Thermally Coupled Distillation with Reduced Number of Intercolumn Vapor Transfers

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The classical thermal coupling between two distillation columns requires two-way communication whereby both vapor and liquid streams are transferred in opposite directions between one specific location in each of the distillation columns. A general framework is presented whereby this classical two-way thermal coupling is converted to a one-way liquid-only transfer. This conversion is achieved by adding one or more distillation sections and a reboiler and/or a condenser with each added section. The resulting equivalent configurations coproduce some of the component product streams from more than one distillation column and are quite flexible. Finally, the techniques developed for this framework are applied to reduce the heat duty of the well-known conventional distillation column configurations with no thermal coupling.

Introduction

Thermally coupled distillation column configurations for multicomponent distillations have been known for quite some time. Examples of ternary distillation can be found in King (1980). Some of the thermally coupled schemes are shown in Figure 1. The side stripper (SS) and side rectifier (SR) schemes have been used for a long time in a number of industrial applications. The fully-coupled scheme (FC-1) of Figure 1c was suggested by Petlyuk et al. (1965) and is often referred as a Petlyuk column. The side stripper with a direct liquid connection (SL) and side rectifier with a direct vapor connection (RV) were suggested recently by Agrawal and Fidkowski (1999a). In these figures, and throughout this article, components in a mixture are ranked according to their relative volatility, that is, for feed mixture ABC, A is the most volatile component and volatility decreases in successive order, with C being the least volatile.

For an n-component mixture, conventional distillation configurations use $n-1$ simple distillation columns. A bottom reboiler and a top condenser is used with each of the distillation columns, and a total of $2(n-1)$ reboilers and condensers are needed. Each distillation column has one feed and produces an overhead and a bottom product stream. For a ternary separation, two well-known conventional distillation configurations are called direct and indirect (Biegler et al., 1997; King, 1980; Agrawal and Fidkowski, 1998a). Each of these configurations use two distillation columns and four boilers and condensers and are shown in Figures 2a and 2b. A nonconventional configuration called prefractionator is also shown in Figure 2c. This prefractionator configuration does not use any thermal coupling and produces all three product streams from the same column.

The process of thermal coupling between the two distillation columns reduces the total number of reboilers and condensers (Petlyuk et al., 1965; Triantafyllou and Smith, 1992; Agrawal, 1996). A thermal coupling requires a two-way communication between the two columns. In a two-way communication mode, when a vapor stream is sent from one column to another column, then a return liquid stream is implemented between the same locations of the two columns. This means, for example, that one condenser can provide the condensing duty for the main column and for the side stripping column (Figure 1a) or one reboiler can provide the boiling duty for the main column and for the side rectifying column (Figure 1b). Comparison of Figure 1 and Figure 2 clearly shows that for each thermal coupling, the total number of reboilers and condensers decrease by one.

The benefit of thermal coupling on the total heat demand of multicomponent distillation has been studied extensively (Lockhart, 1947; Petlyuk et al., 1965; Tedder and Rudd, 1978; Fidkowski and Królikowski, 1987; Glinos and Malone, 1988; Carlberg and Westerberg, 1989a,b; Triantafyllou and Smith, 1992). The thermally coupled distillation column configurations shown in Figure 1 as a family are found to substantially reduce the total heat demand for ternary mixtures when

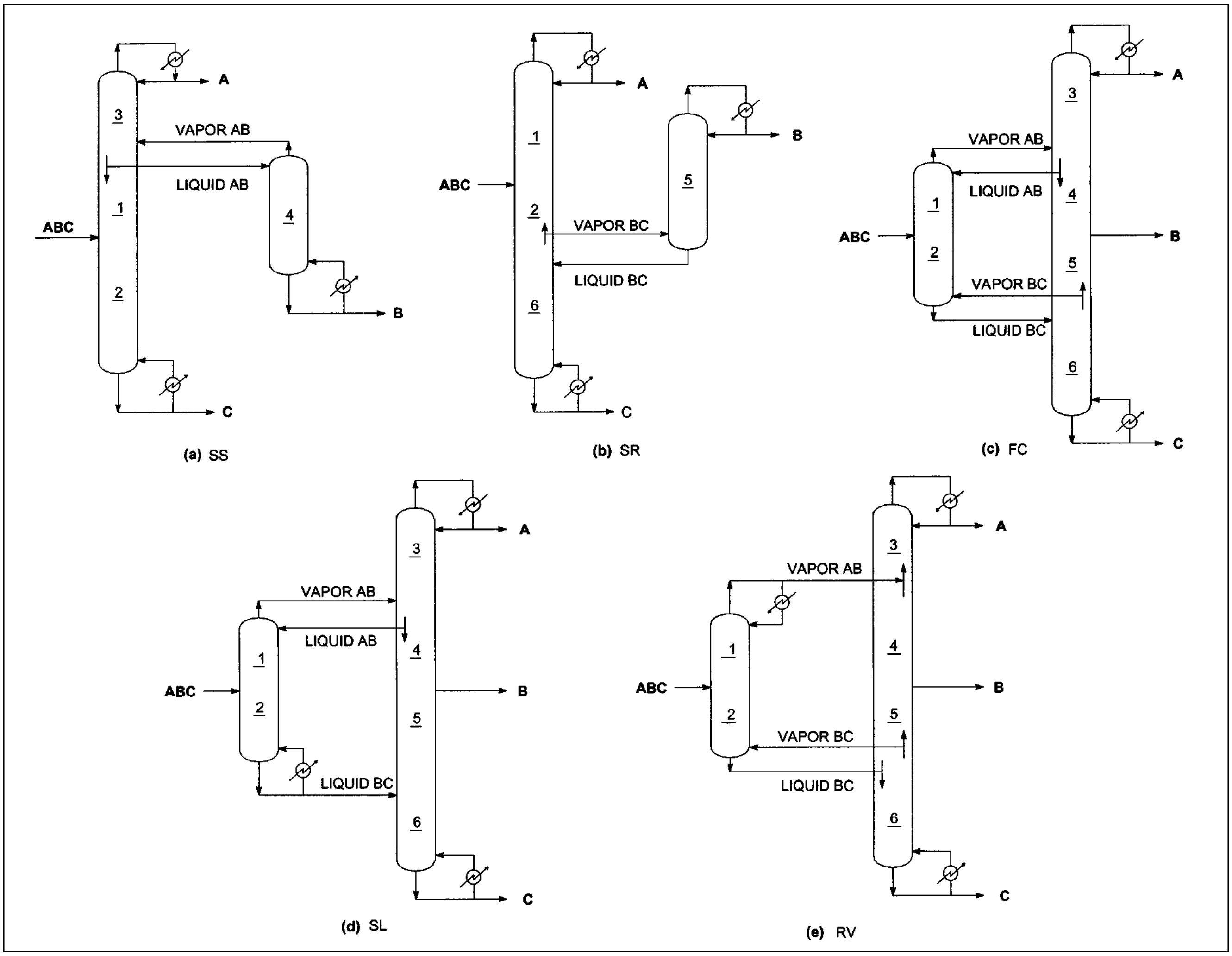

Figure 1. Known thermally coupled ternary distillations.

(a) SS: side stripper; (b) SR: side rectifier; (c) FC-1: fully-coupled; (d) SL: side stripper with direct liquid connection; (e) RV: side rectifier with direct vapor connection.

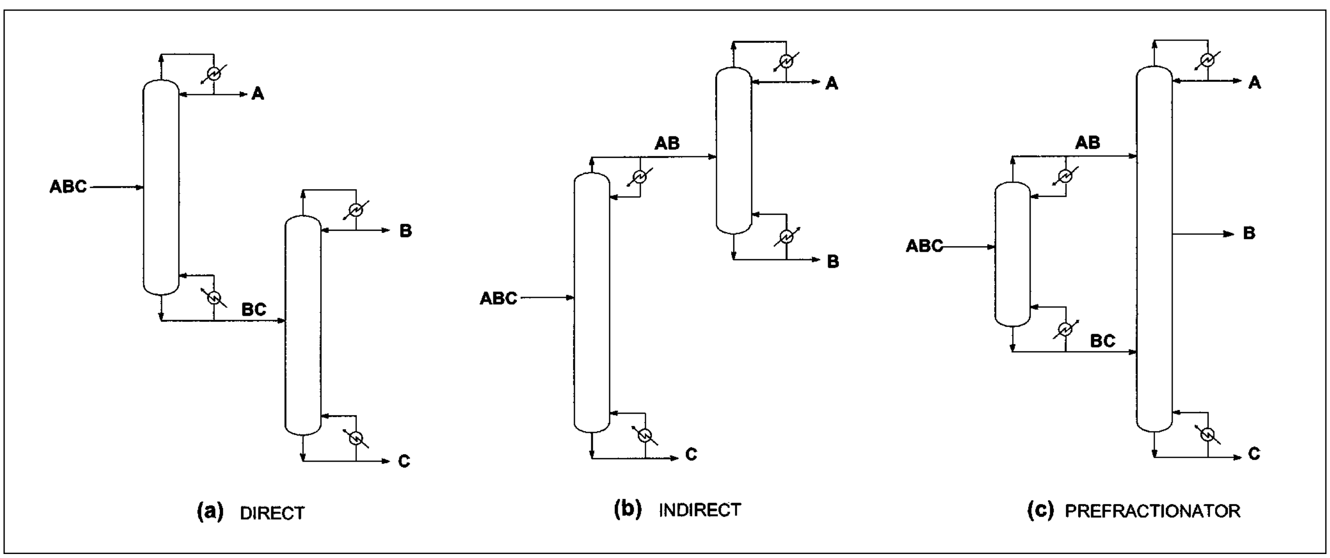

Figure 2. Ternary distillation column configurations without any thermal coupling.

compared to the conventional direct and indirect configurations of Figures 2a and b. It is well known that for ternary distillation over a wide range of relative volatilities and feed compositions, the fully-coupled configuration can require 10 to 50% less heat duty than the two conventional schemes (Triantafyllou and Smith, 1992; Agrawal and Fidkowski, 1998b). However, when the heat duty of the fully-coupled configuration in Figure 1c is compared with the other four thermally coupled configurations in Figure 1, the range of feed conditions for which substantial heat duty reduction can be obtained is limited (Agrawal and Fidkowski, 1999a). The minimum vapor flow for the fully-coupled system is significantly lower than for the other thermally coupled configurations if the relative volatilities between A/B and B/C are similar and the feed mixture contains comparable amounts of all three components. Furthermore, the smaller the values of both the relative volatilities, the greater the relative benefit of the fully-coupled configuration.

Recently, it has been shown that the thermodynamic efficiency of thermally coupled distillation columns can be increased by incorporating intermediate temperature reboilers and condensers to accept/reject heat at intermediate temperatures (Agrawal and Fidkowski, 1999b). Such modified side rectifier or side stripper configurations retain the low vapor flow of the original configurations shown in Figure 1. They have the same total number of reboilers and condensers as do the direct or indirect split, but they provide higher thermodynamic efficiencies than the corresponding direct or indirect split configurations.

In spite of all the energy benefits, thermally coupled columns have not found wide application, especially those configurations in which a column has more than one two-way communication with the other columns. Thus, while side stripper and side rectifier configurations of Figure 1 are used, it is rare to find an industrial application of the fully-coupled configuration of Figure 1c. Fully-coupled configurations for mixtures with more than three components have an even greater number of two-way communications between the distillation columns (Sargent and Gaminibandara, 1976; Agrawal, 1996, 1999). Generally, the vapor transfers associated with multiple two-way communications are perceived to be the source of operating problems. The associated vapor transfers also led Linnhoff et al. (1983) to conclude that for ternary thermally coupled distillations, the two distillation columns need to operate at the same pressure. Therefore, the flexibility of choosing different pressures within different columns to facilitate heat integration is lost.

It can be useful to draw configurations that are equivalent to the thermally coupled configurations, but which have no intercolumn vapor transfers. This would convert a thermally coupled two-way communication to a one-way communication with only liquid transfer between columns. The only such example in the currently available literature is due to Erickson (1989). For cryogenic air separation of N_2, Ar, and O_2, he suggested extending the side Ar rectifier and provide only liquid feed from the low-pressure column to the argon column. The major thrust of Erickson's work was energy savings. Therefore, along with this modification, a number of other energy saving modifications that were thought to be key to the feasibility of the overall configuration were also suggested. These additional modifications brought complexity and operational difficulty to the distillation scheme. As a result, the proposed scheme has drawn only little attention.

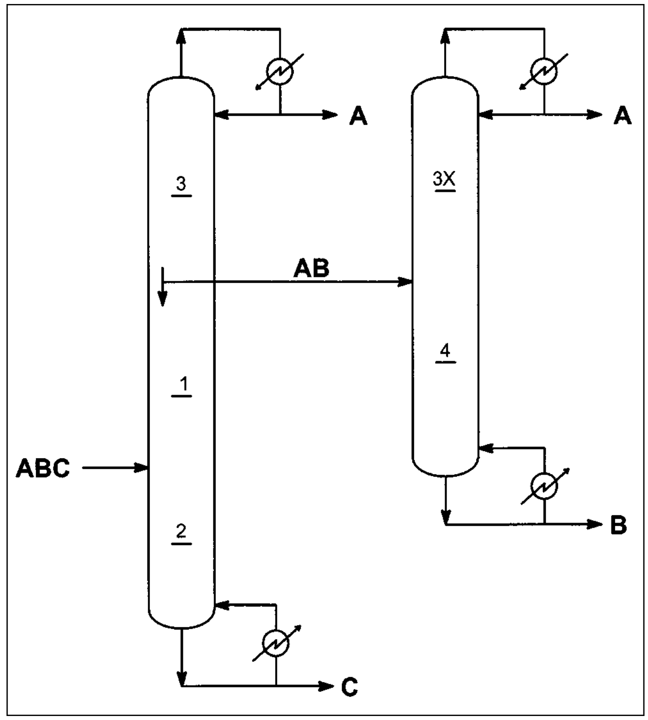

Figure 3. Equivalent side stripper configuration with no intercolumn vapor transfer.

In this article we present a general framework to achieve thermal coupling between distillation columns without any intercolumn vapor transfers. Configurations will be introduced first for ternary mixtures and then later extended to any $n-$component mixture. Finally, the lessons learned will be discussed in the context of conventional multicomponent distillation schemes.

Ternary Distillations

First consider the side stripper configuration shown in Figure 1a. In this configuration, a predominantly binary vapor stream containing components A and B from the top of distillation section 4 (the side stripper column) is fed between the distillation sections 1 and 3 of the feed column. This vapor stream ascends in distillation section 3 to be distilled. Now consider the side stripper configuration operating at the minimum vapor flow. Under these conditions, there will be a pinch between sections 1 and 3 and vapor streams from sections 1 and 4 will be of the same composition. Now it is easy to imagine a case where the vapor streams from distillation sections 1 and 4 are not mixed, but ascend in parallel in distillation section 3. This leads to the configuration shown in Figure 3. A distillation section 3X is added above distillation section 4, and all of the vapor from distillation section 4 is sent to this section. A separate condenser is shown for distillation section 3X. Both distillation sections operate at the same L/V as in the configuration of Figure 1a. Now only a liquid stream is transferred from the feed column to a location between sections 3X and 4. The minimum vapor flow rates of the configurations of Figure 1a and 3 are same and, therefore, the configuration in Figure 3 can be thought of as equivalent to the original side stripper configuration of Figure 1a.

Similarly, an equivalent structure for the side rectifier configuration of Figure 1b can also be drawn. First, a thermodynamically identical side rectifier configuration can be created by moving distillation section 6 below distillation section 5, as shown in Figure 4a (Carlberg and Westerberg, 1989a). The vapor from the top of distillation section 6 is still divided between distillation sections 2 and 5, and liquid streams from distillation sections 2 and 5 are combined and fed to distillation section 6. In order to eliminate the vapor connection between the two columns, a distillation section 6X is added below distillation section 2 (Figure 4b). A reboiler is used at the bottom of this section and the same amount of vapor is transferred between distillation sections 6X and 2 as was between distillation sections 6 and 2. Both distillation sections 6 and 6X operate at the same L/V. The amount of liquid stream transferred between the two columns is decreased. Once again, under minimum vapor flow conditions, the configurations in Figure 1b and 4b would each require the same total vapor flow and can be thought of as equivalent configurations. We have recently found that the equivalent configurations in Figures 3 and 4b have been independently suggested in a soon to be published book by Doherty and Malone (2001).

Once the equivalent configurations for side stripper and side rectifier with no intercolumn vapor transfers have been drawn, the concept can be extended to the three other thermally coupled schemes of Figure 1. For the fully-coupled configuration, either one or both of the two-way communications can be converted to one-way liquid-only communications. The resulting configurations are shown in Figure 5. The configuration in Figure 5a results when the two-way communication at the top of the feed column is converted to liquid-only transfer. The configuration in Figure 5b is obtained by moving distillation section 6 under the distillation section 2 and is thermodynamically identical to the configuration in Figure 5a. Similarly, configurations in Figures 5c and 5d are obtained by converting the bottom two-way communication of the feed column in Figure 1c to liquid-only transfer. The configuration in Figure 5e results when both the two-way communications are converted to liquid-only transfers. The two-way communications in configurations of Figures 1d and 1e are readily converted to the liquid-only transfer configurations in Figures 6a and 6b. Note that the configuration in Figure 6b is not exactly equivalent to the one in Figure 1e, because in order to eliminate all vapor transfers, a liquid rather than a vapor mixture stream AB is transferred from the condenser on top of the feed column to the next column.

It is clear that the conversion of a two-way thermal coupling to liquid-only transfer comes at the cost of an additional distillation section and a reboiler or condenser. Therefore, the operational benefit of such a conversion comes with an added capital cost. The side stripper and side rectifier configurations require only one two-way communication and are used in industrial applications. Therefore, the equivalent fully-coupled configurations in Figures 5a−5d which have only one two-way communication may be able to meet all ease of operation needs. This will particularly be true when the heat

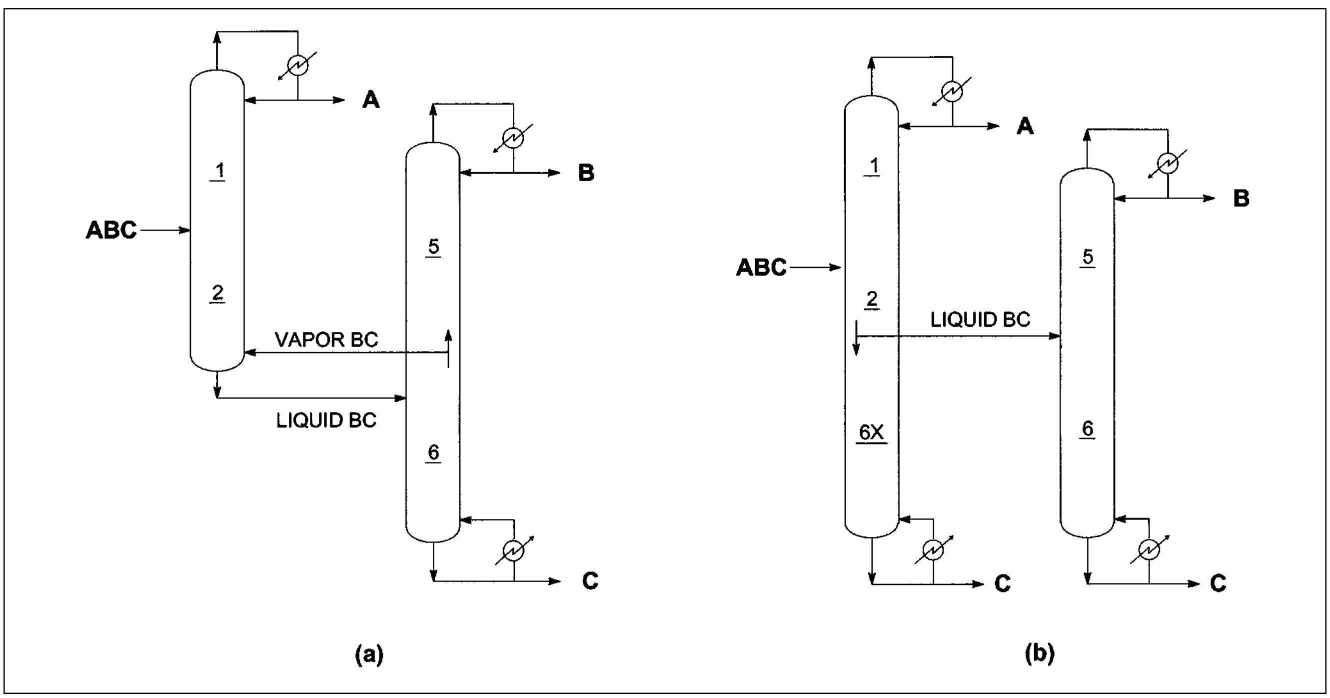

Figure 4. (a) Thermodynamically identical side rectifier; (b) resulting equivalent configuration with no intercolumn vapor transfer.

duty need of the fully-coupled configuration is substantially lower than all the other thermally coupled schemes of Figure 1.

The additional reboiler or condenser in the equivalent thermally coupled configurations does not alter the total heat exchange duty. The heat exchanger duty of one reboiler or condenser in the original thermally coupled configurations of Figure 1 is simply divided between the two reboilers or condensers used in Figures 3 through 6. When feasible, the two reboilers or condensers performing the same function in the equivalent thermally coupled configurations may be combined in one heat exchanger, as shown in Figures 7a and 7b. In Figure 7a, vapor from the top of the distillation columns are condensed in different passages of the same heat exchanger. This may be particularly feasible if the columns are operating at similar pressures and produce top vapor streams of nearly the same composition. Similarly, liquid streams from each column are boiled in separate passages of the same heat exchanger against a common heat source. Another alternative is shown in Figure 7b. Here the vapor streams exiting from each of the distillation columns are first combined and then condensed in one heat exchanger. The condensed liquid can either be pumped or fed through gravitational head to each of the distillation columns as reflux. Similarly, the bottom liquid streams from each of the distillation columns are combined and then vaporized in one heat exchanger. The vapor stream is then fed to each of the distillation columns. For the ease of operation, the pressure of each of the liquid streams or the combined liquid stream may be increased through pumping or gravitational head prior to the vaporization. This will provide the needed pressure drops to regulate the vapor flow to each distillation column. Two other options can be created from Figures 7a and 7b by choosing a condenser from one and a reboiler from the other configuration. The options in Figure 7 provide a means to cut the capital cost of the equivalent thermally coupled configurations.

Once all the intercolumn vapor transfers have been eliminated the equivalent thermally coupled configurations are

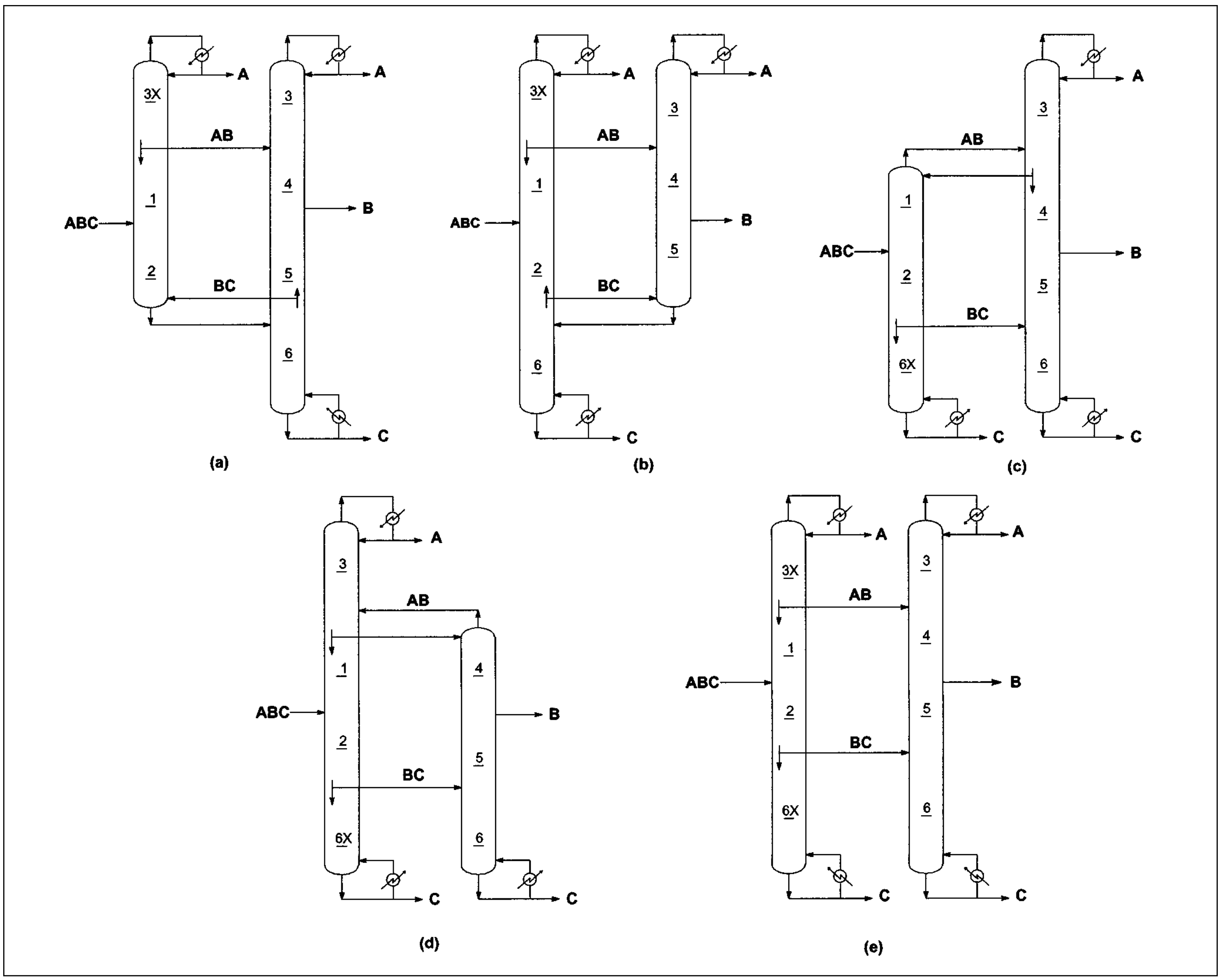

Figure 5. Equivalent fully-coupled configurations.

(a)–(d) only one intercolumn vapor transfer; (e) no intercolumn vapor transfer.

amenable to heat integrations as discussed by Linnhoff et al. (1983). Thus, the two distillation columns in the configurations of Figures 3, 4b, 5e and 6 can be operated at different pressures to match the heat integration within a plant. Specifically, if needed, the pressures in each column may be adjusted such that neither column operates across the pinch.

Even though the original and the equivalent thermally coupled configurations provide identical minimum vapor flow under the pinched conditions, the two may provide slightly different results under unpinched conditions when the vapor flows are higher than the minimum vapor requirements. This could result due to slightly different mixing losses at the transfer points between the distillation columns in the two configurations. Furthermore, the equivalent thermally coupled configurations in Figures 3–6 provide much greater operational flexibility than do those of Figure 1. The similar distillation sections in the two different columns may be operated at different L/Vs, and may contain different numbers of trays or packed height and thus produce products of different purities. For example in Figure 3, similar distillation sections 3 and 3X may operate at different L/Vs, and may contain a different number of trays and produce distillate streams of different purities. This can be especially attractive when only a fraction of the distillate is needed at very high purity.

It is known that the thermodynamic efficiency of the fully-coupled configuration in Figure 1c is often lower than that of the other configurations (Agrawal and Fidkowski, 1998b). This is because all the heat is provided at the highest temperature of component C and is rejected at the lowest temperature of component A. The thermodynamic efficiency of thermally coupled configurations can be substantially increased, however, by incorporating intermediate temperature reboilers and condensers to accept/reject heat at the temperatures of boiling/condensing binary mixtures (Agrawal and Fidkowski, 1999b). Similarly, the thermodynamic efficiency of the equivalent thermally coupled configurations with reduced or no intercolumn vapor transfers can be increased through judicious use of intermediate temperature reboilers and condensers to accept/reject heat at the temperatures of boiling/condensing binary mixtures and/or intermediate component B. An easier place to incorporate such intermediate reboilers and condensers would be at the locations where streams are transferred from one distillation column to another.

Extension to More Than Three Components

The concept of converting a two-way thermal coupling to a liquid-only transfer between the columns can be applied to the distillation of mixtures containing more than three components. Fully-coupled configurations for a four-component mixture are shown in Figure 8. For a four-component mixture, there are two families of fully-coupled configurations. The first one is the sequential column arrangement shown in Figure 8a (Sargent and Gaminibandara, 1976) and the second one is satellite column arrangement shown in Figure 8c (Agrawal, 1996). The equivalent configurations for the se-

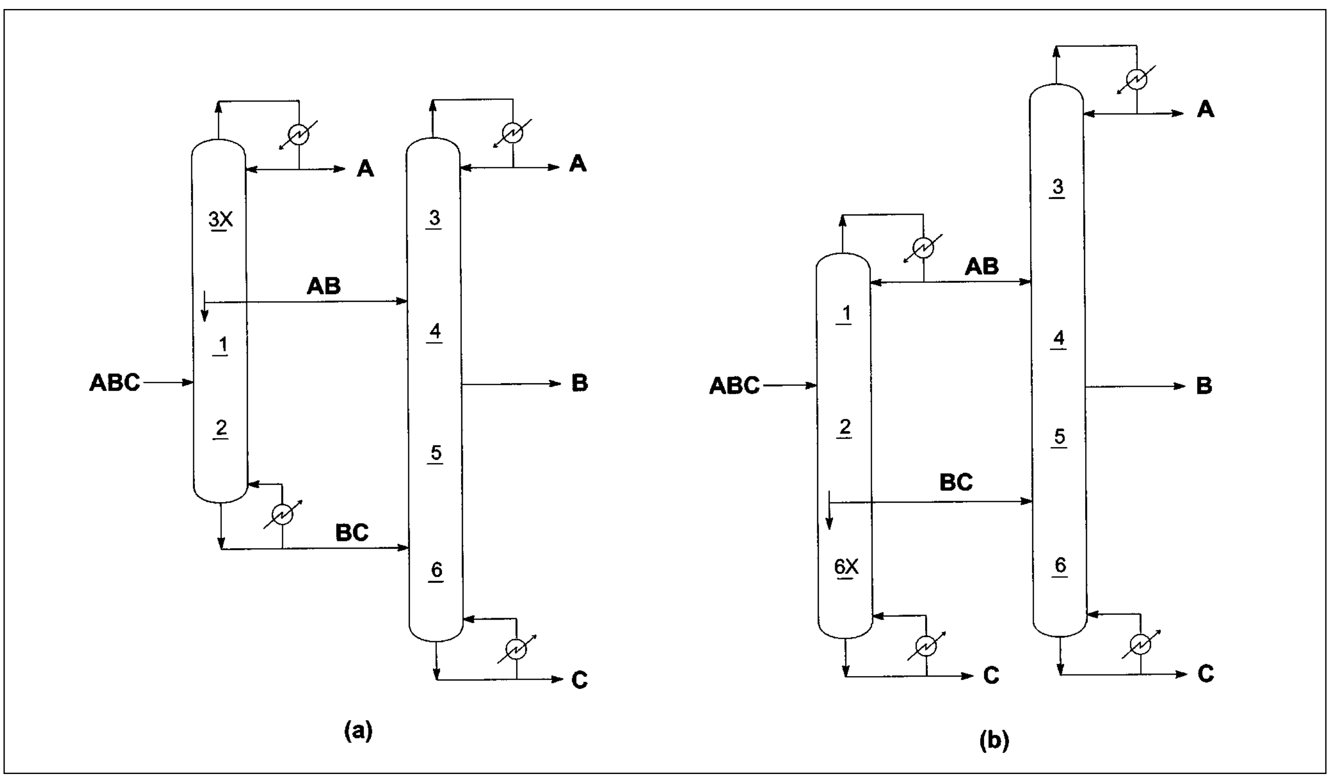

Figure 6. Equivalent configurations with no intercolumn vapor transfer.

(a) Side stripper with direct liquid connection; (b) side rectifier with direct liquid connection.

quential column arrangement is shown in Figure 8b. The thermal coupling between distillation sections 3, 7, and 8 is similar to that for the ternary side stripper. It can be made a liquid-only transfer by adding distillation section 7X on top of distillation section 3. The two-way communication between distillation sections 1, 3, and 4 is converted to liquid-only transfer by adding two distillation sections 3X and 7XX on top of distillation section 1. The two distillation sections are needed to allow for the transfer of liquid stream AB from the first column to the final column and to preserve equivalency between the top two sections of the first and second columns. Similarly, the two-way communications in the bottom sections can also be converted to one-way liquid-only transfers. The equivalent configuration for the satellite column arrangement in Figure 8c is shown in Figure 8d.

Notice that the vapor and liquid transfers of binary mixture BC between the two columns could not be converted to one-way communication by the proposed method. It seems that the method developed so far is applicable only when the mixture involved in the two-way communication contains either the most volatile component or the least volatile component. Such mixtures are found on the outer branches of a network representation of a multicomponent distillation (Hu et al., 1991). The mixtures that primarily contain the components of intermediate volatility and reside at the internal nodes of a network representation must be handled in a slightly different manner.

For mixtures that primarily contain the components of intermediate volatility, one method to convert a two-way communication to a one-way liquid-only transfer is to use an additional distillation column. The vapor and liquid stream flows associated with this additional column depends on the directions of flow in the original two-way communication. The direction of vapor and liquid BC streams between the two columns depends on the feed composition and relative volatilities. To demonstrate the concept, a choice is made for the direction of liquid and vapor flows in the equivalent configuration of Figure 8d. Once the directions of liquid and vapor flows for BC mixtures are known, a fourth column can be added to convert the two-way communication to liquid-only transfer (Figure 8e). Since vapor is transferred from the distillation column producing C product stream, the bottom portion of the new distillation column contains sections 8X, 9X and 6XXX in parallel with distillation sections 8, 9 and 6X. Since in Figure 8e, the BC vapor stream is fed to the distillation column producing B product stream, the top portion of the new column contains distillation sections 1XXX, 10X and 11X in parallel with distillation sections 1X, 10 and 11. Now each of the most volatile component A and the least volatile component D are produced in four product streams. However, the intermediate volatility components B and C are produced in two product streams. It is clear that for mixtures that primarily contain components of intermediate volatility, conversion of two-way communications requires a new distil-

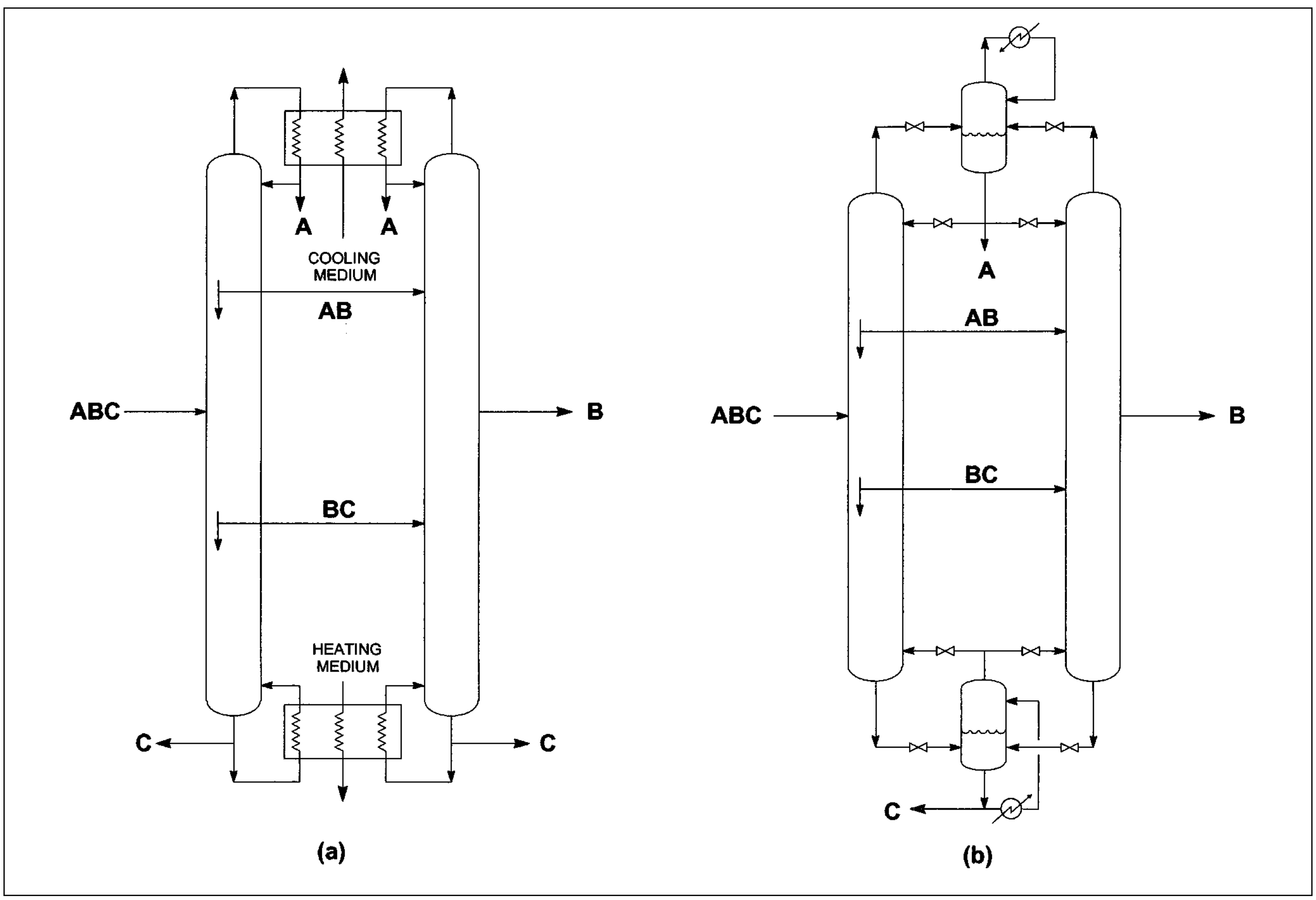

Figure 7. Equivalent fully-coupled configurations with a combined reboiler and a combined condenser.

lation column that is made from portions of two different distillation columns.

For a four-component mixture, once the two-way communications, other than those with mixtures BC, have been converted to liquid-only transfers, it may be feasible to operate the resulting equivalent configuration such as Figures 8b or 8d. The pressures of the two distillation columns involved in this two-way communication can be easily controlled to allow transfer of the BC vapor and BC liquid streams. Furthermore, the equivalent configuration in Figure 8d, derived from the original satellite configuration, can be easily designed to operate without any intercolumn BC transfer stream or with only a liquid BC transfer stream (Agrawal, 1996).

Through the example of a four-component mixture, it has been demonstrated that any two-way thermal coupling involving any mixture can be converted to a one-way liquid-only transfer. Therefore, the method can be easily applied to the distillation of mixtures containing more than four components.

Application to Conventional Distillation Configurations

An interesting pattern emerges when the equivalent configurations in Figures 3, 4b, and 5e are compared with conventional configurations in Figure 2. The indirect split configuration in Figure 2b can be compared with the equivalent side stripper configuration in Figure 3. The difference between these two configurations is that the binary AB condenser in the indirect configuration has been replaced with a pure A condenser. This allows the production of some distillate A from the feed column and maximizes the use of the vapor stream generated at the bottom of the feed column in the pure C reboiler. Due to this effect in Figure 3, the amount of A to be distilled from the second column is decreased. This decreases the vapor requirement in the second column which causes total vapor demand of the side stripper configuration to be decreased relative to that for the indirect split configuration. Similarly, the equivalent side rectifier configuration in Figure 4b can be compared with the direct split configuration in Figure 2a. The replacement of the binary liquid BC reboiler with the pure component C reboiler maximizes the use of heat supplied at the bottom of the feed column by producing a part of the C product stream. This decreases the heat demand in the second column and explains the lower total heat duty of the side rectifier configuration as compared to the direct split configuration. Similarly, the exchange of the binary reboiler and the condenser of the prefractionator configuration in Figure 2c for a pure component reboiler and condenser also explains the lower total heat duty in the equivalent fully-coupled configuration of Figure 5e.

The lesson learned from this comparison is that if the primary objective is to reduce the total heat duty then the use of a condenser at the top of a column condensing a vapor mixture or a reboiler at the bottom of a column boiling a liquid mixture should be avoided. This will lead to the production of multiple streams enriched in the same component from more than one distillation column. (Of course, if thermodynamic efficiency is the primary concern, then intermediate reboilers and condensers may be added at judicious locations of the distillation columns.)

For a mixture containing more than three components, elimination of all the top mixture condensers and bottom mixture reboilers from the distillation columns of a conventional configuration will add several distillation sections, resulting in additional capital cost. Therefore, the potential economic benefits of such a modification must be carefully reviewed. For most mixtures, however, much of the heat duty benefit can be realized by the judicious addition of only one or two distillation sections. Examples will now be offered to illustrate these concepts for some four-component distillation schemes.

For four components, there are five known conventional configurations when only sharp splits are considered across every distillation column (Henley and Seader, 1981). There are two each for the direct and indirect sequences, and one symmetrical sequence. The symmetrical sequence is shown in Figure 9a. Figure 9b results from the addition of a distillation section at the top of the feed distillation column which coproduces an A-enriched distillate stream. This configuration can be quite effective in decreasing the total heat duty when component A is present in the feed mixture in relatively large quantities. Similarly, a section can be added at the bottom of the feed distillation column to coproduce a D-enriched product stream (Figure 9c). This configuration may be effective in reducing the heat duty for a feed mixture containing relatively large quantities of D. When both A and D are present in relatively large quantities, the configuration in Figure 9d, where both A-enriched and D-enriched distillate streams are coproduced from the feed column, can be attractive in reducing the overall heat duty.

Direct and indirect split schemes for four-component mixtures and their corresponding modified configurations are shown in Figures 10 and 11. In the modified configurations, the streams with the question mark (?) may be deleted in order to simplify the process. Figure 10c results from the conventional direct scheme in Figure 10a when distillation sections are added to the bottom of the first two distillation columns such that D-enriched distillates are coproduced from all the columns. A binary mixture CD may be transferred from the feed column to one or both of the other two distillation columns. When the C-producing distillation column receives two binary CD streams, their composition may or may not be similar. When compositions are different, each stream may be fed at appropriate locations in the C-producing distillation column. The configuration in Figure 10d results from the conventional scheme of Figure 10b and coproduces two B-enriched and two D-enriched product streams. This configuration may be effective in reducing total heat duty when both B and D components are present in relatively large quantities in the feed mixture. When only B is present in large quantities, the configuration may be modified such that while B is coproduced from the top of two distillation columns, the D product stream is recovered from only one distillation column. The configuration in Figure 11c results from the conventional scheme in Figure 11a. A-enriched and C-enriched product streams are each recovered from two distillation columns. This scheme may be attractive in reducing heat duty when either one or both A and C are present in relatively large quantities in the feed. When only C is present in large quantities, then only one additional distillation section may be added to coproduce two C-enriched streams and

A may be recovered from only one distillation column. Figure 11d is easily obtained from Figure 11b. It is clear that only partial modifications may be chosen for the configurations in Figures 10 and 11 to maximize the overall economic benefit.

For a four-component mixture, modified configurations in Figures 9 through 11 show modification of the conventional schemes with sharp splits. It is also possible to modify the conventional schemes where nonsharp separations are done across a distillation column. This was illustrated for a ternary mixture between Figures 2c, 5e, and 6.

One result of the suggested modifications is that at least one side liquid stream is transferred from one distillation column to another distillation column. For example, in Figure 9b a side liquid stream AB is transferred from the feed column to the A-producing distillation column. While the side liquid stream transfer is expected to be most beneficial, if needed, this could be either replaced or supplemented with a side vapor transfer stream. Methods to systematically analyze distillation columns with sidestream flows are available in the literature (Glinos and Malone, 1985).

It is worth noting that distillation sections may be added to the direct and indirect sequences such that reboilers or condensers associated with ternary mixtures are converted to only binary mixtures. In such cases, each component product stream is recovered from only one distillation column. An example can be visualized from the configuration in Figure 10c. Both the reboiler for the feed column, as well as that for the B distillate column would boil binary CD mixtures and a portion of each of these mixtures would be fed to the C and D distilling column. Such a configuration would be expected to have a lower heat duty than the original direct sequence in Figure 10a, because the heat supplied to the feed column is now used to do some additional distillation to produce a binary CD mixture that should help the downstream distillation. Such distillations have been earlier suggested by Glinos (1985). However, the reduction in the total heat duty is expected to be less than for the configuration in Figure 10c because, by not coproducing distillate D, the full potential of the heat supplied to the feed column is not exploited. The economic benefit of such partial modifications should also be explored. When feed mixtures contain five or more components, some columns may need to be modified to convert a ternary or a quarternary reboiler or condenser to a binary one, along with modifications to some distillation columns to coproduce some of the components from several columns.

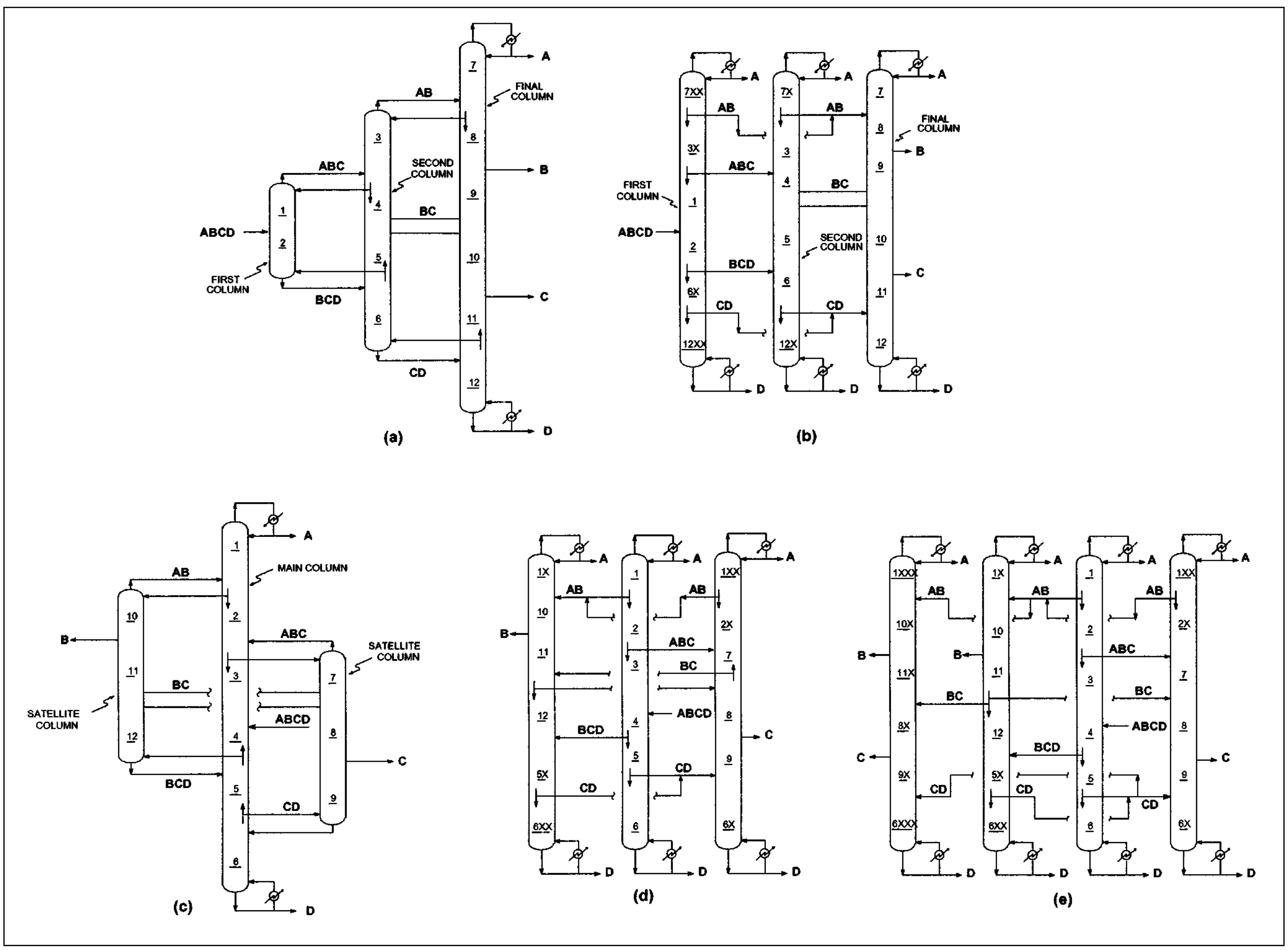

Figure 8. Fully-coupled four-component distillations.
(a)–(b) The sequential and the equivalent configurations; (c)–(e) the satellite and the equivalent configurations.

Conclusions

Classical thermal coupling between two distillation columns requires two-way communication whereby vapor and liquid streams are transferred in opposite directions between one specific location in each of the distillation columns. This requirement can make the operation of a multicomponent distillation configuration difficult with the increasing number of vapor transfer streams between distillation columns. Furthermore, vapor transfer prevents the operation of different distillation columns at substantial different pressures which limits opportunities for heat integration within the process. In this article a general framework is presented whereby the

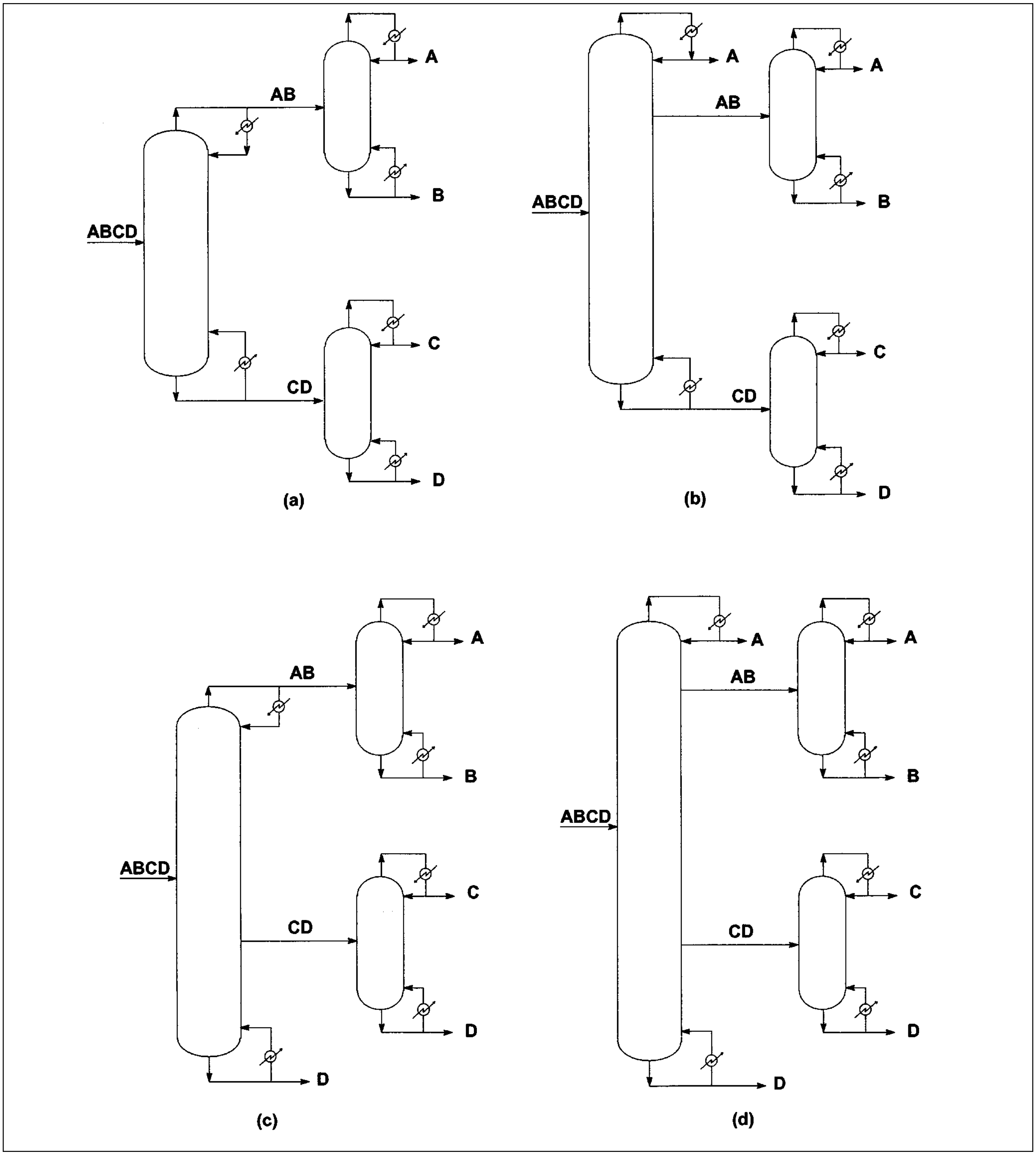

Figure 9. Four-component distillation.

(a) Conventional symmetrical sequence; (b)–(d) sequences with sections added to the feed column of (a).

classical two-way thermal coupling between two distillation columns is converted to a one-way liquid-only transfer.

If the mixture streams involved in two-way thermal coupling between distillation columns contain the most volatile component, then a distillation section and a condenser is added on the top of one of the distillation columns to coproduce a second distillate stream enriched in the most volatile component. Only a side liquid stream is still transferred between the two distillation columns. Similarly, when the mixture streams involved in the two-way thermal coupling between the distillation columns contain the least volatile component, then a distillation section and a reboiler is added at

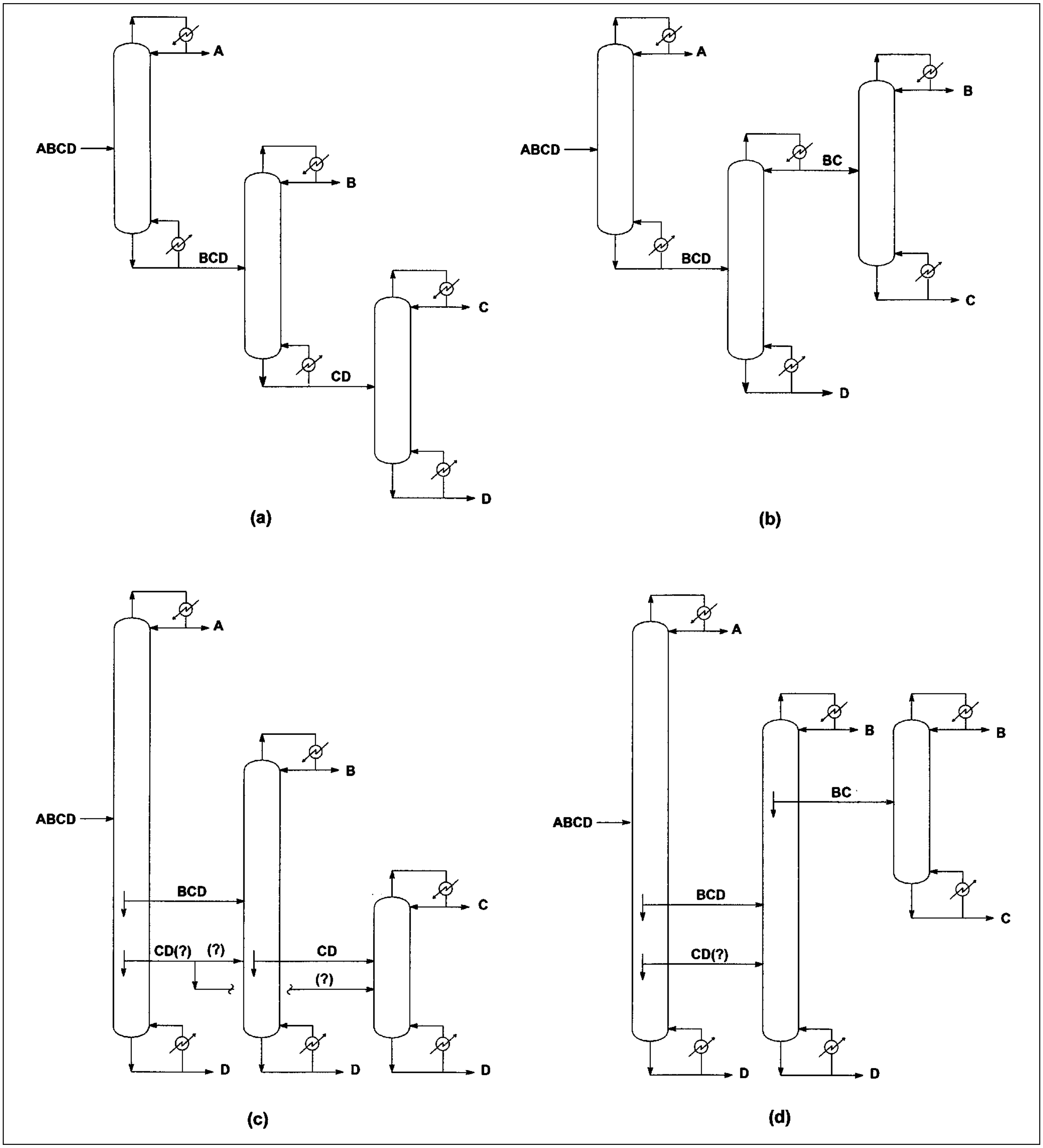

Figure 10. Four-component distillation.

(a)–(b) Conventional direct split sequences; (c)–(d) corresponding modified configurations with sections added to the first two columns.

the bottom of one of the distillation columns to coproduce a second bottoms product stream enriched in the least volatile component. On the other hand, if the mixture streams involved in the two-way thermal coupling between the two distillation columns contain only components of intermediate volatilities, then one more distillation column has to be added to the configuration. The structure of the new distillation column depends on the direction of liquid and vapor flow in the two-way communication. The bottom portion of this additional column is similar to one of the two distillation columns, and the top portion is similar to the other of the two distillation columns.

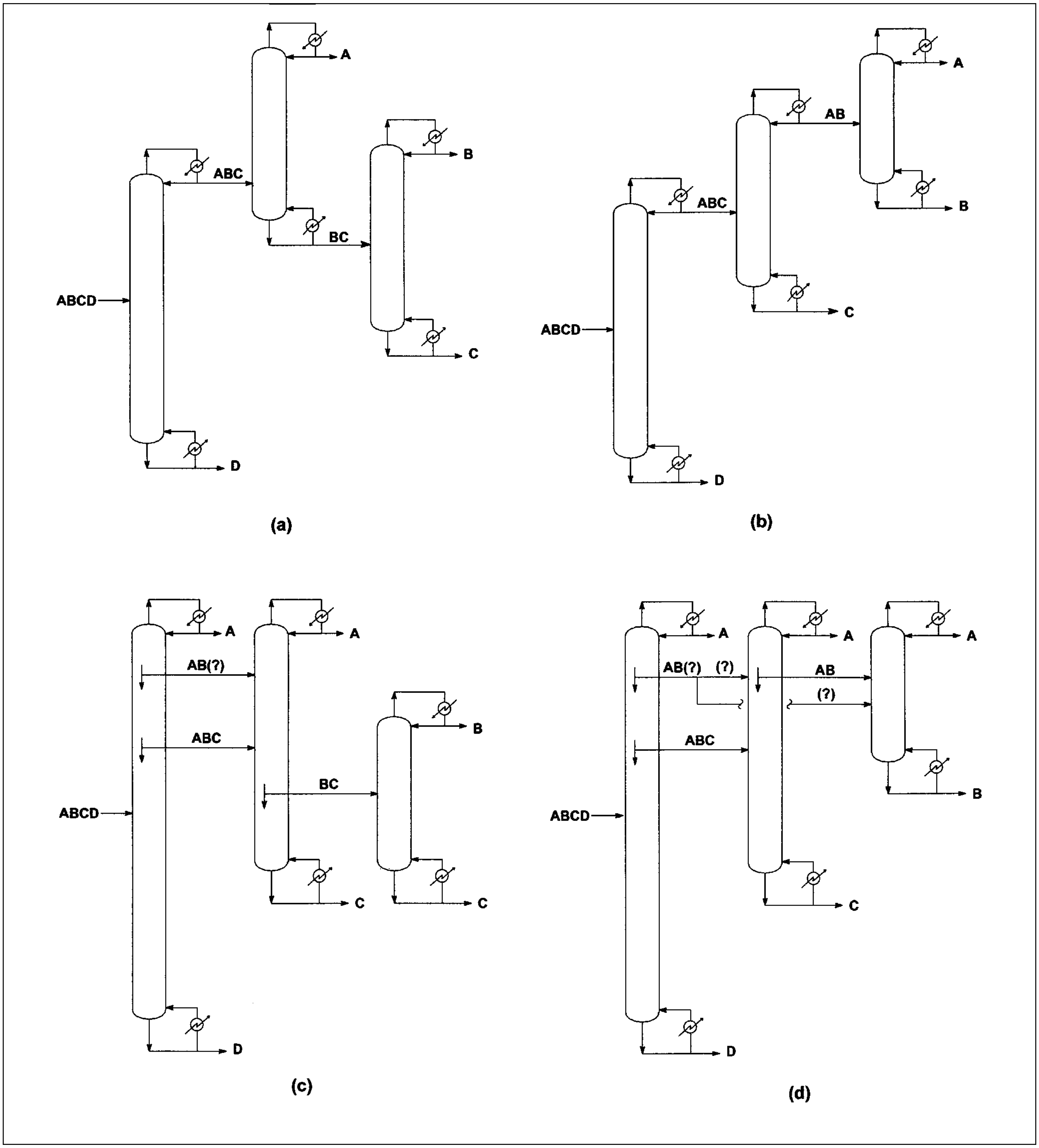

Figure 11. Four-component distillation.

(a)–(b) Conventional indirect split sequences; (c)–(d) corresponding modified configurations with sections added to the first two columns.

The equivalent thermally coupled configurations derived by this method are quite flexible. Product streams enriched in the same component but of different purities can be easily produced. Although the maximum benefit is derived when only liquid streams are transferred between the distillation columns, if it is needed and convenient, a few of the liquid-only transfer connections may be replaced with vapor transfers in the final configuration.

These observations from the equivalent thermally coupled configurations can easily be applied to decrease the heat duty of conventional multicomponent configurations with no thermal coupling. A distillation section is added at the top (or the bottom) of the distillation column with a mixture condensing in the top condenser (or a mixture boiling in the bottom reboiler). The maximum reduction in heat duty resulting from the added distillation section is expected to be obtained when an additional product stream enriched in one of the components is coproduced from the end of the distillation column where the distillation section is added. A side stream is transferred from the distillation column with the new added distillation section to another distillation column in the original configuration. The number and the extent of such modifications to the original conventional multicomponent configuration will be dictated by the economics of the process. It is expected that for most feed mixtures, modification of only a fraction of the distillation columns will result in the greatest economic benefit.

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