The air on entering from the ash-pit gives up its oxygen to the glowing carbon on the bars, and generates great heat in the formation of carbonic acid, and this acid, necessarily at a very high temperature, passing upwards through the body of incandescent solid matter, takes up an additional portion of carbon and becomes carbonic oxide. By the conversion of one volume of carbonic acid into two volumes of carbonic oxide, heat is actually absorbed, while the carbon taken up during such conversion is also lost. The formation of this compound, carbonic oxide, is attended by circumstances of a curious and involved nature, and is probably the cause that, in actual practice, so little is known about it. The direct effect of the union of carbon and oxygen is the formation of carbonic acid. If, however, we abstract one of its portions of oxygen, the remaining portions would be carbonic oxide, and it is equally clear that if we added a second portion of carbon to carbonic acid the same result will be arrived at, namely, have carbon and oxygen in equal proportions, as we have in carbonic oxide. By the addition of still another portion of carbon, two volumes of carbonic oxide will be formed, and if these two volumes of oxide cannot find the oxygen necessary to complete their saturating equivalents, they pass away but half consumed.

Another important peculiarity of carbonic oxide is, that by reason of its already possessing one-half of its equivalent of oxygen, it inflames at a lower temperature than the ordinary coal gas, the consequence of which is that the latter, on passing into the flues, is often cooled down below the temperature of ignition, while the former is sufficiently heated, even after having reached the chimney top, and is there ignited on meeting the air. This is the cause of the flame often seen at the tops of chimneys or the funnels of steamships.

If we could gather and retain the carbonic acid gas which is daily discharged by tons from the chimneys of our factories, we should still have all the carbon of our coal, but we could not do it, because it would take as much power to separate the carbon from the oxygen as they gave out in the form of heat in coming together, and here comes in one of nature's most wonderful and mysterious processes.

It is a peculiar function of vegetation that under the influence of sunlight, it can overcome the attraction which exists between the atoms of carbon and oxygen, appropriating the carbon to its own use, building it into its structure and letting the oxygen go free into the atmosphere, not with a noisy demonstration or prodigious effort, but quietly in the delicate structure of a green leaf moving in the sunshine.

When all the conditions belonging to the introduction of air to the two distinct bodies to be consumed, carbon and hydrogen, have been complied with, there should be very little difficulty in securing perfect combustion in the furnace. But as a rule, these conditions are not complied with, hence the great waste in fuel. If we would economize fuel, we must give attention, not only to the mechanical appliances, but also to the nature of the bodies we have to deal with, their constituent parts and chemical relations respectively, and as the laws of nature are inexorable, mechanical details must yield to those of chemistry.

Great strides have been made in improvements in the boilers and engines now on the market, but until recently scarcely any attention has been given to the grates and furnace, practically overlooking the fact that the furnace, in which the operations of combustion are to be carried out, is of the first importance, as it is here we have the real source of economy and power.

In regard to the proportions of the furnace, we have to consider the area of the grate bars for the holding of the solid fuel, and the kind best adapted to our purpose (some people think that anything will do for a grate that will stand up under hot fires), the size of the air spaces, and the means of keeping these air spaces clear of obstruction to the draught; then the sectional area of the chamber over the fuel for the consuming of the gaseous portion of the coal and the introduction of oxygen to this chamber.

The rule in practice to-day with our best fire-tube boilers, the horizontal return tubular, is to allow 15 square feet of heating surface per horse power, and by dividing the horse power by three, we obtain our grate surface in square feet, allowing 68 square inches of air space per square foot of grate.

Strictly speaking, there is no such thing as "horse-power" to a steam boiler, as it is a measure only applicable to dynamic effect. But as boilers are necessary to drive steam engines, the same measure applied to steam engines has come to be universally applied to the boiler, and cannot well be discarded. In consequence of the different quantity of steam necessary to produce a horse-power, with different engines, there has been great need of an accepted standard by which the amount of boiler required to provide steam for a commercial horse-power may be determined. This standard, as fixed by Watt, was one cubic foot of water evaporated per hour from 212° for each horse-power. This was at that time the requirement of the best engine in use. At the present time Prof. Thurston estimates that the water required per hour, per horse-power, in good engines, is equal to the constant 200, divided by the square root of the pressure, and that in the best engines this constant is as low as 150. This would give for good engines working with 64 pounds pressure, 25 pounds water, and for the best engines working with 100 pounds, only 15 pounds water per hourly horse-power.

The extensive series of experiments made under the direction of C. E. Emery, M.E., at the Novelty Iron Works, and published by Professor Trowbridge, show that at ordinary pressure, and with good proportions, non-condensing engines of from 20 to 300 horse-power required only from 25 to 30 lbs. water per hourly horse-power in regular practice.

The standard, therefore, adopted by the judges at the Centennial Exhibition of 30 lbs. of water per hour, evaporated at 70 lbs. pressure from 100° for each horse-power, is a fair one for both boilers and engines, and has been favorably received by both engineers and steam users. But as the same boiler may be made to do more or less work, with less or greater economy, it should be also required that the rating of a boiler be based on the amount of water it will evaporate at a high economical rate. For the purposes of economy, the heating surface should never be less than one and generally not more than two square feet for each 5,000 British thermal units to be absorbed per hour, though this depends somewhat on the character and location of such surface. The range here given is believed to be sufficient for the different conditions in practice, though a far greater range is frequently employed. Square feet of heating surface is no criterion as between different styles of boilers—a square foot under some circumstances being many times as efficient as in others—but when an average rate of evaporation per square foot