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The Rational Construction of Furnaces, W.E. Groume-Grimailo, Petrograd, Russia, 1911

During my early researches into masonry heaters, I spent quite a bit of time at the National Research Council library in Ottawa in the early 1980's.

One of the more interesting finds was the book above, whose actual title I don't have anymore. This document consists of 25 pages that I xeroxed (literally, since the Xerox machine was fairly high tech at the time.)

It concerns the hydraulic theory of gases (buoyancy) as the basis for furnace design. It is well worth a close study by anybody interested in the design of masonry heaters. In particular, I would direct you to pages 90 to 92, which are very useful for understanding why there are differences between updrafting and downdrafting heat exchange channels.

It is also of interest that a recent novel Russian concept of masonry heater design, developed by Igor Kuznetsov, can be traced back to Groume-Grimailo. Although comparison testing between "double bell" heaters and other heater types remains to be done, we do have some testing planned for the immediate future.

At the upcoming 2006 MHA annual meeting at Wildacres in North Carolina, one of the planned projects is the construction and testing of a "single bell" heater that will be converted into a contraflow heater. After Wildacres, Jerry Frisch, Alex Chernov and I will be driving back to Toronto for a meeting of the ASTM masonry heater task group. Alex has built two double bell heaters in his new house north of Toronto (see http://mha-net.org/docs/v8n2/docs/Workshop0509.htm) We have test planned there for Saturday, April 22.

Norbert Senf

PREFACE FOR THE ENGLISH EDITION

THIS work was originally published in the Journal of the Russian Metallurgical Society, in 1911.

During the past six years, a large number of furnaces have been designed and placed in operation by my pupils, by the technical bureau working under my direction, and by myself; but I do not know of a single instance in which we have met with a failure.

The hydraulic theory of the flow of hot gases has proved to be correct. This method of establishing the design of furnaces by computations has given good results and may be followed without fear.

This is not all; the new idea, that of examining each furnace as a hydraulic recipient or reservoir, has exercised a deep influence upon the working out of new forms of furnaces. During the last six years I have worked out a number of new forms of furnaces, the greater proportion of which have already been controlled by working experience. There is no doubt that we are on the eve of a radical change in the technical utilization of the heat generated by the combustion of fuel.

When the war is over, I hope to publish my work in regard to the establishment of the design of new types of furnaces. In the mean time, I limit myself to the following remarks:

During the last few years, it has happened more than once that a furnace construction thought out by me, solving a problem placed before me by a client, has proved, after some research, to have been described in an American patent. This tends to show that the technique of the United States has approached very close to the solution of many of the problems connected with the design of furnaces. With a little more theory, the American engineers will fully master the science of building furnaces. I am, therefore, extremely obliged to Mr. A. D. Williams for his offer to translate this work. I am convinced that it will prove very useful to our esteemed allies, the Americans.

W.-E. GROUME-GRIMAILO.

PETROGRAD, May, 1917.

live and exist in a vacuum. It is this neglect of the part played by the air which causes error; it is this which prevents a clear conception of the mechanism of the circulation of the hot gases within a reverberatory furnace. When the presence of the air is taken into consideration, the problem becomes very clear.

What is it that forms the flame? It is a mixture of gases at a high temperature, reacting upon each other (combustion) and releasing in this manner a sufficient amount of heat to raise the products of their combustion to incandescence. The solid particles of carbon, by their incandesence, give to the flames that especial appearance which impresses the imagination and causes the flame to be attributed to some infernal power. But, in reality, the idea which the author desires to convey in regard to the " flame " may be better understood if the flame is considered as a current of incandescent gas. This approximation is sufficiently accurate for the purpose.

The reverberatory furnace is accordingly considered as an apparatus immersed in a liquid, the air, which weighs 1 kg 29 per cubic meter, in the interior of which there circulates a current of incandescent gases, that is to say, a liquid much lighter than the air.

It is known that the coefficient of expansion of gases is $\frac{1}{273}$; if, therefore, the specific weight of air at 0° is considered as unity:

at	273° its specific weight will be	$\frac{1}{2}$
	546°	$\frac{1}{3}$
	819°	$\frac{1}{4}$
	1092°	$\frac{1}{5}$
	1365°	$\frac{1}{6}$
	1638°	$\frac{1}{7}$
	1911°	$\frac{1}{8}$

and as the specific weight of air at 0° is 1 kg 29;

at	273° its specific weight will be	0 kg	645
	546°	0	430
	819°	0	323
	1092°	0	258
	1365°	0	215
	1638°	0	184
	1911°	0	161

A very clear idea of the differences in density which are caused by great differences in temperature may be obtained by a consideration of the air (gases) in an open-hearth furnace, of which the temperature is in the neighborhood of 1638° while that of the air is 0°. If it is assumed that the density of the gases in the furnace is equal to water, the density of the air at 0° will be relatively equal to that of molten iron.

A furnace in its regular working condition may be considered as being immersed in a glass tank filled with water, the heavy liquid, while the interior of the furnace is traversed by a lighter liquid; the action of the flame within the furnace may in this manner be considered as similar to that of the lighter liquid flowing within the heavier liquid.

A complete representation of the circulation of the flame or hot gases within a furnace may be made in the following manner;

A model to scale of the longitudinal section of a reverberatory furnace is constructed and immersed in a tank with glass sides; if a stream of a lighter liquid, as for instance, kerosene, is now passed through the model of the furnace, the movement of this liquid will reproduce exactly the movement of the flames within the furnace.

II. EXPERIMENTS WHICH SERVE TO SHOW THE ANALOGY BETWEEN THE CIRCULATION OF THE FLAME AND THE MOVEMENTS OF A LIGHT LIQUID WITHIN A HEAVY LIQUID.(1)

A white metal model reproducing to scale a brick kiln is placed between two sheets of glass and submerged in a glass tank; by means of pipes a stream of colored kerosene is passed into the model(2) through the firebox from which the gases of combustion enter the furnace.

(1) The photographs for Figs. 1, 2, 4, 10, 19, 24, 29, 30, 31, 32. 116, and 117 were supplied by the *Société russe de métallurgie*, whom the author desires to thank for the same.

(2) The illustration (Fig. 2) shows the general arrangement of the apparatus which has been used in conducting the experiments made before the classes at the Polytechnic Institute of Petrograd. The model is a scale reproduction of a brick kiln of the Motovillikha works, the drawing of which is shown in Fig. 3. This is submerged in a tank filled with water. Tubes with control valves serve to introduce streams of colored kerosene through the fireboxes of the kiln, the kerosene flowing from a large bottle which acts as a high-level reservoir. The kerosene, having passed through the furnace, rises to

First Experiment.—Study of the older, or updraft, type of brick kiln (Fig. 1), which has the opening for the escape of the waste gases at the highest part of the arched roof.

Small streams of colored kerosene are introduced through the fireboxes and flow up to the central orifice, which is wide open. The streams of kerosene may be seen as fine threads flowing up close to the walls of the kiln and are not of sufficient volume to fill the kiln chamber. Increasing the flow of the kerosene, or, as it may be expressed, firing the kiln more heavily, does not affect the result. It is very clear that the burning of the brick in a

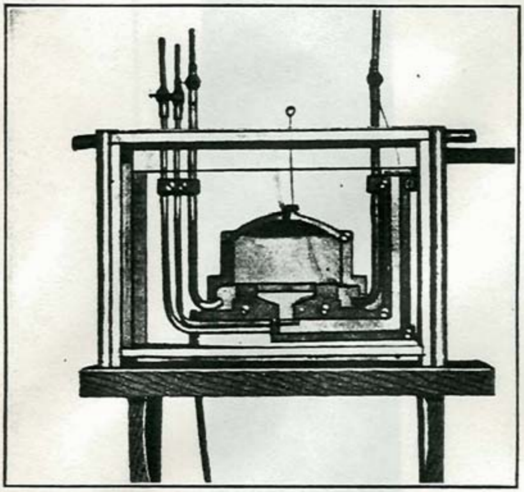

FIG. 1.

kiln working in this manner will be defective. The brick in the lower portion of the kiln will be soft and only partially burned. In order to improve this condition it will be necessary partially to stop up or close the smoke hole. The poor working conditions which exist in the updraft brick kiln are shown in Fig. 1. When the smoke hole is partially closed, the kerosene is forced to accumulate in the upper portion of the kiln; it fills more and more of the

the surface of the water; thence by a trough it flows to the large bottle below. A small pump driven by a motor of $\frac{1}{40}$ hp draws the kerosene from the lower bottle and delivers it to the upper bottle, enabling the kerosene to circulate by gravity as long as desired.

kiln chamber, until an equilibrium is established between its inflow and its outflow. When this equilibrium is established, the lower surface of the layer of colored kerosene assumes a permanent level.

It can be seen in Fig. 2 that only the upper portion of the

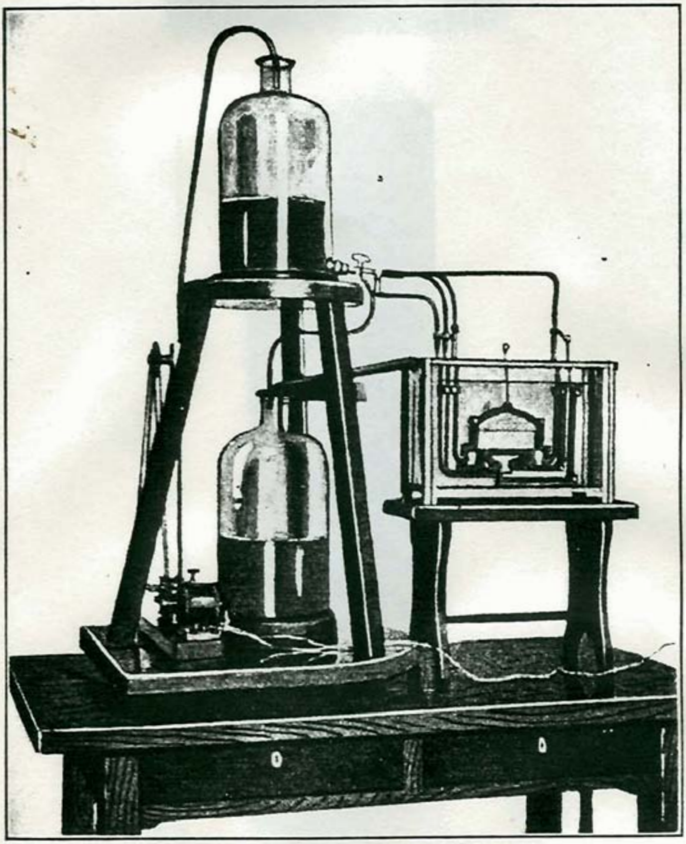

Fig. 2.

kiln, above its mid-height, is filled with hot gases, and that the space between the lower surface of the layer of kerosene and the hearth of the kiln contains none at all. This space, therefore, will only be heated by such eddy currents as form, and these are due entirely to the differences in density which exist between the flame and the cooler gases with which they come in contact. Immediately below the roof of the kiln the hot gases are relatively at rest. The burning of bricks does not permit of sudden or quick changes of temperature, as bricks will crack and spawl if subjected to such changes; therefore it would not be advantageous to use a kiln which worked in this manner.

By still further obstructing the smoke hole of the kiln, the lower surface of the layer of hot gases can be driven downward

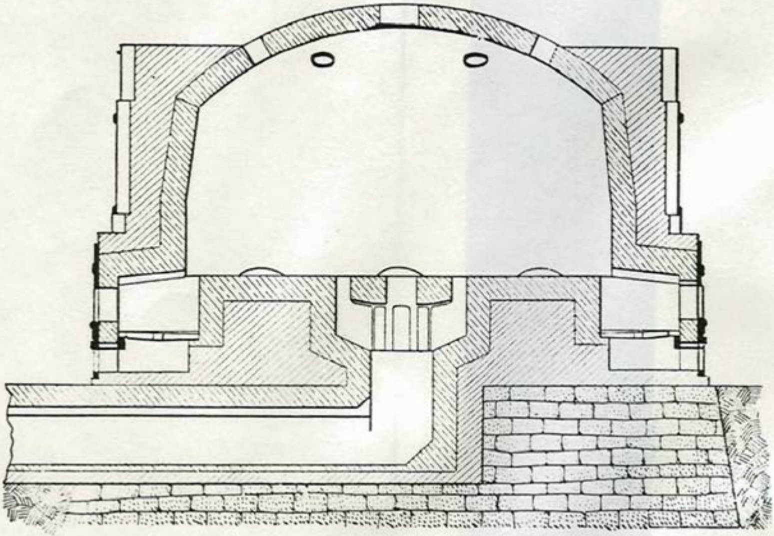

FIG. 3.

until it comes into contact with the sole of the kiln, thus giving the maximum efficiency which is possible with kilns working on the updraft system. Under these conditions, the brick can be burned to an extent which is fairly satisfactory, but they will not be of extra good quality, because, in spite of all, the currents of hot gases have a tendency to flow directly to the highest opening. The equalization of the temperature will be affected very little by the eddy currents which will be formed. These eddy currents will be of very slight intensity when the hot gases in the kiln are as shown in Fig. 1, but nevertheless they do not disappear entirely while the temperature at the sole is less than that which exists immediately below the roof of the kiln.

Note by translator.—A considerable portion of the equalization of the heat in the updraft kiln is due to conduction of the heat, through the kiln structure and the brick set in the kiln. This heat is carried downward in this manner and imparted to the cooler layers of gases at the bottom of the kiln, heating them and promoting eddy currents. The updraft kiln, however, heats very slowly at the bottom, and the upper portion of the setting will be overburned while the lower portion is underburned. As compared with the downdraft kiln, the updraft kiln consumes a larger amount of fuel per unit of output and requires a longer time to complete a kiln round.

Direct or updraft brick kilns were the only ones built up to about twenty years ago. They are still found in many potteries,

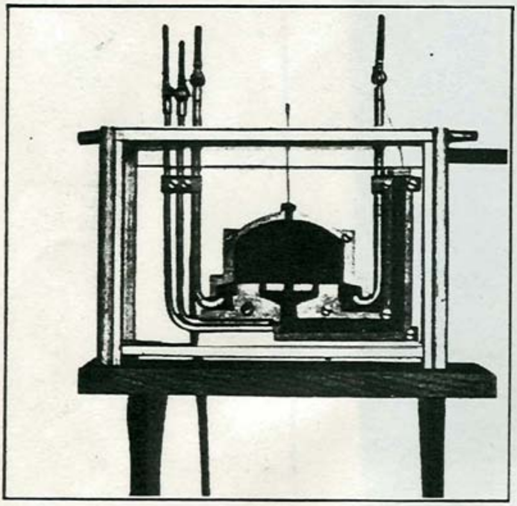

FIG. 4.

as in the works of Korniloff Brothers, at Petrograd. A brick kiln of this type is still in use at the Oboukoff works, and it is only a short time since one was in use at the Poutiloff works. These are not the last updraft kilns in use, but most of them have been replaced by *downdraft* kilns.

Second Experiment.—Continued study of updraft kiln. Method of operating downdraft kiln. For this experiment the smoke hole at the top of the kiln is completely closed. The chimney of the apparatus, as shown in Fig. 4, is filled with kerosene, which is also introduced as before, through the fireboxes. It follows that when the damper or stopper at the top of the chimney is opened slightly, the model will represent a downdraft brick kiln in operation.

It is seen that in the downdraft kiln the hottest gases rise to the highest point under the roof, where they accumulate, forcing the cold gases to the chimney through the ports in the hearth of the kiln. Descending little by little toward the sole of the kiln, the flames or hot gases finally fill the entire kiln chamber and maintain themselves throughout it, only passing to the chimney as they are displaced by hotter gases. In this manner the free lower surface of the hot layer of gases is very nearly stationary, which insures a practically uniform burn to the brick. In this atmosphere, which varies very little, the reactions of combustion are readily effected until only very slight traces of the combustible elements and free oxygen can be found in the gases. That is, combustion takes place with very nearly the theoretical supply of oxygen. The flames of this combustion traverse the entire mass of the gases and there are no definite points at which high temperatures may be found. For this reason the downdraft kiln is successfully employed when it is desired to obtain slow and uniform heating.

These experiments with a model of a furnace immersed in water confirm, with sufficient clearness, the fundamental principle that the circulation of the hot gases within a furnace is similar to the circulation of a light liquid within an enclosure filled with a heavy liquid.

III. THE CURRENT OF THE HOT GASES MAY BE COMPARED TO A STREAM OF WATER TURNED UPSIDE DOWN OR INVERTED

Streams composed of a heavy fluid in motion within a lighter fluid are seen everywhere. Do not all rivers represent the displacement of a light fluid—the air—by a heavy fluid—the water? In this case, it is very well known that the stream is confined on the bottom and the sides.

If the flame and the hot gases within the furnace were fluids heavier than the air, it would be found that they flowed in the same manner as the stream of water. But as they are much lighter than the air, it is found necessary to confine them upon the top and the sides.

This may be more clearly comprehended by means of the following laboratory experiment:

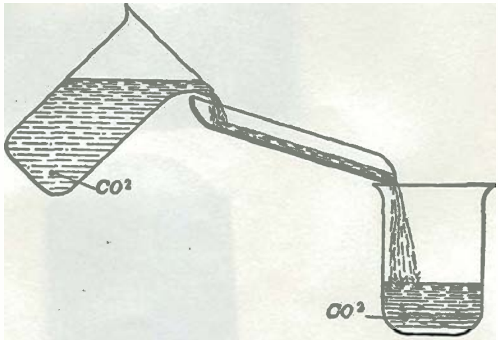

Fig. 5

It is possible to pour a gas from one container to another by employing a sloping trough to guide its flow. This may be done with carbon dioxide gas, which is heavier than air, and also with hydrogen, which is lighter than air. When the carbon dioxide is being poured, the stream of gas must be confined below and upon its sides (Fig. 5). The hydrogen, on the other hand, must be confined upon the top and the sides (Fig. 6).

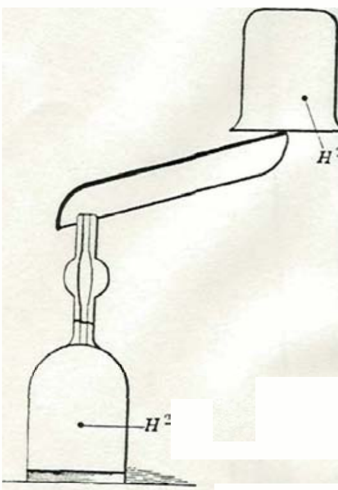

Fig. 6.

There is evidently nothing which confines the current of carbon dioxide upon the top and the stream of hydrogen on the bottom. These experiments require care, but are easy to make if the surrounding air is absolutely still and free from currents.(1) The gases may be poured equally well whether there is a fourth wall or not.

These experiments lead to the following conclusions:

Streams of incandescent gas need be confined only upon the top and sides, and, in effect, all reverberatory furnaces confine the stream of hot gases in this manner, at the top (the roof) and

(1) A condition which is neglected in the above experiment, is the tendency of all gases to form homogeneous mixtures by diffusion. In both experiments there will be a slight mixing with the air, as a result of this tendency.

upon the sides (the walls of the furnace) (Fig. 7). The confining boundary upon the bottom may be present or not. In the same manner, a stream of water may be confined by walls below and upon both sides, while its upper surface is entirely free. In a similar way the gaseous stream has to be confined upon the top and the two sides, while upon the bottom its surface is entirely free.

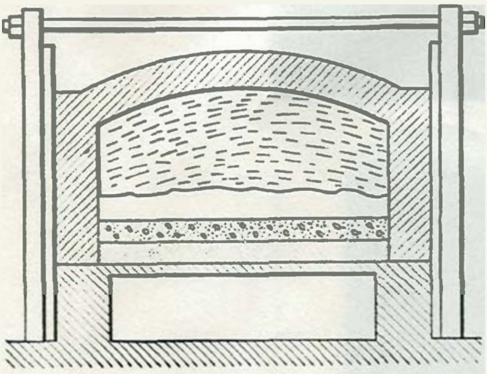

FIG. 7.

It would reveal a serious error in this theory, if, for example, the breeching, or smoke flue, common to four boilers was found to be completely filled with gases without regard to the number of boilers which were in service. This, however, will not be the case. In a correctly proportioned smoke flue the free lower surface of the gaseous stream will be found in the neighborhood of the bottom AA (Fig. 8). If the volume of the gases flowing decreases to one-fourth its former volume, the thickness of the stream decreases two and one-half times [1] or to 0.40 its former thickness, and the lower free surface of the gases will be found at the level BB; within the space $AABB$, no circulation of the gases will be found.[2]

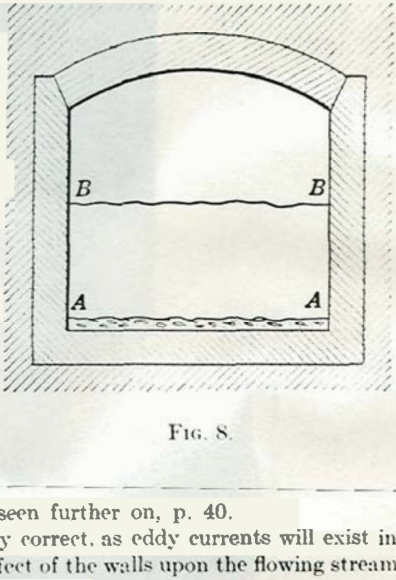

FIG. 8.

[1] Where $2.5 = \sqrt{4^2}$, as may be seen further on, p. 40.

[2] This statement is not absolutely correct, as eddy currents will exist in the space $AABB$ due to the cooling effect of the walls upon the flowing stream of heated gases.

Just as a river has a depth which is a function of the volume of water flowing, it is evident that a stream of gases will have a thickness which is a function of the volume of gases flowing. If, on this basis, water is used to simulate the cold air and colored kerosene to simulate the hot gases flowing in the flue, it would not be difficult to show a smoke flue filled or partially filled with a stream of kerosene. This demonstration is considered useless as it has been thoroughly established that flowing streams of hot gases do not require anything to confine their lower surface and that the thickness or depth of the stream is a function of the volume of the gases which are flowing.

Therefore, when currents of hot gases are dealt with, they will always be represented as *inverted streams of water.*

IV. APPLICATION OF THE LAWS OF HYDROSTATICS TO HOT GASES.

The weight per cubic meter of the products of combustion of the ordinary combustibles varies from 1 kg 29 to 1 kg 33 at 0° and 760 mm. The computations may be simplified, and will be sufficiently exact, if the first of these values is assumed as the weight of the products of combustion, because this value is also the weight of a cubic meter of air. At any temperature t the weight of 1 cu m of the hot gases will be, therefore, $\frac{1.29}{1+\alpha t}$ kg, in which $\alpha = \frac{1}{273} = 0.00367$.

By reason of this large coefficient of expansion of gases, the difference between the weight of a cubic meter of atmospheric air (1 kg 29) and a cubic meter of the gases of combustion, taking, for example, those in an open-hearth furnace (0 kg 17) is quite large, being equal to $1.29 - 0.17 = 1$ kg 12. It is this difference between the weight of the air and the weight of the flame or hot gases which causes the hydrostatic pressure of the latter.

The following experiments will serve to make this clear (Fig. 9). The upper surface of the water in a beaker is at aa; and B is a lamp chimney into which kerosene has been poured until its lower surface is at the bottom of the lamp chimney. It can be seen that the upper surface of the kerosene bb in the lamp chimney is higher than the surface of the water in the beaker.

The difference in level between aa and bb can be computed in the following manner. The column of water h is balanced by the column of kerosene H. The specific weight of water is 1.0 and that of kerosene is 0.80; it follows that:

$$H=\frac{h}{0.8}=1.25h,$$

and the difference in level will be $0.25h$, equivalent to a column of water of $0.25h \times 0.8 = 0.2h$.

This experiment may be modified as follows: take a beaker

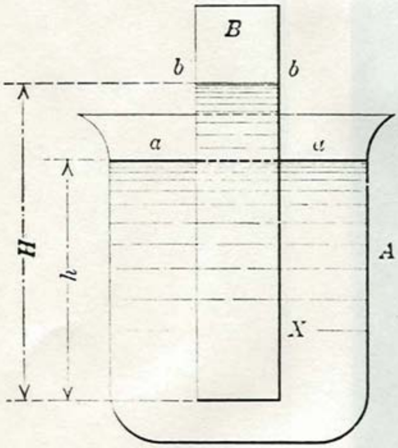

FIG. 9.

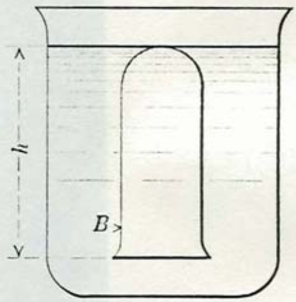

FIG. 10.

of water and immerse therein a test-tube filled with kerosene, until the bottom of the test-tube is even with the surface of the water, the test-tube being inverted (Fig. 10), and determine the hydrostatic pressure which it supports. It is evident that at the level B the pressure exerted by the water upon the kerosene and the pressure reciprocally exerted by the kerosene upon the water are equal, because they are in equilibrium.

The pressure of the water per unit of surface in millimeters of water column is that given by the height h:

$$P_{\text{water}} = h \times \text{density of water} = h \times 1 = h \text{ mm}.$$

The pressure of the kerosene is measured, first, by the weight of the column of kerosene, and, second, by a certain hydrostatic pressure δ to be determined. From which:

$$P_{\text{kerosene}} = h \times \text{density of kerosene} + \delta = 0.8h + \delta \text{ mm of water.}$$

But since $P_{\text{water}} = P_{\text{kerosene}}$, it follows that:

$$h = 0.8h + \delta \quad \text{and} \quad \delta = +0.2h \text{ mm of water}$$

If it is considered that the water in this experiment represents the cold air and that the kerosene represents the incandescent gases in the furnace, the following law may be established with regard to the hydrostatic pressure which will be produced at the different parts of a furnace chamber containing hot gases:

The hydrostatic pressure δ in kilograms per square meter at a point in a chamber bathed by the incandescent gases, located at a distance H above the free surface of those gases, is equal to the difference Δ between the weight in kilograms of a cubic meter of the external air and a cubic meter of the incandescent gases, multiplied by the height H, from which

$$\delta = H\Delta.$$

Example.—If $H = 0$ m 70 and the weight[1] of 1 cu m of hot gases at 1200°,

$$P_{1200} = \frac{1.33}{1 + \frac{1200}{273}} \text{ kg} = 0 \text{ kg } 25,$$

from which

$$\delta = 0.7\ (1.29 - 0.25) = 0 \text{ kg } 728 \text{ per square meter,}$$

or 0 mm 728 of water, since the pressure of 1 kg per square meter is equal to the pressure exerted by a column of water 1 mm in height.

Experiments which may be readily made will show that the light hot gases which fill the furnace are actually exerting a pressure greater than that of the atmosphere.

Open the register connected with any hot-air house-heating system. A jet of hot air escapes with some force. What is it that sets this air in motion? What is it that provides the energy necessary for this motion?

Open the sight hole located at the upper part of an open-hearth regenerator chamber. If the regenerator is not connected

[1] Refer to Appendix II.

with the chimney, a jet of incandescent gas or air will escape with considerable force. What is it that sets this in motion?

Open the bell of a gas producer working with natural draft: the producer gas will escape. What is the force which causes the air to pass through the bed of wood or coal, where it is transformed into gas, and which, in addition, has sufficient pressure to produce the jet of gas?

From the fact that enclosures filled with a cold gas, but one which is lighter than the air, always exert a pressure higher than that of the atmosphere, it follows that the preceding phemonena are due *not to the temperature of the gas*, but to the fact that it weighs less than the air.

Take, for example, a balloon 10 m in diameter, filled with hydrogen (Fig. 11). Compute the hydrostatic pressure of the gas at the top of the sphere. This balloon being open at the bottom, at the level AA the gas is in equilibrium with the air, their pressures being equal.

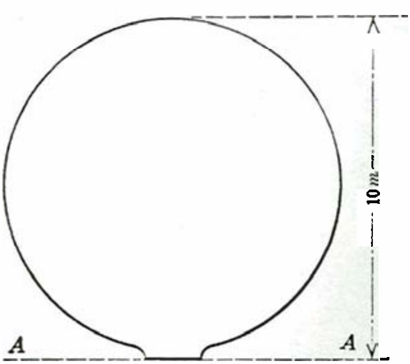

FIG. 11.

Consequently the weight of a column of cold air 10 m in height (1 kg $29 \times 10 = 12$ kg 90) is held in equilibrium by the weight of a column of hydrogen 10 m in height plus a certain hydrostatic pressure δ which may be determined.

The weight of a cubic meter of hydrogen being equal to 1.29×0.06927, the following equation is obtained:

$$1.29 \times 10 = 1.29 \times 0.06927 \times 10 + \delta; \quad \delta = 12 \text{ kg } 006,$$

which is in the neighborhood of 12 mm of water.

It is on account of this hydrostatic pressure of the hydrogen at the top of the balloon that it is necessary to employ a very strong material in the making of this envelope. It is this pressure which causes the balloon filled with hydrogen to ascend and which furnishes the energy for the flow of the hydrogen when the valve at the top of the balloon is opened to permit it to escape. Furthermore, children are often amused by making small hot-air

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

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 $\frac{u_1}{u_2}$.

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).

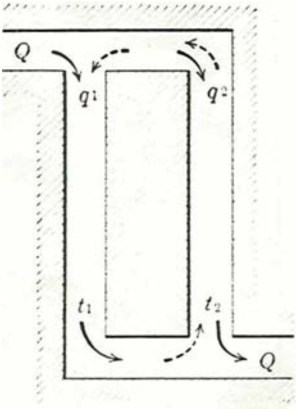

FIG. 48.

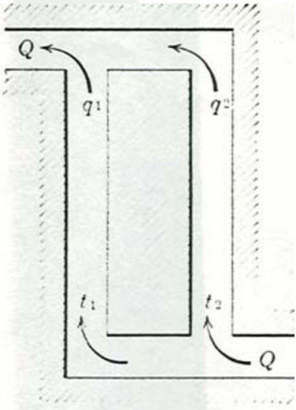

FIG. 49.

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.

These local centers of combustion are due to the excess air supply. In proportion as they cool, the gases drop lower and lower, uniformly heating all of the tubes, which for this reason work in a satisfactory manner.

The Cleveland iron tube air heater, which is not so widely known, likewise works upon the *downdraft principle* (Fig. 76).

The disappearance of the numerous types of iron tube air heaters and the survival of the *Bessèges* and Cleveland designs supplies a very good example of the importance of giving the correct direction to the circulation of the gases in furnaces.

VI. STEAM BOILERS

The constructors of steam boilers very rarely consider the rational distribution of the hot gases. These defects are particularly frequent in the most recently designed types of water-tube boilers, as well as in the older designs. The lack of knowledge of the laws governing the flow of the heated gases explains the

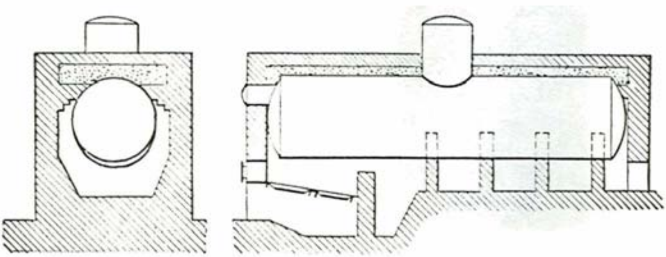

FIG. 77.

numerous and complicated forms of baffling of all kinds, as well as the use of special dampers to force the hot gases to bathe the heating surface of the boiler and its tubes regularly and completely.

(*Note by English translator.*—The absolute neglect and disregard of the most elementary laws of physics is not confined to the circulation of the heated gases, but is grossly violated in the water circulation as well.)

In reality it is not necessary to have any baffling nor walls. The hot gases have a natural tendency to flow in such a way that the entire heating surface of the boiler will be bathed by them in a very uniform and regular manner. Without going into details, some of the useless and erroneous forms of boiler setting and baffling which are given as "good" construction in *Hütte* are shown below. These will very clearly indicate the ideas which the author is endeavoring to set forth.

Fig. 77 shows a single-drum cylindrical boiler as illustrated upon page 865 of the first volume of the French translation of *Hütte* (edition of 1911).

Fig. 78 shows the correct method of setting the same boiler. All of the baffling which was supposed to force the hot gases to travel in a zigzag path has been eliminated. The hot gases, being light, have a tendency to rise and apply themselves to the shell of the boiler. Any constrictions of their path have a detrimental effect, as they tend to increase the velocity of flow. In order to

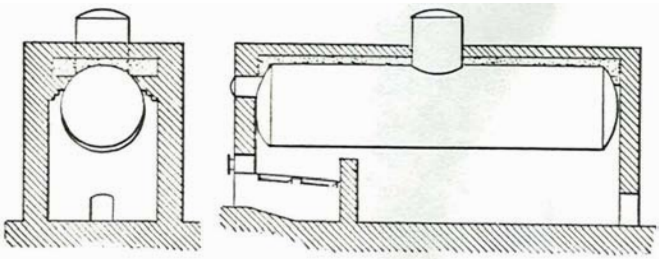

FIG. 78.

increase the time during which the heated gases remain in contact with the boiler after leaving the firebox, the waste gas outlet has been dropped as far as possible by lowering the hearth of the gas chamber behind the bridge wall.

(*Note by English translator.*—This setting would be greatly improved by placing the grate and firebox in a separate setting where the mixing gases would not be chilled below the ignition point.)

The circulation of the gases in a boiler set in this way is effected in the following manner: The boiler will be constantly bathed by the hottest gases which tend to rise to the highest part of the setting. As these gases are cooled they will drop lower and lower by reason of their increase in weight while cooling. They will finally, at their lowest temperature, fall to and pass out through the waste gas outlet.

In order to avoid detrimental eddy currents it is necessary to fix the height of the opening over the bridge wall by the formula for the inverted weir and avoid high gas velocities.

Fig. 79 shows the setting of a four-drum cylindrical boiler,

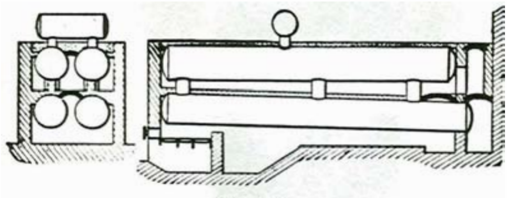

Fig. 79.

having the drums arranged in pairs above each other, according to *Hütte*. The cross-section of this setting shows that the heating chamber is divided into four flues for the hot gases:

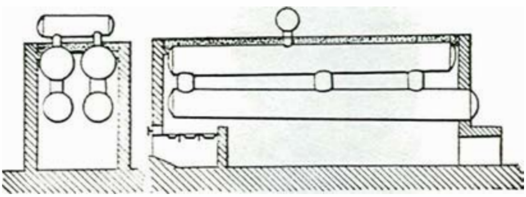

Fig. 80.

1. One passage under the lower drums;
2. Two passages at the sides of the two upper drums;
3. One passage between the two upper drums.

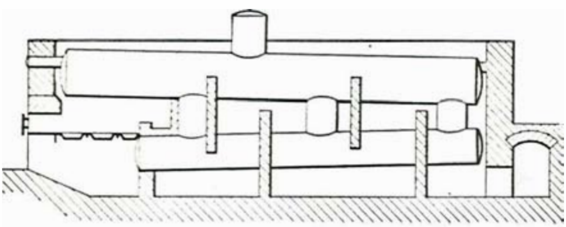

Fig. 81.

A very large proportion of the heating surface of this boiler is covered and insulated by the numerous arches and baffles, making it useless. It is very simple and easy to change this setting by the removal of the walls and arches, as is shown in Fig. 80, at the same time lowering the waste gas outlet to the level of the bottom of the gas chamber where it will remove the coolest gases in the setting.

Fig. 81 shows a two-drum cylindrical boiler (*Hütte*). In this setting, those baffles which are built up from the bottom of the setting are entirely useless and may be removed. This setting will be better if built as shown in Fig. 82.

These three examples will serve to show very clearly the manner in which boiler settings may be greatly simplified. Nevertheless, it is well known that commercial boilers, particularly those designed for use upon ships, such as the Belleville, Niclausse,

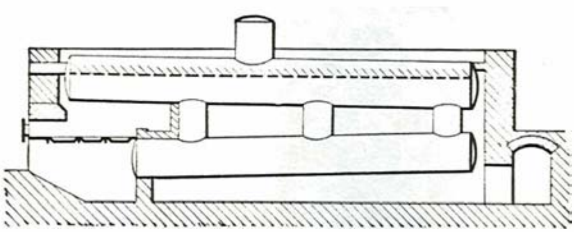

FIG. 82.

Yarrow, etc, are designed to work upon the updraft principle. This is a serious error, as it violates the law of gaseous flow, and as a result there is poor vaporization and a reduction in the efficiency of the application of the heat.

VII. CHAMBER FURNACES, BRICK AND POTTERY KILNS

Barely thirty years ago, direct or updraft kilns were practically the only kind used in the brick and pottery plants. At present their use is decreasing and there is a strong preference for the downdraft kiln.

It may be said that the direct or updraft kilns which are still in service are the last traces of these kilns in this industry. At the same time it is very curious to note that the firm of Ernest Schmatolla,[1] which is engaged almost exclusively in the construction of brick and pottery kilns, in a book published by them, devote almost the entire volume to a description of the old updraft kilns, and make no mention of the downdraft kiln beyond the brief statement that these kilns generally give better results than the updraft kiln.

(1) *Ernest Schmatolla, Die Brennöfen*, 1903.

In a preceding chapter the principles governing the computation for the updraft chamber furnace have been stated. By partially closing the smoke hole in the dome it is possible to force the free lower surface of the hot gases in the kiln chamber down to the hearth level, and thus force the heating of ware placed upon the hearth. Nevertheless such a method of heating is very imperfect and is not uniform. Its mechanics are as follows:

The incandescent and burning gases issuing from the firebox (Fig. 83) rise immediately to the highest point in the chamber; therefore the central portion of the heating chamber does not receive any direct action from these ascending currents, and is accordingly filled by heavier and colder gases than those coming from the fireboxes. These heavy gases gradually drop to the hearth of the chamber as the upper parts of the chamber fill with the hotter gases. Portions of these colder gases in the bottom of the chamber become mixed with the heated gases flowing from the fireboxes and rise with them. Finally a circulation of gases is established within the chamber, so that all portions of the charge are gradually heated.

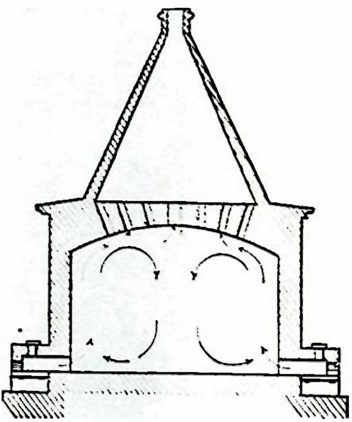

FIG. 83.

Moreover, only a small portion of the heated gases circulate in this manner. The largest portion of the hottest gases escape immediately to the chimney through the smoke holes in the roof of the kiln. For these reasons, all the ware, which is set where it comes into direct contact with the hot gases is hard burned, whereas the burn of the ware which only comes in contact with the colder currents of gases will be less hard and portions of the ware will receive a very slight burn.

While updraft or direct-draft kilns continue to be used in many of the clay products plants, the principles of the downdraft kiln

Note by English translator.—Considerable heat is carried down to the hearth of the kiln by conduction through the charge and the walls.

are so well known in this industry that it will not be necessary to devote much space to them.

Fig. 84 shows the same kiln (Fig. 83) *reconstructed* to work on the downdraft principle. The distribution of the currents of hot gases is very good, as the hottest gases rise to the arch of the furnace and then divide themselves into uniformly descending currents. One of the results of this reconstruction was the reduction of the amount of defective brick turned out from 30 per cent to 1 per cent.

Fig. 85 shows a two-story kiln used in the manufacture of

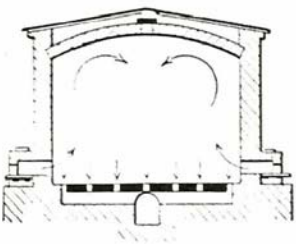

Fig. 84.

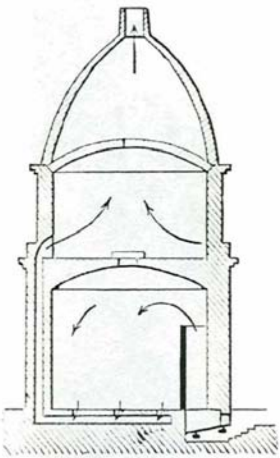

Fig. 85.

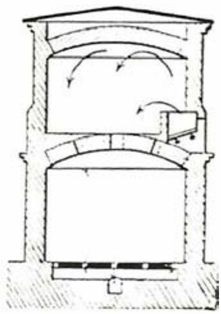

Fig. 86.

porcelain. Such kilns are still actually in use. The upper chamber works in an unsatisfactory manner, the hot gases being divided into ascending currents; it is practically impossible to regulate the distribution of the heat by changing the size of the waste-gas opening. The lower chamber of the kiln, which works on the downdraft principle, has a regular heat distribution.

Fig. 86 shows a kiln of this type correctly constructed, both the upper and the lower chamber working upon the downdraft principle. The firebox has been changed from the lower to the upper chamber.

Note by English translator.—Downdraft "beehive" kilns are widely used in the manufacture of refractory brick. In the silica brick plants it is well known that only one-seventh of the kiln capacity can be used for coke oven shapes, many of which require two burns. The prevailing tendency in

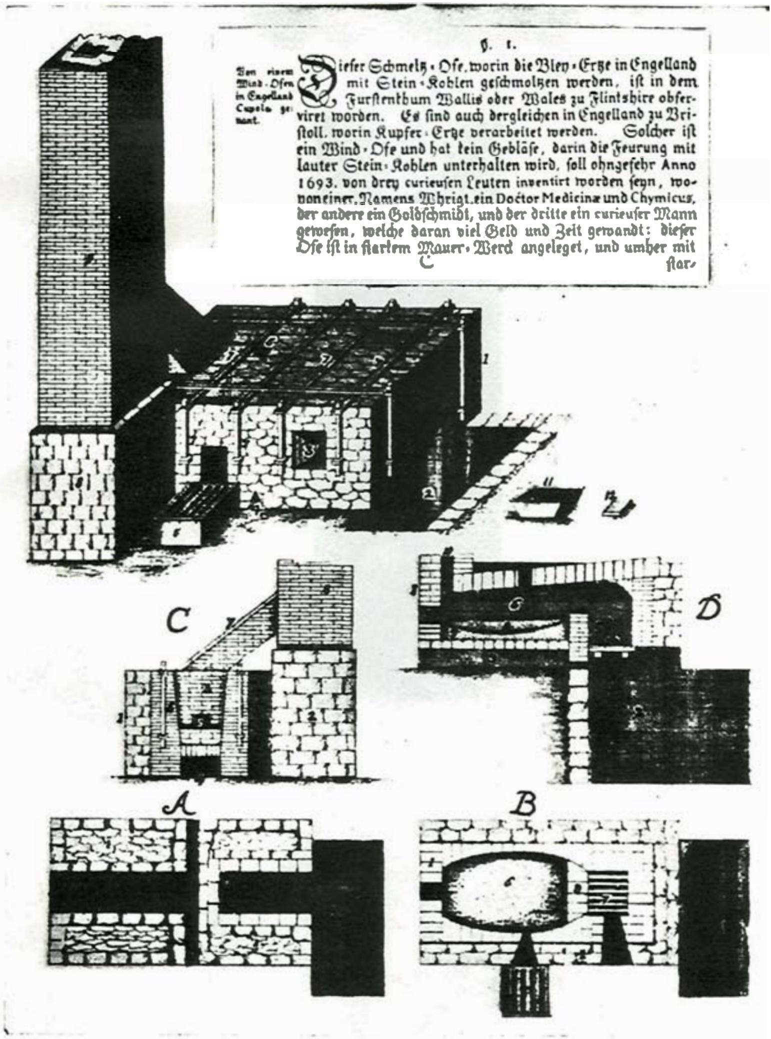
§. 1.
Von einem Wind-Ofen in Engelland Cupola genant.
Dieser Schmeltz-Ofe, worin die Bley-Ertze in Engelland mit Stein-Kohlen geschmoltzen werden, ist in dem Fürstenthum Wallis oder Wales zu Flintshire observiret worden. Es sind auch dergleichen in Engelland zu Bristoll, worin Kupfer-Ertze verarbeitet werden. Solcher ist ein Wind-Ofe und hat kein Gebläse, darin die Feurung mit lauter Stein-Kohlen unterhalten wird, soll ohngefehr Anno 1693. von drey curieusen Leuten inventirt worden seyn, wovon einer, Namens Whright, ein Doctor Medicinæ und Chymicus, der andere ein Goldschmidt, und der dritte ein curieuser Mann gewesen, welche daran viel Geld und Zeit gewandt: dieser Ofe ist in starckem Mauer-Werck angeleget, und umher mit star-
C
D
A
B

FIG. 129.