A heat exchanger with a cooling subsystem and a pressure equalizing system (82) is used in cooling raw gas from a carbonaceous material gasification system. This raw gas contains entrained particles which act as a severe abrasive. A tube sheet onto which this raw gas directly impinges is cooled by a coolant maintained at the same pressure as the raw gas, using a pressure equalizing system comprising a surge tank with a gas/liquid interface to allow pressure transmittal without movement of one fluid into the system of the other fluid.
This invention relates to gasification of carbonaceous materials, and more particularly to apparatus for cooling the raw gas from fluidized bed gasification reactors.

In reactors for the gasification of carbonaceous materials, such as coal, a combustible product gas is produced, as well as solid waste products such as agglomerated ash. In the Process Development Unit (PDU) fluidized bed gasification reactor being operated for the United States Government, particulate coal is injected through one of a number of concentric tubes extending upwardly into the center of a vertical bed-containing pressure vessel. Fluidization occurs in the upper sections.

In the PDU fluidized bed gasification reactor, the untreated product gas from gasified coal is called raw gas and contains a significant amount of particles which are molten at the gasifier exit temperatures of approximately 980°C. These particles, which are of varying chemical composition, will stick both to metallic and non-metallic surfaces regardless of the angle of incidence of the gas flow to the surface, as the gas flows from the gasifier exit. It has been demonstrated that eventually the flow passages plug almost closed with solidified material.
Present information in technical papers and from experimental data obtained from PDU operations indicate that deposition of these molten particles as they exit from the gasifier will not occur if either of the two following conditions are maintained:

(a) The gas temperature does not exceed $705^\circ C$.
(b) The surfaces on which the gas is allowed to impact are metallic and are maintained at less than $260^\circ C$ at the gas/metal interface.

Condition (a) has been achieved by water spray quench, but is not energy efficient for certain operations.

Condition (b) has been achieved by water cooling of an uninsulated metal plate, but erosion has been significant and the pressure differential across the plate necessitates compliance with ASME Boiler and Pressure Vessel Code Section VIII.

It is thus the principal object of the present invention to provide a gasifier system raw gas heat exchanger with tube sheet structures which will not require water spray quenching upstream of the heat exchanger, will not become rapidly plugged by molten particles, will not require compliance with ASME Boiler and Pressure Vessel Codes and when undesirably eroded, permits relatively easy and inexpensive replacement of the eroded parts.

With this object in view, the present invention resides in a heat exchanger for a gas carrying an abrasive particulate comprising a shell having first and second tube sheets extending thereacross at opposite ends thereof and defining particulate containing fluid inlet and outlet chambers, a plurality of tubes supported within said shell between said tube sheets, a third tube sheet extending across said shell adjacent to but spaced from said first tube sheet so as to divide the space between said first and second tube sheets into a first chamber adjacent the inlet end and a second chamber adjacent the outlet end of said shell, inlet means associated with said inlet chamber
for admitting said particulate containing fluid into said inlet chamber, said inlet chamber being in flow communication with the outlet chamber through said tubes, means for flowing a cooling fluid through said second chamber in heat exchange relation with said particulate containing fluid, and means for conducting a buffer fluid through said first chamber, characterized by a pressure equalizing means between said inlet and said first chambers adapted to reduce pressure differential across said first tube sheet.

Preferably, the raw gas which contains entrained particles from gasified material acting as a severe abrasive directly is cooled by a liquid cooling system at the same pressure as the raw gas, using a pressure equalizing system comprising a surge tank to allow pressure transmittal without movement of one fluid into the system of the other fluid.

The invention will become more readily apparent from the following description of a preferred embodiment thereof showing, by way of example only, in the accompanying drawings in which:

Figure 1 is a horizontal sectioned view of a cooled tube sheet heat exchanger, in accordance with the state of the art; and

Figure 2 is a horizontal sectioned view of a cooled pressure equalized tube sheet heat exchanger, in accordance with the invention.

Figure 3 is a horizontal sectioned view of a removable, cooled, pressure equalized tube sheet heat exchanger in accordance with the invention.

Referring now to Fig. 1, there is shown a cooled tube sheet heat exchanger 10 in accordance with the state of the art, comprising a shell 12 containing an inlet port 14, an upper tube sheet 16, a middle tube sheet 18, a lower tube sheet 20, and tubes 22 disposed through the tube sheets 16, 18 and 20, and an outlet port 24.
Penetrating the shell 12 between tube sheets 18 and 20 are an inlet opening 26 and an outlet opening 28 through which flows a first fluid medium in heat exchange relation with tubes 22. Penetrating the shell 12 between tube sheets 16 and 18 are an inlet orifice 30 and an outlet orifice 32 of a tube sheet cooling system 34 using a second fluid medium and comprising piping 36, an auxiliary heat exchanger 38 and a pump 40.

The operation of the heat exchanger 10 in accordance with the state of the art is as follows: A third fluid medium containing an abrasive material, such as raw gas from a coal gasification system, containing entrained particles from gasified coal, enters the shell 12 at the inlet port 14. The particles impinge on the upper tube sheet 16, gradually eroding away the upper tube sheet 16. The raw gas and particles then flow through the tubes 22, and out through the outlet port 24 of the heat exchanger 10. The first fluid medium flows through the inlet opening 26, cools the tubes 22 and flows out the outlet opening 28.

The tube sheet cooling system 34 operates in the following manner. A second fluid medium is moved by pump 40 through inlet orifice 30 between the upper tube sheet 16 and the middle tube sheet 18, cooling the upper tube sheet 16, thence through outlet orifice 32, through piping 36 and the auxiliary heat exchanger 38.

The tube sheet cooling system 34 helps to reduce deposition of the entrained particles on the upper tube sheet 16. However, since the raw gas pressure and the tube sheet cooling system 34 pressure are not related, the upper tube sheet 16 must be built to withstand pressure differentials of greater than 15 psi, thereby necessitating a thicker upper tube sheet 16 and compliance with ASME Code requirements.

Referring now to Fig. 2, there is shown a cooled, pressure equalized tube sheet heat exchanger 50 in accordance with the invention comprising a shell 52 containing
an inlet port 54, an upper tube sheet 56, a middle tube sheet 58, a lower tube sheet 60, tubes 62 disposed through the upper, middle and lower tube sheets 56, 58 and 60 respectively, and outlet port 64. Penetrating the shell 52 between tube sheets 58 and 60 are an inlet opening 66 and an outlet opening 68 through which flows a first fluid medium in heat exchange relation with tubes 62. Penetrating the shell 52 between tube sheets 56 and 58 are an inlet orifice 70 and an outlet orifice 72 of a tube sheet cooling system 74 using a second fluid medium typically water, and comprising piping 76, an auxiliary heat exchanger 78 and a pump 80.

A pressure equalizing system 82 comprising a surge tank 84 and pressure conduit 86 is connected to the heat exchanger 50 by a shell hole 88 and tube sheet cooling system hole 90.

The operation of the heat exchanger 50 in accordance with the invention is as follows: A third fluid medium containing an abrasive material, such as raw gas from a coal gasification system, containing entrained particles from gasified coal, enters the shell 52 at the inlet port 54. The particles impinge on the upper tube sheet 56, gradually eroding away the upper tube sheet 56. The raw gas and particles then flow through the tubes 62, and out the outlet port 64 of the heat exchanger 50.

The tube sheet cooling system 74 operates in the following manner. A second fluid medium is moved by pump 80 between the upper tube sheet 56 and the middle tube sheet 58, cooling the upper tube sheet 56, thence through piping 76 and the auxiliary heat exchanger 78.

The pressure equalizing system 82 operates by transmitting the pressure of the raw gas through shell hole 88, and pressure conduit 86, into the surge tank 84. The surge tank 84 transmits the pressure through the pressure conduit 86 and the tube sheet cooling system hole 90 into the tube sheet cooling system 74.
When it has been determined that the upper tube sheet 56 has outlived its usefulness due to erosion, the upper tube sheet 56 is removed, and new upper tube sheet 56 is installed in its place. Since the pressure between the raw gas and the tube sheet cooling system 74 is now equalized by the pressure equalizing system 82, the upper tube sheet 56 will not be exposed to pressure differentials of greater than about 1kg/cm², the upper tube sheet 56 may be thinner, and the ASME Code requirements need not be met.

Referring now to Fig. 3, there is shown a preferred embodiment of the invention, a cooled, pressure-equalized, removable tube sheet heat exchanger 101 in accordance with the invention comprising a shell 103 having an upper section 105, a middle section 107, and a lower section 109. The upper section 105 and the middle section 107 are mated at an upper flange 111, and the middle section 107 and the lower section 109 are mated at a lower flange 113. The flanges 111 and 113 will typically be mated by bolts 114, but any fastening means is acceptable.

The upper section 105 is comprised of an inlet port 115.

The middle section 107 is comprised of a middle section upper tube sheet 117, a middle section lower tube sheet 119, and a first set of tubes 121 disposed through the middle section upper tube sheet 117 and the middle section lower tube sheet 119.

The lower section 109 is comprised of a lower section upper tube sheet 123, a lower section lower tube sheet 125, a second set of tubes 127 disposed through the lower section upper tube sheet 123 and the lower section lower tube sheet 125, and an outlet port 129 below the lower section lower tube sheet 125.

When the sections 105, 107 and 109 are mated at the flanges 111 and 113, there are formed a first cavity 131 above the middle section upper tube sheet 117, a
second cavity 133 between the middle section upper tube sheet 117 and the middle section lower tube sheet 119, a third cavity 135 between the middle section lower tube sheet 119 and the lower section upper tube sheet 123, a fourth cavity 137 between the lower section upper tube sheet 123 and the lower section lower tube sheet 125 and a fifth cavity 139 below the lower section lower tube sheet 125. The first set of tubes 121 is in flow communication with the first cavity 131 and the third cavity 135, and the second set of tubes 127 is in flow communication with the third cavity 135 and the fifth cavity 139. The first set of tubes 121 will typically abut the second set of tubes 127 within the third cavity 135.

The lower section 109 further comprises inlet opening 141 and outlet opening 143 in the shell 103 in flow communication with the fourth cavity 137.

The heat exchanger 101 further comprises a tube sheet cooling system 145 which is attached to the heat exchanger 101 in the middle section 107 at inlet orifice 147 and outlet orifice 149 and in flow communication with the second cavity 133. The tube sheet cooling system 145 comprises piping 151, an auxiliary heat exchanger 153, a pump 155, and a pressure equalizing flask 157. The pressure equalizing flask 157 is connected to the piping 151 and the shell 103. Thus the pressure equalizing flask 157 is in flow communication with the tube sheet cooling system 145 and the first cavity 131.

The operation of the heat exchanger 101 in accordance with the invention is as follows: A first fluid medium containing an abrasive material, such as raw gas from a carbonaceous material gasification system, containing entrained particles from gasified coal enters the shell 103 at the inlet port 115. The particles impinge on the middle section upper tube sheet 117 gradually eroding away the middle section upper tube sheet 117. The raw gas and particles then flow through the first set of tubes 121, into and through the second set of tubes 127
and into the fifth cavity 139 thence out of the heat exchanger 101 through outlet port 129. Typically, a minimum amount of raw gas and particles will leak into the third cavity 135 because 1) there is no pressure differential to cause flow; and 2) the abutment of the tubes minimizes such leakage. A second fluid medium, typically water, enters the fourth cavity 137 through inlet opening 141, exits through outlet opening 143, and is in heat exchange relation with the second set of tubes 127.

The tube sheet cooling system 145 operates in the following manner. A third fluid medium, typically water, is moved by pump 155 through piping 151 through inlet orifice 147 into the second cavity 133 in heat exchange relation with the middle section upper tube sheet 117, then through outlet orifice 149, then through auxiliary heat exchanger 153. Pressure across the middle section upper tube sheet 117 is equalized by the transmittal of pressure through the pressure equalizing flask 157 which is in flow communication with the first cavity 131 and the tube sheet cooling system 145. Typically, there will be a gas/liquid interface within the pressure equalizing flask 157 which will minimize mixing between the first and third fluid mediums. As an alternative, if the first fluid medium were a liquid, the third fluid medium could be a gas. This embodiment would also result in a gas/liquid interface.

When it has been determined that the middle section upper tube sheet 117 has outlived its usefulness due to erosion, the middle section 107 will be separated from the heat exchanger 101 at flanges 111 and 113 and an identical new middle section 107 comprising middle section upper tube sheet 117, middle section lower tube sheet 119 and first set of tubes 121 is installed in its place. Since the pressure in the first cavity 131 is equalized with 1) the pressure in the second cavity 133 through the pressure equalizing flask 157, and 2) the pressure in the third cavity 135 through the first set of tubes 121, it
can be seen that the pressure differentials across the middle section upper tube sheet 117 and middle section lower tube sheet 119 are all less than 15 psi.

The preferred embodiment of the invention has several advantages over the prior art. One advantage is that, in an abrasive environment which causes severe erosion of the tube sheet, an easily replaceable tube sheet will save a significant portion of the cost of the entire heat exchanger 101 and reduce down time. This results from the ability to repair a heat exchanger 1) using a component cheaper than the whole heat exchanger, 2) faster than the replacement of the whole heat exchanger. Another advantage is that, since the pressure differential across the tube sheets 117 and 119 contained in the removable middle section 107 is less than 15 psi, the requirements of ASME Boiler and Pressure Code Section VIII are not applicable. As a result, the tube sheets 117 and 119 can be made thinner and without the stringent quality controls of the ASME Code. The cost of this section is therefore cheaper than a removable tube sheet without the pressure equalization feature which would have to meet the ASME Code. A further advantage of the invention is that due to the cooled tube sheet feature, the heat exchanger 101 will be less likely to plug and will therefore require less maintenance and repair.
1. A heat exchanger for a gas carrying an abrasive particulate, comprising a shell (52,109) having first and second tube sheets (56,60) extending thereacross at opposite ends thereof and defining particulate containing fluid inlet and outlet chambers, a plurality of tubes supported within said shell (52,109) between said tube sheets (56,60), a third tube sheet (58) extending across said shell (52) adjacent to but spaced from said first tube sheet (58) so as to divide the space between said first and second tube sheets into a first chamber adjacent the inlet end and a second chamber adjacent the outlet end of said shell (52), inlet means associated with said inlet chamber for admitting said particulate containing fluid into said inlet chamber, said inlet chamber being in flow communication with the outlet chamber through said tubes (62), means for flowing a cooling fluid through said second chamber in heat exchange relation with said particulate containing fluid, and means for conducting a buffer fluid through said first chamber, characterized by a pressure equalizing means (84,86) between said inlet and said first chambers adapted to reduce pressure differential across said first tube sheet (56).

2. A heat exchanger according to claim 1, characterized in that said pressure equalizing means (84,86) comprises a duct (86) interconnecting said first chamber and said inlet chamber and including a surge container (84).
3. A heat exchanger as claimed in claim 1 or 2, characterized in that a fourth tube sheet (123) extends across said shell (109) adjacent to, but spaced from said third tube sheet (119) so as to provide a third chamber between said first and second chambers.

4. A heat exchanger according to claim 3, characterized by a second pressure equalizing means between said inlet chamber and said third chamber.

5. A heat exchanger according to claim 3 or 4, characterized in that said tubes consist of first and second sets of aligned tubes (121, 127) separable in said third chamber and said shell (109) is also separable essentially in a plane extending through said third chamber.

6. A heat exchanger as claimed in any of claims 1 to 5, characterized in that said buffer fluid conducting means is a flow circuit including a pump (80,105) and a heat exchanger (78,153) for cooling said buffer fluid.