HEAT-EXCHANGE METHOD AND APPARATUS

FIG. 7

FIG. 8

FIG. 9

INVENTOR.
FRANK J. McENTEE JR.
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Frank J. McEntee, Jr., 1106 Hilcrest Road, Beverly Hills, Calif.
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This application is a division of my copending application Serial No. 41,967 filed July 11, 1960 which is a continuation-in-part of my application Serial No. 628,637, filed December 17, 1956, now Patent No. 2,953,365.

The present invention relates to heat exchange with pulverulent or granular materials, and is more particularly concerned with the cooling of such materials in fluidized beds.

The heating and cooling of pulverulent or granular materials in fluidized beds have been complicated by several problems including short-circuiting of hot material through the cooler to the outlet or discharge; uneven or erratic fluidization because of interference or obstruction of the fluidizing air flow by heat exchange surfaces or elements embedded in the fluidized bed; blockages caused by accumulations or oversize materials; and coating of the material on the heat exchange surfaces.

Prior fluidized heat exchangers have employed arrangements and combinations of overflow and underflow wells within horizontally elongated chambers, vertically elongated chambers, and various types of heat exchange surfaces such as hollow tubes. However, none of the prior arrangements has been found entirely satisfactory.

The present invention provides a method and apparatus for heat exchange in a fluidized bed in which the heat-transfer surfaces are maintained in a clean, uncoated condition by the motion of the material therealong which may be regulated to compensate for variations in operating conditions.

In general, the preferred form of apparatus of the present invention comprises an elongated, preferably upright casing having a material inlet and a material outlet spaced from each other a substantial distance. The material with respect to which heat transfer is to be effected is maintained in a fluidized state in the casing. Between the inlet and the outlet, and in the space occupied by the fluidized material, the casing is provided with a plurality of heat-transfer members having extensive heat-transfer surfaces, such as fins. The heat-transfer members occupy a large portion of the volume and cross-sectional area of the casing, and extend substantially longitudinally between the inlet and outlet. Means are provided for maintaining a relatively high velocity of the material along the heat-transfer surfaces to prevent coating or build-up of material thereon.

A better understanding of the invention may be derived from the accompanying drawings and description in which:

FIG. 1 is a vertical sectional view of a fluidized cooler embodying the preferred form of the invention;

FIG. 2 is an enlarged horizontal sectional view of a portion of the cooler, taken along lines 2—2 of FIG. 1;

FIG. 3 is an enlarged horizontal cross-sectional view of a portion of the cooler, taken along lines 3—3 of FIG. 1;

FIG. 4 is a vertical sectional view of the lower portion of one of the heat-exchange members, taken on line 4—4 of FIG. 3;

FIG. 5 is a vertical sectional view of the discharge conduit of the fluidized cooler of FIG. 1;

FIG. 6 is a horizontal sectional view taken on line 6—6 of FIG. 5;

FIG. 7 is a schematic view of a preferred installation embodying the cooler;
the air flow evenly around the surface of the members 11 to prevent short-circuiting of portions of the air along one side of the members.

The inner pipes 13 of the heat-transfer members 11 terminate short of the lower ends of the outer pipes 14 and are provided with a pair of legs 17, as best seen in FIG. 4, which maintain a gap 18 between the lower end of the inner pipe 13 and the upper portion of the closure cone 16. The legs 17 also function as spacers to maintain the concentric relationship between the inner and outer pipes 13 and 14. At their upper ends, the inner pipes 13 extend through end walls or caps 19 of the outer pipes 14 to provide means for the introduction of a heat-exchange medium.

The lower ends of the heat-transfer members 11 may be secured in proper spaced position with respect to one another by suitable bracing, if desired.

The various heat-transfer members may be connected in series or in parallel, as desired, for the flow of a heat-transfer medium through them. As shown in FIG. 1, the heat-transfer members are connected together in groups to provide series flow of the heat-transfer medium through each group of the members. To this end, the outer pipes 14 of adjacent pairs of heat-transfer members are connected by pipes 21, and the inner pipes 13 of the adjacent members are connected pairs connected to each of the outer pipes 13 by an inverted U-shaped section 13a. With the pipes thus connected, heat-exchange medium supplied through the inlet pipes 13 will first pass downwardly through the inner pipes to the bottom of the heat-exchangers to which the pipes are connected and through the gap 18 into the outer pipes 14. The heat-exchange medium then flows upwardly through the outer pipes and is discharged through the connections 21 into the outer pipe 14 of a second heat exchanger. In the second heat exchanger, it flows downwardly through the outer pipe 14 and upwardly through the inner pipe to be discharged at the upper end thereof into one of the inverted U-shaped sections 13 from which it passes to the inner pipe of a third heat exchanger. This series flow continues until the heat-exchange medium is discharged through the pipe 13b.

The material outlet 3 communicates with the lower end of a discharge conduit 22. The discharge conduit includes a lower leg 23 extending outwardly and upwardly from the outlet 3 to the lower end of a vertically-extending leg 24 which discharges at its upper end into an overflow leg 25. The vertical leg 24 and the overflow leg 25 may be separate conduits, or, as shown in FIGS. 5 and 6, may be compartments of a single discharge conduit 22.

The level of the overflow from the vertical leg 24 into the overflow leg 25 will determine the level of the material in the vessel 1, but due to wall friction in the vertical leg 24, the level of the material in the vessel 1 may be somewhat above the level of the overflow edge 24a of the opening 24b from the vertical leg 24 into the overflow leg 25.

It sometimes is found desirable to alter the level of the overflow edge 24a to correspondingly alter the level of the material in the vessel. To this end, the common wall between the vertical leg 24 and the discharge leg 25 comprises a series of replaceable or removable loose plates 24c and a sliding plate or weir 24d having the overflow edge 24a which may be adjusted vertically by a handle 24e. The handle 24e may be held in its adjusted position by any suitable means. The plates 24c and the plate 24d are held in place by guides 24f secured to the inside of opposite walls of the conduit. By removing or adding plates 24c or by replacing larger plates with smaller plates or vice versa and by the use of the sliding plate or weir 24d, the overflow edge 24a may be positioned at any desired level.

Adjacent the material outlet 3, the lower leg 23 of the discharge conduit 22 is provided with a sump 26 which is open to the interior of the leg 23 and is closed to the atmosphere by a valve 27. The valve 27 may be opened periodically to drain off accumulations of oversize material, lumps, or foreign objects.

Adjacent the leg 24, the lower wall of the lower leg 23 is provided with an aerator 28 which underlies the vertical leg 24 to deliver aerating air upwardly through the air passing upwardly through the conduit 22 escapes through a suitable vent 29 in the upper end thereof.

As best shown in FIG. 7, the cooler C receives material through its inlet 2 from the coarse tailings outlet 31 of the air-swept separator S, and discharges the tailings after being cooled through its outlet 3 and discharge conduit 22 to the inlet of the air-swept mill M, such as a cement finish mill.

The material discharged from the mill is passed to the inlet 32 of the separator S. Under the influence of an air impeller (not shown), which may be an integral part of the separator, the separator classifies the material into coarse and fine fractions and discharges the air through an air outlet 33; the coarse tailings through the outlet 31, and the desired fine fractions of the product through a product outlet 34. Where desired, the finished cement product discharged through the outlet 34 may be passed to a second cooler prior to use or storage.

In operation of the apparatus of FIGS. 1 to 8 for the cooling of hydraulic cement, the mill M, separator S and the fluidizing air-flow to the cooler C are started and a feed of cement clinker is delivered to the mill from storage or from a primary crusher (not shown) for grinding. The grinding of the cement clinker develops considerable heat which subsequently must be removed. It is generally accepted theory that the greater portion of the heat generated in the cooling of cement is carried away with the fluidized bed. Therefore, the new cement distributed by the cone onto the upper surface of the fluidized bed is fluidized and...
mixed with the bed and passes downwardly in the vessel 1 as a part of the fluidized bed. As the cement passes downwardly through the cooler, a portion resulting from the fluidization of the bed causes an efficient heat transfer between the cement and the heat-transfer members 11, since the individual particles of the cement are caused to contact different areas of the heat-transfer members. Preferably the rate of cement fed to the casing 1 is so correlated with the rate at which the cement is discharged through the outlet 3 that the flow of the fluidized cement through the cooler is maintained at a velocity of about three feet per minute. For materials which are moisture-sensitive and which tend to coat on the heat-transfer surfaces, velocities down to about one foot per minute may be satisfactory. However, in some instances even higher or lower velocities may be satisfactory.

Although it is to be understood that the cooler of the present invention is equipped for use in different circuits, such as a direct cooling of the finished cement product, closed circuit cooling of the mill discharge enroute to the separator or of the tailings from the separator while they are enroute back to the mill is preferred in many cases. When the cooler is located in either of these positions, within a closed circuit, it receives a substantial material flow, commonly called the "circulating load," which may be, in terms of weight per hour, from one to eight times the output of finished product from the mill circuit. This substantial load of material makes possible a relatively high velocity of material flow along the heat-transfer surfaces, particularly since the number and size of the heat-transfer members restrict the area within the casing through which the materials may flow. Nevertheless, a bulk of cooled material is maintained in the circuit, within which bulk the heat developed in the mill may be distributed and dissipated.

When operating in a closed circuit and it is desired to change the particle size of the feed to the mill, say from one-fourth inch to three-eighth inch or one-half inch, there will be a higher proportion of rejects from the separator to be passed to the cooler. Under such conditions, if the level of the overflow edge 24a remains the same, there will be a gradual building up of the amount of the material in the cooler, which, if not corrected, may result in a condition in which the entire system will become plugged up. In this case, the overflow edge 24a will be lowered to the extent necessary to maintain the desired level of the fluidized material in the vessel 1.

In the production of hydraulic cement, the desired cooling result is expressed in terms of the temperature of the finished cement. Since the amount of heat produced by a mill is relatively constant for a given rate of output of finished cement, the high circulating load of partially-cooled material being returned to the mill inlet causes the total heat input of the mill to be distributed over a large mass of material, thereby causing a lower actual rise in temperature of that material than would occur with a lesser mass of returned or recycled material. Therefore, when the cooler of the present invention is employed in either of the preferred locations in the circuit, it is not necessary to cool the large circulating load to a very low temperature, since only the extraction of total heat therefrom, in terms of B.t.u.'s, is required to provide for absorption of the mill heat by the large mass. Thus a lower temperature differential may be maintained between the material and the cooling medium while still producing the required result. At the same time, reduction of the temperature of the material in the mill prevents coating of the balls or other grinding media by the material and, in the case of the lower level 51 of the deck to form a central plenum chamber 53. Four radially-extending walls 54, 55, 56 and 57 divide the space between the gas-permeable deck 4b and the bottom wall of the casing and surrounding the central plenum chamber 53 into four quadrants or outer plenum chambers 58, 59, 60 and 61 of sector shape. The
outer plenum chambers are provided with individual gas inlets 62, 63, 64 and 65, respectively, and the central plenum chamber 53 is provided with a separate gas inlet 66. A gas-lift pipe 67 extends upwardly from a position above and spaced from the lower area 51 of the gas-permeable deck 48, through a distributing cone 96 positioned beneath the material inlet 2c, the inlet chamber 50 and into a separating chamber 68 having an air vent 69. The lower end of the gas-lift pipe 67 is flared outwardly to form a frusto-conical section 70 which receives the discharge end of a nozzle pipe 71. The construction of a gas-lift pipe and nozzle is the subject of Patent No. 2,509,983 to Joseph H. Morrow. A discharge pipe 68' extends from the chamber 68 for the discharge of material fed thereto through the gas-lift pipe 67.

At the point at which it passes through the material inlet 2c, the gas-lift pipe 67 and the collar or neck 50 form an annular space 72 through which material is fed from the inlet chamber 50 onto the distributing cone 96.

In operation of the apparatus of FIGS. 12 and 13, a flow of fluidizing gas upwardly through the gas-permeable deck is started and maintained as described more fully hereinafter. The flow of cooling fluid through the heat-transfer member 11b is started either before or after starting the flow of material through the casing, as desired.

The flow of material into the inlet chamber 50 is partially retarded by the size of the annular aperture 72 and by the cone 96, thereby stabilizing the material flow and preventing short-circuiting of the material along one side of the aperture 72 or the casing. The material passes as an annular stream through the annular aperture 72, and is thereafter evenly distributed by the cone 96 over the upper surface of the bed of fluidized material in the casing.

Air or gas is delivered through the central plenum chamber 53 and the lower deck area 51 and through the nozzle pipe 71. The material above the lower deck area 51 is fluidized by the air passing upwardly through and rises in the gas-lift pipe 67 where it tends to seek an equilibrium point or stable level. The air entering the lift pipe 67 from the nozzle 71 further aerates, expands and reduces the density of the material in the lift pipe. The "head" of the material bed in the casing around the gas-lift pipe forces additional material into the lower end of the lift pipe and causes the less dense material therein to move upwardly into the separating chamber 68. In the separating chamber 68 the air separates from the pulverulent material and escapes through the vent 69, while the material is discharged by gravity or by other means through the discharge pipe 68'.

Assuming a substantially constant feed of material into the upper end of the vessel 1b, the level of the material within the vessel can be controlled by the amount of gas introduced through the nozzle pipe 71. Increasing the amount of gas introduced through the nozzle pipe 71 into the lift pipe lowers the density of the fluidized material in the lift pipe and increases the density differential between the fluidized material in the gas-lift pipe and the material in the vessel perpendicular to the lift pipe. This results in a greater flow of material upwardly through the lift pipe and a corresponding lowering of the level of the material in the vessel. In a similar manner, a reduction in the amount of air introduced through the nozzle pipe 71 will result in an increased density of the fluidized material in the lift pipe and a decrease in the density differential between the fluidized material in the gas-lift pipe and the vessel containing it. This will result in a lesser flow of the fluidized material upwardly through the gas-lift pipe and a corresponding raising of the level of the fluidized material in the vessel.

The rate of air flow, or the amount of air in gas per minute per square foot of the gas-permeable deck in each of the sectors 58, 59, 60 and 61 may be regulated by suitable valving (not shown) to control the rate of flow through the gas inlets 62, 63, 64 and 65, respectively. The rate of flow through each of the sectors may be equal, or may be consistently non-uniform, with the higher air flow being cycled or periodically shifted to different sectors as more fully described in Patent No. 2,844,361, issued July 22, 1958, to Dilcher et al.

This control over the aeration of different zones of the material bed permits regulation of material density and material velocity in the various zones. Therefore, when problems such as a local zone of dense or agglomerated material occur, the air flow may be temporarily set to create a high rate of exchange of a high material velocity in the desired zone. Although the temporary turbulence or high velocity may not be the most efficient in terms of heat transfer, it may be used for periodic clearing of the heat-transfer members or breakdown of dense material areas. After the heat-transfer members of one section have been cleared by high aeration, that section may be returned to the rate of air flow desired for effective heat transfer, and another sector may receive the higher air flow.

As shown in FIGS. 14 to 16, a modified embodiment of the invention, which is particularly advantageous for use with a gaseous heat-transfer medium, comprises a casing 1c having a material inlet 2c in its lower region and a material outlet 3c in its upper region. A screw feeder 75 and a star feeder 76 control the flow of material through the inlet 2c and outlet 3c, respectively.

When the unit is to be used for cooling extremely hot pulverulent materials, or where desired for any reason, a layer of insulation 74 is provided about the casing.

A plurality of heat-transfer members 11c extend through the casing longitudinally thereof, and are commonly connected at their opposite ends to an upper supply chamber 77 and a lower collecting chamber 78. The heat-transfer members 11c comprise openings 11d provided in a casing 1c having a material inlet 2c in its lower region and a material outlet 3c in its upper region. A screw feeder 75 and a star feeder 76 control the flow of material through the inlet 2c and outlet 3c, respectively.

Three annular aeration pipes 79, 80 and 81, respectively, are positioned at different vertical zones or levels around the outer heat-transfer members. A corresponding group of inner annular aeration pipes 79', 80' and 81' are positioned adjacent the pipes 79, 80 and 81, respectively, and communicate therewith by means of interconnecting pipes 82. The aeration pipes are uniformly perforated to allow material to pass through the walls and any suitable manner to deliver air or gas into the surrounding material. Preferably, the fins 15c are notched or interrupted as at 83 to permit positioning of the aeration pipes close to the heat-transfer pipes 14c.

The groups of aeration pipes 79, 80 and 81 receive air or gas individually through piping and valves 84, 85 and 86, respectively, from a source (not shown). The spent air or gas is vented from the casing by a cyclone vent 87 which removes stray dust from the gases and returns it to the material bed through a dip leg 88.

In operation of the apparatus of FIGS. 14 to 16, material is conveyed into the casing by the screw feeder 75, and is ultimately removed at the top of the bed by the star feeder 76. Fluidizing air or gas is delivered through the apertures 89 of aeration pipes 79 to 81 and 79' to 81' fluidize the material in the vessel, and escapes from the vessel through the cyclone vent 87. The rate of air introduction, and therefore the degree of fluidization at the various zones, may be regulated by the valves 84, 85 and 86.

A gaseous heat-transfer medium such as cold air is passed into the supply chamber 77 and through the heat-transfer members 11c and is withdrawn from the collecting chamber 78. Alternatively, if desired, the gaseous medium may follow an opposite path upwardly through the heat-transfer members. Also, liquid heat-exchange
media may be used in the apparatus of FIGS. 14 to 16, if desired.

Various changes may be made in the details of construction of the several forms of heat-exchangers herein described without departing from the invention as defined in the subjoined claims or sacrificing any of the advantages thereof.

I claim:

1. A heat-exchange apparatus for treating pulvulent material comprising a vessel to receive the pulvulent material, the portion of the vessel which receives the material and in which the material is treated having an inlet opening located at the top of the vessel for the introduction of the material to be treated and an outlet conduit extending upwardly through the vessel from a portion adjacent but spaced from the bottom of the vessel, the lower end of said conduit being open and forming the discharge from the portion of the vessel in which the material is to be treated, said conduit having an opening adjacent its upper end for the discharge of material, a nozzle pipe having an opening positioned to direct gas passing therethrough upwardly through said conduit to facilitate upward flow of material through said conduit, means adjacent the bottom of the vessel for introducing a fluidized gas to pass upwardly through the material in the vessel to fluidize it, a plurality of heat exchangers within said vessel, said heat exchangers being spaced from the walls of the vessel and from one another to provide spaces for the material being treated, and means for causing a flow of heat-exchange medium through said heat exchangers.

2. Heat-exchange apparatus as set forth in claim 1, which includes a material-inlet chamber above the vessel and surrounding the upper portion of said conduit below the inlet opening for the discharge of material, means for supplying material to said material-inlet chamber and a collar surrounding and spaced from said conduit, the upper end of the collar communicating with said material-inlet chamber and the lower end communicating with the vessel and forming the inlet for the material to the vessel.

3. Heat-exchange apparatus as set forth in claim 1 wherein a separation chamber is positioned above said vessel and communicates with said discharge opening, the separation chamber having a vent in the upper portion thereof for the escape of gas separating from material in the chamber and a material discharge communicating with and leading away from the separation chamber.

4. Heat-exchange apparatus as set forth in claim 1 wherein each heat exchanger carries a plurality of elongated, outwardly extending, radial, heat-conducting fins.

5. Heat-exchange apparatus as set forth in claim 1 having a distributing member positioned below the inlet opening of the vessel to cause incoming material to be spread out over a larger area within said vessel.

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FREDERICK L. MATTESON, JR., Primary Examiner.
D. A. TAMBURRO, Assistant Examiner.