

J. E. RIJNSDORP ETAL  
APPARATUS FOR THE AUTOMATIC CONTROL OF A  
CONTINUOUS DISTILLATION PROCESS

3 Sheets-Sheet 1



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3 Sheets-Sheet 2

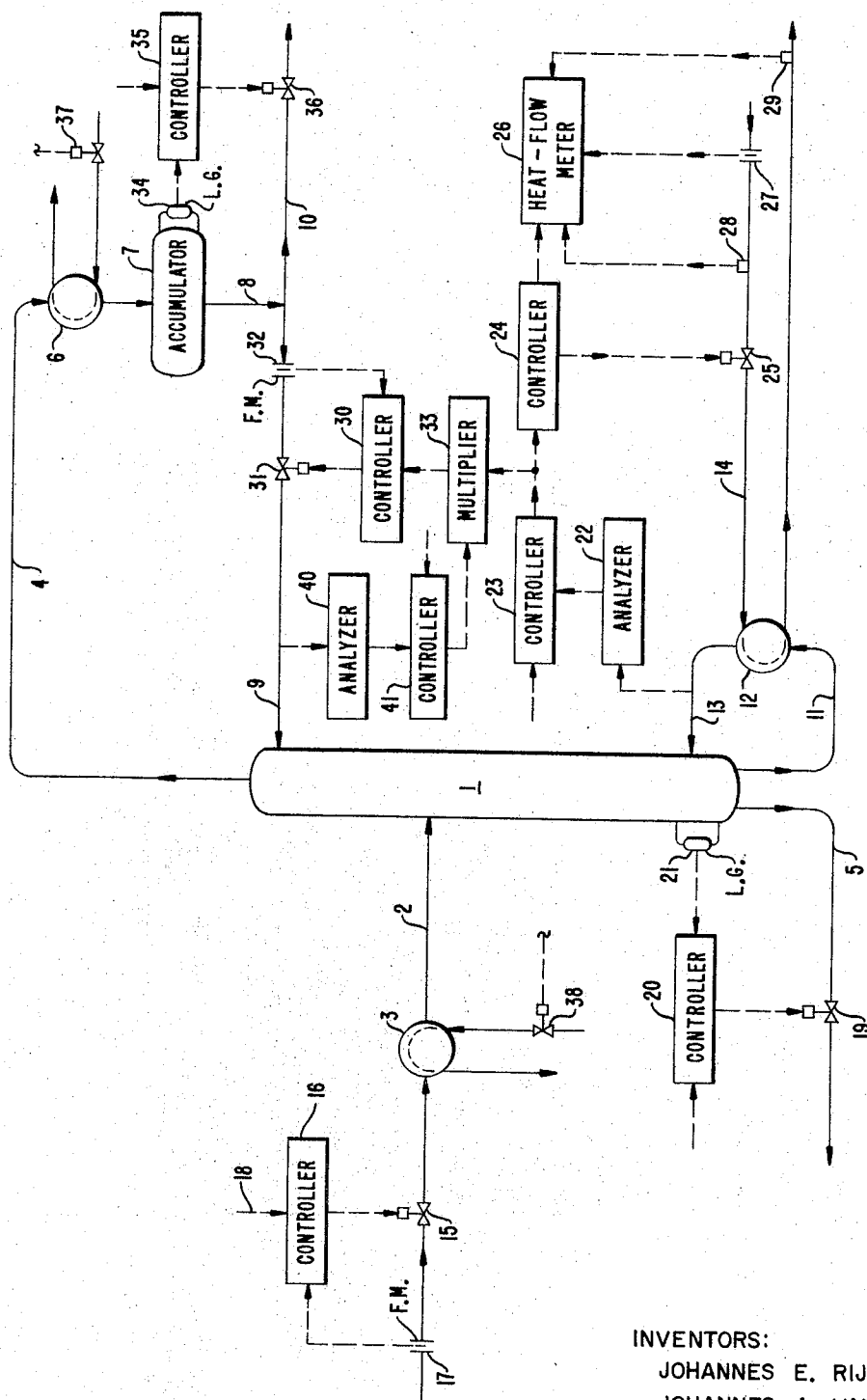


FIG. 2

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APPARATUS FOR THE AUTOMATIC CONTROL  
OF A CONTINUOUS DISTILLATION PROCESS

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The invention relates to a method and apparatus for automatically controlling a continuous distillation process for the separation of an intake mixture into a top and a bottom product stream in a column using reflux and reevaporation whereby upon a control action for keeping the quality of the bottom product constant, the quality of the top product does not change or changes only very slowly.

It often occurs in technical practice that both the top product and the bottom product withdrawn from a continuous distillation process have to meet specific requirements as regards quality. For example, it may be required that the top product contain no more than a specified small amount of impurity, while the bottom product should as far as possible be free from the main constituent of the top product. An example of such a situation in the oil industry is the removal of a valuable light product, such as isopentane, from a mixture of hydrocarbons where the purity of the isopentane must be at least 97% and where the bottom product may contain no more than 2% isopentane.

In such a distillation process, it may also be of importance to weigh the quality of the bottom product highest, for instance, if that product has to be supplied against specification. Accordingly, continuous direct control of the quality of the bottom product must be provided to maintain the bottom product at its desired value. However, at the same time it is also desirable to permit the quality of the top product to vary as little as possible.

In order to reach this aim of maintaining the quality of the bottom product on specification while permitting the top product quality to vary very little, it is attempted in controlling processes of this type to prevent dynamic coupling between the stripping and the rectifying sections of the column. That is to say, when adjusting the process variables to a specific ratio between the vapor flow and the liquid flow in the stripping section of the column in order to maintain the quality of the bottom product, the ratio between the vapor flow and the liquid flow in the rectifying section of the column should be disturbed as little as possible. In this way it is ensured that no or substantially no deviation occurs in the quality of the top product as a result of that control action in the stripping section of the column.

J. K. Kennedy in his thesis, "The Control of Distillation Columns," Manchester, 1963, on pages 173 and 192, describes a control scheme by which it is ensured that to a certain extent decoupling of the stripping section from the rectifying section of the column occurs upon a control action for maintaining the quality of the bottom product. According to this scheme the degree of reevaporation is adjusted by a quality meter for the product on one of the trays in the column while the reflux ratio is kept at a desired value by means of a ratio controller. The intended decoupling is here obtained due to the fact that because of the ratio control at the top of the column the reflux flow follows any change in the vapor flow over the top of the column, and in such a way that the ratio between those flows remains constant. Accordingly, the quality of the top product also ordinarily remains sub-

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stantially constant. However, if there are disturbances that require a permanent change of the process conditions, for example, a different composition of the feed, then the set value of the ratio controller has to be changed. Such a change can be carried out automatically, for example, with the aid of a signal derived from a meter or analyzer for measuring the quality of the top product.

Although, as indicated, a certain amount of decoupling is achieved with the above described control scheme, it should be noted that with this control scheme no adjustment at the top of the column takes place until the increased vapor flow is detected in the rectifying section of the column, and hence a delay between the time of the initiation of the control action for maintaining the quality of the bottom product and the control action for maintaining the quality of the top product. Accordingly, it has been found that the decoupling between the rectifying and stripping sections of the column can be considerably improved if the control action for maintaining the desired ratio between the vapor flow and the reflux flow is initiated at the same time that the control action begins in the stripping section of the column for maintaining the quality of the bottom product.

Briefly, the improved decoupling is achieved by the control scheme according to the invention by: adjusting the heat flow to the reboiler, using a signal derived from a meter or analyzer measuring the quality of the bottom product, in such a way that the quality of the bottom product is maintained at the desired value and adjusting the reflux flow, using a signal derived from the measured heat flow to the reboiler, in proportion to the heat flow to maintain a predetermined ratio between the reflux and heat flows, while at the same time adjusting the extent of preheating of the feed, the top product flow, the bottom product flow, the degree of reflux, the feed flow and/or the degree of cooling in the condenser, in a manner which in itself is known, to maintain the liquid levels in the accumulator and in the bottom of the column within desired limits. According to the preferred embodiment of the invention, the feed stream is maintained at an independently controlled value, the top product flow is adjusted to maintain the liquid level in the accumulator between desired limits and the bottom product flow is adjusted to maintain the liquid level in the bottom of the column between desired limits. The feed stream is therefore preferably an independently controlled variable, i.e., not controlled by another process variable or condition, which is limited by the maximum permissible load for the column.

With the control scheme according to the invention, if the quality of the bottom product does not meet the requirement or requirements made, then the heat flow to the reboiler is increased or decreased, as a result of which the vapor flow in the column increases or decreases, until the ratio between the vapor flow and the liquid flow in the stripping section of the column has reached the value required for the desired quality. Naturally, the change of the vapor flow will always rapidly become noticeable in the rectifying section of the column. However, due to the control of the reflux flow by the heat flow to the reboiler in the process according to the invention, the reflux flow is changed at approximately the same moment that the vapor flow is changed. Accordingly, any fluctuation of the magnitude of the vapor flow in the rectifying section of the column which results from a control action for maintaining the quality of the bottom product is accompanied with almost no delay by the proportional change of the liquid flow. Due to this very rapid control action the ratio between the vapor flow and the reflux flow in the rectifying section of the column does not change upon a control action for maintaining the quality of the bottom product and consequently the

quality of the top product does not change at all or at most changes only very slowly.

The invention will be more clearly understood from the following detailed description taken in conjunction with the accompanying drawings wherein:

FIGURE 1 is a diagrammatic representation of the preferred embodiment of a control system according to the invention;

FIGURE 2 is a diagrammatic representation of a control system showing a modification of the control system shown in FIGURE 1; and

FIGURE 3 is a diagrammatic representation of an alternate embodiment of the control system according to the invention.

The apparatus for carrying out the distillation process control scheme mentioned above is illustrated in FIGURE 1 wherein there is shown a distillation column 1 of any suitable design which contains vapor-liquid contacting elements, such as a vertical series of bubble or valve trays. The feed is continually introduced in either a liquid or vapor form into the column 1 to an intermediate stage through a pipeline 2 containing a preheater 3 if such is required; the top product in the vapor phase is discharged through a pipeline 4; and the liquid bottom product is discharged through a pipeline 5.

Connected to the top product column discharge line 4 is a condenser 6 which condenses the vapor in the line 4; the condensate then flows into a top product accumulator 7. The condensate collected in the accumulator is discharged through a pipeline 8 and a portion of the condensate is returned to the top of the column 1 for reflux by a pipeline 9, while the remainder of the discharged condensate is passed through a discharge pipeline 10 as the liquid top product output stream from the distillation process.

Reevaporation for the column 1 is effected by passing a stream of liquid from the bottom of the column via a pipeline 11 to a reboiler 12 which may, for example, be a heat exchanger, and returning the heated stream entirely or partially in the vapor phase to the column 1 via a pipeline 13. Heat is supplied to the reboiler 12 via a pipeline 14. The particular manner in which reevaporation is attained, however, forms per se no part of this invention since reevaporation may be accomplished in other ways, e.g., with a heating coil in the bottom of the column.

Turning now to the control of the distillation process shown in FIGURE 1, as indicated above, the preferred control scheme is for a process wherein the feed flow rate is maintained at an independently controlled value. Accordingly, the feed flow line 2 is provided with a control valve 15, the position of which is controlled or adjusted by means of a controller 16. The controller 16 compares the measured value of the feed flow rate, as determined by flowmeter 17 connected to the flow line 2, with a signal related to the desired value of the feed flow rate, i.e., the set value of the controller 16. The set value input signal of controller 16, and of all other controllers shown in the drawings which do not have set values which are adjusted by a process variable, is indicated by means of an arrow, e.g., arrow 18. Any differences resulting from the comparison by the controller 16 will cause the output signal from the controller 16 to adjust the valve 15 in a manner to decrease the difference. Thus, by selecting the set value of controller 16, the desired feed flow rate for the distillation process may be maintained.

The bottom liquid product stream flow rate is adjusted by means of a controllable valve 19 connected in the pipeline 5. The valve 19 is controlled by means of a controller 20 which compares the measured value of the liquid level in the bottom of column 1, as determined by the liquid level gauge 21, with a signal proportional to the desired level in the bottom of the column, i.e., the set value of the controller. The controller 20 attempts to keep the liquid level in the bottom of the column within desired limits and hence any differences resulting from

the comparison will produce an output signal from the controller 20 which tends to adjust the valve 19 in such a way that the difference is decreased. Thus, if at a given moment the measured value of the liquid level in the bottom of the column is larger than the set or desired value, the signal supplied from the controller 20 tends to open the valve 19 wider.

In order to maintain the desired constant quality of the bottom product according to the control scheme of the invention, there is provided a quality measuring instrument or analyzer 22, by any suitable design, which continuously analyzes the quality of the bottom product, e.g., a process chromatograph. Although the analyzer 22 is shown as analyzing a sample of the bottom product in the flow line 13, it is understood by those skilled in the art that the sample can equally well be taken from other locations, e.g., the flow line 5 or from a tray in the column. The output signal from the analyzer 22 is fed to the normal input of a controller 23 which compares the value of the signal corresponding to the measured value of the quality of the bottom product to a set value corresponding to the desired quality of the bottom product and produces an output signal related to the difference. The output signal from controller 23 is fed to the set value input of a controller 24 whose output is connected to a controllable valve 25 in the flow line 14 for the purpose of controlling the flow of heating medium supplied to the reboiler 12 for reevaporation. The normal input of controller 24 is connected to the output of a meter 26 which continuously measures the quantity of heat supplied to the column by the reboiler 12. The meter 26 performs this measurement, in a manner well known in the art, by combining the output signals from a flowmeter 27 in the flow line 14 and a pair of transducers 28 and 29 which measure the temperature of the heating medium before and after passing through the reboiler 12. It should be noted that if the heating medium flowing through flow line 14 gives off its heat by condensation of steam, then a sufficiently accurate measurement of the heat flow to the column via the reboiler may be obtained by utilizing only the output signal from the flowmeter 27.

The quality of the product is controlled according to the control scheme of the invention by proper adjustment of the reflux flow. According to the embodiment shown in FIGURE 1, the reflux flow is controlled by a controller 30 whose output signal controls the position of a controllable valve 31 connected in a reflux line 9 and whose normal input is connected to the output of a flowmeter 32 connected in the flow line 9 for measuring the reflux flow. The set value input of controller 30 is connected to the output of a multiplier 33 whose input is connected to the output of heat flowmeter 25. The multiplier 33 multiplies the input signal thereto by a constant but adjustable value which is related to the desired ratio between the heat flow in the reboiler and the reflux flow. As can easily be seen, any change in the quality of heat supplied to the column by the reboiler 12 produces an immediate change in the reflux flow to the column and accordingly the desired quality of the top product is maintained. The top product flow and the liquid level in the accumulator 7 are controlled according to this embodiment by means of a control loop including a liquid level gauge 34, a controller 35 and a control valve 36. The controller 35 adjusts the position of control valve 36, and hence the top product flow, to maintain the liquid level in accumulator 7 within desired limits.

The flow of the cooling medium to the condenser 6 is controlled by means of a valve 37 while the flow of the heating medium to the preheater 3 is controlled by a valve 38. Although the particular control apparatus for adjusting the valves 37 and 38 is not shown, control schemes for adjusting the degree of cooling in the condenser and the degree of preheating of the feed stream are old and well known in the art and such control schemes may be utilized with the control schemes according to the instant invention. For example, by the use of known control schemes,

the flow of heating medium to the preheater 3 and/or the flow of cooling medium to the condenser 6 can be adjusted to control the pressure in the column or to maintain the feed stream at a constant temperature, or to optimize the heat economy or the yield of the process.

With the control system just described, if the quality of the bottom product no longer meets the requirement or requirements made, the output signal from controller 23 changes. If maintenance of the desired quality requires, for instance, a larger vapor flow in the stripping section of the column, then the changed output signal from controller 23 should result, by a change of the set value of controller 24, in an increase of the heat flow to the reboiler 12. This increased heat flow is measured by meter 26 and, in addition, via multiplier 33 the set value of controller 30 is changed, resulting in the control valve 31 being farther opened. The extent to which control valve 31 is farther opened can be adjusted by means of the constant multiplying factor introduced in multiplier 33. The increased vapor flow in the column which, of course, also enters into the rectifying section of the column, there meets an increased reflux flow due to the action of controller 30. By appropriate adjustment of the constant factor in multiplier 33 the ratio between the vapor flow and the reflux flow can be kept constant, and thereby the quality of the top product can also be maintained.

The input signal to multiplier 33 can also be supplied by the output signal from controller 23 instead of by the meter 26 since the output signal from controller 23 determines the set value of the heat flow controller 25 and hence is a measure of the heat flow to the reboiler. This modification is shown in FIGURE 2 wherein structures previously used are denoted by like reference numerals.

Sometimes it may also be desirable to adjust the constant factor provided by multiplier 33 to a different value if, as a result of slow or permanent changes, a different ratio between the vapor flow and the liquid flow in the rectifying section of the column is required for maintaining the desired quality of the top product. Such a change may, for example, occur as a result of changing over to another intake mixture. The magnitude of the constant factor for multiplier 33 can be derived from a meter or analyzer measuring the quality of the top product. This modification is also illustrated in FIGURE 2 wherein there is shown an analyzer 40 for continuously analyzing the quality of the top product. It is understood that the sample for analysis may be secured at other locations than that shown. The output signal from the analyzer is connected to the input of a controller 41 which detects any variation between the measured and desired values of the quality of the top product and produces an output signal which will adjust the constant in multiplier 33 to a new value at which the ratio of the reflux flow to the heat flow to the reboiler will result in the top product being of the desired quality.

The ratio between the heat flow to the reboiler 12 and the reflux flow can likewise be maintained at a desired value by directing the output signal from multiplier 33 to the input for the set value of a controller for the accumulator to adjust the reflux flow. This alternate embodiment of the control scheme is illustrated in FIGURE 3 wherein flowmeter 43, controller 44 and control valve 36 form a control loop for the top product flow. The set value of controller 44 is the output signal from multiplier 33.

In order to explain the operation of this embodiment of the invention, let the vapor flow from the column be represented by V, the reflux flow by R and the top product flow by D. Then, for a stationary condition,  $V=R+D$ . Since it is desired that  $V/R$  remain at a constant predetermined value, and since  $R=V-D$ , it follows that if

$$\frac{V}{V-D} = \frac{1}{1-\frac{D}{V}}$$

remains at a constant predetermined value, the requirement for the control method according to the invention is met. The control system shown in FIGURE 3 meets this requirement by maintaining  $D/V$  at a constant predetermined value. In general, with the mode of control according to FIGURE 3 the response of the reflux flow to changes of the vapor flow in the stripping section of the column is slower than with the example according to FIGURES 1 and 2.

It is to be understood that the control systems mentioned hereinbefore may be pneumatic, hydraulic, electric, electronic or mechanical systems or may constitute a mixture of these types.

We claim as our invention:

1. Apparatus for the automatic control of a continuous distillation process for the separation of a feed stream into top and bottom product streams in a distillation column in which both reflux and reevaporation are applied and wherein an accumulator for the top product is provided comprising:

means for detecting the level of the liquid in the bottom of the column and adjusting the bottom product flow to maintain the liquid level in the bottom of the column between desired limits;

- 25 means for adjusting the feed stream flow to a desired independently controlled value;

a first analyzer for measuring the quality of the bottom product;

- 30 a first controller responsive to the output signal from said first analyzer for determining the variation between the measured and desired values of the quality of the bottom product;

means for measuring the quantity of heat supplied to the reboiler for reevaporation;

- 35 first control means responsive to the output signals from said first controller and said heat measuring means for adjusting the quantity of heat supplied to said reboiler to maintain the quality of the bottom product at a desired value;

- 40 a gauge for measuring the liquid level in the accumulator; and

second control means responsive to the output signals from said gauge and to one of the output signals from said first controller and said heat measuring means for adjusting the top product flow and the reflux flow to maintain a predetermined ratio between the reflux flow and the heat flow to the reboiler, whereby upon a change in the heat flow to the reboiler to maintain a constant quality of the bottom product, the ratio between the reflux flow and the vapor flow in the top of the column is maintained at a desired substantially constant value and thereby prevents variation of the quality of the top product.

2. The apparatus of claim 1 wherein said first control means comprises a controller having its normal input connected to the output signal from said heat measuring means, its set value input connected to the output of said first controller and its output connected to a control valve in the flow line for the heating medium to the reboiler.

- 60 3. The apparatus of claim 1 wherein said second control means comprises:

a third controller responsive to the output signal from said gauge for adjusting the top product flow to maintain the liquid level in the accumulator between desired limits;

- 65 a flowmeter for measuring the reflux flow;

a signal multiplier having its input connected to the output of said heat measuring means, said multiplier producing an output signal equal to the product of the input signal thereto and a predetermined constant; and

- 70 a fourth controller having its normal input connected to the output of said flowmeter, its set value input connected to the output of said multiplier, and its

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output connected to a control valve in the reflux flow line to the column.

4. The apparatus of claim 3 including:

a second analyzer for measuring the quality of the top product;

a fifth controller responsive to the output signal from said second analyzer for determining the variation between the measured and desired values of the quality of the bottom product, said fifth controller having its output connected to said multiplier to vary said predetermined constant whereby the desired ratio between the vapor flow and the reflux flow in the upper portion of the column is adjusted to a new desired value.

5. The apparatus of claim 1 wherein said second control means comprises:

a third controller responsive to the output signal from said gauge for adjusting the reflux flow to maintain the liquid level in the accumulator between desired limits;

a flowmeter for measuring the top product flow;

a signal multiplier having its input connected to the output of said heat measuring means, said multiplier producing an output signal equal to the product of

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the input signal thereto and a predetermined constant; and

a fourth controller having its normal input connected to the output of said flowmeter, its set value input connected to the output of said multiplier, and its output connected to a control valve in the top product flow line to the column.

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