boiling point, (4) Burning index[10] based on API gravity and 50 percent distillation point, and (5) Estimated Carbon-Hydrogen ratio[11] based on API gravity aniline point, and boiling point.

Various investigators have shown correlation between one or more of these indexes and the performance of fuel oils in oil burners. Experiments conducted with the Oil Heat Institute Reference Test Unit[12] indicated good correlation between the smoking tendency of fuel oils and API gravity, burning index, Diesel index, and hydrogen-carbon ratio for a limited number of oils in laboratory apparatus simulating a pressure-atomizing burner. These results are shown graphically in Fig. 3. Smoking tendency is given here in terms of smoke-spot

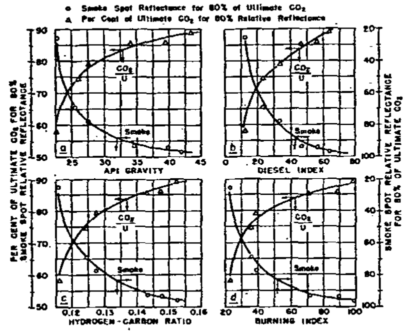

Fig. 3 . . . . Correlation of Burning Qualities of Fuel Oils with Four Combustion Indexes

reflectance, the light reflectance of a smoke-soiled filter paper. A high reflectance, relative to a clean filter paper, indicates low smoking tendency. CO_2/U is the observed CO_2 divided by the ultimate or maximum theoretical CO_2 expressed as a percentage. Reid and Hersberger[14] have related burning qualities and burning index for various oils in a wall-flame burner. Cauley and Delgass[15] cite test results on combustion indexes obtained with vaporizing burners. The present experimental data are probably too meager as yet to correlate adequately any one of these indexes with burning qualities of oil fuel for all types of burners. Few attempts have been made to suggest limits for any of these fuel oil indexes for particular applications, even though correlations between them and burning qualities have been observed.

Experiments have shown that the rate of thermal decomposition or cracking of hydrocarbons becomes appreciable at a temperature of approximately 680 F at atmospheric pressure. Thus distillate fuel oils, whose end point approximates this temperature, cannot be completely evaporated in vaporizing-type oil burners at atmospheric pressure without leaving a residue. A complete distillation curve cannot usually be determined for fuel oils containing fractions that evaporate above 680 F.

Since No. 1 grade fuel oil in *Commercial Standard* CS12-48 has a maximum end point of 625 F, although an end point this high is rare, it can in most cases be completely evaporated in atmospheric vaporizing burners without cracking, although occasionally an oil is found that undergoes cracking at temperatures below 625 F. By the same criterion, No. 2 grade fuel oil in the *Commercial Standard*, which can have a maximum distillation temperature of 675 F at the 90 percent point, would generally be cracked in a vaporizing burner. Vaporizing-type burners, therefore, can use only No. 1 fuel oil with assurance that thermal decomposition will not occur during combustion. On the other hand either No. 1 or No. 2 fuel oils may be employed in high- or low-pressure atomizing burners when the temperatures developed in the combustion chamber are high enough to assure complete combustion, even if the fuel oil is thermally decomposed.

In vaporizing burners there is complete evaporation of fuel before it is exposed to intense heat. Thorough mixing of the air and gasified fuel promote complete combustion without smoke and with a minimum of excess air. In pressure-type burners good atomization of the fuel, good mixing of the atomized oil with the air, air turbulence, and high combustion chamber temperatures (preferably red hot) promote smokeless combustion with a minimum of excess air.

Natural draft burners depend on the motivating force of a chimney to induce enough air into the burner for complete combustion. Forced draft burners are supplied with combustion air by means of a blower or fan; the chimney merely conducts the flue gases outdoors and prevents leakage of flue gases into the building. More details on the operation of the different kinds of oil burners and on chimneys and draft will be found in Chapters 34 and 36 respectively.

FUEL GASES

Fuel gases employed for various heating and air conditioning processes throughout the United States fall into three broad classifications: natural, manufactured, and liquefied petroleum. Natural gas is a mixture of several combustible gases and, usually, a small percentage of inert gases obtained from geologic formations. Manufactured gas is made by the distillation or cracking of oil or coal, by the steam-carbon reaction, or by combinations of these processes. Liquefied-petroleum gases (propane and butane) are higher hydrocarbon gases normally obtained as a by-product of oil refineries or by stripping natural gas. These two compounds are generally gaseous under usual atmospheric conditions although they can be liquefied by the application of moderate pressures at normal temperatures.

In American gas practice the heating value of a gas and also appliance efficiencies are based on the gross heating value. This value is the number of Btu liberated by complete combustion, at constant pressure, of one cubic foot of gas saturated with water vapor and measured at 60 F and 30 in. of mercury, with air at the same temperature and pressure. Products of combustion are cooled to the initial temperature of the gas and air and the water formed by combustion of free and combined hydrogen is condensed to the liquid state.

Classification of Gases

Natural gas contains from 55 to 98 percent methane with various percentages of higher hydrocarbons, chiefly ethane. In addition to these components, non-combustible gases such as carbon dioxide, nitrogen, and helium are sometimes present. Percentages of the different components vary with the area from which natural gas is withdrawn. They may even vary slightly from any given well during its lifetime but these variations are inconsequential insofar as the utilization of the gas is concerned. Heating values of natural gases vary from 900 to 1400 Btu per cu ft but the usual range for use is from 1000 to 1050 Btu (gross) per cu ft. Properties of natural gas as distributed in various cities are shown in Table 6.

Table 6 . . . . Analyses of Natural Gas Distributed in Various Cities[a]

Constituents of Gas[b]—Percent by Volume

No.	City	Methane CH_4	Ethane C_2H_6	Propane C_3H_8	Butane C_4H_{10}	Pentane C_5H_{12}	Hexane C_6H_{14}	CO_2	O_2	N_2	Specific Gravity	Btu per cu ft, Dry[c] (Gross)
1	Akron, Ohio	88.00	8.10	0.40	0.20	0.10	0.10	0.70	0.10	2.30	0.614	1052
2	Atlanta, Ga.	94.95	1.30	0.33	0.10	0.09	0.14	0.70	..	2.39	0.5974	1008
3	Baltimore, Md.	93.80	3.60	0.90	0.70	..	..	0.60	..	0.40	0.602	1062
4	Canton, Ohio	88.00	8.10	0.40	0.20	0.10	0.10	0.70	0.10	2.30	0.614	1052
5	Cheyenne, Wyo.	72.40	5.70	3.40	1.20	0.20	trace	..	..	17.10	0.700	971
6	Cincinnati, Ohio	93.70	3.90	0.60	0.10	..	..	0.80	..	0.90	0.605	1071
7	Cleveland, Ohio	88.00	8.10	0.40	0.20	0.10	0.10	0.70	0.10	2.30	0.614	1052
8	Columbus, Ohio	95.70	2.90	..	..	..	..	1.30	..	0.10	0.609	1037
9	Dallas, Texas	85.00	7.10	2.40	0.50	0.40	..	0.60	..	4.00	0.650	1079
10	Denver, Colo.	73.70	5.40	3.30	1.20	0.10	..	0.15	..	16.15	0.692	973
11	Detroit, Mich.	71.70	14.50	..	..	..	..	0.10	0.20	13.50	0.690	999
12	Houston, Texas	93.94	2.88	0.69	0.44	0.13	..	1.30	..	0.62	0.605	1069
13	Kansas City, Mo.	79.21	4.54	2.71	1.53	0.48	0.12	0.10	..	11.31	0.684	1024
14	Los Angeles, Calif.	85.10	7.40	3.10	0.40	0.10	..	0.10	..	3.80	0.648	1089
15	Memphis, Tenn.	92.80	4.20	0.80	0.20	0.10	0.10	1.00	..	0.80	0.600	1049
16	Milwaukee, Wis.	72.20	6.30	3.80	1.00	..	..	..	..	16.70	0.703	975
17	Minneapolis, Minn.	72.02	15.55	..	..	..	..	0.10	0.07	12.26	0.681	1002
18	New Orleans, La.	92.89	3.23	1.15	0.59	0.24	0.19	0.49	..	1.22	0.611	1065.7
19	Oklahoma City, Okla.	83.23	7.91	2.82	0.75	0.43	..	0.24	0.96	3.66	0.679	1068
20	Omaha, Neb.	75.78	4.97	3.24	2.12	..	..	0.20	0.14	13.55	0.685	1011
21	Pittsburgh, Pa.	90.12	5.64	1.39	0.48	0.07	0.04	0.68	..	1.58	0.6176	1071
22	Pueblo, Colo.	74.90	5.20	3.20	1.10	0.10	trace	0.30	..	15.20	0.684	975
23	St. Louis, Mo.	87.60	7.40	..	..	..	..	1.00	..	4.00	0.610	1027
24	San Diego, Calif.	80.24	12.70	1.60	0.30	0.04	..	2.05	0.10	2.97	0.672	1083.5
25	San Francisco, Calif.	86.50	6.90	2.90	0.30	0.10	..	0.50	..	2.80	0.640	1090
26	Toledo, Ohio	95.70	2.90	..	..	..	..	1.30	..	0.10	0.609	1037
27	Tulsa, Okla.	78.44	13.72	1.35	0.47	0.05	..	0.20	1.20	4.57	0.663	1073
28	Washington, D. C.	87.40	7.10	2.80	0.90	0.40	..	0.20	..	1.20	0.630	1131
29	Wichita, Kan.	79.62	6.40	1.42	1.12	0.48	0.14	0.10	0.10	10.62	0.660	1051
30	Youngstown, Ohio	88.00	8.10	0.40	0.20	0.10	0.10	0.70	0.10	2.30	0.614	1052

[a] This table abstracted from unpublished manuscript of 2nd ed., *Gas Engineers' Handbook*, American Gas Association.

[b] These are average analyses as of November, 1951. The gas may vary considerably from this average. As new supplies may be received from other sources, the analyses may change in the future.

[c] At 60 F and 30 in. Hg, absolute pressure. To convert to a saturated basis, deduct 1.73 percent—i.e., 17.3 from 1000, 19 from 1100

Manufactured gases such as coke oven and carburetted water gas, which were distributed with a heating value of 500 to 600 Btu per cu ft (gross), are no longer common in large communities due to the widespread availability of natural gas.

Mixed gases are a result of increased distribution of natural gas, through transcontinental transmission lines, into areas having existing manufactured gas facilities. In such instances some gas companies supply a 600 to 800 Btu mixture.

Liquefied petroleum gases, such as propane and butane or mixtures thereof have calorific values ranging from 2500 to 3200 Btu per cu ft. Propane is generally available by the bottle or cylinder, or in bulk in tank truck, truck transport or tank car lots. Butane is generally not available in cylinders. In such cases the liquid evaporates when pressure is relieved, the heat necessary for vaporization being obtained from the surrounding air or ground. As butane boils at 32 F some provision is necessary for maintaining the gas above this temperature or for lowering the partial pressure by dilution if the gas is utilized in colder climates. Propane, with a boiling point of −40 F, may be served in localities where temperatures substantially below freezing are encountered. When employed for heating purposes, these gases are usually delivered by tank truck into bulk storage pressure vessels of sufficient size to give the customer an adequate supply of fuel. Both gases, mixed with air, or in undiluted form, are also extensively employed by gas companies to augment their base load supplies during peak load periods. In some smaller communities, where gas manufacturing plants are not economically feasible and natural gas is unavailable, liquefied petroleum gases or liquefied petroleum gas-air mixtures are supplied through mains in much the same manner as manufactured or natural gas.