

LOW ENERGY DISTILLATION SYSTEM AND METHOD

FIELD

[0001] The presently disclosed subject matter relates to energy efficient distillation systems and methods, including energy efficient distillation systems and methods for use in petrochemical refining operations or the like.

BACKGROUND

[0002] Refining and chemical plants consume large amounts of energy. In a typical refinery about 10% of the energy content of crude oil is spent in refining the crude to various finished products. Large amounts of energy are directed to bringing liquid and semi-liquid feeds to near their boiling point in order to stage vapor-liquid equilibrium separations. Distillation technology that requires less energy would significantly improve the overall energy efficiency of refineries and chemical plants.

[0003] In conventional distillation, the waste heat at the condenser at the top of the distillation tower is not recovered. This results in a very low energy efficiency (e.g., exergetic efficiency of less than 10%). Heat Integrated Distillation Columns (HIDiC) have been disclosed previously, but have not been commercialized to date. Either a shell and tube type configuration, or distillation columns with two concentric trays, with the rectifier section inside the stripper section, are generally described. Since HIDiC configurations proposed in academic literature generally use lateral placement of the rectifier and stripper sections, hurdles include complex heat transfer arrangements and the need for dual, side-by-side columns that would be required for heat integration increasing the footprint of the operation. Such arrangements may not be practical for retrofitting existing columns.

[0004] Figure 1 depicts a conventional distillation operation 1000. A condenser 1010, located on top of the column 1020, removes heat from the vapor-rich process stream 1030 to produce a liquid product stream 1040 rich in a higher volatile (“lighter”) product. The condenser also produces a reflux stream 1050 employed to improve the quality of the vapor-liquid staged separation process. The heat removed at the condenser is not recovered, but is

discharged to the cooling water or air, thereby resulting in a low energy efficiency of distillation. The Second Law Thermodynamic Efficiency, also referred to as Exergy efficiency, in a distillation column is generally less than 10%. The Exergy efficiency defines how efficient the system is relative to a thermodynamically perfect system performing the same operation starting with same input feeds and producing the same product streams

[0005] As can be seen in Figure 1, the rectifier section 1060 is located, in vertical proximity, above the stripping section 1070 in a conventional distillation column.

[0006] The column shown in Figure 1 is also provided with a reboiler 1080 which receives a feed rich in less-volatile (“heavier”) components, in which heat is employed to vaporize more volatile components. Heavier liquid products remaining after the input of heat are withdrawn from the column 1090, while some heavier vaporized product 1100 is recycled back to the column to improve the quality of the separation.

[0007] Figure 2 depicts a HiDiC unit operation 2000 described in J. of Chem. Tech. and Biotech., 78:241-248 (2003), which is hereby incorporated by reference in its entirety. Unlike the distillation column of Figure 1 where the rectifier section 1060 is located above the stripper section 1070, the rectifier and the stripper sections 2060 and 2030, respectively, in Figure 2 are located in a lateral position with additional provision for heat transfer from the rectifier to the stripper sections. A compressor 2010 is employed to compress the vapor from the stream 2020 exiting the stripping section 2030, which is the section defined by area below the feed 2040. The compression results in a higher temperature in the rectifier section 2060, which is generally the column 2080 shown on the right of Figure 2. A valve 2090 is provided to control the flow of the stream 2100 exiting the bottom of the rectifying section to a location in close proximity to the feed. The upper portion of the second column 2080 yields a vapor-rich stream 2110 which is directed to a condenser 2120 that yield a low volatile product 2130 and a reflux stream 2140, which is returned to the rectifier section 2060.

[0008] Upon transfer of heat from the rectifier section 2060 to the stripper section 2030, the stream 2100 providing liquid reflux functionality between the rectification and stripping sections is generated. The “reflux ratio” of the stream 2100 providing liquid reflux functionality is set by the column heat balance with proximate control based on level in the rectification section bottoms by valve 2090.

[0009] Another proposed HiDiC operation 3000 is depicted in Figure 3, which is taken from Z. Olujic et al., Energy 31:3083-3096 (2006), and hereby incorporated by reference in its entirety.

[0010] Figure 3, illustrates a concentric tray design with the stripping section located outside of the rectifier section, with heat transfer panels 3030 placed in between trays. Lateral heat transfer occurs between two parallel or concentric columns, which can be provided by, for example, an inner rectifying section 3010 surrounded by an outer stripping section 3020.

[0011] Figure 4, from U.S. Patent No. 4,234,391, hereby incorporated by reference in its entirety, depicts a conceptual design 4000 in which heat pipes 4010 transfer heat from a rectifier section 4040 to a stripping section 4030, which are separated by a partition 4020. The heat pipes are in a lateral position, as shown in Figure 4. Such HiDiC designs have not been commercialized to date.

[0012] Thus, there remains a need and desire to improve energy efficiency of distillation operations, particularly within refineries and chemical plants. There also remains a need for HiDiC designs that can be easily retrofitted to existing distillation column infrastructure.

SUMMARY

[0013] One aspect of the presently disclosed subject matter provides a distillation system for separating at least two components of a multi-component fluid feed. The system includes a stripper section including (i) an inlet to receive a feed of fluid containing at least two components, (ii) a compressor in fluid communication with a more volatile portion of the fluid within the stripper section to provide an output feed, and (iii) a reboiler to receive a heating fluid and in fluid communication with a less volatile portion of fluid within the

stripper section. The distillation system also includes a rectifier section aligned vertically with and disposed below the stripper section, the rectifier section to receive the output feed from the compressor and further including (i) a condenser to receive a cooling fluid and in fluid communication with a more volatile portion of the output feed from the compressor, the condenser including an exit to remove at least one component from the more volatile portion of the output feed, and (ii) an outlet to recycle a less volatile portion of the output feed from the compressor for recycle back to the stripper section.

[0014] Another aspect of the presently disclosed subject matter provides a distillation method for separating at least two components of a multi-component fluid feed. The method includes introducing a feed of fluid containing at least two components to a stripper section, the stripper section including (i) an inlet to receive the feed of the fluid, (ii) a compressor in fluid communication with a more volatile portion of the fluid within the stripper section to provide an output feed, and (iii) a reboiler to receive a heating fluid and in fluid communication with a less volatile portion of fluid within the stripper section. The distillation method also includes directing the output feed from the compressor to a rectifier section aligned vertically with and disposed below the stripper section, the rectifier section including (i) a condenser to receive a cooling fluid and in fluid communication with a more volatile portion of the output feed from the compressor, the condenser including an exit to remove at least one component from the more volatile portion of the output feed, and (ii) an outlet to recycle a less volatile portion of the output feed from the compressor to the stripper section.

BRIEF DESCRIPTION OF THE DRAWINGS

[0015] The invention will now be described in conjunction with the accompanying drawings in which:

[0016] FIG. 1 is a schematic view of a conventional distillation column with a rectifying section located above the stripping section, in which energy removed at the condenser is not recovered.

[0017] FIG. 2 is a schematic view of a conventional HIDiC concept.

[0018] FIG. 3 is a schematic view of a concentric HIDiC design with heat transfer from the inner rectifier to outer stripper section.

[0019] FIG. 4 is a schematic view of a HIDiC design with heat pipes for heat transfer from the rectifier section to the stripper section in lateral positions.

[0020] FIG. 5 is a schematic view of a representative embodiment of the distillation system of the presently disclosed subject matter.

[0021] FIG. 6 is a schematic view of another representative embodiment of the distillation system of the presently disclosed subject matter.

DETAILED DESCRIPTION

[0022] The following definitions are provided for purpose of illustration and not limitation.

[0023] The Exergy efficiency defines how efficient the separation is relative to a thermodynamically perfect system. The Exergy of each stream is the theoretical maximum amount of work it can produce, determined by taking it through a series of reversible steps to bring it into equilibrium with ambient surrounding. The increase in Exergy content of the products versus the feed inputs represents the minimum amount of work needed. The Exergy efficiency is defined as the ratio of this minimum amount of work divided by the total Exergy expended in actually doing the separation

[0024] As used herein, the term “produced in an industrial scale” refers to a production scheme in which end products are produced on a continuous basis (with the exception of necessary outages for plant maintenance) over an extended period of time (e.g., over at least a week, or a month, or a year) with the expectation of generating revenues from the sale or distribution of the end product. Production at an industrial scale is distinguished from laboratory or pilot plant settings which are typically maintained only for the limited period of the experiment or investigation, and are conducted for research purposes and not with the expectation of generating revenue from the sale or distribution of end products.

[0025] In accordance with the presently disclosed subject matter, a distillation system is provided for separating at least two components of a multi-component fluid feed. The distillation system includes a stripper section including (i) an inlet to receive a feed of fluid containing at least two components, (ii) a compressor in fluid communication with a more volatile portion of the fluid within the stripper section to provide an output feed, and (iii) a reboiler to receive a heating fluid and in fluid communication with a less volatile portion of fluid within the stripper section. The distillation system also includes a rectifier section aligned vertically with and disposed below the stripper section, the rectifier section to receive the output feed from the compressor and further including (i) a condenser to receive a cooling fluid and in fluid communication with a more volatile portion of the output feed from the compressor, the condenser including an exit to remove at least one component from the more volatile portion of the output feed, and (ii) an outlet to recycle a less volatile portion of the output feed from the compressor for recycle back to the stripper section.

[0026] In accordance with another aspect of the presently disclosed subject matter, a distillation method is provided for separating at least two components of a multi-component fluid feed. The distillation method includes introducing a feed of fluid containing at least two components to a stripper section, the stripper section including (i) an inlet to receive the feed of the fluid, (ii) a compressor in fluid communication with a more volatile portion of the fluid within the stripper section to provide an output feed, and (iii) a reboiler to receive a heating fluid and in fluid communication with a less volatile portion of fluid within the stripper section. The distillation method also includes directing the output feed from the compressor to a rectifier section aligned vertically with and disposed below the stripper section, the rectifier section including (i) a condenser to receive a cooling fluid and in fluid communication with a more volatile portion of the output feed from the compressor, the condenser including an exit to remove at least one component from the more volatile portion of the output feed, and (ii) an outlet to recycle a less volatile portion of the output feed from the compressor to the stripper section.

[0027] The method and system disclosed herein will be described in conjunction with each other for understanding and enablement.

[0028] For purposes of illustration and not limitation, reference is made to the embodiment of Figure 5, in which the stripper section 5250 and the rectifier section 5500 are contained within a single, at least partially enclosed, structure 5010. A multi-component liquid feed 5100 is introduced above the feed tray or stage 5120 of the distillation column 5010 at a temperature near the boiling point of the feed composition. In a preferred embodiment, the feed to the distillation system is primarily hydrocarbons, although any multi-component feed can be separated using the presently disclosed methods and systems.

[0029] As the feed is introduced to the column, liquid portions rich in less volatile components flow down the column, and gaseous portions rich in more volatile components of the feed flow up toward a gas compressor 5150. A partition 5200 is provided to prevent the liquid portions rich in heavier components of the feed from traveling further down the column into the rectifier section 5500. The section between the feed and the partition constitute the stripping or stripper section 5250 of the distillation column.

[0030] A reboiler 5300, which is supplied with a source of steam or other heating fluid, inputs heat to the column and yields a bottoms product, 5350, rich in less volatile (“heavier”) products and a stream, 5400 that is returned to the stripping section 5250.

[0031] Compressed vapors 5450 exiting the compressor 5150 are directed to the bottom of the rectifier section 5500. The compression of the gases results in a higher temperature in the rectifier section 5500 as compared to the stripper section 5250, which consists of the section of the column below the partition 5200. Thus, in one embodiment, the rectifier section 5500 is operated at a higher average temperature than the stripper section 5250.

[0032] In this particular embodiment, liquid components 5600 are drawn from the bottom of the column and introduced into the stripper section 5250 in the feed 5100 or to the feed tray 5120 by means of, for example, a throttle valve or pump 5650. A condenser 5700 is provided at the top of the rectifying section, which receives a supply of cooling water and yields a product, 5750, rich in lighter products and a reflux stream, 5800 which is redirected to the column into the rectifying section. The composition exiting the condenser can include, or consist of primarily the light, low boiling components of the feed 5100.

[0033] In one embodiment, end products derived from the methods and systems of the presently disclosed subject matter are produced in an industrial scale.

[0034] As noted above, the rectifier section 5500 is operated at a higher temperature than the stripping section 5250. Having the stripper section 5250 located, in vertical proximity, above the rectifier section 5500 allows the use of one or more heat pipes 5850 to transfer heat from the rectifier section 5500 to the stripper section 5250 and reduce the heat load on the reboiler. Thus, in one embodiment of the presently disclosed subject matter, the system includes at least one heat pipe traversing between at least a portion of the rectifier section and at least a portion of the stripper section to transfer heat from the rectifier section to the stripper section.

[0035] The heat duty of the condenser 5700 as well as the reboiler 5300 is significantly reduced and a significantly higher energy efficiency is achieved. Essentially, the liquid reflux in the rectifier is generated not only by any heat removal at condenser but by transfer of heat from the rectifier section to the stripper section.

[0036] The heat pipe 5850 can be oriented substantially perpendicular to a base of the rectifier section, as shown in Figure 5, to direct condensate inside the heat pipe 5800 to the rectifier section via gravity. The system 5000 can be further provided with at least one hollow distillation tray 5900, 5950 located at least one end of the heat pipe. Alternatively, as shown in Figure 5, the system can include, for example, two hollow distillation trays 5900, 5950 that are located on both ends of the heat pipe. The hollow distillation trays 5900, 5950 can be further provided with fins (not shown) to enhance the heat transfer area to and from the heat pipe.

[0037] Condensate inside the heat pipe returns by gravity to the hotter rectifier section 5500 at the bottom. Gravity driven heat pipes have a larger carrying capacity, as compared to wick driven heat pipes such as the heat pipes shown in Figure 4.

[0038] It should be noted that the features summarized in Figure 5 are according to only one, non-limiting embodiment. For example, solely for purposes of clarity, only one heat pipe is shown in Figure 5. In other embodiments, multiple heat pipes are provided from

several or all of the stages (e.g., trays) of the distillation operation, more particularly, from stages of the rectifier section to corresponding trays of the stripper section. Furthermore, multiple heat pipes can be used even between a single set of trays. The use of one or more heat pipes is well within the scope of the present invention.

[0039] The compression provided by the compressor 5150 results in a higher temperature in the rectifier section 5500. Heat is transferred from the rectifier section 5500 to the stripping section 5250 via one or more heat pipes. This heat transfer reduces and/or eliminates the heat discharged at the condenser. Furthermore, the heat duty of the reboiler 5300 at the bottom of the stripping section 5250 is reduced, thus resulting in an overall improvement in exergetic efficiency (e.g., up to and exceeding 50%).

[0040] The heat pipe in the rectification section 5950 acts as an inter-condenser, with the heat pipe in the stripping section 5900 acting as an inter-reboiler. The working fluid inside the heat pipe 5850 condenses in the stripping section 5900 and vaporizes in the rectification section 5950, which transfers heat from the rectifier section to the stripper section. When this heat transfer occurs, process liquid (the material being distilled) in the stripping section is vaporized and process vapor in the rectification section is condensed. Based on the design of the representative embodiment shown in Figure 5 or Figure 6, the stream providing liquid reflux functionality is formed as the heat pipe working fluid condenses in going from the warmer rectifier section to the cooler stripper section, and the working fluid flows back to the rectifier section via gravity. The amount of heat pipe heat transfer is set by the design of the heat pipe including the choice of working fluid, the temperature differential, the working fluid pressure level, the physical layout including surface area of both heat transfer sections and the gravity driving force. The heat pipe design determines the amount of inter-condenser generated reflux and inter-reboiler generated vaporization.

[0041] While the presently disclosed subject matter has been described, merely for purposes of convenience, in terms of a trayed distillation column, it is equally applicable to a packed tower. For example, packed towers can be preferred due to pressure drop considerations in situations involving debottlenecking of distillation units. Also packed towers may offer more capacity to compensate for the lost area if the heat pipe is installed internal to the

column. A packed rectification section with a lower pressure drop will also allow a lower compression ratio for the compression of the stripper section overhead to feed the rectification section. Heat pipes can be used, for example, to transfer heat from different sections of the rectifier to corresponding sections of the stripper. A corresponding section would be a section that maintains the same delta temperature between the rectification section inter-condenser and the stripping section inter-reboiler. This means that an upper inter-condenser would transfer heat to an upper inter-reboiler and a lower inter-condenser would transfer heat to a lower inter reboiler as shown in the system 6000 in Figure 6. These heat pipes can have, according to one non-limiting embodiment, heat exchangers with radially extending fins on both ends of the heat pipe.

[0042] The presently disclosed subject matter, such as the embodiment shown in Figure 5 or Figure 6, provides a more practical column configuration where, unlike conventional distillation, the rectifier section is vertically below the stripper section. Heat transport from the rectifier section 6500 to the stripper section 6250 can be achieved using one or more heat pipes, and the heat is transferred mostly in the axial direction. The vertical configuration allows gravitational force to return the condensate in the heat pipe from the stripper section to the rectifier section below. Heat integration is achieved in a single column, making it easier to retrofit existing columns and reducing the plot area that would be needed for a second column. Figure 6 illustrates an embodiment of the present invention using external heat pipes in a thermo siphon orientation with a vapor riser 6851 and liquid return 6852, which allows the heat pipe working fluid to segregate and help avoid flooding. The riser 6851 and the return 6852 are operatively coupled to internal heat transfer surfaces 6853. The internal heat transfer surfaces 6853 can be a hollow distillation tray, a structural packing in a plate or frame type configuration or any other suitable heat transfer device that promotes heat transfer without restricting column capacity. The same concept can also be achieved with external heat pipe with a single connection with countercurrent vapor and liquid flow provided the heat pipe is sized adequately to avoid flooding.

[0043] Operating conditions for the systems and methods of the presently disclosed subject matter can be determined by a person of ordinary skill in the art. Further insight can be

obtained from, for example, Internal heat integration - the key to an energy-conserving distillation column. Z. Olujic, F. Fakhri, A de Rijke, F de Graauw and PJ Jansens, J of Chemical Technology and Biotechnology, 78, page 241-248 (online 2003); Internal versus External Heat Integration. Operational and Economic Analysis. J. P. Schmal, H. J. Van Der Kooi, A. De. Rijke, Z. Olujic and P. J. Jansens, Trans IChemE, Part A, Chemical Engineering Research and Design, 2006, 84, page 374-380; A new approach to the design of internally heat integrated tray distillation columns. M. Gadalla, Z. Olujic, A. de Rijke and J. P. Jansens, European Symposium on Computer Aided Process Engineering, 15: 805-810; A thermo-hydraulic approach to conceptual design of an internally heat-integrated distillation column (i-HIDiC), M. Gadalla, L. Jimenez, Z. Olujic and P. J. Jansens, Computers and Chemical Engineering (2006), doi:10.1016/j.compchemeng.2006.11.006; and Conceptual design of an internally heat integrated propylene-propane splitter, Z. Olujic, L. Sun, A. de Rijke, P. J. Jansens, Energy 31 (2006) 3083-3096. Each of these references is hereby incorporated by reference in their entirety.

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[0044] The present invention is not to be limited in scope by the specific embodiments described herein. Indeed, various modifications of the invention in addition to those described herein will become apparent to those skilled in the art from the foregoing description and the accompanying figures. Such modifications are intended to fall within the scope of the appended claims.

[0045] It is further to be understood that all values are approximate, and are provided for description.

[0046] Patents, patent applications, publications, product descriptions, and protocols are cited throughout this application, the disclosures of each is incorporated herein by reference in its entirety for all purposes.

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CLAIMS

1. A distillation system for separating at least two components of a multi-component fluid feed comprising:

(a) a stripper section including

(i) an inlet to receive a feed of fluid containing at least two components,

(ii) a compressor in fluid communication with a more volatile portion of the fluid within the stripper section to provide an output feed, and

(iii) a reboiler to receive a heating fluid and in fluid communication with a less volatile portion of fluid within the stripper section; and

(b) a rectifier section aligned vertically with and disposed below the stripper section, the rectifier section to receive the output feed from the compressor and further including

(i) a condenser to receive a cooling fluid and in fluid communication with a more volatile portion of the output feed from the compressor, the condenser including an exit to remove at least one component from the more volatile portion of the output feed, and

(ii) an outlet to recycle a less volatile portion of the output feed from the compressor for recycle back to the stripper section.

2. The distillation system of claim 1, wherein the stripper section and the rectifier section are contained within a single at least partially enclosed structure.

3. The distillation system according to anyone of the preceding claims, wherein the rectifier section is operated at a higher average pressure and temperature than the stripper section.

4. The distillation system of claim 3, further comprising at least one heat pipe traversing between at least a portion of the rectifier section and at least a portion of the stripper section to transfer heat from the rectifier section to the stripper section.

5. The distillation system of claim 4, wherein the heat pipe is oriented substantially perpendicular to a base of the rectifier section.

6. The distillation system of claim 4, wherein the heat pipe directs condensate inside the heat pipe to the rectifier section via gravity.

7. The distillation system of claim 4, wherein at least one hollow distillation tray is located at at least one end of the heat pipe to increase the transfer surface area for heat transfer.

8. The distillation system according to anyone of the preceding claims, wherein the feed is primarily hydrocarbons.

9. A distillation method for separating at least two components of a multi-component fluid feed utilizing a distillation system according to any one of the preceding claims comprising:

(a) introducing a feed of fluid containing at least two components to the stripper section; and

(b) directing the output feed from the compressor to the rectifier section aligned vertically with and disposed below the stripper section.