OXYGEN AND AIR REQUIRED FOR COMBUSTION
AT 32 DEGREES AND 29.92 INCHES
BY WEIGHT

1	2	3	4	5	6	7	8	9	10
Oxidizable Substance or Combustible	**Chemical Symbol**	**Atomic or Combining Weight**	**Chemical Reaction**	**Product of Combustion**	**Oxygen per Pound ofColumn 1Pounds**	**Nitrogen per Pound ofColumn 1.3.32[23] × O Pounds**	**Air per Pound ofColumn 1.4.32[24] × O Pounds**	**Gaseous Product per Pound ofColumn 1[25] +Column 8 Pounds**	**Heat Value per Pound ofColumn 1B. t. u.**
Carbon	C	12	C+2O = CO_2	Carbon Dioxide	2.667	8.85	11.52	12.52	14600
Carbon	C	12	C+O = CO	Carbon Monoxide	1.333	4.43	5.76	6.76	4450
Carbon Monoxide	CO	28	CO+O = CO_2	Carbon Dioxide	.571	1.90	2.47	3.47	10150
Hydrogen	H	12	H+O = H_2O	Water	8	26.56	34.56	35.56	62000
Methane	CH_4	16	CH_4+4O = CO_2+2H_2O	Carbon Dioxide and Water	4	13.28	17.28	18.28	23550
Sulphur	S	32	S+2O = SO_2	Sulphur Dioxide	1	3.32	4.32	5.32	4050

BY VOLUME

1	2	11	12	13	14	15	16	17	18
Oxidizable Substance or Combustible	**Chemical Symbol**	**Volumes ofColumn 1Entering Combination Volume**	**Volumes of Oxygen Combining withColumn 11Volume**	**Volumes of Product Formed Volume**	**Volume per Pound ofColumn 1 in Gaseous Form Cubic Feet**	**Volume of Oxygen per Pound ofColumn 1Cubic Feet**	**Volume of Products of Combustion per Pound ofColumn 1Cubic Feet**	**Volume of Nitrogen per Pound ofColumn 1.3.782[26] ×Column 15Cubic Feet**	**Volume of Gas per pound ofColumn 1 =Column 10 ÷Column 17Cubic Feet**
Carbon	C	1C	2	2CO_2	14.95	29.89	29.89	112.98	142.87
Carbon	C	1C	1	2CO	14.95	14.95	29.89	56.49	86.38
Carbon Monoxide	CO	2CO	1	2CO_2	12.80	6.40	12.80	24.20	37.00

Hydrogen	H	2H	1	$2H_2O$	179.32	89.66	179.32	339.09	518.41
Methane	CH_4	1C4H	4	$1CO_2 2H_2O$	22.41	44.83	67.34	169.55	236.89
Sulphur	S	1S	2	$1SO_2$	5.60	11.21	11.21	42.39	53.60

It will be seen from this table that a pound of carbon will unite with $2\frac{2}{3}$ pounds of oxygen to form carbon dioxide, and will evolve 14,600 B. t. u. As an intermediate step, a pound of carbon may unite with $1\frac{1}{3}$ pounds of oxygen to form carbon monoxide and evolve 4450 B. t. u., but in its further conversion to CO_2 it would unite with an additional $1\frac{1}{3}$ times its weight of oxygen and evolve the remaining 10,150 B. t. u. [Pg 152]When a pound of CO burns to CO_2, however, only 4350 B. t. u. are evolved since the pound of CO contains but $\frac{3}{7}$ pound carbon.

Air Required for Combustion—It has already been shown that each combustible element in fuel will unite with a definite amount of oxygen. With the ultimate analysis of the fuel known, in connection with Table 31, the theoretical amount of air required for combustion may be readily calculated.

Let the ultimate analysis be as follows:

	Per Cent
Carbon	74.79
Hydrogen	4.98
Oxygen	6.42
Nitrogen	1.20
Sulphur	3.24
Water	1.55
Ash	7.82
	100.00

When complete combustion takes place, as already pointed out, the carbon in the fuel unites with a definite amount of oxygen to form CO_2. The hydrogen, either in a free or combined state, will unite with oxygen to form water vapor, H_2O. Not all of the hydrogen shown in a fuel analysis, however, is available for the production of heat, as a portion of it is already united with the oxygen shown by the analysis in the form of water, H_2O. Since the atomic weights of H and O are respectively 1 and 16, the weight of the combined hydrogen will be $\frac{1}{8}$ of the weight of the oxygen, and the hydrogen available for combustion will be $H - \frac{1}{8} O$. In complete combustion of the sulphur, sulphur dioxide SO_2 is formed, which in solution in water forms sulphuric acid.

Expressed numerically, the theoretical amount of air for the above analysis is as follows:

$$0.7479 \text{ C} \times 2\tfrac{2}{3} = 1.9944 \text{ O needed}$$

$$\left(0.0498 - \frac{0.0642}{8}\right) H \times 8 = 0.3262 \text{ O needed}$$

$$0.0324 \text{ S} \times 1 = 0.0324 \text{ O needed}$$

$$\text{Total} = 2.3530 \text{ O needed}$$

One pound of oxygen is contained in 4.32 pounds of air.

The total air needed per pound of coal, therefore, will be 2.353 × 4.32 = 10.165.

The weight of combustible per pound of fuel is .7479 + .0418[27] + .0324 + .012 = .83 pounds, and the air theoretically required per pound of combustible is 10.165 ÷ .83 = 12.2 pounds.

The above is equivalent to computing the theoretical amount of air required per pound of fuel by the formula:

$$\text{Weight per pound} = 11.52 \text{ C} + 34.56 \left(\text{H} - \frac{\text{O}}{8}\right) + 4.32 \text{ S} \qquad (10)$$

where C, H, O and S are proportional parts by weight of carbon, hydrogen, oxygen and sulphur by ultimate analysis.

In practice it is impossible to obtain perfect combustion with the theoretical amount of air, and an excess may be required, amounting to sometimes double the theoretical supply, depending upon the nature of the fuel to be burned and the method of burning it. The reason for this is that it is impossible to bring each particle of oxygen in the air into intimate contact with the particles in the fuel that are to be oxidized, due not only to the dilution of the oxygen in the air by nitrogen, but because of such factors as the irregular thickness of the fire, the varying resistance to the passage of the air through the fire in separate parts on account of ash, clinker, etc. Where the difficulties of drawing air uniformly through a fuel bed are eliminated, as in the case of burning oil fuel or gas, the air supply may be materially less than would be required for coal. Experiment has shown that coal will usually require 50 per cent more than the theoretical net calculated amount of air, or about 18 pounds per pound of fuel either under natural or forced draft, though this amount may vary widely with the type of furnace, the nature of the coal, and the method of firing. If less than this amount of air is supplied, the carbon burns to monoxide instead of dioxide and its full heat value is not developed.

TABLE 32

CALCULATED THEORETICAL AMOUNT OF AIR REQUIRED PER POUND OF VARIOUS FUELS

Fuel	Weight of Constituents in One Pound Dry Fuel			Air Required per Pound of Fuel Pounds
	Carbon Per Cent	Hydrogen Per Cent	Oxygen Per Cent	
Coke	94.0	…	…	10.8
Anthracite Coal	91.5	3.5	2.6	11.7
Bituminous Coal	87.0	5.0	4.0	11.6
Lignite	70.0	5.0	20.0	8.9
Wood	50.0	6.0	43.5	6.0
Oil	85.0	3.0	1.0	14.3

An excess of air is also a source of waste, as the products of combustion will be diluted and carry off an excessive amount of heat in the chimney gases, or the air will so lower the temperature of the furnace gases as to delay the combustion to an extent that will cause carbon monoxide to pass off unburned from the furnace. A sufficient amount of carbon monoxide in the gases may cause the action known as secondary combustion, by igniting or mingling with air after leaving the furnace or in the flues or stack. Such secondary combustion which takes place either within the setting after leaving the furnace or in the flues or stack always leads to a loss of efficiency and, in some instances, leads to overheating of the flues and stack.

Table 32 gives the theoretical amount of air required for various fuels calculated from formula (*10*) assuming the analyses of the fuels given in the table.

The process of combustion of different fuels and the effect of variation in the air supply for their combustion is treated in detail in the chapters dealing with the various fuels.