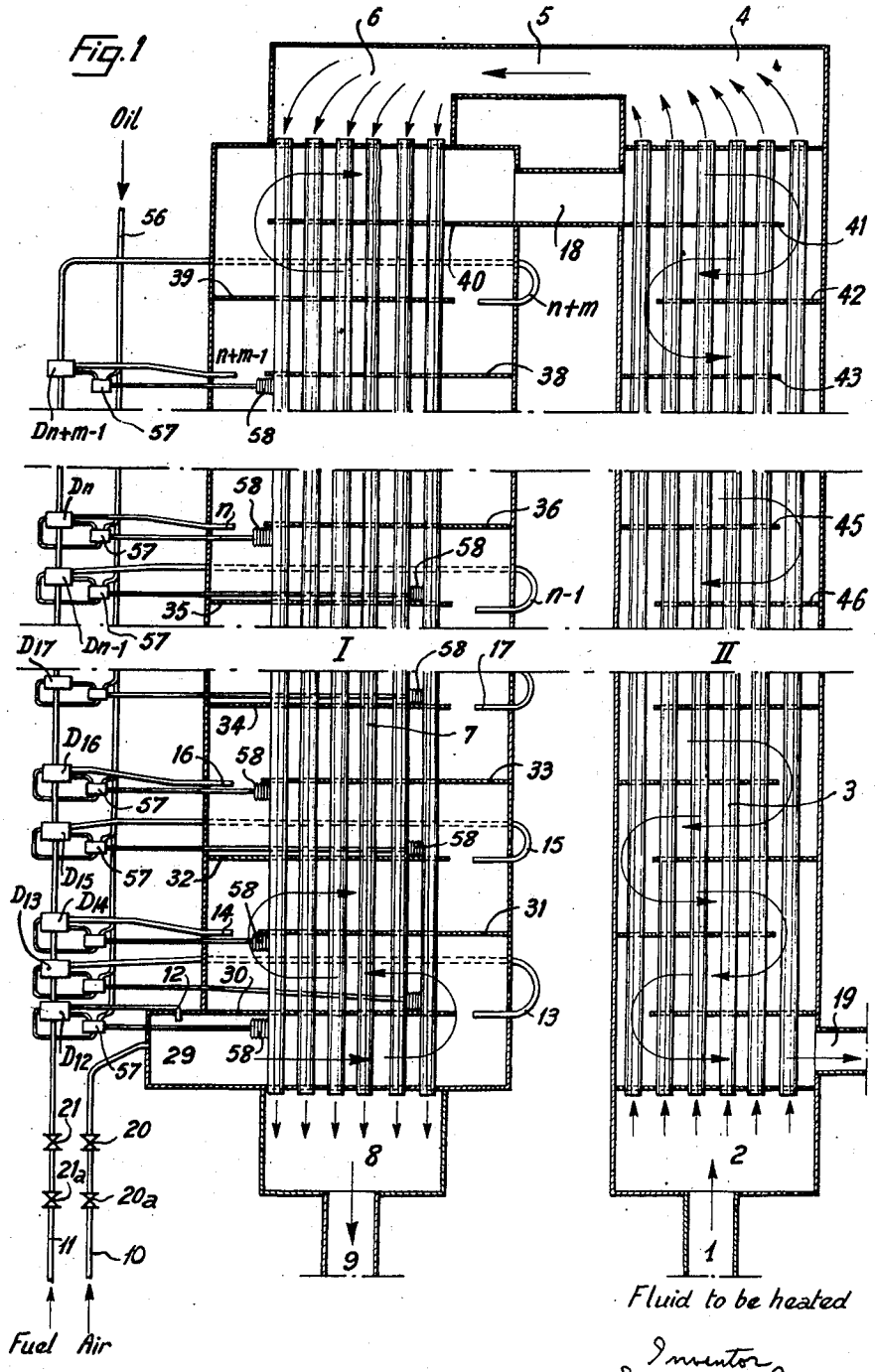
July 28, 1953 L. M. REYGAGNE 2,646,790

PROGRESSIVE FUEL COMBUSTION FLUID HEATING APPARATUS AND CONTROL MEANS THEREFOR

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Fig. 1



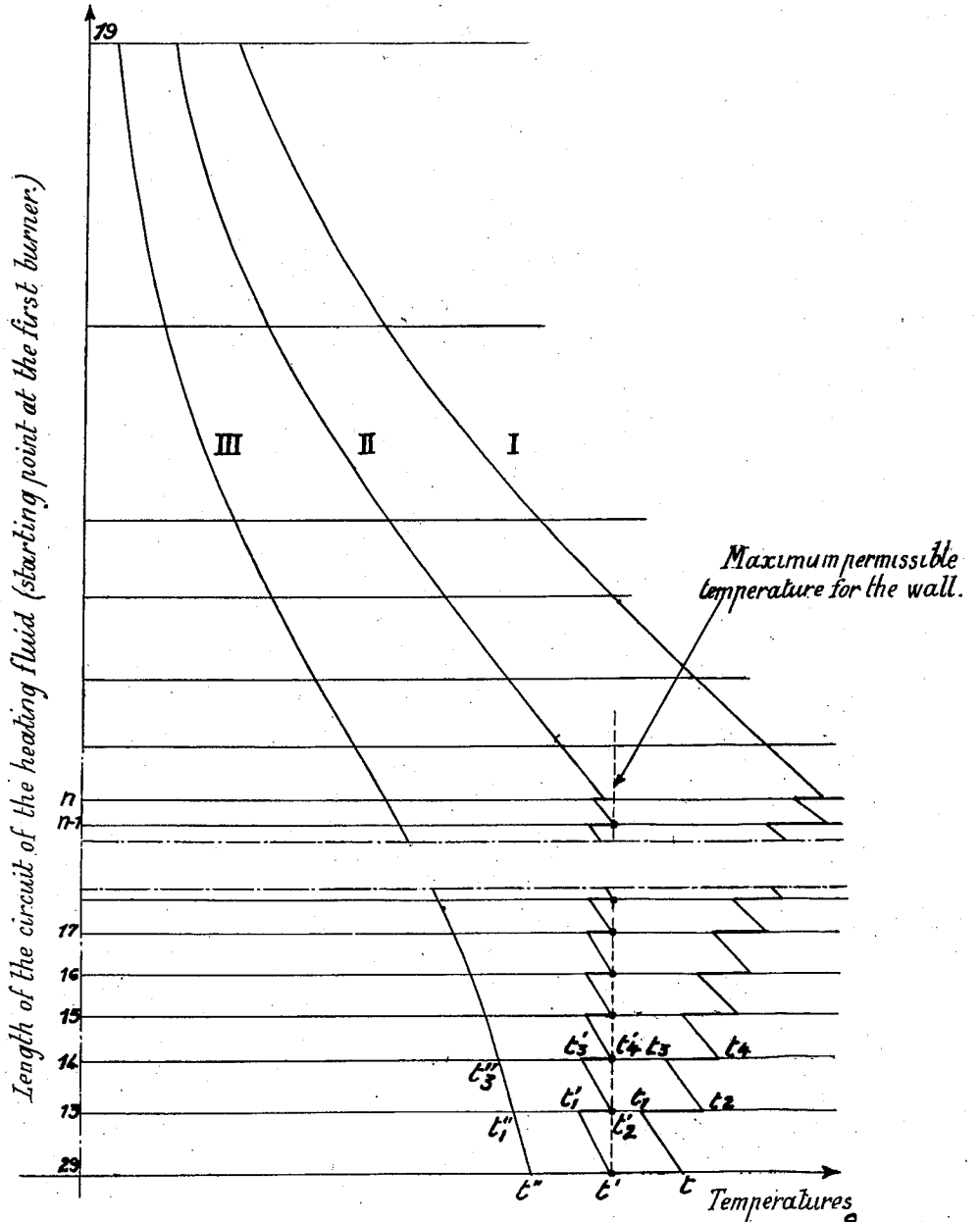
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Fig. 2



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PROGRESSIVE FUEL COMBUSTION FLUID HEATING APPARATUS AND CONTROL MEANS THEREFOR

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fig. 3

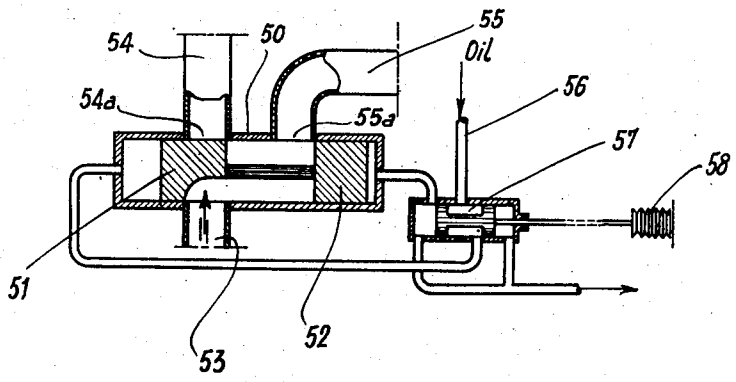
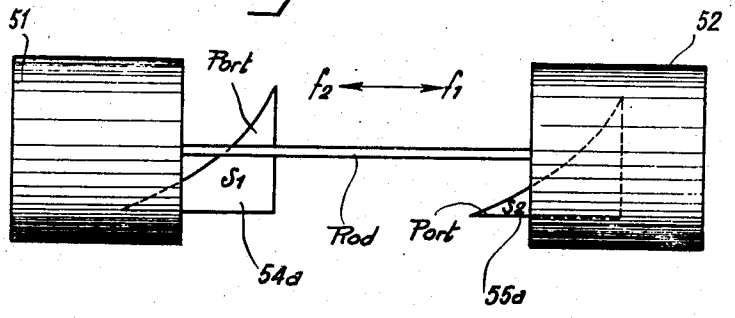


fig. 4



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Patented July 28, 1953 2,646,790

UNITED STATES PATENT OFFICE

2,646,790

PROGRESSIVE FUEL COMBUSTION FLUID HEATING APPARATUS AND CONTROL MEANS THEREFOR

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Application January 31, 1949, Serial No. 73,853
In France February 5, 1948

3 Claims. (Cl. 126—99)

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In many heat apparatuses wherein a fuel is burnt in a combustion supporting agent, the combustion must be regulated so as to obtain predetermined temperatures:

a. Either between two given limits for obtaining certain physico-chemical results, which is the case for example in certain heat treatments;

b. Or below a limit corresponding to the maximum temperature that can be supported by certain materials used in the construction of the heat-treating appliances (refractory bricks and products, metals and alloys, etc.).

Numerous known means make it possible to remain below the desired limits including:

1. Combustion with an excess of air, which is the most usual method.

2. Re-injection of a part of the smoke.

3. Addition of inert gases to the combustion products.

Although it is true that the methods hereinbefore mentioned enable the desired limits to be obtained for the temperature, they do not obviate the drawback that the temperature constantly decreases with the distance from the burner, either owing to the normal use of the heat for the purposes provided (heating, vaporisation, etc.), or owing to the use of one of the methods of regulation hereinbefore mentioned.

The present invention has for its object to provide a method which makes it possible to obtain, in an enclosure or in a circuit of a fluid, a predetermined temperature law which is below the theoretical temperature of combustion of the fuel used and according to which one of the substances (combustion supporting agent or fuel) is introduced at one point of said enclosure, whereas the other substance is introduced by successive fractions at various points spaced along said enclosure or said circuit, effecting successive dosed combustions at the various points of introduction, the spacing of said points and the dosing of the fractions introduced being determined in such a manner that the mean temperature along the circuit obeys the desired law.

The points of introduction may be as close together as desired and at the limit a continuous injection may be reached along the enclosure or the circuit of the fluids.

The invention covers the various applications and embodiments of this method.

Amongst such applications mention may be made of heat exchangers as being particularly interesting.

It is known that these apparatus are intended to transfer heat contained in a first fluid or

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heating fluid to a second fluid or heated fluid. These fluids flow in general in their own circuits, the circuit or circuits of the heating fluid being separated by one or more fluid-tight walls from the circuit or circuits of the heated fluid.

All the known heat exchangers and more particularly metal heat exchangers are limited in their field of action by the properties of the materials of which they are constructed, as regards the maximum temperatures that can be developed. This is the case in particular when the heat of the heating fluid is obtained by combustion, since the temperature reached as a result of the combustion of a perfect mixture of combustion supporting agent and fuel is in general higher than the maximum temperature compatible with the satisfactory behaviour of the materials, particularly in the case of metals.

This difficulty has been overcome heretofore by lowering the temperature by the known means hereinbefore mentioned and the drawbacks which have been indicated were encountered.

If applied to heat exchangers, the method according to the invention enables in particular, the temperature of the heat exchange surface to be kept constant, at any rate over a certain length of said surface, and equal to the critical temperature which has been set, taking into account the nature of the materials used and the desired margin of safety.

In the ensuing description made with reference to the accompanying drawing which is given by way of example, the nature of the invention will be explained by considering the particular case of a temperature exchanger, but without this in any way limiting the scope of the applications of the invention.

Fig. 1 is a diagrammatic sectional view of an embodiment of a heat exchanger according to the invention.

Fig. 2 is a diagram of one of the temperature laws that can be obtained.

Fig. 3 is a diagrammatic section of a distributor.

Fig. 4 is a diagrammatic view illustrating the working of such a distributor.

In the embodiment of the heat exchanger shown in Fig. 1, which comprises two separate bodies I and II, the fluid to be heated is supplied to a first distribution box 2 through the pipe 1, passes through the heat exchange nest 3 of the heat exchanger body II (formed by tubes or surfaces of any shapes), opens into the manifold box 4 and, through the pipe 5, reaches a second distribution box 6, passes through the nest 7

of the heat exchanger body I, opens into the manifold box 8 and escapes at 9. The arrangement of the two heat exchanger bodies I and II is obviously only an example and only a single body might exist with a single nest of tubes of the desired length or several bodies and several nests.

The necessary heat is supplied by a gaseous fuel, the total quantity of which is regulated by the cock 21 and is then distributed between the burner 12 and the first furnace 29 and the successive burners 13, 14 . . . $n-1$, n, $n+1$ . . . $n+m$. The total quantity of combustion supporting agent, which is calculated so as to obtain any desired final combustion which is more or less oxidizing, reducing or perfect, is regulated by the cock 28 and is admitted in bulk through the pipe 10 to the first furnace 29.

The heating fluid, which is itself heated by the successive combustions at 12, 13, 14, 15 . . . $n-1$, n, until complete or substantially complete combustion is obtained, flows outside the heat exchange nest 7, passes from the heat exchanger body I to the body II through the pipe 18, flows through the body II outside the heat exchange nest 3 and finally escapes at 19.

The circuits of the fluids could be permuted; the heated fluid flowing outside the nest of tubes, the heating fluid inside. In this case, the intermediate furnaces would be formed either by intermediate boxes between two successive sections of the nest, or by any other device enabling the dosed fluid to be supplied to the suitable points inside the elements of the nest.

The number of burners should be sufficient to enable all the fuel to be burnt corresponding to the maximum rate of operation of the apparatus. The fluid, combustion supporting agent or fuel, is distributed by priority to the furnaces in the normal order 12, 13 . . . n, . . . $n+m$. At a lower rate of operation than the maximum rate, a number of the last furnaces are inoperative.

Owing to the partial and successive introductions of the fuel into the mass of combustion supporting agent introduced at 10, to the suitable spacing of the points of introduction of the fuel fractions along the path of the heating fluid through the heat exchanger, and finally to the dosing of the various fuel fractions introduced at said points, it is possible to obtain, instead of the sudden, localised and in general excessive rise of temperature which occurs when a perfect mixture of fuel and combustion supporting agent is burnt all at once, any desired law of variation of the temperature between the beginning 29 of the path of the heating fluid and any desired point of said path, while the drawbacks of the palliatives heretofore used are avoided since it is finally possible to obtain a complete combustion with a total consumption of the combustion supporting agent. Naturally, the temperature will be lower at all the points than the theoretical temperature of combustion which is an ideal maximum. The mean value of the temperature along the path of the heating fluid may even be lower than the ignition temperature, because although it is in fact higher than that temperature at the nozzle of each burner, a suitable spacing of the burners and the dilution which takes place between the combustions gases of each burner and the mass of heating fluid, may reduce the temperature of the fluid flowing from one burner to the other and finally produce a mean temperature which is lower than the ignition temperature. In this case, it is prudent to provide, near each burner, a lighting device such as a small independent burner, an electric lighter, etc.

By spacing the burners and adjusting the quantity of fuel introduced into each burner, the means are therefore provided for obtaining various temperature laws along the path of the heating fluid.

As a first example of an advantageous temperature law, mention may be made of the one wherein the temperature law, mention may be made of the one wherein the temperature of the material forming the heat exchange system is kept over a certain length of said system at the maximum value compatible with the properties of said material. This law is eminently favourable for reducing the area of the heat exchange system since the difference of temperatures between the heating and heated fluids is thus raised to a maximum value at each point of the path. If the proportions of combustion supporting agent and fuel are adjusted so as to obtain a perfect combustion, the volume of smoke will thus be reduced to a minimum. In this manner it is possible to obtain a heat exchanger which is much more efficient than any of these heretofore known.

The diagram shown in Fig. 2 illustrates the practical embodiment of such a law. In this diagram, the temperatures are plotted as abscissae and the lengths of travel of the heating fluid are plotted as ordinates; the origin being on a level with the first burner 12. The curve I represents the temperature variation of the heating fluid, the curve II the temperature variation of the heat exchange wall (wall of the tubes) and the curve III the temperature variation of the heated fluid, it being assumed for the sake of simplification that the temperature of the heat exchange wall is equal to the arithmetical average of the temperature of the heating and heated fluids. At 29, i. e. on a level with the first burner, the temperatures are respectively represented by the points t, t', t'' for the heating fluid, the wall and the heated fluid. Between the first burner 12 and the next burner 13, the temperature of the heating fluid falls from t to t_1, that of the wall from the value t' (assumed to be the maximum permissible temperature for the material of the wall) to t'_1, while the temperature of the heated fluid which flows in the opposite direction to the heating fluid changes from t''_1 to t''.

At the burner 13 the partial injection of fuel releases a further quantity of latent heat and the temperature of the heating fluid rises from t_1 to t_2, which causes the temperature of the wall to rise from t'_1 to t'_2. The quantity of fuel injected at the burner 13 is so calculated that the temperature t'_2 is equal to t', i. e. is always equal to the maximum permissible temperature for the material forming the wall etc.

Similar phenomena occur up to the level of the penultimate operative burner $n-1$. At the level of the last operative burner n the heat corresponding to the residual fuel injected is not sufficient to increase the temperature of the wall to the maximum permissible value. The jump of temperature of the heating fluid is slightly less high than previously. From this point where combustion is complete, everything takes place as in the heretofore known apparatus, the temperature of the heating fluid continuously decreases until the instant when it is exhausted which corresponds to the ordinate 19, the temperature of the heat exchange wall likewise continuously decreases up to the beginning of

the nest of tubes 3 of the heat exchanger body II, finally the temperature of the heated fluid flowing in the opposite direction gradually increases from its value at the inlet of the box 2. The figurative diagram is obviously theoretical and does not quite correspond to reality. The variations of temperature of the heating fluid and of the wall, which are shown in the form of saw teeth are in reality more rounded off and are in the form of more or less undulating curves.

The diagram shows the increase in the temperature differences between the heating fluid and the heated fluid as from the first burner. This corresponds to parallel increases in the heat exchanges since such exchanges are themselves proportional to the temperature difference, whence it ensues that, for equal efficiency to the known heat exchangers, there is a substantial decrease of the heat exchange surface, or conversely, a substantial increase in the efficiency for equal heat exchange surfaces.

The invention also makes it possible to obtain that the heated fluid comes out at a temperature which is only slightly lower than that of the heating fluid at the first burner, without the necessary development of the heat exchange surfaces being prohibitive as regards cost of manufacture.

In industrial apparatus the automatic regulation of the ratio

$$\frac{\text{fuel}}{\text{combustion supporting agent}}$$

at the various burners can be obtained by known electric, mechanical, electro-mechanical, etc. means acting on cocks 20 and 21 mounted on the pipes 10 and 11 which supply the combustion supporting agent and the total fuel. The initial impulse of this automatic regulation may be placed under the control either of the output of heated fluid, measured for example by a Pitot tube or a Venturi tube placed at the inlet of the heated fluid to the box 2, or of the temperature of the heated fluid, measured by an adjustable thermostat at the outlet of the box 8, or of a combination of both of these factors, or finally of any other factor according to the object which it is desired to obtain. Distributors for the partial regulation of the fuel D_{12}, D_{13}, D_{14} . . . D_n . . . D_{n+m} are arranged between the pipe 11 and each burner, said distributors being individually controlled according to the temperature law which it is desired to obtain, by means of thermostats arranged on the heat exchange wall at the level of the successive burners 12, 13, 14, 18 . . . $n-1$, n . . . $n+m$ as described below. Particular arrangements may be made for the safety of operation of the apparatus in case of sudden variations of the output of heated fluid. In particular, when such output suddenly falls below a predetermined value, it is necessary on the one hand instantly to reduce or almost stop the flow of fuel by means of a special cock 21a, which may also coincide with the cock 21, and on the other hand to ensure the continuity of the flow of the heated fluid in order to remove part of the heat stored in the heat exchanger and thus lower the temperature of the apparatus below the maximum temperature which was predetermined according to the nature of the materials.

According to Figs. 3 and 4, each distributor D_{12}, D_{13} . . . D_{n+m} comprises in a cylinder 50 a movable system with two pistons 51, 52 which are secured to one another and which form a slide-valve controlling three ports, viz a port 53 through which is supplied the fluid coming from the previous distributor, a port 54 through which flows the fluid going to the next distributor, and finally a port 55 connected to the burner which corresponds to the distributor under consideration. In this manner, one distributor receives the fluid which has not been consumed in the previous furnace and distributes it between its own furnace and the following ones in such a manner that the temperature of its own furnace is raised to the desired value. The position of the distributor, which is shown in Fig. 3, corresponds to the case in which the rate of flow of fluid received at 53 is of just sufficient value to enable the corresponding furnace to give the desired quantity of heat or is less than that value. In this case as shown, the port 54 supplying the next distributor is closed, said distributor therefore receiving nothing and its burner being extinguished, while the port 55 supplying the burner of the distributor shown is fully open. If, on the other hand, the quantity of fluid which is supplied at 53 is larger than is suitable for the distributor in question, the port 55 is closed more or less while the port 54 is correspondingly opened. The distributors are therefore successively actuated in the order D_{12}, D_{13} . . . D_{n+m-1}. This drive may be effected by servo-motors of any type; mechanical, electric, hydraulic, etc., placed under the control of one or more instruments measuring the temperature which it is desired to maintain in the successive furnaces 12, 13, $n+m-1$ or in certain members heated by furnaces. Fig. 3 shows an example in which pressure oil is supplied through an auxiliary distributor 57 to one or the other of the pistons 51, 52. The movable slide-valve of said distributor 57 is connected to a thermostat 58 which detects for example the temperature of the nest of tubes of the heat exchanger in the corresponding furnace. In this embodiment, it has been assumed, as hereinbefore stated, that at the maximum rate of operation of the heat exchanger, the temperature of the last furnace $n+m$ is never raised to the value set as a maximum in the previous furnaces, since the heat that remains to be evolved in this last furnace is insufficient. Consequently, at the maximum rate of operation of the heat exchanger, the last distributor D_{n+m-1} supplies to the last furnace $n+m$ the remainder of the fuel which, by combining with the remaining combustion supporting agent present in the heating fluid, completes the combustion.

For the sake of safety, the thermostat located at the last furnace $n+m$ may act to decrease, either directly or indirectly by means of the combustion supporting agent, the total supply of fuel if, for an accidental reason, the predetermined maximum temperature is exceeded.

The shape of the ports 54a and 55a of the distributor at the beginning of the pipes 54 and 55 may be so determined that the elemental movement of the movable system 51, 52 through a small length ΔL, corresponding to a small variation Δt of the temperature t, produces small variations Δs_1, Δs_2 respectively of the uncovered areas s_1, s_2 of the ports 54a and 55a, in such a manner that the ratios

$$\frac{\Delta s_1}{\Delta L . s_1}$$

and

$$\frac{\Delta s_2}{\Delta L . s_2}$$

equal the product of ΔL and a constant. It is easy to show by calculation that such a shape corresponds to an exponential variation of the area relatively to the displacement of the movable system 51, 52. The regulating action of the member 52 will thus have a constant relative value whatever the momentary value of the temperature *t*. The actual shape given to the ports in practice will be determined by approximation. In the arrangement shown in Fig. 4 the ports 54*a* and 55*a* are identical in shape and the distance between the pistons 51, 52 is equal to the distance between corresponding points of the ports, in order that any variation of cross-section of one is compensated by an equal and opposite variation of the other.

A second example of a temperature law that can be obtained according to the invention is that of maintaining the heating fluid, until the latent heat that can be evolved by combustion is exhausted, at a constant temperature equal to the maximum value which is compatible with the materials used in the construction of the heat exchanger. In this case, the regulation of the inlets of fuel by the cocks distributors may be controlled by thermostats placed in the heating fluid at the level of the various burners 12, 13 . . . *n* . . . *n*+*m*, in such a manner that the temperature of the heating fluid is kept in each of these proportionally operative furnaces, at the maximum value that has been set. This law gives complete safety for the working of a heat exchanger wherein the heat exchange system and the jacket that insulates the heat exchanger from the external medium are of the same nature and are in direct contact with the heating fluid.

In this case, the outer jacket is raised to the maximum permissible temperature throughout the entire path of the spaced combustion, whereas the temperature of the walls of the heat exchange system constantly decreases as it is further away from the first burner by the cooling action of the heated fluid flowing in the opposite direction.

It will be understood what a great advantage it is in this case to protect by means of insulating and refractory materials, the outer jacket from the action of the temperature of the heating fluid, so as to enable said jacket to be heated to increasing temperatures as from the first burner until the latent heat is exhausted, so that the temperature of the walls of the heat exchange system is kept at the maximum compatible with the nature of the materials of which it is constructed. In this manner, the particular temperature law hereinbefore explained will be obtained.

It is advantageous to provide a baffle device such as 30, 31 . . . 45 enabling the heating fluid to effect a flow at right angles to the tubes of the nest, thereby increasing the heat exchange coefficient.

According to the length of such baffles, it is possible to obtain two types of heat exchangers:

One according to the heat exchange body I which is located on the left of Fig. 1 and wherein the baffles extent through all the tubes of the nest, the reversal of the direction of flow of the heating fluid being effected outside said nest and if desired outside the partial combustion chambers corresponding to the various burners:

The other, according to the heat exchanger body II located on the right of Fig. 1 and where-

in the baffles do not extend right through the nest of tubes; the changes of direction of the fluid are in this case effected in the regions of the nest, which enables the transverse dimension to be reduced but slightly decreases the heat exchange coefficient.

It is moreover obvious that numerous modifications could be made in the embodiment which has been described. Instead of having two heat exchange bodies with a change of direction of the fluids of 180° from one another, it would be possible to have a single body with continuous nest of tubes from end to end. The shape of the heat exchange system and the distribution of the spaced furnaces will depend on the conditions of manufacture which will be preponderant, maximum heat efficiency, minimum bulk, etc.

Instead of introducing all the combustion supporting agent at one point and the fuel at spaced points, it is possible to use the reverse arrangement, i. e. introduce all the fuel at once and space the introductions of combustion supporting agent. The number of injection points of the combustion supporting agent or of the fuel and also the relative position of the spaced furnaces or of the first burner or of both these groups of members relatively to the heat exchange system, may be modified.

It is possible to increase the heat exchange coefficient by causing the heating and heated fluid, or only one of them, to flow at pressure.

The heat exchangers described have many applications. Such heat exchangers, if made of metal, can in particular replace the air-heaters or Cowpers which are at present used in blast-furnace plant and which are generally made of brick. In this case, the fuel may be blast-furnace gas.

The substances used in the method of combustion according to the invention may be in the solid, liquid or gaseous state since the invention is applicable to all such substances, including non-powdered solids.

What I claim is:

1. In a heat apparatus including a gas-tight wall delimiting an elongated closed chamber wherein a fuel is burnt in a combustive substance, the combination comprising: means adapted to introduce in bulk either of said substances through said wall at a predetermined point of said chamber; means providing an outlet for products of combustion from said chamber at a point spaced along the length of the chamber from the first-mentioned point; pipe means conducting the other substance; a plurality of spaced channels provided along said chamber and each connected to said pipe means, to supply said last named substance to said chamber by successive fractions from said pipe means, each of said channels passing through said wall and opening directly into said chamber at points disposed in a series arranged longitudinally of said chamber between the first and the second mentioned points, whereby separate combustions take place in successive zones of said chamber near the exit of the various channels; distributors arranged at the connection points between said pipe means and each of said channels, said distributors having each a passage connected to the upstream part of said pipe means and ports connected respectively to the downstream part of said pipe means and to the corresponding channel and a movable member controlling the cross sections of said ports and adapted to vary said cross sections respectively in reverse relation, and tem-

perature sensitive devices distributed along said chamber each operatively connected to the movable member of one of said distributors for individual control of the same.

2. In a heat exchanger for heating fluids, including a gas-tight wall delimiting an elongated closed chamber wherein a fuel is burnt in a combustive substance the combination comprising: means adapted to introduce in bulk either of said substances through said wall at a predetermined point of said chamber; means providing an outlet for products of combustion from said chamber at a point spaced along the length of the chamber from the first mentioned point; pipe means conducting the other substance; a plurality of spaced channels provided along said chamber, each of said channels passing through said wall and opening directly into said chamber at points disposed in a series arranged longitudinally of said chamber between the first and the second-mentioned points, each of said channels being connected to said pipe means to supply said last-named substance to said chamber by successive fractions from said pipe means, whereby separate combustions take place in successive zones of said chamber near the exit of the various channels, at least a heat conducting wall separating a fluid to be heated from the flame and gases in said successive combustion zones; distributors arranged at the connection points between said pipe means and each of said channels, said distributors having each a passage connected to the upstream part of said pipe means and ports connected respectively to the downstream part of said pipe means and to the corresponding channel and a movable member controlling the cross sections of said ports, and adapted to vary said cross-sections respectively in reverse relation; and temperature sensitive devices distributed along said heat conducting wall, each operatively connected to the movable member of one of said distributors for individual control of the same.

3. The combination of claim 1 wherein the cross-sections of said ports have such a shape that when said movable member is in any position, wherein it uncovers a part of the cross-section of each port, the ratios

$$\frac{\Delta s_1}{\Delta L . s_1} = \text{constant}$$

and

$$\frac{\Delta s_2}{\Delta L . s_2} = \text{constant}$$

are satisfied, s_1 and s_2 being the respective parts of the cross-sections of the ports uncovered by said movable member, Δs_1 and Δs_2 being the algebraic variations of said parts for a small algebraic displacement ΔL of said movable member.

LÉONCE M. REYGAGNE.

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