# Designing packed multi-partition wall dividing wall columns

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## ABSTRACT

Separation of three-component mixtures into three pure products using a dividing wall column (DWC) is an established energy, capital and space saving distillation technology with ever growing number and field of applications. This paper addresses potential and possibilities for four or more products separations that could increase potential gains, and, most importantly, could be arranged in an industrially viable way using packed, multi partition DWCs. This paper addresses possibilities and peculiarities associated with establishing the most beneficial internal configuration of a complex DWC for separation of a multicomponent aromatics mixture into four or five product streams, by using V-min diagram method to identify most promising configurations and to provide initial values for detailed simulation based determination of adequate energy and stage requirement.

## Introduction

As proven in industrial practice, application of dividing wall columns (DWC), where appropriate, leads to approximately 30 per cent saving in both energy and capital, compared to equivalent conventional distillation sequences for obtaining three high purity products (Olujić et al., 2009, Asprion and Kaibel, 2010)). Simulation studies performed with well defined, mainly hypothetical pure component systems, have indicated that designing four and more products DWCs could enhance potential energy and capital savings significantly (Dejanović et al., 2010). This implies that there is a strong incentive to consider implementing more complex designs of a DWC. These

can certainly be assembled without great difficulties as structured packing columns, by utilizing well established non-welded, self-fixing partition wall technology that provides full flexibility in this respect (Kaibel et al., 2007). Nevertheless, the lack of experience and insight related to modeling and simulation of industrially relevant separations of multicomponent feeds, as well as suitable design procedures, accompanied often by a fear of unstable operation are main barriers in this respect.

The design and control of four-product DWCs have been addressed and encouraging advancements made in previous efforts (Halvorsen et al., 2010, Dejanović et al., 2010, Stranberg et al., 2010), indicating that a packed DWCs could be arranged as a practical, single partition wall column, or a thermodynamically optimal, but complex, three-partition walls column. These and other simulation studies performed using so called $V_{min}$-diagram method as a practical means to identify and quantify accordingly internal configuration of a DWC, providing reliable data for initialization and effective execution of detailed calculations performed using an appropriate rigorous model arranged for this purpose using facilities available in a commercial software package, indicated a large potential for energy and capital saving by implementing DWCs in aromatics processing plants as encountered in complex refineries (Dejanović et al., 2011). Interestingly, from further elaborations along this line using the V-min method it appeared that another two beneficial internal configurations of a four-product DWC and even a five-product DWC could appear to be an interesting option for aromatics processing plants.


## Previous Work

Table 1 shows feed compositions as well as product compositions for separation of a 15 component aromatics mixture reduced here to key components into four fractions according to given product specifications.


**Table 1.** Base case stream table

| Stream Name | Feed | C5-C6 | BRC | Toluene | Heavy |
|---|---|---|---|---|---|
| Flow rate [kmol/h] | 343.0 | 97.8 | 47.1 | 86.5 | 111.6 |
| Flow rate [t/h] | 31.7 | 7.44 | 3.87 | 8.0 | 12.41 |
| Component mass fractions | | | | | |
| N-Hexane and lighter | 0.2517 | 0.9869 | 0.1642 | | |
| Benzene | 0.0855 | 0.0131 | 0.6750 | - | - |
| 3-Methylhexane | 0.0204 | - | 0.1608 | 0.0026 | - |
| Toluene | 0.2474 | - | - | 0.9718 | 0.0061 |
| Ethylbenzene and heavier | 0.3950 | | | 0.0256 | 0.9939 |


Figures 1 and 2 show schematically internal configurations of a single- and a multi-partition wall configuration that have been conjectured from conceptual design considerations carried out using approximate V-min method (Halvorsen and Skogestad, 2003a), simulated and optimized using detailed methods, dimensioned and worked out in detail and compared elsewhere, eg. Dejanović et al. (2010, 2011).
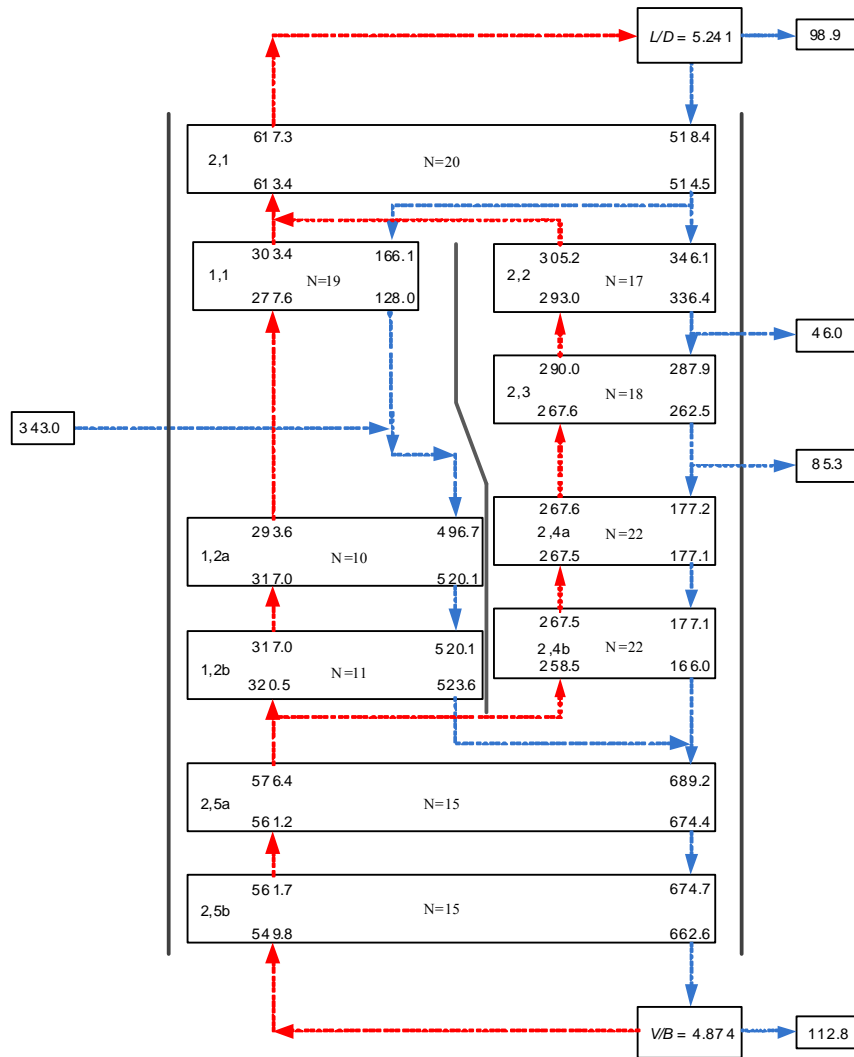
*Figure 1.  Stage requirement, internal configuration and corresponding vapor and liquid flow rates and patterns for single-partition wall DWC (Kaibel or "2-4" column)*

These two configurations, named "2-4" and "2-3-4" according to the number of column/sections in series, have been dimensioned as packed columns and compared on basis of annualized total costs (TAC). Detailed drawings and tables illustrating differences in energy requirement, details of internal configuration and costs can be found elsewhere (Dejanovic et al., 2011). It appeared that both configurations are highly cost effective comparing to conventional three columns sequence. As expected, more complex configuration seems to be more beneficial in this respect, to such an extent that there is a strong incentive to consider practical implementation (technically feasible) of this considerably more complex internal configuration.

For the purposes of present study, just mention the stage and reflux requirement of these two configurations, to have basis for comparison with other potential DWC configurations. The corresponding numbers are given in Table 2.

Table 2  Stage and energy requirements of basic, 4-product DWC configurations

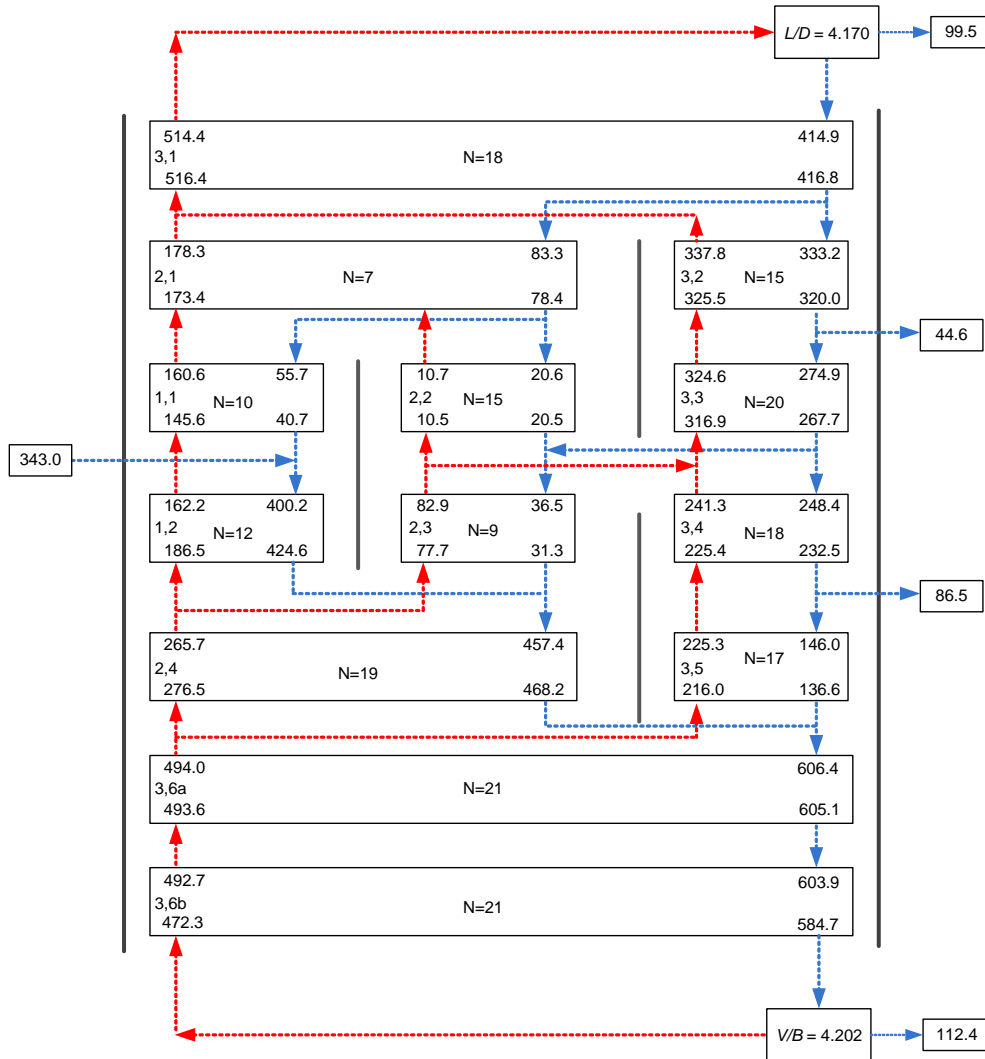| Configuration | Reboiler duty (MW) | Number of equilibrium stages |
|---|---|---|
| "2-4" | 5.82 | 169 |
| "2-3-4" | 4.80 | 202 |



Figure 2.  *Stage requirement, internal configuration and corresponding*
*vapor and liquid molar flow rates and patterns for multiple-partition wall DWC ("2-3-4"),*

One should note that a significantly larger number of stages in case of "2-3-4" configuration does not mean taller column, as it is the case with conventional distillation columns. Namely, with three parallel sections in partitioned part this column is lower. On the other hand a 1 MW saving in reboiler duty is reflected in a reduced column diameter, which means that in present case a multi partition wall DWC is a more compact single shell column than a single partition wall DWC.

## Alternative Configurations

The next step was to further exploit and demonstrate the potential benefits of a V-min diagram based analysis, using a fifteen component feed mixture as base case. In a most recent paper by Halvorsen et al. (2011) detailed explanations are given on how to interpret properly a V-min diagram and use it for a thorough DWC assessment. Emphasis was on how to set the component or fraction splits to maximize potential gains. Interestingly, it appeared that in case of a complex 4-product DWC there is some freedom in manipulation of the middle section, by either changing prefractionator settings or component splits in bottom part, which confirmed usefulness of V-min diagram method and indicated that further performance improvements are possible in present 4-products case. Figure 3 shows working V-min diagram, with corresponding, fully extended Petlyuk arrangement, that is also used as basis for detailed simulation of 4-product DWCs using rigorous methods available in commercial software packages. Dotted lines in V-min diagram shown in Fig. 3 illustrate how the V/F, associated with separation of component A from B and heavier and separation between B and C, represented by corresponding peaks ($P_{AB}$ and $P_{BC}$), are lifted when the flow in C21 column are set to ensure that vapour flow in the top of C22 is equal to the bottom flow of C21.
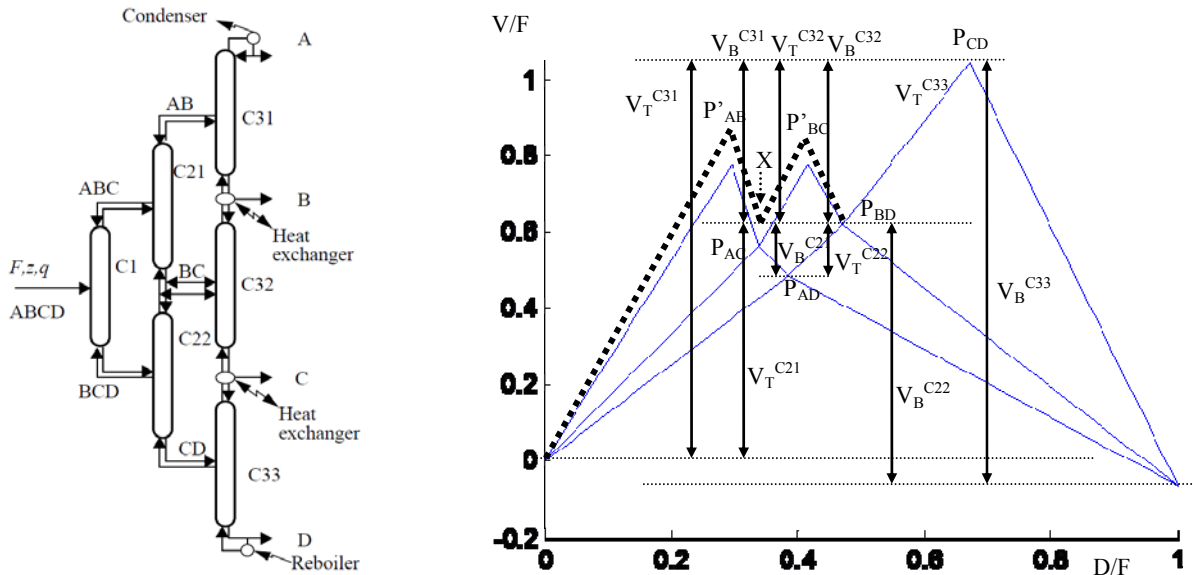


*Figure 3. Fully heat-coupled sequence for separation of a four component mixture into pure components, and a V-min diagram illustrating shifts in peak heights associated with arranging  so called "practical" 4-p DWC, shown schematically in Fig. 4a.*

Since the benzene-rich fraction is essentially a binary mixture, an attempt was done to enrich it further by separation from 3-methylhexane, by rearranging a 4-product DWC into a 5-product DWC. Two novel 4-product DWC and a 5-product DWC configuration as emerged from a detailed study performed with base case aromatics mixture using V-min diagram method (Halvorsen et al., 2011) are shown schematically in Fig. 4.
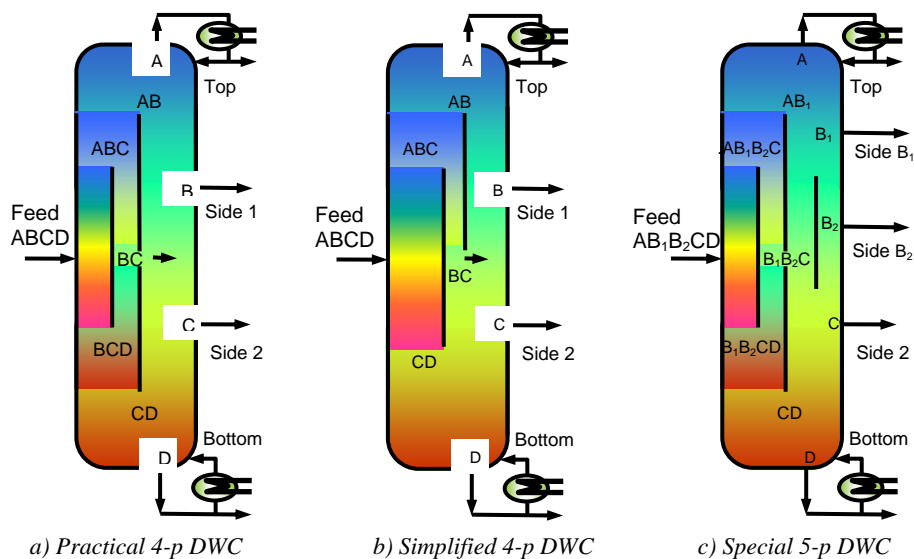
*a) Practical 4-p DWC*   *b) Simplified 4-p DWC*   *c) Special 5-p DWC*

*Figure 4. Multiple partition wall DWC configurations considered.*

Further elaboration by rigorous simulations provided stage requirement for alternative configurations, using a constant reboiler duty, i.e. that of "2-3-4" configuration as basis for comparison.

### (i) A more practical 4-product DWC

The "2-3-4" configuration, that utilizes three vapor splits, could be simplified by separating the main column side from the central section by a continuous partition wall, allowing only the required flow of liquid to enter the main column side (sub-column C32). This means introduction of a larger vapor load in the upper part of the central section (sub-column C21), which should effectively be that of the bottom of the sub-column C22. This can be achieved by shifting the operating point of C21 (point $P_{AC}$ in the V-min diagram, representing the A/C split), until it reaches the same height as the operating point of C22 (point $P_{BD}$ in the V-min diagram, representing the B/D split). This also lifts operating points $P_{AB}$ and $P_{BC}$, increasing vapor demand in sub-columns C31 and C32. Since new operating points are still lower than the highest point (peak) in the diagram, $P_{CD}$, we conclude that this configuration is feasible. Namely, only internal distribution of flows and heat duties is affected, while the overall reboiler duty is fixed by the requirement corresponding to unchanged, highest peak.

Figure 5 shows the flowsheet of "2-3-4" configuration used for rigorous simulation purposes. The reboiler duty was fixed at 4803 kW as in the base-case, and material flows in C21 and C22 adjusted, until desired product specifications were met. The results, i.e. appropriate internal configuration and molar liquid and vapor flows at the top and bottom of each packed bed are shown in Fig. 6. The number of required equilibrium stages appeared to be equal to that of the "2-3-4" configuration, i.e. 202.
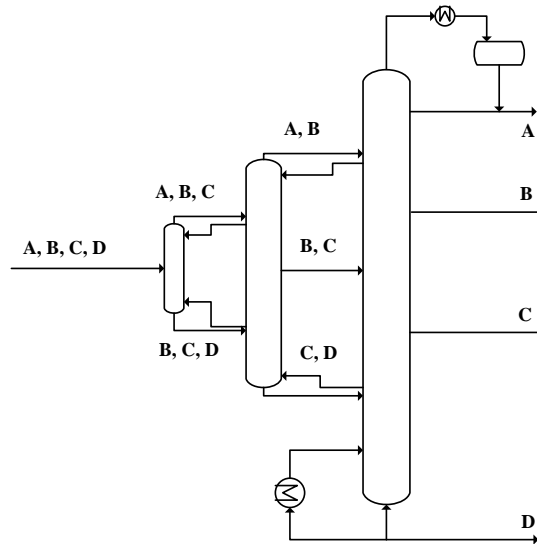
*Figure 5. Equivalent sequence of conventional columns used to simulate rigorously a 4-product DWC, i.e. "2-3-4" as well as configuration (practical 4-p DWC) shown in Fig. 4a*
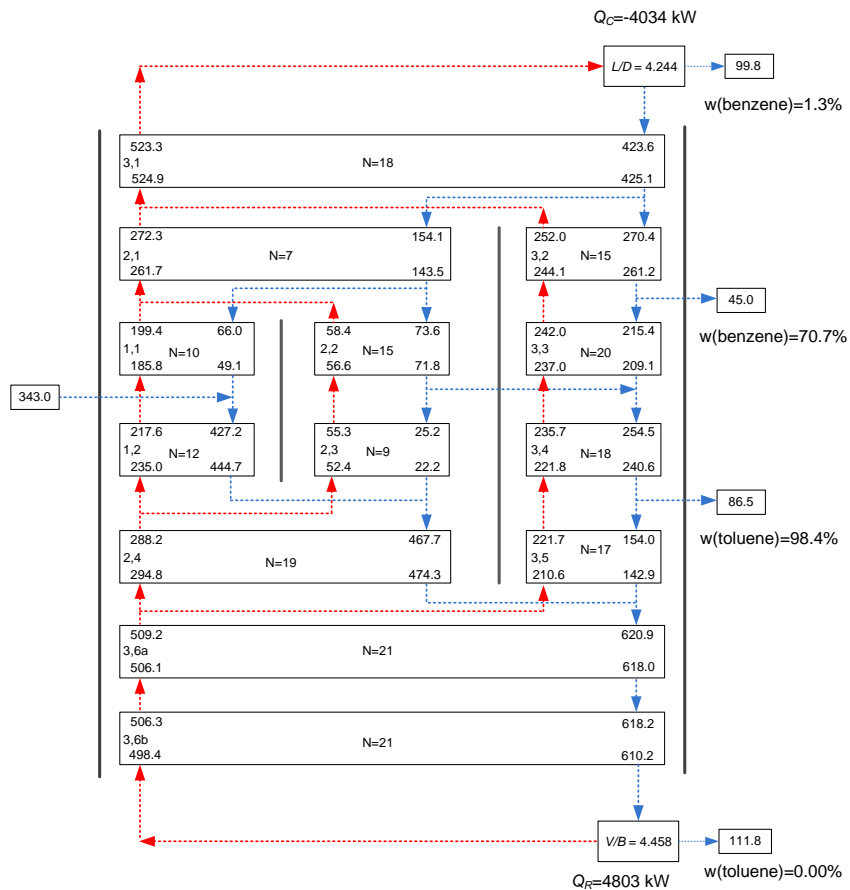


*Figure 6. Stage requirement, internal configuration and molar vapor and liquid flow rates and patterns of practical 4-p DWC (Fig.4a)*

### (ii) Simplified 4-product DWC

Following configuration is based on a change in prefractionator operation point, by moving the split between B and C to C and D, to ensure a full recovery of B in the distillate stream. This is visualized in V-min diagram simply by moving the prefractionator operating point, $P_{AD}$, upwardly to the right until it overlaps with $P_{BD}$. With this, the net distillate flow from sub-column C22 becomes zero, which practically means that this sub-column can be removed. In consequence, this leads to increased prefractionator load, however the overall vapor flow rate remains the same, because peaks $P_{AB}$ and $P_{BC}$ are considerably lower than $P_{CD}$. In practice, this configuration can be realized simply by removing the lower section of the main column side partition wall from the base-case configuration, as indicated in the flowsheet shown in Fig. 7, which served as basis for rigorous simulation of this configuration.

The results of the rigorous simulations are summarized in graphical form in Fig. 8. Interestingly, the stage requirement of this configuration is significantly lower, i.e. 174, approaching that of Kaibel column, i.e. "2-4" configuration.
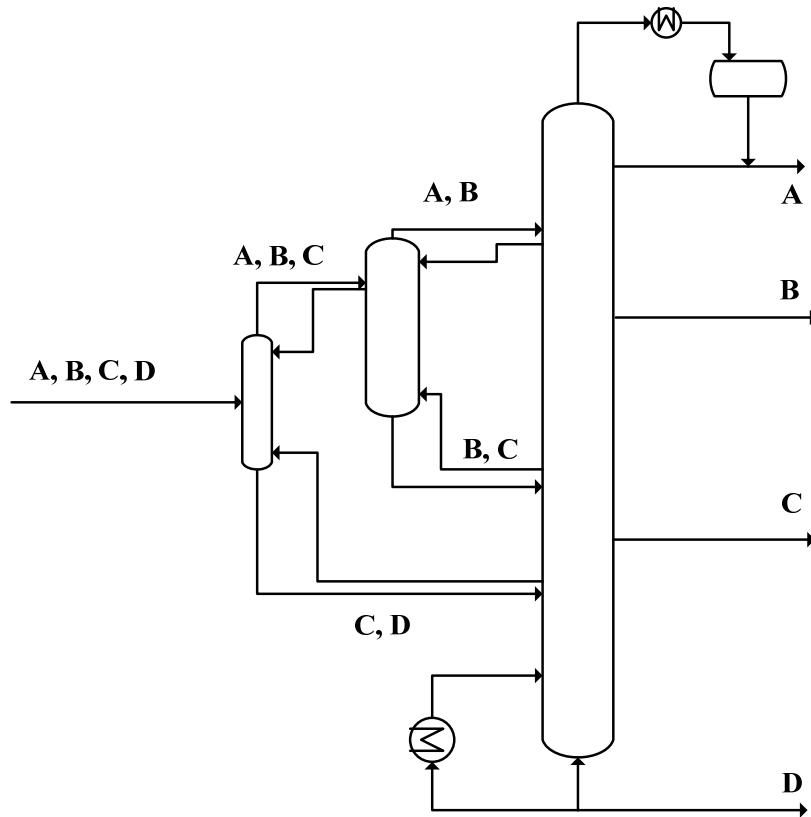


*Figure 7. Equivalent sequence of conventional columns used for rigorous simulation of simplified 4-p DWC configuration (Fig. 4b)*
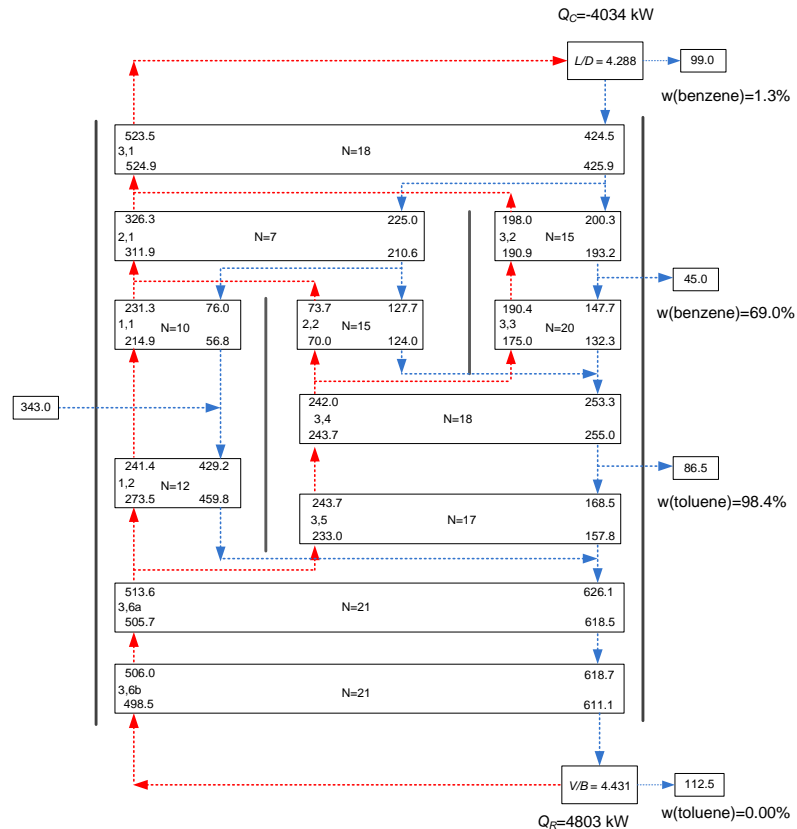
$Q_C$=-4034 kW

| L/D = 4.288 | 99.0 |

w(benzene)=1.3%

| 523.5 | | 424.5 |
| 3,1 | N=18 | |
| 524.9 | | 425.9 |

| 326.3 | | 225.0 | | 198.0 | 200.3 |
| 2,1 | N=7 | | | 3,2 | N=15 |
| 311.9 | | 210.6 | | 190.9 | 193.2 |

45.0

w(benzene)=69.0%

| 231.3 | 76.0 | | 73.7 | 127.7 | | 190.4 | 147.7 |
| 1,1 | N=10 | | 2,2 | N=15 | | 3,3 | N=20 |
| 214.9 | 56.8 | | 70.0 | 124.0 | | 175.0 | 132.3 |

| 242.0 | | 253.3 |
| 3,4 | N=18 | |
| 243.7 | | 255.0 |

343.0

86.5

w(toluene)=98.4%

| 241.4 | 429.2 |
| 1,2 | N=12 |
| 273.5 | 459.8 |

| 243.7 | | 168.5 |
| 3,5 | N=17 | |
| 233.0 | | 157.8 |

| 513.6 | | 626.1 |
| 3,6a | N=21 | |
| 505.7 | | 618.5 |

| 506.0 | | 618.7 |
| 3,6b | N=21 | |
| 498.5 | | 611.1 |

| V/B = 4.431 | 112.5 |

$Q_R$=4803 kW    w(toluene)=0.00%

*Figure 8. Stage requirement, internal configuration and molar vapor and liquid flow rates and patterns of the simplified 4-p DWC shown in Fig. 4b*

## (iii) A 5-product DWC

For the purpose of demonstration of a 5-product DWC design, benzene rich stream is further separated into benzene and 3-methyl hexane rich products, i.e. B1 and B2 streams as shown in Fig. 4c. The corresponding V-min diagram is shown in Fig. 9a, indicating that the characteristic peak and corresponding heat requirement is below the highest one, which means that this additional separation could theoretically be performed without adding more energy. This is appealing, however it is accompanied by an increased complexity of the configuration, because it requires another set of sub-columns in parallel. Figure 9b shows the flowsheet that was used to simulate rigorously this very complex configuration.

Results are shown in Fig. 10, where stage requirements and internal liquid and vapor flows are shown for each section of the column, indicating that compared to 4-product alternatives this column contains an additional section as main column, resulting in a configuration with four sections in parallel in the partitioned part of the column. This implies a configuration with four liquid and four vapor splits, which for the same reboiler duty requires 291 stages. This is difficult to accommodate, because the distribution of stages is highly unsymmetrical, with much more stages required on main column half, which would mean a lot of empty space on the prefractionator column side. All this appears unfavorable and means that in case of need for
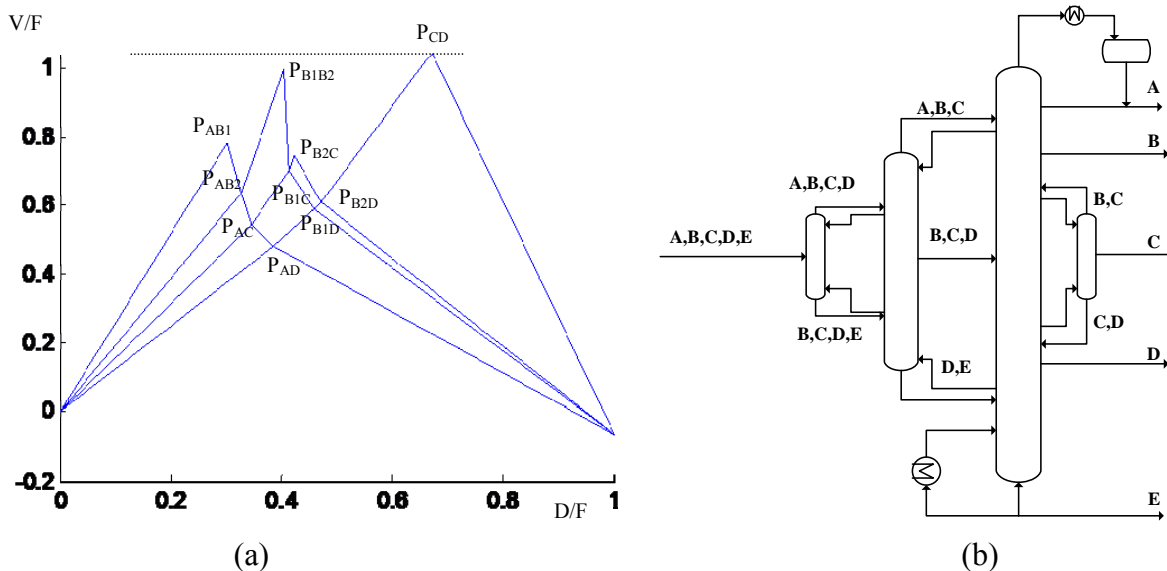
*Figure 9. V-min diagram (a) and (b) an equivalent sequence of conventional columns used to simulate rigorously a 5-product DWC (Fig. 4c)*
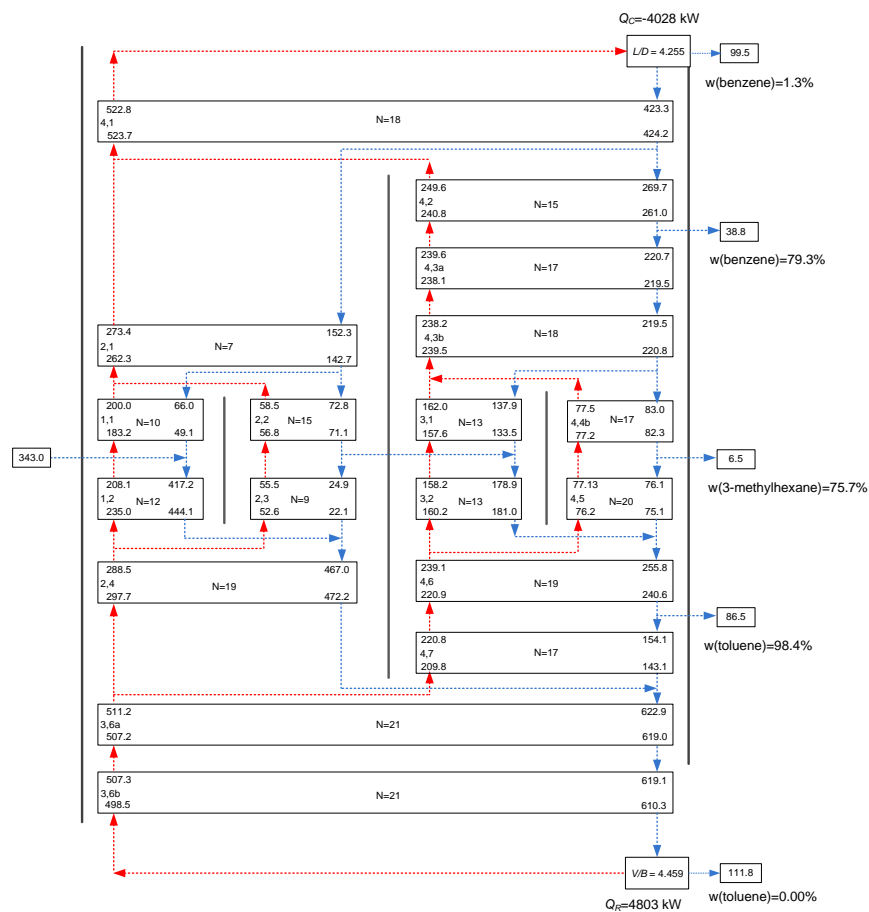


*Figure 10. Stage requirement, internal configuration, and molar vapor and liquid flow rates and patterns of a 5-p DWC*

further purification of benzene rich cut, an external column in addition to a 4-p DWC, as suggested in the flowsheet shown in Fig. 9b, could be a more practical solution.

Stage and reflux requirements of all compared alternatives and designs are summarized in Table 3.

Table 3- Energy and stage requirement of four 4-product configurations and a 5-p configuration

| DWC configuration | "2-4" 4-p | "2-3-4" 4-p | (i) 4-p | (ii) 4-p | (iii) 5-p |
|---|---|---|---|---|---|
| Reboiler duty (MW) | 5.82 | 4.81 | 4.81 | 4.81 | 4.81 |
| Number of stages | 169 | 202 | 202 | 174 | 291 |

In fact, "practical" configuration (i) does not differ from "2-3-4" in overall performance. However it requires one vapor split less, which may be considered as significant advantage from both design and operating point of view. Due to shift in vapor and liquid flows in upper part of middle and main column section, the cross sectional area of the middle section would increase and that on the main column side would decrease accordingly. Striking is effectiveness of the "simplified" configuration (ii), which, in addition to the same gain on vapor split side also reduces the required number of stages considerably. However this will not deliver a reduction in the shell height. The reason is that the stages from the removed lower part of the middle section are now part of the extended, joint bottom section of the middle and main column, while the number of stages on main column side remains the same. On the other hand the internal vapor and liquid flows on critical places are similar, which means that shell diameter will remain the same. However, its internal configuration is simpler, which could turn to be an advantage on construction and installation side.

## Concluding Remarks

Four-product DWCs require a complex internal configuration with a middle or central section in between the prefractionator and the main column. Depending on the chosen arrangement, two or more partition walls in parallel and in series may be needed. The assessment of possibilities in this respect may be carried out using the V-min diagram that will indicate potentially interesting configurations. These can be just refined using rigorous simulation in conjunction with an adequate flowsheet, using results of V-min diagram study as initial guesses that will facilitate detailed calculations.

Our previous studies as well as the present one indicate that a multi-partition wall DWC is a highly attractive, and more importantly an industrially viable option, which, if implemented, could contribute to a significant increase in profitability of aromatics processing plants.

Regarding the fact that the 5-p configuration that was designed to accommodate also a separation between benzene and 3-Methylhexane would require additional 53 stages, a more practical solution would be to arrange it in a separate external column in conjunction with one of 4-p configurations considered.

## References

Asprion, N., Kaibel, G., *Dividing wall columns: fundamentals and recent advances*, Chem. Eng. Processing 49 (2010) 139-146.

Dejanović, I., Matijašević, Lj., Olujić, Ž., *Dividing wall column – a breakthrough towards sustainable distilling*, Chem. Eng. Processing 49 (2010) 559-580.

Dejanović, I. Matijašević, Lj., Jansen, H., Olujić, Ž., *Designing a packed dividing wall column for an aromatics processing plant*, Ind. Eng. Chem. Res, 2011 (dx.doi.org/10.1021/ie1020206)

Dejanović, I. Matijašević, Lj., Halvorsen, I.J., Skogestad, S., Lj., Jansen, H., Kaibel, B., Olujić, Ž., *Designing four-product dividing wall columns for separation of a multicomponent aroimatics mixture*, Chem. Eng. Res. Des., 2011 (doi:10.1016/j.cherd.2011.01.016).

Halvorsen, I.J., Skogestad, S., *Minimum energy consumption in multicomponent distillation. 1. V-min diagram for a two-product column*, Ind. Eng. Chem. Res. 42 (2003a) 596-604.

Halvorsen, I.J., Skogestad, S., *Minimum energy consumption in multicomponent distillation. 3. More than three products and generalized Petlyuk arrangements*, Ind. Eng. Chem. Res. 42 (2003b) 616-629.

Halvorsen, I.J., Skogestad, S., Dejanović, I., Matijašević, Lj., Olujić, Ž., *Multi-product dividing wall columns: A simple and effective assessment and conceptual design*, Proceedings of PRES 11 Conference, 8-12 May 2011, Florence, Italy, in print.

Kaibel, B., Jansen, H., Rietfort, T., Zich, E., Olujić, Ž., *Unfixed wall: the key to breakthrough in dividing wall technology*, In Proceedings of Distillation Topical Conference, AIChE Spring Meeting, April 22-27, 2007, Houston, Texas, USA, pp. 29-41.

Olujić, Ž., Jödecke, M., Shilkin, A., Schuch, G., *Equipment improvement trends in distillation*, Chem. Eng. Process. 48 (2009) 1089-1104.

Stranberg, J., Skogestad, S., Halvorsen, I.J., *Practical control of dividing wall columns*, Proceedings of Distillation and Absorption 2010 Conference, Eindhoven, The Netherlands, pp. 527-532.