

[54] HEAT EXCHANGER

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[22] Filed: June 15, 1972

[21] Appl. No.: 263,201

[52] U.S. Cl. 165/145, 165/157, 122/7 R, 165/119

[51] Int. Cl. F28f 7/00

[58] Field of Search 165/140, 143, 145, 157, 165/164, 5, 69, 119; 122/7 R

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[57] ABSTRACT

An improved heat exchanger for transferring heat between a gas containing solid contaminant particles and a secondary fluid. The heat exchanger is composed of a plurality of substantially parallel, uniformly spaced flat pieces and a surrounding shell. The interior of each plate is provided with a passage for the flow of the secondary fluid. Moreover, the surrounding shell is so sized and shaped that the solid particle-containing gas is made to flow past the flat plates in a direction parallel thereto. Consequently, gas side fouling is substantially eliminated. The plates are preferably arranged vertically and, in one embodiment, are provided with a mechanism for removing small quantities of contaminant particles.

15 Claims, 3 Drawing Figures

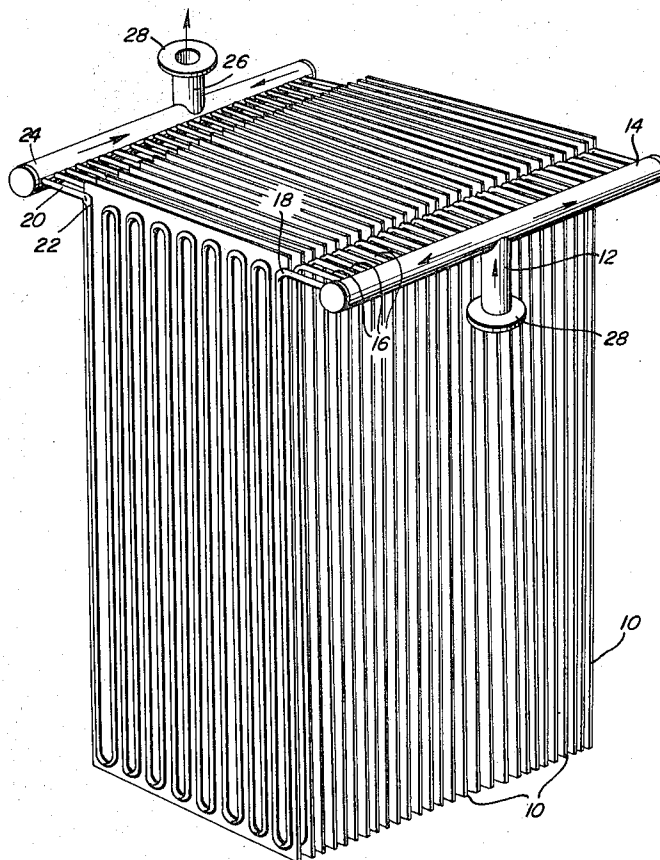


Fig. 1

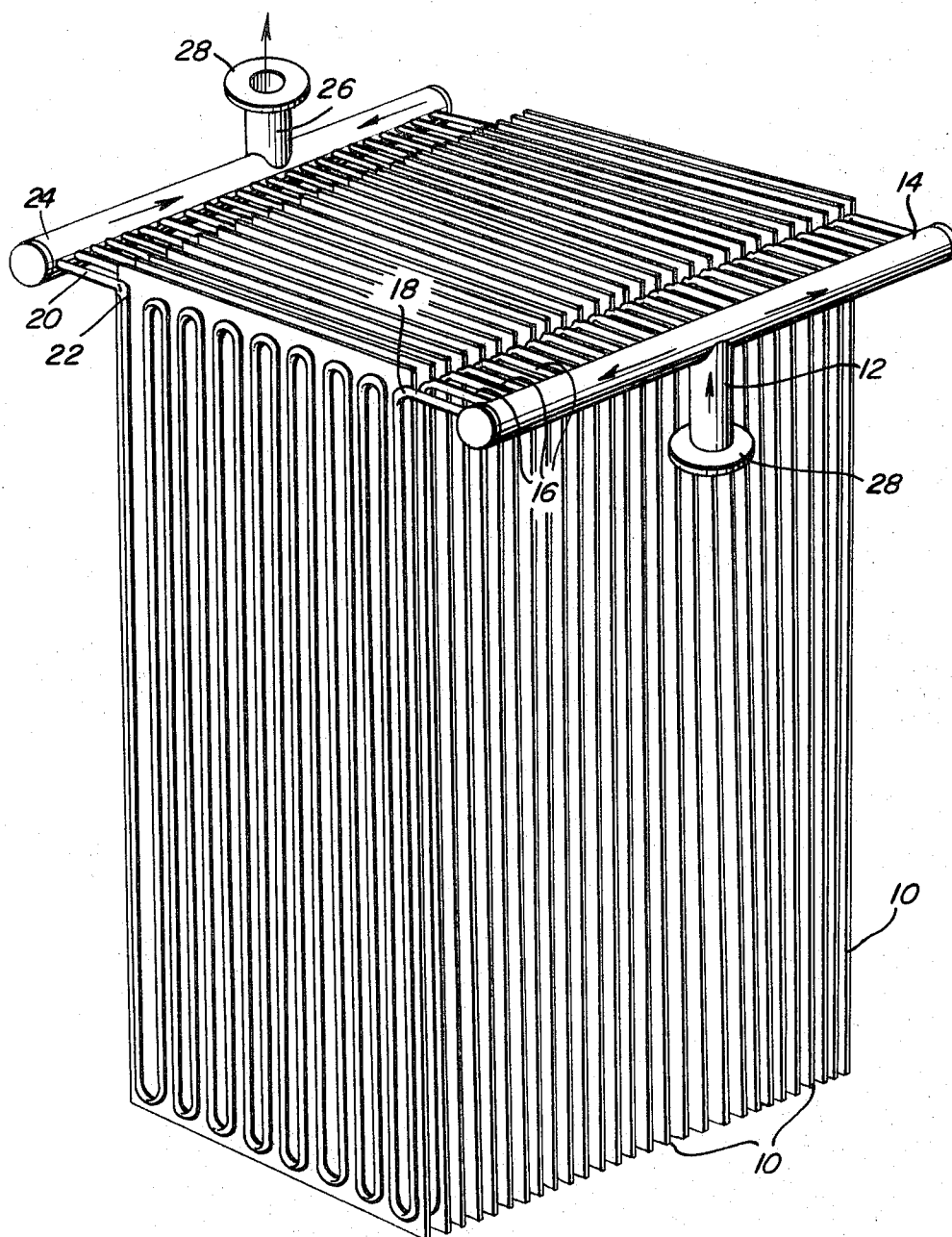
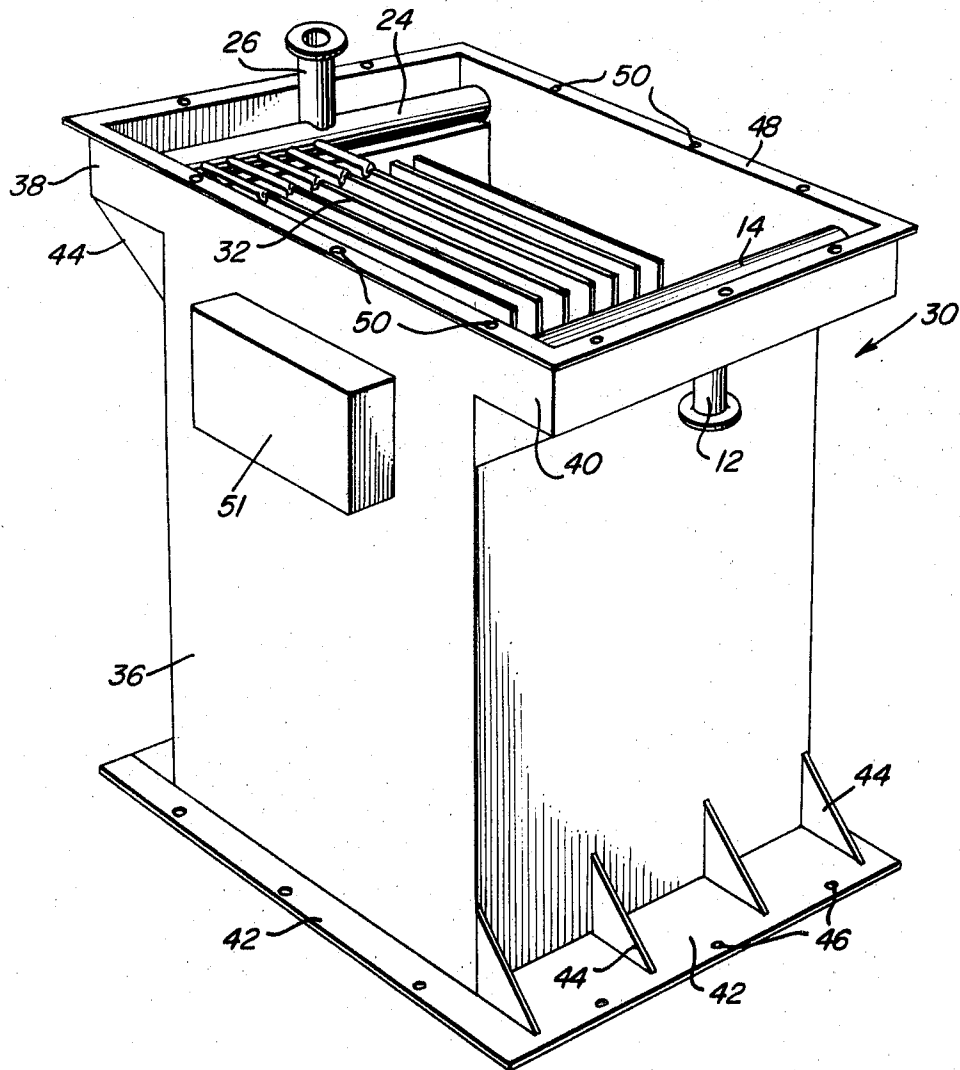
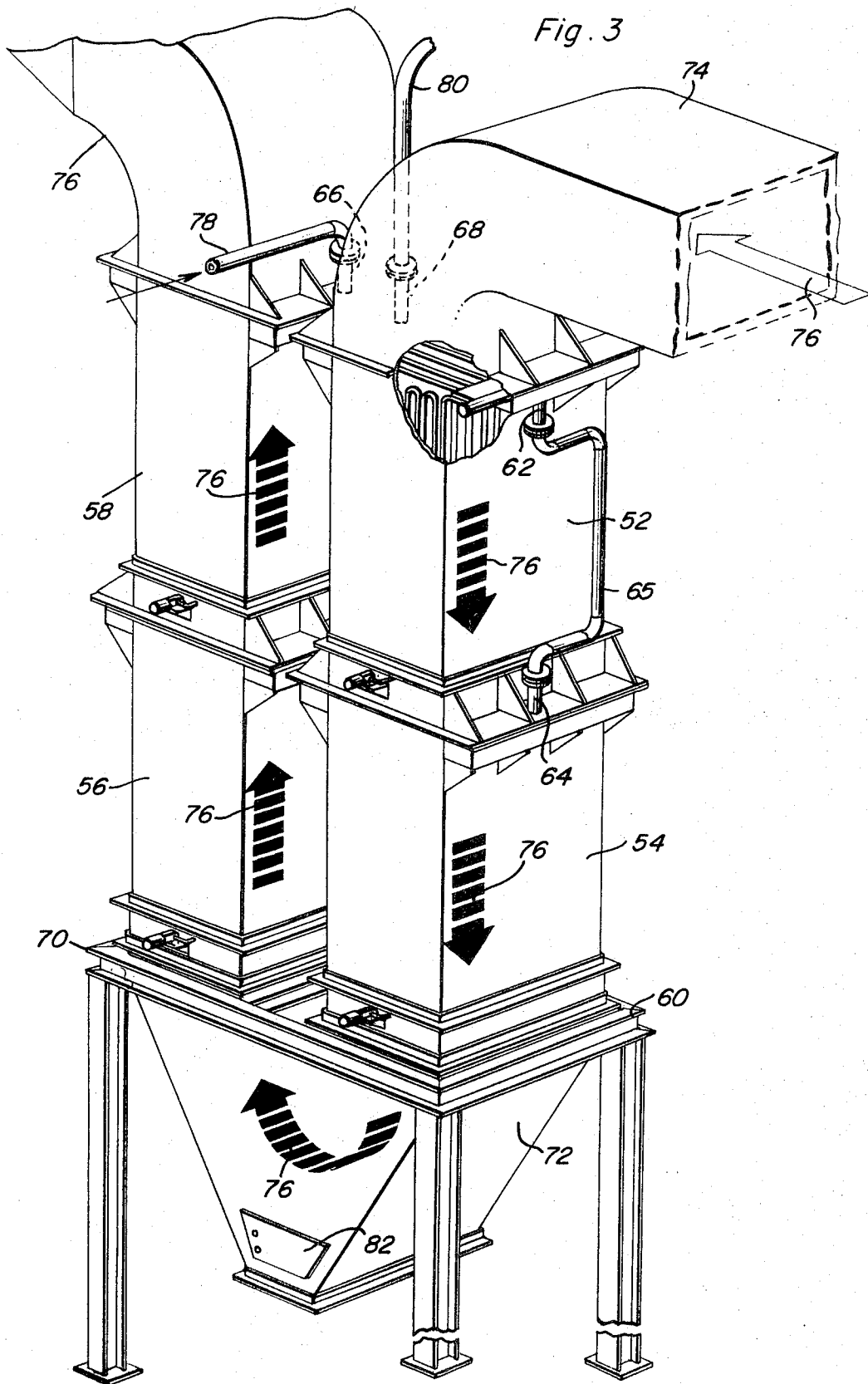


Fig. 2





This invention relates to heat exchangers for recovering waste thermal energy from a gas stream containing solid particles.

In many industrial applications, it is often necessary or desirable to transfer thermal energy from a high temperature gas containing solid particles to a secondary fluid medium, either gaseous or liquid. In the past, this has been accomplished by employing the well-known shell and tube heat exchanger, with the secondary fluid flowing through the tubes and the particle-containing gas flowing through the shell outside the tubes. Other common types of heat exchange systems have also been used for this purpose.

Unfortunately, in operation, most known heat exchanger systems are subject to fouling on the gas side when solid particle-containing gases are processed. Almost immediately, individual particles are deposited from the gas on tubes, and in a short time sizeable masses of particles are built up. As a consequence, not only is the heat exchanger efficiency drastically reduced, but also, eventually, the entire gas side passageway can become completely blocked.

In the past, this gas side fouling problem has been overcome by installing specially designed cleaning equipment in each heat exchanger. Such cleaning equipment is not only expensive, costly to operate and costly to maintain, but may often fail to do a completely satisfactory job.

Another problem associated with known heat exchangers employed for removing waste thermal energy from solid particle-containing gases is that maintenance and repair of the heat exchanger systems are often difficult, time-consuming and expensive. For example, when a typical shell and tube heat exchanger develops a leak or is otherwise inoperable, it is necessary to shut down the entire system employing the heat exchanger for extended periods of time, since the heat exchanger must be completely disassembled, the broken, worn or leaking tubes replaced, and the entire heat exchanger reassembled again. Obviously, extended periods of downtime decrease the overall efficiency of the heat exchanger, and hence the total system, and therefore add to the expense of using a heat exchanger of this general design.

Accordingly, it is an object of the present invention to provide a heat exchanger system useful for recovering thermal energy from a solid particle-containing gas which can operate for extended periods of time without gas side fouling.

It is a further object of this invention to provide a heat exchanger for solid particle laden gases which is of simple design and easy to manufacture.

It is a still further object of this invention to provide a heat exchanger, as set forth above, which is simple to maintain and can be quickly and easily repaired by simple replacement of some of its parts.

These and other objects are accomplished according to the present invention, wherein a heat exchanger composed of an outer shell and a series of substantially parallel flat plates is provided. The series of parallel flat plates is arranged within the heat exchanger outer shell

so that the solid particle-containing gas flows parallel to the flat surfaces. Each flat plate is provided within its interior with a conduit for receiving the secondary fluid so that transfer of heat can occur between the interior conduit and exterior of the flat plates.

Because the solid particle-containing gas flows parallel to the flat surfaces of the flat plates, there is little or no opportunity for the particles contained in the gas to collect in crannies or nooks in the heat exchanger. Consequently, fouling on the gas side of the heat exchanger with the particles contained in the gas is substantially eliminated.

In a preferred embodiment, the inventive heat exchanger is arranged so that the solid particle-containing gas flowing therethrough travels vertically as it passes the series of parallel flat plates. Such an arrangement is advantageous in that particles not positively carried by the gas stream which would otherwise tend to accumulate on the heat exchanger internals fall in a direction parallel to the flat plates. Consequently, solid particle accumulation is minimized. Moreover, since simple tapping or vibrating of the heat exchanger causes loosely-packed accumulated particles to be dislodged, arrangement of the heat exchanger in this manner enables simple tapping or vibrating equipment to effectively clean the gas side of the heat exchanger when and if necessary.

In another preferred embodiment, the inventive heat exchanger employs a modular concept, each module being composed of its own shell and flat plate system. A number of modules are connected end to end so that solid particle-containing gas flows in series relationship through the assembled modules. Because the heat exchanger of this embodiment is composed of a series of individual heat exchange modules, a breakdown of the heat exchanger in any one area can be quickly remedied by simply replacing the malfunctioning heat exchange module. Moreover, if the heat transfer requirements of a heat exchanger employing the modular concept should increase or decrease, the capacity of the heat exchanger can be increased or decreased by simply adding additional modules or removing modules already in the system. This arrangement of modules also permits the heat transfer characteristics of the heat exchanger to approach that of a counterflow heat exchanger rather than a crossflow and therefore improves the heat transfer efficiency. Finally, when and if special cleaning of the heat exchanger is required, easy disassembly and reassembly of the modular heat exchanger make such maintenance a comparatively simple task.

The present invention may be more readily understood by reference to the following drawings wherein:

FIG. 1 is an isometric view of the internals of the inventive heat exchanger system including a plurality of uniformly spaced flat plates, an inlet header and an outlet header.

FIG. 2 is an isometric view of the inventive heat exchanger when the internals of the system as shown in FIG. 1 are assembled in an appropriately shaped shell.

FIG. 3 is an isometric view illustrating the modular concept of the invention wherein four of the heat exchange modules shown in FIG. 2 are assembled together to form a single heat exchanger unit.

DETAILED DESCRIPTION OF THE DRAWINGS

The inventive heat exchanger employs a series of uniformly spaced flat plates as the heat exchange surfaces. These heat exchange plates take the form of flat plates or sheets with essentially two uniformly flat and parallel large area surfaces. Each plate is provided with a secondary fluid passageway which usually extends transversely back and forth across the plate body from one end to the other so that heat transfer is maximized between a fluid flowing through the passageway and the heat exchange plate itself. The fluid passageway of each plate is provided with an inlet opening and an outlet opening so that fluid can be introduced into one side of the plate, flow entirely through the plate where heat transfer occurs, and flow out the other side of the plate.

Heat exchange plates as above described are known in the art and any type heat exchange plate of this general construction can be used. In this regard, it has been found that heat exchange plates known in the art as "embossed panel bundles" can advantageously be used to construct the heat exchanger assembly according to the present invention.

Referring to FIG. 1, the individual heat exchange plates 10 are assembled parallel to one another and are spaced uniformly apart by a predetermined distance. In this position, the plates are secured together by suitable means (not shown) conventional in the art.

Located on one side of the system of flat plates is the secondary fluid inlet supply means which is composed of an inlet pipe 12 and an inlet header 14. Communicating with inlet header 14 are a plurality of inlet tubes 16, each inlet tube 16 fluidly connecting inlet header 14 and the inlet opening 18 of each heat exchanger plate 10.

Located on the other side of the uniformly spaced heat exchange plates 10 is the secondary fluid outlet means which is constructed basically of the same components as the secondary fluid inlet means. The secondary fluid outlet means is composed of a plurality of outlet tubes 20, each of which fluidly connects the secondary fluid outlet opening 22 of a respective heat exchange plate 10 with the outlet header 24. The outlet header 24 is in turn connected to outlet pipe 26 for providing a means for the secondary fluid to exit from the internals of the system.

As shown in FIG. 1, the inlet pipe 12 and the outlet pipe 26 can, if desired, be provided with a circular flange 28 to facilitate the attachment of inlet and outlet conduits thereto.

As further shown in FIG. 1, the junction between each inlet tube 16 and its inlet opening 18, and likewise the junction between each exit tube 20 and its outlet opening 22, is preferably made as streamlined as possible with respect to the gas flow in the gas side of the heat exchanger. This is done to minimize the number of nooks, crannies, cracks or crevices encountered by the gas as it flows through the heat exchanger. This construction minimizes the risk of gas side fouling.

Referring now to FIG. 2, the inventive heat exchanger assembly is generally indicated at 30. The assembly 30 is composed of system internals 32 such as those described with reference to FIG. 1 and an exterior shell 34 secured to the system internals 32 by conventional means (not shown). The shell 34 has a rectangular main body portion 36 which is so sized and

shaped that it conveniently fits around the outside of the assembled heat exchange plates 10. As shown in FIG. 2, the uppermost portion of the shell body 36 is made wider than the remaining portion of the body so that upper extensions 38 and 40 are formed making the overall shell 34 substantially T-shaped. Upper extensions 38 and 40 are sized and shaped to accommodate inlet header 14 and exit header 24 of the system internals.

As further shown in FIG. 2, a horizontal flange 42 extends outwardly from the bottom edge of the shell body 36 around its entire periphery. Flange 42 is secured in place by means of a plurality of triangular supports 44, which are welded or otherwise secured between main body 36 and flange 42. Moreover, flange 42 is provided with a number of holes 46 adapted to receive bolts (not shown) to secure the heat exchange module to a suitable support or onto another heat exchanger of the same design.

As further shown in FIG. 2, the upper edge of the heat exchanger shell 34 is also provided with a horizontal flange 48 extending outwardly from the shell body. This flange is also secured in position by means of a plurality of triangular supports 49 and is provided with a number of holes 50 positioned to align with the holes 46 in lower flange 42. Because holes 50 are positioned in flange 48 in this manner, two identical modules can be easily stacked and secured together by means of bolts extending through holes 46 and 50.

Located on one T-shaped face of shell 34 is an optional cleaning device 51. This device is adapted to either impart a vibrating motion to or simply rap the heat exchange plates 10 so that particles tending to accumulate and/or loosely packed particles already accumulated between the plates are dislodged.

In operation, a secondary fluid supply line is connected to the fluid inlet pipe 12 so that a secondary fluid flows into and through heat exchange plates 10 and out of exit pipe 26. Gas containing solid particles is made to flow through the shell 34 of the heat exchanger either from bottom to top or top to bottom so as to flow in a direction substantially parallel to the plurality of heat exchange plates 10. As a result, heat is transferred between the gas and the secondary fluid according to well known heat transfer phenomena.

As indicated above, a significant feature of the inventive heat exchanger is that it can process a solid particle-containing gas with substantially no gas side fouling. While not wishing to be bound to any theory, it is believed that this result is due to the fact that a laminar boundary layer of gas is formed on the surfaces of the heat exchange plates 10 as the gas flows through the heat exchanger. This laminar boundary layer, it is believed, acts as a barrier preventing solid particles from coming into contact with the heat exchange plate surfaces. As a result, solid particles are unable to readily lodge on the internals of the system and, hence, fouling of the heat exchanger is prevented, or at least delayed.

Moreover, a further advantage of the inventive heat exchanger design is that the resultant gas pressure drop or resistance to gas flow is substantially lower than that experienced by conventional tube type heat exchanger designs.

As can be appreciated by those skilled in the art, the inventive heat exchanger transfers heat between a solid particle-containing gas and a secondary fluid accord-

ing to well known heat transfer phenomena. Accordingly, the exact specifications of an inventive heat exchanger to be designed for a particular application should be determined with regard to those factors known in the art affecting heat exchanger performance. Thus the thermoconductivity of the solid particle-containing gas, the inlet temperature of the solid particle-containing gas, the thermoconductivity of the secondary fluid, the inlet temperature of the secondary fluid, the desired exit temperature of the gas, the desired exit temperature of the fluid, the flow rate of the gas, the flow rate of the fluid, the desired pressure drop of the gas, and the desired pressure drop of the fluid are all factors to be taken into account in determining the length, number, width and spacing between heat exchange plates.

In a preferred embodiment of the invention, illustrated in FIG. 3, a number of the heat exchange modules shown in FIG. 2 are assembled together so that a heat exchanger of substantially larger size is formed. As illustrated, the composite heat exchanger assembly is composed of heat exchange modules 52, 54, 56 and 58, all of which are supported on a steel I-beam structure 60. Heat exchanger modules 52 and 54 are secured together so that gas can serially flow through both modules in a straight line. Heat exchange modules 56 and 58 are similarly secured together.

In order to provide a continuous flow path through the heat exchanger assembly for secondary fluid, inlet pipe 62 of heat exchange module 52 is fluidly connected to exit pipe 64 of heat exchange module 54 by means of connecting pipe 65. Likewise, the inlet pipe of heat exchange module 54 is connected to the outlet pipe of heat exchange module 56 and the inlet pipe of heat exchange module 56 is connected to the outlet pipe of heat exchange module 58 by suitable connecting pipes (not shown). Accordingly, secondary fluid introduced into the heat exchanger assembly at inlet pipe 66 of heat exchange module 58 flows in order through heat exchange modules 58, 56, 54 and 52, and then out of the assembly through exit pipe 68 of heat exchange module 52.

As shown in FIG. 3, gas inlet duct 74 is attached to the upper end of heat exchange module 52 for transporting solid particle-containing gas to the gas side of the heat exchanger assembly. Similarly, gas exit duct 76 is attached to the upper end of heat exchange module 58 for transporting solid particle-containing gas away from the gas side of the heat exchanger assembly. Moreover, located underneath the rectangular portion 70 of I-beam structure 60 is a trapezoidal shaped bin 72. This bin is adapted to place the gas side of heat exchange module 54 in fluid communication with the gas side of heat exchange module 56 so that solid particle-containing gas flowing downwardly through heat exchange module 54 is forced to flow upwardly through heat exchange module 56.

In operation, solid particle-containing gas is introduced into gas inlet duct 74 so that it flows, in the direction of arrows 76, through heat exchange modules 52, 54, 56 and 58, respectively, and out of gas exit duct 76. Secondary fluid is introduced through secondary fluid supply line 78, and flows countercurrently to the solid particle-containing gas through heat exchange modules 58, 56, 54 and 52, respectively, for the desired heat transfer and then out of secondary fluid exit line 80.

The composite heat exchanger system shown in FIG. 3 has numerous advantages which make it useful in a number of varied and different applications. First, because the direction of gas flow is reversed from heat exchange module 54 to heat exchange module 56, the entire heat exchanger assembly is more compact than if the four heat exchange modules were assembled in a straight line configuration. Moreover, turning of the gas 180° as shown also allows the larger and heavier particles in the solid particle-containing gas to fall to the bottom of hopper 72 and thus be removed from the system. In this regard, an optional door 82 can be provided at the lower portion of the hopper 72 to remove any particles which have accumulated.

Finally because the gas vertically flows through the heat exchange modules, deposition of any solid particles on the heat exchange surfaces and the sides of each heat exchange module shell are minimized.

While only two specific embodiments of the inventive heat exchanger have been illustrated and described, it should be appreciated that many changes and modifications of the specifically disclosed heat exchanger can be made without departing from the spirit and scope of the present invention. For example, the location of the inlet and outlet headers can be varied at will. Alternately, inlet and outlet headers can be completely eliminated, with connecting tubes being employed between the various heat exchange plates so that the secondary fluid flows through the plates of each module in series.

In addition, the size and shape of the shell 34 of the inventive heat exchanger can be varied to any shape desired, although it is preferably that the shell have flat sides generally positioned parallel to the uniformly spaced heat exchanger plates. Furthermore, any suitable securing means can be employed to attach respective heat exchange modules to adjacent modules or to appropriate ducting and piping. Finally, it should be understood that the heat exchanger composite shown in FIG. 3 can be run concurrently as well as counter-currently as desired.

The foregoing description and the drawings associated therewith have been provided for illustrative purposes only and are not intended to limit the invention in any way. All reasonable modifications not specifically set forth are intended to be included within the scope of the invention which is to be limited only by the appended claims.

What is claimed is:

1. A heat exchanger module for transferring heat from a hot solid particle-containing gas to a secondary liquid, the heat exchanger module comprising: a plurality of vertically oriented substantially parallel flat rectangular plates, each plate having first and second substantially flat surfaces, a passage for the flow of said secondary liquid between said surfaces and a substantially smooth exterior to permit the unobstructed passage of said solid particle-containing gas thereby, said passage comprising an array of at least one liquid-conducting tubular conduit having a diameter confined within the boundaries of said first and second surfaces and a length substantially in excess of the perimeter of its flat rectangular plate, lying in a pattern extending substantially through the entire area of its flat rectangular plate and having an inlet opening and an outlet opening; shell means surrounding said plurality of flat plates and forming a gas flow path having a gas inlet

end and a gas outlet for the passage of said solid particle-containing gas, said gas flow path enabling said gas to intimately flow by said plurality of flat plates in a direction parallel thereto, and to transfer heat to said secondary liquid flowing through said tubular conduits; supply means to supply said secondary liquid to the inlet opening of each flat plate; withdrawal means to convey heated secondary liquid away from the exit opening of each flat plate; and gas supply means for supplying said hot solid particle-containing gas to the gas inlet end of said gas flow path.

2. The heat exchanger according to claim 1, comprising at least three substantially parallel flat plates, the distance between each of said adjacent flat plates being substantially uniform.

3. The heat exchanger of claim 1, wherein said supply means is an inlet header adapted to distribute secondary liquid to each flat plate for parallel flow through said plurality of flat plates; and further wherein said withdrawal means is an outlet header for collecting the secondary liquid from the secondary liquid outlet of each flat plate.

4. The heat exchanger according to claim 3, wherein said secondary liquid inlet header is located on one side of said plurality of flat plates and wherein the outlet header is located on an opposite side of said plurality of flat plates.

5. The heat exchanger according to claim 1, and further comprising: means to secure the shell of said heat exchanger at the inlet end of said gas passageway to the shell of a substantially identical heat exchanger at the outlet end of the gas passageway in said substantially identical heat exchanger.

6. The heat exchanger module according to claim 1, wherein said shell is rectangular in configuration.

7. The heat exchanger according to claim 1, wherein the secondary liquid passage in each flat plate is so positioned that liquid flows transversely back and forth across the plate.

8. The heat exchanger of claim 1, wherein said solid particle-containing gas flows vertically through said gas flow path.

9. A heat exchanger assembly for processing a gas containing solid particles, developed from at least two heat exchange modules, and wherein each heat exchange module comprises: a plurality of vertically oriented substantially parallel flat rectangular plates, each plate having first and second substantially flat surfaces, a passage for the flow of secondary liquid between said surface and a substantially smooth exterior to permit the unobstructed passage of said gas and its contained solid particles thereby, said passage comprising an array of at least one liquid-conducting tubular conduit

having a diameter confined within the boundaries of said first and second surfaces and a length substantially in excess of the perimeter of its flat rectangular plate, lying in a pattern extending substantially through the entire area of its flat rectangular plate and having an inlet opening and an outlet opening; shell means surrounding said plurality of flat plates and forming a gas flow path having a gas inlet end and a gas outlet end for the passage of said solid particle-containing gas, said gas flow path enabling said gas to intimately flow by said plurality of flat plates in a direction parallel thereto and to transfer heat to said secondary liquid flowing through said tubular conduits; supply means to supply said secondary liquid to the inlet opening of each flat plate; withdrawal means to convey secondary liquid away from the exit opening of each flat plate; means for connecting said supply means to a source of secondary liquid or the withdrawal means of a substantially identical module; means for connecting said withdrawal means to an exhaust of secondary liquid or to the supply means of a substantially identical module; means for connecting said gas inlet end to a gas source or to the gas outlet end of a substantially identical module; and means for connecting said gas outlet end to the gas exhaust or to the inlet end of a substantially identical module; said heat exchanger assembly further including gas supply means fluidly connected to the gas inlet of said gas flow path for supplying a solid particle-containing gas to said heat exchange module.

10. The assembly of claim 9, and further comprising: support means for supporting said heat exchange modules so that at least two modules are in a side by side relationship on said support means; gas conduit means for fluidly connecting the gas outlet end of one of said heat exchange modules to the gas inlet end of the adjacent heat exchange module so that said gas flows through said modules in series.

11. The assembly of claim 10, wherein said gas conduit means changes the gas flow direction by substantially 180°.

12. The assembly of claim 10, wherein said gas conduit means is located below said heat exchanger modules.

13. The assembly according to claim 9, composed of at least four heat exchange modules.

14. The assembly of claim 12 wherein said primary gas conduit means is a trapezoidal shaped bin for collecting particles which become disentrained from said particle-containing gas.

15. The assembly of claim 12 further including means for removing particles which have accumulated in said primary gas conduit means.

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