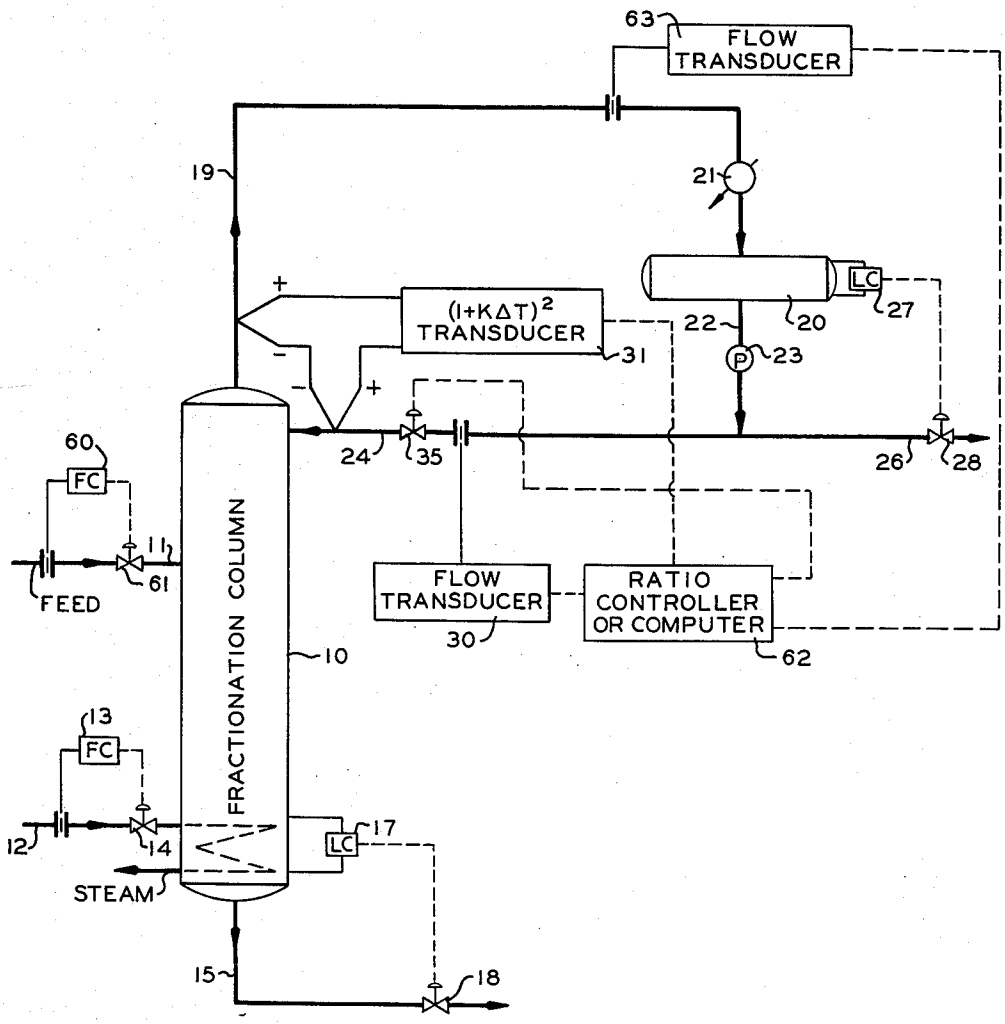
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FRACTIONATION CONTROL SYSTEM

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FRACTIONATION CONTROL SYSTEM

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This invention relates to improved systems for controlling the operation of fractionation columns.

In recent years increasing use has been made of fan coolers for condensing overhead vapor 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 atmosphere temperature changes, such as occur during a rainstorm, for example, result in condensation of vapor within the column because of cooling of the reflux below its bubble point. This results in an increase in overhead product purity at the expense of decreased overhead product rate, and therefore, a decrease in column throughput.

It has recently been discovered that the control of fractionation columns can be improved by computing the amount of internal reflux in the column and utilizing this computation for control purposes. Internal reflux is defined herein as the external reflux returned to the column plus the vapor which is condensed near the top of the column by the sub-cooled external reflux. Such a computation can be made from a measurement of the rate of flow of the external reflux and a measurement of the temperature differential between external reflux returned to the column and a region near the top of the column, such as the overhead vapor. Signals representative of these two measurements are combined so as to provide a measurement of the internal reflux in the column. In accordance with the present invention, improved fractionation column control systems are provided which are based upon measurements representative of internal reflux, but which do not actually require a computation of the internal reflux. Fractionation column control systems are provided wherein the ratio of internal reflux to overhead vapor flow is maintained at a preselected value. These control systems result in increased product purity with a smaller expenditure of energy.

Accordingly, it is an object of this invention to provide improved fractionation column control systems which are based on measurements representative of internal reflux in the column.

A further object is to provide a fractionation control system wherein the ratio of internal reflux to overhead vapor flow is maintained at a preselected value.

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

Accompanying drawing which is a schematic representation of one embodiment of the control system of this invention.

Referring now to the drawing in detail 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. Steam, or other heating medium, is circulated through the lower region of column 10 by a conduit 12 at a predetermined rate which is maintained by a flow controller 13 that adjusts a valve 14. A kettle product stream is withdrawn from the bottom of column 10 through a conduit 15. The rate of product withdrawal

through conduit 15 is regulated by a liquid level controller 17 which adjusts a valve 18. Vapors are withdrawn from the top of column 10 through a conduit 19 which communicates with an accumulator 20 through a condenser 21. The control system of this invention is particularly useful when condenser 21 is a fan cooler, but the invention is by no means restricted to such a condenser. Condensed liquid in accumulator 20 is removed through a conduit 22 which communicates with the inlet of a pump 23. Pump 23 returns a portion of this liquid to the upper region of column 10 through a conduit 24. This flow of liquid through conduit 24 is referred to hereinafter as the "external" reflux. The remainder of the liquid removed from accumulator 20 constitutes the overhead product and is removed through a conduit 26. The flow through conduit 26 is regulated by a liquid level controller 27 which adjusts a valve 28 to maintain a predetermined liquid level in accumulator 20.

As previously mentioned, the control system of this invention is based upon a measurement representative of the internal reflux in the column, even though this internal reflux is not measured direclty. In order to explain the operation of the controller 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:

$$R_e+V_1=R_1+V_o \tag{1}$$

where:

R_e=mass flow of liquid entering top tray (external reflux)
V_1=mass flow of vapor entering top tray
R_1=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 expresseed:

$$R_eh_e+V_1H=R_1h_1+V_oH \tag{2}$$

where:

h_e=enthalpy of external reflux
h_1=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:

$$H=h_1+\lambda \tag{3}$$

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

The enthalpy of the external reflux can be expressed:

$$h_e=h_1-C_p\Delta T \tag{4}$$

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:

$$V_1(h_1+\lambda)-V_o(h_1+\lambda)=R_1h_1-R_eh_e \tag{5}$$

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

$$(h_1+\lambda)(V_1-V_o)=h_1(R_1-R_e)+R_eC_p\Delta T \tag{6}$$

From Equation 1 it is known·

$$V_1-V_o=R_1-R_e \tag{7}$$

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

$$R_1=R_e\left(1+\frac{C_p\Delta T}{\lambda}\right) \tag{8}$$

Equation 8 can be modified by substituting a constant K for

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

and squaring both sides to obtain:

$$R_i^2=R_e^2(1+K\Delta T)^2 \quad (9)$$

The term R_e^2 in Equation 9 is measured by a flow transducer **30** which establishes an output signal representative of the flow of external reflux through conduit **24**. Such a signal can conveniently be established by a differential pressure transmitter connected across an orifice in conduit **24**. This pressure differential is representative of the square of the flow. The term $(1+K\Delta T)^2$ is established by comparing the temperature of the reflux in conduit **24** with the temperature of the vapor removed from column **10** through conduit **19**. A temperature transducer **31** is calibrated to provide an output signal representative of the term $(1+\Delta T)^2$ when provided with input signals from respective sensing means, such as thermocouples. The terms C_p and λ, and thus K, are substantially constant for any given fluid mixture. From this information, it is possible to provide a signal representative of the internal reflux in the fractionation column.

The control system of the drawing is provided to maintain the ratio of the internal reflux to the overhead vapor withdrawal rate substantially constant at a preselected value. The feed through conduit **11** is maintained at a predetermined rate by a flow controller **60** which regulates a valve **61**. A second flow transducer **63** establishes an output signal O^2 which is representative of the square of the flow rate of overhead vapor through conduit **19**. The output signals from flow transducers **30** and **63** are applied to the respective inputs of a ratio controller or computer **62**. The output signal from temperature transducer **31** is applied to an input of controller **62** to adjust the set point thereof. The output signal of controller **62** is representative of

$$\frac{R_e^2}{O^2}(1+K\Delta T)^2$$

and is utilized to adjust a valve **35** in conduit **24** to control the flow of external reflux to column **10**.

The preselected value of the ratio of internal reflux to overhead vapor withdrawal rate or

$$\frac{R_i}{O}$$

can be expressed as follows:

$$\frac{R_i}{O}=\frac{R_e}{O}(1+K\Delta T) \quad (10)$$

or

$$\frac{R_i^2}{O^2}=\frac{R_e^2}{O^2}(1+K\Delta T)^2 \quad (11)$$

where O represents the rate of withdrawal of overhead vapors through conduit **19**. The signal applied to ratio controller **62** from flow transducer **30** is representative of the term R_e^2 and the signal applied to ratio controller **62** from flow transducer **63** is representative of the term O^2. Temperature transducer **31** is calibrated by adjusting the zero point and the span so that the output signal, which is applied to the set point of ratio controller **62**, is representative of the term $(1+K\Delta T)^2$. The output of this transducer is reasonably linear over the range of ΔT normally encountered in column separation. The normal range of ΔT of the specific column under control is considered in making the calibration. If greater accuracy is required, the transducer can be calibrated to yield the output term $1+K\Delta T$, and this signal can be squared

using, for example, a Sorteberg Force Bridge to yield the term $(1+K\Delta T)^2$. This results in the signal

$$\frac{R_e^2}{O^2}$$

being multiplied by the factor $(1+K\Delta T)^2$ by ratio controller **62**. Controller **62** adjusts the flow of external reflux through valve **35** to maintain the ratio of R_i^2 to O^2 at a preselected value. For any given value, this ratio is representative of the ratio of R_i to O. The particular ratio desired will depend on a number of factors such as compositions, flow of feed, desired separation and size of the fractionation column, for example.

The control apparatus illustrated in the drawing can advantageously employ conventional pneumatic or electrical equipment which is well known to those skilled in the art and which can be obtained commercially. Instead of a ratio controller, controller **62** can be a computer, such as a force bridge of the type described in U.S. Patent 2,643,055, for example, and can be provided with input signals R_e^2 $(1+K\Delta T)^2$ and O^2. The output signal of the computer is representative of

$$\frac{R_e^2}{O^2}(1+K\Delta T)^2$$

which, as indicated by the Equation 11, is equal to the ratio of R_i^2 to O^2. This output signal controls valve **35** to maintain the ratio at a preselected value.

In another embodiment Equation 11 can be expressed:

$$X^2=\frac{R_e^2}{O^2}(1+K\Delta T)^2 \quad (12)$$

where X^2 is the square of the desired ratio of internal reflux to overhead vapor withdrawal rate. Equation 12 can be expressed:

$$R_e^2=\frac{O^2X^2}{(1+K\Delta T)^2} \quad (13)$$

The term R_e^2 is representative of a signal to be employed to control the external reflux to maintain X^2 at a preselected value. In this embodiment controller **62** can comprise a computer and a flow controller. The computer is provided with input signals representative of terms O^2, X^2 and $(1+K\Delta T)^2$ of Equation 13 and supplied an output signal R_e^2. This output signal can be used to reset the flow controller which in turn regulates valve **35** in conduit **24**. Signal X^2 is supplied from an external source, which can be manually or automatically set, to provide the desired ratio. Where it can be assumed that the temperature of the overhead vapor remains substantially constant, the signal $(1+K\Delta T)^2$ can be based on a measurement of the temperature of the external reflux alone.

From the foregoing description it should be evident that improved fractionation control systems are provided in accordance with this invention. These systems utilize indirect measurements of the internal reflux in the column. In response to such measurements, the ratio of internal reflux to feed or overhead vapor can be maintained at preselected values. This substantially increases the stability of the column by elimination or reduction of column upsets which are due to changes in the temperature of reflux returned to the column.

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 to be separated is introduced into a fractionation column through a first conduit, vapors are removed from the top of said column through a second conduit, said vapors are condensed and a portion of the condensate is returned to said column as reflux through a third conduit, and liquid is removed from the bottom of said column

through a fourth conduit, a control system comprising first means operatively connected to said second conduit to establish a first signal representative of the square of the rate of flow through said second conduit, second means operatively connected to said second and third conduits to establish a second signal representative of the quantity $(1+K\Delta T)^2$ where K is a constant and ΔT is the difference in temperature of fluids in said second and third conduits, third means operatively connected to said third conduit to establish a third signal representative of the square of the rate of flow through said third conduit, fourth means responsive to said first, second and third means to establish a fourth signal representative of the product of said second and third signals divided by said first signal, and fifth means responsive to said fourth means to adjust the rate of flow through said third conduit.

2. The system of claim 1 further comprising means to maintain the flow through said first conduit at a predetermined rate.

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