

Nov. 24, 1964

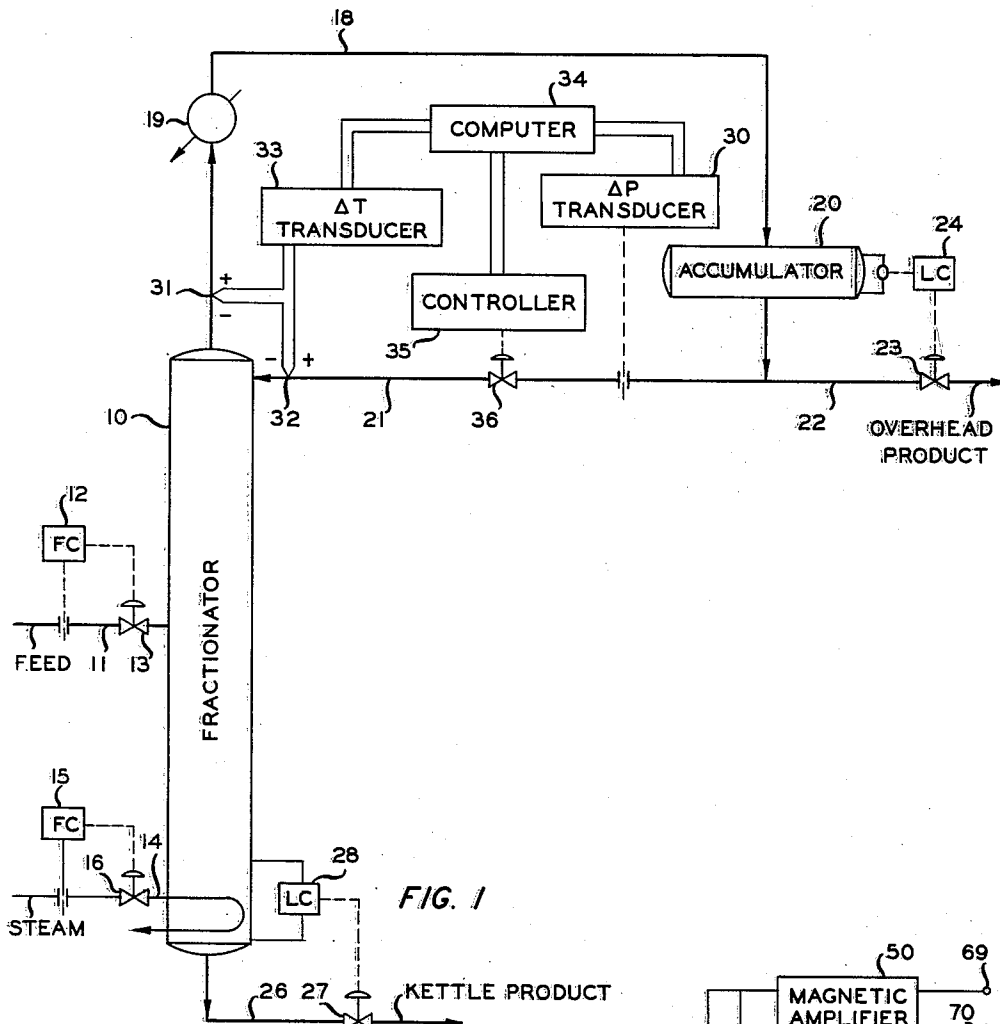
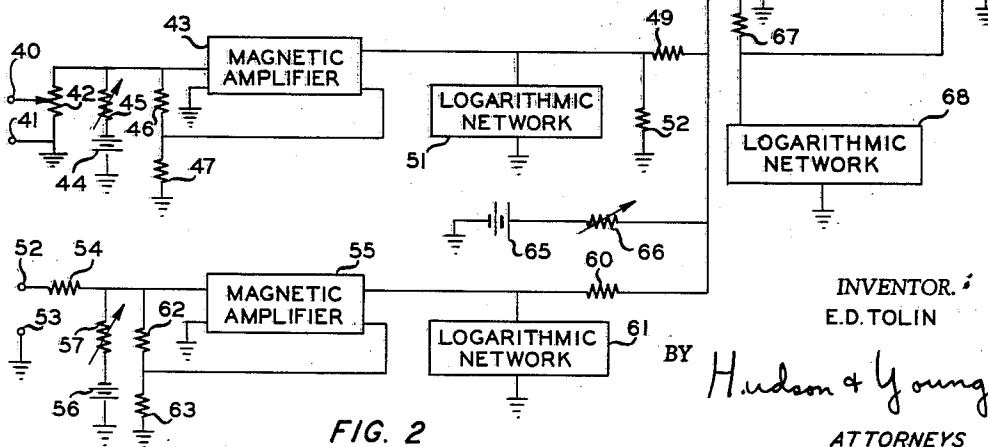
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3,158,557

FRACTIONATION CONTROL

Filed June 16, 1960

2 Sheets-Sheet 1



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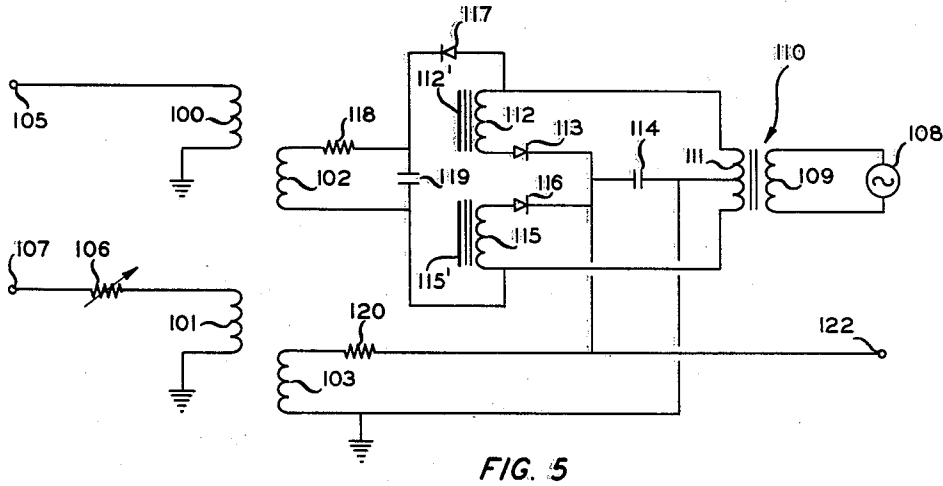


FIG. 5

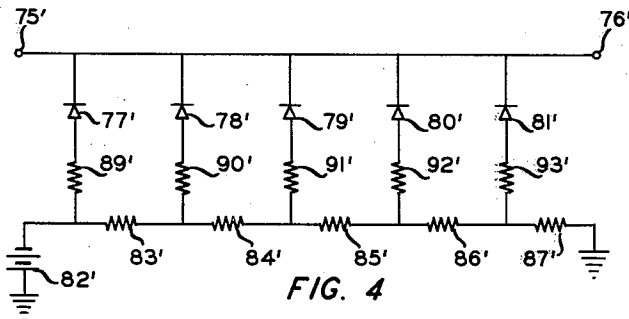


FIG. 4

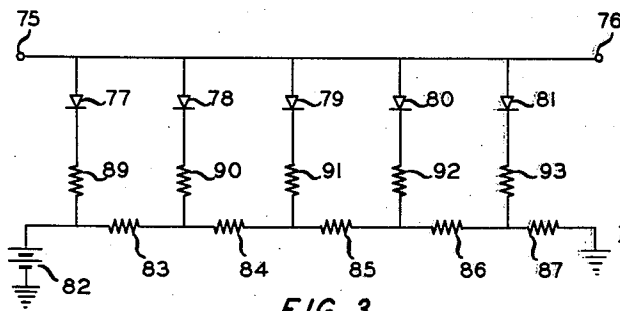


FIG. 3

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1

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FRACTIONATION CONTROL

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This invention relates to the computation of internal reflux in a fractionation column. In another aspect it relates to control systems for fractionation columns which are based on computations of internal reflux.

In recent years an increasing use has been made of fan coolers for condensing overhead vapors from fractionation columns. However, this type of cooler has resulted in a rather serious operating problem because it is difficult to control the exact amount of cooling provided. Such schemes as fan speed control, variable pitch fan blade control and hot vapor by-pass control have been employed in an attempt to solve this problem, but have not been entirely satisfactory. Sudden atmospheric temperature changes, such as occur during a rainstorm, for example, result in a lowering of the reflux temperature. This causes an increase in the flow of liquid leaving the top tray because more of the vapor which enters this tray is condensed. This results in an increase in overhead product purity at the expense of a decreased overhead product rate.

In accordance with the present invention there is provided a novel system for computing the amount of internal reflux in a fractionation column. Internal reflux constitutes the external reflux returned to the column plus the vapor which is condensed near the top of the fractionation column by the sub-cooled external reflux. This computation is made from a measurement of the rate of flow of the external reflux and a measurement of the temperature differential between the external reflux returned to the column and a region near the top of the column. Electrical signals are established which are representative of these two measurements. The electrical signals are combined to provide a measurement of the internal reflux in the column. A signal representative of this internal reflux can be employed to control the operation of the column to maintain desired steady state operating conditions. This control can be made automatically or by an operator from the information provided.

Accordingly, it is an object of this invention to provide a system for computing the internal reflux in a fractionation column.

Another object is to provide control systems for fractionation columns which utilize computations of the internal reflux in the column.

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 fractionation column having the computer and control system of this invention associated therewith.

FIGURE 2 is a schematic circuit drawing of the computer employed in the control system of FIGURE 1.

FIGURE 3 is a schematic circuit drawing of a positive logarithmic network employed in the computer of FIGURE 2.

FIGURE 4 is a schematic circuit drawing of a negative logarithmic network employed in the computer of FIGURE 2.

FIGURE 5 is a schematic circuit drawing of the magnetic amplifier which is employed in the computer of FIGURE 2.

Referring now to the drawing in detail and to FIGURE 1 in particular, there is shown a conventional fractionation column 10 which contains a number of vapor-liquid contacting trays. A fluid mixture to be separated is intro-

2

duced into column 10 through a conduit 11 at a predetermined rate which is maintained by a flow controller 12 that adjusts a valve 13. Steam, or other heating medium, is circulated through the lower region of column 10 through a conduit 14 at a predetermined rate which is maintained by a flow controller 15 that adjusts a valve 16.

Vapors are withdrawn from the top of column 10 through a conduit 18 which has a condenser 19 therein. Conduit 18 communicates at its second end with an accumulator 20. A portion of the condensate in accumulator 20 is returned to column 10 as external reflux through a conduit 21. The remainder of the condensate is removed as overhead product through a conduit 22 which has a control valve 23 therein. Valve 23 is adjusted by a liquid level controller 24 to maintain a predetermined level in accumulator 20. A kettle product stream is withdrawn from the bottom of column 10 through a conduit 26 which has a control valve 27 therein. Valve 27 is adjusted by a liquid level controller 28 to maintain a predetermined liquid level in the bottom of column 10.

In order to explain the operation of the internal reflux computer and control system of this invention, an equation which is representative of the internal reflux in a fractionation column will be derived.

The material balance at the top tray of the fractionator can be expressed:

$$R_e + V_i = R_i + V_o \quad (1)$$

Where:

R_e = mass flow of liquid entering top tray (external reflux)

V_i = mass flow of vapor entering top tray

R_i = mass flow of liquid leaving top tray (internal reflux)

V_o = mass flow of vapor leaving top tray.

The heat balance at the top tray can be expressed:

$$R_e h_e + V_i H = R_i h_i + V_o H \quad (2)$$

where:

h_e = enthalpy of external reflux

h_i = enthalpy of internal reflux

H = enthalpy of vapor streams (assumed to be equal).

The enthalpy of the vapor streams entering and leaving the top tray can be expressed:

$$H = h_i + \lambda \quad (3)$$

where λ = heat of vaporization of liquid on the tray.

The enthalpy of the external reflux can be expressed:

$$h_e = h_i - C_p \Delta T \quad (4)$$

where:

C_p = specific heat of the external reflux stream

ΔT = the difference in temperature between the top tray and external reflux.

Equation 3 can be substituted into Equation 2 to eliminate H and rewritten:

$$V_i (h_i + \lambda) - V_o (h_i + \lambda) = R_i h_i - R_e h_e \quad (5)$$

Equation 4 can be substituted into Equation 5 to eliminate h_e and rewritten:

$$(h_i + \lambda) (V_i - V_o) = h_i (R_i - R_e) + R_e C_p \Delta T \quad (6)$$

From Equation 1 it is known:

$$V_i - V_o = R_i - R_e \quad (7)$$

Equation 7 can be substituted into Equation 6 and reduced to obtain:

$$R_i = R_e \left(1 + \frac{C_p}{\lambda} \Delta T \right) \quad (8)$$

The computer of this invention solves Equation 8. The term R_e is obtained from a measurement which is representative of the rate of flow through conduit 21.

This is accomplished, for example, by the use of a differential pressure transmitter 30 which establishes an output electrical signal representative of the differential pressure across an orifice in conduit 21. It is assumed that the temperature of the vapor leaving the top tray of column 10 is equal to the temperature of the liquid on the top tray. The term ΔT is then measured by comparing the vapor temperature with the external reflux temperature. Thermocouples 31 and 32 are connected in opposing relationship to the input of a differential temperature transducer 33. This transducer can be a suitable amplifier to provide an output current of sufficient magnitude to be employed in making the internal reflux computation. The output signals from transducers 30 and 33 are applied to the inputs of a computer 34.

Computer 34 operates in the manner described hereinafter to establish an output signal representative of the internal reflux in the fractionation system. The output signal from computer 34 is employed to adjust the set point of a controller 35. Controller 35, in turn, adjusts a control valve 36 in reflux conduit 21. The control system operates to maintain the computed internal reflux constant at a preselected value. If the computed internal reflux should increase, valve 36 is adjusted to reduce the flow through conduit 21. If the computed internal reflux should decrease, valve 36 is adjusted to increase the flow through conduit 21.

Computer 34 is illustrated schematically in FIGURE 2. The output electrical signal from differential pressure transducer 30 is applied to respective input terminals 40 and 41 of the computer. As is well known, the differential pressure measurement across an orifice is proportional to the square of the flow through the conduit. Terminal 40 is connected to the contactor of a potentiometer 42. Terminal 41 is connected to the grounded first end terminal of the potentiometer. The contactor of potentiometer 42 is set so that the input signal is multiplied by a constant K^2 which is representative of the orifice flow constant. This is accomplished by adjusting the flow of input current through the two arms of the potentiometer. The current flow through the upper arm is thus representative of the term $K^2\Delta P$. This signal is applied to the input of a magnetic amplifier 43. A reference bias signal is applied to the input of amplifier 43 from a constant current source formed by a battery 44 and an adjustable resistor 45. Amplifier 43 is provided with a feedback resistor 46, and a resistor 47 is connected between this feedback resistor and ground. The output of signal of amplifier 43 is applied through a resistor 49 to the input of a second magnetic amplifier 50. A first logarithmic network 51 and a resistor 52 are connected between the output of amplifier 43 and ground. Resistors 49 and 52 are of equal value so that one half of the output signal from amplifier 43 is shunted to ground. Therefore, the signal applied to amplifier 50 is representative of the logarithm of the quantity $\sqrt{K^2\Delta P}$.

The output electrical signal of transducer 33 is applied between terminals 52 and 53 of the computer of FIGURE 2. Terminal 52 is connected through a resistor 54 to the input of a third magnetic amplifier 55. Resistor 54 is selected so that this input signal is attenuated so as to be multiplied by the constant

$$\frac{C_p}{\lambda}$$

A constant current source formed by a battery 56 and a variable resistor 57 is connected to the input of amplifier 55 to add a signal representative of the numeral one so that the output signal from amplifier 55 is representative of the term

$$\left(1 + \frac{C_p}{\lambda} \Delta T\right)$$

of Equation 8. The output signal of amplifier 55 is applied through a resistor 60 to the input of magnetic am-

plifier 50. A second logarithmic network 61 is connected between the output of amplifier 55 and ground. This results in a signal representing the logarithm of the quantity

$$\left(1 + \frac{C_p}{\lambda} \Delta T\right)$$

being applied to amplifier 50.

A bias signal is applied to amplifier 50 from a constant current source formed by a battery 65 and a variable resistor 66. Amplifier 50 is provided with a feedback resistor 67, and a logarithmic network is connected between this feedback network and ground. Amplifier 50 serves as a summing amplifier to sum the logarithmic output signals from amplifiers 43 and 55. Logarithmic network 68 in the feedback path of amplifier 50 results in the output signal from amplifier 50 being representative of the anti-logarithm of the summed logarithms. This output signal, which is applied to terminals 69 and 70, is thus representative of the computed internal reflux.

The two logarithmic networks 51 and 61 are positive logarithmic networks which can be of the form illustrated in FIGURE 3. This network is provided with an input terminal 75 which is connected directly to an output terminal 76. Terminals 75 and 76 are connected to the first terminals of respective rectifiers 77, 78, 79, 80 and 81. The positive terminal of a voltage source 82 is connected to ground through series connected resistors 83, 84, 85, 86 and 87. The negative terminal of voltage source 82 is connected directly to ground. The second terminal of rectifier 77 is connected through a resistor 89 to the positive terminal of voltage source 82. A resistor 90 is connected between the second terminal of rectifier 78 and the junction between resistors 83 and 84. A resistor 91 is connected between the second terminal of rectifier 79 and the junction between resistors 84 and 85. A resistor 92 is connected between the second terminal of rectifier 80 and the junction between resistors 85 and 86. A resistor 93 is connected between the second terminal of rectifier 81 and the junction between resistors 86 and 87.

The circuit illustrated in FIGURE 3 is a conventional logarithmic network. The resistors 83 to 87 serve to bias the rectifiers so that they normally do not conduct. Thus, for low values of input signals, all the input current flows from terminal 76 through the external load circuit. As the input current is increased, rectifier 81 begins to conduct so that some of the current is shunted to ground through resistor 93. As the input current increases still further, additional rectifiers begin to conduct in sequence so that more of the current is shunted to ground. A logarithmic transfer characteristic can thus be approximated by a series of straight line segments provided by the sequential conduction of the rectifiers. Almost any desired degree of accuracy can be obtained by increasing the number of rectifiers in the circuit.

Logarithmic network 68 of FIGURE 2 is illustrated schematically in FIGURE 4. This network is similar in many respects to the network of FIGURE 3 and corresponding elements are designated by like primed reference numerals. It should be observed, however, that the rectifiers are connected in the network in the opposite direction and the polarity of voltage source 82' is reversed from that shown in FIGURE 3.

A suitable magnetic amplifier for use in the computer of FIGURE 2 is illustrated schematically in FIGURE 5. This amplifier includes six coils 100, 101, 102, 103, 112, and 115. Coil 100 is the control winding of the circuit and the input current to the amplifier flows through this coil from input terminal 105 to ground. A variable resistor 106 is connected between a potential terminal 107 and the first terminal of bias coil 101. The second terminal of coil 101 is connected to ground. A predetermined current flows through coil 101 to bias the amplifier. Coil 102 provides voltage compensation in the amplifier. This coil is energized from a source of alter-

5

nating current 108 which is connected across the primary winding 109 of a transformer 110. One end terminal of the secondary winding 111 is connected to the external tap of winding 111 through coil 112, a rectifier 113 and a capacitor 114. The second end terminal of transformer winding 111 is connected to the external tap of this winding through coil 115, a rectifier 116 and capacitor 114. The first end terminal of transformer winding 111 is connected to the second end terminal of this winding through a rectifier 117, a resistor 118 and coil 102. A capacitor 119 is connected across resistor 118 and coil 102. The amplifier is provided with a feedback coil 103 which has one terminal connected through a resistor 120 to the junction between rectifier 113 and capacitor 114. This junction is also connected to an output terminal 122. The second terminal of coil 103 is connected to the grounded center tap of transformer winding 111.

Coils 112 and 115 are mounted on separate cores 112' and 115', respectively, in opposing relationship. First halves of each of coils 100, 101, 102 and 103 are mounted on core 112' in series-aiding relationship; and second halves of each of coils 100, 101, 102 and 103 are mounted on core 115' in series-aiding relationship.

Magnetic amplifiers are employed in the computer of this invention in order to provide a simplified circuit which is highly reliable. However, it should be evident that conventional voltage amplifiers can be employed in this computer if desired.

In view of the foregoing description it should be evident that there is provided in accordance with this invention an improved reflux computer which employs electrical computing elements. While the invention has been described in conjunction with present preferred embodiments, it should be evident that it is not limited thereto.

What is claimed is:

1. In a fractionation system wherein a feed mixture of two or more components is directed to a fractionation column, a vapor stream is removed from the top of said column, said vapor stream is cooled to condense at least a part of same, and at least a part of the resulting condensate is returned to said column as external reflux; a system to compute the internal reflux in said column comprising first means to establish a first electrical signal representative of the rate of flow of external reflux to said column, second means to establish a second electrical signal representative of the temperature difference between said vapor stream and said external reflux, third means responsive to said first means to establish a third electrical signal representative of the logarithm of said first signal, fourth means responsive to said second means to increase said second signal by a preselected amount and then to establish a fourth electrical signal representative of the logarithm of the increased second signal, fifth means responsive to said third and fourth means to establish a fifth electrical signal representative of the sum of said third and fourth signals, and sixth means

6

responsive to said fifth means to establish a sixth signal representative of the antilogarithm of said fifth signal, said sixth signal being representative of said internal reflux, said first and third means comprising an orifice positioned in the external reflux flow, means to establish a seventh signal representative of the pressure differential across said orifice, means to multiply said seventh signal by a constant to establish an eighth signal, means to establish a ninth signal representative of the logarithm of said eighth signal, and means to divide said ninth signal into two equal signals, one of which is said third signal.

2. In a fractionation system wherein a feed mixture of two or more components is directed to a fractionation column, a vapor stream is removed from the top of said column, said vapor stream is cooled to condense at least a part of same, and at least a part of the resulting condensate is returned to said column as external reflux; a system to compute the internal reflux in said column comprising first means to establish a first electrical signal representative of the rate of flow of external reflux to said column, second means to establish a second electrical signal representative of the temperature difference between said vapor stream and said external reflux, a potentiometer, first and second amplifiers, means applying said first signal across said potentiometer, means connecting the contactor and one end terminal of said potentiometer to the input of said first amplifier, means applying said second signal to the input of said second amplifier, a summing amplifier having a logarithmic network in the feedback network thereof so that the output signal of said summing amplifier is the antilogarithm of the input signal thereto, means including a second logarithmic network connecting the output of said first amplifier to the first input of said summing amplifier, and means including a third logarithmic network connecting the output of said second amplifier to the second input of said summing amplifier.

3. The system of claim 2 wherein said first and second amplifiers and said summing amplifier are magnetic amplifiers.

4. The system of claim 2, further comprising means responsive to the output signal of said summing amplifier to control the rate of flow of said external reflux to increase the flow of said external reflux when said sixth signal decreases and to decrease the flow of said external reflux when said sixth signal increases.

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