The theory of combustion is well understood by scientists, but in practice the art of burning coal economically, and of converting all its natural elements into heat and power, is but little understood. It is also a well known fact that carbon and hydrogen require certain quantities of atmospheric air to effect their combustion, yet, in practice, the means necessary to find out what quantity is supplied, is generally neglected and treated as though it was of no importance.

The bituminous portion of coal is convertible into heat in the gaseous state alone, and then only in proportion to the right mixture and union effected between them and the oxygen of the air, while the carbonaceous portion is only combustible in its solid state, and neither can be consumed while they remain united. To obtain combustion they must be separated, and a new union formed with the oxygen of the air. In combustion there must be a combustible and a supporter of combustion, which means chemical union, and oxygen is this supporter. In fact oxygen is just as essential in combustion as it is in the maintenance of life in the animal kingdom.

You all know from experience that on putting a fresh supply of coals into the furnace, they do not immediately increase the general temperature, but, on the contrary, become the absorbent of heat, the source of the volatilization of the bituminous portion of the coal; *and until these constituents are evolved from it, its solid* or carbonaceous part remains black, and at a comparatively low temperature. Now volatilization is the most cooling process of nature by reason of the quantity of heat directly converted from the sensible to the latent state.

On the application of heat to bituminous coal the first result is its absorption by the coal, then follows the liberation of its gases from which flame is exclusively derived. These gases are composed of carbon and hydrogen, and the union is known as carburetted hydrogen and bi-carburetted hydrogen. Carburetted hydrogen by itself is not combustible, but must be united with oxygen, and notwithstanding the strong attraction which exists between them, they will not rush together or enter into chemical union, which we call combustion, until they have been raised to a certain temperature, and this temperature, according to Sir Humphrey Davy, should not be under 800 degrees Fahrenheit, since below that flame cannot be produced or maintained.

The first essential to effect the combustion of gas is to ascertain the quantity of oxygen with which it will chemically combine, and the next the quantity of air required to supply the necessary quantity of oxygen. Now while this may be well understood and correctly arrived at by an expert chemist in his laboratory, we know that in the management of combustion in the furnace the ordinary engineer can at best only approximately apply the exact laws of chemistry to the very imperfect conditions found at every furnace. It is important, however, that every engineer in charge of a steam plant should at least understand theoretically the analysis of the elements with which he has to deal in producing combustion, and the proportional part of each element entering into the same.

According to chemical analysis an atom of hydrogen is double the bulk of carbon vapor, but the latter is six times the weight of the former. (Atom in modern scientific usage is the smallest portion into which matter can be divided—the chemist's unit. In chemistry two atoms of hydrogen and one atom of oxygen make a molecule of water.) Again, an atom of hydrogen is double the bulk of an atom of oxygen, yet the oxygen is eight times the weight of hydrogen. So of the constituents of atmospheric air, which is a mechanical mixture of nitrogen and oxygen, not in chemical union, but simply shaken up together. These constituents, nitrogen and oxygen, are mixed in the proportion of 79 parts of nitrogen to 21 parts of oxygen out of every 100, and by weight 77 lbs. of nitrogen to 23 lbs. of oxygen, or one pound of oxygen to every 3.3478 pounds of nitrogen.

To accomplish the combustion of six pounds of carbon, sixteen pounds of oxygen are necessary, forming 22 lbs. of carbonic acid gas, which will have the same volume as the oxygen, and therefore a greater density, and to accomplish the combustion of one pound of hydrogen eight pounds of oxygen are required. When therefore we know the proportions of carbon and hydrogen existing in coal it is easy to tell the quantity of oxygen, and consequently the quantity of air necessary for combustion.

As a general rule it may be stated that for every pound of coal burned in a furnace about 12 lbs. of air, or 150 cubic feet, will be necessary to furnish the oxygen required, even if every particle of it entered into combustion. But from careful experiment it has been found that in ordinary furnaces about as much more air will in practice be necessary, or about 24 lbs. per pound of coal burned, since, besides the air required to furnish the oxygen necessary for the complete combustion of the fuel, it is also necessary to furnish an additional quantity for the dilution of the gaseous products of combustion. Now one cubic foot of air, at a temperature of 40 degrees, weighs ·08 of one pound, and it requires twelve and a-half cubic feet of atmospheric air to equal one pound in weight, and each pound of air contains 3·68 ounces of oxygen, and it will take 1,200 lbs. or 15,000 cubic feet of air for the perfect combustion of 100 pounds of coal. We thus perceive that each pound of coal requires 150 cubic feet of air for its perfect combustion, or in other words, for the conversion of its carbon into carbonic acid, and all its hydrogen into water, and it must be remembered that just in proportion as this proper quantity is deficient, combustion is imperfect and fuel wasted.

Air expands or contracts an equal amount with each degree of variation in temperature, and its weight and volume for any condition of temperature and pressure may be found by the following formulas, which are nearly exact:—

$$\text{Weight} = \frac{2{\cdot}71 \times \text{Pressure in lbs. on the barometer.}}{\text{Absolute temperature.}}$$

$$\text{Volume} = \frac{\text{Absolute temperature.}}{2{\cdot}71 \times \text{Pressure on barometer in lbs.}}$$

$$\text{Absolute temperature} = 460 + \text{temperature shown on thermometer.}$$

$$\textit{Pressure in lbs. on barometer} = \frac{\text{Height in inches.}}{2{\cdot}0408.}$$

It is erroneously supposed by some that when no smoke appears at the chimney top, combustion is perfect; smoke, however, may be absent, yet the carbon may have only united with one atom of oxygen forming carbonic oxide (a colorless gas), instead of with two atoms forming carbonic acid, and consequently have only performed half the duty as a fuel of which it was capable, and this loss is constantly going on in all furnaces where all the air has to pass through a body of incandescent carbonaceous matter.