

Use of Dividing Wall Columns for Process Intensification

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Dividing Wall Column (DWC) technology provides refiners with a unique way of improving the efficiency and profitability of the traditional refining techniques (Dejanovic et al., 2010 and Kiss 2009). This technology, developed first in the 1940s, can be tailored to apply in a variety of applications ranging from naphtha/reformate splitters to gas plants and established technologies like isomerization and naphtha hydrotreating (Kalita et al, 2018). Most DWC applications found in the refining or chemical industry are based on a middle dividing wall concept (Yildirim et al., 2011). This paper discusses the distinct advantages of applying a top dividing wall column, which uses absorption and distillation concurrently (Bhargava et al., 2015), to traditional gas plant process schemes. Additionally, top DWCs offer a variety of benefits over using middle DWCs, some of which are discussed here. Each DWC solution is uniquely, specifically tailored to meet the refiner's product and energy specifications. Hence, the paper aims to provide a baseline criterion for identifying the gas plant configurations, which can benefit from the DWC concept by discussing three different gas plant process schemes.

1. Introduction

DWCs are often characterized by the presence of a vertical wall in a distillation column. A top dividing wall column places the distinctive wall at the top of the column. Top DWCs offer a host of advantages, especially in gas plants, which are generally operated under high pressures. Unlike a conventional distillation column, the top of these columns is segregated into two separation zones within the same shell with no intermixing between the two zones. As a result, they can be operated in separate modes and basically behave as two independent columns. Absorption and distillation can be carried out in a single column.

In the following sections, this concept has been implemented in a reformer unit gas plant and a FCC (fluid catalytic cracking) unit gas plant, wherein two or more columns operate in a sequence and under similar operating pressures and temperatures. The new configuration with DWC combines the operation of two or more columns, thereby minimizing both capital and energy consumption of the whole sequence.

2. Top Dividing Wall Columns in LPG Recovery from Off-gas

LPG (Liquefied Petroleum Gas) recovery units are an integral part of any refinery. In a LPG unit, two or more columns remove the C_1 - C_2 components along with other non-condensable gases, while concentrating the C_3 - C_4 components to generate LPG. Figure 1 shows an existing design consisting of a deethanizer column followed by a depropanizer column in a Texas refinery. The deethanizer column operates at a high pressure, wherein the C_1 - C_2 components are removed as the top product. The C_3 rich stream is removed in the next column. The recovery of LPG in this design is generally poor (55 wt%) due to the high operating pressures and propane losses in the off-gas. In some processes, these losses can be mitigated by using refrigeration in the overhead system, albeit with higher capital and operating costs.

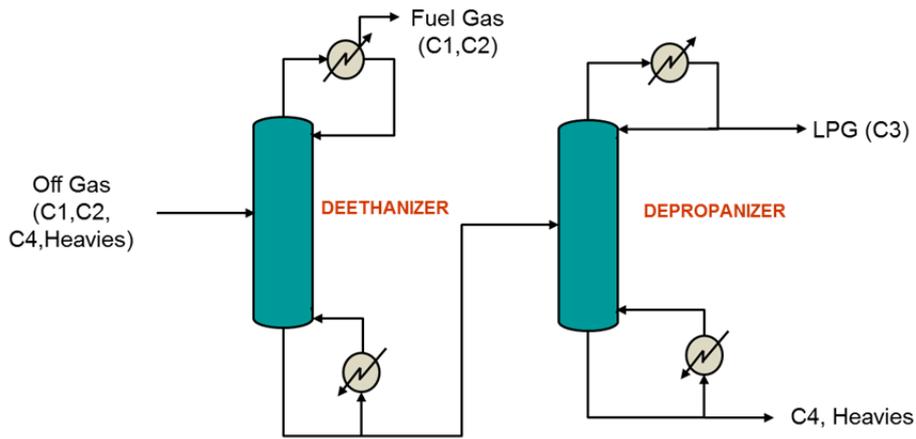


Figure 1: Conventional LPG Recovery Unit

These problems are mitigated by using a top dividing wall design. The top section of the column is operated under two different unit operations, i.e., absorption and distillation (Bhargava et al., 2015). The section of the column where the feed enters, operates under reboiled absorption. The other section of the column separates a light liquid product and a heavy bottom product using distillation. The arrangement offers the following advantages.

First, use of absorption allows the column to be operated at a lower pressure (2.2 MPa) as compared to the original deethanizer column (3.2 MPa). The absorbing solvent captures the valuable C₃-C₄ components in the off-gas and moves them towards the bottom of the column. These components are then concentrated on the other side of the DWC using distillation. The feed to the column contains a substantial amount of C₅ (30-40 wt%) and heavier components (Table 1). Hence, a portion of the heavy bottom product is used as the absorption medium (Figure 2a). This internal recirculation of the heavier components helps to minimize the energy consumption of the column. If the C₅ concentration in the feed is low, the bottoms fraction can be supplemented by an additional heavy oil solvent from nearby processes.

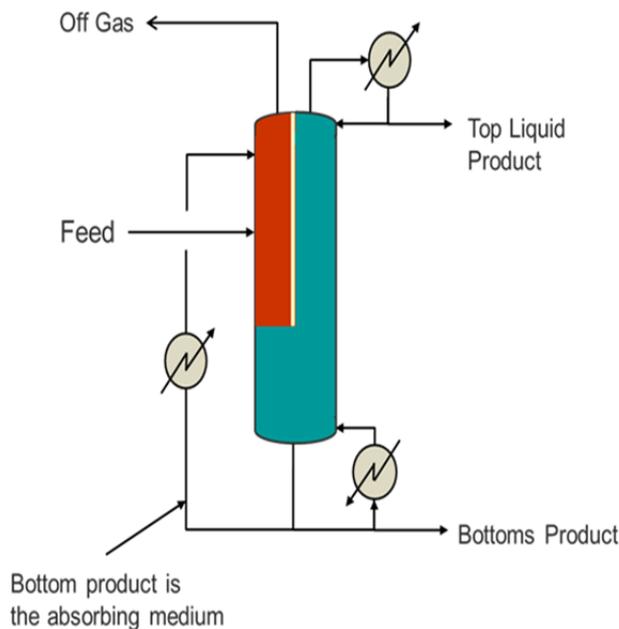


Figure 2a: Proprietary DWC Process Scheme; Figure 2b: Inside View of a Top Dividing Wall Column

Table 1: Feed Composition for Proprietary DWC Design

| Product Class | Feed Composition | | Product Specifications |
|--------------------------|----------------------------|-------|------------------------------|
| | Components | wt. % | |
| Fuel Gas | Hydrogen | 0.0 | Minimize Propane |
| | Methane | 0.3 | |
| | Ethylene | 0.0 | |
| | Ethane | 3.0 | |
| | H ₂ S | 0.5 | |
| | CO ₂ | 0.0 | |
| LPG Product | Propene | 0.1 | Propane > 90.0 wt. % |
| | Propane | 11.7 | Ethane < 1.0 wt. % |
| i-C ₄ Product | i-Butane | 8.3 | Propane < 3.0 wt. % |
| n-C ₄ Product | n-Butane | 19.6 | n-C ₄ < 4.0 wt. % |
| | | | i-C ₅ < 3.0 wt. % |
| | | | i-C ₄ < 5.3 wt. % |
| Debutanizer Bottoms | C ₅ and heavier | 56.6 | |

A combination of absorption and relatively lower operating pressure enables the use of water-cooled partial condensation in the off-gas side of the column. This is highly economical as compared to using refrigeration to mitigate C₃-C₄ losses. The benefits of the DWC configuration are shown in Table 2.

Table 2: Project Economics of Proprietary DWC Design

| Variables | Units | Conventional Design (Existing) | | DWC Design |
|----------------------|--------------------|--------------------------------|--------------|------------|
| | | Deethanizer | Depropanizer | |
| Operating Pressure | MPa | 3.2 | 2.2 | 2.2 |
| Reboiler Duty | MW | 6.4 | | 5.8 |
| Propane Recovery | % | 55.0 | | 97.0 |
| LPG Product | m ³ /hr | 5.9 | | 9.6 |
| LPG benefit/yr. | \$MM | Existing | | 10.2 |
| Total Installed Cost | \$MM | Existing | | 15 |
| Simple Payback | months | Existing | | 18 |

3. Top Dividing Wall Columns in Reformer Unit Gas Plants

A typical reformer unit gas plant proposed for an Asian refinery is shown in Figure 3. The configuration consists of a depentanizer column, followed by a debutanizer and a deethanizer. The C₅- cut, C₆ and heavier cuts are removed from the depentanizer. In the next column, the C₅s are concentrated in the bottom of the column. The C₄ and lighter cut is then processed in a deethanizer column, which removes a LPG cut at the bottom.

The three columns in this sequence operate at high pressures to condense the lights (Table 3). Additionally, the debutanizer and deethanizer columns see partial overhead condensation. Hence, a major portion of the LPG components (C₃-C₄) are lost in the off-gas.

Figure 4 shows an alternate Top DWC integrated gas plant. The depentanizer column in the traditional scheme is replaced by a hybrid DWC. The column combines the operation of the deethanizer with the depentanizer with two distinct zones – a pre-fractionation zone and a main fractionation zone. The lights are separated on the pre-fractionation side as the off-gas, with absorption reducing the liquid losses. On the main fractionation side, the C₅ and lighter components are removed as the other top product by distillation. Similar to the first design (Figure 2a) a portion of the heavy bottoms (C₆-C₇) is used to strip the gas. This arrangement allows for removal of the deethanizer column.

With the lights being removed in the first column, the debutanizer column has a total overhead condenser. LPG and the C₄ cut are obtained here. Table 3 compares the performance of the two configurations. The grassroots DWC configuration minimizes the amount of equipment (column, pumps etc.) needed as compared to a traditional grassroots reformer unit gas plant. Due to high utility costs in Asia, the column provides 20% utility savings based on less duty consumed. Additionally, 4 t/hr more LPG is recovered with a lower total installed cost over the conventional configuration.

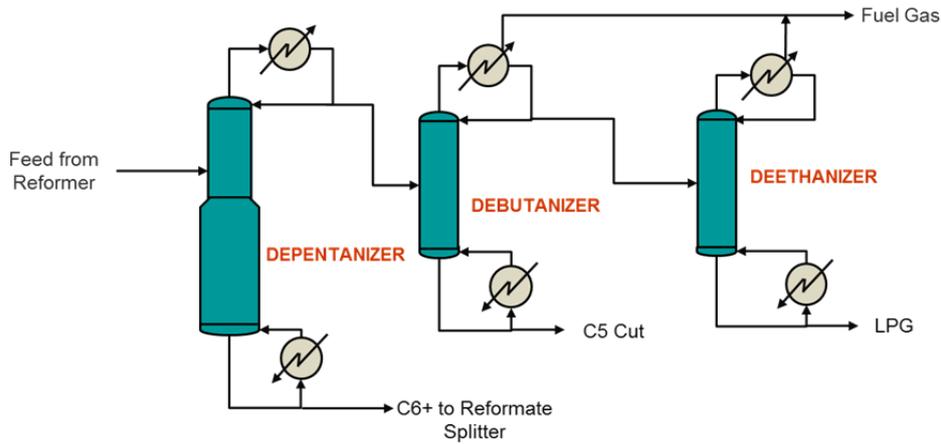


Figure 3: Conventional Reformer Unit Gas Plant Configuration

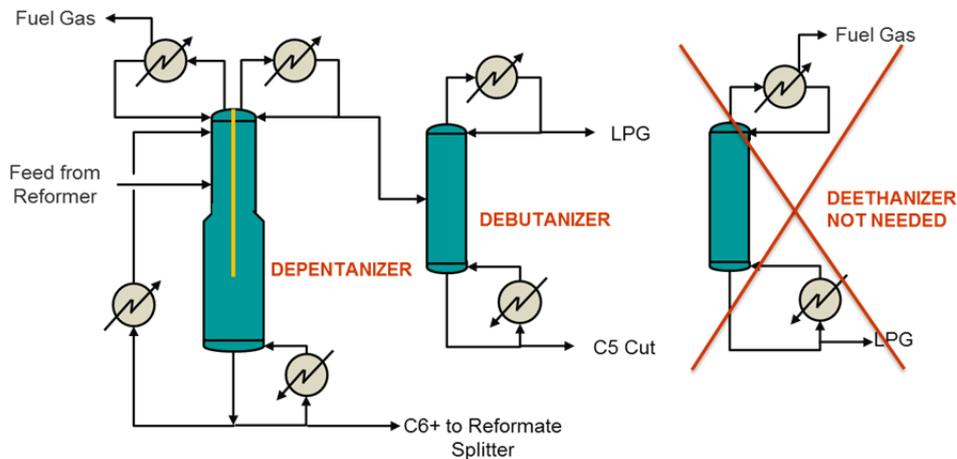


Figure 4: Reformer Gas Plant Configuration with Proprietary DWC Technology

Table 3: Performance of GT-DWC® vs Conventional Design

| Parameters | Units | Conventional Design | | | Proprietary DWC Design | |
|----------------------|-------------------|---------------------|-------------|-------------|------------------------|-------------|
| | | Depentanizer | Debutanizer | Deethanizer | Depentanizer | Debutanizer |
| Columns | | Depentanizer | Debutanizer | Deethanizer | Depentanizer | Debutanizer |
| No. of Trays | - | 40 | 33 | 27 | 40 | 40 |
| Operating Pressure | MPa | 1.0 | 1.2 | 3.2 | 0.6 | 1.2 |
| Total Heating Duty | MW | 43.1 | 2.6 | 0.6 | 33.7 | 3.1 |
| Total Installed Cost | MM\$ | 10.7 | | | 8.5 | |
| Feed | t h ⁻¹ | 386.8 | | | 386.8 | |
| C6+ Cut | t h ⁻¹ | 365.5 | | | 365.5 | |
| C5- Cut | t h ⁻¹ | 8.1 | | | 8.2 | |
| Off Gas | t h ⁻¹ | 5.8 | | | 1.7 | |
| LPG | t h ⁻¹ | 7.4 | | | 11.4 | |

4. Top Dividing Wall Columns in FCC Unit Gas Plants

Figure 5 shows an existing traditional FCC unit gas plant. The process scheme primarily consists of absorber/stripper columns, where the gases and the liquid in the feed are separated. Unstabilized naphtha (supplemented with a portion of stabilized naphtha bottoms) prevents the C₃-C₄ losses from the absorber column. The remaining C₃-C₄ are extracted by using lean oil in the sponge absorber column. Sour fuel gas and rich oil get separated at the top and bottom. The liquid product from the stripper column is processed in a debutanizer column. Sour LPG is extracted as the top product, while stabilized naphtha is recovered at the bottom. The feed for the example presented consists of 10% C₂ and lighter gases.

The conventional design generally consists of three stages for the separation, the absorbing and stripping section followed by distillation in a debutanizer column. Using Top DWC technology, the three stages can be integrated into a single column (Figure 6).

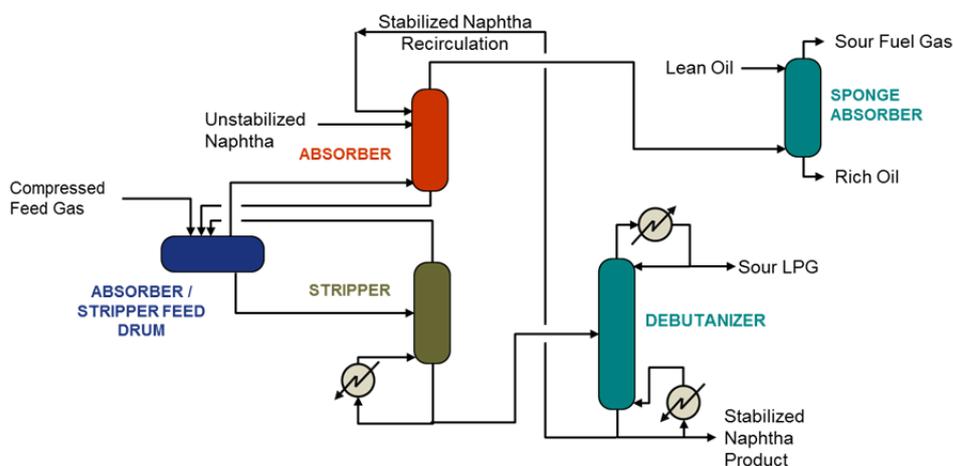


Figure 5: Typical FCC Unit Gas Plant Configuration

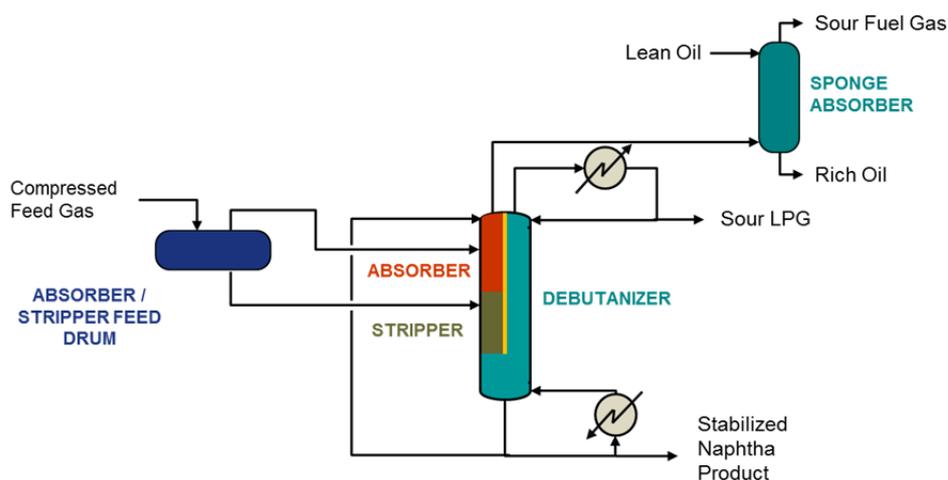


Figure 6: FCC Unit Gas Plant Configuration with Proprietary DWC

For feed cases where a large amount of C₂ and lighter gases are present, the DWC column as shown in Figure 6 needs to be supplemented by use of an additional absorber/stripper column. The absorber/stripper column in that case will remove the lightest gases while the DWC column can be used to recover the LPG product.

In Figure 6, the two sides of the top half of the DWC column essentially behave as individual columns with independent overhead systems and controls. The wall is designed mechanically to avoid leakage between the two sides, thereby avoiding contamination. Additionally, the parallel zones can be designed process-wise and mechanically to provide similar stages for separation as compared to regular columns. Doing so results in a column which is 20% bigger in size as compared to individual columns. However, lower equipment requirements in DWCs (Table 4) still result in a capital cost savings of approximately 20-30% than in the conventional columns (Asprion et al, 2010).

A portion of the bottoms product is circulated as the absorption medium in the section where the feed enters. This operation is similar to that of the absorber in the conventional design. The liquid portion of the feed enters below the absorption section. The C₃-C₄ components move down the wall aided by absorption. Once across the wall, these components are concentrated as the top product by rectification and stripping. The stabilized naphtha is removed as the bottom product. Table 4 gives a comparison between the two designs.

Table 4: Comparison between Conventional Design and GT-DWC® Design

| Parameters | Units | Conventional Design | GT-DWC® Design |
|----------------------------|-------------------|---------------------|----------------|
| No. of Columns | - | 4 | 2 |
| Total Heating Duty | MW | 11.5 | 9.2 |
| Utility Savings (Quantity) | % | - | 20.0 |
| Feed rate | t h ⁻¹ | 55.3 | 55.3 |
| LPG Recovery | Vol % | 85.1 | 85.1 |
| C4 Recovery | Vol % | 98.8 | 99.6 |

In top DWCs, the two top sides of the column typically see a temperature difference of around 30-40°C. The heat transfer across the wall in such situations has been observed to be minimal and can be minimized by appropriate mechanical design. Figure 2b shows an operating top dividing wall column at a BPCL refinery in India. The design of DWCs requires a synergy between the process design and mechanical design. In many cases, the position of the dividing wall is not symmetrical. One side can be either equal or larger than the other based on the feed and product specifications. To minimize process inconsistencies in such cases, it is recommended to have the dividing wall and the dividing wall section internals as a part of the whole internals package. The wall and internals are fabricated separately from the shell. At the site, the internals and wall are installed in parts in the shell.

5. Conclusion

Gas plants are a vital component of any refinery. These columns have always been operated using well-established distillation techniques. However, Dividing Wall Column concept, primarily top DWCs, can generate a leaner and efficient system. DWCs lower both equipment cost and energy consumption of most configurations. These are highly customized solutions that are engineered based on the refiner's particular product and energy requirements. In some cases, as shown in the examples in this paper, these novel distillation columns can even provide better products as compared to the conventional columns. Integrating DWCs in gas plants is a viable option for process intensification in existing and future gas plant configurations.

References

- Asprion, N., Kaible, G., 2010, *Dividing Wall Columns: Fundamentals and Recent Advances*, Chemical Engineering Processing: Process Intensification, 49, Issue 2, 139-146
- Bhargava, M., Kalita, R., Kockler, D., 2018, *Dividing Wall Columns for Gas Plants*, PTQ Magazine, Q2, 75-78.
- Bhargava, M., Nelson, C., Gentry, J.C., Siddamshetti, V., 2015, *Improved Distillation Efficiency*, Hydrocarbon Processing, January, 1-4.
- Dejanovic I., Matijasevic L., Olujic Z., 2010, *Dividing Wall Column: A breakthrough towards sustainable distilling*, Chemical Engineering and processing, 49, 6, 559-580.
- Kalita, R., Kanda, A., 2018, *Create a Network of Dividing Wall Columns in Complex Process Units*, Hydrocarbon Processing: Process Optimization, May, 85-88.
- Kiss A., 2009, *Reactive Dividing-Wall Columns – How to get more with Less Resources*, Chemical Engineering Communications, 196, 1366-1374
- Yildirim O., Kiss A., Kenig E., 2011, *Dividing Wall Columns in Chemical Process Industry: A review on current activities*, Separation and Purification Technology, Elsevier, 80, 403-417