Nov. 24, 1964 E. E. HOPPER 3,158,556

FRACTIONATION CONTROL

Filed Sept. 24, 1959 3 Sheets-Sheet 1

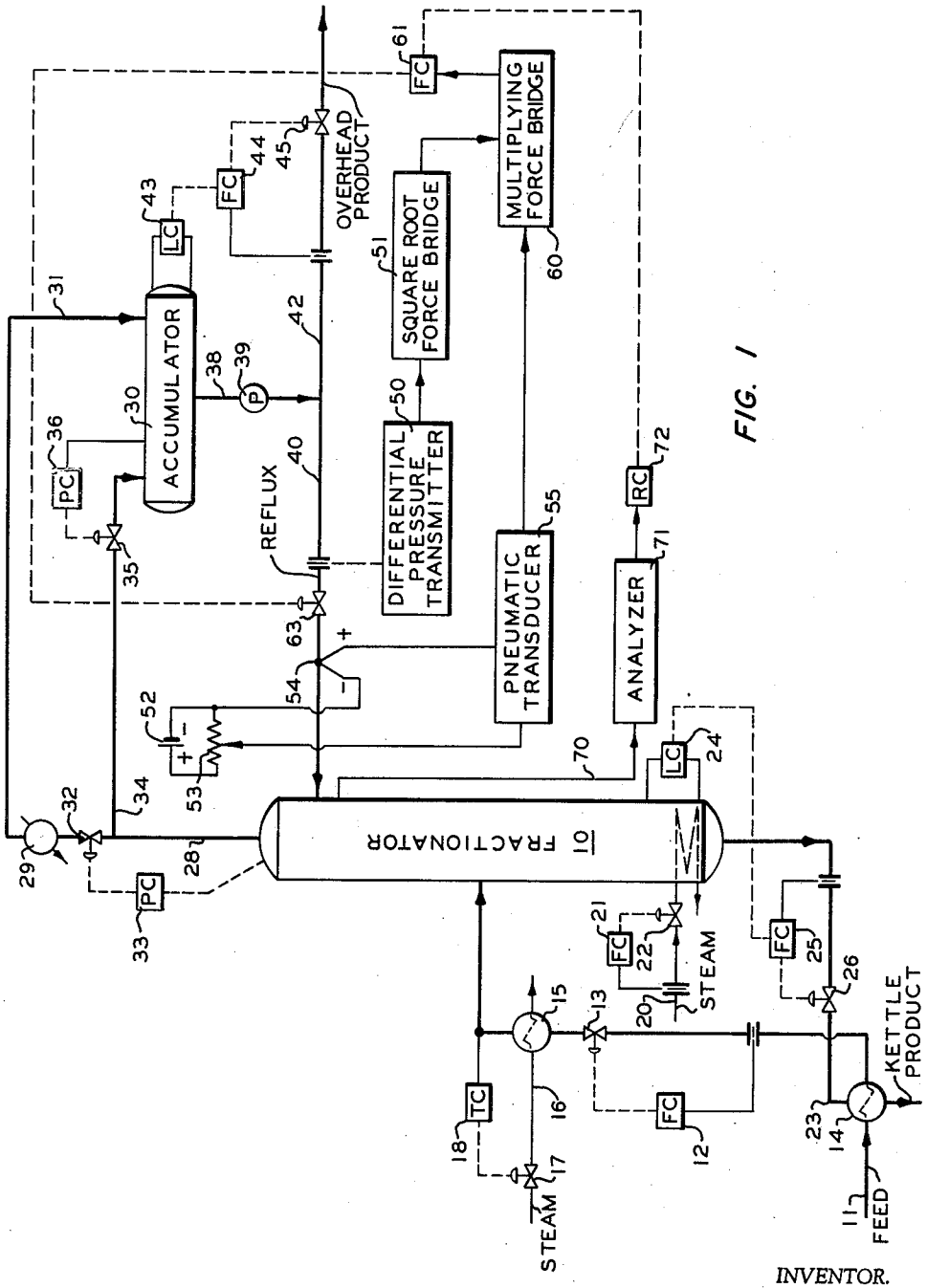


FIG. 1

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Nov. 24, 1964 E. E. HOPPER 3,158,556

FRACTIONATION CONTROL

Filed Sept. 24, 1959 3 Sheets-Sheet 2

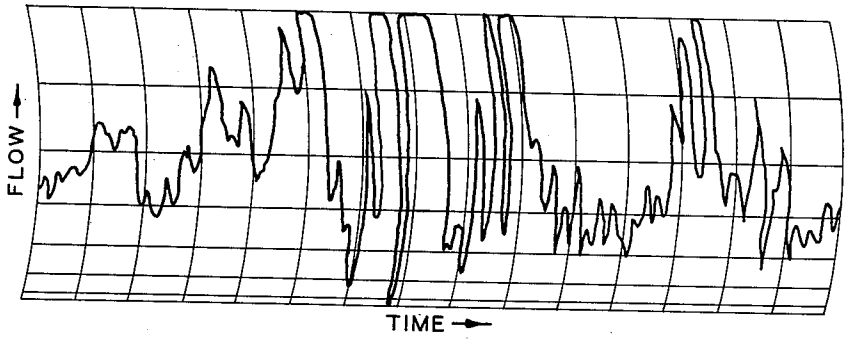


FIG. 2a

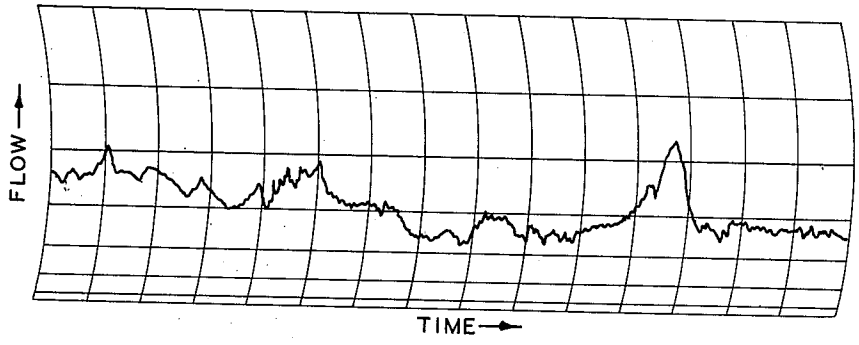


FIG. 2b

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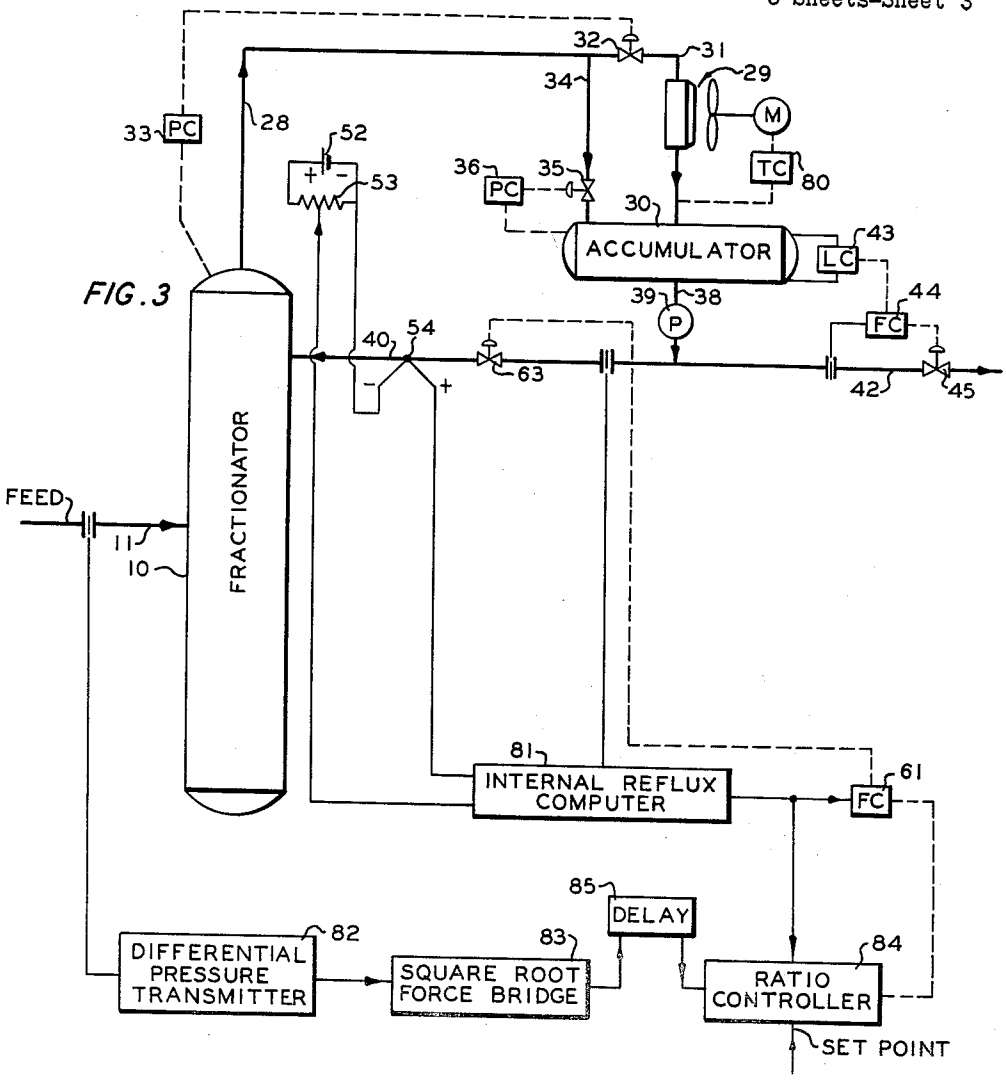
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FRACTIONATION CONTROL

Filed Sept. 24, 1959 3 Sheets-Sheet 3

FIG. 3



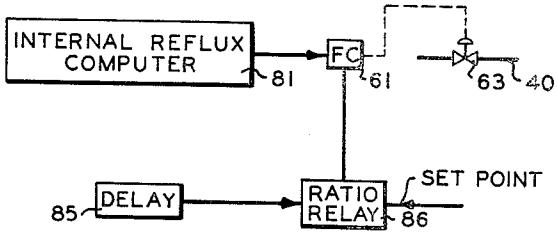


FIG. 4

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FRACTIONATION CONTROL

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2 Claims. (Cl. 202—160)

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, use of 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 the 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. The net result is 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 differential between a fixed reference temperature and the temperature of the external reflux returned to the column. Signals representative of these two measurements 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.

In another aspect of this invention, a fractionation column control system is provided which combines the output signal from a process analyzer with the output signal from the internal reflux computer. In still another aspect, a fractionation column is controlled so as to maintain a preselected ratio between the column feed and the computed internal reflux.

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 which is 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 incorporated therein.

FIGURES 2*a* and 2*b* are graphical representations of the operation of a fractionation column without and with the control system of FIGURE 1, respectively.

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 of this invention.

Referring now to the drawing in detail and to FIGURE 1 in particular, there is shown a conventional fractionation column **10** which is provided with a number of vapor-liquid contacting trays. A fluid mixture to be separated is introduced into column **10** through a conduit **11** at a predetermined rate which is maintained by a flow controller **12** that adjusts a valve **13**. Conduit **11** extends through first and second heat exchangers **14** and **15**. Steam, or other heating medium, is directed through heat exchanger **15** by means of a conduit **16** which has a control valve **17** therein. A temperature controller **18** adjusts valve **17** in response to a measurement of temperature in conduit **11** downstream from heat exchanger **15** so as to tend to maintain the temperature of the feed stream constant.

Steam, or other heating medium, is circulated through the lower region of column **10** through a conduit **20** at a predetermined rate which is maintained by a flow controller **21** that adjusts a valve **22**. A kettle product stream is withdrawn from the bottom of column **10** through a conduit **23** which communicates with heat exchanger **14**. The rate of product withdrawal through conduit **23** is regulated by a liquid level controller **24** which resets a flow controller **25**. Controller **25** adjusts a valve **26** in conduit **23** so as to tend to maintain a constant level in the bottom of column **10**.

Vapors are withdrawn from the top of column **10** through a conduit **28** which communicates with the inlet of a condenser **29** through a control valve **32**. Valve **32** is set by a pressure controller **33** so as to tend to maintain a constant pressure in the top of column **10**. The outlet of condenser **29** communicates with an accumulator **30** through a conduit **31**. A conduit **34**, which has a control valve **35** therein, is connected between conduit **28** and accumulator **30**. The amount of vapor which bypasses condenser **29** through conduit **34** is adjusted by a pressure regulator **36** which controls valve **35** to tend to maintain a constant pressure in accumulator **30**. Liquid in accumulator **30** is withdrawn through a conduit **38** which has a pump **39** therein. A conduit **40** extends from the discharge end of pump **39** to the top of column **10** to return liquid to the column as reflux. The remainder of the liquid removed from accumulator **30** is removed from the system through a conduit **42** as the overhead product. The rate of withdrawal of liquid through conduit **42** is adjusted by a liquid level controller **43** which resets a flow controller **44** that regulates a valve **45** in conduit **42** so as to tend to maintain a constant liquid level in accumulator **30**.

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:

$$R_e+V_1=R_1+V_o \qquad (1)$$

where:

R_e=mass flow of liquid entering top tray (external reflux)
V_i=mass flow of vapor entering top tray
R_l=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:

$$R_e h_e + V_i H = R_l h_l + V_o H \quad (2)$$

where:

h_e=enthalpy of external reflux
h_l=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:

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

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

Then enthalpy of the external reflux can be expressed:

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

where:

C_p=specific heat of the external reflux stream
ΔT=the difference between the bubble point temperature of the reflux at the fractionator pressure and the actual external reflux temperature.

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

$$V_i(h_l+\lambda) - V_o(h_l+\lambda) = R_l h_l - R_e h_e \quad (5)$$

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

$$(h_l+\lambda)(V_l - V_o) = h_l(R_l - R_e) + R_e C_p \Delta T \quad (6)$$

From Equation 1 it is known:

$$V_l - V_o = R_l - R_e \quad (7)$$

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 measured by a flow transducer which establishes a signal representative of the rate of flow through conduit **40**. This flow transducer can advtantageously be a differential pressure transmitter **50** which establishes an output pressure representative of the pressure differential across an orifice in conduit **40**. This pressure is transmitted to the inlet of a square root force bridge **51** which establishes an output pneumatic pressure that is representative of the square root of the input pressure. The output pressure of bridge **51** is thus directly proportional to the flow through conduit **40**.

In accordance with this invention, the term ΔT is not measured directly. Instead, a signal is established which is representative of the difference between a fixed reference temperature and the temperature of the external reflux. A thermocouple **54** is positioned in reflux conduit **40** to establish a first voltage representative of the temperature of the external reflux. A voltage source **52** is connected across the end terminals of a potentiometer **53**. The negative end terminal of potentiometer **53** is connected to the negative terminal of thermocouple **54**. The positive terminal of thermocouple **54** and the contactor of potentiometer **53** are connected to the respective input terminals of a pneumatic transducer **55**. The contactor of potentiometer **53** can be adjusted to vary the reference voltage supplied by the potentiometer. This can be changed as required to approximate the bubble point temperature of the external reflux at the pressure within column **10**. The resulting signal applied to the input of transducer **55** is thus representative of ΔT. Transducer **55** is calibrated so that the output signal is proportional to $(1+K\Delta T)$. The term K is equal to

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

The output pressures from transducer **55** and force bridge **51** are applied to the respective inputs of a multiplying force bridge **60** which establishes an output pressure that is proportional to the product $R_e(1+K\Delta T)$. The output signal from force bridge **60** thus represents the computed internal reflux of the fractionation column.

The output signal from bridge **60** is applied through a conventional flow recorder-controller **61** to adjust a valve **63** in reflux conduit **40** in such a manner as to tend to maintain the computed internal reflux constant at a preselected value. If the computed internal reflux should increase, valve **63** is adjusted to reduce the flow through conduit **40**. Conversely, if the computed internal reflux should decrease, valve **63** is adjusted to increase the flow through conduit **40**.

As a specific example of the computer and control system of this invention, reference is made to a fluid separation wherein a feed stream containing primarily isopentane and normal pentane is separated to provide an overhead product stream containing primarily isopentane and a kettle product stream comprising primarily normal pentane. Typical compositions (percentages) and flow rates (barrels per hour) of the three streams are set forth in the following table:

	Feed	Overhead	Kettle
Normal butane	0.05	0.1	----
Isopentane	51.40	99.5	3.3
Normal pentane	47.35	0.4	94.3
Cyclohexane	0.90	----	1.8
Hexanes, plus	0.30	----	0.6
	100.0	100.0	100.0
Flows	360	180	180

The reflux to feed ratio is of the order of five to one. ΔT normally is of the order of 55° F.

FIGURE 2*a* of the drawing is a typical record of the kettle product flow rate obtained when the column is provided with the control system thus far described except for the internal reflux computer. FIGURE 2*b* illustrates the kettle product flow when the internal reflux computer override control is provided. It should be evident that a substantially smoother operation of the column is obtained by use of this control system.

The computer components illustrated in FIGURE 1 can be conventional pneumatic equipment well known in the art. For example, bridges **51** and **60** can be of the type described in U.S. Patent 2,643,055. However, the computer can also be constructed of electrical components well known in the art. Multiplication can be accomplished by potentiometers actuated by servo motors, for example.

The fractionation column control system can be improved still further by overriding the internal reflux flow controller **61** set point by a signal from an analyzer which measures a property of the fluid mixture within the column. A sample stream is withdrawn from the upper region of column **10** through a conduit **70** which communicates with the inlet of an analyzer **71**. This analyzer can advantageously be a differential refractometer which establishes an output signal representative of the refractive index of the sample fluid. The output signal from analyzer **71** is applied through a recorder-controller **72** to adjust the set point of flow controller **61**. If the measured refractive index tends to increase in the example described, thus indicating a less pure isopentane overhead product, controller **61** is reset so that valve **63** is opened more to increase the reflux rate. Conversely, if the refractive index decreases, the reflux rate is decreased. It should be evident that other types of analyzers can be employed for this purpose. Examples of such analyzers include infrared analyzers, ultraviolet analyzers, mass

spectrometers and chromatographic analyzers. The choice of the particular analyzer employed depends to a large extent upon the constituents being separated in the fractionation column.

An important feature of this invention resides in the use of a reference temperature representative of the desired vapor temperature at the top of the column. This can prevent errors which might result from an actual temperature measurement at this point. For example, a column upset or change in feed could result in an increase in the higher boiling constituent of the feed mixture in the column overhead. This would increase ΔT so that the controller would decrease external reflux. However, this is opposite the proper control step that should be applied. The higher boiling constituent would increase still further to compound the error. However, the fixed reference temperature prevents this error from being made.

Heretofore, it has beeen common practic in fractionation control systems to maintain the reflux flow at a predetermined value to give a desired reflux to feed ratio. If the feed rate should change, the reflux flow must be reset manually to maintain the desired ratio. It is generally desirable to operate a fractionation column with a minimum amount of reflux in order to conserve the heat supplied to the column. In accordance with another aspect of this invention, an improved method of control is provided wherein the internal reflux to feed ratio is maintained constant at a preselected value. FIGURE 3 is a schematic diagram of such a control system.

The controls associated with the kettle and feed streams of column **10** are identical to those shown in FIGURE 1 except that flow controller **12** is omitted. However, controller **12** can be employed, if desired. The overhead and reflux flow controls are substantially identical to those in FIGURE 1. Condenser **29** is an air fan cooler which is provided with an auxiliary temperature recorder-controller **80** that responds to the temperature of condensed vapors introduced into accumulator **30**. This controller adjusts either the speed of the fan or the pitch of the blades so as to reduce temperature fluctuations in the liquid directed to accumultor **30**. As previously discussed, such a control system is helpful but does not eliminate all temperature fluctuations.

The control system of FIGURE 3 is provided with an internal reflux computer **81** which includes elements **55**, **50**, **51** and **60** of FIGURE 1. The output signal from the reflux computer is applied to flow recorder-controller **61**. A differential pressure transmitter **82** establishes a signal representative of the pressure differential across an orifice in feed conduit **11**. The output signal of transmitter **82**, which is representative of the square of the flow rate in conduit **11**, is applied to the input of a square root force bridge **83**. The output signal of bridge **83**, which is representative of the flow, is applied through a delay means **85** to the first input of a ratio controller **84**. The second input signal to ratio controller **84** is the output signal of computer **81**. Ratio controller **84** provides an output signal which is representative of a desired ratio between the two input signals. This signal is applied to the set point of flow controller **61**. The desired ratio to be provided by controller **84** can be adjusted manually by manipulating the set point of the controller. The control system of FIGURE 3 thus provides a method of maintaining the ratio of the internal reflux to the feed rate constant at a preselected value. This is a decided improvement over control systems previously known.

Delay means **85** is provided so that the reflux will be adjusted some time after the feed flow rate changes. Otherwise, a sudden increase in feed, for example, would result in a proportional increase in external reflux. Such an increase in external reflux would decrease the overhead product flow, perhaps to zero. This type of operation is obviously undesirable. The delay, on the other hand, permits the column to become stabilized at the increased feed flow rate before the ratio is reset. If a pneumatic control system is employed, delay means **85** can comprise a restriction followed by a storage tank, or a series of such restrictions and storage tanks. If an electrical control system is employed, delay means **85** can comprise a conventional active type RC delay network.

A second embodiment of the ratio control system is illustrated in FIGURE 4. The output signal from delay means **85** is applied to the first input of a ratio relay **86**. The set point constitutes the second input of relay **86**. The output signal of relay **86** resets flow controller **61** which adjusts valve **63** in the reflux conduit.

In view of the foregoing description it should be evident that there is provided in accordance with this invention a novel computer for measuring the internal reflux in a fractionation column. Control systems utilizing such a computer to regulate the rate of external reflux stabilize the operation of fractionation columns substantially. Furthermore, such a control system permits a fractionator to operate at a higher load than is otherwise possible. The computer of this invention utilizes a minimum number of standard components which are available commercially and which are of a type that is generally familiar to process operators. The computer of this invention can readily be adapted for use in existing columns without extensive modifications.

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 fluid mixture of two or more components is directed to a fractionation column, a vapor stream is removed from 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 the column as external reflux, a control system comprising means to establish a first signal representative of the flow of external reflux to said column, a thermocouple positioned to establish a second signal representative of the temperature of said external reflux, an adjustable voltage source for establishing a third signal representative of a predetermined desired fixed reference temperature which approximates the bubble point temperature of the external reflux at the pressure within said column, means responsive to said second and third signals to establish a fourth signal

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

where C_p is the specific heat of said external reflux, λ is the heat of vaporization of liquid in the top of said column, and ΔT is the difference between said third and second signals, means to multiply said first signal by said fourth signal to establish a fifth signal representative of internal reflux in said column, and means responsive to said fifth signal to control the operation of said column by regulating the flow of said external reflux.

2. In a fractionation system wherein a fluid mixture of two or more components is directed to a fractionation column, a vapor stream is removed from 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 the column as external reflux, apparatus to compute the internal reflux in said column comprising means to establish a first signal representative of the flow of external reflux to said column, a thermocouple positioned to establish a second signal representative of the temperature of said external reflux, an adjustable voltage source for establishing a third signal representative of a predetermined desired fixed reference temperature which approximates the bubble point temperature of the external reflux at the pressure within said column, means responsive to said second and third signals to establish a fourth signal

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

where C_p is the specific heat of said external reflux, λ is

the heat of vaporization of liquid in the top of said columns, and ΔT is the difference between said third and second signals, and means to multiply said first signal by said fourth signal to establish a fifth signal representative of internal reflux in said column.

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