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Modified Basic Distillation Configurations with Intermediate Sections for Energy Savings

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Basic distillation configurations have been well studied, comprising of energy efficient (n − 1)-column configurations that can be used to separate an n-component nonazeotropic feed mixture into its components. In this article, we present new (n − 1)-column configurations which differ from the conventional basic configurations due to the introduction of extra intermediate sections and the additional transfer-streams associated with submixtures of these sections. We demonstrate using four-component examples that these small differences lead to some interesting nonintuitive physical effects in the new configurations, resulting in large energy savings compared to the basic configurations. The proposed configurations offer more operable and energy efficient options for onsite implementation than the corresponding optimally operated basic configurations. © 2014 American Institute of Chemical Engineers *AIChE J*, 60: 1091–1097, 2014
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Introduction

Distillation of a multicomponent feed mixture is usually carried out in a sequence of distillation columns. Each distillation column performs designated separation tasks. A sequence of distillation columns with the assigned separation tasks constitutes a distillation configuration. One approach to economically separate a given multicomponent feed mixture into pure products is to identify from the search space of distillation configurations, a few configurations, which can achieve the required separation at minimal or close-to-minimal cost. The search for a suitable configuration from this set can be further narrowed down based on other factors like operability, flexibility, and/or controllability of the configuration. However, to successfully accomplish this overall task, it is important that the search space of distillation configurations includes all potentially useful configurations.

Figure 1a shows a five-column distillation configuration that can be used to separate a four-component feed mixture. In this figure and in all the figures that follow, condensers are denoted by filled circles and reboilers, by unfilled circles. Further, pure components are denoted by *A*, *B*, *C, D,* and so forth. Component volatilities decrease in alphabetical order, that is, *B* is less volatile than *A*, whereas *C* is less volatile than *B*, and so forth. All the distillations considered in this article are assumed to be nonazeotropic. Any intermediate composition consisting of two or more components will be referred to as a submixture, and any stream of such a submixture that exchanges mass between two distillation columns will be referred to as a transfer-stream. Transfer/product streams are named according to the components that are present in significant quantities. For example, in the distillation configuration of Figure 1a, transfer-stream *ABC* contains components *A*, *B,* and *C* in significant quantities, but could also be contaminated by component *D* in acceptably small amounts.

The sequence of separations associated with the distillation configuration of Figure 1a is characterized by five splits, with each split performed in a separate distillation column. The configuration has two transfer-streams with components *B* and *C* only, one produced as the bottom product of distillation column 2, and the other produced as the top product of distillation column 3. To consolidate various columns to synthesize a simpler flow sheet, the condenser and reboiler associated with the two *BC* transfer-streams can be eliminated and the respective distillation columns could be combined. A single *BC* transfer-stream is usually withdrawn from such a combined distillation column. The resulting configuration is shown in Figure 1b. Methods to synthesize multicomponent distillation configurations that result from this kind of column consolidation have been proposed in the literature.[1–11]

The distillation configuration of Figure 1b is a three-column basic configuration[4,10] for the separation of a four-component feed mixture. A basic configuration is a configuration that uses (n − 1) distillation columns, reboilers, and condensers to separate an n-component feed mixture into n pure product streams, with each pure product and submixture recovered from only one location in the configuration. For

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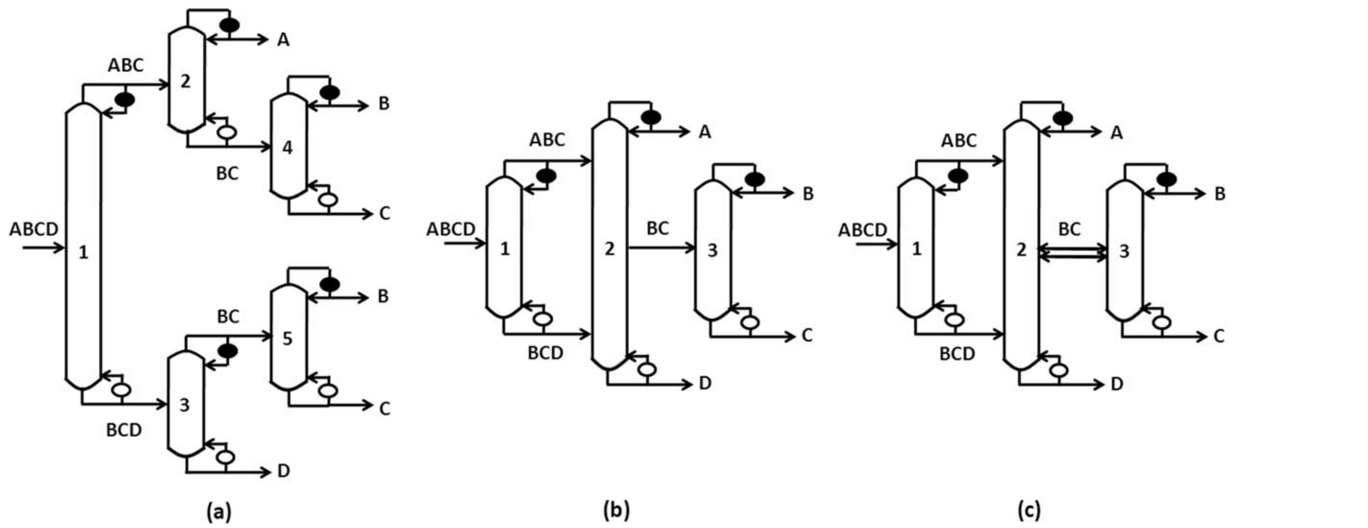

Figure 1. (a) A five-column distillation configuration for the separation of a four-component feed mixture; (b) basic configuration obtained by the consolidation of columns of the configuration in (a)—the [1] configuration; and (c) configuration of (b) with the *BC* one-way communication replaced by a two-way communication set—the [2s] configuration.

the separation of multicomponent mixtures containing four or more components, there are many basic configurations which are obtained by eliminating a reboiler and a condenser from two columns. The eliminated reboiler and condenser are associated with submixtures that contain the same components. For example, Figure 2 shows three other such four-component basic configurations apart from the one shown in Figure 1b. More configurations of this type can be derived by introducing thermal coupling links at some of the reboilers and condensers of these distillation configurations. Such configurations have received considerable attention in the literature, and have been the subject of many studies in the past.[12–15]

It should be observed that, in the configurations of Figures 1b and 2, the mass exchange of submixture *BC* between distillation columns 2 and 3 differs in nature from that of other submixtures. As this net mass exchange of submixture *BC* occurs between intermediate stages of two distillation columns, we term this and other such exchanges as an intermediate exchange (IE). The direction of mass transfer in the transfer-stream associated with the *BC* IE is known *a priori* to be from Column 2 to Column 3, and we call such a transfer-stream a one-way communication.

From the early days of the synthesis of multicomponent distillation configurations, it has been realized that the *BC* IE between distillation columns 2 and 3 of Figures 1b and 2, need not be a one-way communication. As shown in Figure 1c, use of two transfer-streams between the same stages of two distillation columns has been proposed for substantial reduction in overall heat duty of the configuation.[2,3,15] Each transfer-stream between distillation columns 2 and 3 in the figure is shown with arrows pointing in opposite directions and is referred to as a two-way communication. A two-way communication is characterized by the transfer-stream having mass flow in one direction only, but the direction of mass transfer between the two distillation columns it connects is not prespecified and is determined through an optimization exercise. Of the set of two transfer-streams, each

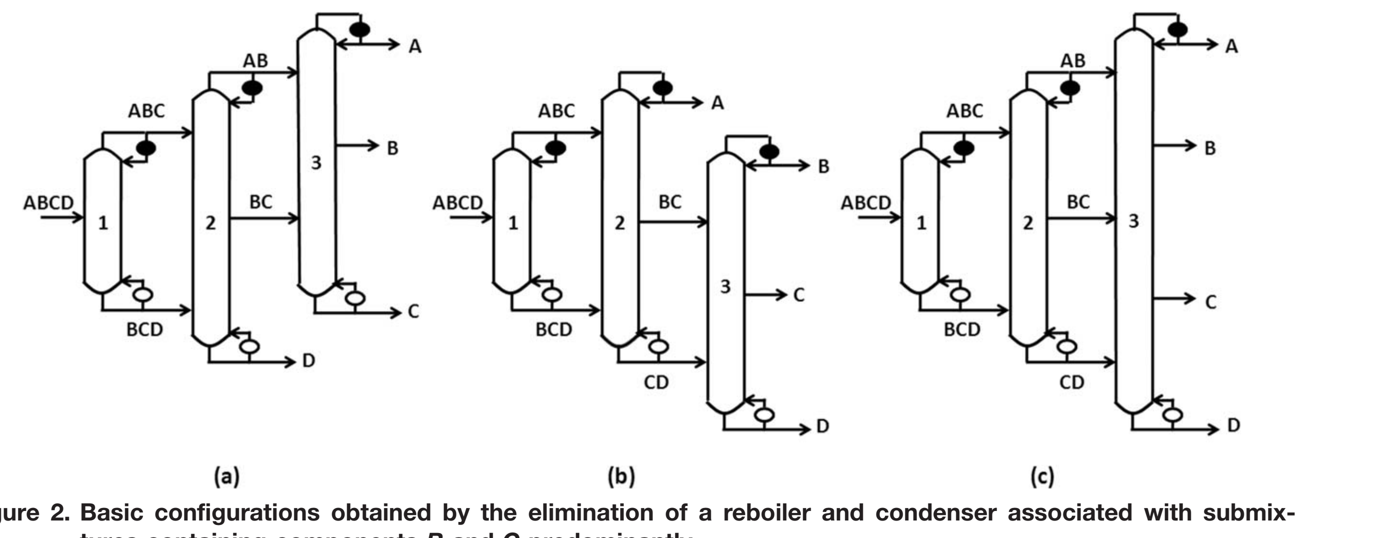

Figure 2. Basic configurations obtained by the elimination of a reboiler and condenser associated with submixtures containing components *B* and *C* predominantly.

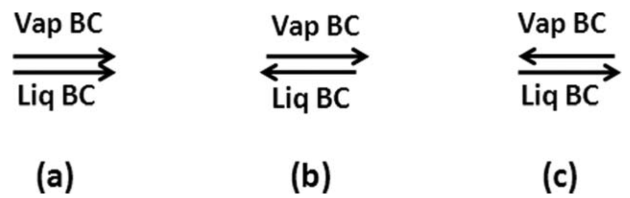

Figure 3. Possible combinations of the *BC* transfer streams that can exist in the two-way communication set, IE_{BC}(2s), for IE between distillation columns 2 and 3 of the [2s] configuration.

represented as a two-way communication, one of them is meant for vapor transfer, whereas the other is meant for liquid transfer. Together, we refer to these two transfer-streams as a two-way communication set. For a given feed separation, the process of optimizing the performance of a configuration like the one in Figure 1c collapses the two-way communication set into one of the two-way communication sets shown in Figure 3, with net mass flow being from Column 2 to Column 3.

We have discussed two kinds of possible IEs for submixture *BC* (a one-way communication and a two-way communication set), between distillation columns 2 and 3, of Figures 1b and 2. We now fix a compact notation for referring to these IEs. In particular, we will henceforth denote a *BC* IE comprising of a one-way communication by $IE_{BC}(1)$ and a two-way communication set by IE_{BC}(2s). The "1" and "2s" in brackets come from the words one-way communication and two-way communication set, respectively.

Furthermore, as the configurations of Figures 1b, c will be the focus of our study in the article, we will use the following notation for easy repeated reference of these configurations. The configurations of Figures 1b, c will henceforth be referred to as the [1] and [2s] configurations. The notation for the two configurations is simply based on the *BC* IE that exists between distillation columns 2 and 3.

In the notation that has been developed so far for IEs and configurations, to refer to a one-way communication that is known to be either in the liquid or vapor phase, the "1" in brackets will be followed by an "L" or "V" accordingly. For example, [1L] configuration would denote the configuration of Figure 1b, with the *BC* one-way communication in the liquid phase.

The purpose of this article is to suggest an alternative manner in which distillation columns in configurations such as the one in Figure 1a for an *n*-component mixture can be consolidated to result in $(n-1)$-column modified configurations. Through examples, we show that the modified configurations often have much lower heat duty and are easy to implement. We discuss the reason behind the improved performance of these configurations. Finally, we make some observations on some additional benefits that the new configurations could potentially offer over the existing ones.

New Column Consolidation Scheme

We focus our attention on one of the intermediate steps during the synthesis of the basic configurations. More specifically, we focus on Step 6 of the method proposed by Shah and Agrawal.[10] At the end of Step 5 of the method, one has all the submixtures that exist in a basic configuration. Situations such as the one shown in Figure 1a often emerge. The

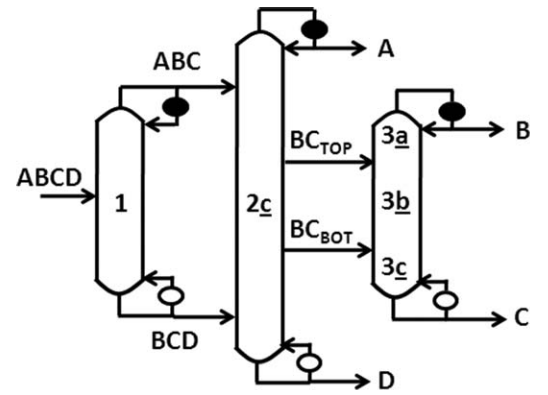

Figure 4. New configuration obtained from the proposed column consolidation scheme—the [1,1] configuration.

bottom of one column produces a submixture containing predominantly the same components as the top of another column. In Step 6, some of the intermediate columns are consolidated to result in a total of $(n-1)$ columns, like the [1] configuration. We now propose that, two such columns be consolidated with the introduction of a distillation section between them and we retain the transfer of two streams, one from the top and the other from the bottom of the new distillation section. Figure 4 shows the resulting new configuration obtained from the one in Figure 1a. The reboiler from the bottom of Column 2, and the condenser from the top of Column 3 of the configuration in Figure 1a have been eliminated. The two columns have been joined together via a new distillation section 2c between them, resulting in the new distillation column 2 of Figure 4. This leads to a dual *BC* IE, namely BC_{TOP} and BC_{BOT}, between distillation columns 2 and 3. Both IEs are one-way communications. In line with our notation, the configuration of Figure 4 will be referred to as the [1,1] configuration in the article. The first "1" in brackets refers to the BC_{TOP} one-way communication, and the second "1" refers to the BC_{BOT} one-way communication. For a four-component mixture, each basic configuration in Figure 2 can be similarly modified with two one-way communications, a BC_{TOP} and a BC_{BOT}, between distillation columns 2 and 3. Such a combination of IEs for submixtures BC_{TOP} and BC_{BOT} in any modified basic configuration will in general be denoted by $IE_{BC_{TOP},\ BC_{BOT}}(1,1)$.

Distillation columns from which two one-way communications, viz. BC_{TOP} and BC_{BOT}, are withdrawn, have two more degrees of freedom than those from which just one *BC* one-way communication is withdrawn. The two additional degrees of freedom appear in the form of the quality of the extra one-way communication, and the ratio in which the net *B* and *C* component flows are distributed between the two one-way communications. Furthermore, as shown in Figure 5, either one or both of the IEs can be made a two-way communication set. The two-way communication sets provide additional degrees of freedom to the new configurations. Comments on such configurations will be made in the latter part of the article.

Performance of the Proposed Configurations

Methodology

In this section, we use a few examples to demonstrate that the newly proposed [1,1] configuration has potential benefits

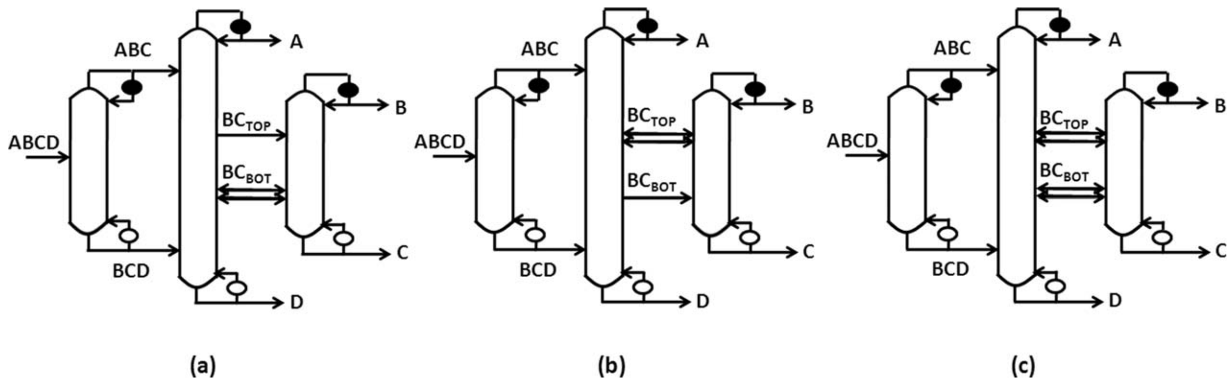

Figure 5. Configuration of Figure 4 with (a) BC_{BOT} converted to a two-way communication set; (b) BC_{TOP} converted to a two-way communication set; and (c) both BC_{TOP} and BC_{BOT} converted to two-way communication sets.

over the [1] and [2s] configurations. We simulated and optimized these configurations using ASPEN Plus®. Sufficient theoretical stages are used in each section of all the distillation columns so that the simulation results are not sensitive to the exact tray locations of the feeds and sidestreams. In all the simulations of the three configurations, the first column is simulated with 65 stages in each section, and the second column is simulated with 70 stages in each section except the new Section 2c̲ of the [1,1] configuration which is provided with 35 stages. Each section in distillation column 3 of the [1] and [2s] configurations has 65 stages, whereas the Sections 3a̲, 3b̲, and 3c̲ of the third column in the [1,1] configuration, respectively, have 45, 45, and 40 stages. All distillation columns are operated at a pressure of two atmospheres. All transfer-streams associated with condensers and reboilers are withdrawn, respectively, in the vapor and liquid phase. All products are collected as pure liquids.

The configurations are simulated for three different saturated liquid feed conditions of an ideal mixture of *A*, *B*, *C*, and *D* shown in Table 1. It is desired that the final product streams are at least 99.5% (in moles) pure in the respective components. The stage-by-stage distillation model RADFRAC in Aspen Plus® is used to simulate and optimize the distillation configurations for minimum overall reboiler duty under constant molar flow conditions. For quick and reliable convergence, the initial guesses for the operating variables of these simulations are obtained from the Global Minimization Algorithm (GMA),[15] which calculates the overall minimum vapor duty requirement for an entire configuration based on Underwood's equations.[16] For configuration [2s], it is determined from GMA[15] that under optimal conditions of operation, feed conditions F1, F2, and F3, respectively, correspond to Figures 3a–c. These feed conditions were chosen to span all three cases of Figure 3.

$$IE_{BC}(1)\ vs.\ IE_{BC_{\mathrm{TOP}},BC_{\mathrm{BOT}}}(1,1)$$

In this section, we draw a general comparison between configurations with the customary $IE_{BC}(1)$ and the proposed $IE_{BC_{\mathrm{TOP}},\ BC_{\mathrm{BOT}}}(1,1)$ by simulating one representative configuration of each kind.

Case study

First, the [1] configuration with a single *BC* IE (Figure 1b) is optimized for feed F2. Although not essential, the *BC* one-way communication between distillation columns 2 and 3 is assumed to be in the liquid phase for the optimization. The optimized values of flow rates for the transfer-streams *ABC* and *BCD*, as well as the vapor duties in the reboilers of distillation columns 1 and 2, from the [1] configuration, are used as fixed input variables during the optimization of the [1,1] configuration (Figure 4). For the optimization of the [1,1] configuration, only the reboiler duty of distillation column 3 is minimized while assuming both one-way communications, BC_{TOP} and BC_{BOT}, to be in the liquid phase. It is found that the vapor duty requirement of distillation column 3 in the [1L,1L] configuration is reduced by 37.8% over that of the [1L] configuration to give an overall saving in vapor duty requirement of 10.1%.

Why does the new configuration have lower heat duty?

It should be noted that an energy penalty is paid in the [1L] configuration of Figure 1b due to remixing of the separated streams. In this configuration, the feed mixture *ABCD* is separated into two submixtures, *ABC* and *BCD*, in distillation column 1. The relative concentration of *B* with respect to *C* is higher in *ABC* than in *BCD*. By withdrawing a single *BC* transfer-stream from distillation column 2, the advantage of the relative separation between *B* and *C* in the two transfer-streams, *ABC* and *BCD*, is somewhat eliminated. Thus, the configuration incurs a penalty due to remixing, and an increased heat duty is needed in the distillation column 3. This remixing is observed even in the presence of a two-way communication set between distillation columns 2 and 3. It should be noted that for the special case of a fully thermally coupled configuration such as the one derived from Figure 2c, also known as the Petlyuk configuration, in which all the splits are transition splits, Halvorsen and Skogestad[17] showed that this remixing is absent for ideal mixtures.

In the new [1L,1L] configuration, there are two feeds, *ABC* and *BCD*, to the distillation column 2, and the distillation column is assigned two splits. The first split is characterized by the separation of *A* from *B* and *C* that is in submixture *ABC*. The second split is characterized by the separation of *D* from *B* and *C* that is in submixture *BCD*. These two splits dictate the minimum vapor flow requirement in the reboiler of the distillation column. This is also true for distillation column 2 of the [1L] configuration. However, in the distillation column 2 of the [1L,1L] configuration, with the same vapor that is generated in its reboiler, it is interesting to note that the intermediate section between the two IEs, BC_{TOP} and BC_{BOT}, can be exploited to perform some additional separation. In the intermediate section, there

Table 1. Three Feed Conditions used for Simulations

Feed Conditions	Component Flow (kmol/h)				Relative Volatility		
	A	B	C	D	α_{AB}	α_{BC}	α_{CD}
F1	25	25	25	25	2.5	2.5	2.5
F2	20	30	30	40	1.5	2	1.5
F3	25	10	10	10	1.5	1.75	1.5

is some natural separation of B from C, and there is a net flow of B in the upward direction and a net flow of C in the downward direction. The flow rates of BC_{TOP} and BC_{BOT} transfer-streams determine the direction of net mass flow in the intermediate section.

In the case study example, it is observed that the intermediate section is accompanied by a net flow of 6.98 kmol/h of Component B in the upward direction, and a net flow of 3.31 kmol/h of Component C in the downward direction. This can be verified by comparing individual Component B and C flows in the transfer-streams that enter and leave distillation column 2 from the data given in Table 2. It also follows from the table that the BC_{TOP} transfer-stream is 95.8% rich in Component B, whereas the BC_{BOT} transfer-stream is 83.9% rich in Component C. The two transfer-streams are fed to the next distillation column at appropriate locations which makes the overall separation of B from C in the third distillation column less energy intensive compared to that of the [1L] configuration.

It should be noted that the above phenomenon is observed when suitable flow rates in the two one-way communications, BC_{TOP} and BC_{BOT}, are chosen. If, for instance, in the [1L,1L] configuration, the flow rate of BC_{TOP} transfer-stream is less than the Component B flow in transfer-stream ABC, then in such a case, the intermediate section is characterized by net mass flow and net component flows in the same downward direction. Similarly, if the flow rate of BC_{BOT} transfer-stream is less than the Component C flow in transfer-stream BCD, then the intermediate section is characterized by net mass flow and net component flows in the same upward direction. However, even in such cases, it should be noted that the extent of remixing can be lower compared to the case where a single BC transfer-stream is withdrawn.

Thus, in general, from the overall heat duty perspective, we expect the configurations with $\mathrm{IE}_{BC_{TOP},\ BC_{BOT}}(1,1)$ to be often superior, but never inferior to configurations with $\mathrm{IE}_{BC}(1)$, because $\mathrm{IE}_{BC}(1)$ can be construed as a special case of $\mathrm{IE}_{BC_{TOP},\ BC_{BOT}}(1,1)$ where one of either BC_{TOP} or BC_{BOT} is set to zero. This trend is also demonstrated in Table 3 which presents the overall optimal total vapor duty requirements of the [1L] and [1L,1L] configurations for each of the three feed conditions. The vapor duty requirement of the [1L,1L] configuration is found to be lower than that of the [1L] configuration by 12.2, 10.3, and 8.2%, respectively, for feed conditions F1, F2, and F3.

Table 2. Component Flows in all the Transfer-Streams Entering and Leaving Distillation Column 2 of the [1L,1L] Configuration (Figure 4) for the Case Study

		Submixture Streams					
		ABC	BCD	A	D	BC_{TOP}	BC_{BOT}
Component mole flow (kmol/h)	A	20.00	0	20.00	0	0	0
	B	17.49	12.51	0	0	24.47	5.53
	C	4.38	25.62	0	0.04	1.07	28.89
	D	0.06	39.94	0	39.96	0.01	0.03
Total flow (kmol/h)		41.94	78.06	20.00	40.00	25.55	34.45

Table 3. Operational Specifications for Configurations [1L] and [1L,1L]

Feed		Flow Rates in kmol/h for Distillation Configuration [1L]	[1L,1L]	Heat Duty Savings (%)
F1	ABC	36.16	33.39	
	V_1	44.58	48.96	
	V_2	73.84	78.38	
	V_3	59.64	29.03	
	Total vapor duty	178.06	156.37	12.2
F2	ABC	41.30	41.40	
	V_1	75.56	77.28	
	V_2	169.51	170.57	
	V_3	91.16	53.69	
	Total vapor duty	336.23	301.54	10.3
F3	ABC	32.25	32.30	
	V_1	50.75	51.18	
	V_2	60.63	61.41	
	V_3	36.86	23.48	
	Total vapor duty	148.24	136.07	8.2

V_1, V_2, and V_3 are the optimal vapor requirements in the reboilers of distillation columns 1, 2, and 3, respectively.

$IE_{BC}(2s)\ vs.\ IE_{BC_{TOP},BC_{BOT}}(1,1)$

In this section, we draw a general comparison between configurations with $\mathrm{IE}_{BC}(2s)$ and $\mathrm{IE}_{BC_{TOP},\ BC_{BOT}}(1,1)$ by simulating one representative configuration of each kind. For each feed given in Table 1, the heat duty of the [2s] configuration is compared with the dual BC IE case of the [1,1] configuration. In the [1,1] configuration, we assume that BC_{TOP} is saturated liquid and BC_{BOT} is saturated vapor. The results are summarized in Table 4. The total vapor duty requirement of the [1L,1V] configuration for the three feed conditions, F1, F2, and F3 is, respectively, lower by 9.1, 6.4, and 6.4% than that of the [2s] configuration. Moreover, the heat duty of the [1L,1V] configuration can be further reduced by optimally deciding the phase of the two one-way communications, BC_{TOP} and BC_{BOT}.

Also, similar energy savings are obtained in the [1,1] configuration for all the three feed conditions when the phase of BC_{TOP} is fixed to vapor and that of BC_{BOT} to liquid. Furthermore, for a wide range of flow rates of the transfer-stream BC_{TOP} (and, therefore, BC_{BOT}), the vapor duty requirement of the [1L,1V] and [1V,1L] configurations is lower than that of the [2s] configuration. These attributes show that the proposed [1,1] configuration often brings in operational flexibility.

As noted earlier, for configuration [2s], the optimal two-way communication set for feeds F1, F2, and F3 is, respectively, the combination of transfer-streams shown in Figures 3a, b, c. Thus, our simulations show that the energy savings due to two one-way communications, BC_{TOP} and BC_{BOT}, can potentially be observed irrespective of the kind of two-way communication set that makes up the single BC IE between distillation columns 2 and 3.

Table 4. Operational Specifications for Configurations [2s] and [1L,1V]

Feed		Flow Rates in kmol/h for Distillation Configuration [2s]	[1L,1V]	Heat Duty Savings (%)
F1	*ABC*	36.8	49.96	
	V_1	45.44	64.85	
	V_2	73.23	57.59	
	V_3	34.55	16.83	
	Total vapor duty	153.22	139.27	9.1
F2	*ABC*	41.81	41.50	
	V_1	76.39	77.12	
	V_2	169.70	170.15	
	V_3	52.85	32.47	
	Total vapor duty	298.94	279.74	6.4
F3	*ABC*	32.21	32.22	
	V_1	50.83	51.24	
	V_2	50.12	62.06	
	V_3	44.18	22.57	
	Total vapor duty	145.13	135.87	6.4

V_1, V_2, and V_3 are the optimal vapor requirements in the reboilers of distillation columns 1, 2, and 3, respectively.

Although we have observed energy savings in our simulations, in general, replacing an $IE_{BC}(2s)$ in configurations like the [2s] configuration with $IE_{BC_{TOP},\ BC_{BOT}}(1,1)$, like the [1,1] configuration, may not always bring in energy savings. This is mainly because a two-way communication set allows sharing of the vapor generated in the reboiler of distillation column 3 with distillation column 2, whereas a one-way communication does not. Thus, either one or both of the one-way communications of $IE_{BC_{TOP},\ BC_{BOT}}(1,1)$ can be converted to a two-way communication set. From an overall heat duty perspective, we expect such configurations with $IE_{BC_{TOP},\ BC_{BOT}}(1,2s)$, $IE_{BC_{TOP},\ BC_{BOT}}(2s,1)$, and $IE_{BC_{TOP},\ BC_{BOT}}(2s,2s)$ like those in Figure 5 to be often superior, but never inferior to configurations with $IE_{BC}(2s)$, like the [2s] configuration. This is because $IE_{BC}(2s)$ can be construed as a special case of $IE_{BC_{TOP},\ BC_{BOT}}(1,2s)$ or $IE_{BC_{TOP},\ BC_{BOT}}(2s,1)$, or $IE_{BC_{TOP},\ BC_{BOT}}(2s,2s)$.

Additional observations on single vs. dual BC IE

An attractive feature of the proposed configurations can be recognized by comparing the vapor duty requirements of the [2s] and [1L,1L] configurations (from Tables 3 and 4). The vapor duty requirement of the [1L,1L] configuration for feed conditions F1 and F2, is more than that of the [2s] configuration by only 2.1 and 0.9%, respectively, whereas, for feed condition F3, it is less by 6.2%. It is well known that configurations with liquid transfers between distillation columns are preferred from an operating perspective than configurations with vapor transfers between distillation columns. Thus, the proposed configurations have the potential to simultaneously offer operationally attractive and energy efficient options for onsite implementation when compared to the optimal operation of the customary basic distillation configurations.

Conclusions

Typically, two distillation columns producing submixtures having the same components from the stripping and rectifying sections are combined into a single distillation column. A one-way communication or a two-way communication set containing the same components is withdrawn from the resulting distillation column. This kind of column consolidation, which results in a single submixture IE, is known to simultaneously reduce capital and operating costs significantly and thus, configurations with such distillation columns have received considerable attention in the literature. Especially, this is true of the well-studied basic configurations. However, combining distillation columns in the above manner generally leads to losses due to remixing of the separated components. Among four-component configurations, the remixing losses have been shown to be absent only for the fully thermally coupled Petlyuk configuration. It seems that the column stacking scheme used for the fully thermally coupled Petlyuk configuration has simply been extended to the other configurations as well, and the ensuing remixing losses have not been addressed.

In this article, simple modifications to the existing configurations are suggested. The new modified configurations presented in the article differ from the existing ones due to the introduction of extra intermediate sections and the dual IE of the associated submixture. It was noted that, by virtue of reduction in remixing of the separated components and some natural useful separation between the associated components in the introduced intermediate section, the proposed configurations are largely less energy intensive than the existing basic configurations. The energy saving potential of such modifications has been demonstrated for one basic configuration. Furthermore, the studied modified configuration is found to be more operable, flexible, and energy efficient than its parent basic configuration. We expect similar benefits to hold for this entire general class of new configurations over the well-known basic configurations. Thus, the inclusion of this new class of configurations in the search space of distillation configurations is necessary. Due to the creation of additional sections in the new configurations, a conclusive comparison with the basic configurations based on overall costs cannot be easily made. But, it is worth noting that the creation of additional sections in the new configurations may not necessarily lead to an increase in the total number of stages. Thus, a detailed evaluation of the expanded search space based on the desired parameters like overall costs, total heat duty, controllability of the configuration, and so forth for any given feed is necessary.

The dual-submixture IE between distillation columns in the proposed configurations can comprise of any combination of one-way communications and two-way communication sets. The two IEs for a submixture, both comprising of only one-way communications not only always results in a lower heat duty than the customary only one one-way communication, but often provides lower heat duty when compared to the single two-way communication set. Of course, when at least one of the two one-way communications is converted to a two-way communication set, the resulting configuration always has lower heat duty than the corresponding configuration with only one IE between distillation columns. It is also of interest to note that the simplest dual IE for a submixture, both comprising of only liquid one-way communications, can potentially offer simultaneous energy efficient and more operable options for onsite implementation than any single IE of that submixture. The above comparison between a dual and a single IE for a submixture is not limited to only basic configurations. It should thus be beneficial to incorporate a dual IE for a submixture in any configuration, wherever applicable.

A natural question that arises in the context of the article is whether more than two IEs of a submixture between distillation columns is beneficial from a heat duty perspective. In a subsequent article, we show that no more than two IEs of a submixture are needed to obtain maximum energy savings in all the pertinent cases.

The article presented an elaborate account on the usage of an intermediate section when the transfer-streams associated with the eliminated reboiler and condenser were binary submixture streams. The ideas discussed here are easily extendable to ternary and higher component submixtures as well. Such configurations can be conveniently drawn by modifying the consolidation of columns in Step 6 of the Shah and Agrawal's method.[10] A detailed study on this topic will be presented in a future work.

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