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Grimes, deceased

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[54] **MODULATABLE HEAT EXCHANGER WITH RESTRAINT TO AVOID CONDENSATION**

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[21] Appl. No.: **431,121**

[52] **U.S. Cl.** **165/1,** 165/134, 165/143, 165/154, 165/39

[51] **Int. Cl.** **B60h 1/00**

[58] **Field of Search** 165/1, 39, 40, 154, 134, 165/143

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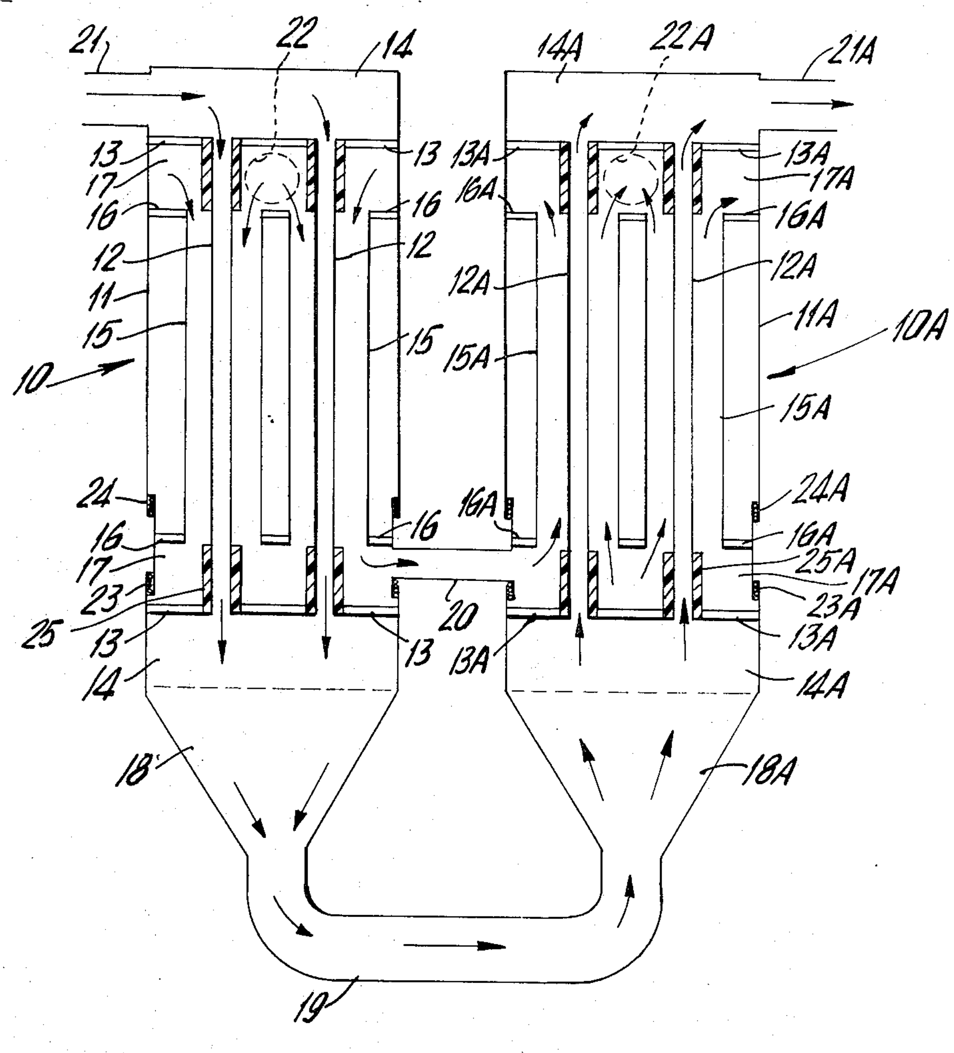
[57] **ABSTRACT**

A heat exchanger system capable of being modulated for cooling hot dust-laden flue gas having an elevated dew point is provided comprising, a heat exchanger formed of a vertical cylindrical shell containing a bank of tubes vertically disposed therein coupled to tube manifolds at opposite ends thereof such that the bank of tubes communicates with a hot gas inlet and a hot gas outlet coupled respectively to said manifolds each of said tubes being surrounded by a tube to provide annular spaces having manifolds communicating therewith through which air is circulated in said heat exchanger in concurrent flow with said hot flue gas, means being provided for maintaining a flow of hot flue gas through said heat exchanger to a downstream line, including a closed circuit air line with a blower for maintaining a flow of air through said heat exchanger in concurrent flow and heat exchanging relationship with said hot flue gas, valve means and temperature-sensing devices being provided in the system to control the air flow and thus the temperature of the heat exchanger at above the dew point temperature of the cooled flue gas.

9 Claims, 6 Drawing Figures



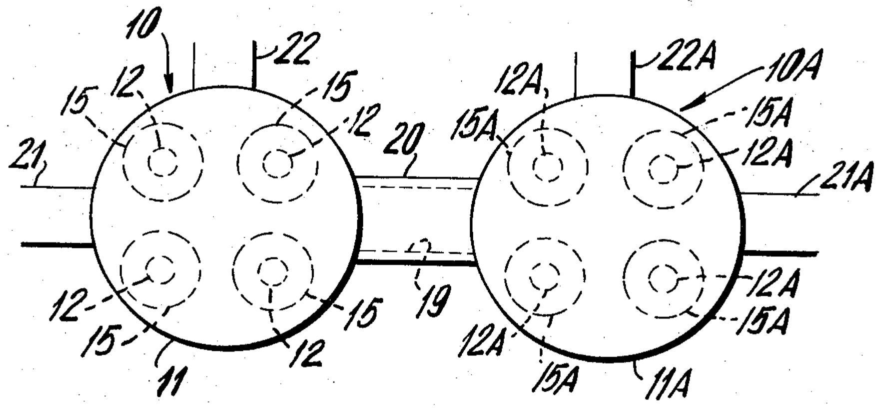

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FIG.1

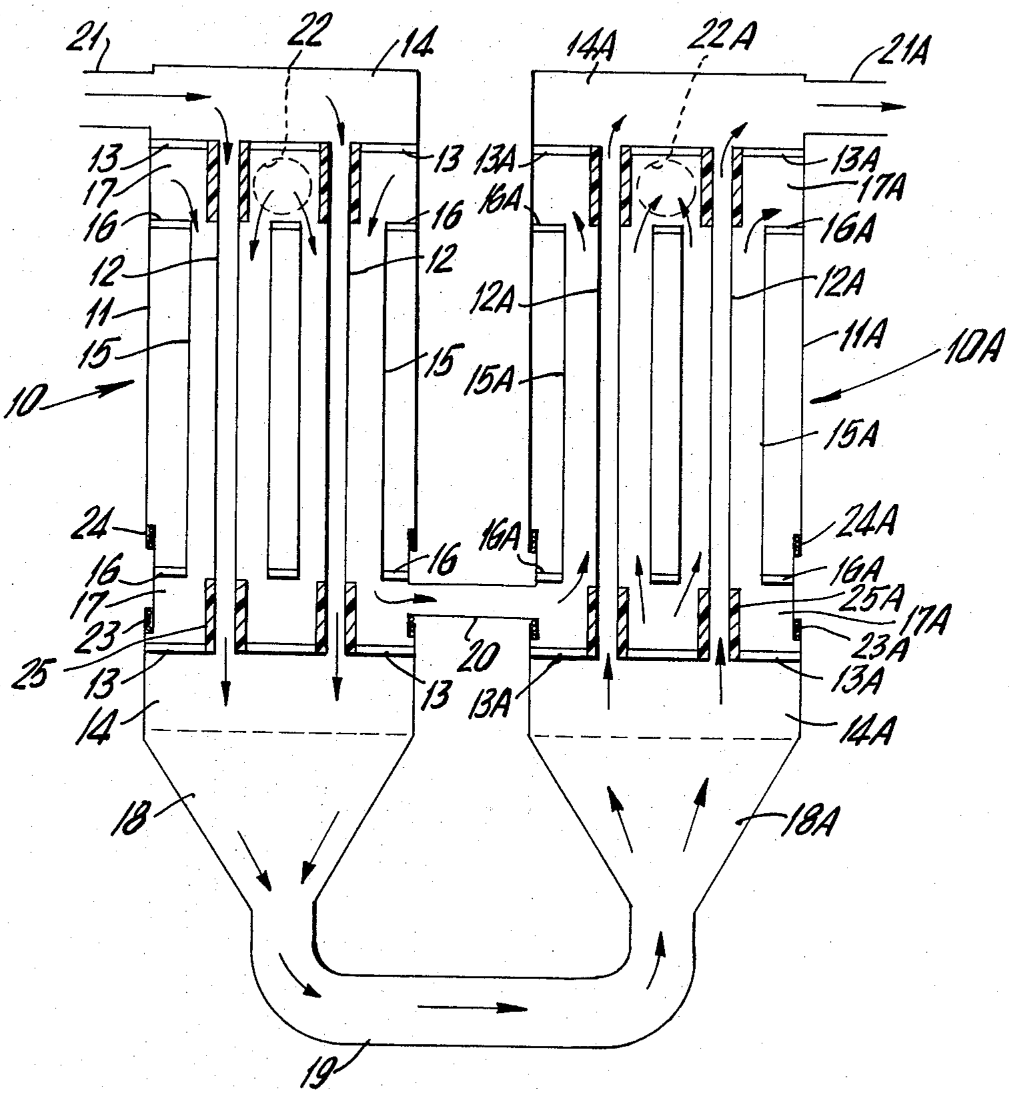
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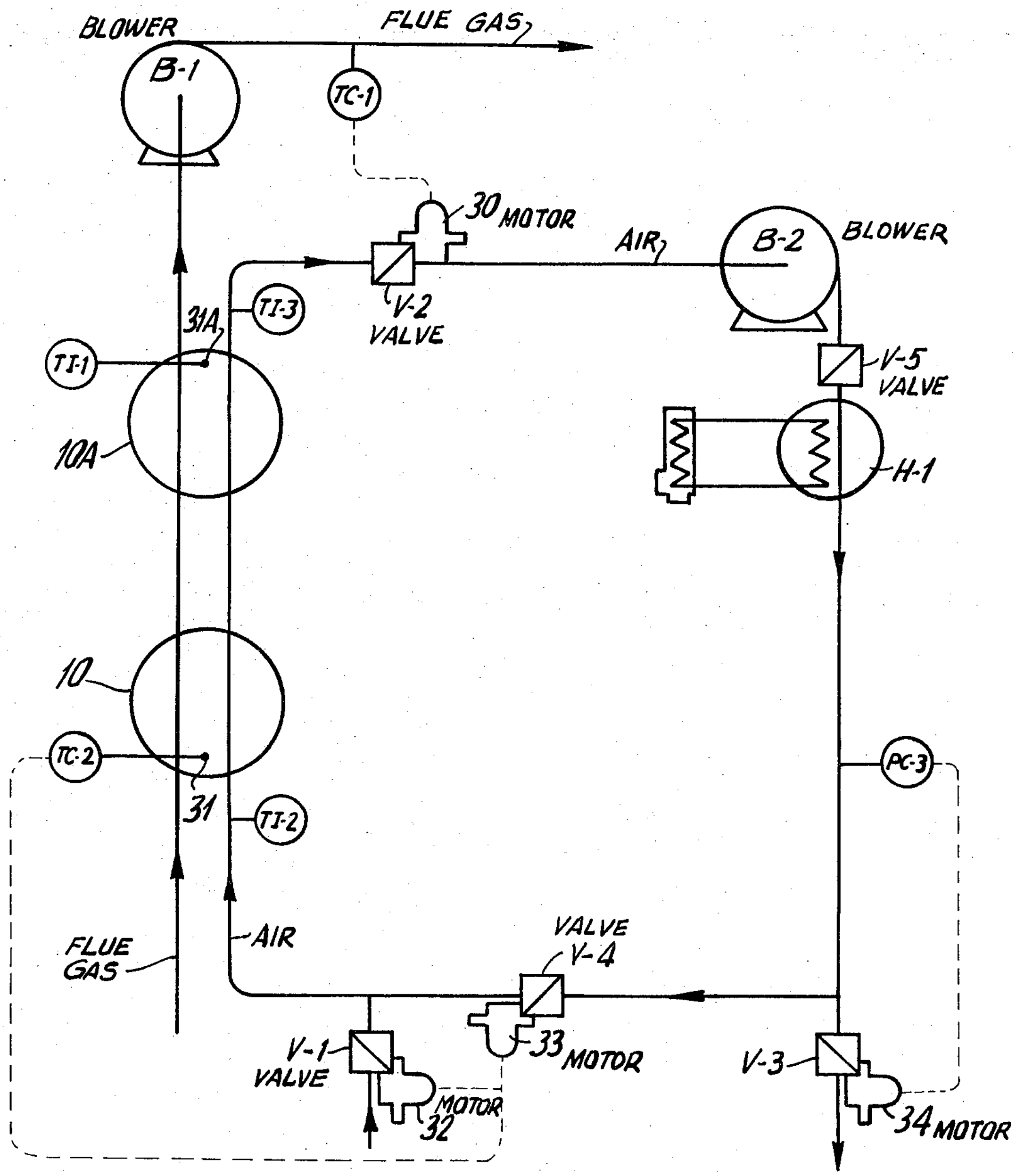
FIG.2


BLOWER
B-1
FLUE GAS
TC-1
30 MOTOR
AIR
B-2
BLOWER
V-2
VALVE
TI-3
31A
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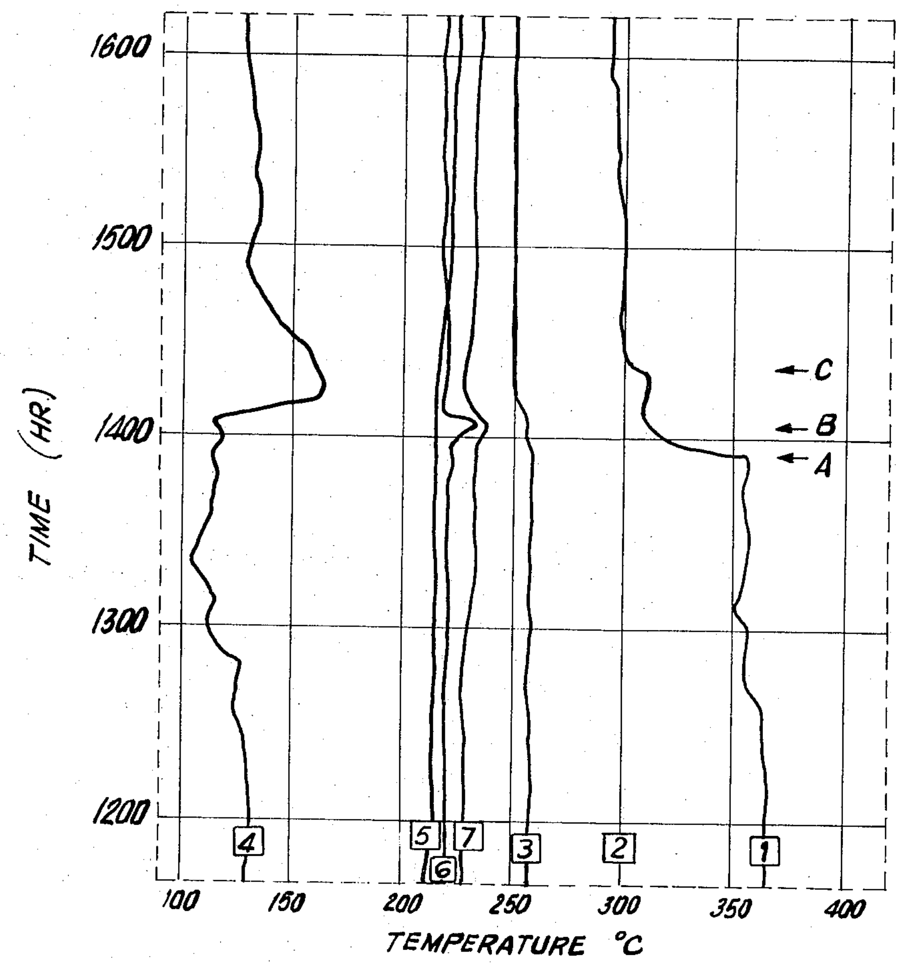
V-5
VALVE
10A
H-1
10
TC-2
31
TI-2
PC-3
AIR
FLUE
GAS
VALVE
V-4
33 MOTOR
V-1
VALVE
MOTOR
32
V-3
34 MOTOR

FIG.3



MULTIPOINT TEMPERATURE RECORDER CHART FROM HEAT EXCHANGER OPERATION

THERMOCOUPLE IDENTIFICATION

TEMPERATURE OF FLUE GAS: [1] ENTERING FIRST UNIT, [2] LEAVING FIRST UNIT, [3] LEAVING SECOND UNIT

TEMPERATURE OF FLUE GAS: [4] ENTERING FIRST UNIT, [5] LEAVING SECOND UNIT.

TEMPERATURE OF HEAT EXCHANGE SURFACE: [6] ENTERING FIRST UNIT, [7] LEAVING SECOND UNIT.

NOTES

A. FLOW RATE OF FLUE GAS INCREASED FROM 7122 TO 9038 LBS./HOUR FT.^{2}.
B. REDUCED SET POINT OF FLUE GAS TEMPERATURE CONTROLLER FROM 260°C (500°F) TO 250°C (482°F).
C. FLOW RATE OF FLUE GAS INCREASED FROM 9038 TO 10,284 LBS./HOUR FT.^{2}.

FIG. 4

TC-1 AND TC-2 TEMPERATURE CHARTS FROM HEAT EXCHANGER OPERATION

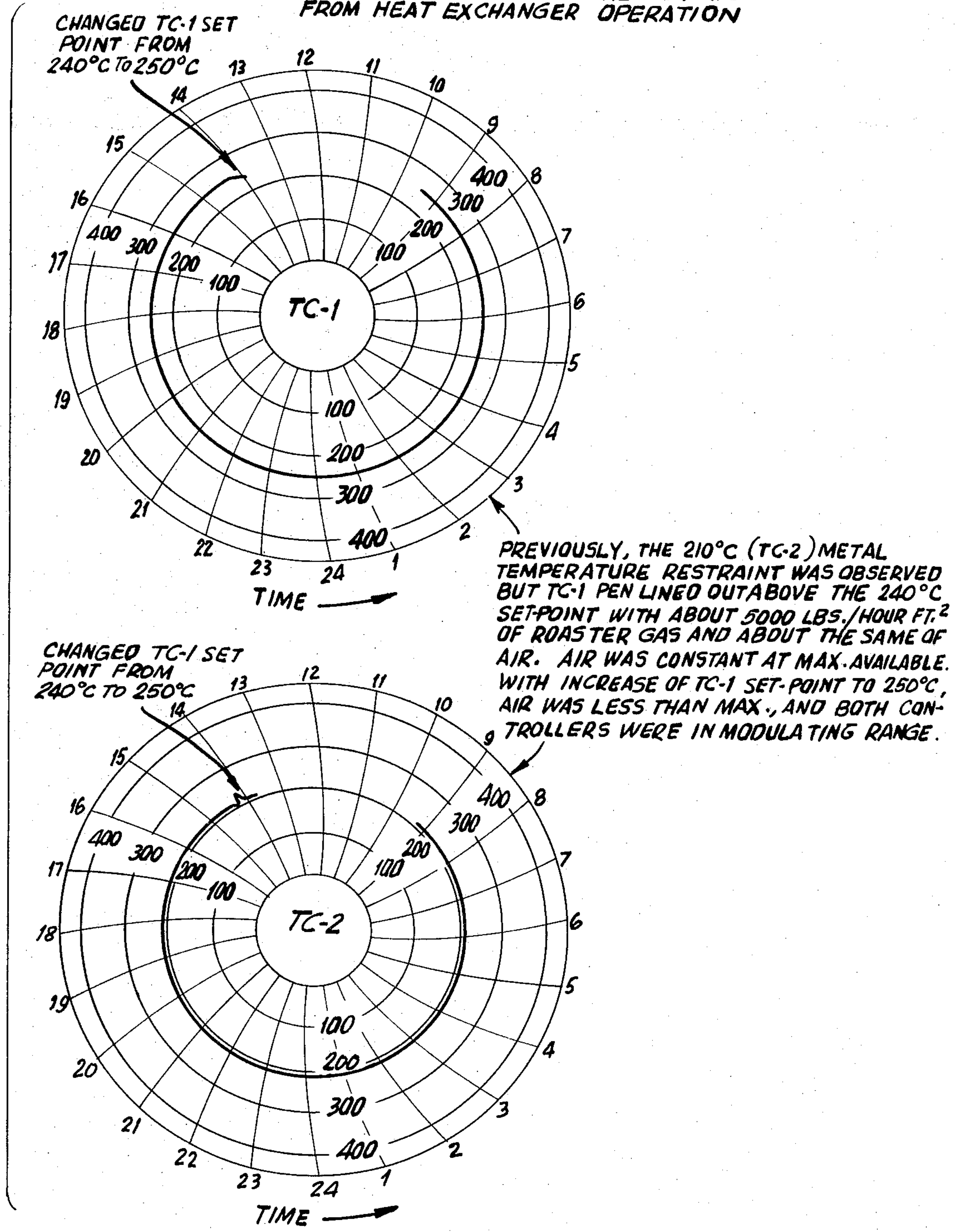


FIG.5

TC-1 AND TC-2 TEMPERATURE CONTROLLER CHARTS FROM HEAT EXCHANGER OPERATION

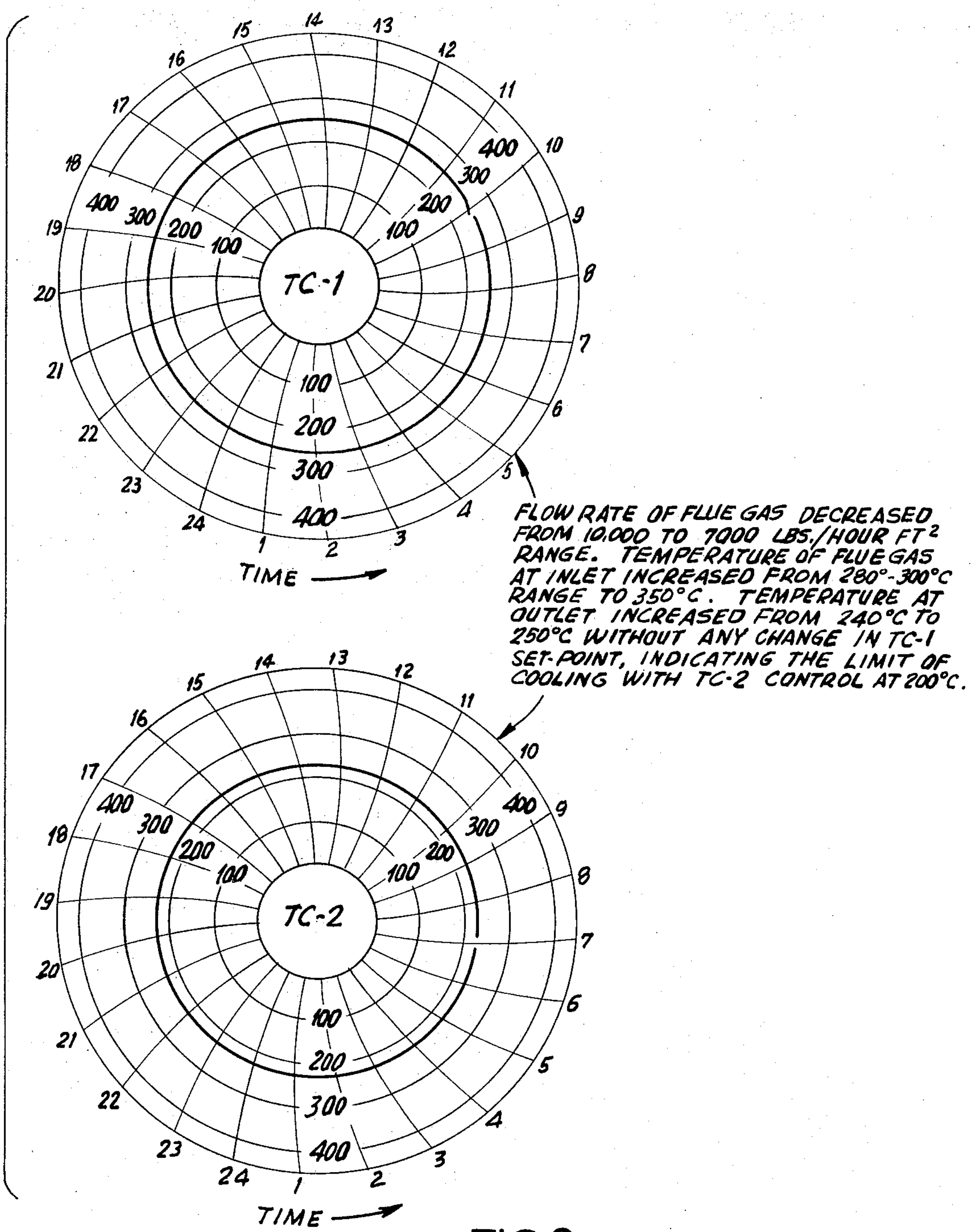


FIG.6

MODULATABLE HEAT EXCHANGER WITH RESTRAINT TO AVOID CONDENSATION

This invention relates to a heat exchange system and method for cooling hot dust-laden flue gases having an elevated dew point, while inhibiting condensation of moisture on heat exchanger surfaces.

BACKGROUND OF INVENTION

Normally, molybdenum sulfide roasters are operated in a manner to assure substantially constant temperatures in the hearth atmosphere. The flue gas emanating from the roaster is dust-laden and fairly hot. The flow rate of the flue gas varies with the operation.

By way of illustration, in a known roaster installation, the flue gas temperature is nominally 400°C (752°F), but may vary between the limits 38020 C and 420°C (716°F and 788°F). The flue flow rate varies between 43,000 and 81,000 pounds per hour, depending on the production level and operation, and may contain as much as 15% of the roaster input as dust, which may be removed by mechanical or electrostatic collectors.

The use of cyclones, multiclones or electrostatic precipitators has limitations in that they cannot be operated at the flue gas temperature without fouling.

Cooling of the flue gas without admission of cold air reduces the volume and favors subsequent treatment to control sulfur oxide emissions for environmental reasons.

For these and other reasons, a control system is required to regulate the temperature of the flue gas to somewhere between dew point, about 200°C (392°F), and 260°C (500°F).

It would be desirable in light of the foregoing to provide a cooling system for cooling dust-laden flue gas, while maintaining the temperature of the heat exchange surface at or above the dew point of the flue gas in order to avoid corrosion and fouling of the heat exchange surface due to condensation of fluids in the system.

OBJECTS OF THE INVENTION

One object of the invention is to provide a modulatable heat exchanger system for cooling dust-laden flue gas, such as flue gas from a molybdenum sulfide roaster having an elevated dew point.

Another object is to provide a method of cooling dust-laden flue gas using a modulatable heat exchanger system in which the conditions are automatically controlled during the heat exchange cycle to avoid condensation of fluids on heat exchanger surfaces.

These and other objects will more clearly appear from the following disclosure and the appended drawings, wherein:

FIGS. 1 and 2 depict plan and elevation views, respectively, of a pair of series connected heat exchangers which may be employed in carrying out the invention,

FIG. 3 is a schematic drawing of the flow circuit together with control devices for carrying out the various embodiments of the invention,

FIG. 4 represents a multipoint temperature recorder chart illustrating heat exchanger operation with respect to flue gas temperature, air temperature and the temperature of the heat exchange surface; and

FIGS. 5 and 6 are temperature recording charts showing the temperature control obtained with thermocouples TC-1 and TC-2.

BROAD STATEMENT OF THE INVENTION

Stating it broadly, a modulatable heat exchanger system is provided for cooling hot dust-laden flue gas having an elevated dew point. The system utilizes a heat exchanger formed of a vertical cylindrical shell containing a bank of tubes vertically disposed therein coupled to tube manifolds at opposite ends thereof such that the bank of tubes communicates with a hot gas inlet and a hot gas outlet coupled to said shell, each of said tubes being surrounded by another tube to provide annular spaces with manifolds communicating therewith through which air is circulated in said heat exchanger in concurrent flow with said hot flue gas. The system has means for maintaining a flow of hot flue gas through said heat exchanger to a downstream line and a closed circuit air line including a blower for maintaining a flow of air through said heat exchanger in concurrent flow and heat exchanging relationship with the hot flue gas. A first valve means is provided for feeding air into said line when needed and a first temperature-sensing means for sensing the temperature of the flue gas downstream of said heat exchanger.

In addition, a second valve means is provided in the air line operable in accordance with the temperature sensed by the first temperature-sensing means for controlling the flow of the air through said heat exchanger, a second temperature-sensing means being associated with a portion of the heat exchanger in contact with the flue gas for sensing the temperature of the heat exchanger at said portion, the second temperature-sensing means being operably coupled to said first valve means for feeding fresh air to the air line. A pressure-sensing device is provided in the air line coupled to an exit air gas valve for opening said valve to expel air from the line when the pressure rises above a predetermined set pressure, whereby the flow of air through the heat exchanger is independently controlled so as to maintain the average temperature of the heat exchanger at above the dew point of the hot flue gas during the cooling thereof. The circulating air may be heated to preheat the heat exchanger during start-up to avoid condensation of fluids during the start-up period.

An advantage of the invention is that by maintaining the heat transfer at above the dew point of the gas, the unit can be constructed of mild steel and the problem of dust collection on a wet surface avoided or greatly inhibited.

DETAILS OF THE INVENTION

In carrying out the invention, the flow of hot fluid (flue gas) inside a heat exchange tube is preferred for the reason that (1) all heat exchange from the flue gas is under control and (2) the tubes are more accessible for cleaning when necessary.

The flow of colder fluid (air) in the annular space surrounding the heat exchange tube is also preferred in that it assures flow of the air parallel to the flow of the flue gas and also assures a substantially equal mass flow of air for each heat exchange tube. The temperature change for both hot and cold fluids is a function of the relation of the mass flow of each to the combined mass flow of both fluids.

Concurrent flow of the two fluids is desirable as otherwise longer heat exchange tubes would be required for countercurrent flow of the two fluids.

As illustrative of one embodiment of a heat exchanger which may be employed, reference is made to FIGS. 1 and 2, FIG. 1 being a plan view and FIG. 2 a sectional view in elevation of the inner parts of a pair of heat exchanger units connected in tandem.

Referring to FIGS. 1 and 2, a pair of heat exchanger units **10, 10A** is shown, the "A" designation indicating the same corresponding elements in the corresponding unit. The two units comprise vertically disposed shells **11, 11A** having confined therein a bank of heat exchange tubes **12, 12A** which are solidly connected to and between tube sheets or headers **13, 13A**, said bank of tubes communicating with manifolds **14** and **14A** located adjacent the tube sheets or headers of heat exchanger units **10** and **10A**.

Surrounding each tube are annular tubes **15, 15A** which are solidly attached to and between tube sheets or headers **16, 16A**, said annular tubes communicating with manifolds **17, 17A** adjacent headers **16, 16A**.

The two units have a converging bottom **18, 18A** in the form of an inverted cone connected together by a U-shaped conduit **19.** The air manifolds **17, 17A** at the lower portion of the units are coupled together via conduit **20.** Thus, as the hot flue gas passes through the two series-connected heat exchange units by way of conduit **19,** the air passes through annular tubes **15** as well as through annular tubes **15A** by way of connecting conduit **20.**

The hot flue gas is drawn into unit **10** through inlet **21** by means of a blower, not shown, the flue gas entering manifold **14** and, hence, heat exchange tubes **12.** Concurrently with the flow of flue gas, air is similarly drawn into unit **10** via inlet **22** into manifold **17** and down through the annular spaces surrounding tubes **12.**

The hot flue gas flows through the tubes into lower manifold **14** and via U-shaped conduit **19** into the bottom of heat exchange unit **10A** through lower manifold **14A**, tubes **12A**, upper manifold **14** and then through flue gas exit **21A** downstream of the gas flow.

Meanwhile, the cooling fluid (heated or unheated air) flows concurrently and in parallel with the flue gas through annular tubes **15** into lower manifold **17**, via conduit **20** into lower manifold **17A**, up through annular tubes **15A** into upper manifold **17A** and finally through exit **22A**.

By controlling the flow and temperature of the air independently of the flow of the flue gas, the temperature of the heat exchanger surfaces can be maintained at above the dew point of the flue gas being cooled and condensation of corrosive fluids within heat exchanger tubes **12** and **12A** substantially inhibited, if not avoided. A schematic illustrating one embodiment of a system for achieving such a control is shown in FIG. 3 to be discussed later.

As will be noted further from FIG. 2, packed joints **23, 23A** are provided to allow for differential expansion of heat exchange tubes **12, 12A** and annular tubes **15, 15A.** Similarly, expansion joints **24, 24A** are provided to allow for differential expansion between shell **10, 10A** and annular tubes **15, 15A.**

It is preferred that the extremities of heat exchange tubes **12, 12A** be insulated, e.g. with insulation **25, 25A.** The insulation around the heat exchange tubes within the colder fluid manifolds **17, 17A** is provided to eliminate problems associated with heat exchange in cross flow. With a multiple number of heat exchange tubes, the colder fluid is heated by contact with the first heat exchange tubes in the flow path. Theoretically, at least, the hotter fluid in these first heat exchange tubes enters the parallel flow section at lower temperature than the hotter fluid in subsequent heat exchange tubes. Conversely, the colder fluid entering the first annular spaces in the flow path enters the parallel flow section at lower temperature than subsequent annular spaces. It is desirable to have uniform temperature distribution for all heat exchange tubes and substantially equal temperature differentials between the hot and cold fluids for each tube.

The shell **11** (and **11A**) serves as a base insulation on each unit, and to provide an insulating blanket of air around the annular tubes **15, 15A**, otherwise temperature loss through the annular tube wall will result in an uneven temperature distribution between the colder fluid in the various annular spaces.

It is desirable that all components of the air circulating system be well insulated. Heat loss from the air circulating system determines the maximum available temperature of the air entering the heat exchanger, when the possibility of adding extraneous heat is neglected. The maximum available air temperature determines the maximum allowable air supply for any stated minimum hot fluid flow. In turn, the maximum available air flow determines the maximum heat exchange capacity of the heat exchange unit.

It is preferred that the heat exchange units be erected vertically. This avoids the problem of dust settling out on heat transfer surfaces when the velocity of the hot fluid is low. The heat exchanger may be constructed as a single unit or as a group of units connected in series.

FIG. 3 shows schematically the manner in which the heat exchanger control system functions, using a closed circuit air circulating line with provisions for feeding fresh air into the line and provisions for bleeding off air in instances where the air pressure in the line exceeds a predetermined value, particularly heated air.

A motorized butterfly valve V-**2** in the air circulating line is adjusted to control via motor **30**, the amount of air flow in the line in response to the downstream flue gas temperature measured by a temperature controller TC-**1.** The motorized valve may open further to permit greater air flow when the downstream flue gas temperature is above the predetermined set point or turned down to decrease the flow when the downstream flue gas temperature falls below the predetermined set point. The temperature controller, well known in the art, has a proportional band and automatic reset which causes the valve (damper) to move to a position to maintain the downstream flue gas temperature at the set point. Temperature controller TC-**1** operates to move the valve via motor **30** towards its full open or to its full closed position in striving to satisfy the required set point.

A second temperature controller TC-**2** is provided to sense the temperature of the heat exchange surface in contact with the flue gas as shown at Point **31.** Calculations indicate that the sensing point may be advantageously located at the inlet of the first heat exchange unit or alternatively, at the outlet of the last heat exchange unit. These calculations indicate that the lowest heat exchange surface temperature must either be at the inlet of the first unit or the outlet of the last unit depending upon the particular mass flow rates and inlet fluid temperatures. As a practical operation, the inlet of the first unit is the preferred location of the sensing point for the reason that observations have shown the lowest heat exchange surface temperatures would be at the inlet of the first unit 10; the temperature of the heat exchange surface at the inlet of the first unit is immediately affected by a change in mass flow rates or inlet temperatures, whereas the heat transfer surface temperatures response at the outlet of the last unit 10A is tempered by the heat capacity of the heat exchanger metal.

Temperature controller TC-2 controls motorized butterfly valves V-1 and V-4 via motors 32 and 33, respectively. These two valves are mechanically linked so that they move in opposite directions, one opening as the other closes and vice versa. The motorized butterfly valve V-1 controls the amount of fresh air entering the air circulating system. The motorized butterfly valve V-4 controls the amount of heated air which is recirculated. If the temperature is below the set point, temperature controller TC-2 moves valves V-1 and V-4 in a way to increase the temperature of the air entering the heat exchanger by reducing the amount of fresh air intake and increasing the amount of heated air recirculated. If the heat exchange surface temperature is above the set point, temperature controller TC-2 moves the motorized butterfly valve (damper) V-1 via motor 32 toward the open position and the motorized butterfly valve (damper) V-4 toward the closed position. As with the first controller TC-1, temperature controller TC-2 is free to move the valves under its control to their full travel positions in its effort to maintain the heat transfer surface temperature at the set point.

The two temperature controllers, TC-1 and TC-2, are free to act independently, but with the action of either affecting the temperature element measured and controlled by the other. Under these circumstances, there are conditions under which the action of one controller counteracts the action of the other, only one of the two set points (flue gas outlet temperature and heat transfer surface temperature) can be satisfied. The air handling capacity is engineered so that the maximum air flow at its highest realizable temperature is insufficient to reduce the heat transfer surface below the dew point with the minimum design flue gas flow in the system. This insures that the heat transfer surface temperature restraint is observed in preference to observing the set point for flue gas temperature control. Maximum air flow setting is determined by a predetermined setting of manually operable valve V-5.

A pressure controller PC-3 senses the pressure in the air circulating system downstream from the air blower B-2. A motorized butterfly valve V-3 is controlled by the pressure controller PC-3 to which motor 34 is responsive. This valve controls the amount of heated air exhausted from the air circulating system. As the pressure controller PC-3 senses an increase in pressure, it causes motorized butterfly valve V-3 to open to discharge heated air from the air circulating system to maintain a constant pressure at the air blower discharge irrespective of the proportions of ambient air and recirculated hot air to be introduced into the heat exchanger. As pressure controller PC-3 senses a decrease in pressure, it causes the motorized butterfly valve V-3 to move toward the closed position and reduce the exhaust of heated air from the air circulating system. Inasmuch as the lowest heat transfer surface temperature may occur at either end of the heat exchanger, it is suggested that a temperature indicator TI-1 be provided at point 31A at the end (unit 10A) opposite the location of temperature controller TC-2. Test calculations have found only a few degrees' difference in the heat transfer surface temperature at the two ends of the heat exchanger. In the absence of temperature indicator TI-1, some small elevation of the set point above the dew point of the flue gas will suffice.

A system for preheating the heat exchangers by circulating heated air is desirable. This is indicated by the presence of heater H-1 shown in the schematic flow and control of FIG. 3. Its function is to heat a suitable quantity of air for circulation in the closed system as a means for preheating the heat exchange tubes prior to introduction of flue gas. Temperature indicators TI-2 and TI-3 may be placed in the air line as shown to provide a check on the air temperature. Introduction of flue gas into cold heat exchange tubes could cause some condensation with consequent fouling of the heat transfer surface during start-up. Thus, preheating the tubes prior to start-up may be desirable.

As is apparent from the foregoing, a method is provided for modulating the temperature of a heat exchanger in which hot flue gas is passed through a bank of heat exchanger tubes, each of the tubes being surrounded by an annular tube to provide annular spaces through which air is passed in concurrent and heat exchanging relationships with the flow of said flue gas, the flue gas flowing through the heat exchanger to a downstream line for further treatment, the air used for extracting heat from the flue gas being continuously circulated through the heat exchanger via a closed circuit air circulating system.

The method in its broad aspects comprises continuously feeding flue gas at variable temperatures and flow rates through the heat exchanger tubes; continuously feeding air (either heated or unheated) concurrently along and around the outside surface of the heat exchange tubes at a variable but not exceeding a predetermined maximum flow rate to effect cooling of said flue gas; continuously sensing the temperature of a portion of said heat exchanger in heat exchange contact with said flue gas with respect to a predetermined set condition; when needed, varying the input of air into said air circulating system via a first valve responsive to the difference of temperature sensed at the heat exchanger portion; continuously sensing the temperature of the flue gas leaving said heat exchanger downstream thereof with respect to a predetermined set condition; varying the flow of air through said heat exchanger via a second valve in the air circuit responsive to the difference in temperature between said flue gas and the set condition; continuously sensing the air pressure in said air circulating system with respect to the predetermined pressure set condition; controlling the pressure in said air line with respect to said set condition via a third valve responsive to the difference in pressure sensed, such that when the pressure exceeds the predetermined set condition, the valve is opened to bleed air from the line in order to adjust the pressure to the set condition; and maintaining the foregoing controls independent of each other; whereby the temperature of the heat exchange surface is maintained at a predetermined temperature above the dew point of the flue gas during the cooling thereof in order to inhibit condensation of fluids on heat exchange surfaces.

According to a detailed study, the control system functions as follows:

1. Whenever the set point for the flue gas temperature is above the temperature which can be attained while still satisfying the metal wall temperature restraint, the system will drive toward minimum air flow and minimum air temperature entering the heat exchanger. In this case, the metal wall temperature rises above the set point.
2. However, with increasing quantities of flue gas flow, the metal wall temperature will decrease toward the set point until the unique condition is reached that both set points are satisfied.
3. Whenever the flue gas flow rate is above the unique condition that both set points can be satisfied, the control system will drive towards maximum air flow and maximum air temperature entering the heat exchanger. If maximum air volume is reached prior to attaining maximum air temperature, the metal wall temperature set point will be satisfied but the flue gas temperature will rise above the set point. If the maximum air temperature is reached prior to attaining maximum air volume, the flue gas temperature set point will be satisfied but the metal wall temperature will fall below the set point.
4. Lower ambient air temperature has no effect on the range of flue gas flow rates through which the exchanger may be operated without driving to maximum air flow rate and air temperature entering the heat exchanger. It does decrease the amount of air required for heat balance, and reduces the maximum air flow rates which can be provided without fear of violating safe metal wall temperature restraints.
5. Decreasing the set point of the flue gas temperature controller reduces the operating range below the unique conditions at which both set points can be satisfied.

Thus, the heat exchanger design and control system comprises:

1. A system capable of handling a variable flow of dust-laden flue gas at variable input temperature with restraint to hold the heat transfer surface temperature above the dew point of the flue gas.
2. A system capable of maintaining constant heat transfer surface temperature irrespective of the flue gas flow rate or temperature (so long as flue gas flow rates and/or temperature are within design limits).
3. A system capable of maximizing heat transfer allowable while observing the heat transfer surface temperature restraint.
4. A system capable of maintaining reasonably constant downstream flue gas temperature irrespective of flue gas flow rates. (With 750°F [400°C] inlet temperature to 40 feet heat exchange length and 400°F [205°C] heat exchange surface temperature restraint downstream flue gas temperature varies from 523 to 538°F [263°C to 281°c] as the flow rate increases from 5000 lbs/hour ft^2 to 10,000 lbs/hour ft^2.)
5. A system with a ratio of maximum to minimum design flow rate of flue gas limited only by allowable pressure drop through the system and required temperature differential through the heat exchanger.
6. A system capable of extended length to effect increased temperature differential through the heat exchanger without changing flow quantities or the ratio of maximum to minimum flow design.
7. A system capable of handling flue gas at input temperatures approaching the dew point of the flue gas, provided that the allowable heat loss is no less than the heat loss from the circulating air system.
8. A system capable of handling flue gas at higher than design temperature, provided the temperature does not exceed the temperature limitations for the materials of construction, and provided that higher downstream flue gas temperatures are permissible.

In respect to Items 5, 6, 7 and 8, heat balance calculations have covered mass flow rates of flue gas from 5,000 lbs/hr ft^2 to 15,000 lbs/hr ft^2 with input temperatures from 530°F to 750°F (278°C to 400°C) and heat exchange lengths of 40 to 80 feet, assuming the dew point of the flue gas as 400°F (205°C). For a flue gas flow rate of 15,000 lbs/hr ft^2 at 750°F (400°C) input temperature to the unit of Item 4, the downstream flue gas temperature would be 584°F (306°C) compared to 538°F (281°C) for 10,000 lbs/hr ft^2, when using the same maximum air flow rate. Increasing the maximum allowable air flow rate would reduce the downstream flue gas temperature of 15,000 lbs/hr ft^2 from 584°F (306°C) to 548°F (287°C). Changing the length of the heat exchange tubes will change the downstream temperature measurements of flue gas and air, but has little effect on the temperature of the heat transfer surface. Changing the number of heat transfer tubes down not change the downstream temperature measurements to any great extent. Changing the size of the tubes will, of course, alter the applicable flow rates.

In actual operation, data obtained for a particular heat exchanger system of the type of the present invention is illustrated by FIGS. **4, 5, 6** and Table 1. The particular heat exchange unit consisted of two units in series, each 6 meters (19.68 feet) long with 165 × 4.5 millimeter tubes inside 267 × 5 millimeter tubes, with the flue gas flowing through the annular space between the two pipes in accord with the control system described. FIG. **4** is a continuous record of flue gas, air, and heat exchange surface temperatures as monitored by a multipoint recorder during an interval that the flue gas flow rate changed from 7,100 lbs/hr ft^2 at about 360°C (680°F) to 10,200 lbs/hr ft^2 at about 300°C (572°F). FIGS. **5** and **6** are a record of the temperature control effected by TC-**1** and TC-**2** of FIG. **3.**

The data of Table 1 were compiled from a pilot run in which the system was continuously operated for about 3 months. Continuous records were kept and Table 1 represents typical measurements for selected heat transfer surface temperature set points (note last column of Table 1) correlated with instantaneous changes in flue gas flow rates and inlet temperature (note the third and fourth columns of the table). In Table 1 below, the set point for the temperature controller (TC-**2**) was successively changed from 230°C to 215°C to 210°C.

TABLE I

TIME	DATE	MASS FLOW RATE OF FLUE GAS LBS./(HR.)(FT.)²	TEMPERATURE OF FLUE GAS INLET °C	(°F)	OUTLET °C	(°F)	METAL TEMP. °C	(°F)
0800	March 21	6,992	370	(698)	262	(504)	230	(446)
1345	March 22	7,122	357	(674)	262	(504)	230	(446)
1595	March 22	10,284	298	(568)	253	(487)	230	(446)
1600	March 23	10,286	288	(550)	244	(471)	230	(446)
1015	March 30	7,471	341	(646)	241	(466)	215	(419)
1105	March 31	7,357	360	(680)	245	(473)	215	(419)
1210	March 31	10,974	366	(691)	264	(507)	215	(419)
1540	April 1	10,685	371	(700)	270	(518)	215	(419)
0600	April 6	5,653	378	(712)	250	(482)	210	(410)
0800	April 7	4,933	395	(743)	260	(500)	210	(410)
1130	April 7	5,834	388	(730)	258	(496)	210	(410)
1730	April 8	6,088	367	(693)	250	(482)	210	(410)
0800	April 8	6,247	358	(676)	250	(482)	210	(410)
1835	April 13	5,299	374	(705)	250	(482)	210	(410)
1110	April 14	7,892	367	(693)	261	(502)	210	(410)
1215	April 15	6,768	376	(709)	254	(489)	210	(410)

Although the present invention has been described in conjunction with preferred embodiments, it is to be understood that modifications and variations may be resorted to without departing from the spirit and scope of the invention as those skilled in the art will readily understand. Such modifications and variations are considered to be within the purview and scope of the invention and the appended claims.

What is claimed is:

1. A modulatable heat exchanger system for cooling hot dust-laden flue gas having an elevated dew point which comprises,

a heat exchanger unit formed of a bank of tubes coupled to tube manifolds such that the bank of tubes communicates with a hot gas inlet and a hot gas outlet coupled respectively to said manifolds,

each of said tubes being surrounded by a tube to provide annular spaces having manifolds communicating therewith through which air is circulated in said heat exchanger in concurrent flow with said hot flue gas,

means for maintaining a flow of hot flue gas through said heat exchanger to a downstream line,

a closed circuit air line including a blower for maintaining a flow of air through said heat exchanger in concurrent

flow and heat exchanging relationship with said hot flue gas,

first valve means for feeding fresh air into said air line when needed,

first temperature-sensing means for sensing the temperature of the flue gas downstream of said heat exchanger,

second valve means in said air line operable in accordance with the temperature sensed by said first temperature sensing means for controlling the rate of flow of said air through said heat exchanger according to the temperature sensed by said first temperatures-sensing means,

second temperature-sensing means associated with a portion of the heat exchanger in contact with said flue gas for sensing the temperature of the heat exchanger at said portion,

said second temperature-sensing means being operably coupled to said first valve means for controlling the feeding of fresh air to said air line,

and a pressure-sensing device in said air line coupled to a third valve means comprising an exit air gas valve for opening said valve to expel air from said line when a pressure above a predetermined pressure is sensed in the air line,

whereby the flow of air through the heat exchanger is independently controlled relative to the flow of said flue gas so as to maintain the temperature of said heat exchanger above the dew point of said hot flue gas during the cooling thereof in accordance with the temperature sensed by the temperature-sensing means of the system.

2. The heat exchanger system of claim 1, wherein,

said second temperature-sensing means coupled to said first valve means is also operably coupled to a fourth valve means located in said air line,

said fourth valve means being mechanically linked to first valve means,

such that when said first valve means is caused to open in response to said second temperature-sensing means, the mechanically linked valve is caused to move towards the closed position, and when the first valve means is caused to move to the closed position, the mechanically linked valve is caused to move towards the open position.

3. The heat exchanger system of claim 1, wherein a manually operable valve means is coupled to the air line to provide a fixed maximum air flow setting for the system below which the air flow rate through the heat exchanger unit is automatically controlled.

4. The heat exchanger system of claim 1, including a heater coupled to a portion of the air line for preheating the air to a predetermined temperature, said air line portion being connected to said third air valve means for bleeding air from the system when the air pressure increases above the predetermined air pressure set point.

5. A modulatable heat exchanger system for cooling hot dust-laden flue gas having an elevated dew point which comprises,

a heat exchanger formed of a vertical cylindrical shell containing a bank of tubes vertically disposed therein coupled to tube manifolds at opposite ends thereof such that the bank of tubes communicates with a hot gas inlet and a hot gas outlet coupled respectively to said manifolds,

each of said tubes being surrounded by a tube to provide annular spaces having manifolds communicating therewith through which air is circulated in said heat exchanger in concurrent flow with said hot flue gas, means for maintaining a flow of hot flue gas through said heat exchanger to a downstream line,

a closed circuit air line including a blower for maintaining a flow of air through said heat exchanger in concurrent flow and heat exchanging relationship with said hot flue gas,

first valve means for feeding fresh air into said air line when needed and another valve means in said air line mechanically linked with said first valve means, such that when the first valve means opens, said other valve means closes and when said first valve means is caused to move to the closed position, the mechanically linked valve is caused to move towards the open position,

first temperature-sensing means for sensing the temperature of the flue gas downstream of said heat exchanger,

second valve means in said air line operable in accordance with the temperature sensed by said first temperature-sensing means for controlling the rate of flow of said air through said heat exchanger according to the temperature sensed by said first temperature-sensing means,

second temperature-sensing means associated with a portion of the heat exchanger in contact with said flue gas for sensing the temperature of the heat exchanger at said portion,

said second temperature-sensing means being operably coupled to said first valve means for controlling the feeding of fresh air to said air line and for controlling the flow of air through said valve means mechanically linked to said first valve means,

a manually operable valve means in said air circuit to provide a fixed maximum air flow setting to said air line,

a heater coupled to a portion of said air line for preheating the air to a predetermined temperature,

and a pressure-sensing device in said air line coupled to a third valve means comprising an exit air gas valve for opening said valve to expel heated air from said line when a pressure above a predetermined pressure is sensed in said line,

whereby the flow of air through the heat exchanger is independently controlled relative to the flow of said flue gas so as to maintain the temperature of said heat exchanger at above the dew point of said hot flue gas during the cooling thereof in accordance with the temperature sensed by the temperature-sensing means of the system.

6. A method of modulating the temperature of a heat exchanger in which hot flue gas is passed through a bank of heat exchanger tubes, each of said tubes being surrounded by an annular tube to provide annular spaces through which air is passed in concurrent and heat exchanging relationship with the flow of said flue gas, the flue gas flowing through said heat exchanger to a downstream line for further treatment, said air being continuously circulated through said heat exchanger via a closed circuit air line which comprises,

continuously feeding flue gas at a variable temperature and flow rate through said heat exchange tubes,

continuously feeding air concurrently along and around the outside surface of said heat exchange tubes at a variable flow rate to effect cooling of said flue gas to a temperature above the dew point of the flue gas being cooled,

continuously sensing the temperature of a portion of said heat exchanger in heat exchange contact with said flue gas with respect to a predetermined set condition,

varying the input of fresh air into said air line via a first valve responsive to the difference in temperature sensed at the heat exchanger portion,

continuously feeding air concurrently along and around the outside surface of said heat exchange tubes in a variable flow rate to effect cooling of said flue gas to a temperature above the dew point of the flue gas being cooled,

continuously sensing the temperature of the flue gas leaving said heat exchanger downstream thereof with respect to a predetermined set condition,

varying the flow of air through said heat exchanger via a second valve in the air circuit responsive to the difference in temperature between said downstream flue gas and said set condition,

continuously sensing the air pressure in said air line with respect to a predetermined pressure set condition,

controlling the pressure in said air line with respect to said set condition via a third valve responsive to the difference in pressure sensed, such that when the pressure exceeds the predetermined set condition, the valve is opened to bleed air from the line to return the pressure to the set condition,

and maintaining the foregoing controls independent of the flow of flue gas,

whereby the temperature of the heat exchanger is maintained at a predetermined temperature above the dew point of the flue gas during the cooling thereof.

7. The method of claim **6**, wherein as the input of fresh air into said air line is varied by means of said first valve means in response to the temperature-sensing means at the heat exchanger, the flow rate of the air in the air line is oppositely varied simultaneously through a valve means in said air line mechanically linked to said first valve means, such that as the fresh air input to the air line is being increased, the flow rate of the air in the air line through the mechanically linked valve is decreased and vice versa.

8. The method of claim **6**, including the step of fixing the maximum flow rate of the air through the air line by means of a manually operable air valve in said air line.

9. The method of claim **6**, including the step of heating the circulating air to a predetermined temperature.

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