the heat thereby represented is lost. The amount of heat energy that is lost will depend upon the amount of air which is admitted to the furnace and the increase of the temperature at which it escapes, and the more air admitted the greater will be the loss. The fallacy of all arrangements, whereby air and fuel are admitted above the fire, to produce perfect combustion will be readily understood when comparison is made between that method and the underfeeding of fuel with a combination of the proper amount of oxygen by means of mechanical forced draft, which combination will take place below the fire.

It is a common practice to estimate that the amount of air chemically required for use in the combustion of coke or bituminous coal is 12 lbs. per pound of fuel, this calculation of air supply being based on the assumption that each individual atom of oxygen in the air will come in contact and unite with its proportion of hydrogen or carbon in the fuel.

As this oxygen, however, is intimately united with about four times its volume of nitrogen, whereby to a certain extent it is separated from the fuel, and as the quality and the distribution of the fuel and the passages arranged in an attempt at an equal distribution of the air, increase the obstacles, it will be evident that the above assumption cannot be maintained in practice. It is, therefore, necessary in practice to furnish air in excess of the calculated amount to insure complete combustion in all parts of the furnace, and the amount of air so supplied for dilution must vary greatly in different cases.

Accepting that 12 lbs. of air per pound of fuel is necessary for complete combustion, the amount required where 100% is supplied for dilution, as is the case with natural draft and hand firing, would be 24 lbs., but with mechanical forced draft and underfeed stoking, this amount can be reduced to from 14 to 15 lbs. per pound of fuel.

As an insufficient supply of air causes imperfect combustion of the fuel, which in bituminous coal will be indicated by the production of smoke, and as an excess of air causes a waste of heat to the amount corresponding to the weight of the air in excess of that which is necessary, and to the elevation of the temperature at which it is discharged from the stack above that of the external air, it is obvious that the maximum efficiency to be secured in the process of combustion must be between these two extremes, and which will more nearly be produced by the use of the underfeed stoking and mechanical forced draft.

The heat produced by the burning of one pound of carbon to carbon dioxide is 14,650 heat units, and to carbon monoxide 4,400 heat units. The great loss of heat, due to incomplete combustion of carbon, is clearly represented in the differences between the total heat of perfect combustion, or 14,650 units, and the product of incomplete combustion, or 4,400 units.

The average bituminous coals contain from 75 to 80% of carbon, 5 to 6% of hydrogen and 14 to 20% of earthy and miscellaneous matter. In the case of the coal referred to 2.53 lbs. of oxygen would be required for the complete combustion of each pound of coal, which would necessitate about 1.8 lbs. of air to burn its hydrogen, 9.6 lbs. for the carbon, and as a portion of the other substances of which coal is composed is combustible, we can estimate the amount of air required for the total combustion at about 12 lbs., and which combustion will yield from 13 to 30 lbs. of gas, the volume varying according to the temperature. As it is impossible to remove the whole of the oxygen from the air in any ordinary furnace, it will be found necessary to supply about 14 lbs. of air per pound of coal to secure satisfactory combustion, and as each pound of free air at 60° temperature contains 13.06 cubic feet, about 183 cubic feet of air will be required for the proper combustion of the pound of coal. Such coal when heated to about 1,200° Fahr., will have the 5 or 6% of the hydrogen united with three times its weight of carbon, about 20% of the coal will be converted into gas, and a large amount of the heat will be absorbed or becomes latent. The temperature of a fire such as is usually found in a locomotive furnace varies from a dull cherry, or 1,470° Fahr., to a clear cherry, or 1,830°, orange, or 2,010 to 2,190°, white heat, 2,370°, and incandescent, 2,730 to 2,900°.

The ideal temperature of combustion for bituminous coal, which is the case where the exact amount of oxygen required for the complete combustion of a pound of carbon is supplied, is given as 4,718° Fahr. With 50% for dilution, or when 18 lbs. of air is supplied per pound of carbon; this is reduced to 3,353°, with 100% to 2,600°, with 150% to 2,124°, and so on. Automatic underfeed mechanical stoking with mechanical forced draft should give a temperature at no time of less than 2,500°, and with the blast air supplied, previously heated by special means, the increased and ideal temperatures should be even more nearly reached.

As one pound of pure carbon when burned yields 14,650 heat units, this heat would, if all utilized in a boiler, evaporate fifteen pounds of water at 212° Fahr., at atmospheric pressure. A boiler which will evaporate 7½ lbs. of water for each pound of combustible, utilizes but 50% of the total heat, and even this is much more than the average result of the ordinary American type of locomotive boiler. As about 15% can be considered as good practice for the loss in smoke stack gases and in radiation, an evaporation of 12½ lbs. of water per pound of combustible can be considered as about the practical limit.

In the present universal type of locomotive boiler when coal is burned at the rate of about 50 lbs. per square foot of grate surface per hour, about 8 lbs. of water will be evaporated per each pound of coal, and if this rate of combustion is increased to 120 lbs. per square foot of grate surface, the evaporation falls to about 5 lbs. This is equivalent to a loss of water evaporated per pound of coal of nearly 40%, this loss being due to the failure of the heating surfaces to properly absorb the heat from the increased volume of gases passing over them, and to the imperfect combustion of the fuel upon the grate. All practical results have shown that the most efficient furnace action will accompany the lowest rates of combustion. The above will show the wastefulness of burning coal without a properly regulated supply of air coming in contact with the fuel to promote perfect combustion, and the latter cannot be obtained more satisfactorily than by the proposed arrangement of underfeed stoking in connection with mechanical forced draft.

The heat being transmitted through the heating surface of a boiler in proportion to the difference in the temperature of the products of combustion on the one side and of the water on the other, it will be understood that the admission of too much air, providing oxygen which will not combine with the fuel, will diminish, instead of increasing the amount of steam which is generated, by reducing the temperature of the gases in contact with the heating surface and by increasing the volume or quantity of the gases which must be passed through the tubes. Thus, if the volume of the gases is doubled by the admission of too much air, then, in order to pass through the tubes they must move at double the velocity, so that not only is the temperature reduced, but the time that they are in contact with the heating surface will be diminished in a like proportion, and the pressure of the steam in the boiler will suffer accordingly.

The gases going to stacks of the usual type of locomotive boilers, carry with them, on an average, according to good authority, 50% of the fuel, and even in the most economical types of boilers this cannot be reduced below 12%.

Referring to the loss of heat by sparks, while this has apparently received little consideration and has appeared small, at the same time, data from practical tests with different rates of combustion, will substantiate that this loss may represent from between 5 to 15% of the full value of the coal that is fired.

### MECHANICAL FORCED DRAFT.

For the production of the forced draft there will be installed an arrangement of two volume blowers, each having 16 inch inlet and discharge openings, 48 inches outside diameter by 18 inches in width, weighing about 750 lbs. each. These blowers each to be capable of supplying 6,000 cubic feet of air at two ounces pressure, when operated at about 1,000 revolutions per minute, or 8,000 cubic feet of air at four ounces pressure when operated at about 1,500 revolutions per minute. Each blower will be capable of supplying a sufficient amount of air for the operation of the furnace when the boiler is being worked to the full capacity, the additional one being applied for relay service.

Each blower will be directly connected by a gear wheel and pinion with an independent six horse-power steam turbine, constructed to make use of steam by quadruple expansion, and the operation of the turbines to be controlled by an automatic governor, located in the cab, under the complete control of the engineer or fireman. The blowers and turbines to be supported on a self-contained cast steel bracket, fastened over the top of the boiler proper, just ahead of the coal tank, located in an accessible position, where there will be no restriction as regards the inlet of free air, and with suitable provision for protection during severe weather.

The blower discharge pipes to be connected with the main discharge inlet, which will enter the blast retort under the stokers, and suitable blast gates arranged in connection with the discharge pipe of each blower, which will be under the immediate control of the engineer and fireman, so that the blowers can be operated independently, or jointly.

With reference to the use of steam turbines to operate the blowers, improvements have been made in this type of generator which have resulted in almost a theoretical mean efficiency, as quadruple expansion turbines, constructed and operated, have shown about 87% of the power that would have been given out in the adiabatic expansion of the steam. That a steam turbine can be maintained at an economical cost and be depended upon for continuous service, has been demonstrated through six horse-power generators having operated from four to five years at a speed of 18,000 revolutions per minute and without failure, and also that in connection with high initial pressure, and especially with superheated steam, the efficiency of the steam turbine is made much more practicable.

It has been recorded by experiment that with 37° of superheat the capacity of a small steam turbine was doubled, and this indicates that much better results may be expected in the future, even though the economy of exceptionally large turbines has been taken at 14 lbs. of steam per indicated horse-power when running at full load.

Steam turbines, while not universally applicable for the work done by the ordinary steam engines, appear to be particularly well adapted to the driving of generators where a uniform speed is required, and their self-contained construction reduce the possibility of failure to the minimum.

The actual steam expenditure for producing the mechanical forced draft will not exceed 1% of the total steam produced, and even this percentage has in many instances been large-