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

Substance	Molecular Symbol	Chemical Reaction of Combustion	Ignition Temperature[a] F Deg	Calorific Value: Btu per Lb, Gross	Calorific Value: Btu per Lb, Net	Calorific Value: Btu per Cu Ft[b], Gross	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	—	—	1.33	5.76	—	—
Carbon (to CO_2)	—	$2C + 2O_2 = 2CO_2$	—	14093	—	—	2.66	11.53	—	—
Sulfur (to SO_2)	—	$S + O_2 = SO_2$	—	3983	—	—	1.00	4.29	—	—
Sulfur (to SO_3)	—	$2S + 3O_2 = 2SO_3$	—	5940	—	—	1.50	6.43	—	—
Carbon Monoxide	CO	$2CO + O_2 = 2CO_2$	1166–1319	4347	—	321.8	0.57	2.47	0.5	2.39
Methane	CH_4	$CH_4 + 2O_2 = CO_2 + 2H_2O$	1260–1380	23879	21520	1013.2	3.99	17.27	2.0	9.53
Acetylene	C_2H_2	$2C_2H_2 + 5O_2 = 4CO_2 + 2H_2O$	763–824	21500	20776	1499	3.07	13.30	2.5	11.91
Ethylene	C_2H_4	$C_2H_4 + 3O_2 = 2CO_2 + 2H_2O$	986–1123	21644	20295	1613.8	3.42	14.81	3.0	14.29
Ethane	C_2H_6	$2C_2H_6 + 7O_2 = 4CO_2 + 6H_2O$	990–1120	22320	20432	1792	3.73	16.12	3.5	16.68
Hydrogen	H_2	$2H_2 + O_2 = 2H_2O$	1063–1166	60958[c]	51571[c]	325	7.94	34.34	0.5	2.39
Hydrogen Sulfide	H_2S	$2H_2S + 3O_2 = 2H_2O + 2SO_2$	599–608	7100	6545	647	1.41	6.10	1.5	7.15
Propane	C_3H_8	$C_3H_8 + 5O_2 = 3CO_2 + 4H_2O$	950–1080	21661	19944	2590	3.63	15.70	5.0	23.82
n-Butane	C_4H_{10}	$2C_4H_{10} + 13O_2 = 8CO_2 + 10H_2O$	890–1020	21308	19680	3370	3.58	15.49	6.5	30.97
Commercial Propane	—	—	920–1020	21560	19865	2520	3.60	15.58	4.9	23.4
Commercial Butane	—	—	900–1000	21180	19591	3260	3.54	15.3	6.3	30.0

[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*.

ing value so determined is termed the *gross* or *higher* heating value, and this is what is ordinarily meant when the heating value of a fuel is specified. In burning the fuel, however, the products of combustion are not cooled to the dew-point and the higher heating value cannot be utilized.

When combustion is complete, the carbon in the fuel unites with oxygen to form carbon dioxide, CO_2, the hydrogen unites with oxygen to form water vapor, H_2O, and the nitrogen, being inert, passes through the reaction without change. When combustion is incomplete, some of the carbon may unite with oxygen to form carbon monoxide, CO, and some of the hydrogen and hydrocarbon gases may not be burned at all. When carbon monoxide or other combustible gases are present in the flue gases, there is a loss of heat produced per unit of fuel consumed, and a lower combustion efficiency is obtained. Incomplete combustion may result from any or all of the following three conditions: (1) inadequate air supply, (2) insufficient mixing of air and gases, and (3) a temperature too low to produce ignition or maintain combustion.

AIR REQUIRED FOR PERFECT COMBUSTION

Air requirements for combustion of solid and liquid fuels are ordinarily expressed in pounds. On the other hand similar requirements for gaseous fuels are usually stated on a cubic foot basis. For solid and gaseous fuels this method of treatment corresponds to the standards of measurement commonly employed by these two industries.

The weight of air required for perfect combustion per pound of solid or liquid fuel may be calculated after substitution of the proper percentages by weight of the various elements obtained from an ultimate analysis of the fuel in Equation 2. For gaseous fuels see Equation 3 for volume of air required.

Solid or Liquid Fuels:

$$\text{Pounds air required per pound fuel} = \frac{34.56}{100}\left[\frac{C}{3} + \left(H - \frac{O}{8}\right) + \frac{S}{8}\right] \quad (2)$$

For Gaseous Fuels:

$$\text{Cubic feet air required per cubic foot gas} = 2.39\,(CO + H_2) + 9.53\,CH_4 + 16.68\,C_2H_6 + 23.82\,C_3H_8 + 30.97\,C_4H_{10} + 11.91\,C_2H_2 + 14.29\,C_2H_4 + 7.15\,H_2S - 4.78\,O_2 + 30.47\ \text{Illuminants} \quad (3)$$

Gaseous fuels may contain a wide variety of components classified as *illuminants*, which are not separated by the usual methods of gas analysis. The principal ones in addition to ethylene and acetylene which are included in Equation 3, with the air required per cubic foot of gas are: propylene, 21.44; butylene, 28.58; pentene, 35.73; benzene, 35.73; toluene, 42.88; and xylene, 50.02. Since toluene and xylene are normally scrubbed from the gas before distribution, they may be disregarded in computing air required for a fuel gas. An approximate value of 30.47 (as shown in Equation 3) may, therefore, be employed. If ethylene and acetylene are included as *illuminants*, it is suggested that the value 19.65 be used.

If it is desired to make the gas calculations on a weight basis the equation is expressed as follows:

$$\text{Pounds air required per pound fuel} = 2.47\,CO + 34.34\,H_2 + 17.27\,CH_4 + 16.12\,C_2H_6 + 15.70\,C_3H_8 + 15.49\,C_4H_{10} + 13.30\,C_2H_2 + 14.81\,C_2H_4 + 6.10\,H_2S - 4.32\,O_2 \quad (4)$$