cent. of carbon dioxide is present, the amount of air per pound of coal will be 28.5 pounds, and the weight of flue gas per pound of fuel will be about 29.5 pounds.

The volume of flue gas at any given temperature may readily be calculated from data given above; moreover, it may be assumed that the volume of the flue gas is equal to the volume of air originally taken, both volumes being, of course, measured at the same temperature. Thus in the above example for every pound of coal the volume of air taken into the furnace at 60 degrees F. will be:—

$$\frac{28.5}{0{\cdot}076} = 375 \text{ cubic feet}$$

and the resulting volume of flue gas at 400 degrees F. will be:—

$$375 \times \left\{\frac{461 + 400}{461 + 60}\right\} = 620 \text{ cubic feet.}$$

The rate of combustion allowed for, per square foot of grate area, should be the maixmum that is expected to be attained, and may be decided by reference to the table given in the first part of this paper; from the table it will be seen that 30 pounds per square foot will be a common figure.

It only remains now to determine the velocity of flow that may be allowed in the flue. A pressure of one inch of water is equivalent to the weight of a column of air at 60 degrees F., 5.2 ÷ .076 = 68.5 feet high. Thus the air entering the furnace may theoretically be considered as moving under the action of a head of 68.5 feet. By the law of falling bodies, the velocity of flow resulting from any given head h, will be theoretically given by:—

$$v = \sqrt{2gh} \text{ feet per second.}$$
$$= 8\sqrt{h} \quad \text{,,} \quad \text{,,}$$

Further, the velocity of flow of gases is proportional to their volumes. As we have already seen the volume of a given mass of air, or of the resulting flue gas depends on its absolute temperature, so that if T_1 be the absolute temperature of the outside air, and if T_2 be the absolute temperature of the flue gas, the velocity of the latter will be theoretically given by:—

$$V = 8\sqrt{h}\,\frac{T_2}{T_1}$$

Owing to the resistance offered by the various parts of the furnace and flues, especially the fire, the velocity found by the above formula will not be nearly attained in practice. A co-efficient that will give results very close to what actually occurs in ordinary practice is .3, but if the flue is short and straight, the value of this co-efficient may be raised and, on the other hand, if flue conditions are bad its value may have to be decreased. Using the value .3, the above formula may be put in the form:—

$$V_1 = 2{\cdot}4\ \sqrt{h}\ \frac{T_2}{T_1}$$

In the present example we have:—

$$V_1 = 2{\cdot}4\ \sqrt{68{\cdot}5}\ \times \left\{\frac{461 + 400}{461 + 60}\right\}$$

$$= 33 \text{ feet per second.}$$

The value of co-efficient given above, will provide, under the above temperature conditions, for a flue area equal to about one sixth of the grate area on the assumption that the flue gases contain about 7.4 per cent. of carbon dioxide. It should be noticed that the percentage of carbon dioxide in the flue gases has a very marked effect on the size of flue required; this is a point that is very seldom put forward with due emphasis. Where combusiton is being properly provided for, the saving in cost of flue may be no inconsiderable amount, and, on the other hand, in the case of an existing plant, on account of the above effect, draught conditions may be much improved by proper attention to combustion, or, again, the same flue may be enabled to cope with the requirements of a considerably greater number of boilers. Such matters are obviously by no means of negligible importance.

Part III.—Practical Application of the Conditions for Economic Coal Combustion.

It is not possible, of course, in a paper of this kind to refer to every type or method of arrangement of the furnace parts of a boiler plant. The individual types referred to are intended to serve rather as examples than as special cases, and on the whole an attempt has been made to make the scope of this part of the paper in effect, at any rate, as wide as possible.

The conditions essential to the economic combustion of the hydro-carbons of bituminous fuel will first be considered in turn, commencing with condition (2), and then a discussion will follow of actual examples of their practical application.

Condition (2) is a condition that is never completely complied with in practice, but it may be complied with to a far greater extent than is usually the case, and such compliance would generally mean a very material gain as already indicated.

As has been stated before it is necessary for each molecule of the hydro-carbon gases to come into contact with the molecules of oxygen necessary for its combustion. For this occurence a time limit is set, which depends on the extent of the combustion chamber, and it is more readily accomplished with an excess of air than with the correct proportion of air. In practice, it is found more economical to curtail somewhat the length of the combustion chamber, and then to admit a slight excess of air to ensure the necessary contact of gas and oxygen molecules in the shorter time, but the excess of air need only be very small if proper attention be paid to combustion conditions as a whole. Sixteen per cent. of carbon dioxide in the flue gases is considered by experts to be a percentage that is attainable in practice, whereas 8 or 10 per cent. is a figure seldom attained in ordinary present-day boiler plants.

The flue pressure being sufficient, the total amount of air supplied to the furnace may be regulated by means of a main flue damper. It is often advisable, however, to utilise the full available flue suction by leaving the main damper practically full open, and then to regulate the total air supply, as well as its distribution, by means of furnace-door and ash-pit dampers. An idea of the flue pressures required may be gained from the following figures which are given by Messrs. Booth and Kershaw:—A pull of at least three-quarter inch of water ought to be observed at a point about two feet on the furnace side of main flue, the furnace doors and air slides being closed and dampers being drawn to fullest extent. This would signify a one-inch pull at the base of the chimney. Draught above boiler fires should be about $\frac{3}{8}$ inch of water under normal conditions. The draught required, however, will vary somewhat with the quality and fineness of the fuel, the length and size of flues and so on. Dr. R. H. Thurston has prepared a table of pressures required to properly burn different grades of fuel, and this table is reproduced below; but if the flues are long, or if the flow of gases through them is restricted in any way, the pressures given in the table should be correspondingly increased.

Kind of Fuel.	Pressure Required in Inches of Water Column.
Good Steam Coal	0·4 to 0·7
Ordinary Slack	0·6 to 0·9
Very Fine Slack	0·7 to 1·1
Semi-Anthracite	0·9 to 1·2
Anthracite Slack	1·3 to 1·8

The distribution of the air supply with regard to its admission above the furnace and through the grate from the ash-pit should be regulated by means of furnace-door and ash-pit dampers. The necessity for the use of such dampers is insisted upon, and proper provision in this direction (a state of affairs that is seldom met with in practice) is undoubtedly of great economic importance.

That the air which is admitted above the grate should be admitted at the fire door end of the furnace is advisable for reasons which may perhaps be summed up in the two following statements. Firstly, the hydro-carbons as they are driven off from the coal will at once commence to mingle with the air, and thus a proper mixing of the air and gases will be facilitated; and, secondly, the air having to pass over the whole length of the furnace will doubtless be better heated than would otherwise be the case.

It is frequently admitted through openings in the bridge wall at the back of the grate. This practice may certainly result in a diminution in smoke production; but, from what has already been said, and also from consideration of the fact that the percentage of carbon dioxide in the flue gases will almost certainly be considerably lowered, it should be clear that from an economic standpoint it is a practice that is most decidedly to be avoided.

In connection with distribution of air supply there is a further point that needs attention in certan cases. This relates to the local distribution of the ash-pit air supply over the grate surface, but it will be best to consider this matter a little later, when dealing with a case in point.

Many of the remarks made above in connection with condition (2) apply also more or less directly to condition (3), and so there is little more to be said at this point about the latter condition. It will have been gathered by now that the air supply for the combustion of the hydro-carbons is mainly, if not entirely, admitted to the furnace from the neighbourhood of the furnace door. To aid as far as possible the intermingling of the air and gases, the admission of the air should be effected through numerous, small apertures, and these apertures should be spread as far as possible across the furnace front. The mixing of the gases may also be encouraged where possible by the use of suitable baffles.

Condition (1) is perhaps the condition that meets with least attention in actual practice, although it is of the utmost importance. Its application lies primarily in the use of a properly designed fire-box and combustion chamber. The extent and design of furnace should be such that the hydro-carbon gases do not come into contact with the heating surfaces of the boiler until combustion is complete. The design should also be such as to ensure that the gases will attain the ignition temperature as rapidly as possible after distillation.

The question of stoking is also a matter that is closely wrapped up in a consideration of the practical application of condition (1), but as it also has a good deal to do with the practical application of the other conditions, it will doubtless be best to consider methods of stoking as a subject in itself, and to this subject we will now proceed.

The chain-grate stoker may be quoted as an example of a good solution of the stoking problem, as far as condition (1) is concerned. For, with this method of stoking, the coal is choked almost as soon as it enters the furnace, and the gases then driven off may be led, along with the above grate air supply over the whole of the remaining part of the furnace. Under these conditions, proper heating of the gases is assured; also, with proper attention in other directions, a maximum amount of time may be obtained for the process of admixture of the aid and gases.

With regard to condition (2), almost all methods of mechanical stoking have the advantage, as compared with hand stoking, that for any given rate of coal feed the position of the dampers may be fixed and left unaltered, and a change in coal feed has merely to be accompanied by corresponding changes in the damper openings.

A great enemy to economy is the formation of bare or thin patches in the fire, for through such openings large volumes of unneeded air are bound to enter the furnace. This trouble is often met with in the case of chain grates, bare patches being formed towards the back of the grate where there is little else but ash. This objection, however, may be more or less obviated by means of some form of bridge plate extending across the back of the grate, and with its forward portion or nose resting on the top of the grate. Such a plate will cause the advancing fire to heap up to a certain extent; and, incidentally, it may also be of considerable assistance in preventing air admission through the grate at the point where it turns at the back; with certain forms of grate links this is a trouble that is especially prominent. It may be necessary to make the bridge plate hollow, and cool it by means of water in order to prevent too rapid burning out.

In the case of a chain grate, however, it is evident that the ash-pit air supply should be so regulated, with regard to its distribution, that there should be a maximum supply towards the front of the grate where the fire is thick, and a comparatively small supply towards the back where the fire is thin and the fuel has been almost completely burnt out. Such distribution may be brought about by means of a sheet-iron box, divided by partitions and situated under the chain. The air admission to the various divisions of the box may be regulated as desired. A design of chain grate stoker provided with air regulation of this kind is shown diagrammatically

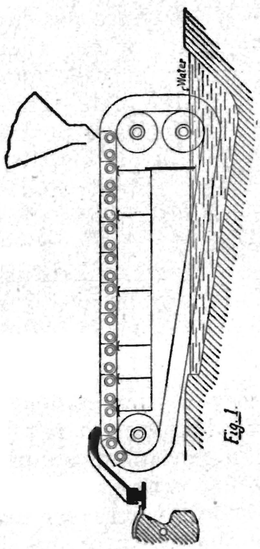

Fig. 1.

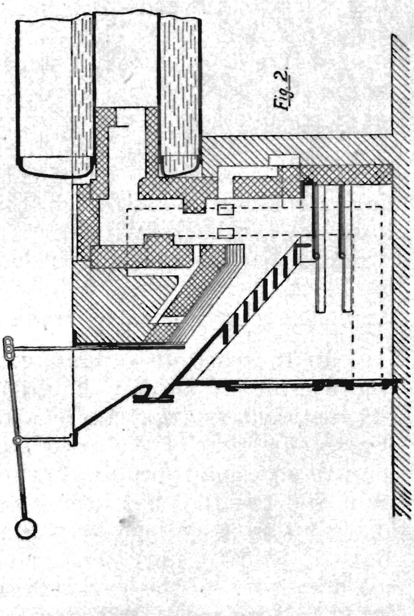

Fig. 2.

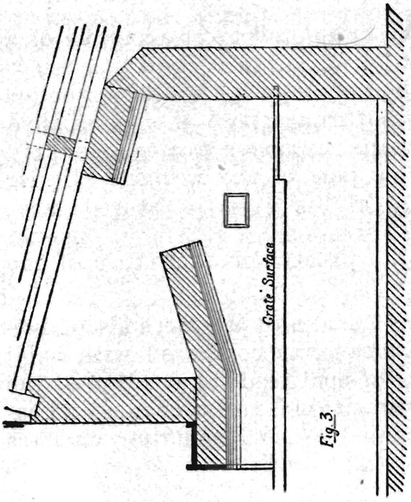

Fig. 3.

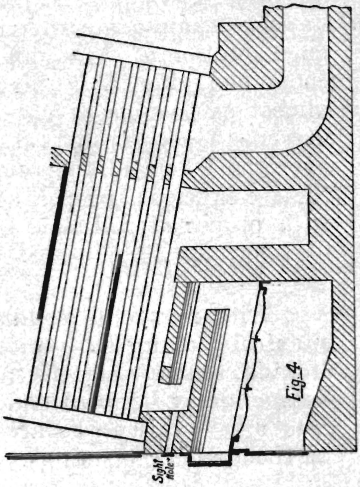

Fig. 4.

in Figure 1, and incidentally the design also illustrates a water lock scheme, with the help of which very complete control may be attained over the ash-pit air supply.

Step and inclined grates are forms of grate which do not suffer from the trouble of bare patches, for the fuel, moving by gravity along the grate, automatically closes over anything of that nature, and a good thickness of fire is maintained right to the back. Figure 2 illustrates a form of hand-fed step grate furnace, but there are other forms, which are doubtless superior in which the feed is controlled mechanically, and in which the motion of the coal down the grate is assisted by automatic movement of the grate bars. This form of furnace may almost be regarded as the connecting link between ordinary coal firing on the one hand, and gas firing on the other hand, and in this connection the use of the seperate producer plant with only a combustion chamber directly attached to the boiler should certainly not be omitted from mention as a method of obtaining very complete combustion. The step grate is an admirable form for fine coals; it is also very suitable for fuels like lignite, peat and sawdust, which cannot be burnt well on ordinary grates.

Hand-firing is a method of firing that is beset with difficulties in regard to obtaining economic combustion. It is only with specially skilled manipulation, such as is seldom procurable, that satisfactory results may be obtained with bituminous fuel supplied to the furnace in this way.

An obvious objection to hand-firing is that large quantities of cold air are admitted to the furnace when firing, and this results in the cooling of boiler, flues, tubes, brickwork and economiser, if used. This objection may be counteracted to some extent by a more or less complete closure of the main damper whilst firing, but in practice such a condition is hardly likely to receive proper attention.

Another, and more important objection is, that the fresh supply of coal, when spread over the surface of the fire, acts momentarily as a very effective heat screen, and thus prevents the proper heating of the hydro-carbons, which just at that time are being driven off from the fresh coal. There are methods by which this difficulty may be more or less obviated, and of these the following three may be quoted as giving most satisfaction:—

1. The coal may be fed in comparatively small quantities, and correspondingly more frequently.

2. The fresh coal at each firing may be spread over only one-half of the grate area, the two halves of the grate being treated alternately in this way. Half of the furnace is thus always free from fresh coal and can supply heat to the gases escaping from the fresh coal on the other part of the furnace.