

[54] **DISTILLATION COLUMN REBOILER CONTROL SYSTEM**

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[22] Filed: **Apr. 11, 1974**

[21] Appl. No.: **459,975**

[57] **ABSTRACT**

A control system for regulating the heat input to the reboiler section of a distillation (fractionation) column. Flow-measuring means, for determining the quantity of vapor, passing upwardly from the reboiler section into the fractionation section (stripping and rectification), and internally disposed within the reboiler section, provides a signal which is transmitted to the reboiler heater, thereby adjusting the fuel input thereto in order to regulate the degree of vaporization being effected therein.

[52] U.S. Cl. **202/160; 202/206; 202/181; 203/1; 196/132**

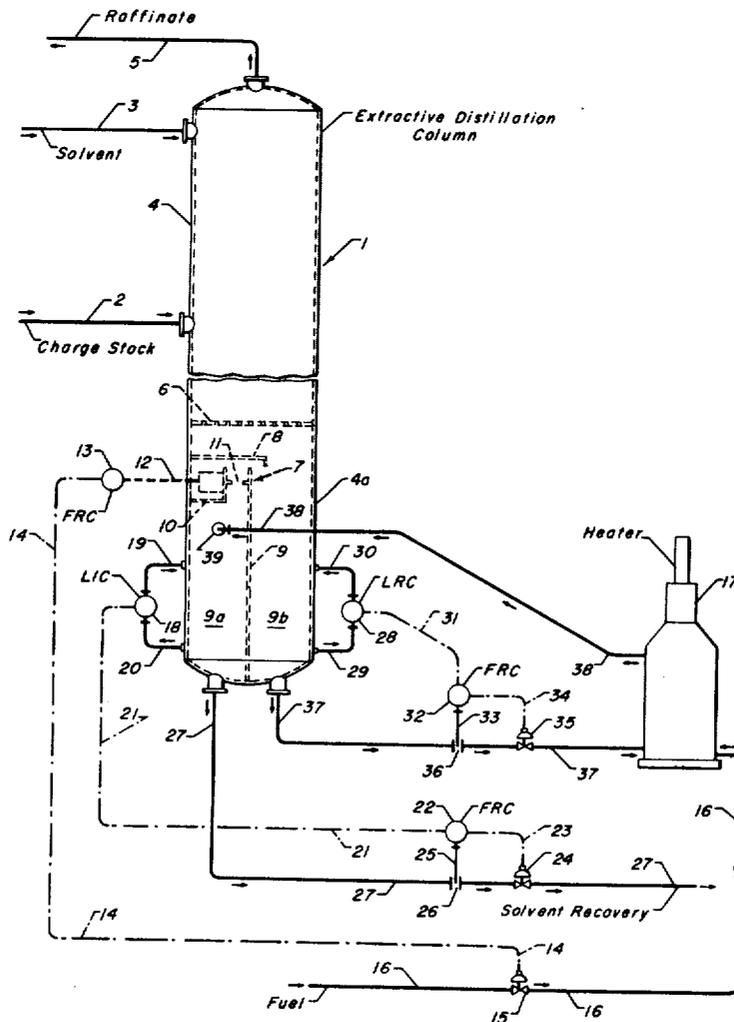
[51] Int. Cl. **B01d 3/42; C10g 7/00**

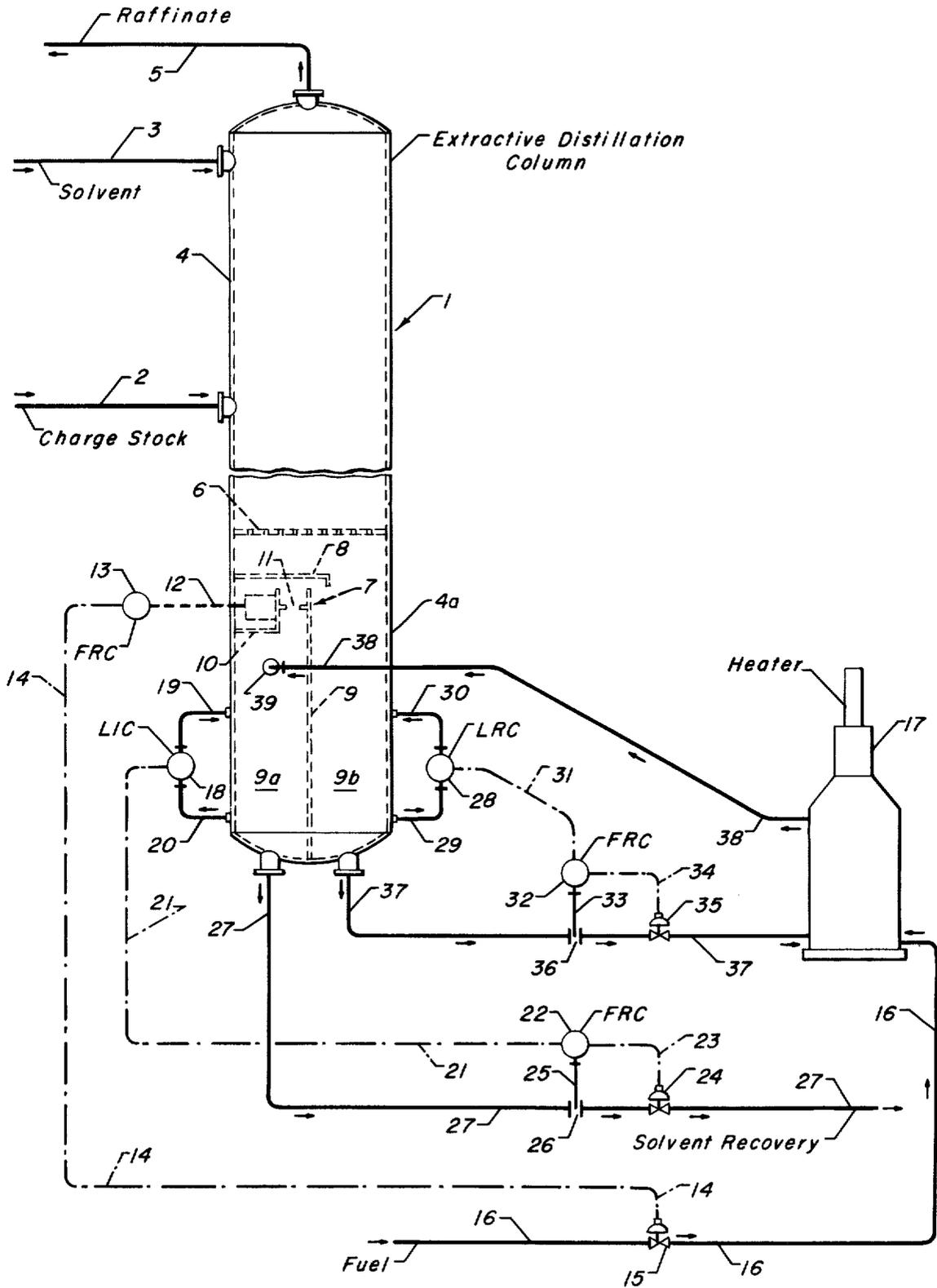
[58] Field of Search **203/1, DIG. 18; 202/153, 202/160, 206, 181; 196/132; 208/DIG. 1**

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5 Claims, 1 Drawing Figure





DISTILLATION COLUMN REBOILER CONTROL SYSTEM

APPLICABILITY OF INVENTION

My inventive concept, as herein described, encompasses a unique control system, and method, for regulating and/or controlling the heat input to the reboiler section of a continuous-flow distillation, or fractionation column. In the present specification, as well as the appended claims, the use of the term "distillation column" synonymously alludes to "fractionation columns", "rerun columns", "stripping columns", "extractive-distillation columns," etc. Similarly, for the purposes of describing the present invention, the "reboiler section" of the distillation column connotes that portion disposed below the lowermost tray, or deck. That portion of the column above the lowermost tray is herein referred to as the "fractionation section," and is inclusive of the rectification zone (above the feed tray) and the stripping zone (below the feed tray).

As is recognized by those possessing the requisite expertise in the appropriate art, reboiling a distillation column connotes the circulation of a hot liquid bottoms fraction from the reboiler section through an external reboiler heater, wherein at least a portion of the liquid is vaporized; the heated, mixed-phase bottoms material is returned to the reboiler section. The vapors pass upwardly from the reboiler section into the fractionation section wherein they serve to remove lower-boiling constituents from the liquid phase traversing the column in downward flow. A most important aspect, to be considered for efficient functioning of a distillation column, resides in its thermal balance and, although many operating variables have an effect upon thermal balance, the effect of heat input via the reboiler section is perhaps the most pronounced. Furthermore, as hereinafter set forth, control of the heat input to the reboiler section is generally the most difficult to achieve to the degree required for substantially stable thermal balance.

The foregoing is applicable to reboiler operation considerations regardless of the precise boiling range of the circulating reboiler bottoms material; however, the difficulties attendant reboiler heat input control become more pronounced when the reboiler liquid is a pure compound, or exhibits a relatively narrow boiling range — i.e. about 10°F., or less. Heat input by way of circulating reboiler liquid takes two forms; (i) the increased sensible heat of the heated liquid passing back into the reboiler section and, (ii) the latent heat of vaporization absorbed by the vapors generated in the external reboiler heater. The latter constitutes the source of the greatest quantity of heat input to the reboiler section and, of necessity, must be subject to close control and/or regulation. Additionally, the efficiency of separation, to obtain the desired product purity, is largely dependent upon the amount of vapor produced and the control thereof.

Briefly, the control system and method of the present invention is designed to achieve a constant rate of vapor production in the reboiler heater by adjusting, or regulating the flow of fuel to the heater in response to a signal which is representative of the actual quantity of vapor passing into the fractionation section of the distillation column.

OBJECTS AND EMBODIMENTS

A principal object of the present invention is to provide a method for measuring and controlling the vapors produced in the reboiler section of a distillation column. A corollary objective is directed to a control system which is capable of constant heat input during steady-state operation.

Further, it is a specific object to afford a control system and method, both of which permit rapid recovery of a steady-state operation after significant changes in various operating variables.

Therefore, in one embodiment, my invention provides a control system for regulating the heat input to the reboiler section of a distillation column which comprises, in cooperative combination: (a) an inventory of liquid bottoms material contained in a suitable chamber in said reboiler section; (b) flow-regulating means for passing a portion of said liquid bottoms to a reboiler heater; (c) conduit means for passing heated, mixed-phase bottoms material from said heater into said reboiler section; (d) fuel-varying means for adjusting the fuel input to said heater; (e) flow-measuring means for determining the quantity of vapor, in said mixed-phase bottoms material, passing from said reboiler section upwardly into the fractionation section of said distillation column, said flow-measuring means internally disposed within said reboiler section; and, (f) signal-receiving means for establishing a signal representative of the quantity of vapor passing into said fractionation section and for transmitting said signal to said fuel-varying means, whereby the fuel input to said heater is adjusted in response to the quantity of said vapor; said control system further characterized in that said reboiler section is partitioned to provide two inventory chambers of said liquid bottoms material, the first of which has said flow-measuring means disposed therein, and from the second of which said bottoms material is passed into said reboiler heater.

Other objects and embodiments, encompassed by the present inventive concept, will become evident from the following, more detailed description. Included is the embodiment which is directed toward a method for controlling the heat input to the reboiler section of a distillation column, in response to variations in the steady-state operation of said column.

SUMMARY OF INVENTION

Distillation operations and techniques are extensively employed throughout the petroleum and petrochemical industries for the separation and recovery of select fractions of the feed, or of substantially pure compounds. For example, in a process for the catalytic reforming a naphtha boiling range charge stocks, the normally liquid portion of the reaction zone effluent is "rerun," often to provide a light gasoline — i.e. boiling range of 110° to 280°F. — and a heavy gasoline — i.e. boiling range of 280° to 400°F. In adsorption processes, wherein polar hydrocarbons are separated from a mixture thereof with non-polar hydrocarbons, employing a solvent having greater selectivity for adsorbing the polar constituents, the ultimately recovered product has a relatively narrow boiling range, and its distillation characteristics are substantially similar to those of pure compounds. Although applicable in both types of distillation techniques, my invention is most advantageously employed in situations where the column bottoms frac-

tion, a portion of which serves as the circulating reboiler heating medium, is a pure compound, or a narrow boiling range mixture. Briefly, the basic reboiling technique is designed to provide the amount of vaporous material required for thermal balance and separation efficiency by adjusting the quantity of fuel input to the reboiler heater, in order to regulate the heat input to the reboiler section of the distillation column.

It is recognized that the published literature is replete with techniques designed to control the quantity of heat input to the reboiler section of a distillation column. In view of the voluminous nature of such techniques, no attempt will be made herein to delineate exhaustively the appropriate prior art; a few typical illustrations will suffice. One popular and ancient prior art technique, now since improved upon, involves instituting an energy balance around the reboiler heater; a similar scheme computes the energy balance around the reboiler section of the column. While affording a small measure of control, both techniques entail too many measurements, accompanied by an extremely difficult, tedious energy balance, and are comparatively inefficient. Other control techniques involve controlling the flow of fuel medium to the reboiler heater in response either to the temperature of the heated material return to the reboiler section, or to the rate of mixed-phase flow. For the latter such method, the quantity of liquid reboiler bottoms material introduced into the reboiler heater must be pre-set by way of flow control means. Flow control of the heated material re-entering the reboiler section suffers from the disability of not being capable of precisely measuring vapor flow and depends upon, as an essential element, a constant flow rate to the heater. Temperature control will generally suffice acceptably in situations where the reboiler liquid has a relatively wide boiling range, but fails miserably where it is either a substantially pure compound, or possesses a comparatively narrow boiling range, or where a relatively minor degree of vaporization is desired.

As hereinbefore set forth, a most important criterion is the measurement of the degree of vaporization in the heated, mixed-phase material returning to the reboiler section of the column. This is especially critical with respect to substantially pure column bottoms material. Correlations of heat content versus temperature, at given vaporization percentages, indicate that a comparatively large delta-T exists per unit of heat content as the percentage vaporization increases in the case of a liquid bottoms material having a relatively wide boiling range. Thus, a measurable change in temperature will indicate a significant change in the degree of vaporization, and a corresponding change in the thermal balance of the column. Such changes can be employed to reset the flow of fuel medium to the heater so that more or less liquid will be vaporized and the column can be held in close proximity to thermal equilibrium.

However, temperature control in the return conduit is not satisfactorily effective when the reboiler bottoms liquid is a substantially pure compound, or one having a narrow boiling range approximately 10°F. or less. The correlations described above indicate that very little (if any) delta-T is available for percent vaporization determination. That is to say, temperature measurement in any portion of either the reboiler heater circuit, or the lower reboiler section, does not indicate accurately the degree of vaporization achieved. The temperature will

remain virtually the same whether excess vapor, or insufficient vapor, is being generated in the reboiler heater. It becomes, therefore, extremely difficult to maintain the distillation column at or near thermal equilibrium.

Similarly, when a pure compound, or narrow boiling range component mixture, is being reboiled, temperature control of the reboiler heater heat input is not feasible due to the effect of pressure variations within the distillation column. Any shift in column pressure will produce a corresponding shift in the boiling point of the pure compound, or in the vapor temperature of the narrow boiling range mixture, without noticeably changing the rate or degree of vaporization. Therefore, a change in column pressure will produce a temperature fluctuation which is not truly indicative of a change in the reboiling function. Accordingly, a temperature control system will effect a compensating change in heat input when no such compensation is required.

The control system of the present invention overcomes the deficiencies of prior art techniques, especially with respect to substantially pure compounds, or narrow boiling component mixtures. This is accomplished through the use of a novel reboiler section design which permits direct, internal measurement of the flow of generated vapor upwardly from the reboiler section to the fractionation section. A signal, representative of the quantity of vapor passing into the fractionation section is transmitted to fuel-varying means for adjustment, or regulation of the fuel input to the reboiler heater. Thus, there is afforded a constant rate of vaporized material, passing into the fractionation section, for a steady-state status of the various operating variables, and a control system which readily and rapidly responds to compensate for variations in the steady-state operation, such that desired separation efficiency is substantially unaffected. An additional advantage resides in the fact that the lowest percentage vaporization, for a given set of operating variables, is capable of being maintained. The internal measurement of the flow of vapors is extremely accurate and sensitive since it is accomplished within the reboiler section in a substantially liquid-free environment.

Examples of processes, wherein the separation and recovery of a pure compound, or narrow boiling range mixture forms an integral part, and to which the present invention may be advantageously applied, include, but not by way of limitation: (i) the recovery of styrene from an ethylbenzene dehydrogenation system; (ii) the separation of one xylene isomer from a mixture thereof with other xylene isomers; (iii) aromatic hydrocarbon separation from a mixture thereof with non-aromatic hydrocarbons; and, (iv) the separation and recovery of ethylbenzene from a mixture thereof with various xylene isomers, etc. The particular use, to which the present invention is put, is not to be considered a feature limiting upon the scope and spirit thereof as defined by the appended claims.

For the purpose of additional illustration, as well as the description of the accompanying drawing, further discussion will be restricted to the integration of the present reboiler control system into a process for the selective extraction of aromatic hydrocarbons from a mixture thereof with non-aromatic hydrocarbons including both paraffins and naphthenes. One such process involves extractive distillation of the mixed hydro-

carbonaceous feed stream with a water-soluble solvent selective for the adsorption of aromatic hydrocarbons — e.g. a sulfolane-type solvent. Extractive distillation conditions include a solvent water content of about 0.5 to 20.0 percent by weight, a solvent to hydrocarbon feed ratio of about 2.0:1.0 to 6.0:1.0, a distillation column pressure ranging from 90 mm. Hg., absolute, to about 40.0 psig., an overhead temperature from 130° to about 330°F. and a reboiler bottoms temperature from 170° to about 355°F. There is provided a liquid extract bottoms stream relatively free from non-aromatics and comprising solvent and aromatic hydrocarbons, and an overhead vaporous raffinate comprising non-aromatics, water (as steam) and a relatively minor quantity of the sulfolane solvent. The raffinate is condensed and water-washed to recover substantially solvent-free non-aromatic hydrocarbons contained in the extract phase are recovered in a solvent recovery column of the variety well known and thoroughly described in the prior art. Steam is employed as a stripping medium to separate aromatic hydrocarbons from the sulfolane solvent. An overhead product of aromatics and steam, substantially free from solvent, is condensed to recover the final extract product. The water is generally returned to the raffinate water-wash column. Aromatic hydrocarbon recovery generally exceeds 96.5 percent by volume, based upon the charge stock, and the aromatic purity is greater than 99.0 percent.

BRIEF DESCRIPTION OF DRAWING

In further describing the present control system and its method of operation, reference will be made to the accompanying drawing. It is understood that the drawing is presented solely for illustration purposes, and the same is not intended to be construed as limiting upon the scope and spirit of my invention as defined by the appended claims. Therefore, miscellaneous appurtenances, not required for an understanding of the inventive concept, have been eliminated, or reduced in number. Such items are well within the purview of one possessing skill in the art. Presented in the drawing is an extractive distillation column 1 which is typically employed in the solvent extraction of aromatic hydrocarbons, utilizing sulfolane as hereinabove described. Extractive distillation column 1 is shown as having a fractionation section 4 located above the lowermost tray 6, and a reboiler section 4a located below tray 6. Reboiler section 4a is partitioned by chordal baffle 9 to provide two liquid inventory chambers 9a and 9b.

DETAILED DESCRIPTION OF DRAWING

With particular reference now to the drawing, the control system and method will be described in conjunction with a commercially-scaled unit designed to process 6,723 Bbl./day (863.04 mols/hr.) of a heptane-plus fraction obtained from an attendant catalytic reforming unit. The charge stock consists of 83.96 percent by volume of aromatic hydrocarbons, 2.45 percent of naphthenes and 13.59 percent paraffins. The solvent is sulfolane (2,515.5 mols/hr.) containing 3.25 percent water, and enters the upper portion of column 1, via line 3, at a temperature of about 260°F. The solvent to feed mol ratio approximates 3.0:1.0, and the hydrocarbon feed is introduced via line 2. Operating pressures include a reboiler section pressure of about 17.0 psig., a pressure of about 12.0 psig. at the locus of hydrocar-

bon feed and a top pressure of about 7.0 psig. The reboiler section temperature is about 350°F. and the vaporous raffinate overhead stream, in line 5, is at a temperature of about 285°F.

Distillation column 1 is shown as having an upper fractionation section 4 which, for the purposes of the present illustration, includes all trays above tray 6, or both the stripping and rectification sections. That portion of column 1 below tray 6 is herein referred to as the reboiler section. Located entirely within reboiler section 4a, is flow-measuring means generally indicated as 7. Flow-measuring means 7 is formed, in part, by chordal baffle 9 which terminates a finite distance below tray 6, and extends downwardly through reboiler section 4a, being immovably connected to the internal surface of the bottom head of column 1. There is provided, thereby, two liquid inventory chambers 9a and 9b, and, in combination with partition 10, there is formed a riser 11. In this illustration, an orifice plate is placed in riser 11 which supplies the flow-measuring means to determine the quantity of vaporous material passing therethrough into fractionation section 4. A riser cap 8 is also provided in order to prevent liquid material from tray 6 from entering riser-orifice 11. Although illustrated and referred to herein as an orifice, the flow-measuring means can take the form of a venturi. The essential feature resides in the internal measurement of vapor flow into the fractionation section, and preferably in a substantially liquid-free environment. Thus, all the liquid material passing downwardly from tray 6 is collected in liquid inventory chamber 9b.

During the start-up of the extractive distillation process, all the illustrated controls are set, and initial operating variables are attained manually, to achieve thermal equilibrium and a substantially steady-state operation in accordance with the desired separation efficiency. Flow-Recorder-Controller (FRC) 13, which receives a signal, via line 12, representative of the quantity of vapors passing upwardly through riser-orifice 11, is pre-set to transmit the signal via line 14 to fuel-varying means 15.

For a given quantity of charge stock, at a constant composition, FRC 13 is set to provide the minimum quantity of vapors, passing upwardly into fractionation section 4a. If an insufficient quantity of stripping vapors are supplied by reboiler heater 17, non-aromatic hydrocarbons will appear in the liquid bottoms product; conversely, an excess quantity of vapors will, in effect, "throw" solvent and/or aromatics into the non-aromatic raffinate overhead. In either situation, the resulting upset in thermal balance adversely affects the desired separation efficiency of the distillation column. Only through the use of the present invention, wherein the vapor flow is internally measured, can controlled, steady-state operation be maintained. Fluctuations in operating variables, which ultimately manifest an adverse affect with respect to thermal balance, result primarily from: (i) changes in feed composition (aromatic/non-aromatic ratio); (ii) varying hydrocarbon charge stock rate; and, (iii) a change in the solvent/feed mol ratio. Certainly, other operating variables, such as temperature, pressure, reflux rate (if any), water content of the solvent, desired product state, etc., affect thermal balance, but not to as great a degree.

Control valve 15, in line 16, regulates the fuel input to reboiler heater 17, in response to the signal being

transmitted from FRC 13 via line 14. Reboiler liquid is withdrawn from inventory chamber 9b in response to Level-Recorder-Controller (LRC) 28 which senses the level of liquid bottoms therein via conduits 29 and 30. LRC 28 transmits a signal to FRC 32 via line 31, reset the set-point thereof. FRC 32 senses, via line 33 and orifice 36, the flow of liquid through conduit 37, and makes the necessary adjustment in control valve 35. The amount of liquid bottoms material, at a temperature approximating 312°F., flowing through conduit 37 into heater 17, is about 4,381 mols/hr. Sufficient fuel is supplied to heater 17, through line 16, to produce a heated mixed-phase fluid, in line 38, having a temperature of about 350°F. The mixed-phase is reintroduced into reboiler section 4a through inlet port 39. In inventory chamber 9a, a phase separation takes place to the extent that 1,164 mols/hr. of vapor pass upwardly through the riser-orifice 11, into the fractionation section. The 3,217 mols/hr. of liquid are withdrawn by way of conduit 27, and transported thereby to a solvent recovery system not illustrated in the drawing.

Level-Indicating-Controller 18 senses the liquid level in inventory chamber 9a by way of conduits 19 and 20. Its principal function is to maintain a liquid seal at the bottom of the inventory chamber, while simultaneously maintaining the liquid level out of contact with the riser-orifice. A signal is transmitted by way of line 21 to FRC 22, to re-set the set point thereof. FRC 22 senses the flow of liquid through line 27 via conduit 25 and orifice 26, and accordingly adjusts, via line 23, the flow through control valve 24.

In the present illustration, the steady-state operation thus far described results in an overhead raffinate stream, transported to a water-wash column via line 5, in the amount of about 159.8 mols/hr. of which 1.25 percent is sulfolane solvent and 13.52 percent is aromatic hydrocarbons. The stream in line 27, being transported to the solvent recovery system, is in an amount of 3,720.7 mols/hr., of which 2,515.5 mols/hr. are solvent. Following removal of solvent and water, there is recovered an aromatic-rich product stream, in the amount of 705.2 mols/hr., of which only 0.31 percent by volume constitute non-aromatic hydrocarbons.

From the foregoing, it will be noted that 97.02 percent of the feed aromatics are recovered (on a once-through basis), and that the purity thereof exceeds 99.0 percent. The control system of my invention measures and maintains a steady stripping vapor rate to the fractionation section. As hereinbefore set forth, any one or a combination of operating variable fluctuations can cause an upset in the thermal balance of the column, and an accompanying upset in the desired separation efficiency. Regardless of the precise cause, or causes, it will be presumed that the ultimate effect is an increase in the flow of liquid material downwardly in the fractionation section. Since riser cap 8 effectively channels all the liquid into inventory chamber 9b, the liquid level therein will cause LRC 28 to cascade a reset signal to FRC 32 which, in turn, effects an opening of control valve 35.

The increased rate of liquid flow through conduit 37 into reboiler heater 17, effectively decreases the degree of vaporization being effected therein. As previously stated, the resulting heated mixed-phase in conduit 38 is introduced into the second inventory chamber 9a, and FRC 13 senses the rate of vapor flow through riser-orifice 11. The representative signal is, of course, to the

effect that the vapor rate upwardly in the fractionation section is lower than desired. This signal is transmitted by FRC 13, through line 14, to heat-varying means 15, and increases the fuel input to heater 17, via line 16. As a result, the rate of vaporization is increased and the quantity of vapors passing through riser-orifice 11 correspondingly increases.

Simultaneously with the foregoing, LIC 18 senses an increasing liquid level in inventory chamber 9a. The resulting transmitted signal causes control valve 24 to open wider, thereby sending the additional liquid bottoms to the solvent recovery facility. It is understood that the cascade-type control loops represented (1) by LRC 28, FRC 32 and control valve 35, and (2) LIC 18, FRC 22 and control valve 24, are not essential to my invention. They are illustrated as preferred instrumentation techniques to achieve smoother functioning in the operation thereof. Likewise, reboiler heater 17 may take the form of a tube and shell heat-exchanger, or a direct-fired heater as illustrated.

The foregoing is believed to convey the essence of the control system of the present invention and its method of operation. Advantages attendant its integration into fractionation and/or distillation facilities will be evident to those having expertise in the art.

I claim:

1. A control system for regulating the heat input to the reboiler section of a distillation column which comprises, in cooperative combination:

- a. a chamber in said reboiler section for receiving liquid bottoms material from the fractionation section of said column;
- b. a reboiler heater having feed input means thereto connected to said chamber, flow regulating means for controlling the flow of said liquid bottoms from said chamber to said reboiler heater in accordance with the liquid level in said chamber;
- c. conduit means in interconnection with said reboiler heater for passing heated, mixed-phase bottoms material from said heater into a partitioned and segregated portion of said chamber in said reboiler section;
- d. fuel-varying means in a fuel input means in interconnection with said heater for adjusting the fuel input to said heater;
- e. vapor flow-measuring means in said reboiler section responsive to the total quantity of upward flowing vapor from said mixed-phase bottoms material passing from said segregated portion of said reboiler section upwardly into the fractionation section of said distillation column, said flow measuring means being internally disposed within said segregated portion of said reboiler section; and
- f. signal-generating means in said segregated portion of said reboiler section for establishing a signal representative of the volumetric flow rate of vapor from said segregated portion passing into said fractionation section, and signal transmitting means for modifying and transmitting the resulting signal to said fuel varying means, whereby fuel input through said fuel input means to said heater is decreased in response to increasing flow rates of said vapor and increased in response to decreasing flow rates of said vapor; said control system being further characterized in that said reboiler section is partitioned to provide two inventory chambers of said liquid bottoms material, the first of which is

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said segregated portion which has said vapor flow measuring means disposed therein and the second of which is connected to said freed input means.

2. The control system of claim 1 further characterized in that a second flow-regulating means effects withdrawal of bottoms material from the first of said inventory chambers and out of said distillation column.

3. The control system of claim 2 further characterized in that said second flow-regulating means, includes means to maintain the level of the liquid bottoms in said first inventory chamber out of contact with said flow-measuring means.

4. A method for controlling the heat input to the reboiler section of a distillation column, in response to variations in the steady-state operation of said column, which method comprises the steps of:

- a. regulating the quantity of liquid bottoms material withdrawn from one side of a partitioned reboiler section in response to the liquid level in said one side and introducing same into a reboiler heater;
- b. passing heated, mixed-phase bottoms material from said heater into the second side of said partitioned reboiler section;

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c. measuring within said second side of said reboiler section the quantity of vapor in said heated, mixed-phase bottoms, which passes from said second side of said reboiler section into the fractionation section of said distillation column;

d. regulating the fuel input to said reboiler heater in response to a signal representative of the said measured quantity of vapor flowing into said fractionation section, said regulation comprising reducing the fuel input with reduced vapor flow and vice versa; and,

e. withdrawing excess liquid bottoms material out of said distillation column from the second side of said partitioned reboiler section in response to the liquid level in said second side maintained below the point of measuring vapor flow.

5. The method of claim 4 further characterized in that the quantity of vapor, in the heated, mixed-phase bottoms material from said heater, which passes into said fractionation section, is measured within said reboiler section in a substantially liquid-free atmosphere.

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