that the determination of true flame temperatures is not a simple process. What is frequently done is to estimate the flame temperature from a consideration of the heat values of the fuel and the sensible heats of the products of combustion resulting from the burning of the fuel, assuming that all of the heat liberated is used to raise the temperature of the products of combustion. Thus from a knowledge of the initial temperature, of the mass and specific heats of the various products of combustion, and of the heat units liberated, the final temperature can be estimated. This temperature is purely a theoretical value and does not take into account the effect of radiation; it is, therefore, not the true temperature found in the furnace. However, a knowledge of theoretical temperatures is important in the analysis of certain problems. Theoretical temperatures are shown as a function of air-fuel ratio in figure 6. The rapid decrease in flame temperature as the excess air is increased is shown clearly by this curve.

FUELS USED

The oil fuels used in the tests here presented are designated as fuel oils Nos. 2 and 3 in the log sheets presented later. The numbers indicate the commercial grades as defined by commercial standards for fuel oils in publications by the National Bureau of Standards. The analyses given in table 9 are for two typical samples of the oils used.

TABLE 9.—*Typical analyses of oil fuels used during tests*[1]

Property determined		No. 2 fuel	No. 3 fuel
Flash point, closed cup	°F	150	165
Pour point	°F	-20	-20
Water and sediment	percent	0	
Carbon residue	do	0.022	0.022
Distillation temperatures:			
10-percent point	°F	412	441
90-percent point	°F	589	594
End point	°F	626	613
Viscosity, Saybolt universal at 100° F	seconds	34	35
Specific gravity at 60/60	°F	0.855	0.876
A. P. I. degrees		34.0	30.2
Pounds per gallon		7.13	7.29
Gallons per pound		.140	.137
Higher heating value per pound	B. t. u.	19,700	19,500

[1] Analyses made by the Engineering Experiment Station, U. S. Naval Academy, Annapolis, Md.

METHODS OF TESTING

In the first edition of this bulletin the performance data for several burners in four-, five-, and six-section round boilers of 25-inch diameter were given. Since then the Bureau of Agricultural Engineering has studied the performance of most of the leading burners on the market in several typical boilers designed originally for burning coal. Performances of special oil-burning boilers and burner-boiler units have been investigated for comparison and some study has been given to economizing devices designed to improve the operation of boilers of limited flue travel and heat-absorbing surface.

In all the tests the control of the burners was manual, automatic devices being omitted. The commendable work of the Underwriter's Laboratories deals with the safety phase of oil-burning equipment with no direct concern as to the efficiency. Safety necessarily involves the proper functioning of the automatic controls and limiting devices, and the underwriters apparently have dealt thoroughly with this subject.

The specific object of the series of tests reported on was to determine the thermal efficiencies to be realized with the burners, boilers, etc., under various conditions of operation. The thermal efficiency is the proportion of the heat energy of the fuel which is transmitted to the heating medium, and is sometimes referred to as the "over-all" efficiency. The thermal efficiency is a function of the boiler design as well as of the burner design, and therefore the type of boiler used must be taken into account.

The three coal-burning boilers tested were of American Radiator Co. manufacture. One was a 20-inch, four-section Arco, designated W-2004; another was a 22-inch, six-section Arco, designated S-2206.

The third described by the manufacturers as a water-tube type, was a rectangular sectional boiler of 23-inch width, consisting of seven sections, designated S-2307. These boilers represent types found in a large percentage of the plants which are converted to oil and also in new installations in which oil burners are used.

The special oil-burning boiler used in the tests was of cast-iron sectional design, used as standard equipment by several important burner manufacturers. The boiler-burner unit reported on was of steel construction and included the so-called tankless scheme for the generation of hot water.

Principally, the tests conducted on the various burners were of a continuous nature. Some, however, were intermittent and so designated on the log sheets presented. In the continuous tests the burner was operated for a sufficient length of time preceding each test to insure steady conditions before readings were begun.

In the intermittent tests the burner was operated as follows: 1 hour on, one-half hour off; one-half hour on, 1 hour off; one-fourth hour on, 2 hours off; one-fourth hour on (with reading continuing until conditions were the same as those prevailing at the beginning of the test).

The heat absorption was determined from a knowledge of the temperature rise of a known quantity of water passing through the boiler. Thus the boiler was operated as a Junker calorimeter. The readings of fuel quantity, draft, and temperatures were made at 10-minute intervals or less, and the analysis of the flue gases by means of the ordinary engineering flue-gas analyzer, was made every 15 minutes of burner operation. The quantities of water and oil were measured by means of accurate platform scales and the temperatures were determined by means of mercury thermometers.

The tests were planned with a view to disclosing the operating characteristics of the various burners in the boilers used. To do this the fuel rate was generally varied from a point considerably below to a point considerably above the boiler rating. Air-fuel ratios which would prevail in good practice for the several types of burners were generally adhered to in adjusting the burners for test. Some departure from this setting was made to study the effect of higher or lower air-fuel ratios. From these data the curves of over-all efficiency, flue-gas temperature, and heating effect were plotted to show the effects of the variables.

DEVICES FOR IMPROVEMENT OF BOILER EFFICIENCY

Principally because many oil burners have been installed in boilers originally intended for coal burning, and hence not very efficient for oil burning, several economizing devices have been designed. Some of these are simple and inexpensive to install while others are somewhat more costly and more difficult of installation. Because of the importance of such accessories, representative economizing devices of the general class mentioned were studied.

The simplest scheme, and one used since early in domestic oil-burner history, is the sheet-metal baffle pictured in figure 7. In this case the baffle is installed in the flue passages of a small round cast-iron boiler having a rather limited secondary heating surface. The baffle, *b*, consists of an annular sheet of metal resting on split brick, *a*. The effect of the baffle is principally to cause the products of combustion to "scrub" more of the heat-absorbing surface. The view shows the necessary clearance between the circumference of the baffle and the boiler wall to permit passage of the gases. This opening must not be too small or a back pressure will be built up in the combustion chamber. Such an installation should be made by an experienced man with the aid of a draft gage to determine the draft in the combustion chamber in order to avoid excessive back pressure. The gun-type, retort or pot-type, and the yellow-flame vertical-rotary burner can withstand the effects of more baffling than can the blue-flame vertical rotary. This form of baffle is referred to as type P.

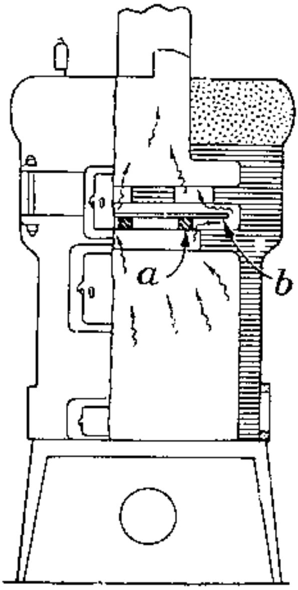

FIGURE 7.—Four section round boiler showing use of baffles: *a*, Split brick; *b*, baffle.

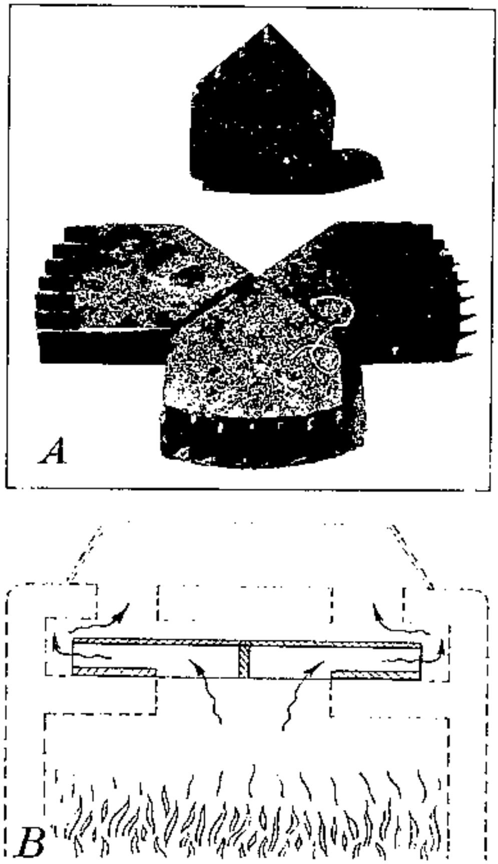

FIGURE 8.—Installation of S type baffle in a small round boiler: *A*, Baffle sections; *B*, diagram of baffles in position in furnace.

The device shown in figure 8 is an elaboration of the baffle idea. This serves not only to increase the scrubbing effect as described in connection with the type P baffle (fig. 7) but also serves to "collect" additional heat and transmit it to the boiler heating surface to which the economizer is fastened, and thence to the boiler water. The use of such a device is shown in figure 8 in a small round heating boiler. The baffle is made in four sections to permit installation. Each section consists of a base plate and a top or cover plate. The base plate is secured to the flue surface of the boiler by metallic cement of high thermal conductivity. The top plate makes good thermal contact with the bottom one through the several fins. Thus the top plate gives the baffling effect illustrated in figure 7 and at the same time the heat "collected" by the top plate, fins, and bottom plate is conducted to the boiler water, thus increasing the effectiveness of the surface of the boiler to which the device is attached. This type of economizing device will be referred to as type S.

Another relatively simple scheme used in an attempt to step up the efficiencies or capacities of inadequate boilers is the familiar device shown in figure 9. This is called a fire-pot type of water heater. When placed in the fire pot of an oil-fired boiler and piped in parallel with the boiler itself rather than being used as a domestic hot-water

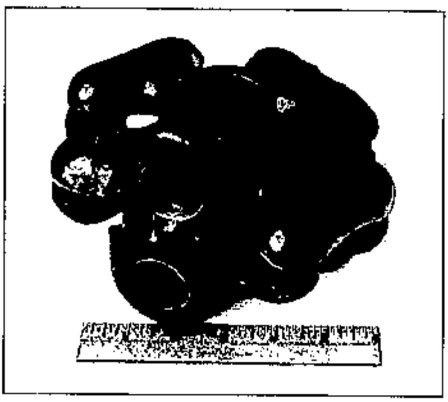

FIGURE 9.—Domestic water-heating unit used as boiler booster.

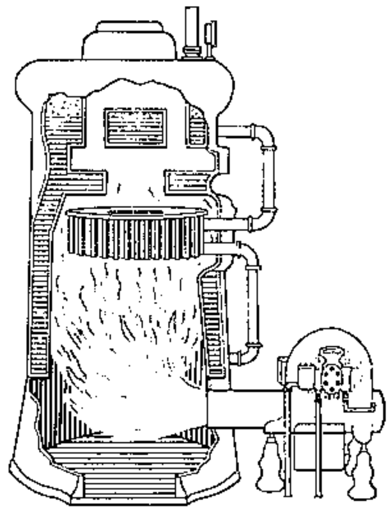

FIGURE 10.—Economizer unit providing additional primary heating surface.

generator, the device serves to step up the efficiency to some degree as will be shown later. This type of economizer will be referred to as type W.

Similar in principle to type W, but specially designed for the purpose, is the economizing device shown in figure 10. This is installed and tied in with the boiler in a fashion similar to that described above but the heating surface is greater and the economizing effect is presumably greater. It will be referred to as type F.

Another type is shown in figure 11. Here again increased heat-absorbing surface is provided in the form of castings placed in the firebox and the water-bearing compartments of these castings are tied in parallel with the boiler proper, thus providing additional primary heating surface. In the particular economizer tested the annular portion rests on the top of the combustion-chamber walls and is piped into the lower portion of the boiler. The annular portion is in turn fitted with a hoodlike casting over the fire and from the top of this portion a circulating line connects with the upper portion of the boiler as shown in the cut. This will be referred to as type V.

Still another well-known combination of economizing devices is shown in figure 12. This consists of two principal parts: (1) A water-containing casting lined with refractory material forming a combustion chamber and providing additional heat-absorbing surface which is tied in with the boiler by means of piping as shown. This gives additional direct heating surface; (2) "fingers" of metal cemented to the surface of the upper flues, as shown, provide additional indirect heating surface to collect heat and transmit it to the boiler walls and thence to the water. These two components of the economizing system are not connected in any way, therefore either may be employed without the other if it is unnecessary or impractical to use both. This will be referred to as type H.

Various combinations of the above-described devices can be employed. For example, type P with types F or V; or type S with type F. Such combinations were made in the tests and the performance results are presented later.

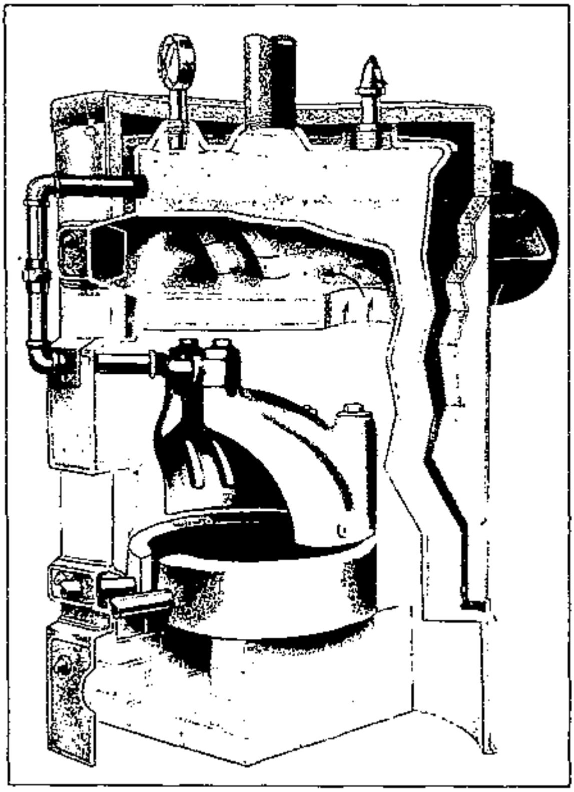

FIGURE 11.—Design of economizer providing additional primary heating surface.

DISCUSSION OF RESULTS

Tables 10 to 22 give data covering a large portion of the tests of domestic oil burners made in the laboratories of the Johns Hopkins School of Engineering, Baltimore, Md. The tables are presented for students of the subject of domestic oil burning interested in the details of the performance of oil burners in various boilers. However, for the purpose of simplification, the salient results of the laboratory studies have been presented more conveniently in graphic form in figures 13 to 23. For the discussion of test results reference will be made to the graphs.

The comparison of test results is on the basis of thermal efficiency only. In selecting a burner for a particular installation the buyer would need to consider other factors, such as type of boiler, grade of oil burned, and amount of service required. The writer has already presented information in more detail on this point.[7] In the tests upon which the graphs in figures 13 to 23 are based the burner was always operated long enough preceding each test to insure steady conditions before readings were begun. The output in gross equivalent square feet of steam radiation at any given fuel rate is equal to the fuel rate multiplied by the calorific value of the fuel in British thermal units per gallon, multiplied by the efficiency (expressed as a decimal), and divided by 240, which is the number of British thermal units emitted in 1 hour by 1 square foot of standing cast-iron steam radiation.

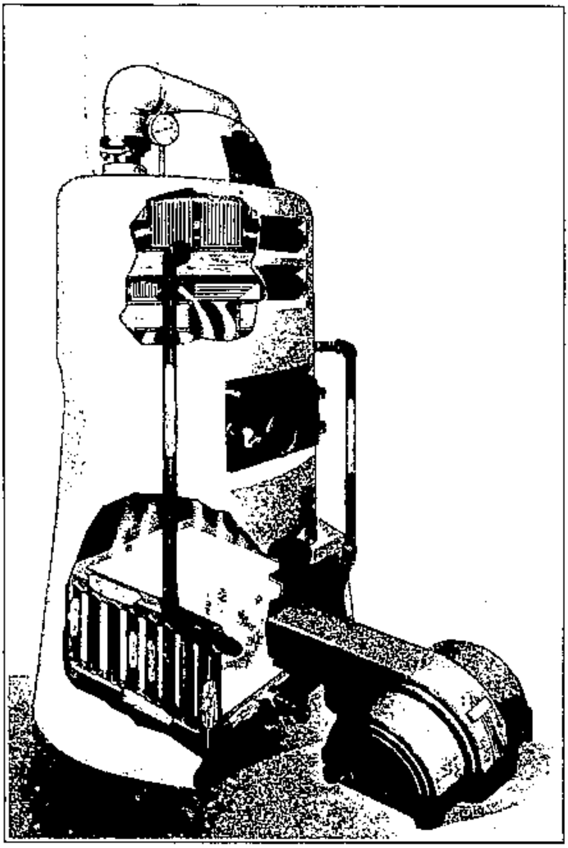

FIGURE 12.—Economizer providing additional primary and secondary heating surface

It was the purpose in the presentation of the data in figures 13 to 23 to generalize as much as feasible. Accordingly performance data are presented for representative burners of good design for each of the several types of burners. The difference in efficiencies of any of the better burners of a given type under a given set of operating conditions is not sufficient to be of practical importance; for that reason the performance graphs in figures 13 to 23 can be regarded as typical performances of good equipment of the several types when operated under the specified conditions. In the case of the operation of the vertical rotary burners in figures 13 and 16 representing performances in a six-section 22-inch round type and in a seven-section 23-inch water-tube type, respectively, the performances of the blue-flame vertical-rotary and the yellow-flame atomizing types of burners were so nearly alike that for simplicity they were averaged and presented merely as performance for a vertical-rotary burner.

[7] SENNER, A. H. See footnote 1.

Figures 22 and 23 indicate the performances of the various economizer schemes described on pages 18 to 21. The reference letters are those used in classifying the various devices and in labelling the test points and graphs in figures 22 and 23. The carbon dioxide content of the flue gases for each of the individual test points and graphs is also shown in figures 22 and 23.

TABLE 10. *Log of test data for vertical-rotary, yellow-flame atomizing burner G*

[Fuel oil No. 2]

BOILER S 2306

Date of test	Fuel burned per hour	Draft at base of flue	Room temperature	Stack temperature	CO_2 by volume	C_2H_4 by volume	O_2 by volume	H_2 by volume	CO by volume	CH_4 by volume	N_2 by volume	Thermal efficiency
1930	*Gallons*	*Inches of water*	*°F*	*°F*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Dec. 10	1.57	0.016	60	453	11.20		5.10		0.50		82.90	76.1
10	1.13	.017	61	366	10.80	0.06	6.10	0.12	.31	0.00	82.61	77.2
11	1.90	.070	62	485	13.00		3.70		.20		83.10	75.8
12	1.26	.037	63	409	11.10		6.20		.20		82.50	76.9
12	1.79	.045	60	478	12.80		3.50		.30		83.90	76.9
BOILER S 2307												
Dec. 17	1.94	0.029	58	457	13.40		2.70				84.10	75.8
17	1.31	.020	66	581	13.30		2.20		0.70		83.80	78.2
19	2.79	.017	51	565	13.10		3.00		.00		83.90	72.9
19	1.79	.017	56	490	11.20		5.00		.20		83.60	75.8

NOTE.—Burner operated until equilibrium was established.

TABLE 11. *Log of test data for pressure atomizing burner H*

[Fuel oil No. 2]

BOILER S 2306

Date of test	Fuel burned per hour	Draft at base of flue	Room temperature	Stack temperature	CO_2 by volume	C_2H_4 by volume	O_2 by volume	H_2 by volume	CO by volume	CH_4 by volume	N_2 by volume	Thermal efficiency
1931	*Gallons*	*Inches of water*	*°F*	*°F*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Sept. 19	1.80	0.040	77	550	10.20	0.05	7.30	0.05	0.10	0.05	82.25	65.2
20	1.25	.040	77	458	9.50	.05	7.65	.05	.10	.10	82.55	66.5
20	1.28	.040	84	481	9.15	.05	7.15	.05	.10	.10	83.40	67.8
26	1.06	.035	82	436	9.55	.10	7.80	.10	.10	.10	82.25	71.3
BOILER S 2307												
Sept. 28	1.18	0.033	77	373	9.25	0.05	8.30	0.10	0.15	0.05	82.10	71.8
29	1.55	.037	75	437	9.65	.10	7.35	.15	.20	.10	82.45	74.2

NOTE.—Burner operated until equilibrium was established.

TABLE 12.—*Log of test data for retort-type burner J*

[Fuel oil No. 2]

BOILER S-2206

Date of test	Fuel burned per hour	Draft: Base of flue	Draft: Over fire	Room temperature	Stack temperature	CO_2 by volume	Thermal efficiency	Remarks[1]
1934	*Gallons*	*Inches of water*	*Inches of water*	*°F.*	*°F.*	*Percent*	*Percent*	
Sept. 5	1.28	0.023			478	10.2	72.2	a, c.
Sept. 17	1.27	.010	0.022	70.0	471	11.3	71.3	a, c.
Sept. 18	1.16	.012	.023	70.0		10.4	67.9	b, c.
Sept. 19	1.71	.015	.022		553	14.0	68.3	a, c.
Sept. 20	1.65	.021	.031	70.0		12.8	71.3	b, c.
Sept. 24	1.76	.020	.027		527	14.2	70.6	a, c.
Sept. 25	1.70	.038	.047	78.0		13.1	68.3	b, c.
Sept. 26	1.37	.030	.040	81.0	404	10.8	67.9	a, c.
Oct. 16	1.38	.011	.018	81.0	538	10.3	66.2	a, d.
Oct. 17	1.10	.012	.015	81.0		8.8	65.6	b, d.
Oct. 25	1.30	.035	.043	75.0	539	10.9	66.7	a, d.
Oct. 29	1.58	.042	.049	71.0	598	11.0	66.2	a, d.
Nov. 5	1.52	.017	.020	83.0	600	11.8	66.2	a, d.
Do	1.49	.020	.026	83.0	563	11.3	68.6	a, d.
Do	1.55	.012	.023	84.0	549	13.8	70.5	a, d.
Do	1.41	.009	.020	84.0	540	11.9	69.5	a, e.
Nov. 7	1.10	.008	.018	82.0		12.4	70.5	b, e.
Nov. 12	1.33	.010	.022	76.0	522	11.5	68.4	a, e.
Do	1.49	.003	.013	75.5	565	11.2	66.8	a, e.
Do	1.31	.028	.021	71.0	445	10.8	69.6	a, e, f.
Nov. 13	1.34	.023	+.040	77.0	447	12.7	71.5	a, e, f.
Nov. 19	1.40	.020	+.030	81.0	460	14.1	72.2	a, e, f.
Do	1.51	.022	.003	81.0	495	14.2	71.6	a, e, f.
Do	1.58	.028	+.020	86.0	510	11.4	68.6	a, e.
Do	1.59	.026	+.010	86.3	525	13.1	69.5	a, e.
Do	1.65	.028	.019	83.0	500	11.7	69.3	a, e, f.
BOILER S 2206								
Do	1.63	.025	.016	83.0	496	11.5	69.6	a, e, f.
Do	1.63	.020	.015	82.0	499	11.9	73.9	a, e, f, g.
Nov. 20	1.60	.021	.017	85.0	490	12.5	74.8	a, e, f, g.
Nov. 21	1.65	.023	.032	84.0	506	12.4	71.8	a, e, g.
BOILER S 2307								
Dec. 27	1.14	0.034	0.036	71.0	427	9.4	74.8	a, e.
1935								
Jan. 7	1.38	.025	.028	75.0	387	11.0	78.4	a, e.
Jan. 9	1.66	.005	.007	79.0	396	12.7	79.4	a, e.
Jan. 15	1.81	.029	.030	68.0	465	12.6	76.7	a, e.
Jan. 17	1.82	+.005	+.010	69.0		13.0	76.1	b, e.
Jan. 22	1.33	.005	.008	73	360	10.0	78.1	a, d.
Jan. 28	1.11	+.038	+.022	61	340	11.3	78.1	a, e
Jan. 30	1.14	+.028	+.023	63	333	11.8	78.6	a, e
BOILER W-2004								
Apr. 20	1.08	0.065	0.021	78	650	10.1	67.2	a, d, f.
Do	.99	.025	.024	79	826	9.7	59.1	a, d.
Do	.95	.024	.025	79	800	10.3	60.8	a, e.
May 1	.97	.021	.014	70	693	10.6	70.8	a, e, f, g.
Do	.93	.024	.027	69	782	10.0	61.8	a, e, g.

[1] a = Continuous operation; b = intermittent operation; c = original distributor; d = new distributor; e = new short distributor; f = with type P economizer; e = deck installed.

NOTE.—Burner operated until equilibrium was established, except during intermittent runs.

TABLE 13.—*Log of test data for pressure-atomizing burner K*

[No. 2 fuel oil used for first 5 tests; No. 3 for remainder]

BOILER W-2004

Date of test	Fuel burned per hour	Draft: Base of flue	Draft: Over fire	Room temperature	Stack temperature	CO_2 by volume	Thermal efficiency	Oil pressure per square inch gage	Remarks [1]
1934	*Gallons*	*Inches of water*	*Inches of water*	*°F.*	*°F.*	*Percent*	*Percent*	*Pounds*	
Sept. 27	1.59	0.070	0.041	80.0	778	10.7	68.0	102	a, c.
Do	1.74	.075	.022	80.0	845	10.4	66.3	123	a, c.
Oct. 1	1.82	.070	.033	72.0	----------	10.2	65.2	125	b, c.
Do	1.93	.075	.022	73.0	888	10.7	65.0	150	a, c.
Oct. 2	1.97	.078	.026	72.0	----------	10.3	65.3	145	b, c.
Oct. 3	1.96	.070	.029	76.0	902	10.8	65.1	152	a, c.
Oct. 4	1.09	.050	.012	73.0	669	10.3	67.8	100	a, c.
Oct. 5	1.07	.052	.038	72.0	----------	10.1	66.5	102	b, c.
Oct. 8	1.46	.074	.040	75.0	706	10.6	64.2	110	a, c.
Oct. 9	1.45	.070	.043	76.0	650	9.6	63.9	111	a, c.
Do	1.61	.071	.042	76.0	685	10.8	65.6	150	a, c.
1935									
Jan. 8	1.62	.055	.021	73.0	613	10.1	68.7	150	a, c.
Jan. 9	1.06	.052	.021	72.0		10.4	68.6	150	b, c.
Jan. 11	1.72	.059	.021	75.0	635	11.0	68.1	150	a, c.
Jan. 18	1.83	.057	.017	72.0		10.7	69.6	150	b, c.
Jan. 23	1.33	.041	.023	70.0		10.8	72.5	150	b, c.

[1] a=Continuous operation; b=intermittent operation; c=with type H economizer.

NOTE. Burner operated until equilibrium was established, except during intermittent runs

TABLE 14.—*Log of test data for vertical-rotary atomizing burner L*

BOILER S-2307

Date of test	Kind of fuel	Fuel burned per hour	Draft: Base of flue	Draft: Over fire	Room temperature	Stack temperature	CO_2 by volume	Thermal efficiency	Remarks [1]
1934		*Gallons*	*Inches of water*	*Inches of water*	*°F.*	*°F.*	*Percent*	*Percent*	
Oct. 18	No. 2	1.47	0.033	0.042	82	423	12.3	77.2	a.
Do		1.82	.038	.048	82	468	13.2	77.3	a.
Do		2.03	.038	.044	83	507	13.9	76.1	a.
Do		2.28	.036	.039	83	532	13.9	75.3	a.

BOILER W-2004

Date of test	Kind of fuel	Fuel burned per hour	Draft: Base of flue	Draft: Over fire	Room temperature	Stack temperature	CO_2 by volume	Thermal efficiency	Remarks [1]
Oct. 19	No. 2	1.56	0.047	0.054	72	908	13.6	63.3	a.
Do		1.56	.043	.033	72	710	13.7	71.1	a, c.
Do	No. 3	2.14	.057	+.020	73	891	11.6	63.2	a, c.
Do		1.90	.085	.014	74	850	10.8	63.2	a, c.
Oct. 20		1.39	.049	.030	74	709	11.3	67.6	a, c.
Oct. 23		1.68	.059	.013	77	797	11.1	65.1	a, c.
Oct. 21		1.68	.058	.009	76	----------	10.9	66.6	b, c.
Oct. 29	No. 4	1.06	.078	.022	67	805	10.5	63.7	a, c.
Nov. 2	No. 3	1.52	.069	.025	76	---	9.7	64.7	b, c.
Do		1.34	.036	.038	76	893	10.4	57.2	a.
Nov. 7		1.43	.063	.063	81	922	10.7	56.6	a.
Nov. 9		1.42	.087	.064	76	----	9.9	57.1	b.

[1] a=Continuous operation; b=intermittent operation; c=with type P economizer.

NOTE.—Burner operated until equilibrium was established, except during intermittent runs.

TABLE 15.—*Log of test data for vertical rotary blue-flame burner M*

[Fuel oil No. 2]

BOILER W-2004

Date of test	Fuel burned per hour	Draft: Base of flue	Draft: Over fire	Room temperature	Stack temperature	CO_2 by volume	Thermal efficiency	Remarks [1]
1934	*Gallons*	*Inches of water*	*Inches of water*	*°F.*	*°F.*	*Percent*	*Percent*	
Nov. 12	1.19	0.046	0.057	75.0	756	11.9	64.3	a, e.
Nov. 14	1.27	.063	.072	72.0		11.3	67.3	b, e.
Nov. 15	1.62	.069	.070	75.0	931	11.1	58.4	a, e.
Do	1.40	.054	.059	73.0	873	11.0	59.8	a, e.
Nov. 16	1.41	.052	.077	73.0		10.9	62.4	b, e.
Do	1.12	.046	.055	75.0	754	11.1	63.5	a, e.
Nov. 28	1.00	.015	.056	81.0		10.8	68.9	b, e.
Do	1.02	.039	.029	87.0	589	11.1	70.9	a, e, d.
Nov. 29	1.00	.036	.023	77.0		11.1	74.4	b, e, d.
Nov. 30	1.61	.071	.003	75.0	764	12.2	67.5	a, e, d.
Do	1.60	.068	.011	74.0		12.1	69.1	b, e, d.
Do	1.02	.100	.009	73.0	833	12.5	65.1	a, e, d.
Dec. 3	1.90	.097	.002	69.0		12.0	63.3	b, e, d.
Do	1.05	.050	.035	74.0	607	10.9	68.0	a, e, d.
Dec. 5	1.02	.055	.036	71.0		10.3	69.1	b, e, d.
Do	1.02	.064	.074	72.0	736	11.2	61.3	a, e.
Do	1.13	.068	.075	73.0	756	10.9	61.5	a, e.
Dec. 7	1.20	.071	.077	69.0		10.7	60.4	b, e.
Dec. 10	1.37	.064	.066	65.0	919	11.2	61.2	a, e.
Dec. 12	1.10	.066	.069	66.0		11.2	57.8	b, e.
Dec. 13	1.07	.070	.074	67.0		12.5	64.3	b, e.
Do	1.06	.064	.072	71.0	818	13.2	64.8	a, e.
Do	1.07	.059	.072	71.0	773	13.1	66.2	a, e.
Dec. 14	1.05	.051	.024	71.0	575	12.3	71.9	a, e, d.
Dec. 17	1.06	.049	.024	76.0	573	12.4	71.7	a, e, d.
Dec. 21	1.05	.052	.027	73.0	555	11.5	76.7	b, e, d.

[1] a = Continuous operation; b = intermittent operation; c = standard refractory (tile segments); d = with type P economizer; e = standard refractory plus grids.

NOTE.—Burner operated until equilibrium was established, except during intermittent runs.

TABLE 16.—*Log of test data for pressure-atomizing burner N*

[Fuel oil No. 3]

Date of test	Boiler	Fuel burned per hour	Draft: Base of flue	Draft: Over fire	Room temperature	Stack temperature	CO_2 by volume	Thermal efficiency	Oil pressure per square inch gage	Remarks [1]
1935		*Gallons*	*Inches of water*	*Inches of water*	°F.	°F.	*Percent*	*Percent*	*Pounds*	
Mar. 11	S-2307	2.60			71	530	10.1	72.1	100	a.
28	S-2307	2.04	0.019	0.043	71	534	10.1	70.5	100	a.
28	S-2307	2.04	.045	.040	71	535	10.2	71.1	100	a.
28	S-2307	2.24	.016	.009	66	562	10.2	69.5	110	a.
28	S-2307	1.81	.038	.030	67	491	10.2	72.1	115	a.
29	S-2307	2.68	.030	.029	75	594	12.2	71.7	175	a.
Apr. 5	S-2307	1.87	.032	.027	75	495	10.8	71.0	120	a.
			.038	.037						
[Fuel oil No. 2]										
Apr. 6	S-2307	1.86	0.037	0.035	76	514	10.1	70.9	120	a.
8	S-2307	1.56	.063	.034	64	488	9.8	70.0	150	a.
8	S-2307	1.33	.010	.039	64	435	9.8	74.5	100	a.
9	S-2307	1.72	.012	.010	60	511	9.8	69.1	100	a.
10	S-2206	1.76	.011	.016	74	573	11.0	66.1	120	a.
10	S-2206	1.40	.018	.027	74	586	11.5	67.9	100	a.
10	S-2206	1.25	+.001	.005	74	466	12.1	69.3	80	a.
11	S-2206	1.26	.011	.021	80	508	10.0	67.5	80	a.
11	S-2206	1.42	.021	.030	80	518	10.0	64.6	100	a.
16	S-2206	1.30	.004		68	438	12.2	68.9	102	a, d.
16	S-2206	1.61	.011		68	483	12.2	70.2	102	a, d.
16	W-2004	1.26	.033	.000	69	547	11.8	65.0	80	a, e, f.
16	W-2004	1.24	.035	.000	69	555	11.8	67.0	80	a, e, f.
16	W-2004	1.25	.026	.000	69	556	12.2	67.1	80	a, e, f.

[1] a = Continuous operation; d = with type W economizer; e = with type P economizer; f = with type V economizer.

NOTE.—Burner operated until equilibrium was established.

Table 17.—*Log of test data for vertical-rotary, blue-flame burner O. Boiler S–2206*

[Fuel oil No. 2]

Date of test	Fuel burned per hour	Draft: Base of flue	Draft: Over fire	Room temperature	Stack temperature	CO_2 by volume	Thermal efficiency	Remarks [1]
1935	*Gallons*	*Inches of water*	*Inches of water*	*° F.*	*° F.*	*Percent*	*Percent*	
Mar. 24	1.25	0.042	0.057	72.0	430	12.8	75.5	a, c, f.
Do	1.62	.040	.052	71.0	528	12.0	73.5	a, c, f.
Do	1.59	.001	.008	73.0	520	11.7	73.2	a, c, f.
Do	1.59	.024	.034	73.0	519	12.8	75.3	a, c, f.
Mar. 25	2.33	.020	.025	65.0	654	13.2	70.8	a, c, f.
Do	1.44	.018	.030	67.0	481	14.1	75.5	a, c, f.

[1] a=Continuous operation; c=metal hearth segments; f=with grills.

Note.—Burner operated until equilibrium was established.

Table 18.—*Log of test data for vertical-rotary, blue-flame burner P, boiler S–2206*

[Fuel oil No. 2]

Date of test	Fuel burned per hour	Draft: Base of flue	Draft: Over fire	Room temperature	Stack temperature	CO_2 by volume	Thermal efficiency	Remarks [1]
1935	*Gallons*	*Inches of water*	*Inches of water*	*° F.*	*° F.*	*Percent*	*Percent*	
Mar. 18	1.48	0.023	0.036	77.0	539	11.6	73.5	c, d.
Mar. 19	1.47	.038	.055	73.0	480	13.0	76.2	c, e.
Do	1.49	.038	----	73.0	516	11.8	74.6	c, d, e.
Do	1.66	.038	.048	77.0	528	11.6	76.7	c, d, e, f.

[1] c=Cast-iron segments; d=metal grids; e=hearth pad; f=extended-blade fan.

Note.—Burner operated until equilibrium was established.

Table 19.—*Log of test data for pressure-atomizing burner R*

[No. 3 fuel oil used with first 2 tests; No. 2 with remainder]

Date of test	Boiler	Fuel burned per hour	Draft: Base of flue	Draft: Over fire	Room temperature	Stack temperature	CO_2 by volume	Thermal efficiency	Oil pressure per square inch	Remarks [1]
1935		*Gallons*	*Inches of water*	*Inches of water*	*° F.*	*° F.*	*Percent*	*Percent*	*Pounds*	
Apr. 1	W–2004	1.42	0.048	0.028	75	785	8.7	51.6	125	c.
5	W–2004	1.36	.068	.050	73	730	8.1	57.3	125	c.
12	S–2307	1.33	.043	.047	74	420	10.2	72.5	103	
12	S–2307	1.56	.018	.048	75	481	9.8	72.5	155	
12	W–2004	1.30	.053	.009	74	525	9.6	69.9	100	c, d.
14	W–2004	1.28	.054	.015	81	515	10.6	69.3	105	c, d.
16	W–2004	1.28	.056	.043	72	725	9.7	61.4	101	c.
23	W–2004	1.27	.060	.022	73	594	8.7	66.2	100	c, d.
24	W–2004	1.35	.063	.021	75	746	9.7	61.4	100	d.
24	W–2004	1.33	.069	.059	74	881	9.7	51.4	100	
26	W–2004	1.35	.030	.022	76	910	9.8	52.1	100	
26	W–2004	1.33	.067	.014	75	758	9.8	59.2	100	e.

[1] c=with type F economizer; d=with type S economizer; e=with type P economizer.

Note.—Burner operated until equilibrium was established.

TABLE 20.—*Log of test data for pressure-atomizing burner S*

[Fuel oil No. 2]

BOILER S-2206

Date of test	Fuel burned per hour	Draft: Base of flue	Draft: Over fire	Room temperature	Stack temperature	CO_2 by volume	Thermal efficiency	Oil pressure per square inch
1935	*Gallons*	*Inches of water*	*Inches of water*	*°F.*	*°F.*	*Percent*	*Percent*	*Pounds*
Nov. 18	2.31	0.036	0.034	72	705	13.6	65.0	102
Do	2.02	.047	.051	70	646	13.6	66.2	102
Nov. 19	1.91	.048	.049	59	665	11.2	62.9	102
Nov. 20	2.35	.051	.041	71	704	11.6	64.2	102
Do	1.59	.058	.065	64	539	13.5	68.8	102
Nov. 21	1.58	.048	.053	64	590	10.5	65.4	102
Nov. 22	1.57	.060	.058	66	580	11.1	66.5	102
BOILER S-2307								
Dec. 30	1.41	0.049	0.053	64	447	11.0	76.0	101
1936								
Jan. 1	1.38	.049	.055	69	395	12.3	74.8	101
Jan. 2	1.60	.049	.053	64	439	12.4	74.3	102
Jan. 3	1.50	.051	.057	69	440	11.0	74.8	101
Jan. 9	1.97	.050	.052	72	523	11.0	72.9	100
Jan. 10	1.60	.051	.054	71	468	10.9	73.7	101
Jan. 13	1.89	.051	.058	75	486	12.5	74.0	100

NOTE.—Burner operated until equilibrium was established.

TABLE 21.—*Log of test data for pressure-atomizing burner T, boiler S-2206*

[Fuel oil No. 2]

Date of test	Fuel burned per hour	Draft: Base of flue	Draft: Over fire	Room temperature	Stack temperature	CO_2 by volume	Thermal efficiency	Oil pressure, per square inch
1935	*Gallons*	*Inches of water*	*Inches of water*	*°F.*	*°F.*	*Percent*	*Percent*	*Pounds*
Nov. 8	1.70	0.040	0.045	70	635	11.6	65.3	100
Nov. 14	1.67	.030	.035	70	670	10.0	61.9	100
Do	2.10	.030	.030	67	728	11.2	61.2	100
Nov. 15	1.59	.030	.035	65	621	10.9	65.7	100

NOTE.—Burner operated until equilibrium was established.

TABLE 22.—*Log of test data for boiler-burner unit C*

[Fuel oil No. 2]

Date of test	Boiler	Fuel burned per hour	Draft: Base of flue	Draft: Over fire	Room temperature	Stack temperature	CO_2 by volume	Equivalent evaporation steam/oil from and at 212° F.	Thermal efficiency	Equivalent output of steam radiation (gross) [1]	Oil pressure per square inch gage
1935		*Gallons*	*Inches of water*	*Inches of water*	*°F.*	*°F.*	*Percent*	*Pounds per pound*	*Percent*	*Square feet*	*Pounds*
June 3	1,200	2.49	0.057	0.042	70	379	10.5	16.7	81.8	1,161	--
3	1,200	2.47	.051		77	344	12.6	17.3	85.0	1,108	--
4	600	1.43	.053	.034	83	375	9.5	16.6	81.8	678	----
4	600	1.60	.050	.036	81	415	9.6	16.1	79.5	734	----
4	600	1.32	.052	.034	79	377	9.4	16.5	81.6	627	---
5	1,200	3.32	.071	.031	80	469	11.2	16.4	80.5	1,488	--
5	1,200	2.82	.061	.031	80	413	11.8	16.7	82.1	1,324	----
5	1,200	2.48	.051		81	366	11.6	16.9	83.2	1,181	80
6	600	1.01	.048	.029	80	292	8.2	16.7	82.0	472	110
6	1,200	1.87	.045	.020	70	288	11.1	17.6	86.4	923	

[1] 240 B. t. u. per square foot of steam radiation per hour.

NOTE.—Burner operated until equilibrium was established.

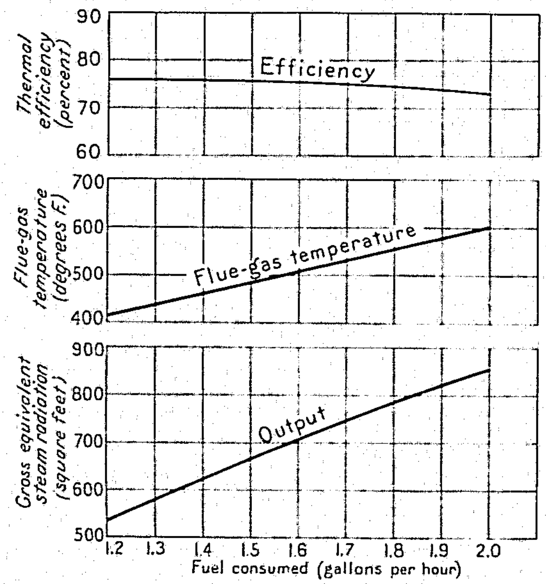

FIGURE 13.—Performance of vertical-rotary burner in a six-section 22-inch round boiler.

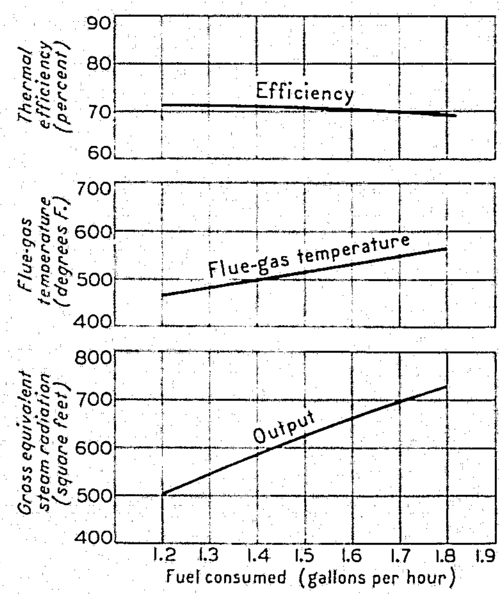

FIGURE 14.—Performance of retort type in a six-section 22-inch round boiler at 12.1 percent average carbon dioxide.

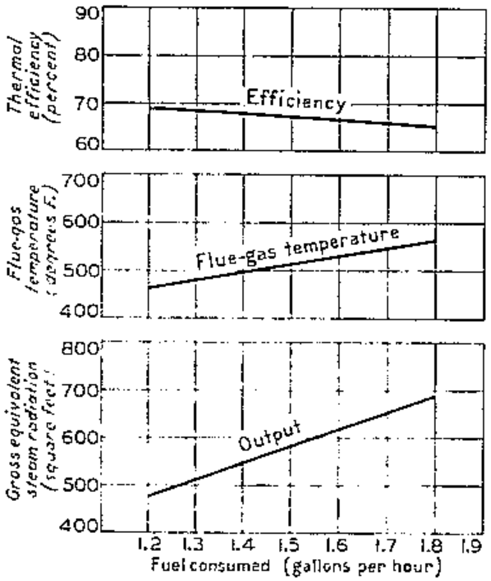

FIGURE 15.—Performance of pressure-atomizing (gun) burner in a six-section 22-inch round boiler at 11 percent average carbon dioxide.

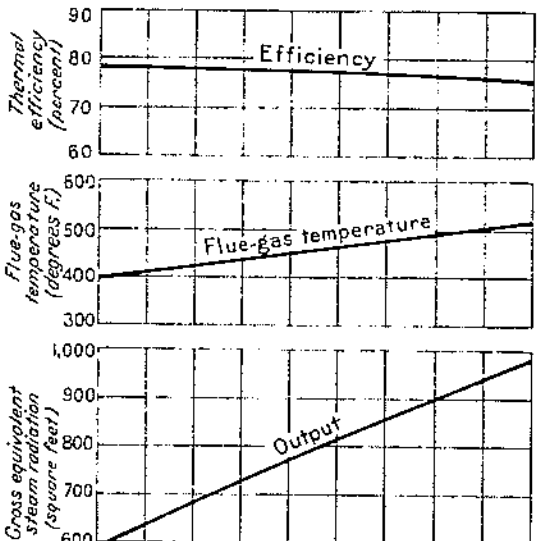

FIGURE 16.—Performance of vertical-rotary burner in a seven-section 23-inch water-tube boiler.

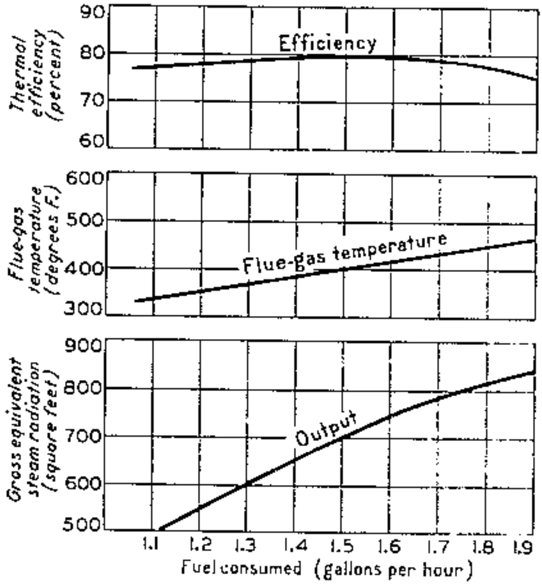

FIGURE 17.—Performance of retort-type burner in a seven-section 23-inch water-tube boiler at 11.8 percent average carbon dioxide.

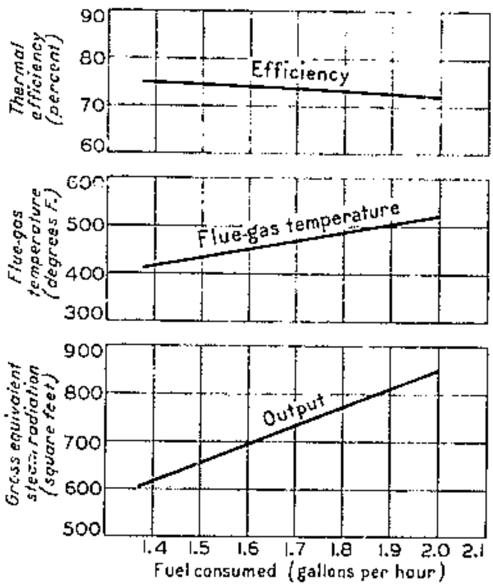

FIGURE 18.—Performance of pressure-atomizing (gun) burner in a seven-section 23-inch water-tube boiler at 11 percent average carbon dioxide.

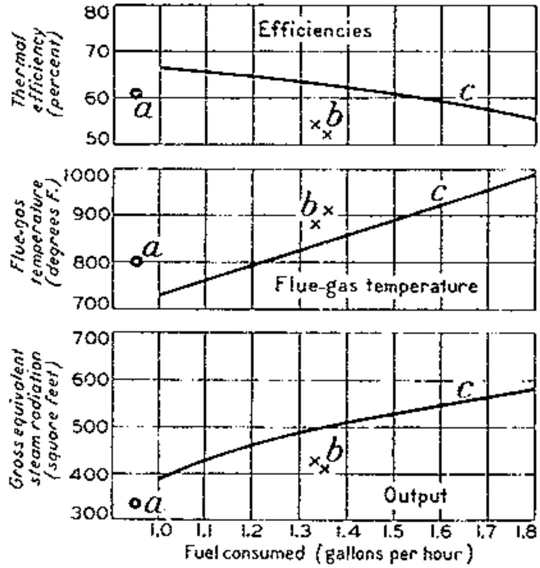

FIGURE 19.—Performances of *a*, Retort; *b*, gun; and *c*, blue-flame rotary burners in a four-section 20-inch round boiler.

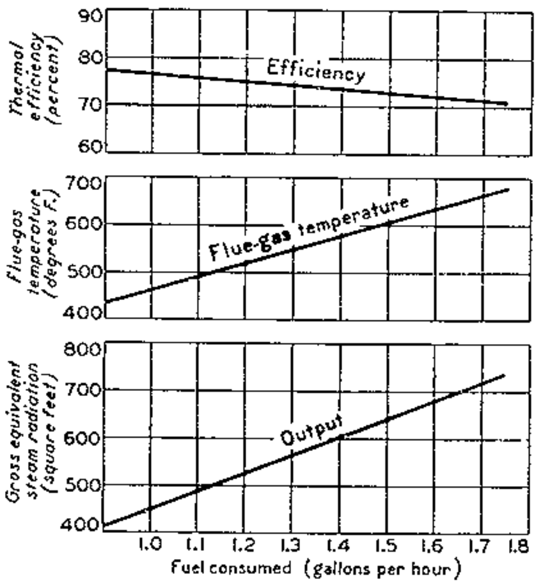

FIGURE 20.—Performance of vertical-rotary burner in a special cast-iron oil burning boiler at 12.7 percent average carbon dioxide.

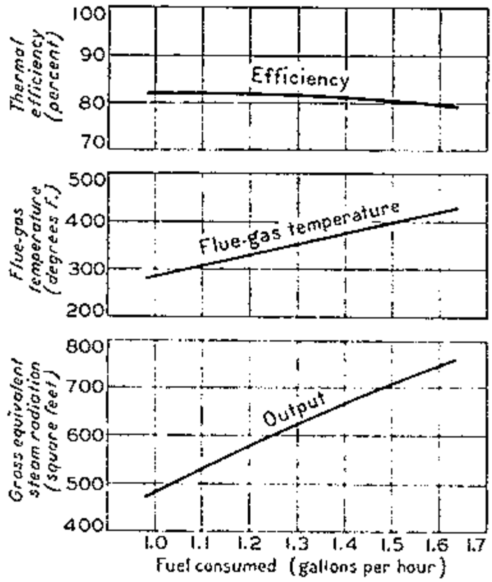

FIGURE 21.—Performance of modern steel boiler-burner unit, fired by a pressure-atomizing (gun) burner at 9.2 percent average carbon dioxide.

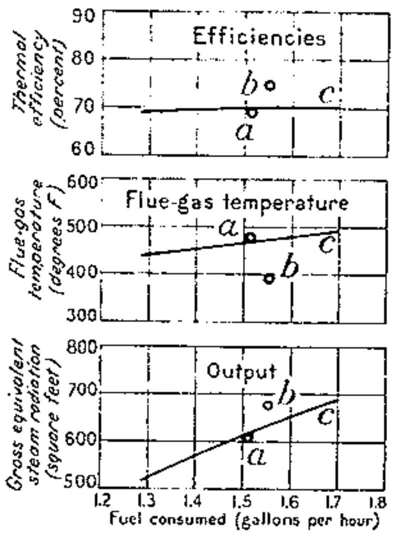

FIGURE 22.—Performances of gun-type burners in a six-section 22-inch round boiler with the following economizing devices: *a*, Type P; *b*, types V and P; *c*, type W. All at approximately 12 percent carbon dioxide.

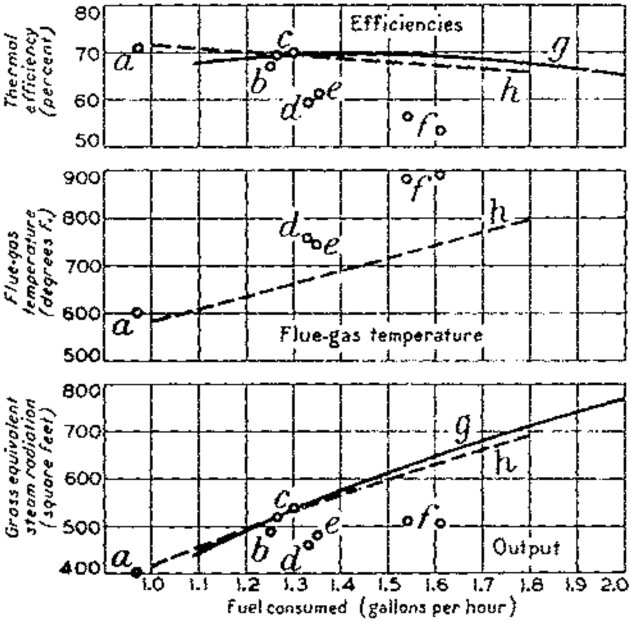

FIGURE 23.—Performances in a four-section, 20-inch round boiler with the following burners and economizing devices: *a*, Retort-type 10.6 percent CO_2, P economizer; *b*, gun-type, 11.9 percent CO_2, P and V economizers; *c*, gun-type (two tests), 9.8 percent CO_2, F and S economizers; *d*, gun-type, 9.8 percent CO_2, P economizer; *e*, gun-type 9.7 percent CO_2, S economizer; *f*, gun-type (two tests), 10.2 percent CO_2, fire-box portion only of type H; *g*, gun type, 10.5 percent CO_2, H economizer; *h*, blue-flame vertical-rotary, 12.1 percent CO_2, P economizer.

EFFICIENCIES

The curves of efficiency in figures 13–23, are either concave downward or straight lines within the range of fuel rates shown. In all cases, except perhaps the four-section 20-inch boiler, the efficiency graph slopes downward gradually, as the fuel rate increases. Thus the boilers and burners may, in general, be said to have flat efficiency characteristics. The efficiencies recorded are for relatively good conditions of operation but since we are interested principally in comparisons between the several types of burners such conditions are equally advantageous to all types concerned.

The effects on the efficiencies of the two round boilers (the six-section 22-inch and the four-section 20-inch) of the use of various economizing devices as depicted in figures 22 and 23 are particularly interesting to the practical oil-burner man. The economizers studied were the types in most common use at the time of writing.

FLUE-GAS TEMPERATURE

To produce high over-all efficiencies, there must be (1) complete combustion, which presupposes adequate combustion volume, atomization, admixing, etc., and (2) there must be sufficient direct and indirect heating surface to absorb the heat evolved by combustion. In short, the fuel must be completely burned and the heat extracted thoroughly from the products of combustion.

The effect of fuel rate and air-fuel ratio upon the exit loss should be clearly understood. It will be noted from the various curves that the flue-gas temperature for a given air-fuel ratio increases as the number of gallons of oil burned is increased. Take, for example, figure 13. In this figure the performance of a burner in a six-section boiler, with a constant carbondioxide content of 12.8 percent in the flue gases is considered. Now, as the fuel rate is increased from 1.2 gallons per hour to 2 gallons the flue-gas temperature is seen to increase from 415° to 600° F., in a straight-line relation.

On the other hand, what is the effect on flue-gas temperature when the rate is held constant but the air-fuel ratio is altered? As heretofore brought out, the addition of excess air decreases the flame temperature; that is, the inert material added acts as a diluent, and as

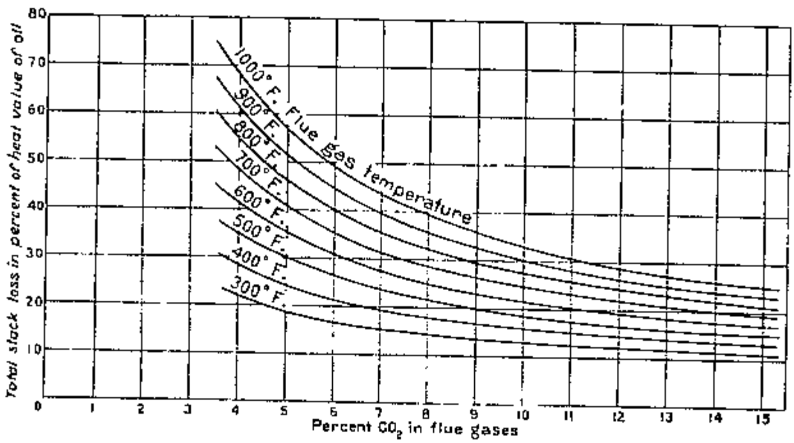

FIGURE 24.—Stack-loss curves for combustion of domestic oil-burner distillates.

a result the final temperature is diminished. Thus with a given fuel rate and a given furnace, the initial temperature, with complete combustion, is higher with a flame producing, for example 12 percent carbondioxide than with a flame producing 10 percent of carbondioxide. In regard to stack temperature, although the furnace temperature is higher in the case of less excess air, the exit temperature is lower. As has been stated, the radiant heat emitted by a body is a function of the fourth power of its absolute temperature; also, not only the incandescent carbon particles but certain gases—in particular carbon dioxide and H_2O are good radiators. Thus the products of combustion at the higher initial temperature have the power to emit comparatively large amounts of radiant energy to the direct heating surface of the boiler, and to a part of the indirect surface. Moreover, according to the laws of heat transmission by convection, the larger volume of gas—which is the condition with large amounts of excess air—gives the lower efficiency in heat transmission. Thus the combination of these two effects produces higher stack temperatures in the case of large amounts of excess air. Stack loss as a function of air-fuel ratio and stack temperature is shown by the curves in figure 24.

HEATING EFFECT

In figures 13–23 are plotted curves of output or heating effect in terms of gross equivalent square feet of steam radiation. The graphs of output, for the range of fuel rates used, are either straight lines or concave downward. The output is an increasing function of the fuel rate, whereas the efficiency is a decreasing one.

EFFICIENCY IN RELATION TO CONTINUOUS AND INTERMITTENT OPERATION

The tests described herein were principally of a continuous nature, and readings were not begun until constant conditions of carbon-dioxide, stack temperature, heating effect, etc., were attained. However, in actual operation of intermittent-type burners these conditions are not secured, and equilibrium may not always be established. Take, for example, the case of a gun-type burner firing a boiler with the characteristic bricked-up furnace. After the burner has been inactive for some time the brickwork becomes comparatively cool. When the burner resumes operation, the relatively cool brickwork temporarily causes a certain loss from unburned gases. For a given boiler this loss due to starting is a definite quantity for each thermal state of the furnace. Moreover, there may be some loss due to the residual heat of the brick which is not available for producing useful heating effect to the boiler, for the reason that when the burner is inoperative the draft caused by the stack effect carries a certain quantity of heat up the flue. Obviously, when dealing with the smaller types of boiler in which the mass of refractory material or brickwork is relatively small, the starting loss will be negligible for all practical purposes.

The starting loss is made up of two parts (1) the loss due to the chilling effect of the cold brickwork—a "chemical" loss, and (2) the loss due to the direct absorption of heat by the brickwork or refractory material in the furnace. These combined losses may be relatively small, because the catalytic effect of the brickwork is appreciable even when the temperature is much below that at equilibrium operation, and also because a large part of the heat that goes into heating the brickwork is recovered when the burner is inoperative. The relations between the various factors involved in intermittent operation and their effects on resultant efficiencies have been convincingly brought out by Theodorsen at Johns Hopkins University. In his series of tests the boiler was operated as a calorimeter with practically zero radiation, and the heat transmission from the hot brickwork to the water was determined after the shut-down.[8]

UNCONSUMED FUEL

One of the most interesting incidents of this study was the discovery of considerable unburned gases when the burners were operating under conditions which are generally conceded to give perfect combustion. It has been the general practice to analyze the flue gases

[8] Theodore Theodorsen, at Johns Hopkins University, in a series of experiments for the American Oil Burner Association, has studied this problem of unburned fuel for starting conditions as well as for conditions of equilibrium. Results of these experiments are embodied in his report to the association, together with an interesting stoichiometric analysis of the products of combustion resulting from incomplete combustion of a kind referred to in this section. (Unpublished data.)

by means of the conventional Orsat apparatus which shows percentages of CO_2, O_2, CO, and by difference N_2. When this is done and a heat balance is made, it is often found that the unaccounted-for losses run rather high—perhaps as much as 15 percent of the heat value of the fuel. This indicates that there must be some fuel that is unconsumed but which is not detected by the ordinary flue-gas analyzer.

This unaccounted-for fuel could not be entirely in the form of soot without being readily noticeable and, moreover, it was found that even with a comparatively clear stack this loss was always present to a degree. In some instances of oil-burner tests, particularly in the case of large industrial boilers, losses up to several percent have been attributed to soot formation.[9] When the presence of carbon monoxide was detected at all the amount was only a trace—unless there was an appreciable deficiency in the air supplied. The assumption is sometimes made that radiation might account for a large percentage of this heat. However, when the boiler is used merely as a low-temperature calorimeter and relatively cool water is passed through it—thus rendering the radiation very small—this unaccounted-for loss still persists.

For a more complete heat balance the flue gases were therefore analyzed by means of the Bureau of Mines[10] gas analyzer, whereby H_2, unsaturated hydrocarbons, and saturated hydrocarbons could be determined in addition to the compounds indicated by the ordinary engineering type of flue-gas analyzer. Table 23 presents test data resulting from the operation of four principal types of domestic oil burners in three cast-iron boilers. The data present the performance at miscellaneous and widely divergent air-fuel ratios and fuel rates, and therefore may not be used to compare the efficiencies of combustion of the various types of burners. The purpose of this table is to compare the results obtained in using the simple engineering gas analyzer with those obtained by using the more complete gas analyzer. The analyses as presented in the table were made after equilibrium had been reached.

If only the simple gas analyzer had been used the values contained after the items of C_2H_4, H_2, and CH_4 would be lacking. The two sets of percentages under the item of excess air or deficiency show the differences between the computed values of air-fuel ratios when the computations are based on what might be termed the incomplete and the complete analyses. When based on the complete analyses in which practically all the unburned gaseous fuel is included, the air-fuel ratio is less than when based on the relatively incomplete data yielded by the ordinary engineering gas analyzer. The first two tests on the blue-flame vertical-rotary burner were made with air deficiencies for the purpose of studying the products of incomplete combustion under such conditions.

The percentages of the heat value of the oil represented by the products of incomplete combustion are given. The sum of the losses due to C_2H_4, H_2, and CH_4 which would not be detected by the ordinary

[9] BARKLEY, J. F. EXPERIENCES WITH THE COMBUSTION OF FUEL OIL IN POWER PLANT BOILERS. Fuel Oil Heat and Power 4 (12): [13]-11, 40-42, 44, 46, illus. 1926.

[10] BURRELL, G. A., and SEIBERT, F. M. SAMPLING AND EXAMINATION OF MINE GASES AND NATURAL GAS. Revised by G. W. Jones, U. S. Bur. Mines Bull. 197, 108 pp. illus. 1926.

TABLE 23.—*Complete heat balance*

Item	Blue-flame vertical rotary			Pressure atomizing (gun)	Retort	Air atomizing (gun)		
	Test 1	Test 2	Test 3			Test 1	Test 2	Test 3
Boiler type	S-2206	S-2206	S-2206	W-2004	S-2307	S-2307	S-2307	S-2307
Fuel rate per hour ... pounds	10.4	10.4	8.9	11.6	8.5	19.5	19.1	19.1
Flue gas by volume:								
CO_2 ... percent	13.75	12.10	12.70	9.10	11.00	9.20	12.00	6.90
C_2H_4 ... do	0	.35	0	0	0	.10	.40	.35
O_2 ... do	1.25	1.35	4.05	8.90	6.50	8.20	3.40	11.30
CO ... do	1.60	5.10	.60	.80	.10	.10	.10	.50
H_2 ... do	.80	.70	.35	.60	1.00	.80	.50	.40
N_2 ... do	82.05	79.80	82.20	80.10	81.30	81.30	82.40	80.55
CH_4 ... do	.55	.60	.10	.20	.10	0	0	0
Air excess or deficiency (computed):								
Ordinary Orsat ... do	−2.9	−15.5	10.8	41.7	32.3	53.1	11.8	96.3
Complete analysis ... do	−7.6	−21.1	10.5	39.8	30.1	47.8	4.5	79.7
Stack temperature ... ° F	455	385	436	638	399	750	740	850
Useful heat:								
Per pound of oil ... B. t. u	14,230	11,564	14,874	13,000	14,243	11,800	13,000	9,800
Heat value ... percent	72.2	58.7	75.5	66.0	72.3	61.2	67.3	50.8
Incomplete combustion loss in terms of heat value of oil:								
C_2H_4 ... percent	0	4.1	0	0	0	2.3	6.3	9.6
CO ... do	4.4	12.0	2.0	3.4	.4	1.8	1.3	2.8
H_2 ... do	2.2	1.7	1.2	2.5	3.9	3.7	1.6	2.2
CH_4 ... do	4.7	4.1	1.0	2.6	1.2	0	0	0
Total	11.3	22.2	4.1	8.5	5.5	7.7	9.1	11.5
Dry stack loss in percent of heat value	6.3	4.4	6.9	13.9	7.3	17.6	12.2	21.5
Loss from combustion of H_2, percent of heat value	6.4	6.1	6.9	7.1	6.3	7.3	7.1	7.2
Heat value per pound of oil, B. t. u	19,700	19,700	19,700	19,700	19,700	19,300	19,300	19,300
Radiation and unaccounted losses:								
Based on ordinary Orsat, percent	10.7	18.8	8.8	9.6	13.7	12.2	11.9	11.8
Based on complete analysis ... do	3.8	8.6	6.6	4.5	8.6	6.2	4.0	3.0

gas analyzer are in some instances greater than the loss due to carbon monoxide in the flue gases, the only product of incomplete combustion that could be detected in the so-called incomplete analysis. The values of the total incomplete-combustion losses vary from a low value of 4.1 percent to a maximum value of 22.2 percent. During the operation of the burner under the latter conditions, when nearly one-fourth of the fuel passed up the stack unburned, comparatively little soot was produced. The value of the incomplete-combustion loss in one instance, with considerable air deficiency, was greater than the sum of the dry stack loss and the loss of heat in the moisture resulting from combustion of the H_2 of the fuel. Even when adequate air was supplied, the unburned-fuel loss averaged two-thirds of the dry stack loss and usually exceeded the loss in the moisture resulting from combustion of the H_2 of the fuel. The last two lines of table 23 indicate a much better accounting for the total heat of the fuel when the heat balance is based on the complete analysis rather than on the incomplete analysis. The average value of the radiation and unaccounted-for loss based on the ordinary gas analyzer for the several runs listed is 12.6 percent, while based on the complete analysis it is 5.7 percent. Assuming a radiation loss of 3 percent in both cases, this would leave net unaccounted-for losses of 9.6 and 2.7 percent, respectively.

Thus, while the ordinary engineering Orsat apparatus is useful and perhaps indispensable in field adjustments of oil fires, it may not be satisfactory when an accurate heat accounting is to be made in precise laboratory work. Since the carbon monoxide measurement is of relatively little value by itself, probably the most practicable type of gas analyzer for the oil-burner man who is confronted with the task of making oil-burner adjustments in the field is the single-pipette variety utilizing a caustic solution for the absorption of carbon dioxide.

BOILER RATINGS

Few problems are so troublesome to the oil-burner engineer as that of the ratings of boilers designed for burning coal. In many instances the engineer is forced to use the rating given by the manufacturer as based on coal as fuel, and often this results in inefficient operation. To ascertain why the ratings for coal do not generally hold for oil, reference is made to figure 25 which is a characteristic efficiency curve for a heating boiler when burning coal. This curve shows a constantly increasing efficiency from zero to a maximum value at about 40-percent rating. The efficiency then diminishes, the curve being concave downward. At 100-percent rating the efficiency is only about 85 percent of its maximum value. Now this 100-percent rating is fixed at the point of peak load for the season, which is the time when the boiler is being pushed to raise the temperature of the house in the morning to, say, 70° F. during the season of lowest outside temperature. However, it is estimated that the average output for the season is actually less than one-third of this peak demand. The manufacturers take advantage of this fact and so rate their boilers that the operating point of maximum efficiency coincides with the average seasonal demand on the boiler, not with the peak demand. Hence during the time a coal-burning boiler is forced the efficiency suffers.

The intermittently operating oil burner must be so adjusted as to rate of fuel consumption that this peak demand can be handled. Moreover, it must be so adjusted that the rate of burning will be sufficient to heat the house to the desired temperature on the coldest day and to perform this task without running continuously, in order to leave a margin for automatic control. Thus it is the providing for this peak demand which fixes the rate at which a burner must operate. This rate of heat liberation will be at least as great as, and probably greater than, the maximum rate of heat liberation for the coal fire. The important point to bear in mind is that the oil burner of the intermittent variety when once set operates at that same rate all through the season from the mildest to the most severe day. The control of room temperature is obtained by intermittent operation of the burner. In mild weather the burner is inactive for longer periods than it is during cold weather. Now this condition is not objectionable if the allowance for peak demand with coal has been liberal, but if not the oil burner will operate at unduly low efficiencies. Hence if oil is to be used as fuel in a standard coal-burning boiler, some adjustment in rating must be made.

One leading boiler manufacturer, in order to allow for the peak demand, adds about 80 percent to the radiation load in determining the size of boiler for coal. Hence it might be well to add from 100 to 150 percent to the radiation load in order to determine the boiler capacity when burning oil.

From the foregoing it is evident that both the amount of radiation and the total operative time of the burner are factors in selecting the proper size of boiler. Ratings for coal-burning boilers are applicable for oil burning only when proper allowances are made for the differences in conditions.

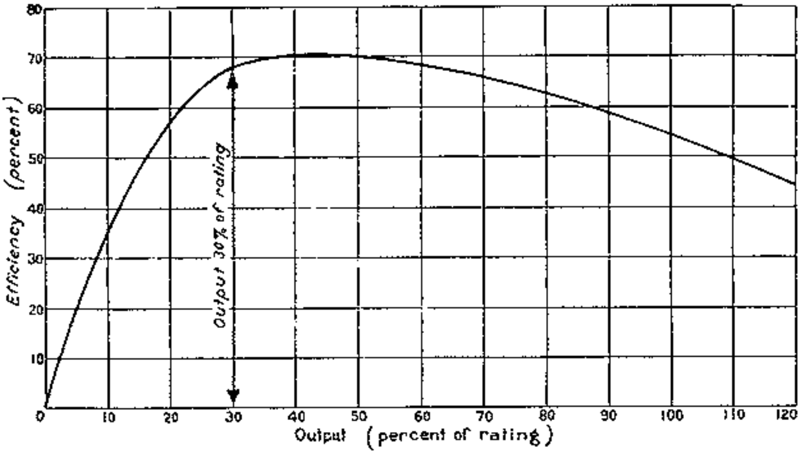

FIGURE 25.—Typical efficiency curve for a heating boiler when burning coal.

COSTS OF HEATING WITH COAL AND OIL

In comparing the cost of heating with coal and oil, it is important that all of the factors be considered. The personal element enters to a much greater extent with the coal fire than with the oil fire, and therefore there is greater opportunity for poor firing. It is safe to say that only a small percentage of householders operate their furnaces to best advantage. With the coal fire there is overheating during the milder periods of the heating season, especially when no automatic room-temperature control is used. The temperature regulation frequently is achieved by opening windows and doors rather than by control of the fire. Moreover, in homes where coal is burned, some auxiliary heating devices—such as portable oil, gas, or electric heaters—are frequently put into service in the spring and fall. The cost of operating these should be charged against the coal-burning plant.

With the oil burner the personal element is largely removed, assuming that the burner has been properly installed and regulated. There are characteristics of the oil burner which tend to increase the cost of heating, but they are additional costs for additional comfort. The oil burner is likely to be operated earlier and later in the heating season than the coal burner, because of the ease of starting up and the probability that little attention is required afterward. The room temperature, with a good automatic oil-burning installation, is maintained practically constant at any ordinary temperature desired, which may or may not be the case with the coal burner.

It should be borne in mind that the average oil-burning installation is merely a change from coal to oil without any radical change in the boiler. Some boilers are far more suitable for oil burning than others. A comparison of the costs of burning oil and coal should therefore be confined to one type of boiler because in another boiler, the relations may be somewhat different.

Perhaps the best way to compare fuel costs is on the basis of the number of gallons of oil which are equivalent to a ton of coal. This will eliminate the variable of prices, and the figures presented can be used for comparison in any locality where the prices of oil and coal are known. The Department of Agriculture investigated the comparative consumption of coal and oil with small round boilers such as would be found in homes of 6 to 10 rooms. From these investigations it was concluded that, under present conditions, 1 short ton of coal is the approximate equivalent of from 150 or less to 200 gallons of fuel oil.

Such a comparison involves only the fuel cost. A true comparison should include many more items. Some of these items can be stated as follows: The cost of the burner installation may be several hundred dollars, and interest and depreciation must be charged against the oil burner. On a small installation these fixed charges alone may represent a large percentage of the cost of the fuel. The cost of the auxiliary power must be added—that is, the gas or electricity or both, depending on the type of burner. Moreover, after the free-service period, which generally is 1 year, service-call charges must be reckoned with, although with good burners, properly installed, this item should be small.

As against this the principal arguments advanced for the oil burner are its convenience, comfort, and cleanliness. It is maintained that with the use of oil burners the cost of cleaning and redecorating is greatly lessened. As compared with burning soft coal this is undoubtedly true, provided the oil burner is in proper adjustment, otherwise it may produce a quantity of soot that will permeate the house in a very short time. The employment of an attendant for an oil-burning heating plant in the home is unnecessary. In the average-sized house, where no great saving in furnace attendance can be shown, the cost of heating with oil is generally greater than the cost of heating with coal—all things considered.

COST OF HEATING WITH OIL AND GAS

When one is contemplating an automatic house-heating system he usually has in mind oil, gas, or electricity. Accordingly he is justly concerned with the relative costs of heating. Electric heating is in many respects ideal but at this time the area in which the rate for electric current is low enough to permit its economical use for house heating is very limited.

In many instances the cost of heating with gas compares favorably with that of heating with oil, especially when considering the inherent advantages of gas heating over oil heating. Many factors affect the seasonal efficiency of the two kinds of fuel and as time goes on and more data are assembled we shall be in a better position to use fair average figures for seasonal efficiency.

In considering a number of the comparisons made between oil and gas heating, two outstanding tendencies—conducive to erroneous conclusions—were observed: (1) Many items of cost had been overlooked, and (2) when these items were included, the fact that they are functions of the size of the plant was ignored. The first questions, when one is asked to compare cost of heating with any two fuels such as oil and gas should be—Of what size is the heating plant; how many square feet of radiation are installed? The effect of the size of plant on comparative cost figures will be apparent when the items of cost are considered. With an oil-burning installation the major items are as follows:

(1) Cost of installation.
(2) Cost of average reserve of oil in storage tank.
(3) Cost of boiler for oil burning.
(4) The sum of (1), (2), and (3) is the investment.
(5) Interest on investment, item (1).
(6) Cost of oil for season.
(7) Depreciation of oil burner, estimating life at x years.
(8) Depreciation on oil-burning boiler, estimating life at y years.
(9) Cost of service on equipment after first year.
(10) Cost of operation of pilot or other ignition device per season.
(11) Cost of operation of motor per season.

The total cost per season of heating with oil will, in general be as follows:

$$\text{Cost} = (5) + (6) + (7) + (8) + (9) + (10) + (11)$$

Under certain conditions of operation, some of these items may become zero, or at least very small.

Most comparisons take account of only item 6, while some include also 10 and 11. However, it is easy to show that the sum of the other items of cost may easily be as much as 75 to 100 percent of the sum of those ordinarily considered. For convenience the various costs will be grouped and called the "fixed" cost and the "fuel" cost. The fixed cost will be the sum of items, 5, 7, 8, 9, 10, and 11. The fuel cost will be item 6. As the plant increases in size the ratio of the fixed costs to the fuel costs becomes smaller, but the former is never negligible and should always be taken into account when comparisons are made.

Consider now the major cost items when gas is the fuel. They are as follows:

(1) Cost of installation.
(2) Interest on investment, item (1).
(3) Cost of gas per season.
(4) Depreciation of gas boiler, estimating life at z years.
(5) Service charge.

Item 5, may be zero: that is, in some cases the service charge is included with fuel costs. The total cost per season of heating with gas will be, $\text{Cost} = (2) + (3) + (4) + (5)$.

In this case, as with oil, there are two kinds of costs, namely, fixed costs and fuel costs. Accordingly the fixed cost will be the sum of items 2, 4, and 5, and the fuel cost will be item 3. This item, of course, includes pilot-light cost. These costs again bear a certain relation to each other as a function of the size of plant, but the ratio of the fixed costs to fuel costs is not, in general, as great with gas as with oil.

Curves have been plotted (fig. 26) to show the effect of these various cost factors—particularly that of size of plant. The comparison is between specially designed gas burning equipment and special oil burning boilers. These curves represent the true costs of heating with oil and with gas for 1 year in one of the large cities of the country where, on the basis of oil and gas costs only, gas heating would appear under any conditions to cost almost twice as much as oil heating. The fuel costs are represented by lines 2 and 4. However, when the fixed costs are added we get lines 1 and 3, which represent, respectively, the total costs of heating with gas and with oil. It will be noted that for the smaller installations these total costs differ but little, but as the plants become larger the total-cost lines diverge. To illustrate this, table 24 shows relative cost figures for a comparatively small plant and a somewhat larger one.

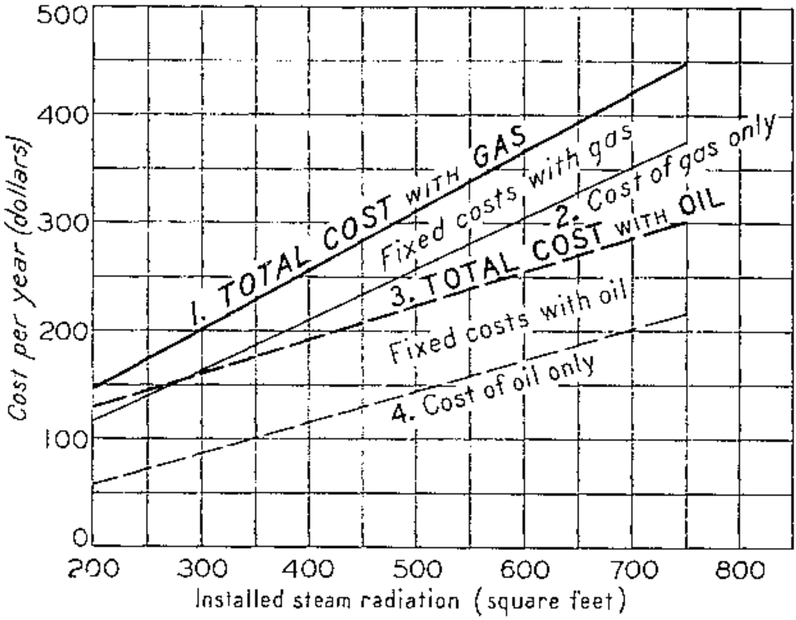

FIGURE 26.—Comparative cost of heating with gas and oil.

TABLE 24.—*Comparison of fuel costs and total heating costs*

Size of plant radiation	Cost of heating fuel only		Ratio gas to oil	Total cost of heating		Ratio gas to oil
	Gas	Oil		Gas	Oil	
	Dollars	*Dollars*		*Dollars*	*Dollars*	
300 square feet	162	85	1.91	200	163	1.23
750 square feet	377	217	1.74	448	302	1.48

It will be observed from table 24 that gas heat would cost an average of about 80 percent more than oil heat if fuel costs only were considered. However, when the total costs are considered, gas would cost only about 23 and 48 percent more, respectively, for the 300 square feet and 750 square feet of radiation. These figures, moreover, indicate clearly that as the plant increases in size the relative expense of gas heating to that of oil heating becomes greater, at least within the limits and under the conditions depicted in figure 26.

ESTIMATING FUEL CONSUMPTION

Frequently it is desired to determine the absolute values of the fuel cost with regard to various types of plant in different sections of the country. One of the best methods of attacking this problem is by means of the "degree-day" method which has been devised by the American Gas Association. The degree-day is the product of 1 day of time and 1° F. difference in temperature between the heated space and the outside air.

From the United States Weather Bureau data the number of days of the year for which the average temperature is below a given figure can be determined. The period so determined may be called the heating season. The American Gas Association has found that a mean daily temperature of 65° F. is a reasonable heating season limit. That is, it was determined that with a daily mean temperature of 65°, the daytime temperatures will average around 70°, and the only time room temperatures would fall below the comfort point would be around midnight. Thus the number of heating days per year is determined from the basis of 65° as a minimum allowable mean daily temperature without heating. The product of the number of heating days per year and the average difference in temperature as between spaces to be heated and the outside temperature gives the number of degree-days per heating season.

From a knowledge of the number of degree-days and of the square feet of installed radiation, the quantity of fuel consumed can be estimated, an assumption of plant efficiency having been made. Fansler[11] has tabulated degree-days data for the various parts of the United States and Canada and has presented the data in the useful form of an iso-degree-day chart. Similarly, he has worked out iso-fuel-consumption charts for oil, gas, and coal for corresponding places. These charts are convenient and are sufficiently accurate when used with the discretion urged in accompanying instructions.

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[11] FANSLER, P. E. THE ISO-DEGREE-DAY CHART. Heating and Ventilating Mag. 22 (9): 73), illus. 1925.

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