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# Optimal Operation of Dividing Wall Column using Enhanced Active Vapor Distributor

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Due to its outstanding energy and capital cost-saving potential, a dividing wall column (DWC) has gained importance for the last two decades. Unlike conventional distillation columns, the DWC has more design and operation variables, such as controlling liquid split and vapor split ratios. Liquid split and vapor split ratios need to be actively tuned during the operation to obtain optimal performance of DWC. However, it is not yet reported any active vapor split control device implemented in any existing industrially applied DWCs. Recently, Benit M has successfully developed an enhanced active vapor distributor (EAVD®) to overcome the existing problems of DWC associated with the vapor split control. In the EAVD®, the window opening area of the vapor flow path is hydraulically adjusted by changing the liquid level of a modified chimney tray. The adjustment of liquid level can be done by operating the control valve in each section of DWC. The EAVD® was tested under different operating conditions to demonstrate its reliability. The results showed that the EAVD® was able to actively adjust the desired vapor split ratio during operation along with the liquid split ratio variations. Currently, despite its great potential to notably reduce costs, only hundred DWCs are being operated in the industry. The EAVD® considerably aims to close this gap. Without any risk, the modification of existing DWCs also could be done easily by substituting the conventional chimney tray with the EAVD® to improve its operability and flexibility to maximize the benefit obtained by the advantages of DWC.

## 1. Introduction

Distillation processes are the most important separation technique used in the chemical industries (Zaine et al, 2015). In the distillation column, the components are separated through the vapor-liquid contact (Kister, 1992). In the last few decades, for the separation of multi-component mixtures, a dividing wall column (DWC) is gained huge interest due to its ability to save energy and capital cost (Chaniago et al., 2016). DWC is combining two conventional distillation columns into one shell-column equipped with one or more vertical wall-partitioned inside of the column which divides the internal space into two or more separation zones (Zhang et al., 2017). Therefore, as can be seen from Figure 1, in the general DWC, liquid flowing down from above and vapor flowing up from the bottom of the dividing walls needs to be split properly into different sections, usually called by pre-fractionation and main-fractionation sections.

Similar to the conventional distillation column operation, in the most existing DWCs, the operator can simply adjust only the liquid split ratio by using an active liquid splitter, while at the bottom, the vapor flow is split according to the hydrostatic pressure on both sides of the dividing wall. Vapor splitting device is fixed at the designing stage according to the size and number of a chimney for vapor flowing in each section. Consequently, when the feed condition is changed, the DWC requires higher reboiler duty to maintain the purity of the product streams. Therefore, it is irrelevant to the original purpose of using DWC instead of two conventional column system. To address this issue, several methods were proposed for vapor split ratio adjustment during the last five years as summarized by Huaqiang et al. (2016). However, real implementation of those proposed methods in the industrial application has not been reported yet, due to the issues related to the structural problem, mechanical stability, or uneven vapor distribution. Accordingly, the present study is to solve the problems related to the vapor splitter in DWC by providing a noble vapor splitter called an Enhanced Active Vapor Distributor (EAVD®) which has a simple structure and easily adjusting the vapor split ratios with

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respect to the liquid level in the chimney tray. The main objective of this study is to investigate the pressure drop behaviour in the EAVD® during vapor split adjustment by maintaining all the advantages of the DWC. In the previous study (Kang et al., 2017), the EAVD® with type-H cap was carried out. The present study was carried out by using the pilot of EAVD® with type-S cap which is equivalent to the bottom section of dividing wall section.

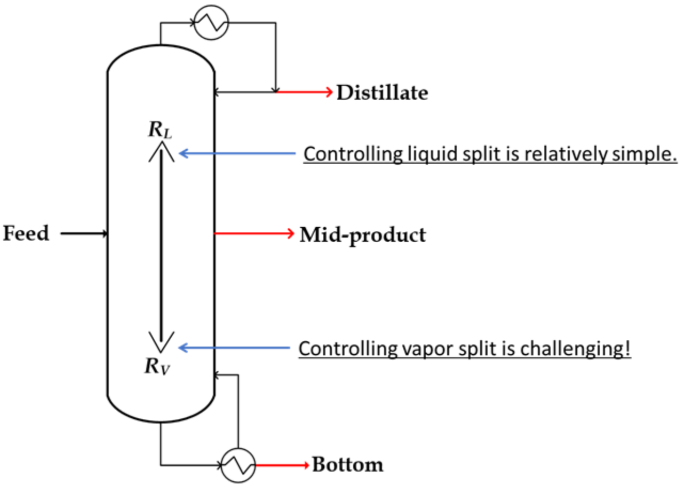

*Figure 1: Dividing Wall Column and its concerns during the operation*

## 2. Enhanced Active Vapor Distributor and its experimental study

### 2.1 EAVD® configuration

As can be seen in Figure 2, the EAVD® including a chimney tray dividing an internal space of a column into an above and bottom section. A cap with certain height is installed above the top plate, and the cap is covering the chimney with a window in the side of the cap. Thus, the vapor coming out through a window in the end of the chimney discharges to the above section through the window. The liquid which flows from the above section is collected on the chimney tray, and the vapor flow through the cap window is tuned by adjusting the liquid level on the chimney tray. Similar to the principle of the conventional liquid splitter, the liquid pipeline in the side of dividing wall is connected to drain the liquid from the chimney tray to the section below. This chimney tray is called EAVD®.

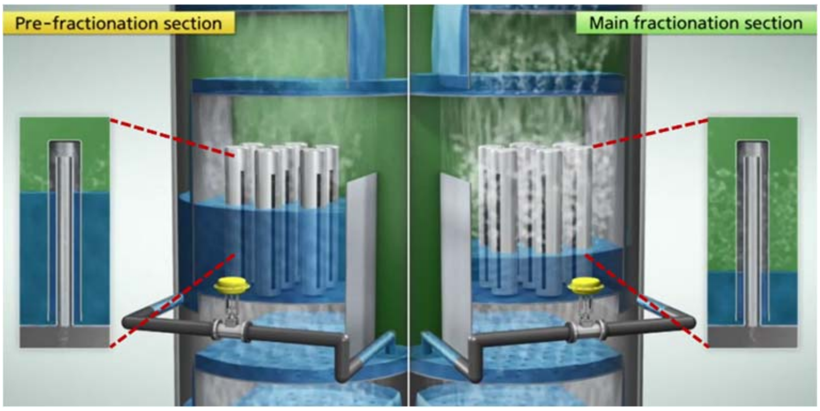

*Figure 2: EAVD® configuration in Dividing Wall Column and its visualization of the liquid level adjustment.*

### 2.2 Experimental study

Figure 3 shows the photograph and schematic of the EAVD® laboratory setup simulated DWC which includes two columns equivalent to each dividing wall section of DWC. Table 1 lists the dimensions of the column, tray, and caps used in the EAVD® laboratory setup. Note that the two partitioned sections were designed symmetrically. In this study, a single S-cap was used to investigate the reliability of EAVD®.

*Table 1: Details of the caps and internal column dimensions*

| Variable | Value |
|---|---|
| Diameter of sieve tray hole | 2.6 mm |
| Sieve tray % hole area | 5.84% |
| Height of type S-cap | 280 mm |
| Inside diameter of cap | 54 mm |
| Outside diameter of cap | 60 mm |
| Inside diameter of vapor channel | 27.8 mm |
| Number of window in the cap | 1 |
| Window area in the cap | 675 mm$^2$ |

For evaluating the performance of EAVD® at the different circumstances, the vapor and liquid split ratios can be defined as Eq(1).

$$R_V = \frac{V_1}{V_2};\ R_L = \frac{L_1}{L_2} \tag{1}$$

where $R_V$ and $R_L$ are the vapor split and liquid split ratios, respectively. $L_1$ and $V_1$ are the liquid and vapor flow into section 1, respectively, and $L_2$ and $V_2$ are the liquid and vapor flow into section 2, respectively. Note that the total inlet liquid and vapor flow rates were maintained at 15 L/h and 15 Nm$^3$/h, respectively, in all experiment runs.

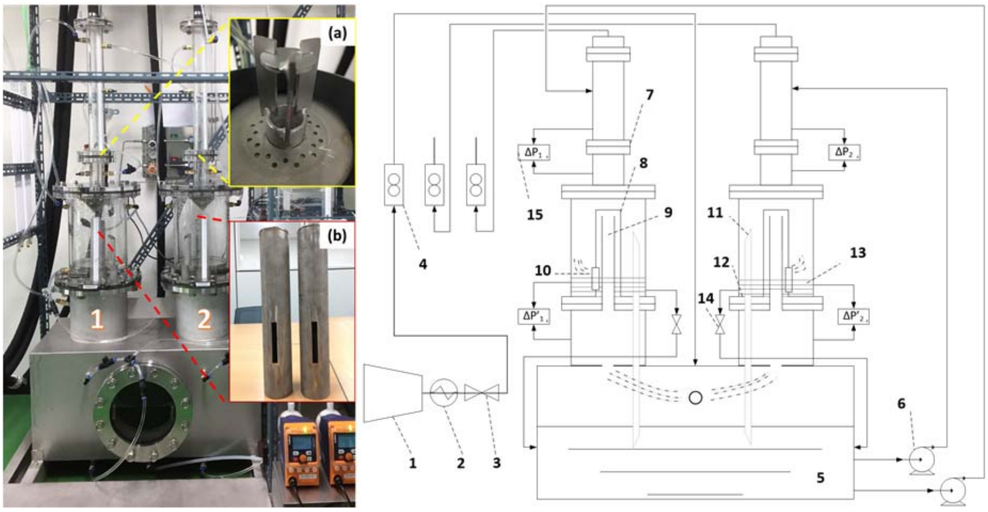

*Figure 3: Left: Photograph of the EAVD® laboratory setup (1 and 2 are pre-fractionation and main fractionation sections, respectively) with inset showing (a) sieve tray and (b) S-cap used in this study. Right: Schematic of laboratory setup for the assessment of the EAVD®: 1. Air compressor; 2. Air cooler; 3. Valve; 4. Air flow meter; 5. Water storage; 6. Metering liquid pump; 7. Sieve tray; 8. S-cap; 9. Chimney for vapor channel; 10. Window; 11. Liquid drain channel; 12. The base of EAVD® chimney tray; 13. Liquid level; 14. Liquid level control valve; 15. Manometer.*

### 2.3 Study of pressure drop behavior

During the design and operation of DWC, the vapor divides into two sections to give an equal pressure drop between the sections on each side of the dividing wall. Therefore, the vapor splits are dependent on the position of the dividing wall and the liquid loading of the two sections at each side of the dividing wall (Mutalib and Smith, 1998). By having a conventional chimney tray for vapor distribution, the equal pressure drop can be given by the Eq(2).

$$\Delta P_1 + \Delta P_1' = \Delta P_2 + \Delta P_2' \tag{2}$$

where $\Delta P_1$ and $\Delta P_2$ are the pressure drop across the packing or trays in section 1 and section 2, respectively. $\Delta P_1'$ and $\Delta P_2'$ are the pressure drop in the chimney tray of vapor splitter on section 1 and section 2, respectively.

Generally, optimum vapor split ratio is fixed during the design stage for a certain operating condition. It is given by the pressure drop across both sections, which depends on the internal type and geometry that cannot be changed during continuous operation. Meanwhile, the vapor split ratio deviates from the designed value in operation, once other operating parameters are changed (Sangal et al., 2013). The vapor split ratio is changed automatically to approach the equal pressure drop state (Maralani et al., 2013) which was mentioned in Eq(2). Here, the EAVD® is expected to be able to compensate the change of pressure drop differences across the packing or fractionation trays between each section above by adjusting the pressure drop differences in the EAVD®. The adjustment of pressure drop can be done by manipulating the liquid level in the chimney tray. In the present work, it was decided to demonstrate the study using a sieve tray as internals. The experiments were carried out to demonstrate the compensation of change of pressure drop difference across the sieve tray that can be covered by adjusting the liquid level in the EAVD®. In this study, the pressure drop can be measured through the manometer.

The correlation to evaluate the change of pressure drop differences ($\Delta\,(\Delta P)$) that can be covered by single S-cap EAVD® across the sieve tray is described in Eq(3).

$$\Delta\,(\Delta P) = |\Delta P_1 - \Delta P_2| = |\Delta P_1' - \Delta P_2'| \tag{3}$$

## 3. Results and discussion

The EAVD® was designed to distribute the vapor flow properly in both sections of DWC. During operation, any operating conditions can be changed depending on the feed compositions, product purity, etc. In order to obtain a desired L/V ratio, vapor flow needs to be tuned to increase the vapor flow in the section where the liquid load is increased. In an imbalanced L/V ratio, the efficiency reduction of fractionation tray or packing can be observed and non-uniform froth height generation can reduce overall column capacity (Bolles, 1976). Therefore, three sets of experiments were done to examine the EAVD® performance: (a) the EAVD® was operated at the constant liquid split ratio ($R_L$: 1), (b) the EAVD® was operated to obtain a constant L/V ratio, (c) a case study of DWC operation.

### 3.1 Assessment of the pressure drop behavior of DWC using the EAVD®

The change of pressure drop difference across the sieve tray above should be compensated by the pressure drop change in the EAVD® so that proper distribution of the vapor to the section above could be achieved.

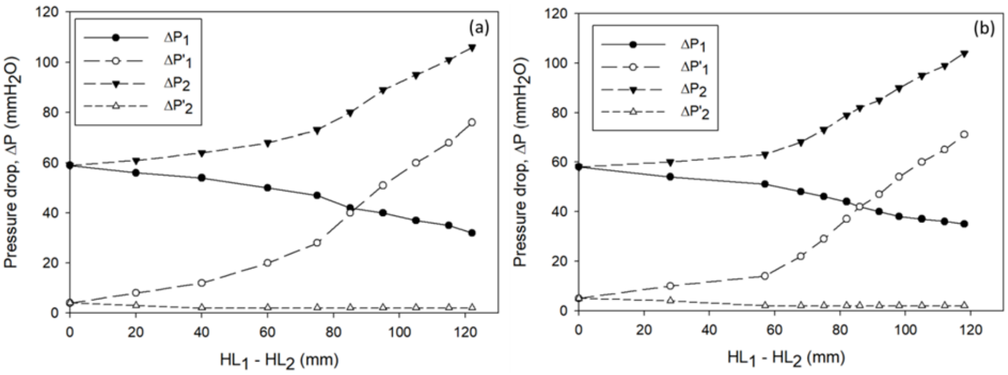

*Figure 4: Effect of the liquid level difference in both sections to the pressure drop in two different set of the experiment: (a) using the constant liquid split ratio: 1 and (b) to obtain constant L/V ratio.*

Thus, the effects of the liquid level variation on the pressure drop behaviour and its vapor split ratio were examined in two experiment sets. In the first experiment, initially, the liquid level of both sections was maintained at the same level (35 mm above the bottom of the window). In this manner, the vapor was divided equally into both sections. Further, for each run, the liquid level of section 1 was increased by every 10 mm until the maximum level (liquid overflowed through the downcomer) and the liquid level of section 2 was decreased by every 10 mm up to the minimum level (window was fully open). In the second experiment, the liquid level was adjusted to maintain constant L/V ratio for each experiment run. To obtain the proper vapor split ratio, the height of liquid level increasing in section 1 was same with the decreasing of the liquid level in section 2 until the window in section 2 was fully open, while the liquid level in section 1 can be adjusted up to the maximum level. As can be seen from Figure 4a, by altering the liquid level of chimney tray sequentially, one can change the pressure drop behavior in the chimney tray and sieve tray above. Moreover, it is clearly seen in Figure 4b, once the $\Delta P_2$ becomes higher due to the higher liquid load in section 2, one can increase the pressure drop in chimney tray of section 1 ($\Delta P_1'$) to supply more vapor in section 2. Therefore, it can be concluded that the EAVD® was able to compensate the pressure drop differences of the tray in each section, ($\Delta P_2 - \Delta P_1$), by adjusting the pressure drop differences of EAVD® in each section, ($\Delta P_2' - \Delta P_1'$).

Figure 5 shows the change of vapor split ratio as the effect of the liquid level difference and the change of pressure drop differences. The vapor split ratio (solid line) changes as the result of a change of pressure drop differences in both sections. For this reason, the vapor split ratio decreased with the liquid level difference ($HL_1 - HL_2$) due to lower liquid level in section 2 and higher liquid level in section 1. As can be seen in Figure 5a, in the constant liquid split ratio, sequential difference of liquid level can easily change the vapor split ratio. Further, Figure 5b shows once the liquid split ratio is reduced or increased, the vapor split ratio can be adjusted in the same manner. It shows that the EAVD® could adjust a required vapor split ratio to maintain a constant L/V ratio simply by changing the liquid level in both sections. Besides, this experiment shows that when the window is closed in section 1, yet one can adjust the liquid level in each section to fulfil a desired vapor split ratio.

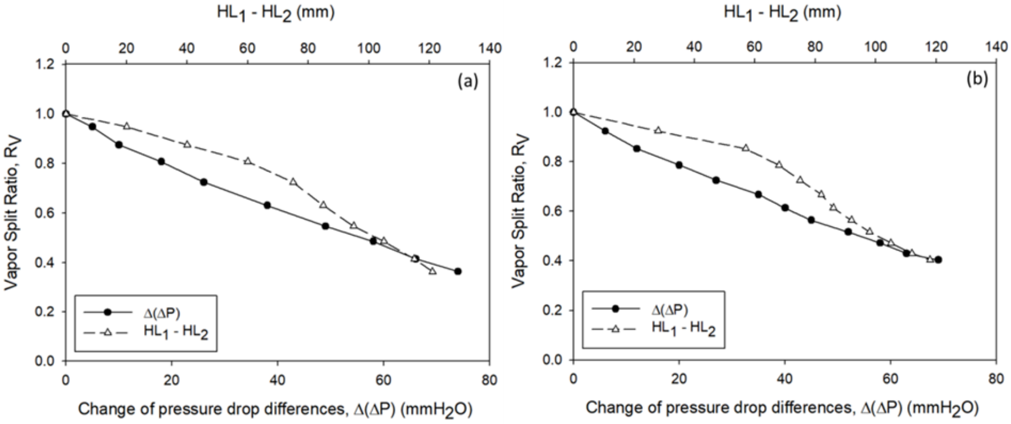

*Figure 5: Effect of the liquid level difference in both sections to the vapor split ratio for the different set of the experiment: (a) using the constant liquid split ratio: 1 and (b) to obtain constant L/V ratio.*

### 3.2 Assessment of the EAVD® to adjust proper vapor split ratio during DWC operation

The case study which will be discussed here is to illustrate DWC operation where the liquid and vapor flow rate to both sections of DWC changes from its optimal design. Experimental results of the case study are summarized in Figure 6.

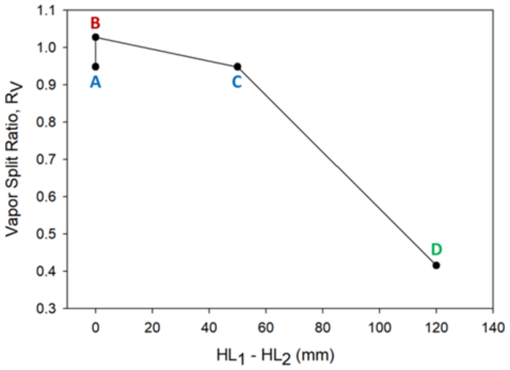

*Figure 6: Summary of a case study during DWC operation: (A) Design, (B) Without EAVD®, (C) EAVD® adjust the same $R_V$ as designed, and (D) EAVD® adjust to supply more vapor in section 2.*

In the design stage, the optimum vapor split ratio was 0.95 (see point A in Figure 6). A conventional chimney tray was designed to have a vapor distribution in both sections as a designated value. In order to simulate any changes of circumstances during operation, a higher liquid flowrate was loaded to section 2 while the total reflux rate remains the same. It means the liquid split ratio is lower than designed ratio. Without active vapor splitter in the conventional chimney tray, vapor flow rates in the two sides of the DWC have been adjusted naturally in such a way that the pressure drop across the two sides of the column remains the same (see Eq(2)). Thus, the vapor split ratio responds in the opposite way to the liquid split ratio change. As a result, the vapor split ratio was increased to 1.03 (see point B), which means higher than the designed value. It results in an unfavourable loss of separation efficiency (Lee et al., 2011). The EAVD® was able to adjust the vapor split back as designed by maintaining the higher liquid level in section 1 in order to provide liquid level difference about 50 mm (see point C). Moreover, when the liquid load in section 2 increases significantly, the vapor load also needs to be increased in this section to maintain a desired L/V ratio in both sections. By lowering the liquid level in section 2 and lifting the liquid level in section 1, the higher vapor flow can be accomplished intentionally as can be seen in point D of Figure 6. It shows that the control or change of the pressure drop in the EAVD® is accomplished as desired, thereby uniformly distributing the vapor being presented over the chimney tray which comes from a lower section of a DWC. Therefore, it can improve the operation performance of a DWC and maintain its energy-saving efficiency.

## 4. Conclusions

Practically, DWC had some application limitations, that limited its advantage in the chemical industries. The most concern was the unavailability of vapor split ratio adjustment during operation to control the vapor flow on each section of DWC. The proposed EAVD® addressed the need for vapor split control during DWC design and operation successfully. In the EAVD®, vapor split control was implemented using a modified chimney tray with a specially designed cap. The liquid level of the chimney tray on each side of the dividing wall section was adjusted to control the vapor flow split. By altering the liquid level in the modified chimney tray of both sections, the EAVD® was proven to be able to compensate the change of pressure drop differences across a packing or fractionation trays in both DWC sections above the EAVD®. From the three experiment sets performed in this study, it can be concluded that once the EAVD® installed in a DWC, the operator could increase a vapor flow in the section in which the liquid load is increased and rigorously maintain a desired L/V ratio during operation in accordance with changes in any operating conditions. Furthermore, the EAVD® can be implemented and designed not only to control the vapor split ratio precisely and continuously, but also to distribute the vapor uniformly to the upper section. By addressing critical issues associated with vapor splitting during operation, it is expected the proposed EAVD® technology can provide a promising solution to expand the DWC implementation over the next few decades and make a contribution to establish DWC as a standard distillation equipment.

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