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Dividing Wall Columns in Operation

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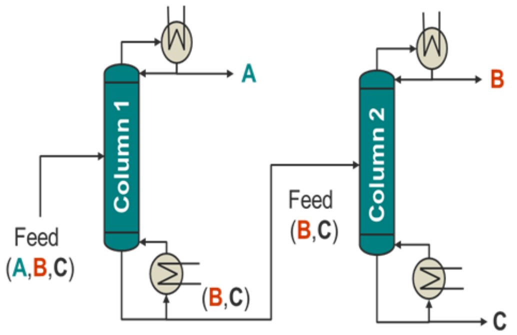
Dividing Wall Columns (DWC) provide a new approach to age-old distillation techniques (Dejanovic et al., 2010 and Kiss 2009). These columns have become popular lately owing to the energy and capital benefits that they provide. DWCs, with their versatility and flexible operation, are found in both retrofit and grassroots applications for reformate splitters, naphtha splitters, among others.
DWCs work on the principle of removing thermodynamic design flaws in traditional distillation columns (Yildirim et al., 2011). These limitations are encountered in both two-column separation sequences as well as side-cut columns. This paper highlights these inherent design flaws in side-cut columns and illustrates how middle DWC technology helps to eliminate them.
Two examples of revamping naphtha splitter columns with DWC technology are presented. In one case, a DWC column produces better product specifications than the original design. In the other case, a two-column sequence is replaced by a single DWC column for the same product quality. This results in freeing up the second column for use in another service. In both cases, a DWC helps to achieve a better side-cut product. The product specifications of the top and middle cuts are somewhat flexible. Both columns are operational in one of the largest refineries in South East Asia.

1. Introduction

Conventional distillation of three products is generally carried out in a sequence of two columns. In some separations, a side-cut column is used. Both two-column separation and side-cut columns have certain thermodynamic inadequacies as follows.First, let us consider a two-column separation sequence (Figure 1a). The first column removes the lightest key (A). The middle cut (B) and the heaviest key are removed at the top and the bottom of the second column in that order. However, the middle boiling components reach a concentration peak somewhere near the centre of the first column. As the concentration of C is increasing in the column bottoms, the composition of B is diluted due to remixing of the two components (Figure 1b). The remixed components are then separated in the next column, utilizing additional heating duty. The separation achieved in the first column using heating duty is somewhat wasted. As a result, conventional two-column separation sequences generally see high reboiling and cooling duties.



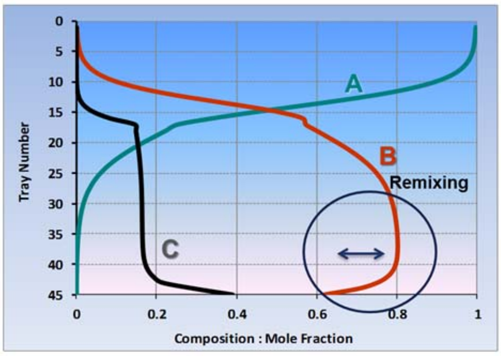


Figure 1a: Conventional Two-Column Separation; Figure 1b: Composition profile of components in a Two-Column Separation.

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Next, a side-cut column (Figure 2a and 2b) also faces a similar thermodynamic problem. Here, the feed intermixes with the side-cut affecting the product quality. For side-cuts below the feed, heavier components end up in the middle cut affecting the final boiling point (FBP) of the product. Likewise, a side-cut above the feed has problems meeting the initial boiling point (IBP).

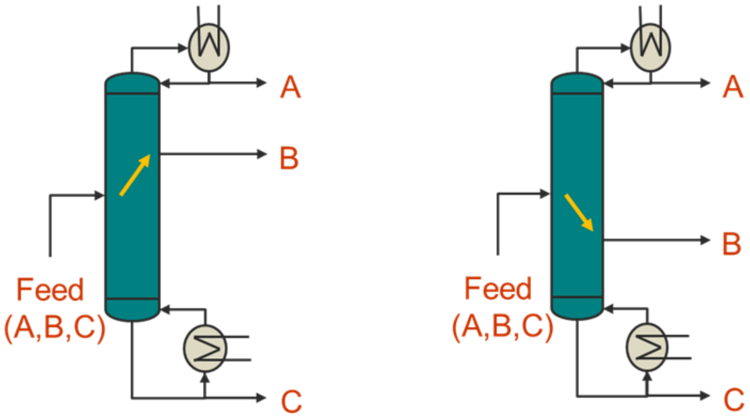

Figure 2a: Thermodynamic Inadequacies in Side-Cut Column for a Side-Cut above the feed; Figure 2b: Thermodynamic Inadequacies in Side-Cut Column for a Side-Cut below the feed.

A dividing wall column (Figure 3) successfully eliminates these inadequacies and makes the whole separation more efficient, while minimizing the utility requirements for the same separation. This is done with the aid of a dividing wall design, where the wall is located somewhere in the middle of the column. As a result, the column is split into a pre-fractionation side and a main fractionation side. The wall removes the possibility of the feed mixing with the side-cut, leading to a better product quality. Due to the pre-fractionation area available, the middle boiling components distribute among the lightest and the heaviest key based on the degree of volatility. The middle components are eventually concentrated and removed in the center of the main fractionation side. A DWC is hence able to generate a better product quality in a single column. The heating requirements are also lowered by about 20-30% due to the added advantage of pre-fractionation.

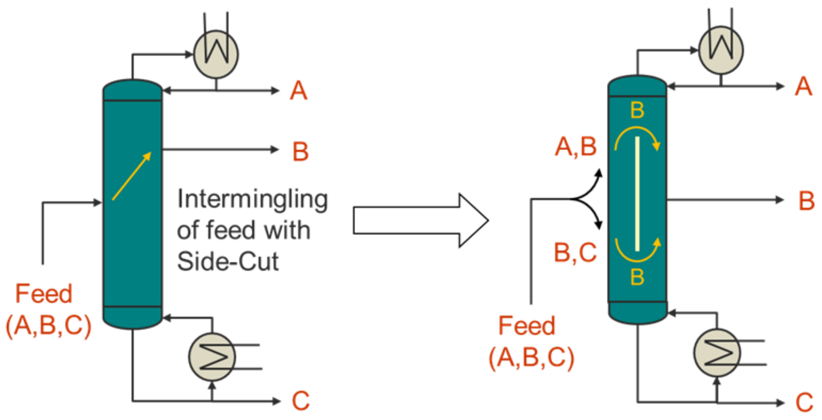

Figure 3: Conventional Side-Cut Column v/s Proprietary DWC

2. DWC for better product specification in a single column

DWC technology has been used to retrofit a FCC unit naphtha splitter column (Figure 4a) at the largest refinery in India (Bhargava et.al. 2017). The unit in question separates cracked naphtha into three products: light naphtha, heart-cut naphtha and heavy naphtha. The light and heavy products are routed for gasoline blending, while the heart-cut naphtha feeds a reforming unit. For improving xylene concentration in the reforming unit, the heart-cut naphtha should be rich in C_8 and C_9 aromatic precursors.

The column has two reboilers. The side reboiler operates on a low temperature utility, LCO (Light Cycle Oil). The bottom reboiler operates on a high temperature utility, HCO (Heavy Cycle Oil).

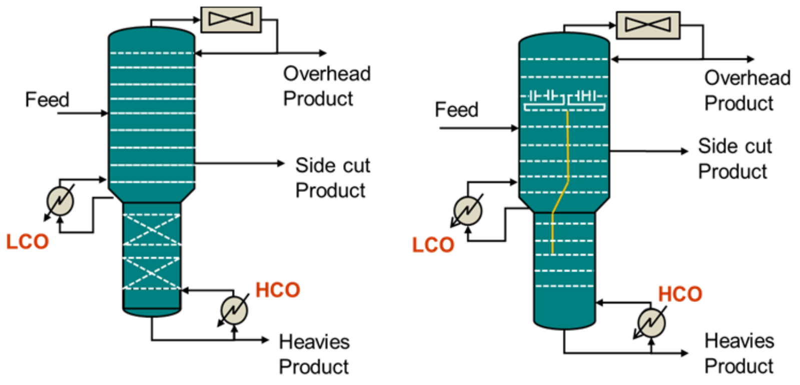

Figure 4a: Original Design of the FCC Unit Naphtha Splitter; Figure 4b: After Revamp to Proprietary DWC

In the original design, the side-cut location is located below the feed tray location. The lower reboiler duty cannot be increased further due to the smaller diameter section. The client now has a requirement to process a higher feed rate, but this eventually led to slippage of heavier components in the heart-cut affecting its quality. The heart-cut naphtha FBP ended up in the range of 190°C-198°C. This adversely affects the downstream reformer unit. Thus, one of the main objectives of the revamp is to lower the FBP of the heart-cut naphtha to 180°C to meet the reformer feed specifications.
One of the common approaches to such a revamp is to install an additional column to process the heart-cut naphtha. However, as mentioned earlier, a two-column separation sequence requires higher heating and reboiling duties. Plus, the new column requires additional capital investment for the extra equipment needed. Considering these increases, the refiner chose DWC technology to revamp the column.
The naphtha splitter column is retrofitted with a middle dividing wall column (Figure 4b). The wall is placed slightly off-center such that the side reboiler duty is confined to the pre-fractionation section. The lightest components are moved towards the top of the column using maximum duty from the LCO reboiler. A portion of the wall also extends to the smaller diameter section. This prevents the lightest components from moving downward, and without significantly affecting the duty of the bottom reboiler. The heart-cut naphtha and the heavy naphtha are separated using the HCO reboiler. The wall eliminates the back-mixing of the feed with the side-cut while optimizing the duties on the reboiler. As a result, a better-quality heart-cut naphtha is separated in the same column.

Table 1: Heart Cut Naphtha Specifications before and after Revamp

Parameters	Units	Naphtha Splitter before Revamp	Naphtha Splitter after Revamp to DWC
Heart-cut Flowrate	t h-1	180.4	151.0
D86 (IBP/FBP)	°C	110.5-190.6	110.5-172.0
Overlap (Side-Cut D86 @ 95% - Bottoms D86 @ 5%)	°C	37	-3

For this revamp, the capital investment is minimal as most of the modifications are confined to the column. There was no change in any of the associated equipment. Table 1 shows the heart-cut naphtha product quality before and after the revamp. The following observations are based on test runs after the start-up of the column:

- The overlap between the heart-cut and the bottom cut was reduced from 37°C to -3°C. The overlap is defined as the difference between heart-cut naphtha D86 95% and heavy naphtha D86 5%. The positive gap indicates a good separation between the two products.
- The naphtha splitter overhead air condenser duty increased by 15%. This required no modification due to the excess hydraulic capacity available in the existing condenser.

Figure 5a: Installation of the Dividing Wall in the FCC Naphtha Splitter at an Indian Refinery; Figure 5b: Dividing Wall Internals inside the Tower

3. Two-Column Application to a Single Column Application

In another revamp at the same refinery, DWC technology was employed to produce the same product specifications in a single column as opposed to a conventional configuration of two-columns (Bhargava et. al, 2017). The original design (Figure 6) includes two naphtha splitter columns, Naphtha Splitter-1 followed by Naphtha Splitter-2. Column 1 separates the feed into light naphtha and heavy naphtha at the top and bottom respectively. Additionally, a side-cut is removed which acts as the feed to Naphtha Splitter-2. This column separates a heart-cut naphtha stream at the top of the column. The remaining heavy naphtha is removed at the bottom.

Naphtha Splitter-1 is also a two-diameter column with two reboilers. The side reboiler operates on LCO, while the bottom reboiler operates on HCO. Similar to the previous example, the side-cut is removed from below the feed tray location. Naphtha Splitter-2 is a single diameter column, with two bottom reboilers. A combination of HCO and high pressure (HP) steam provides the heating duty to this column. Additionally, the column has a low pressure (LP) steam generator in the overhead system. On the whole, the two columns combined require a substantial amount of energy to produce high-quality heart-cut naphtha.

One of the main objectives of the revamp was to lower the utility consumption of the two columns to improve profits. Furthermore, the refiner had plans to use Naphtha Splitter-2 in a different service. Thus, another objective is to produce heart-cut naphtha in the first column.

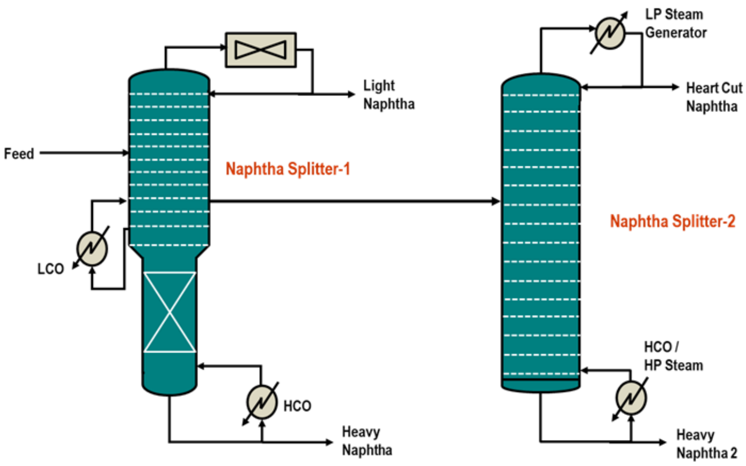

Figure 6: Original Design of Naphtha Splitter-1 and Naphtha Splitter-2

For the revamp, Naphtha Splitter-1 is converted into a middle dividing wall column (Figure 7). The column produces a better-quality heart-cut by following the same principles as the FCC unit naphtha splitter column. Thus, Naphtha Splitter-2 is removed from the service.

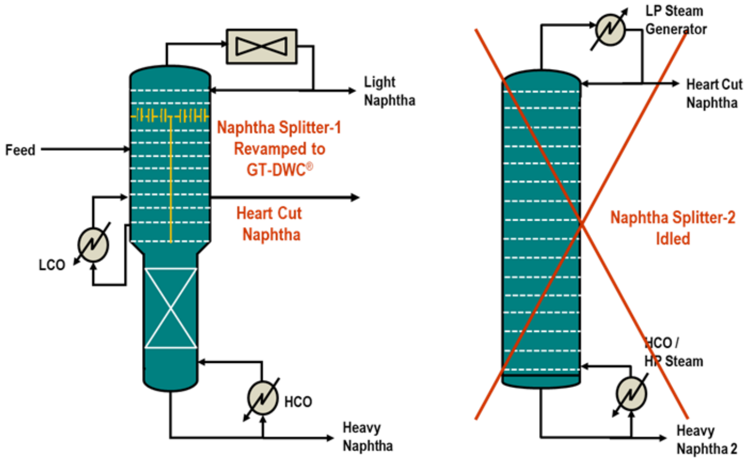

Figure 7: Naphtha Splitter-1 and Naphtha Splitter-2 after Revamp using Proprietary DWC

Table 2: Heart Cut Naphtha Specifications before and after Revamp

Parameters	Units	Naphtha Splitter before Revamp	Naphtha Splitter after Revamp to DWC
Heart-cut Flowrate	t hr-1	165.0	165.0
D86 (IBP/FBP)	°C	110.6-170.0	110.0-170.0

Revamping NS-1 into a DWC column resulted in the following improvements:

- Heating duty is reduced by approximately 25%.
- High pressure steam usage is eliminated.
- Heart-cut naphtha is obtained in NS-1 resulting in an idle NS-2 column.
- Product recoveries increased by 3.2 t/h as compared to the original design.
- Equipment modifications were avoided outside the column. The column internals were replaced with proprietary DWC column internals.

Figure 8a: Liquid Splitting Distributor in DWC column; Figure 8b: Dividing Wall Column Trays at Manufacturing Workshop

Table 3: Performance of Naphtha Splitter-1 and Naphtha Splitter-2 before and after Revamp

Parameters	Units	Conventional Design	DWC Design
Feed Rate	t hr-1	308.0	308.0
C_8/C_9 (naphthenes and aromatics)	t hr-1	110.6	110.6
C_8/C_9 (naphthenes and aromatics) Concentration	wt.%	63.9	66.5
C_8/C_9 (naphthenes and aromatics)	t hr-1	105.4	108.6
C_8/C_9 Recovery in Heart-cut Naphtha	wt.%	95.0	98.0
Reboiler Duty (LCO)	MW	12.8 (NS-1)	14.5
Reboiler Duty (HCO)	MW	10.5 (NS-1) and 6.4 (NS-2)	21.7
Reboiler Duty (HP Steam)	MW	14.3	-
Condenser Duty	MW	23.2 (NS-1) and 19.3	37.2

In both of the cases, flexibility in operation is maintained by the use of a proprietary liquid splitting arrangement (Figure 8a). In the event of a drastic change in feed, the device enables smooth and easy operation. For both of these DWCs, a combination of external and internal liquid splitting devices exists on either side of the wall. The mechanism is facilitated by gravity and therefore, does not require an additional pump or drum. Moreover, the resultant external split piping diameter is low and requires the use of low pressure drop control valves.

4. Conclusions

DWCs have been successfully implemented in the two revamp columns with favorable outcomes. In both cases, the refinery has benefitted in a variety of ways, including

- Better side-cut product quality in a single column with the same utility requirements.
- A whole column is idled in the second revamp by making the same product in one column instead of the original two columns.
- The equipment modifications are limited to the column internals.

DWCs are highly profitable in cases like these where adequate hydraulic margins are available in the original equipment. Otherwise, new equipment might be required leading to a higher CAPEX.

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