PART II

PRINCIPLES FOR THE RATIONAL CONSTRUCTION OF
FURNACES

THE problems of furnace construction will be solved when it is possible to regulate the temperature within the enclosure of their heating chambers according to the requirements of the material to be heated. The gas passes from the firebox into the heating chamber without having completed combustion. The first problem to be solved, therefore, is to afford space in the heating chamber within which combustion may be completed. With a short concentrated core of burning gases the highest temperatures are obtained. At other times, according to the material and the method by which it must be heated, it is necessary to prevent the formation of a jet of burning gases and to provide a general combustion of the gases throughout the heating chamber (*a long, soft flame*).

The second problem is in the heating, by means of the hot gases obtained, of those objects which have been placed in the heating chamber of the furnace for this purpose.

For the time being, the first of these problems will be neglected, and this portion of the present work will be devoted exclusively to the solution of the second problem, which may be more definitely stated as follows: In what manner may the hot gases be circulated so that they will, in the most perfect manner, surround the objects being heated and be carried out of the heating chamber, in order that their place may be taken by hotter gases? In what manner may the heating chamber be adapted to obtain such a circulation of the hot gases?

The solution of this second problem is very simple, but in spite of its simplicity it is very poorly understood by practicing furnace designers. Upon the following pages are collected a number of designs of furnaces which have been operated or are

still in operation, and which infringe the most simple natural laws, that is to say, a veritable collection of the monstrosities of furnace design.

The Subdivision of a Current of Hot Gas.—Assume that the current of hot flowing gas Q, which is giving off heat or cooling, is to be divided between two vertical ascending channels, q_1 and q_2, this division to be effected in the manner shown in Fig. 45. The veins of gas q_1 and q_2 are at temperatures t_1 and t_2 and $q_1 = q_2$ and $t_1 = t_2$. Assume that during the operation of this system the amount of heat lost from the branch q_1 is a little greater than the amount of heat lost from the branch q_2 and that, accordingly, the temperature t_1 becomes slightly less than t_2. When $t_2 > t_1$, the
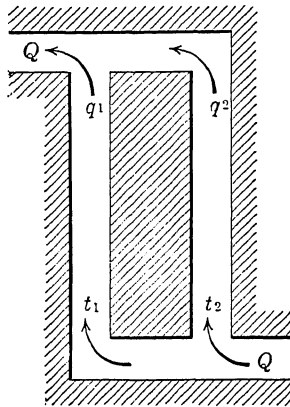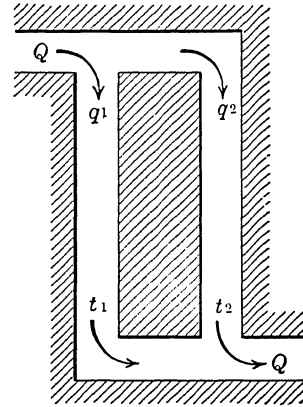

Fig. 45.   Fig. 46.

weight of the column of gas q_1 becomes greater than that of the column of gas q_2, and accordingly the velocity of the current q_1 will become less than that of the current q_2. The decrease of the velocity of the current of gas q_1 results in a further lowering of its temperature t_1; in other words, the velocity of the current of gas q_1 will continue to diminish, and its temperature t_1 will continue to decrease. During this time the velocity of the current of gas q_2 will, on the contrary, be increased, and its temperature will become higher. The current of gas q_1 will finally cease to flow and the entire volume of the current of gas Q will then pass through the branch q_2. But there will still be a loss of heat from the channel q_1 and after the velocity of this current has decreased to zero it will reverse and travel in the opposite direction, as is

indicated in Fig. 47.   From the preceding, it may be readily seen that *a current of hot gas which is giving off heat or cooling cannot be subdivided into equal ascending currents.*

When, however, the attempt is made to subdivide the current of gas Q into two equal *descending currents* (Fig. 46), it will be completely successful.

Fig. 47.

Assuming, for example, that the temperature of one of these currents, q_1, should become less than the temperature of the current q_2.   In this case the weight of the column of gas q_1 will be increased, and the velocity of its descending motion will be increased.   The current of gas q_1 will become stronger than q_2, its temperature will gradually increase and it will finally become equal to q_2.   It can be concluded from this that the problem of subdividing a current of gas which is cooling or giving off heat into equal descending channels may be solved in a very simple manner, owing to the fact that there is always a tendency for the temperatures of these descending streams to remain uniform.
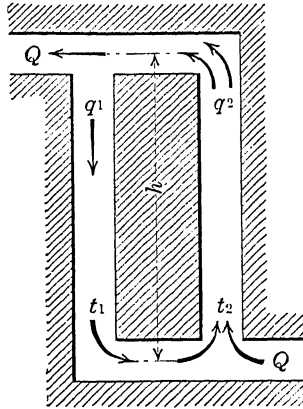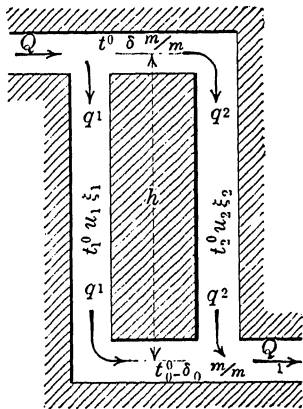
Therefore, *if it is desired to subdivide a current of hot gas which is cooling or giving off heat, into equal streams, it is necessary to give these streams a downward or descending direction of flow; or, in other words, a current which is cooling may be subdivided into uniform descending streams.*[1]

Fig. 48a.

[1] Accordingly, it is possible to approximate the frictional resistance in the two channels between which the current is divided, when one branch has a higher resistance or a higher heat loss than the other, because the stream of gas divides itself accordingly.

In Fig. 48a, such a case is shown.   The stream of gas Q is divided into two descending streams q_1 and q_2, the average temperatures of which are different, being denoted by t_1 and t_2.   The average

It is frequently necessary to subdivide a current of cold air or gas which is being heated, as in the hot-blast stove or in furnace regenerators.   This problem may be solved as follows: Figs. 48 and 49 show a current of a cold gas circulating through a channel, having walls heated to incandescence.   Assume that the stream of cold gas being heated has been equally divided between two

velocities of these two streams are denoted by u_1 and u_2 and the friction in the two branches in millimeters of water is ξ_1 and ξ_2.

The condition necessary for the maintenance of equilibrium, in this case, is that the increase of the hydrostatic pressure in the two branches q_1 and q_2 shall be equal.   If there were no loss of hydrostatic pressure in impressing the velocities u_1 and u_2 upon the two branches and in overcoming the frictional resistance ξ_1 and ξ_2 of the two channels to the passage of the gas, the hydrostatic pressure in millimeters of water in the channel q_1 of a height h would be, taking 1.29 kg as the weight of a cubic meter of the furnace gas at 0°

$$1.29h\left[1-\frac{1}{1+\alpha t_1}\right]=1.29\cdot h\cdot\frac{\alpha t_1}{1+\alpha t_1}.$$

For the branch q_2, the hydrostatic pressure would be

$$1.29\cdot h\cdot\frac{\alpha t_2}{1+\alpha t_2}.$$

A part of these increases in the hydrostatic pressure will be expended in overcoming the frictional resistances ξ_1 and ξ_2, and in impressing the velocities u_1 and u_2 upon the columns of gas.   These last losses, in millimeters of water, may be expressed in the following manner:

$$\frac{u_1{}^2}{2g}\times\frac{1.29}{1+\alpha t_1}\quad\text{and}\quad\frac{u_2{}^2}{2g}\times\frac{1.29}{1+\alpha t_2},$$

and the condition for the equality of the increases in hydrostatic pressure in the two branches is given by the following equation:

$$1.29h\cdot\frac{\alpha t_1}{1+\alpha t_1}-\xi_1-\frac{u_1{}^2}{2g}\cdot\frac{1.29}{1+\alpha t_1}=1.29h\cdot\frac{\alpha t_2}{1+\alpha t_2}-\xi_2-\frac{u_2{}^2}{2g}\cdot\frac{1.29}{1+\alpha t_2}.$$

In this equation there are six variables; five of these must be known in order to fix the value of the sixth.

For example, the checker openings around the outside of the checkerwork of a Cowper hot-blast stove lose a great deal more heat by radiation and by the cooling effect of the outside of the stove than the central passes. By reason of this they have a much greater cooling effect upon the current of hot gases, and therefore the current of gases flowing downward through these openings is reinforced, since if $t_2<t_1$, $u_2>u_1$.   By measuring t_2 and t_1, it is not difficult to find $\dfrac{u_1}{u_2}$.

descending channels q_1 and q_2 having equal temperatures t_1 and t_2, that one of these streams takes up the heat a little faster than the other and that, for example, t_1 becomes slightly less than t_2. The column of gas q_1 becomes, therefore, slightly heavier than the column q_2, the current q_1 commences to flow with greater energy, and its velocity increases; t_1 commences to become sensibly less than t_2, the current q_1 has a greater cooling effect than the current q_2 which continues, on the contrary, to take up more heat; and, in the end, the entire stream of gases passes through the branch q_1, while in the branch q_2 there will be established at the same time a reverse current which circulates as indicated by the dotted arrows (Fig. 48).
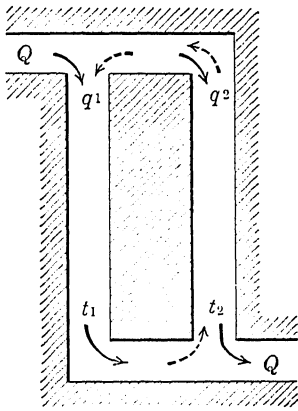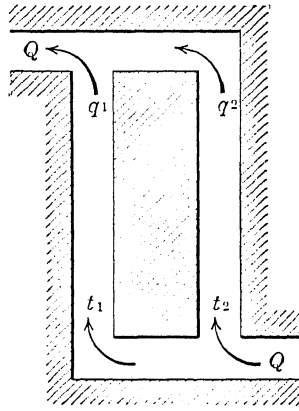

FIG. 48.   FIG. 49.

Therefore, *a current of cold gases which are being heated cannot be subdivided equally between descending channels.*

When the subdivision of a stream of cold gases is made through ascending channels, the results will be as desired. Assuming that the currents flowing as indicated in Fig. 49 were not equal, $q_1 > q_2$ and, consequently, $t_2 > t_1$. If $t_2 > t_1$, the weight of the column q_2 will be less than the weight of the column q_1, the current q_2 will become stronger; this will cause the temperature t_2 to become lower; at the same time t_1 will increase in this manner and the two temperatures will be equalized; the two currents q_1 and q_2 will therefore be maintained equal.

It therefore follows that *when a current of cold gas is to be heated it should be subdivided into a number of ascending streams.*

These rules regarding the subdivision of gaseous currents, while extremely simple and elementary in character, have received very little attention from metallurgists. The experienced chimney builder, who installs hot-air-heating apparatus in residences, is well acquainted with these laws, which are absolutely ignored by a number of very eminent engineers.

A number of examples of incorrect furnace construction are shown below. These furnaces are designed to work in complete or partial opposition to the foregoing rules; they accordingly work very poorly, and many of them have had to be completely abandoned.

In industrial practice, so many of these defectively designed furnaces are encountered that it is absolutely impossible to enumerate all of them. It is therefore thought that the best method of illustrating these defects will be a systematic description of the various types of furnaces and heating apparatus, with a brief description of the correct and incorrect constructions.

They will be taken up in the following order:

    I. Vertical Regenerators;
    II. Horizontal Regenerators;
    III. Hot-blast Stoves;
    IV. Hot-blast Temperature Equalizers;
    V. Iron Tube Hot Blast or Air Heaters;
    VI. Steam Boilers;
    VII. Chamber Furnaces, Brick and Pottery Kilns;
    VIII. Cementation Furnaces;
    IX. Annealing Furnaces for Malleable Iron;
    X. Continuous or Multiple-chamber Kilns;
    XI. Muffle Furnaces;
    XII. Vertical Furnaces for Tempering, Annealing and Heat Treating;
    XIII. Horizontal Tempering Furnaces;
    XIV. Annealing and Heating Furnaces for Boiler Plates;
    XV. Coal-fired Reverberatory Furnaces;
    XVI. Siemens or Regenerative Heating Furnaces;
    XVII. Pit Furnaces, Heating and Soaking Pit;
    XVIII. Continuous-heating Furnaces;
    XIX. Tunnel Furnaces.