pressure and evaporate when pressure is relieved, obtaining the heat of vaporization from the surrounding air or ground. As butane boils at 32 F, tanks must be buried below the frost line, if used in the colder climates. Propane, which has a boiling point of −40 F, is more often used where temperatures fall below freezing. These gases are supplied in small mobile tanks, but when used for heating, a large high pressure tank is usually used and the gas delivered by tank truck to the consumer, much the same as oil. These gases, when mixed with air, are used to augment peak loads of many gas companies, and in smaller cities, where gas manufacturing plants are uneconomical, liquefied petroleum-air mixtures are delivered through the mains in place of manufactured gas.

FUNDAMENTAL PRINCIPLES OF COMBUSTION

Combustion may be defined as the chemical combination of a substance with oxygen, with a resultant evolution of heat. The rate of combustion depends partly upon the specific rate of reaction of the combustible substance with oxygen, partly upon the rate at which oxygen is supplied, and upon the temperature obtained due to surrounding conditions.

Complete combustion is obtained when all of the combustible elements in the fuel are oxidized with all of the oxygen with which they can combine. All of the oxygen supplied may not be utilized.

Perfect combustion is defined as the result of supplying the required amount of oxygen for combination with all of the combustible elements of the fuel, and utilizing all of the oxygen so supplied.

The oxygen required for the process of combustion is obtained from air which is a mechanical mixture of oxygen, nitrogen and small amounts of carbon dioxide, water vapor and inert gases. These inert gases are generally included with the nitrogen. Hence, the composition of air (percent) may be taken as: 20.9 oxygen and 79.1 nitrogen by volume, and 23.15 oxygen and 76.85 nitrogen by weight.

The combination of oxygen with the combustible elements and compounds of a fuel is in accordance with fixed laws. In the case of perfect combustion the reactions and resultant combinations are shown in Table 7.

The most important condition governing the process of combustion is temperature. It is necessary to bring a combustible substance to its ignition temperature before it will unite in chemical combination with oxygen to produce combustion. The ignition temperatures for several of the combustible constituents of fuels are presented in Table 7.

HEAT OF COMBUSTION

As previously stated, the process of combustion results in the evolution of heat. The heat generated by the complete combustion of a unit of fuel is constant for a given combination of combustible elements and compounds, and is known as the *heat of combustion*, *calorific value*, or *heating value* of the fuel. The heat of combustion of the several substances found in the more common fuels is given in Table 7.

The calorific value of a fuel may be determined either by direct measurement of the heat evolved during combustion in a calorimeter, or it may be computed from the ultimate analysis and the heat of combustion of the several chemical elements in the fuel. When the heating value of a fuel is determined in a calorimeter, the water vapor is condensed and the latent heat of vaporization is included in the heating value of the fuel. The heating value so determined is termed the *gross* or *higher* heating value, and

TABLE 7. GENERAL DATA OF COMBUSTIBLE ELEMENTS AND COMPOUNDS [a]

Substance	Molecular Symbol	Chemical Reaction of Combustion	Ignition Temperature[b] F Deg	Calorific Value: Btu per Lb, Higher	Calorific Value: Btu per Lb, Lower	Calorific Value: Btu per Cu Ft[b], Higher	Theoretical Oxygen and Air Requirements: Lb per Lb, O_2	Lb per Lb, Air	Cu Ft per Cu Ft, O_2	Cu Ft per Cu Ft, Air
Carbon (to CO)	—	$2C + O_2 = 2CO$	—	3950	—	—	1.332	5.763	—	—
Carbon (to CO_2)	—	$2C + 2O_2 = 2CO_2$	—	14093	—	—	2.664	11.527	—	—
Sulfur (to SO_2)	—	$S + O_2 = SO_2$	—	3983	—	—	0.998	4.285	—	—
Sulfur (to SO_3)	—	$2S + 3O_2 = 2SO_3$	—	5940	—	—	1.497	6.428	—	—
Carbon Monoxide	CO	$2CO + O_2 = 2CO_2$	1166-1319	4347	—	321.8	0.571	2.471	0.5	2.382
Methane	CH_4	$CH_4 + 2O_2 = CO_2 + 2H_2O$	1260-1380	23879	21520	1013.2	3.990	17.265	2.0	9.528
Acetylene	C_2H_2	$2C_2H_2 + 5O_2 = 4CO_2 + 2H_2O$	763-824	21500	20776	1499	3.073	13.297	2.5	11.911
Ethylene	C_2H_4	$C_2H_4 + 3O_2 = 2CO_2 + 2H_2O$	986-1123	21644	20295	1613.8	3.422	14.807	3.0	14.293
Ethane	C_2H_6	$2C_2H_6 + 7O_2 = 4CO_2 + 6H_2O$	990-1120	22320	20432	1792	3.725	16.119	3.5	16.675
Hydrogen	H_2	$2H_2 + O_2 = 2H_2O$	1063-1166	60958[c]	51571[c]	325	7.937	34.344	0.5	2.382
Hydrogen Sulfide	H_2S	$2H_2S + 3O_2 = 2H_2O + 2SO_2$	599-608	7100	6545	647	1.409	6.097	1.5	7.146
Propane	C_3H_8	$C_3H_8 + 5O_2 = 3CO_2 + 4H_2O$	950-1080	21661	19944	2590	3.629	15.703	5.0	23.821
n-Butane	C_4H_{10}	$2C_4H_{10} + 13O_2 = 8CO_2 + 10H_2O$	890-1020	21308	19680	3370	3.579	15.487	6.5	30.967
Commercial Propane	—	—	—	21650	—	2500	—	—	—	—
Commercial Butane	—	—	—	21400	—	3200	—	—	—	—

[a] Values in table taken chiefly from page 51 of Fuel Flue Gases published by *American Gas Association.*
[b] Gas measured at 60 F and 30 in. Hg.
[c] Value from *National Bureau of Standards.*