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RESEARCH

Evaluation of a novel configuration of bottom flashing on dual distillation columns for saving energy

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Abstract

Vapor recompression and bottom flashing are among the developed technologies for enhancing energy efficiency of distillation processes. In this paper, a novel configuration of bottom flashing system is proposed for enhancing energy efficiency of dual columns such as direct distillation sequences. The system is designed to operate between two distillation columns. The proposed system engages two separate distillation columns, both of which can be wide boiling systems. The system incorporates two interacting bottom flashing systems that engage the two distillation columns through heat transfer from the top product of the second column to the bottom product of the first column which in turn results in elimination/reduction of utility requirements of condenser of the second column along with reboiler of the first column. Based on the results of this study, compared to conventional direct sequence distillation, 40.3% reduction in energy requirements and 20.7% reduction total annual costs of the process can be obtained through application of the proposed system.

Keywords Vapor recompression · Bottom flashing · Energy · Distillation · Sequence

Introduction

Separation of chemicals is an integral part of any chemical plant because this task is necessary in the following circumstances:

- Presence of unwanted components in the feed.
- Presence of bi products in outlet stream of chemical reactors.
- Presence of unreacted feeds in outlet stream of chemical reactors.
- Presence of inert components in outlet stream of chemical reactors.

A number of methods have been used for performing different types of separations throughout the years. For separation of liquid–liquid mixtures, the most common technology is still distillation [1, 2]. Distillation is an energy intensive method, especially for close-boiling separations. This is probably its main draw back. Various technologies such as heat pump assisted distillation [3–5], distillation with vapor recompression [6–9], distillation with bottom flashing [10, 11] and internally heat integrated distillation columns (i-HIDiC) [12–17] have been developed previously for reducing energy requirements of distillation systems. Simplified process flow diagrams of bottom flashing heat pump is shown in Fig. 1 [18, 19]. In bottom flashing systems, pressure, temperature and bubble point temperature of the bottom product of the distillation column are reduced by an expansion valve. This process provides the opportunity for heat transfer from the top product of the column to the bottom one. Through this heat transfer, required reflux and boil up for operation of the distillation column are provided. Reflux and boil up streams are then separated from the top and bottom products and returned to the distillation column. The same concept is utilized in the other introduced systems, but the configurations of the four systems are different.

Various configurations of these systems have been presented in previous studies [7, 8, 18, 20–25]. These configurations include: vapor recompression with intermediate reboiler(s) [20, 26, 27], vapor recompression with self-heat

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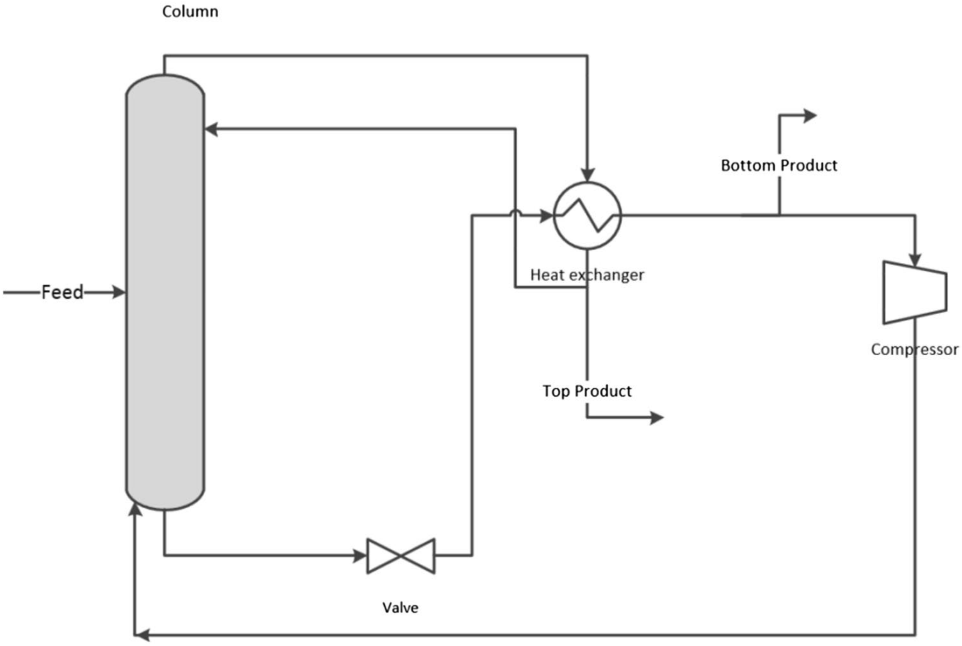

Fig. 1 Simplified process flow diagrams of bottom flashing heat pump

recuperation [28], vapor recompression with extra heat transfer units [7], vapor recompression and bottom flashing on petlyuk column [8], simplified heat integrated distillation column [25], heat integrated distillation with additional heat transfer between top product and feed [12] and heat integrated distillation columns for separating ternary mixtures [14]. Current trends of using process intensification principles, along various optimization techniques for simultaneous control and design for improving performance of distillation systems were studied in a recent paper [29].

Previous studies on application of these systems on dual columns are very limited. For separating a ternary mixture, various sequences of columns can be used, including direct sequence, indirect sequence, conventional distillation, Petlyuk, divided wall column, side rectifier and side stripper [30–34].

In this study, a novel configuration of bottom flashing system is proposed for dual distillation columns such as direct sequence distillation. The system incorporates two interacting bottom flashing systems that engage the two distillation columns through heat transfer from the top product of the second column to the bottom product of the first column which in turn results in elimination/reduction of utility requirements of condenser of the second column along with reboiler of the first column. Previous models incorporated condenser and reboiler of a single column. The scope of the proposed model is wider in comparison to previous models. Generally, larger compression ratios are required for systems with larger temperature difference across the column. One of the key advantages of the proposed system is that it can be applied between two wide boiling distillation systems utilizing a smaller compression ratio, compared to the single columns, which in turn results in higher energy savings and smaller size of bottom flashing system. Additionally, a model is presented that utilizes two interconnected bottom flashing systems. One of these systems is designed to make sure that the products of the first column are produced at the pre specified conditions and the second system eliminates the utility sources required in the system. This system was shown to have a better performance compared to the basic bottom flashing system.

Overview

Separation of C1, C2 and C3 hydrocarbon cuts, encountered in petrochemical processes, was investigated. The performance of the proposed configurations was investigated on this separation system. Based on temperature difference between the products, this distillation system is a wide boiling one. If vapor recompression, bottom flashing or heat pump assisted distillation systems are applied on the C1–C2 and/or C2–C3 distillation columns, extremely large values of compression ratio (~ 3–5) will be required for providing the possibility of heat transfer from the top product to the bottom one. This means that application of bottom flashing or vapor recompression on these distillation columns is not economical. However, an opportunity for energy saving may arise when a process engineer considers the two columns together as a system. The systems are operated in such a way that application of a vapor recompression or bottom flashing system is feasible between two columns.

In this work, a commercial process simulator was used as a tool for evaluating performance of the systems. The base case (direct sequence) was composed of two distillation columns. Generally, degree of freedom of a conventional two-product distillation column with a condenser and reboiler is 2. Therefore, for a two-product column, it is only possible to specify two specifications. In our simulations for two-product columns, recovery and purity of one of the products were the two used design parameters. These specifications, along with feed conditions and feed stage govern performance of the column. So, the other characteristics of the separation processes (including required reflux ratios, boil up ratios, condenser duties and reboiler duties) were obtained by running the simulation and solving Mass balance, Equilibrium, Summation of mole fractions = 1 and Heat balance (MESH equations) at all stages of the column. The energy requirements of the systems were evaluated by solving MESH equations. In designing the proposed bottom flashing configuration, operating parameters were adjusted to supply the same operating conditions for the columns. The main idea was to reduce energy requirements of the system by transferring heat from top to bottom products. For a specific compression ratio, a fraction of required energy was saved through heat transfer from top to bottom products, and the remaining energy was supplied by heaters/coolers.

Simulation

In this study, a simulator was used to examine feasibility of application of bottom flashing system on a three component distillation process.

Performance of the systems was evaluated using a process simulator, namely Aspen HYSYS v8.4. Peng-Robinson property package was used in all the simulation cases. Structural specifications of the distillation columns were the same for the proposed model and base direct sequence case. The first and second columns contained 50 and 40 stages, respectively. Additionally, the columns were operated at 33 barg and pressure drops across the columns were neglected. The feed at − 10 °C and 33 barg entered the first distillation column at 25th stage where C1 cut is separated from the mixture as the top product. C2 and C3 cuts, at the bottom product of the first column are entered the second column at the 20th stage where C2 and C3 hydrocarbon cuts are separated. Process flow diagram of the base direct sequence distillation column is shown in Fig. 2. The first column was designed with reflux and boil up rates of 739.8 and 907.8 kmoles/h, respectively. Additionally, the second column was designed with reflux and boil up rates of 1200.0 and 2233.0 kmoles/h, respectively. Furthermore, design of the two columns was performed in such a way that it allows production of 493.2, 1200.0 and 306.3 kmoles/h of

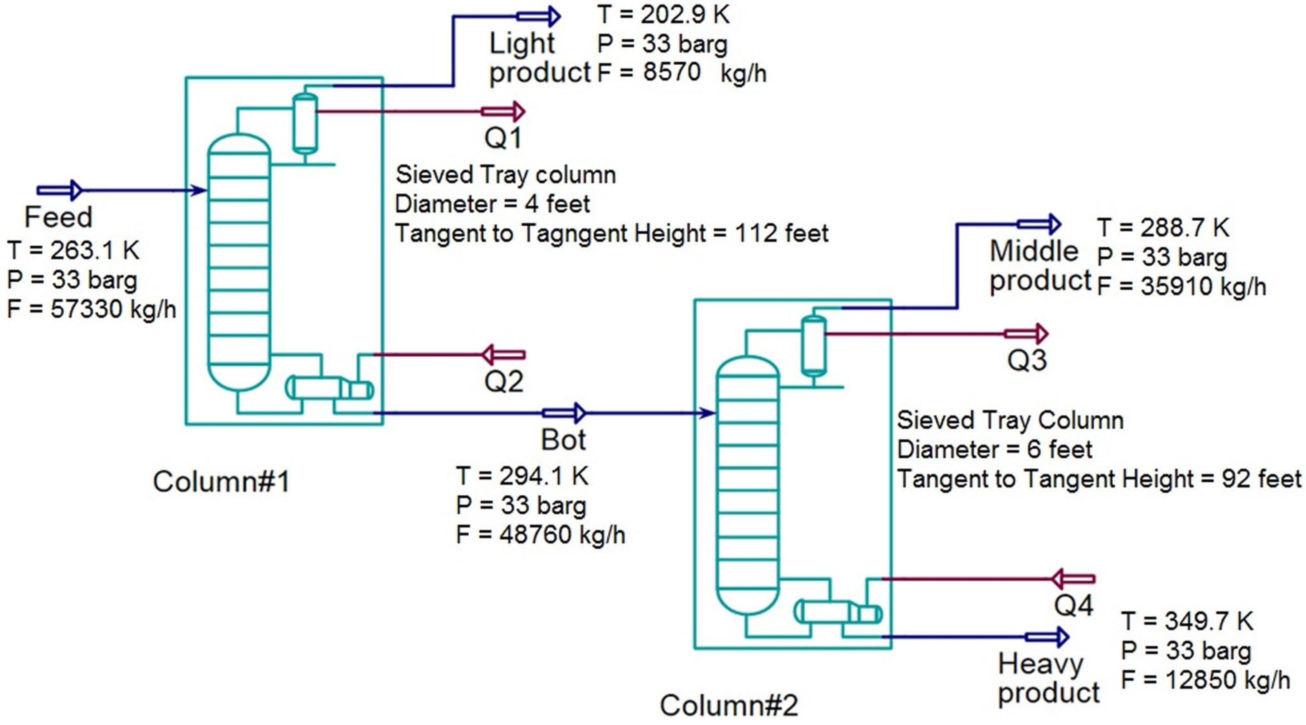

Fig. 2 Flow sheet of direct distillation sequence for ternary separation

Table 1 Specifications of the three products

Product	C1 mole fraction	C2 mole fraction	C3 mole fraction	Temperature (°C)	Pressure (barg)	Flow rate (kmoles/h)
Light product	0.922	0.0778	0.000	− 70.36	33.0	493.2
Middle product	0.035	0.941	0.024	13.41	33.0	1200.0
Heavy product	0.000	0.116	0.884	74.66	33.0	306.3

Table 2 Comparison of obtained VLE results from simulation and experiment [35, 36]

Pressure (atm)	Temperature (K)	Liquid mole fraction			Vapor mole fraction from experiment [35]			Vapor mole fraction from simulation		
		C1	C2	C3	C1	C2	C3	C1	C2	C3
27.2	213.71	0.3656	0.0000	0.6344	0.9741	0.0000	0.0239	0.9742	0.0000	0.0258
27.2	213.71	0.3720	0.1412	0.4868	0.9440	0.0345	0.0215	0.9464	0.0332	0.0204
27.2	213.71	0.3725	0.5193	0.1082	0.8673	0.1270	0.00573	0.8658	0.1290	0.0052
27.2	213.71	0.3878	0.6122	0	0.8532	0.1468	0.0000	0.8423	0.1577	0.0000
40.85	213.71	0.5563	0.0000	0.4437	0.9767	0.0000	0.0233	0.9775	0.0000	0.0225
40.85	213.71	0.5453	0.0971	0.3576	0.9576	0.0234	0.0190	0.9581	0.0226	0.0193

light middle and heavy products, respectively. Other conditions of the light, middle and heavy products are reported in Table 1. As shown in this Table 1, temperature differences among the three product streams are high. This issue results in low efficiency of conventional vapor recompression and bottom flashing systems in reducing energy requirements of this system. In fact, conventional bottom flashing and vapor recompression systems would require very high compression ratios to be able to transfer heat from top to bottom product. However, the systems are applied in a different method to utilize bottom flashing system with a low compression ratio for reducing energy requirements of the system. Pressure drops in shell and tube sides of all the heat exchangers were neglected. Pumps and compressors of the systems were designed based on adiabatic efficiency of 75%.

Before performing the simulations, it was required to check the accuracy of obtained results with experimental results. The vapor–liquid equilibrium (VLE) data were taken from a previously published paper [35], and the same conditions were applied in simulation environment. The results are presented in Table 2. Based on Table 2, the results of simulation are in good accordance to the experimental data. Additionally, steps in designing a bottom flashing system are shown in Fig. 3.

Process flow diagram of bottom flashing system, applied on a direct sequence three component distillation column is shown in Fig. 4. This system is designed for reducing energy requirements of the conventional direct sequence system. It is based on elimination of reboiler of the first column, condenser of the second column and addition of a compressor. The compression ratio of the compressor in this case is much lower compared to application of the bottom flashing system on individual columns. In fact, required compression ratio is directly related to the temperature difference between condenser and reboiler. For a specific temperature difference across the column, the compression ratio must be large enough to provide positive logarithmic mean temperature difference (LMTD) for heat transfer from top to bottom products. Therefore, for a larger temperature difference, larger compression ratio is required to provide the positive LMTD for heat transfer from top to bottom products. Based on the difference in temperatures of various streams in the systems, vapor recompression or bottom flashing

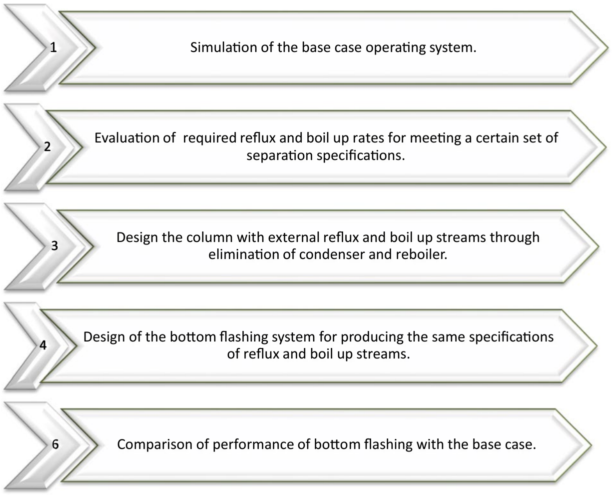
1 Simulation of the base case operating system.
2 Evaluation of required reflux and boil up rates for meeting a certain set of separation specifications.
3 Design the column with external reflux and boil up streams through elimination of condenser and reboiler.
4 Design of the bottom flashing system for producing the same specifications of reflux and boil up streams.
6 Comparison of performance of bottom flashing with the base case.

Fig. 3 Steps in designing bottom flashing systems

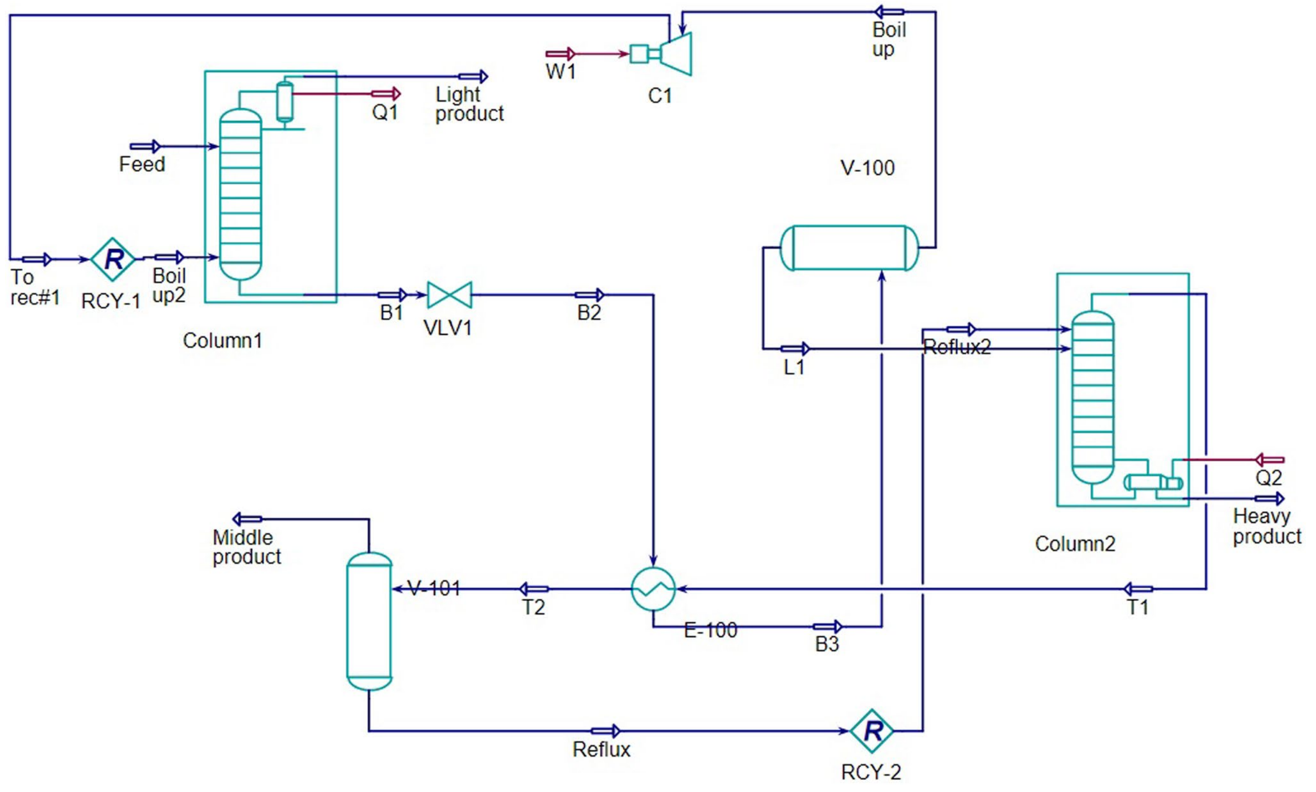

Fig. 4 Flow sheet of simple bottoms flashing system applied on direct sequence system

interconnecting the two columns is more economic compared to its application on individual columns. It should be mentioned that a similar system can be designed for application on indirect distillation sequence based on elimination of condenser of the first column, reboiler of the second column and addition of a compressor. Based on the same concepts, vapor recompression systems can also be designed for direct and indirect distillation sequences.

In this study, a novel system is proposed for further energy saving in direct sequence distillation columns. The proposed system is shown in Fig. 5. The system is a modified version of the model presented in Fig. 4. This system is also designed on the basis of elimination of reboiler of the first column, condenser of the second column and addition of a two compressors to the direct sequence system. The results of this study show that the proposed system can lead to higher energy performance compared to the base direct sequence and model 1. The proposed system utilizes two interconnected bottom flashing systems. One of the bottom flashing systems is designed based on reduction of pressure, temperature and bubble point temperature of the bottom product of the first column for receiving thermal energy from the top product of the second column. In the other system, the same concepts are utilized for transferring thermal energy between two intermediate streams. Addition of the second system helps to reduce thermal energy requirements of the system while maintaining product specifications. It should be mentioned that in each of the two bottom flashing systems, pressure ratio across the compressor were the same as pressure ratio across the corresponding valve. If only the compressors were taken into account, the lower the compression ratio, the better because increasing compression ratio results in higher power requirements of the compressor. However, increasing compression ratio can lead to variation in important characteristics of the system such as heat transfer driving force of heat exchangers, required surface area for the heat exchangers and total utility requirement of the system. Effects of the compression ratio of the compressors along with the most important parameters of the system are investigated in the following sections.

Results and discussion

In this research, a parametric study was carried out on the proposed system to reveal how variations of different parameters affect performance of the system. Initially, the most important variables affecting performance of the system were identified and then their influence on energy

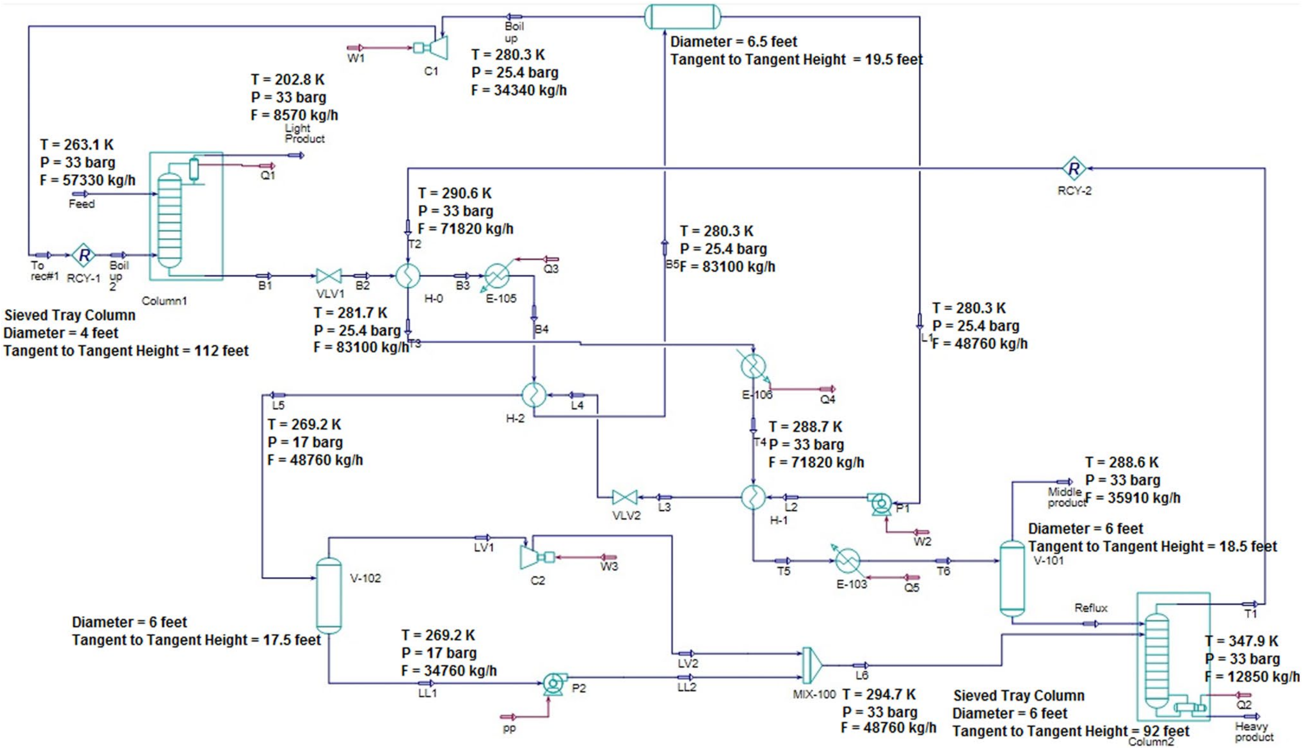

Fig. 5 Flow sheet of the proposed processing system based on incorporation of two interconnected bottoms flashing systems on a direct sequence distillation system

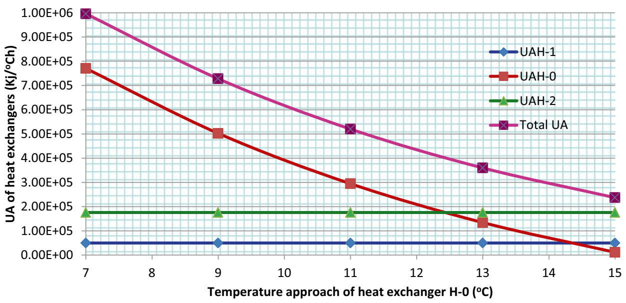

Fig. 6 Influence of temperature approach of heat exchanger H-0 on required UA of heat exchangers

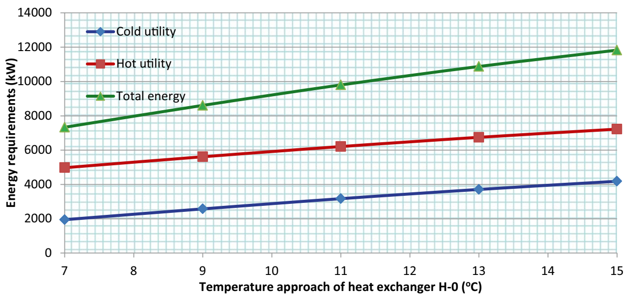

Fig. 7 Influence of temperature approach of H-0 on energy requirements of the system

consumption and required surface area of heat exchangers were evaluated.

One of the important variables of the system is the temperature approach of heat exchanger H-0 (based on Fig. 5). A fraction of required boil up for the first column and required reflux for the second one is provided through heat transfer in this heat exchanger. Reducing this temperature approach requires higher surface area of this heat exchanger and results in higher transferred heat which in turn provides higher rates of reflux and boil up streams. Influence of temperature approach of H-0 on UA (overall heat transfer coefficient × surface area) of the three heat exchangers is reported in Fig. 6. As indicated in Fig. 6, increasing temperature approach of H-0 results into lower UA for H-0. However, UA of H-1 and H-2 heat exchangers remain relatively the same when temperature approach of H-0 changes. This observation is logical, because for a lower temperature approach, higher surface of contact between hot and cold streams is required. For instance, temperature approach of 0 requires extremely large (physical ∞) contact area between hot and cold streams. Additionally, based on Fig. 6, increasing temperature approach of H-0 significantly reduces total UA of heat exchangers.

Along with required UA of heat exchangers, temperature approach of H-0 affects utility requirements of the system (Fig. 7). This is because a fraction of required energy is saved in heat exchangers and the remaining must be provided in additional heaters and coolers. If the temperature approach is changed, heat transfer in the heat exchanger is influenced, which in turn leads to changing required energy of the system. Based on the presented results, upon increasing temperature approach of H-0, required cold utility, hot utility and total energy for separation were significantly increased. This result was due to reduced rate of heat transfer in H-0 at higher temperature approaches. Upon decreasing heat transfer rate in H-0, higher rates of utility streams such as cooling water and steam were required for providing thermal energy in the system. Thus, based on Figs. 6 and 7, the temperature approach of this heat exchanger should be selected based on a compromise between energy requirements and surface area of the heat exchangers.

Other important parameters affecting performance of the system were pressure ratio across the two compressors (and corresponding valves). In bottom flashing systems, decreasing pressure of the bottom product in a valve provides the possibility of heat transfer from the top product to the bottom product through reduction of temperature and bubble point temperature of the bottom product. Upon reduction of the valve' outlet pressure (increasing pressure ratio), higher energy for compression is required in the compressor and also, lower thermal utilities were required because of increased heat transfer rate in the corresponding heat exchanger. Influence of pressure ratio across compressor C-1 and corresponding valve VLV-1 on UA of heat exchangers, utility requirements and power requirements of the process are shown in Figs. 8, 9 and 10, respectively. Based on Fig. 8, UA of heat exchangers H-1 and H-2 were slightly increased upon increasing pressure ratio across compressor C-1 and valve VLV-1. Additionally, this pressure ratio affects UA of heat exchanger H-0. UA of H-0 was increased upon increasing the pressure ratio. This result is attributed to higher rates of heat transfer in this heat exchanger at higher pressure ratios. Also, based on the presented results in Fig. 8, increasing pressure ratio across C-1 and VLV-1 results in higher total required UA of heat exchangers.

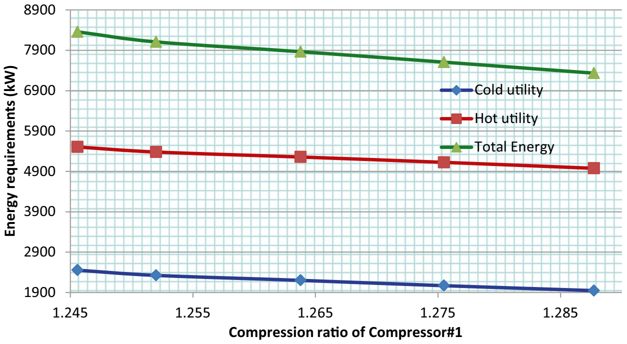

Fig. 9 Influence of compression ratio of C-1 on utility requirements of the system

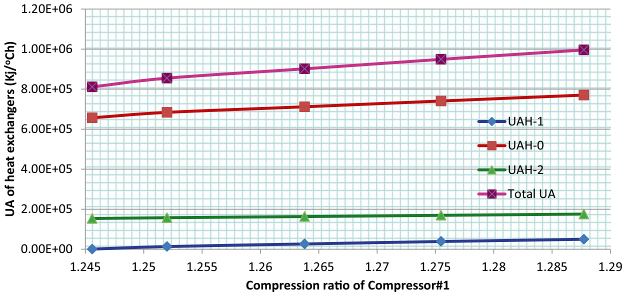

Fig. 8 Influence of compression ratio of compressor C-1 on required UA of heat exchangers

Based on Fig. 9, upon increasing pressure ratio across C-1 and VLV-1 (from 1.245 to 1.285), required cold utility, hot utility and total energy for separation are decreased. This result is attributed to higher rates of heat transfer in heat exchanger H-0 at higher pressure ratios. When the pressure ratio is increased, heat transfer driving force in H-0 is increased due to lower temperature and bubble point temperature of the outlet stream of the valve which in turn results in higher heat transfer rate in H-0 at a constant temperature approach. However, increasing this ratio results in higher power requirements of the compressor (Fig. 10). Thus, decreasing utility requirements of the system can be obtained at the expense of higher power requirements through increasing pressure ratio across compressor C-1 and valve VLV-1.

Pressure ratio across compressor C-2 and valve VLV-2 was another important parameter affecting performance of the system. As shown in Fig. 11, increasing this pressure ratio from 1.88 to 2.58 can lead to lower UA of heat exchanger H-2 and total required UA of heat exchangers.

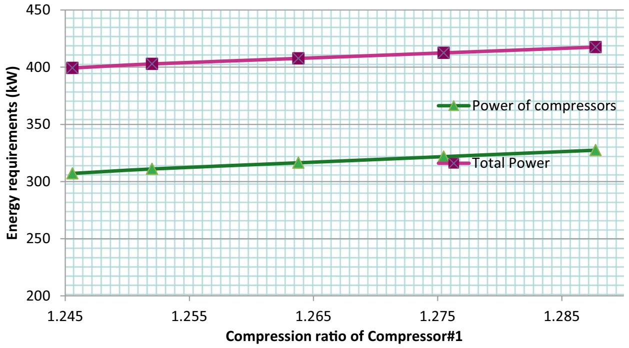

Fig. 10 Influence of compression ratio of C-1 on power requirements of the system

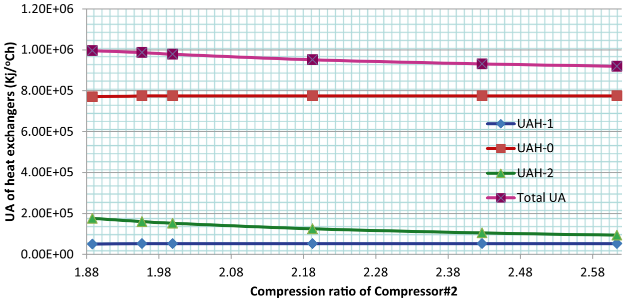

Fig. 11 Influence of compression ratio of compressor C-2 on required UA of heat exchangers

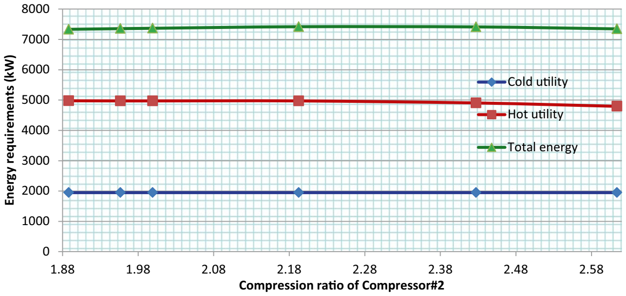

Fig. 12 Influence of compression ratio of compressor C-2 on energy and utility requirements of the system

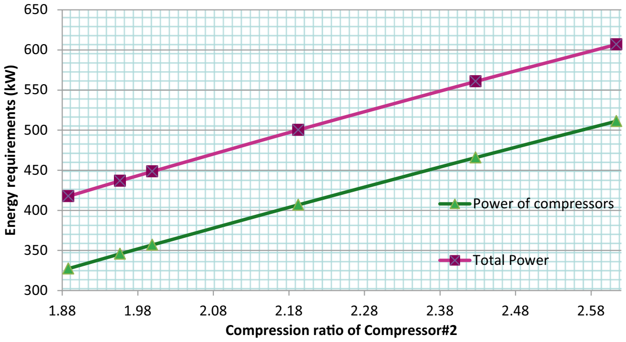

Fig. 13 Influence of compression ratio of compressor C-2 on power requirements of the system

Also, based on Fig. 12, changing this parameter between 1.88 to 2.58 did not significantly affect utility requirements of the processing system. Upon increasing pressure ratio across compressor C-2 and valve VLV-2 hot utility requirements of the system were slightly reduced. Also, based on Fig. 13, required power for operation of compressors and total required power for the system are increased upon increasing this pressure ratio from 1.88 to 2.58. Thus, the results indicate that increasing compression ratio of compressor C-1 leads to reduction of required energy for separation. However, increasing compression ratio of compressor C-2 does not affect utility requirements of the process, therefore leading to increased total energy requirements of the system.

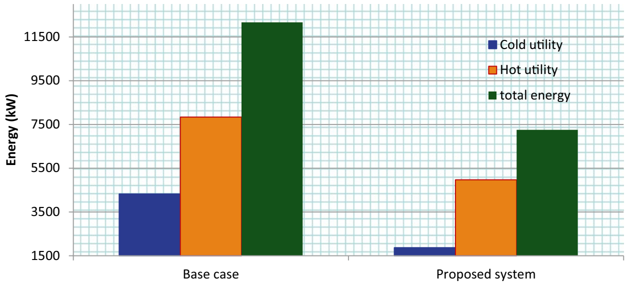

Fig. 14 Comparison between utility and energy requirements of the base case and the proposed system

A comparison of energy consumption between the base case and the new proposed system is required to evaluate the performance of proposed system. Based on the presented results in Fig. 14, 56.8, 36.6 and 40.3% reduction in cold utility, hot utility and total energy requirements of the system can be obtained, respectively through applying the proposed system. In previous studies, the authors proposed interesting designs for improving a certain separation system and they reported various aspects of their design such as energy savings. But the results cannot be compared to related studies, because the assumptions and basically the separation systems are different. In this study, a direct sequence of distillation columns was studied and the separation system is different from the previous studies. The results are influenced by various parameters of separation systems, such as temperature difference across the column and antione constants of the materials. Therefore, comparison between obtained results and previous studies is not reported. Based on the obtained results, application of the proposed system can result in lower energy and utility requirements of the separation system. However, performance of a system is cannot be summarized in its energy consumption. Because a process can be energy efficient and economically unattractive.

It was shown that the proposed process can lead to reduced energy requirements of the system. However, it was also required to see whether this system can lead to reduced costs of separation process. Therefore, the systems were economically evaluated using Aspen Economic Evaluation software. The economic analysis was based on the economic indexes of 2013 and location of United States. Based on the results of economic analysis, the proposed system can lead to 20.7% reduction in total annual costs (TAC) of the system. The previous studies showed that application of vapor recompression and bottom flashing can result in saving energy in close-boiling systems. However, for the systems with larger temperature difference across the column, larger compression ratios are required. The proposed system was designed in such a way that it resulted in energy saving for a wide boiling separation system.

Based on the obtained results, it was concluded that, for direct sequence, the proposed system will result in energy and costs savings, when the temperature difference between bottom product of first column (feed of the second column) and top product of the second column is small (i.e. smaller than °C). Similarly, for indirect sequence, the proposed system will result in energy and costs savings, when the temperature difference between top product of first column (feed of the second column) and bottom product of the second column is small (i.e., smaller than 15 °C). Required compression ratio is directly dependent to these temperature differences. For instance, in indirect sequence, the main idea was to transfer heat from top product of the column to the bottom product of the first column. Outlet pressure of the valve should be small enough for having a minimum logarithmic mean temperature difference (LMTD) in the heat exchanger. The larger the temperature difference, the smaller the required outlet pressure of the valve (and compression ratio). Therefore, compression ratio is directly dependent to this parameter, and the mentioned temperature difference plays a significant role in economic performance of the system.

Conclusions

In this paper, a novel processing system is introduced for reduction of energy requirements of direct sequence distillation systems. The system incorporates two interacting bottom flashing systems that engage the two distillation columns through heat transfer from the top product of the second column to the bottom product of the first column. The following concluding remarks were proposed:

- Application of bottom flashing (and vapor recompression) can lead to enhanced energy and economic performance of dual distillation systems.
- Usually bottom flashing (and vapor recompression) systems are utilized on close-boiling systems for saving energy. It was shown in this study, that utilizing concepts of bottom flashing (vapor recompression) can lead to energy saving in wide boiling systems as well.
- The results indicate that for direct sequence, the proposed system will result in energy and costs savings, when the temperature difference between bottom product of first column (feed of the second column) and top product of the second column is small (i.e. smaller than 15 °C). This temperature difference directly influences required compression ratio and therefore economic performance of the system. The results indicate that increasing compression ratio of compressor C-1 leads to reduction of utility requirements and required energy for separation. However, increasing compression ratio of compressor C-2 does not affect utility requirements of the process, therefore leading to increased total energy requirements of the system.
- Compared to conventional direct sequence distillation system, 40.3% reduction in energy requirements and 20.7% reduction in TAC of the process can be obtained by application of the proposed system on direct sequence distillation system.

References

1. Soave G, Feliu JA (2002) Saving energy in distillation towers by feed splitting. Appl Therm Eng 22:889–896
2. Sadeghzadeh Ahari J, Pakseresht S, Mahdyarfar M, Shokri S, Zamani Y, Naderi F (2006) Predictive dynamic model of air separation by pressure swing adsorption. Chem Eng Technol 29:50–58
3. Kazemi A, Faizi V, Mehrabani-Zeinabad A, Hosseini M (2017) Evaluation of performance of heat pump assisted distillation of ethanol–water mixture. Sep Sci Technol 52(8):1387–1396
4. King CJ (2013) Separation processes. Courier Corporation, USA
5. Kiss AA (2014) Distillation technology—still young and full of breakthrough opportunities. J Chem Technol Biotechnol 89:479–498
6. Kazemi A, Hosseini M, Mehrabani-Zeinabad A, Faizi V (2016) Evaluation of different vapor recompression distillation configurations based on energy requirements and associated costs. Appl Therm Eng 94:305–313
7. Waheed M, Oni A, Adejuyigbe S, Adewumi B, Fadare D (2014) Performance enhancement of vapor recompression heat pump. Appl Energy 114:69–79
8. Navarro-Amorós MA, Ruiz-Femenia R, Caballero JA (2013) A new technique for recovering energy in thermally coupled distillation using vapor recompression cycles. AIChE J 59:3767–3781
9. Johri K, Babu G, Jana AK (2011) Performance investigation of a variable speed vapor recompression reactive batch rectifier. AIChE J 57:3238–3242
10. Minh LQ, Long NVD, Duong PLT, Jung Y, Bahadori A, Lee M (2015) Design of an extractive distillation column for the environmentally benign separation of zirconium and hafnium tetrachloride for nuclear power reactor applications. Energies 8:10354–10369
11. Díez E, Langston P, Ovejero G, Romero MD (2009) Economic feasibility of heat pumps in distillation to reduce energy use. Appl Therm Eng 29:1216–1223
12. Nakaiwa M, Huang K, Naito K, Endo A, Owa M, Akiya T et al (2000) A new configuration of ideal heat integrated distillation columns (HIDiC). Comput Chem Eng 24:239–245
13. Iwakabe K, Nakaiwa M, Huang K, Nakanishi T, Røsjorde A, Ohmori T et al (2006) Energy saving in multicomponent

separation using an internally heat-integrated distillation column (HIDiC). Appl Therm Eng 26:1362–1368

14. Huang K, Shan L, Zhu Q, Qian J (2007) Design and control of an ideal heat-integrated distillation column (ideal HIDiC) system separating a close-boiling ternary mixture. Energy 32:2148–2156
15. Horiuchi K, Yanagimoto K, Kataoka K, Nakaiwa M, Iwakabe K, Matsuda K (2008) Energy saving characteristics of the internally heat integrated distillation column (HIDiC) pilot plant for multi-component petroleum distillation. J Chem Eng Jpn 41:771–778
16. Suphanit B (2010) Design of internally heat-integrated distillation column (HIDiC): uniform heat transfer area versus uniform heat distribution. Energy 35:1505–1514
17. Jana AK (2016) A new divided-wall heat integrated distillation column (HIDiC) for batch processing: feasibility and analysis. Appl Energy 172:199–206
18. Kazemi A, Mehrabani-Zeinabad A, Beheshti M (2017) Development of a novel processing system for efficient sour water stripping. Energy 125:449–458
19. Shahandeh H, Ivakpour J, Kasiri N (2014) Internal and external HIDiCs (heat-integrated distillation columns) optimization by genetic algorithm. Energy 64:875–886
20. Kumar V, Kiran B, Jana AK, Samanta AN (2013) A novel multi-stage vapor recompression reactive distillation system with intermediate reboilers. AIChE J 59:761–771
21. Kiran B, Jana AK (2015) Introducing vapor recompression mechanism in heat-integrated distillation column: impact of internal energy driven intermediate and bottom reboiler. AIChE J 61:118–131
22. Shi L, Huang K, Wang S-J, Yu J, Yuan Y, Chen H et al (2015) Application of vapor recompression to heterogeneous azeotropic dividing-wall distillation columns. Ind Eng Chem Res 54:11592–11609
23. Feng S, Lyu X, Ye Q, Xia H, Li R, Suo X (2016) Performance enhancement of reactive dividing-wall column via vapor recompression heat pump. Ind Eng Chem Res 55:11305–11314
24. Xu L, Li M, Yin X, Yuan X (2017) New intensified heat integration of vapor recompression assisted dividing wall column. Ind Eng Chem Res 56:2188–2196
25. Chen H, Huang K, Wang S (2010) A novel simplified configuration for an ideal heat-integrated distillation column (ideal HIDiC). Sep Purif Technol 73:230–242
26. Asprion N, Rumpf B, Gritsch A (2011) Work flow in process development for energy efficient processes. Appl Therm Eng 31:2067–2072
27. Jana AK, Mane A (2011) Heat pump assisted reactive distillation: wide boiling mixture. AIChE J 57:3233–3237
28. Long NVD, Lee M (2013) A novel NGL (natural gas liquid) recovery process based on self-heat recuperation. Energy 57:663–670
29. Aneesh V, Antony R, Paramasivan G, Selvaraju N (2016) Distillation technology and need of simultaneous design and control: a review. Chem Eng Process 104:219–242
30. Khalili-Garakani A, Ivakpour J, Kasiri N (2016) Three-component distillation columns sequencing: including configurations with divided-wall columns. Iran J Oil Gas Sci Technol 5:66–83
31. Kiss AA, Rewagad RR (2011) Energy efficient control of a BTX dividing-wall column. Comput Chem Eng 35:2896–2904
32. Ramírez-Corona N, Jiménez-Gutiérrez A, Castro-Agüero A, Rico-Ramírez V (2010) Optimum design of Petlyuk and divided-wall distillation systems using a shortcut model. Chem Eng Res Des 88:1405–1418
33. Torres-Ortega CE, Segovia-Hernández JG, Gómez-Castro FI, Hernández S, Bonilla-Petriciolet A, Rong B-G et al (2013) Design, optimization and controllability of an alternative process based on extractive distillation for an ethane–carbon dioxide mixture. Chem Eng Process 74:55–68
34. Le Q-K, Halvorsen IJ, Pajalic O, Skogestad S (2015) Dividing wall columns for heterogeneous azeotropic distillation. Chem Eng Res Des 99:111–119
35. Wichterle I, Kobayashi R (1972) Vapor–liquid equilibrium of methane–ethane–propane system at low temperatures and high pressures. J Chem Eng Data 17:13–18
36. Kazemi A, Mehrabani-Zeinabad A, Beheshti M (2018) Distillation without hot utilities; development of novel distillation configurations for energy and costs saving for separation of propylene/propane mixture. Chemical Engineering and Processing: Process Intensification 123:158–167