

Jan. 26, 1965

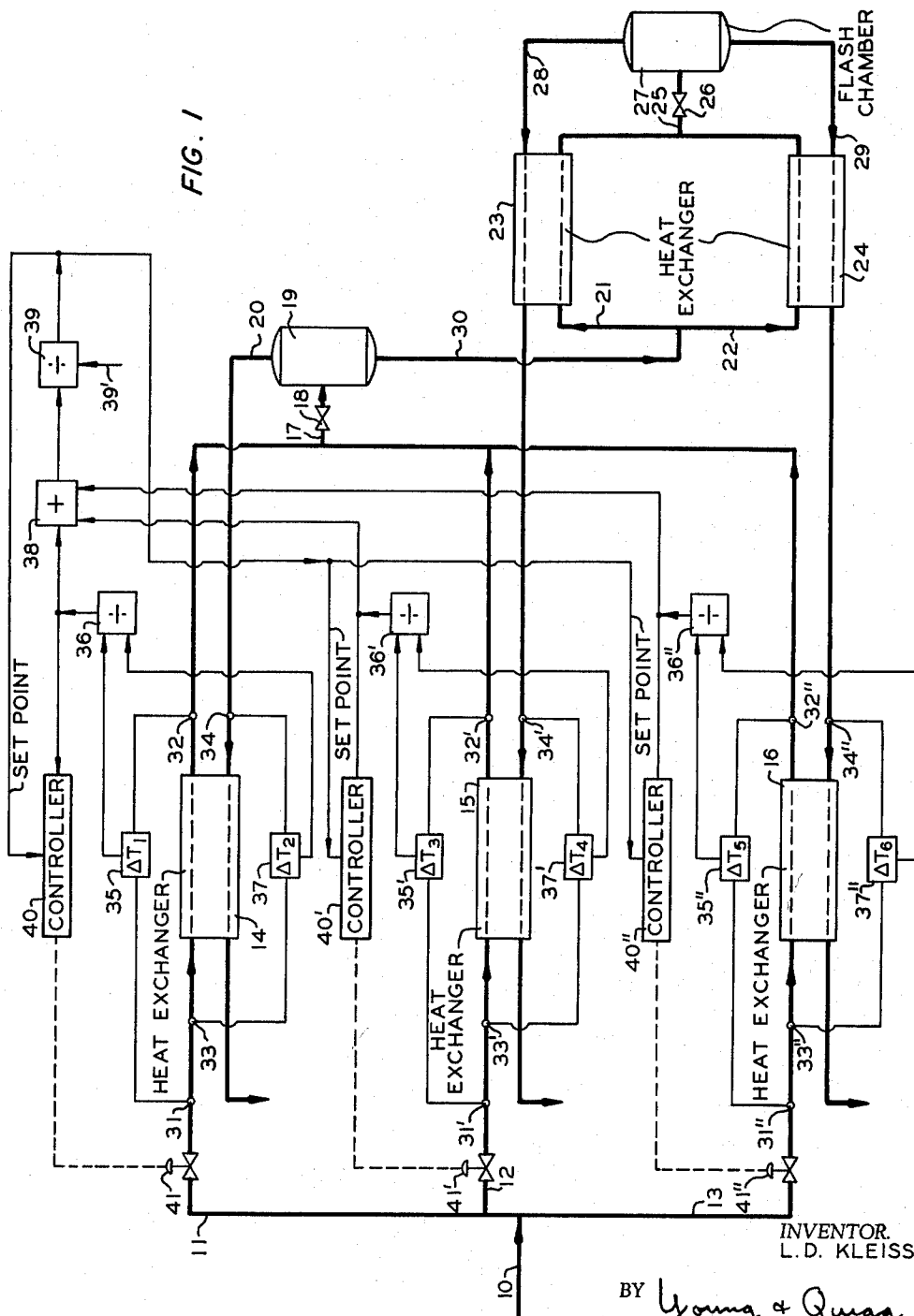
L. D. KLEISS

3,167,113

EQUALIZATION OF LOADS ON HEAT EXCHANGERS

Filed Sept. 13, 1962

2 Sheets-Sheet 1



Jan. 26, 1965

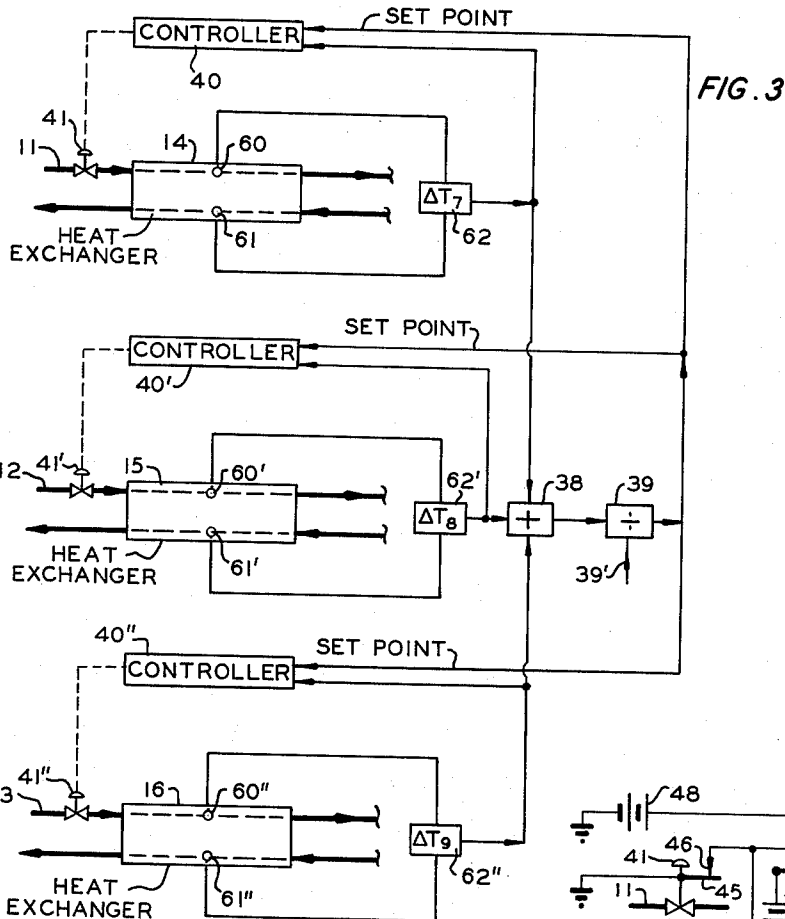
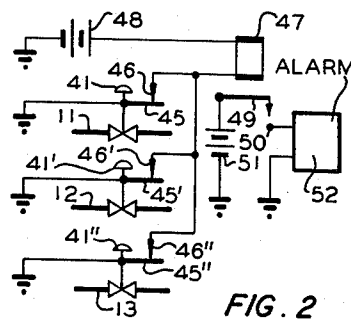
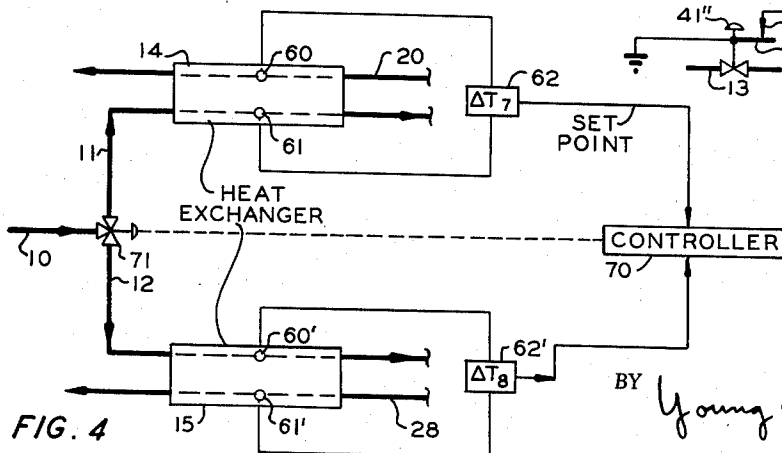
L. D. KLEISS

3,167,113

EQUALIZATION OF LOADS ON HEAT EXCHANGERS

Filed Sept. 13, 1962

2 Sheets-Sheet 2



INVENTOR
L. D. KLEISS

BY *Young & Quigg*

ATTORNEYS

1

3,167,113
EQUALIZATION OF LOADS ON HEAT
EXCHANGERS

Louis D. Kleiss, Borger, Tex., assignor to Phillips
Petroleum Company, a corporation of Delaware
Filed Sept. 13, 1962, Ser. No. 223,447
7 Claims. (Cl. 165—1)

This invention relates to the control of heat exchangers to obtain maximum efficiency.

In various industrial processes it is common practice to pass fluids in heat exchange relationship with one another. One example of such a process occurs in the separation of helium from a natural gas stream. This can be accomplished by a series of cooling and flashing steps. The gas stream being cooled is passed in heat exchange relationship with a plurality of cooler streams resulting from the flashing steps. A plurality of heat exchangers connected in parallel relationship can be employed for the purpose. In operations of this type, the various fluid streams will often vary in temperature and volume. Furthermore, the efficiencies of individual heat exchangers may change with time due to such factors as hydrate formation and deposits forming on the walls of the tubes.

In accordance with this invention, a system is provided for dividing the flow of fluid through a plurality of heat exchangers in such a manner that maximum heat transfer is achieved. This is accomplished by computing the performances of each individual heat exchanger and obtaining the average performance of the several exchangers. If one or more individual exchangers are operating below the average, the performances of these exchangers are increased by reducing the flows there-through. Such a reduction in flow raises the performances of the less efficient heat exchangers because of the increased residence times which permit greater transfer of heat. The performances of all of the heat exchangers can be equalized in this manner to obtain maximum heat transfer for the entire bank of heat exchangers.

Accordingly, it is an object of this invention to provide a method of operating a plurality of heat exchangers to obtain a maximum efficiency.

Another object is to provide apparatus for controlling the flow of a first fluid in heat exchange relationship with a plurality of second fluids.

A further object is to provide apparatus for computing the efficiencies of heat exchangers.

Other objects, advantages and features of the invention should become apparent from the following detailed description, taken in conjunction with the accompanying drawing in which:

FIGURE 1 is a schematic representation of a heat exchanger system having a first embodiment of the control apparatus of this invention incorporated therein.

FIGURE 2 is a schematic view of a safety system which can be incorporated in the control system of FIGURE 1.

FIGURE 3 is a schematic representation of a second embodiment of the control system of this invention.

FIGURE 4 is a schematic representation of a third embodiment of the control system.

Referring now to the drawing in detail and to FIGURE 1 in particular, a liquid mixture of normally gaseous materials to be separated is introduced through a first conduit 10. Conduit 10 communicates with conduits 11, 12, and 13 which divide the feed stream into three separate flow paths. Conduits 11, 12, and 13 pass through respective heat exchangers 14, 15, and 16 and communicate with a common conduit 17 downstream from the heat exchangers. Conduit 17, which has an expansion valve 18 therein, communicates with a flash chamber 19. The constituents which are vaporized in chamber 19 are re-

2

moved through a conduit 20 which communicates with heat exchanger 14. The liquid portion from flash chamber 19 flows through a conduit 30 and is divided into two streams flowing through conduits 21 and 22. These streams flow through respective heat exchangers 23 and 24, are combined in a conduit 25, and are expanded through a valve 26 into a flash chamber 27. A vapor stream is removed from flash chamber 27 through a conduit 28 and is passed through heat exchangers 23 and 15. The liquid stream from flash chamber 27 is passed through heat exchangers 24 and 16. The feed stream is thus separated into portions according to the boiling points of their constituents and their relative volatility. The use of heat exchangers permits this separation to be made with a minimum expenditure of energy.

The performance of heat exchangers in the following discussion is defined as the ratio of actual heat energy transferred from the hot stream to the cold stream as compared to the maximum possible transfer. In a parallel bank of heat exchangers, the greatest heat energy transfer will occur when all exchangers have equal performances. This can be done by controlling the loading on each individual exchanger, a higher loading contributing to a lower efficiency.

The performance of a heat exchanger may be approximated by the following formula:

$$\text{Performance} = \frac{T_x - T_y}{T_x - T_z} \quad (1)$$

where T_x is the temperature of the feed in conduit 11 supplied to exchanger 14, for example, T_y is the temperature of the feed removed from exchanger 14 through conduit 11, and T_z is the temperature of the fluid supplied to exchanger 14 through conduit 20.

In order to measure the performance of heat exchanger 13, temperature sensing elements 31 and 32 are disposed in conduit 11 upstream and downstream from heat exchanger 13, respectively. Temperature sensing element 33 is disposed in conduit 11 upstream of exchanger 14, and temperature sensing element 34 is disposed in conduit 20 upstream from heat exchanger 14. Elements 31 and 32 are connected to the input of a transducer 35 which establishes an output signal ΔT_1 that is representative of the temperature difference detected by elements 31 and 32. Elements 31 and 32 can conveniently be thermocouples connected in a series E.M.F. opposing relationship. The output of transducer 35 is applied as the numerator to a divider 36. Temperature sensing elements 33 and 34 are connected to a second transducer 37 which establishes an output signal ΔT_2 that is representative of the difference between the two measured temperatures. This output signal is applied as the denominator to divider 36. Similar elements are associated with heat exchangers 15 and 16 and are designated by like primed and double primed numbers, respectively. As indicated by Equation 1, the output signals from dividers 36, 36' and 36'' represent the performances of respective heat exchangers 14, 15 and 16. These signals are added in adder 38, and divided in divider 39 by a constant representing the number of parallel heat exchangers. Divider 39 receives a constant set point signal from 39' representative of the constant 3. The output signal from divider 39 is thus equal to the average performance of all three heat exchangers.

The output signal from divider 39 is applied to the set points of respective controllers 40, 40', and 40''. The output signals from controllers 40, 40', and 40'' adjust respective valves 41, 41', and 41'' in conduits 11, 12, and 13. The output signals from dividers 36, 36', and 36'' are applied as the respective controlled variable signals to controllers 40, 40' and 40''. If the perform-

ance of exchanger 14, for example, should become less than the performances of exchangers 15 and 16, the output signal from divider 36 is less than the average output signal from divider 39. Since the signal applied to controller 40 from divider 36 differs from the set point, controller 40 actuates valve 41 to decrease the flow of fluid through conduit 11. This increases the residence time of the fluid in exchanger 14 so as to increase the efficiency of this exchanger. The control system thus operates by throttling the load on the less efficient heat exchangers, and diverting the load to the more efficient exchangers. When this control system is at balance, one control valve will be fully open, and the others in various degrees of closure.

In the control system of FIGURE 1, it is desirable that some type of safety system be incorporated to prevent valves 41, 41', and 41'' from all being closed completely due to some equipment failure. A suitable alarm system for this purpose is illustrated in FIGURE 2. Valve 41 is provided with an arm 45 which engages a contact 46 until the valve is closed by a preselected amount. When the valve is closed beyond this amount, arm 45 is moved out of engagement with contact 46. Contact 46 is connected through a relay coil 47 to the first terminal of a voltage source 48. The second terminal of voltage source 48 is connected to ground, as is arm 45. Valve 41' is provided with a similar arm 45' which engages a contact 46'. Valve 41'' is provided with a similar arm 45'' which engages a contact 46''. As long as any of the valves remains open an electrical circuit is completed to keep relay coil 47 energized. If all valves should close, the circuit is broken and relay coil 47 is deenergized.

As long as relay coil 47 remains energized, an arm 49 remains out of engagement with a contact 50. When relay coil 47 is deenergized, arm 49 moves into engagement with terminal 50 to connect a voltage source 51 in circuit with an alarm 52. This alarm alerts an operator to the fact that all valves have closed so that appropriate corrections can be made. In addition to the alarm, a signal can be established to override the set points of controllers 40, 40', and 40'' to move the valves to open positions until appropriate corrective action is taken by the operator.

In some heat exchange systems, it can be assumed that in a properly loaded bank of parallel heat exchangers, the average temperature differential between the hot and cold sides will be the same in individual heat exchangers. By making this assumption, the control system of FIGURE 1 can be simplified as illustrated in FIGURE 3. With reference to FIGURE 3, temperature sensing elements 60 and 61 are disposed in exchanger 14 to sense the temperature difference between hot and cold fluids. If this temperature difference is not constant throughout the exchanger, elements 60 and 61 can be located to show the average difference, as elements 60 and 61 can be of an averaging type, for instance, multiple thermocouples. Elements 60 and 61 are connected to the input of transducer 62, whose output is representative of the average heat differential ΔT_7 in exchanger 14. Similar elements are disposed with respect to exchangers 15 and 16, and are designated by like primed and double primed numbers, respectively. These produce signals ΔT_8 and ΔT_9 . Signals ΔT_7 , ΔT_8 , and ΔT_9 are related to the performances of exchangers 14, 15, and 16, respectively, the lower differential indicating the higher performance. These signals are employed to control valves 40, 40', and 40'' in the same manner as previously described, except that the controllers are changed to reverse action. If ΔT_7 is higher than the average of all ΔT 's, for instance, controller 40 will partially close valve 41 until ΔT_7 falls to the average. In this manner, all performances are equalized.

When only two heat exchangers are employed, the control system can be simplified in the manner illustrated

in FIGURE 4. A first transducer 62 establishes a signal ΔT_7 which is representative of the difference in temperatures detected by elements 61 and 60. A second transducer 62' establishes a signal ΔT_8 representative of the difference in temperatures detected by elements 61' and 60'. The output signal from transducer 62 is applied as the set point to a conventional controller 70. The output signal from transducer 62' is applied as the input to controller 70. As long as the two temperature differential measurements remain equal, the output signal from controller 70 remains at the initial preset value. If the temperature differential measurements become unequal, controller 70 provides an output signal which deviates from the original value in accordance with which of the temperature differential signals is the larger. The output signal from controller 70 adjusts a valve 71 which regulates the relative flows of fluid from conduit 10 to conduits 11 and 12.

As an example of the operation of the control system of FIGURE 4, it will be assumed that transducer 62' eventually provides an output signal which becomes greater than the output signal from transducer 62. This results in controller 70 manipulating valve 71 to decrease the flow through conduit 12 and to increase the flow through conduit 11. The decreased flow through conduit 12 reduces the temperature differential measured by transducer 62', and at the same time increases the temperature differential measured by transducer 62. The combined actions are such as to restore the system to a new point of balance where the two measured temperature differentials are again equal. The use of three-way valve 71 has an additional advantage in that the safety control system of FIGURE 2 can be eliminated. This is possible because there will always be at least some flow through both conduits 11 and 12.

It should be evident that the control systems of this invention can be employed where the common fluid is either heated or cooled in the heat exchangers. In either event, the temperature differential measurements are made so as to provide positive quantities. While three parallel exchangers have been illustrated for purposes of describing the principles of this invention, it should be evident that any number of exchangers and associated control equipment can be utilized. The individual computer elements employed can be conventional devices known in the art, such as electrical or pneumatic computing elements.

While the invention has been described in conjunction with presently preferred embodiments, it should be evident that it is not limited thereto.

What is claimed is:

1. A heat exchange system comprising a plurality of heat exchangers, first conduit means to introduce a first fluid into the system, a plurality of second conduit means communicating between said first conduit means and respective ones of said heat exchangers, a plurality of third conduit means communicating with respective ones of said heat exchangers to remove said first fluid, a plurality of fourth conduit means communicating with respective ones of said heat exchangers to pass fluids into said heat exchangers to be heat exchanged with said first fluid, a plurality of fifth conduit means communicating with respective ones of said heat exchangers to remove fluids supplied by said fourth conduit means, means to establish a plurality of first signals representative of the temperature differences of said first fluid entering and leaving respective ones of said heat exchangers, means to establish a plurality of second signals representative of the temperature differences of the fluids entering respective ones of said heat exchangers through said second and fourth conduit means, means to divide said first signals by said second signals for respective ones of each of said heat exchangers to establish a plurality of third signals, means to sum said third signals to establish a fourth signal, means to divide said fourth signal by the number of said heat exchangers to establish a fifth signal, a plurality of valves

positioned to control the flows of said first fluid through said heat exchangers, a plurality of controllers to actuate respective ones of said valves, means to apply said fifth signal to the set points of said controllers, and means to apply said third signals to the respective controllers to actuate same.

2. A heat exchange system comprising a plurality of heat exchangers, first conduit means to introduce a first fluid into the system, a plurality of second conduit means communicating between said first conduit means and respective ones of said heat exchangers to pass said first fluid through said heat exchangers, a plurality of third conduit means communicating with respective ones of said heat exchangers to pass fluids through said heat exchangers to be heat exchanged with said first fluid, means to establish a plurality of first signals representative of the temperature differences between the two fluids passing through respective ones of said heat exchangers through said second and third conduit means, means to sum said first signals to establish a second signal, means to divide said second signal by the number of said heat exchangers to establish a third signal, a plurality of valves positioned to control the flows of said first fluid through said heat exchangers, a plurality of controllers to actuate respective ones of said valves, means to apply said third signal to the set points of said controllers, and means to apply said first signals to the respective controllers to actuate same.

3. A heat exchange system comprising first and second heat exchangers, first conduit means to introduce a first fluid into the system, second and third conduit means communicating between said first conduit means and respective ones of said first and second heat exchangers to pass said first fluid through said heat exchangers, fourth and fifth conduit means communicating with respective ones of said first and second heat exchangers to pass fluids into said heat exchangers to be heat exchanged with said first fluid, means to establish first and second signals representative of the temperature differences between the two fluids passing through respective ones of said first and second heat exchangers, means to compare said first and second signals, and means responsive to said means to compare to regulate the relative flows of said first fluid through said second and third conduit means to keep said first and second signals equal.

4. The system of claim 3 wherein said means to compare comprises a controller, one of said first and second signals is applied as the input to said controller and the other of said signals is applied as the set point of said controller, the output of said controller adjusting said relative flows.

5. In a heat exchange process wherein a first fluid is

passed through first and second heat exchangers in parallel and wherein second and third fluids are passed through respective ones of said first and second heat exchangers in heat exchange relationship with said first fluid; a method of control which comprises measuring the temperature difference between said first and second fluids in said first heat exchanger, measuring the temperature difference between said first and third fluids in said second heat exchanger, and adjusting the relative flows of said first fluid through said first and second heat exchangers to keep the two measured temperature differences equal.

6. In a heat exchange process wherein a first fluid is passed through a plurality of heat exchangers in parallel and wherein a plurality of second fluids are passed through respective ones of said heat exchangers in heat exchange relationship with said first fluid; a method of control which comprises computing the performances of each of said heat exchangers, each of said performances being computed by measuring the temperature differential of the first fluid in passing through the corresponding heat exchanger and establishing a first signal representative thereof, measuring the temperature differential between the first and second fluids entering the corresponding heat exchanger and establishing a second signal representative thereof, and dividing the first signal by the second signal; computing the average performance of said plurality of heat exchangers from the computed performances of each of said heat exchangers; and regulating the relative flows of said first fluid through said plurality of heat exchangers to equalize the performances thereof.

7. In a heat exchange process wherein a first fluid is passed through a plurality of heat exchangers in parallel and wherein a plurality of second fluids are passed through respective ones of said heat exchangers in heat exchange relationship with said first fluid; a method of control which comprises computing the performances of each of said heat exchangers, each of said performances being computed by measuring the temperature differential between first and second fluids in each heat exchanger; computing the average performance of said plurality of heat exchangers from the computed performances of each of said heat exchangers; and regulating the relative flows of said first fluid through said plurality of heat exchangers to equalize the performances thereof.

References Cited in the file of this patent

FOREIGN PATENTS

355,461	Switzerland	Aug. 31, 1961
626,223	Great Britain	July 12, 1949
1,264,239	France	May 8, 1961