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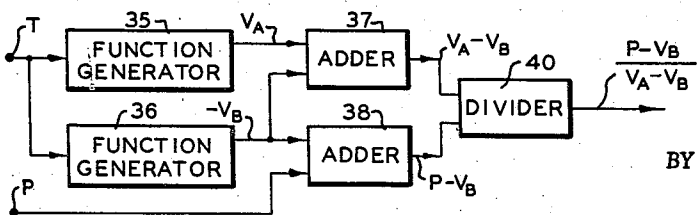
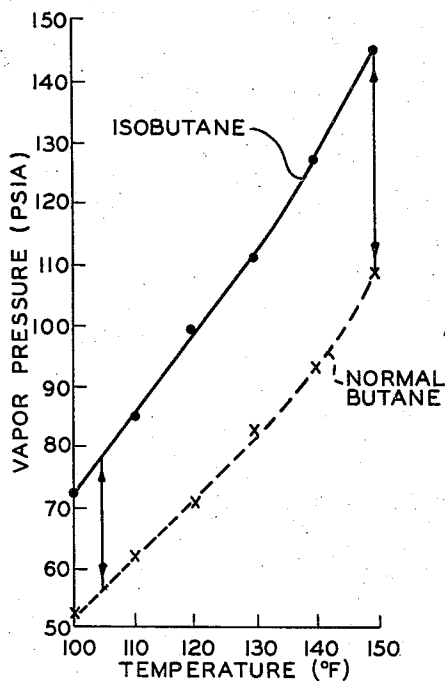
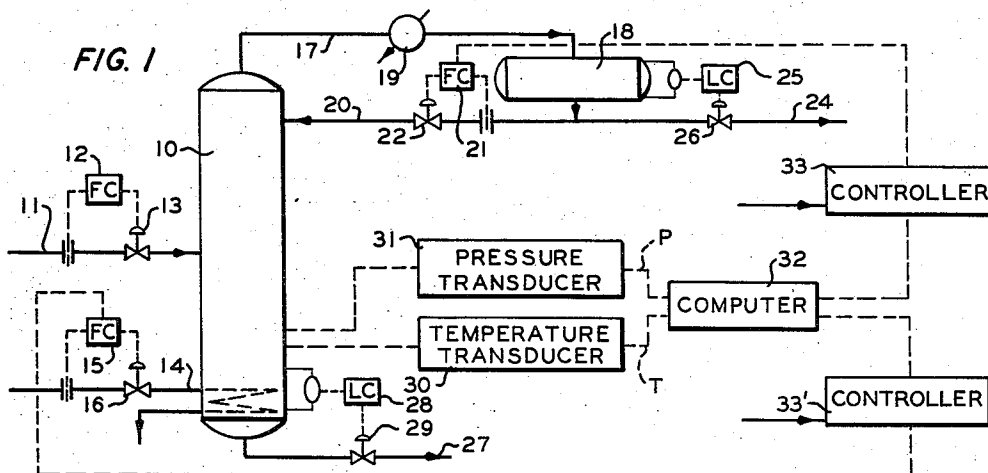
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3,108,929

FLUID ANALYZER FOR CONTROL SYSTEM

Filed Jan. 15, 1960

3 Sheets-Sheet 1



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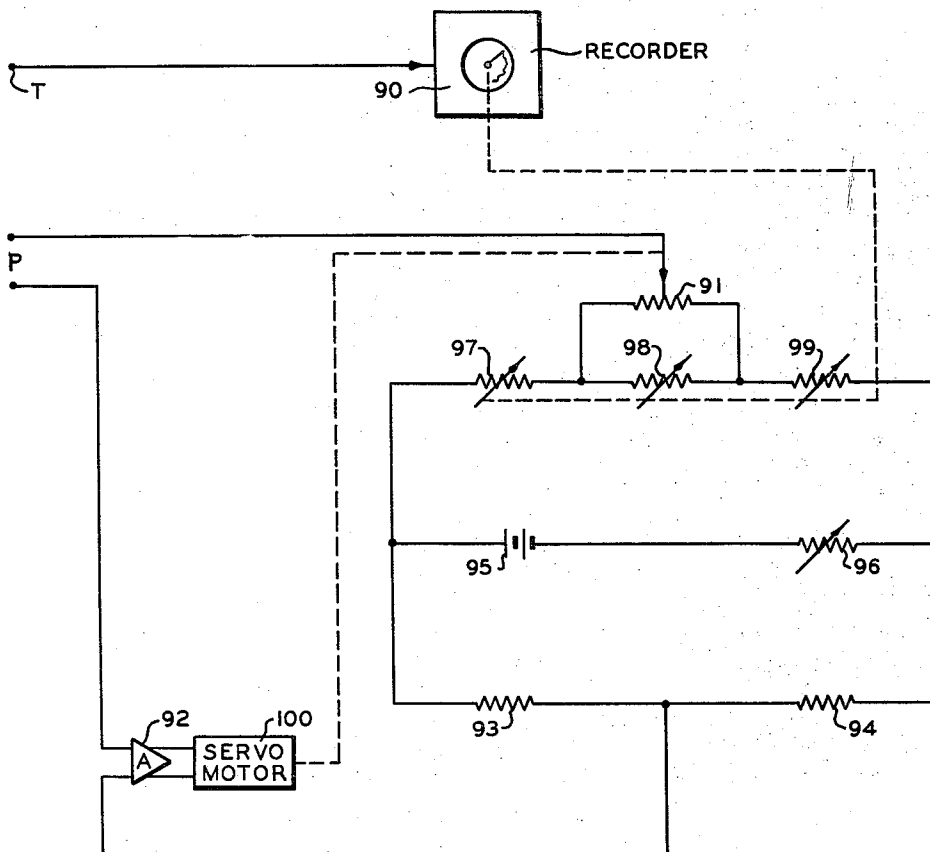


FIG. 7

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3,108,929
FLUID ANALYZER FOR CONTROL SYSTEM
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This invention relates to the analysis of binary fluid mixtures. In another aspect it relates to control systems for fluid separation processes.

It is common practice in the petroleum and chemical industries to separate liquid mixtures by distillation processes. Various types of fractionation columns have been devised for this purpose. Many of these columns are provided with a plurality of trays which are spaced vertically from one another. The fluid mixture to be separated is introduced into the column and heat is applied to the lower region of the column to vaporize liquids. The column is operated so that liquid at its boiling temperature flows downwardly across the trays and is contacted by rising vapor at its condensing temperature. In the simplest columns, a first product stream comprising the lower boiling constituent of the fluid mixture is removed from the top of the column and a second product stream comprising the higher boiling constituent is removed from the bottom of the column. A portion of the overhead vapor is normally condensed and returned to the column as reflux.

In order to control the operation of such a fractionation column, it is desirable to measure the composition of the fluid mixture at one or more locations within the column. Various types of analyzers have been proposed for this use. These analyzers measure a variable representative of fluid composition, such as temperature, for example, or actually withdraw and analyze a fluid sample. However, all of these analyzers have certain drawbacks. The former do not provide the desired accuracy and freedom from ambiguity, while the latter are often complex and require rather elaborate sample systems.

In accordance with the present invention, there is provided an improved analyzer which is capable of measuring the composition of a binary mixture within a fractionation column or in any region where a liquid is boiling and in contact with its vapor. This analysis is made from measurements of the temperature and the pressure of the mixture. Computing apparatus provides an output signal representative of the composition of the fluid mixture from these two measurements.

Accordingly, it is an object of this invention to provide apparatus for measuring the composition of binary fluid mixtures.

Another object is to provide control systems for fractionation processes.

A further object is to provide apparatus for analyzing a fluid mixture in a distillation process without withdrawing samples of the mixture from the process.

Other objects, advantages and features of this 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 control system in accordance with this invention.

FIGURE 2 is a graphical representation of vapor pressures of selected hydrocarbon as a function of temperature.

FIGURE 3 is a schematic representation of a first embodiment of the analyzer of this invention.

FIGURE 4 is a schematic representation of electrical equipment which can be employed in the analyzer of FIGURE 3.

FIGURE 5 is a schematic representation of pneumatic equipment which can be employed in the analyzer of this invention.

FIGURE 6 is a schematic representation of a second embodiment of the analyzer of this invention.

FIGURE 7 is a schematic representation of a third embodiment of the analyzer of this invention.

Referring now to the drawing in detail and to FIGURE 1 in particular, there is shown a fractionation column 10 which is provided with a number of liquid-vapor 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. Steam, or other heating medium, is circulated through the lower region of column 10 by means of a conduit 14. The flow through conduit 14 is regulated by a flow controller 15 which adjusts a valve 16. Vapors are removed from the top of column 10 through a conduit 17 which communicates with an accumulator 18 through a condenser 19. A portion of the resulting condensed liquid is returned to column 10 through a conduit 20. The flow through conduit 20 is regulated by a flow controller 21 which adjusts a valve 22. The remainder of the liquid in accumulator 18 is removed as the overhead product through a conduit 24. The flow through conduit 24 is regulated by liquid level controller 25 on accumulator 18 which adjusts a valve 26 in conduit 24. A liquid kettle product is withdrawn from the bottom of column 10 through a conduit 27. The flow through conduit 27 is regulated by liquid level controller 28 which adjusts a valve 29 to maintain a predetermined liquid level in the bottom of column 10.

The apparatus thus far described comprises a conventional fractionation system for separating fluid mixtures. Such a system can be employed, for example, to separate a binary mixture of isobutane and normal butane into two product streams comprising the nearly pure individual constituents of this fluid mixture. In accordance with the present invention, an analysis is made to determine the composition of the mixture at a selected tray in the column. In response to this analysis, the operation of the fractionation column is regulated to provide the desired separation.

A temperature transducer 30 provides a first signal representative of the temperature of the liquid on the selected tray. A pressure transducer 31 provides a second signal representative of the absolute pressure of the vapor above this tray. These two signals are transmitted to a computer 32 which provides an output signal representative of the composition of the fluid mixture at the selected tray. This output signal can be employed as the measurement for controller 33 where, as the result of comparison to the desired value of composition, an output signal is generated which manipulates the set point of flow controller 21, or alternatively is employed as the measurement for controller 33' which manipulates flow controller 15. For example, if the output signal from computer 32 should indicate that the concentration of the low boiling constituent is becoming excessive at the sample point, more heat is supplied to the column to vaporize additional amounts of this constituent. Alternatively, the rate of flow of reflux is decreased to increase the amount of the low boiling constituent removed as overhead product. If the measured concentration of the low boiling constituent should decrease, less heat is supplied to the column or the reflux rate is increased. It is also possible to make both adjustments simultaneously. The sample point at which the temperature and pressure measurements are made is selected so as to provide a region where the composition of the fluid mixture is essentially binary and changes rather abruptly. Generally, suitable sample points can be

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located near the mid-point between feed and either the top or bottom of the column.

The total pressure P exerted by the vapor of a binary fluid mixture can be expressed as follows:

$$P = P_A + P_B \quad (1)$$

where P_A is the partial pressure of constituent A and P_B is the partial pressure of constituent B. Equation 1 can be expressed:

$$P = XV_A + (1-X)V_B \quad (2)$$

where X is the mol fraction of A in liquid phase, $(1-X)$ is the mol fraction of B, V_A is the vapor pressure of A, and V_B is the vapor pressure of B, both at the temperature existing at the point where P is measured. Equation 2 can be solved for X to obtain:

$$X = \frac{P - V_B}{V_A - V_B} \quad (3)$$

The computer of this invention is adapted to provide an output signal representative of Equation 3 when supplied with input signals representing the temperature of the liquid and the absolute pressure of the vapor. The computer must also be calibrated with respect to changes in the vapor pressures of the two constituents of the fluid mixture as functions of temperature. The vapor pressures of isobutane and normal butane for example, at selected temperatures are illustrated in FIGURE 2 of the drawing.

A first embodiment of computer 32 is illustrated schematically in FIGURE 3. Transducer 30 of FIGURE 1 establishes an output signal T representative of the temperature of the liquid on the sample point tray. This temperature transducer can advantageously be a resistance thermometer which establishes an output electrical signal representative of temperature. However, other temperature measuring devices, such as sensitive thermocouples, can also be employed. The temperature signal T is transmitted to the input of a first function generator 35 which establishes an output signal V_A representative of the vapor pressure of component A at temperature T . Signal T is also applied to a second function generator 36 which establishes an output signal representative of $-V_B$, at temperature T . Function generators 35 and 36 are calibrated in accordance with the respective curves of FIGURE 2, for example, so that output signals are provided which correspond to the respective vapor pressures of normal butane and isobutane at the measured temperature. The output signals from function generators 35 and 36 are applied to the inputs of an adder 37 which provides an output signal representative of the quantity $(V_A - V_B)$. Pressure transducer 31 provides an output signal P which is representative of the absolute pressure of the vapor above the sample tray. This transducer can advantageously be an electrical bridge network employing strain gauges. However, other known types of pressure measuring devices can also be employed. Signal P is applied to the first input of a second adder 38, and signal $-V_B$ from function generator 36 is applied to the second input of adder 38. The output signal of adder 38 is thus representative of the quantity $(P - V_B)$. The output signals from adders 37 and 38 are applied as the respective input signals to a divider 40 which provides an output signal representative of the quantity

$$\frac{P - V_B}{V_A - V_B}$$

This signal, as indicated by Equation 3, is representative of the mol fraction of constituent A of the fluid mixture.

The computer elements illustrated in FIGURE 3 can be commercially available equipment known in the art. An electrical embodiment of this computer is illustrated in FIGURE 4. The input signal T , which is a voltage, is applied to the input of a first self-balancing potentiometer servo unit 45. The drive shaft of the servo motor of unit 45 is mechanically connected to the contactors of re-

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spective potentiometers 46 and 47. Voltage sources 48 and 49 are connected across the end terminals of respective potentiometers 46 and 47. The polarities of voltage sources 48 and 49 are such that the signals at the contactors of potentiometers 46 and 47, taken with respect to ground, are positive and negative, respectively. Potentiometers 46 and 47 normally are non-linear so as to conform to the shapes of the respective curves of FIGURE 2. In this manner, the balance position of the motor of unit 45, which is a linear function of temperature, is converted into voltages V_A and $-V_B$ which vary in accordance with the vapor pressure curves. The contactors of potentiometers 46 and 47 are connected through respective resistors 50 and 51 to the input of a summing amplifier 52. The output signal of amplifier 52 is applied across a potentiometer 53. A voltage representative of pressure P is applied through a first resistor 54 to the input of a second summing amplifier 55. The contactor of potentiometer 47 is also connected to this input of amplifier 55 through a resistor 56. The output signal of summing amplifier 55 is applied across a potentiometer 53. The contactor of potentiometer 80 is connected to one input of a differential amplifier 81. A reference voltage from a source 82 is applied to the second input of amplifier 81. The output of amplifier 81 energizes a reversible servo motor 83, the drive shaft of which is connected to the contactor of potentiometer 80. The contactor of potentiometer 80 is thus adjusted until the voltage at this contactor is equal to the reference voltage from source 82. The position of the contactor of potentiometer 80 is then representative of the reciprocal of the voltage applied across potentiometer 80. The drive shaft of motor 83 is also connected to the contactor of potentiometer 53. In this manner, the voltage $(P - V_B)$ applied across potentiometer 53 is multiplied by the quantity

$$\frac{1}{V_A - V_B}$$

to provide an output voltage X in accordance with Equation 3.

As previously mentioned, the elements of the computer of FIGURE 3 can be pneumatically operated means. Transducers 30 and 31 are selected to provide output pneumatic pressures representative of the respective temperature and pressure measurements. A suitable function generator for use in such an embodiment of the computer is illustrated schematically in FIGURE 5. The input signal is applied to a pneumatic motor 60 which rotates a shaft 61 by an amount representative of the input pressure applied to the motor. A cam 62 is attached to motor shaft 61. A chain 63 connects cam 62 with a wheel 64 on the input shaft 65 of a pneumatic transmitter 66. Cam 62 is designed to impart a rotation to shaft 65 which is a non-linear function of rotation of shaft 61. This cam is designed so that the rotation of shaft 65 corresponds to the vapor pressure of one of the curves of FIGURE 2 when the rotation of shaft 61 corresponds to the measured temperature. A spring 67 is employed to maintain chain 63 under tension at all times. Transmitter 66 provides an output air pressure V_A , for example, which is the desired vapor pressure of one of the fluid constituents at the measured temperature. Adders 37 and 38 of FIGURE 3 can be conventional summing relays, and divider 40 can be a force bridge, such as is described in U.S. Patent 2,643,055, for example.

A second embodiment of the computer of this invention is illustrated in FIGURE 6. The output signal P of pressure transducer 31 is applied to the input of a conventional recorder-controller 70. This controller provides an signal in a line 71 which manipulates the set-point of flow controllers 15, 21 or both. Recorder-controller 70, which preferably is an electronic instrument, is provided with both a zero adjustment means 72 and a span adjustment means 73. The output signal of summing amplifier 52, which is representative of the

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quantity ($V_A - V_B$), is applied to a servo unit 74 which sets span adjustment means 73 of recorder-controller 70. The output signal from potentiometer 47, which is representative of the quantity ($-V_B$), is applied to a servo motor 75 which sets zero adjustment means 72 of recorder-controller 70. The signal V_B is effectively subtracted from the measured pressure P by suppression of the zero point of the recorder-controller. Division by the quantity ($V_A - V_B$) is effectively accomplished by adjusting the span of the recorder-controller. Thus the output signal of the recorder portion is representative of the mol fraction of component A of the fluid mixture. Then by conventional means this measured value is compared with the desired value (set point) and an output control signal is generated to correct the process to the desired value.

A third embodiment of the computer is illustrated in FIGURE 7. The output signal T of temperature transducer 30 is applied to the input of a conventional recorder-controller 90. One output terminal of pressure transducer 31 is connected to the contactor of a potentiometer 91, and the second output terminal is connected to the first input terminal of a servo amplifier 92. The second input terminal of amplifier 92 is connected to the junction between resistors 93 and 94 which are connected in series relationship with a current source 95 and a variable resistor 96. Variable resistors 97, 98 and 99 are connected in series relationship with one another across current source 95 and resistor 96. Potentiometer 91 is connected in parallel with resistor 98. The output terminals of amplifier 92 are connected to a reversible servo motor 100. The drive shaft of motor 100 is connected to the contactor of potentiometer 91.

The indicating arm of recorder 90 is mechanically connected to variable resistors 97, 98 and 99 to adjust the three resistors in unison. Resistor 97 adjusts the zero point of the bridge network; resistor 98 adjusts the span; and resistor 99 adjusts the current. The bridge network is self-balancing because a change in input signal P actuates motor 100 to move the contactor of potentiometer 91 to restore a balance. The composition of the fluid mixture being measured is a temperature compensated pressure measurement. Resistor 98 is calibrated in accordance with the function ($V_A - V_B$), and resistor 97 is calibrated in accordance with the function V_B , both being functions of the measured temperature T. These functions can be obtained from the curves of FIGURE 2, for example. The rotation of motor 100 is representative of composition. Obviously, this motor rotation can be read on a dial or employed as the measurement for a controller.

It should be evident that the computer of this invention can be employed to measure the mol fraction of either component of the binary mixture by proper calibration of the function generators. While absolute measurements of the mol fractions can be made only if the fluid mixture contains only two components, it should be evident that useful control signals can be provided when additional components are present if these components are present in small amounts which remain relatively constant.

While the apparatus of this invention has been described in conjunction with controlling a fractionation column, it should be evident that the computer can be employed to measure the composition of binary fluid mixtures wherever such mixtures occur in the boiling state. The computer of this invention provides an accurate measurement of the compositions of a mixture without actually withdrawing a sample from the vessel containing the mixture.

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 fluid separation system comprising a fractiona-

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tion column having a plurality of vapor-liquid contacting trays therein, first conduit means communicating with said column to introduce a mixture of fluids A and B to be separated, an accumulator, second conduit means communicating between the top of said column and said accumulator, cooling means associated with said second conduit means, third conduit means communicating between said accumulator and an upper region of said column to return liquid to said column as reflux, fourth conduit means communicating with said accumulator to remove an overhead product, fifth conduit means communicating with the bottom of said column to remove a kettle product, and means to supply heat to the lower region of said column; a control system comprising means to measure the temperature of liquid on a pre-selected tray in said column, means to measure the pressure of the vapor above said tray, means responsive to said two means to measure to establish a signal representative of the quantity

$$\frac{P - V_B}{V_A - V_B}$$

where P is the measured pressure of said vapor, V_B is the vapor pressure of fluid B at the measured temperature, and V_A is the vapor pressure of fluid A at the measured temperature, said signal being representative of the mol fraction of fluid A on said tray, and means responsive to said signal to adjust the operation of said column to maintain said signal constant.

2. The control system of claim 1 wherein said means to adjust regulates the flow through said third conduit means.

3. The control system of claim 1 wherein said means to adjust regulates said means to supply heat to said column.

4. The control system of claim 1 wherein said means to adjust regulates both the flow through said third conduit means and said means to supply heat to said column.

5. In a fluid separation system comprising a fractionation column having a plurality of vapor-liquid contacting trays therein, first conduit means communicating with said column to introduce a mixture of fluids A and B to be separated, an accumulator, second conduit means communicating between the top of said column and said accumulator, cooling means associated with said second conduit means, third conduit means communicating between said accumulator and an upper region of said column to return liquid to said column as reflux, fourth conduit means communicating with said accumulator to remove an overhead product, fifth conduit means communicating with the bottom of said column to remove a kettle product, and means to supply heat to the lower region of said column; a control system comprising means to measure the temperature of liquid on a preselected tray in said column and to establish a first signal representative thereof, means to measure the pressure of the vapor above said preselected tray and to establish a second signal representative thereof, a bridge network comprising first and second impedance elements, a first current source connected in series with said first and second element, third and fourth variable impedance elements connected in series with one another across said current source, and a potentiometer connected across said fourth element, means responsive to said first signal to adjust said fourth element as a function of ($V_A - V_B$) where V_A is the vapor pressure of fluid A at the measured temperature and V_B is the vapor pressure of fluid B at the measured temperature; means responsive to said first signal to adjust said third element in accordance with V_B , a servo motor having the drive shaft thereof connected to the contactor of said potentiometer to adjust same, means connecting the junction between said first and second element to one input of said servo motor, means applying said second signal between the contactor of said potentiometer and the second input of said servo

motor, the position of the drive shaft of said servo motor being representative of the composition of the fluid on said preselected tray, and means responsive to the position of said drive shaft of said servo motor to adjust the operation of said column to maintain the position of said drive shaft of said servo motor substantially constant, thereby maintaining the composition of the fluid on said preselected tray substantially constant.

6. In a fluid separation system comprising a fractionation column having a plurality of vapor-liquid contacting trays therein, first conduit means communicating with said column to introduce a mixture of fluids A and B to be separated, an accumulator, second conduit means communicating between the top of said column and said accumulator, cooling means associated with said second conduit means, third conduit means communicating between said accumulator and an upper region of said column to return liquid to said column as reflux, fourth conduit means communicating with said accumulator to remove an overhead product, fifth conduit means communicating with the bottom of said column to remove a kettle product, and means to supply heat to the lower region of said column; a control system comprising means to measure the temperature of liquid on a preselected tray in said column and to establish a first signal representative thereof, means to measure the pressure of the vapor above said preselected tray and to establish a second signal P representative thereof, means responsive to said first signal to establish a third signal V_A representative of the vapor pressure of fluid A at the measured temperature, means responsive to said first signal to establish a fourth signal V_B representative of the vapor pressure of fluid B at said measured temperature, means responsive to said third and fourth signals to establish a fifth signal $V_A - V_B$, a controller adapted to provide an output signal representative of the input signal applied thereto, said controller being provided with a zero adjusting means and a span adjusting means, means to apply said second signal to the input of said controller, means responsive to said fifth signal to adjust said span adjusting means, means responsive to said fourth signal to adjust said zero adjusting means whereby the output signal of said controller is representative of

$$\frac{P - V_B}{V_A - V_B}$$

and means responsive to said output signal of said controller to adjust the operation of said column to maintain said output signal substantially constant.

7. In a fluid separation system comprising a fractionation column having a plurality of vapor-liquid contacting trays therein, first conduit means communicating with said column to introduce a mixture of fluids A and B to be separated, an accumulator, second conduit means communicating between the top of said column and said accumulator, cooling means associated with said second conduit means, third conduit means communicat-

ing between said accumulator and an upper region of said column to return liquid to said column as reflux, fourth conduit means communicating with said accumulator to remove an overhead product, fifth conduit means communicating with the bottom of said column to remove a kettle product, and means to supply heat to the lower region of said column; a control system comprising means to measure the temperature of liquid on a preselected tray in said column and to establish a first signal representative thereof, means to measure the pressure of the vapor above said preselected tray and to establish a second signal P representative thereof, first and second potentiometers having voltage sources applied across the end terminals thereof, a servo motor having the drive shaft thereof connected to the contactors of said potentiometers, means to energize said servo motor responsive to said first signal to produce a third signal V_A at the contactor of said first potentiometer representative of the vapor pressure of fluid A at the measured temperature and to establish a fourth signal V_B at the contactor of said second potentiometer representative of the vapor pressure of fluid B at said measured temperature, said third and fourth signals being taken with respect to first end terminals of said potentiometers, means responsive to said third and fourth signals to establish a fifth signal $V_A - V_B$, means responsive to said second and fourth signals to establish a sixth signal $P - V_B$, means responsive to said fifth and sixth signals to establish a seventh signal

$$\frac{P - V_B}{V_A - V_B}$$

said seventh signal being representative of the mol fraction of fluid A in the fluid on said preselected tray, and means responsive to said seventh signal to adjust the operation of said column to maintain said seventh signal substantially constant.

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