Feb. 3, 1942. L. BRADLEY 2,272,108

REGENERATIVE STOVE

Filed Jan. 19, 1940 4 Sheets-Sheet 1

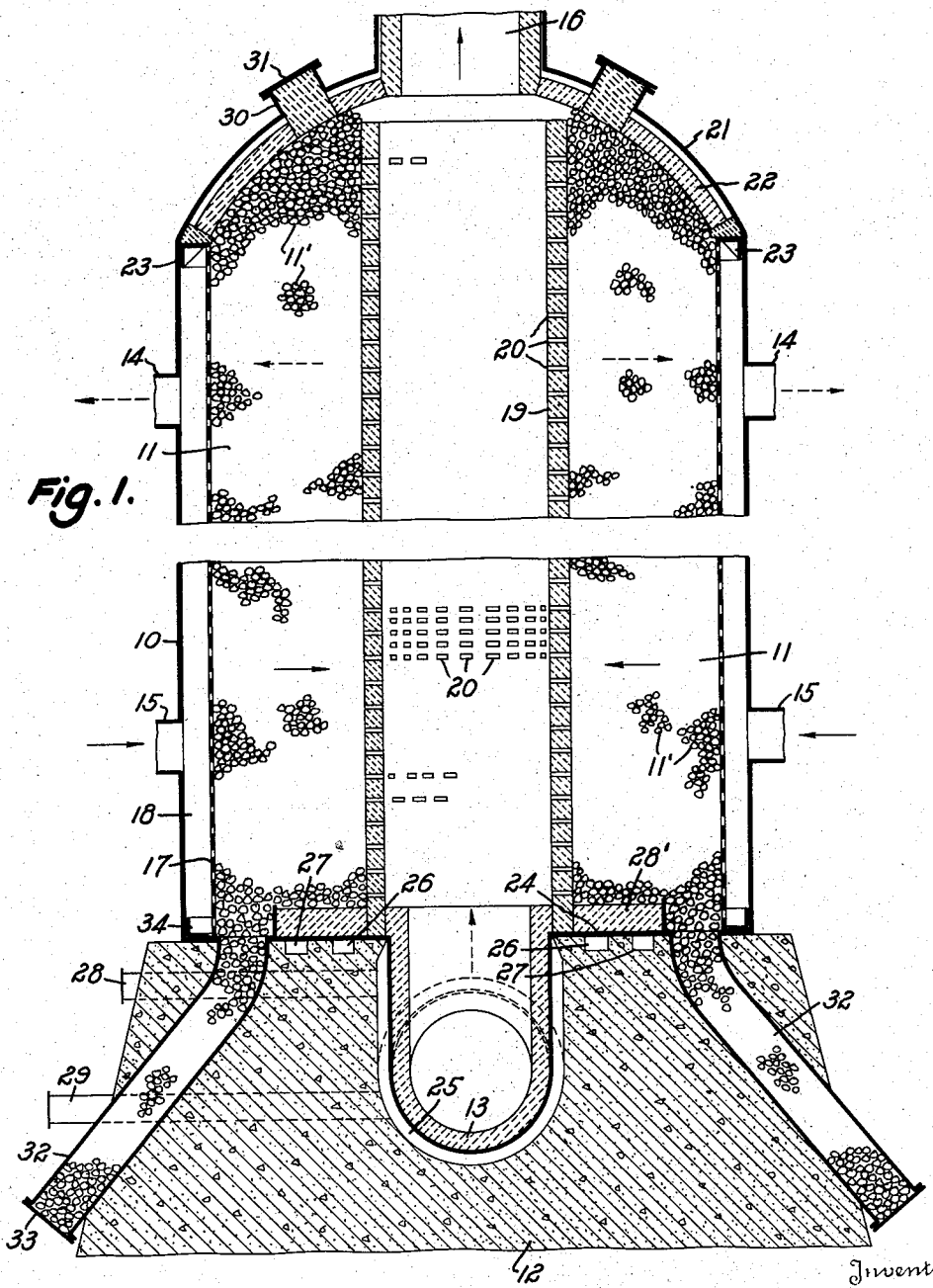


Fig. 1.

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Fig. 2.

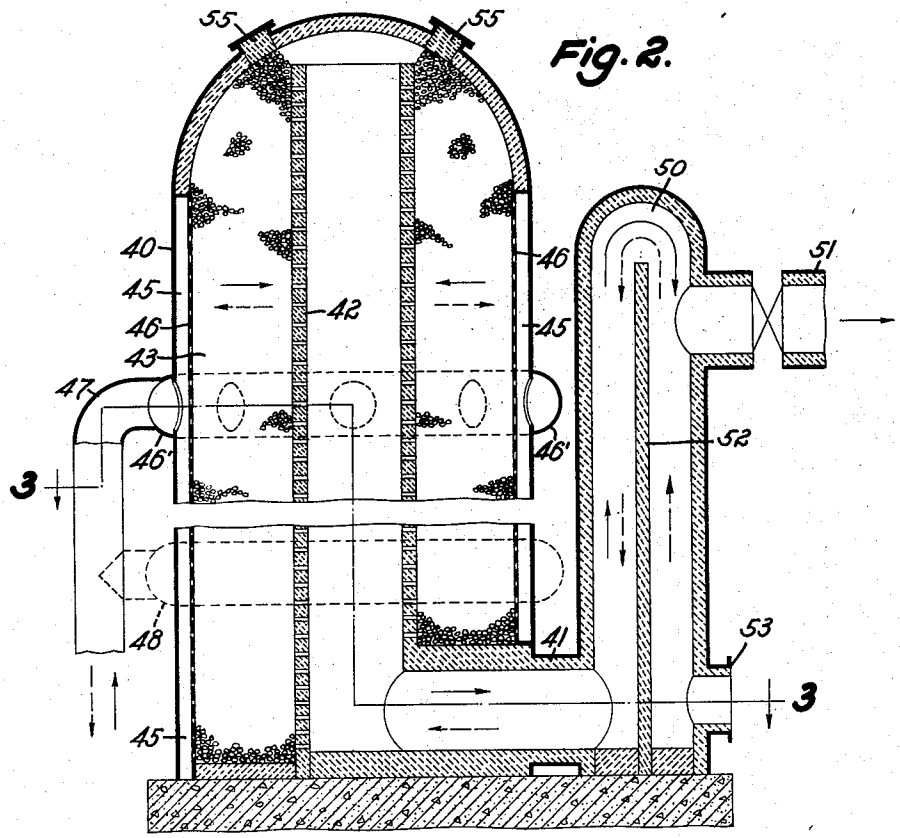
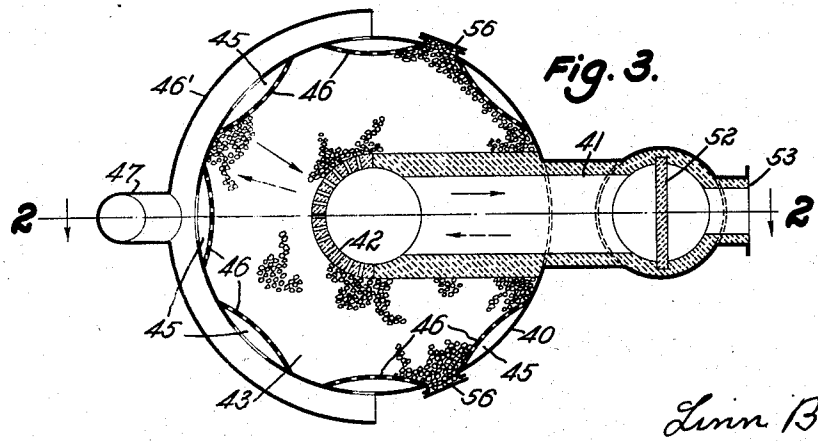


Fig. 3.



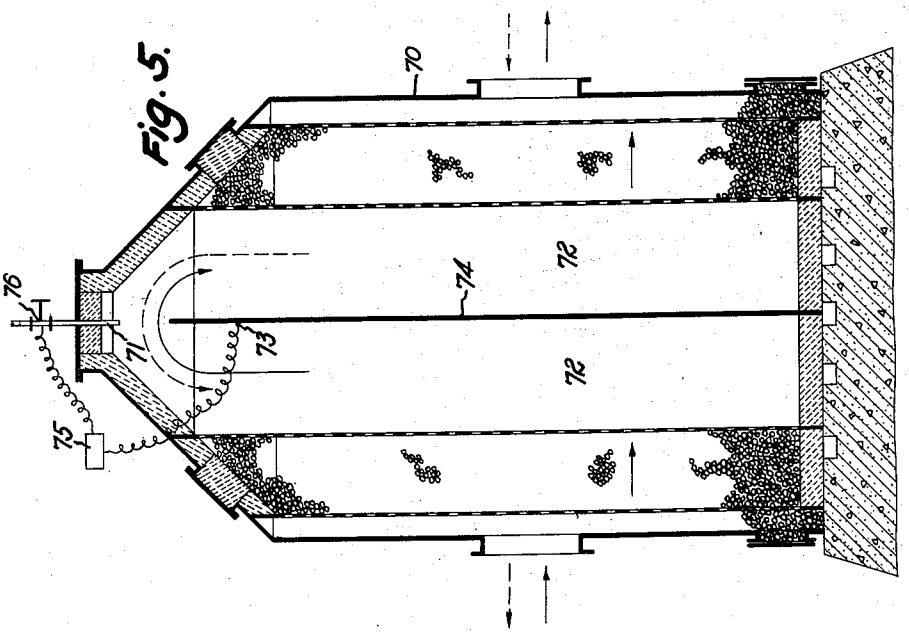
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REGENERATIVE STOVE

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Fig. 5.



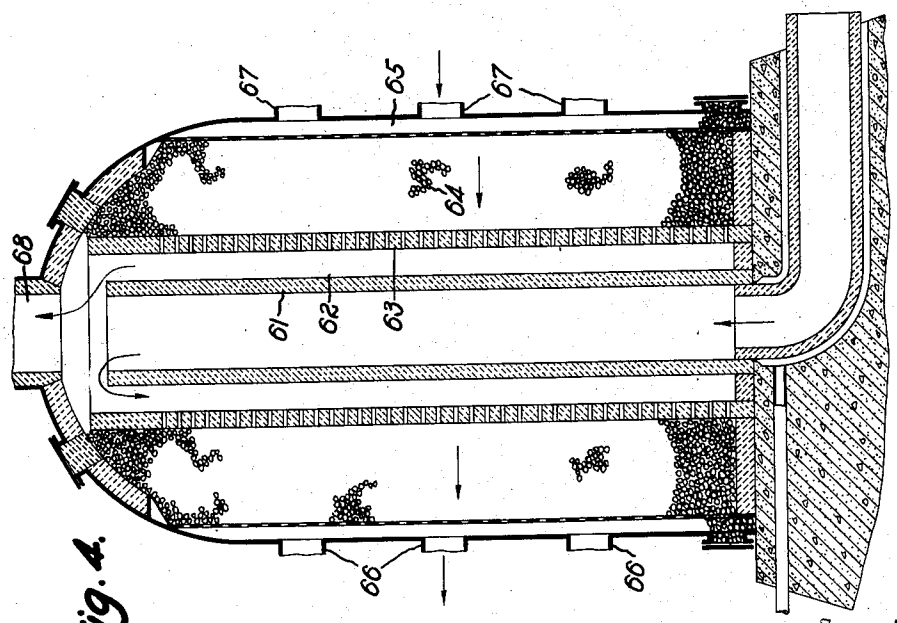


Fig. 4.

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REGENERATIVE STOVE

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Fig. 6.

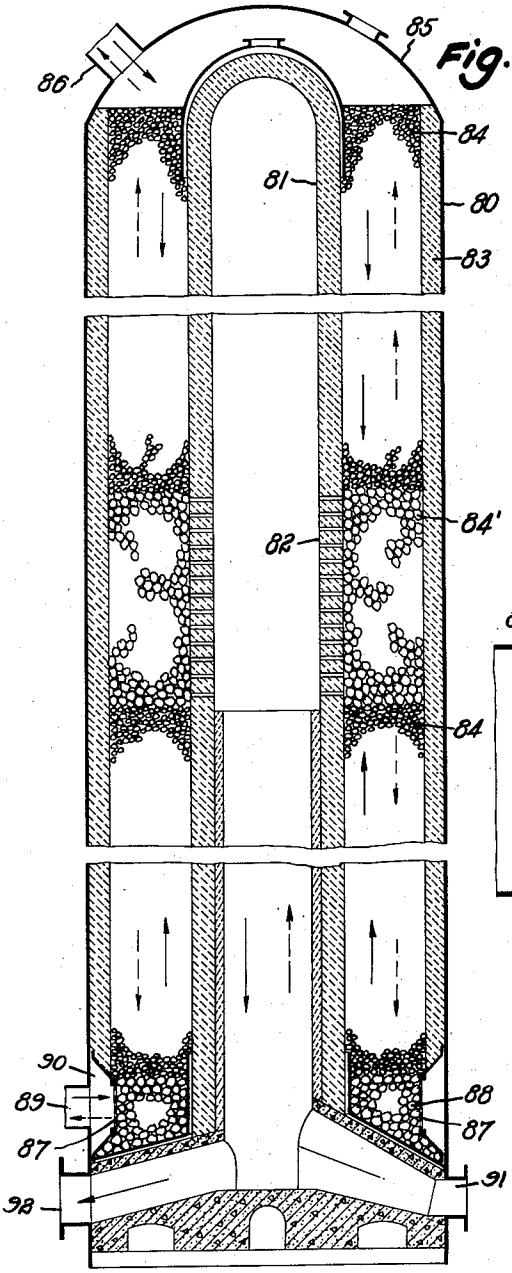
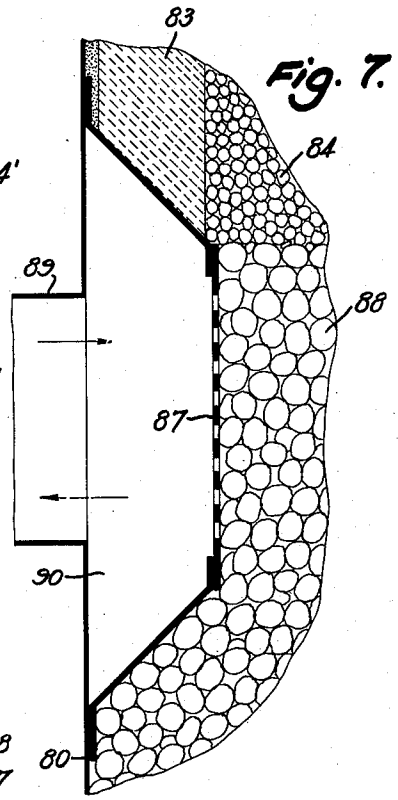


Fig. 7.



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Patented Feb. 3, 1942 2,272,108

UNITED STATES PATENT OFFICE

2,272,108

REGENERATIVE STOVE

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Application January 19, 1940, Serial No. 314,706

19 Claims. (Cl. 263—19)

This invention relates to heat exchangers of the type commonly referred to as regenerative heat exchangers, in which a stream of relatively hot gas is passed through a heat-exchange mass during one period, to store up heat in the mass, and a stream of relatively cool gas is passed through the mass during a subsequent period, to recapture heat thus stored up. With heat exchangers of this type, it is customary to have these periods alternately recur and to provide at least two heat-exchange masses in order that while heat is being stored up in one, heat is being recaptured from the other. In some industries such heat exchangers are termed stoves.

One of the objects of the present invention is to provide a heat exchanger which can serve as a hot blast stove for iron blast furnaces, the stove being comparatively low in first cost and yet suitable for operation at a comparatively high thermal efficiency.

Another object is to provide a heat-exchange mass which comprises a rather large volume of refractory or other solids having a comparatively large surface per pound, and yet does not occupy excessive ground space.

Another object is to provide a heat-exchange mass the whole or a portion of which can readily be placed in and removed from the shell or housing of the heat exchanger.

Another object is to provide a heat-exchange mass comprising refractory or other solids having a comparatively large surface per pound and yet exhibiting a low to moderate resistance to flow of a stream of gas through the same.

Another object is to utilize steel sheels of existing hot blast stoves associated with iron blast furnaces in such a way as to provide economically hot blast stoves of high thermal efficiency, with readily replaceable refractory or other solids constituting the heat-exchange mass, which mass exhibits a low to moderate resistance to the flow of a stream of gas passing through it.

Another object is to provide a heat-exchange mass of such composition, shape and dimensions that heat may be transferred at relatively high rates per square foot of surface while a stream of gas is passing through the high-temperature portions of the heat-exchange mass.

Other objects will appear from the description and explanation given hereinafter, particularly in connection with the accompanying drawings.

While the invention is applicable to heat exchangers for a variety of services, it is especially advantageous with hot blast stoves for iron blast furnaces. Hence, it will be more particularly described and explained in that connection.

It is desirable to utilize clean fuel and air and to avoid excessive temperatures such as might soften or otherwise damage the refractory or other solids constituting the heat-exchange masses of the stoves.

Prior to the time when comparatively clean blast furnace gas became available as fuel for hot blast stoves serving iron blast furnaces, it was customary to construct their heat-exchange masses of checker brick so arranged as to provide large openings or ducts for passage of streams of dust-laden products of combustion. Comparatively clean blast furnace gas having now become commonly available, heat-exchange masses of hot blast stoves have been undergoing changes in design. Several special forms of refractory brick or inserts are now on the market, some of them being of such shape and dimensions that the individual gas passageways in a heat-exchange mass constructed therewith are quite small. The total surface of refractory solids in the heat-exchange masses exposed to the streams of gas has been recently increased in some stoves to such an extent that the temperatures of the gas passing from the stoves to the chimney have been substantially lowered, consequently their thermal efficiency is quite high. Also, the ratio of refractory surface to weight of refractory solids in the heat-exchange masses of some modern stoves has been improved appreciably.

There are a number of objections to the modern hot blast stoves, resulting from the developments outlined, which the present invention either overcomes or decreases. One of these is the large investment involved. Another is the cost of labor and material for effecting replacements of refractory solids. Because of the cost involved in constructing the heat-exchange masses and in effecting replacements therein, the hot blast is frequently held down below its optimum temperature. Moreover, partly because of the high cost of refractories, per square foot of surface and per pound, in hot blast stoves of modern design, and partly because the rate at which heat can be stored up in one of such heat-exchange masses is in part determined by the total amount of such surface therein and in part by the rate of heat transfer per square foot of such surface, it is customary to equip each iron blast furnace with at least three hot blast stoves, so that not less than two will be heating up, while one is being cooled down by the wind en-

route to the furnace. Furthermore, the temperature distributions within their heat-exchange masses, both while on gas and while on wind, and the drooping temperature of the heated air stream, are such that it is customary to by-pass relatively large volumes of cold blast immediately after a hot stove has been put on wind, and gradually to decrease these volumes until the stove is taken off wind. Consequently, the straight line temperature at which the hot blast can be maintained at the bustle pipe of the furnace often is far below the optimum level. Under present-day conditions, the comparatively broad or flat wave fronts in the heat-exchange masses of the stoves lead operators to endanger the refractory solids therein by supplying the products of combustion thereto at excessive temperatures when they desire to elevate their hot blast to abnormal temperatures in order to supply more heat to the furnace, and likewise to maintain such abnormal temperatures throughout a considerable period of time. Of course, where the furnace is equipped with modern stoves of superabundant capacity, thereby entailing an excessive investment in hot blast stoves, this danger is substantially lessened.

Some if not all of the foregoing objections to hot blast stoves of modern design, and also some others, may be decreased or even avoided by utilizing the present invention.

A heat exchanger or stove of this invention contains a heat-exchange mass made up of refractory solids formed into what may be termed an annular bed of pebbles. This bed of pebbles may be readily and advantageously provided, for example, by dropping these solids into space between two substantially concentric, perforate cylindrical walls. The volume of this space is so chosen that it will hold a weight of such solids not less than that sufficient to capture from a stream of gas and thus to store a desired quantity of heat during a chosen solids-heating period, and thereafter to surrender to another stream of gas a desired quantity of heat during a chosen solids-cooling period. The size of these solids is so chosen that the heat-exchange masses (beds of pebbles) present to the respective streams of gases a total surface not less than that sufficient to transfer heat at desired overall rates, respectively, throughout the solids-heating periods and the solids-cooling periods.

The diameters of the respective concentric perforate cylindrical walls may be so chosen that the radial distance through the bed of pebbles is sufficient substantially to prevent gas above a predetermined low temperature from passing through the outer perforate cylindrical wall near the termination of the solids-heating periods, and substantially to prevent gas below a predetermined high temperature from passing through the inner perforate cylindrical wall near the termination of the solids-cooling periods. However, by increasing the quantity of gas passed during any such solids-heating period, over and above the quantity for which the bed of pebbles is designed, gas hotter than the predetermined low temperature may be passed through the outer perforate cylindrical wall and by increasing the quantity of gas passed through the bed of pebbles during any such solids-cooling period, over and above the quantity for which the bed of pebbles is designed, gas cooler than the predetermined high temperature may be passed through the inner perforate cylindrical wall.

Since the velocity of the gases through the annular bed of pebbles is greatest near the inner perforate wall, and it is lowest near the outer perforate wall, partly because of the inherent differences in surface areas of these respective walls, and partly because the gases near the inner perforate wall are at a higher temperature than those near the outer perforate wall, the diameter and length of the inner perforate wall is chosen first, to the end that gas velocities in the high temperature region adjacent the inner wall shall be neither too high nor too low. This diameter and length having been chosen, and also having determined the volume of the annular bed between the two concentric perforate walls, the diameter and length of the outer perforate wall is determined accordingly.

The required volume of the annular pebble bed for any specific stove depends upon several factors such as the size and properties of the refractory or other solids available therefor. In this connection it should be kept in mind that a bed of spheres of small size has more total surface of solids per unit of mass and per cubic foot of bed than does a bed of spheres of large size.

When a stream of gas of uniform composition is at substantially a uniform pressure and portions thereof are at temperatures above the average, the hotter portions of the stream occupy more space per pound of gas than do the cooler portions. This being true when a stream of gas passes through a bed of pebbles of uniform size and shape, and the areas of planes through the bed normal to the direction taken by the stream, in the cool portion and the hot portion of the bed, respectively, are substantially equal, the gas velocities within the hot portion will exceed those within the cool portion. Moreover, the heat conductivity of refractory solids usually rises with increase in their temperature. Wherefore, the time-quantity rates at which heat can be exchanged between refractory solids and streams of gases sweeping their surfaces will tend to be at the maximum in the hottest portion of such a bed, this rate conveniently being referred to as B. t. u. per square foot of surface per hour per degree of temperature-difference between the surfaces of the solids and the gas in the immediate vicinity of these surfaces. Consequently, the temperature gradient in the bed of pebbles on the cooler side of the high temperature zone in such bed will be comparatively high or steep and the smaller the pebbles the steeper this temperature gradient. Steep temperature gradients in the region referred to are advantageous in that they facilitate delivering the heated stream of gas or blast at or near the entrant temperature of the heating gas, e. g. the products of combustion and they minimize the drooping temperature of the heated stream of gas, e. g. the hot blast for an iron blast furnace.

According to the invention a further improvement is made available by the annular bed of pebbles which has its hottest zones close to the inner perforate wall, the streams of gas being passed radially through the annular bed, a stream of hot products of combustion entering through the inner perforate wall and the resulting cooled stream leaving through the outer perforate wall, during the solids-heating period and a stream of cold blast entering through the outer perforate wall and the resulting heated stream leaving through the inner perforate wall during the subsequent solids-cooling period.

One of the advantages of this radial flow annular bed of rather small pebbles pertains to the comparatively long period during which a stream of heated blast can be delivered at temperatures approximating that shortly after a heated stove first is placed on wind or blast, thus facilitating the maintenance of high straight line temperature blast at the bustle pipe of the furnace. Hence, comparatively small volumes of cold blast need to be by-passed around the stove on wind or blast, particularly in case moderate entrant temperatures of the hot products of combustion were maintained while the stove was on gas, in order to avoid jeopardizing the refractories in the hottest zones of the heat-exchange mass. Another advantage pertains to the fact that a large mass of rather small pebbles may be utilized thereby providing a comparatively large amount of heat-exchange surface in a stove and yet without its heat-exchange mass exhibiting a high resistance to flow of gas passing through the same. Moreover, since these pebbles provide large surface per pound at a comparatively low cost and the radial flow annular bed exhibits rather low resistance to gas flow the invention affords a regenerative heat exchanger of high thermal efficiency at moderate cost and which minimizes the drooping-temperature characteristic of the heated stream of blast. An additional advantage is afforded by the invention in that comparatively little heat insulation is required. This will be apparent from reference to the accompanying drawings which illustrate a hot blast stove for an iron blast furnace, for it will be appreciated that the steel shell around the annular bed of pebbles always is at comparatively low temperatures, thus obviating need for insulating the same to protect it against gas at high temperatures. One more advantage relates to the feasibility of utilizing steel shells of existing stoves by removing the brick lining thereof, also the brickwork within the stove and thereafter installing the two perforate cylindrical walls and the annular bed of pebbles and by effecting such other structural alterations as may be needed.

Having cited certain objects of the invention and pointed out several advantages afforded by it the invention will be further disclosed and explained by the description of a specific example illustrative of one embodiment thereof in connection with the accompanying drawings.

In the drawings in which the apparatus of the invention is semi-diagrammatically illustrated:

Fig. 1 is an axial vertical section of a regenerative stove in accordance with the invention;

Fig. 2 is an axial vertical section of another embodiment of a regenerative stove in accordance with the invention;

Fig. 3 is a section on line 3—3 of Fig. 2;

Fig. 4 is an axial vertical section of a further embodiment of the invention;

Fig. 5 is an axial vertical section of a stove in accordance with the invention designed for use for deodorizing gases;

Fig. 6 is an axial vertical section of still another embodiment of the invention; and

Fig. 7 is an enlarged fragmentary section of the lower portion of Fig. 6 showing the gas distributing means.

In Fig. 1, 10 is a cylindrical steel shell supported upon a substantial masonary foundation 12 into which is built an inlet 13 for the hot combustion gas which results from burning clean blast furnace gas or other fuel in a burner (not shown). Outlets from shell 10 for the products of combustion are by pipes or flues 14. Also connected to shell 10 are inlets 15 for the air to be heated and an outlet 16 for the heated air is connected to the top of the shell. Within shell 10 and separated from it by concentric space 18 is a perforated cylinder 17 and inside cylinder 17 is a cylinder or flue 19 built of fire brick or other heat resisting material and having in the walls thereof perforations 20. The annular space 11 between cylinder 17 and flue 19 is filled with heat absorbing pieces 11' which may be quartz pebbles or other objects having the properties of readily absorbing heat and being resistant to disintegration or fusing by heat at the temperatures employed.

The dome shaped top 21 of shell 10 is lined with a dome 22 of fire brick and this is supported by a circular bracket or shelf 23 fastened to shell 10. Flue 19 extends almost to brick dome 22. The space 11 is filled with pebbles 11' until a considerable portion of dome 22 is in contact with the pebbles. A space 25 is left around hot gas inlet 13 and through this space, and through concentric channels 26 and 27 cold air entering through pipe 28 and leaving through pipe 29 is circulated to prevent the foundation from reaching undesirable temperatures because of heat supplied by the hot gases in flue 13. A floor 28' of heat resisting material is placed over the foundation around flue 13 where it joins flue 19 as a further precautionary measure against deterioration of the foundation and of the bottom plate 24 by heat.

The pebbles 11' are put into annular space 11 through openings 30 having closures 31. The pebbles are removed for cleaning or renewal through pipes or channels 32 projecting through foundation 12. Closures 33 are removed, in part, at least, when the pebbles are to be removed from space 11 and collected in a dump car, for instance.

Dome 21 can be bolted either in one piece or in segments to casing 10 but a connection less liable to leak is made by welding. If the dome is welded or riveted to the casing, the brick walls and perforated cylinders can be inserted in pieces through opening 16, as can the necessary scaffolding for assembling the pieces on the inside of the casing. Flue 19 is made up of heat resisting brick notched at the edges. The brick are laid with the notches in alignment which causes the wall of the finished flue to be perforate. The perforations are commonly slots with a cross section 1½ to 2½ inches high by about 8 inches wide, for example. Cylinder 17 is made of perforated steel plate. It is built of sections which may be separately introduced into shell 10 and then bolted together. Expansion joints, not shown, may be used to hold the sections together whereby springs permit a slight circumferential lengthening of the cylinder when the material in space 11 expands upon heating. But, in general, such joints have not been found necessary because the pebbles during the initial heating period undergo considerable change in position and expand into voids in the pebble mass left when the pebbles were dumped into place. The outer shell or casing 10 is made of steel plate of sufficient thickness to withstand the pressure and lift of the gases and the structural loads flues and the like, it carries. It is gas tight and imperforate except for the openings where flues are attached. The bottom 24 of shell 10 is made flat. This is possible because the weight of the

pebbles keeps the bottom down on the foundation and prevents it being dished by the pressure within the shell. Joint 34 formed where shell 10 meets bottom 24 is reinforced to take the stresses at these places.

The filling material for space 11 is made up of small pieces 11' which may have an average thickness or diameter as small as one inch or smaller or as large as four or five inches. Instead of using pebbles of rather uniform size throughout the annular bed, it is sometimes advantageous to use graded sizes. For example, pebbles about 2 to 2½ inches in diameter may be placed in the region extending about a foot or so outward from the inner perforate wall 19 and pebbles of gradually decreasing sizes may be placed in the other regions of the bed, the smallest size being in the region extending about a foot or so inward from the outer perforate wall 17. This places the smaller sizes in the regions where the gas velocities are relatively low and the hot zone in the bed extends farther away from the inner perforate wall. The smaller pebbles near the outer perforate wall effectively transfer heat at the relatively low temperatures and velocities partly because of their high ratio of surface to mass and partly because the maximum distance over which heat must be conducted within small pebbles is less than where large pebbles are involved.

It is unnecessary for the pebbles to be in the form of spheres. They may be somewhat egg-shape, such as pebbles or large gravel. Although desirable, it is not necessary that they have well-rounded corners. It is feasible to fill the space between the two cylindrical walls with broken firebrick or with other solids similar thereto. Particularly desirable are solids of proper size and shape obtained by dead burning low-silica dolomite or limestone at temperatures up to around 1900° C., thus substantially rendering the oxides chemically inert to the gases. It must be borne in mind, however, that dead burned materials are apt to be light in weight and have less heat capacity than heavier natural materials.

The invention will now be described as applied to the problem of heating an air blast for a blast furnace for smelting iron ore. Seventy thousand (70,000) cubic feet of air per minute, measured at 60° F. and 29.92" of mercury pressure, is to be heated from atmospheric temperature to 1800° F. Computations show that this can be done with a heat absorbing bed containing approximately 1,100,000 pounds of 1½ inch pebbles with a travel for the gases through the bed of about five feet. To provide such a bed the stove illustrated in Figure 1 can have an annular space 11 with an inside diameter of 10 feet, an outside diameter of 20 feet and a height of 50 feet. These dimensions will let the bed be placed in an existing blast furnace stove shell 23 feet in diameter from which the usual interior brick and fixtures have been removed. The overall height of the shell will be 55 to 60 feet. Space 18 will be 18 inches wide and flue 19 will be 7 feet inside diameter, assuming a wall thickness of the flue of 18 inches.

Using three stoves of the dimensions given above for one blast furnace, a schedule can be arranged with heating periods of 100 minutes alternating with on blast periods of 60 minutes. Allowing for heat losses, hot gases of combustion with a maximum temperature of 2200° F. will supply the required heat if put through the pebble bed at the rate of 185,200 c. f. m. To permit such volume of gases to enter the pebble bed through openings 20 in the wall of flue 19 at a velocity of, say, 10 feet per second, the total cross sectional area of the openings 20 is about one-third of the inside area of flue 19 and about one-fifth the area of the outside of the flue. The area of openings 20 can be changed to provide different velocities of the entering gas, and, of course, the smaller the openings the more effective they are for gas distribution, but at proportionally higher pressure drop.

The stove illustrated is operated very much as other stoves of the same general type and for the same purpose are operated. Because of the small spaces between the pebbles, the fuel burned should carry little or no suspended solids to coat the pebbles and so fill the spaces and reduce the area of the gas passages. Blast furnace gas which has been thoroughly cleaned, preferably with an electrical precipitator, before burning, is recommended. The hot combustion gas from the burner (not shown) but which may be positioned in, or connected to, flue 13 is forced by a fan or fans, (not shown) serving the burner through flue 13, into flue 19, through openings 20, radially through the bed of pebbles 11', through openings in cylinder 17 and into space 18. From space 18 the gases, now relatively cold, having given up sensible heat to the pebbles, are exhausted through outlet pipes 14. At the end of the heating period, the burner is shut down, the valves in pipes 13 and 14 closed and the valves in pipes 16 and 15 are opened.

It can readily be appreciated that the stove just described fulfills the objects of the invention and provides the advantages previously pointed out. Certain other embodiments of the invention will now be briefly described which also fulfill the objects mentioned, at least in part.

In Figs. 2 and 3 a construction is illustrated in which the gases entering and leaving the stove pass through a brick lined flue 41 in the side of shell 40 to and from central perforate brick flue 42. The gases passing radially through pebble mass 43 enter and leave spaces 45 which are formed between shell 40 and pebble supporting member 46. Member 46 is made by placing arch shaped members against the inside of shell 40 and having the edges of the several vertically extending arches join, or at least be adjacent each other, where the edges contact shell 40. The arches give pebble container 46 a scalloped shape and the concave surfaces leave spaces 45 as gas collecting spaces. This arched construction for enclosure 46 makes it, as supported by shell 40, very strong and it provides more space for pebbles than does the concentric shell design. A bustle pipe 46' communicates with spaces 45 and gases pass to and from the bustle pipe through flue 47. A second bustle pipe 48 may be used. No top outlet for the hot blast is required in this construction, the hot air being removed through flues 41, 50 and 51. Flue 50 is divided by partition 52 and the gas of combustion from the burner, (not shown), enters at 53. This arrangement of flues gives the hot gas an opportunity to mix and come to an even temperature before it enters the stove. Pebbles are introduced through inlets 55 and removed through outlets 56 in the side of shell 40 near the bottom.

Fig. 4 shows a stove with an added central flue 61. This is of heat resisting brick and is imperforate but open at both ends. The hot combustion gas enters the bottom of flue 61 and

passes upwardly through it. The hot gas then turns downwards and flows into the space 62 between imperforate flue 61 and perforate wall 63 and from space 62 flows through the wall 63, through the mass of pebbles 64 into space 65 and out pipes or flues 66. The flues can be arranged so that all air to be heated during the on blast period can enter from one side of the stove through pipes 67 and all combustion gas during the heating period can leave the stove from the other side through pipes 66. The heated blast collected in space 62 leaves by flue 68 at the top of the stove.

Fig. 5 shows a divided stove, really two stoves in one, which embodies radial flow and is particularly useful in deodorizing gases and for other purposes in which the gas temperatures are not very high and metal dividing walls, here illustrated by wall 74, and the like are used in its construction. The gas to be deodorized is switched back and forth as described in Cottrell Patent 2,121,733, the heat lost from the stove being made up by burner 71. In this stove, as in the radial flow stoves previously described, the coolest parts of the stove are at the exterior of the stove thereby permitting the use of an unlined steel shell 70 without undue heat losses. High temperature zones surge back and forth—outwardly from one side of central space 72 while inwardly towards the other and then the order is reversed. The construction shown provides good distribution of gas through the pebble bed, quick and efficient heat transfer, cheap and compact construction, and easy and cheap maintenance. Automatic heat controls can be used, to control burner 71. For instance, a thermocouple 73 sensing the temperature of the gases in the central zone 72 where the temperature is at or near the maximum can be connected to a relay 75 and the relay to a valve 76 controlling the supply of fuel to burner 71.

The stove illustrated in Figs. 6 and 7 comprises many of the advantageous features found in the stoves previously described although differing in some respects from those stoves. Positioned concentrically with outer vertical shell 80 is a central high temperature flue 81 with perforate section 82. Steel shell 80 is lined with fire brick and between this brick lining 83 and flue 81 are concentric beds of pebbles 84, 84, one below the perforate portion of flue 82 and one above that section. The pebbles adjacent the perforated section 82 of flue 81 are preferably of larger size than those in beds 84, 84, and this bed 84' of larger pebbles facilitates the entrance of the gases through section 82 and the distribution of the gas through the pebble beds 84, 84. The burner gases and air to be heated pass alternately upwards and downwards through pebble beds 84, 84. The air and other gases are always hot at section 82 but always at comparatively low temperatures at the extreme opposite upper and lower ends of the beds 84, 84. This permits the top or dome 85 of the shell 80 to be unlined and the space immediately thereunder to be used as a collecting space for cooled burner gas and as a distributing space for air at ambient temperatures. The cool gas leaves and enters by flues 86 and 89. The gas distributing means at the bottom may preferably be made up of a perforate circular steel structure 87 which retains a pebble bed 88 of large pebbles, say 5" in diameter as against 2½" to 3" pebbles for beds 84. A flue or pipe 89 is connected to annular space 90 within shell 80 and adjacent structure 87. The hot burner gas enters through brick lined flue 91 and the hot blast leaves through brick lined flue 92.

I claim:

1. A heat regenerator comprising an annular, vertically disposed bed of promiscuously deposited refractory heat conducting bodies, concentric walls supporting said bed and means for alternately passing heating gas and gas to be heated in opposite directions through said bed, comprising a substantially cylindrical perforated wall portion permitting radial movement of gas into and out of said bed.

2. A heat regenerator comprising concentric perforate vertically disposed cylindrical walls, a mass of promiscuously deposited heat conducting refractory bodies supported between said walls and means for passing heating gas and gas to be heated alternately radially through said mass.

3. A heat regenerator comprising at least two vertically disposed, concentric cylindrical spaced-apart perforate walls, a mass of promiscuously deposited, heat conducting refractory bodies supported between said walls, an imperforate wall surrounding the outermost of said perforate walls forming a space surrounding said outermost wall and means for passing heating gas and gas to be heated alternately from the space within the innermost perforate wall outward through said perforate walls and said mass of bodies to said space surrounding said outermost wall and from said space surrounding said outermost wall inwardly through said perforate walls and mass of bodies to said space within the innermost perforate wall.

4. A heat regenerator comprising an outer substantially cylindrical imperforate metallic wall, a concentric perforate metallic wall within and spaced from said imperforate wall, a concentric perforate refractory wall within and spaced from said metallic perforate wall, a mass of promiscuously deposited, refractory, heat conducting bodies between said perforate walls, means for passing a heating gas into the space within said refractory perforate wall and radially through the perforations therein, radially through said mass of bodies and through the perforations in said metallic perforate wall into the space between said metallic perforate wall and said imperforate metallic wall and means for passing a gas to be heated in the opposite direction from said last named space to the space within said refractory perforate wall.

5. A heat regenerator comprising an outer cylindrical imperforate metallic shell, a plurality of perforate plates positioned around the inside of said shell with their vertical edges contacting said shell and their intermediate portions spaced from said shell providing open spaces between the shell and said plates, a cylindrical perforate refractory wall within said shell and spaced from said plates, a mass of promiscuously deposited, heat conducting refractory bodies filling the space between said plates and said perforate wall, openings in said outer shell connecting said spaces between the outer shell and said perforate plates, means for passing a heating gas into the space within said perforate wall, radially outwardly through the perforations therein and said mass of bodies and said perforate plates and said openings, and means for passing a gas to be heated in the opposite direction.

6. A heat regenerator comprising an outer substantially cylindrical imperforate shell, two concentric perforate walls within said shell and spaced therefrom and from each other, a mass of

heat-exchange material filling the space between said perforate walls, an imperforate partition passing through the longitudinal axis of said shell and dividing the spaces between the shell and said walls into two parts, said partition terminating short of one end of the space within the inner perforate wall, and means for passing a gas alternately in opposite directions into the space between the shell and the outer perforate wall on one side of said partition, through said outer perforate wall, through the heat-exchange mass, through the inner perforate wall, around the end of said partition, through the inner perforate wall on the other side of the partition, through the adjacent mass of heat-exchange material, and through the outer perforate wall into the space between the outer perforate wall and the shell.

7. A heat regenerator comprising an outer substantially cylindrical imperforate refractory wall, a substantially cylindrical refractory inner wall within and spaced from and concentric with said outer wall, said walls defining an inner cylindrical chamber and an outer concentric annular chamber, heat-exchange material filling said outer annular chamber, means adjacent the opposite ends of said outer wall for introducing gas into and withdrawing gas from said annular chamber, and means adjacent the middle of said refractory inner wall for introducing gas into and withdrawing gas from said annular chamber.

8. A heat regenerator as defined in claim 7 in which said refractory inner wall is perforated for the passage of gas adjacent the middle thereof.

9. A heat exchanger as defined in claim 7 comprising means for introducing a heating gas into and withdrawing heated gas from the inner cylindrical chamber.

10. A heat regenerator comprising a substantially cylindrical outer wall, a substantially cylindrical inner wall within and spaced from and substantially concentric with said outer wall, said outer wall and said inner wall defining a chamber, heat-exchange means within said chamber, and means between the ends of said inner wall for introducing gas into and withdrawing gas from said chamber.

11. A heat regenerator as defined in claim 10 in which said chamber contains a plurality of heat-exchange masses.

12. A heat exchanger comprising a substantially cylindrical outer wall, a substantially cylindrical flue within and spaced from and substantially concentric with said outer wall, said outer wall and said flue defining a substantially annular chamber, a plurality of heat-exchange masses within said chamber, means between the two ends of said chamber for introducing gas into and withdrawing gas from said chamber, and means for passing a portion of a gas stream through one of said heat-exchange masses and another portion thereof through another of said heat-exchange masses.

13. A regenerative stove comprising a plurality of annular, vertically aligned heat-exchange masses contained within the same enclosure, means for alternately passing gas through said masses in opposite directions, said means comprising means for passing one portion of a stream of gas through one of said masses and simultaneously passing another portion of said stream through another of said masses.

14. A heat exchanger comprising an imperforate shell defining a chamber, within said chamber two heat-exchange masses separated by an imperforate wall, said masses having substantially the same heat exchange capacity, and means for passing a stream of gas through one of said masses to remove heat therefrom, and thereafter through the other of said masses to transfer heat thereto.

15. A heat regenerator comprising a heat-exchange mass containing solid particles, a combustion chamber, a substantially vertical stationary wall separating said solid particles from said combustion chamber, and means comprising a perforate section in said wall in direct contact with said mass for passing gases from said combustion chamber into said mass.

16. A hot blast stove comprising a substantially cylindrical imperforate outer wall, a substantially cylindrical inner wall within and spaced from and substantially concentric with said outer wall, said walls defining a substantially cylindrical inner chamber and a substantially annular outer chamber, within said outer chamber a plurality of heat-exchange masses comprising relatively small solid particles, within said outer chamber and between a plurality of said masses another heat-exchange mass comprising relatively large solid particles, and means for passing one portion of a stream of gas through one of said masses first mentioned and simultaneously passing another portion thereof through another of said masses first mentioned.

17. A heat regenerator comprising an outer wall, a heat-resistant wall within and spaced from said outer wall, a heat-exchange chamber between said walls, within said chamber heat-exchange means comprising solid particles of relatively small size in a zone adjacent to said outer wall and solid particles of relatively large size in a zone adjacent to said heat-resistant wall, and means for passing relatively cool gas through said zone first mentioned and relatively hot gas through the other of said zones, said means last mentioned comprising a perforate section in said heat-resistant wall adjacent to solid particles of relatively large size.

18. A heat regenerator comprising a vertically disposed substantially cylindrical outer wall, a vertically disposed heat-resistant wall within and spaced from said outer wall, between said walls a plurality of heat-exchange masses comprising relatively small solid particles, and means for passing one portion of a stream of gas upward through one of said masses and simultaneously passing another portion of said stream downward through another of said masses, said means comprising a bed of relatively large solid particles between two of said masses and a perforate section in said heat-resistant wall adjacent to said bed permitting substantially horizontal flow of a stream of gas through said heat-resistant wall and directly into said bed.

19. The method of effecting transfer of heat between solid particles and streams of gases alternately passed through a bed of said particles, which comprises passing a stream of gas at relatively high mass velocity through a relatively hot zone of said bed, said zone having a relatively small cross sectional area normal to the direction of the stream, and thereafter passing the stream at relatively low mass velocity through a relatively cool zone in said bed, said relatively cool zone having a relatively large cross sectional area normal to the direction of the stream.

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