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IMPROVED HIGH PERFORMANCE TRAYS

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Abstract
From a design and hydraulic standpoint, trays are relatively complex distillation internals. In the ongoing search for higher performance trays, one first must understand the hydraulic and mass transfer aspects of the tray operation such as entrainment, downcomer flooding, and vapor liquid contact. When this is well understood, then various aspects of the deck and/or downcomer designs can more easily be modified to achieve performance improvements.

As a result of this process, Sulzer has developed a promising new design for a high performance distillation tray that demonstrates significant improvements in capacity over a broad range of air/water simulator operating rates. Depending on the operating region, capacity gains in excess of 10% have been verified in comparison to existing high performance trays.

This paper will discuss design strategies and important tray operating parameters. Design characteristics of the new high performance tray will be presented and discussed. Test data from this new tray will be shown to demonstrate its improved performance.

Keywords: tray, deck, valve, performance, capacity

1. Introduction

As with any distillation device, trays are judged on performance by a combination of capacity and efficiency. For a device to be successful, it must have good baseline efficiency and have the capacity to meet process requirements as compared to other design alternatives. Trays have a variety of mass transfer and hydraulic capacity mechanisms that vary with process conditions; understanding these mechanisms and providing the proper internal is of critical importance.

When looking at tray capacity, the balance between vapor and liquid handling must be well understood. For example, in low pressure distillation, the vapor densities are low and there will be volumetrically a much larger amount of vapor flowing through the column. In this case, vapor handling capacity is a critical factor. In these highly vapor loaded systems, entrainment capacity is typically more important than downcomer capacity. Conversely, in high pressure distillation operations, the vapor density is higher and the vapor volume is lower so the liquid handling within the downcomer becomes the most important aspect.

Sulzer's tray development efforts have recently produced some interesting devices that provide performance improvements for a variety of process conditions. These devices show that improvements of over 10% can be achieved in air/water test systems with identical test conditions and configurations. An elevation drawing of the test column is shown in Figure 1.

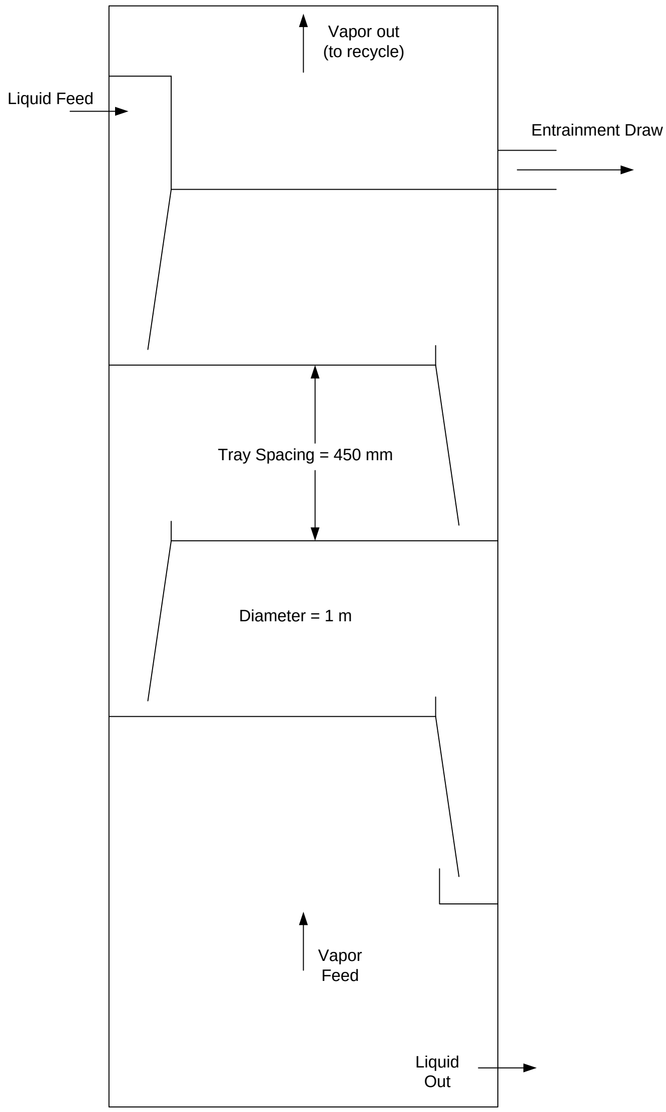

Figure 1. Air/Water Simulator Test Configuration

Since this test system operates at atmospheric pressure, which is considered a "low" pressure, the tray improvements deal mainly with entrainment control rather than liquid handling. Varied liquid rate testing shows that these improvements will likely decrease with liquid loading rates but still remain substantial through moderate to high liquid load conditions.

The emphasis on hydraulics for the new devices that were operating in the entrainment regime was two-fold. First, the device needed to be resistant to entrainment from the tray below. Since most low pressure tray designs lose efficiency prior to flooding due to excessive amounts of entrainment, a device that is resistant to entrainment from below should extend the efficient capacity of the tray. One thing that needs to be understood is that entrainment typically increases exponentially with vapor loading; once entrainment starts, it increases very quickly with further increases in vapor loading. This means that, unless the device is capable of handling 100% liquid entrainment (like a Shell ConSep™ tray), improvements for partial entrainment handling can only hope to increase the vapor side capacity by a modest amount, perhaps 10% or less, before being inundated with entrainment. The intent of these device modifications was therefore to delay the effects of incipient entrainment rather than process vast amounts of entrainment.

The second point of emphasis for hydraulics was the reduction of entrainment generation from the top of the tray deck itself. This function must also be weighed against the efficiency of the device. If the device is to have good efficiency, there must be good mixing between the vapor and liquid. This means that the momentum of the vapor must be imparted into the liquid pool on the tray deck above to generate the interfacial area required for mass transfer. However, as the vapor moves through and mixes with the liquid, it is likely to drag the liquid upward and increase the amount of entrainment. This brings us to another point where the balancing of the tray design to achieve good performance is extremely important.

2. Entrainment Resistance

When looking at a tray operating in an atmospheric pressure system, it can be seen that the flow is quite violent at moderate to high vapor loading levels. Large amounts of liquid are being projected all around the tray deck. At very high loadings, much of this liquid reaches the tray deck above and much of that liquid is then entrained upward through the deck orifices and is effectively backmixed with the liquid on the tray above. Entrained liquids can be classified into primary or secondary types. Primary entrainment is liquid that carries directly to and through the deck orifices. Secondary entrainment is liquid that coalesces on the bottom of upper tray deck and remains there until it is subsequently drawn into the surrounding deck orifices by the vapor flowing through them.

When trying to improve the entrainment resistance of trays, the designer has the option to address either of the entrainment mechanisms separately or together. The most common method of entrainment resistance is the use of a layer of structured packing placed beneath the bubbling area of the tray. The packing coalesces entrained liquid and directs it back to the tray below. This effectively addresses both entrainment mechanisms by capturing liquid and not allowing liquid to reach the tray deck level until entrainment rates become excessive and the packing becomes overloaded with liquid. This method is generally effective in delaying the effects of entrainment but is rather expensive. Material selection is also quite important for this design since structured packings tend to be quite thin compared to tray construction materials.

The new Sulzer tray design minimizes primary entrainment but also reduces secondary entrainment. Through extensive testing, an optimized design has been developed which improves tray capacity by approximately 5% over a wide range of liquid loading conditions. For this comparison, the downcomers are identical and valve size and layout are identical. The only change is that the decks have been modified with de-entrainment devices. These results are shown below in Figure 2.

3. Reduced Entrainment Production

Another method of minimizing the effects of entrainment is to reduce the source of entrainment generation. As mentioned earlier, this generally must be done without sacrificing tray efficiency. For example, if the deck orifices of a sieve tray were fitted with tubes that extended 100 mm above the tray deck, entrainment would be greatly reduced. However, tray efficiency would also be dramatically reduced since the vapor would effectively bypass most of the liquid on the tray deck. Therefore, the vapor must be introduced into the liquid pool on the tray deck in a uniform manner that creates effective mixing while minimizing entrainment.

Over the years, various valve or orifice designs have been used on distillation trays in an effort to increase performance. Sieve holes, round valves, rectangular valves have all been tried with only minimal differences seen with respect to capacity versus valve or orifice shape. Much work has also been done with valve and orifice sizes where smaller valves tend to produce less entrainment and pressure drop than larger orifice devices. Results show that an orifice with an equivalent diameter of about 15 mm gives the optimum balance between capacity and efficiency. This is the size region where Sulzer's MVG™ valves have been successfully applied.[1]

As a result, Sulzer's tray development programs often use the basic MVG valve shape and size as a starting point and then make modifications to improve the performance. Specifically, Figure 3 shows that in the air/water test system, an improvement in the order of 15% can be seen with this new tray deck and valve configuration. When combined with the tray modifications discussed in the entrainment resistance section, this new tray valve achieved even further improvements in performance in air/water, showing that the benefits of both these valve modifications are essentially cumulative (see Figure 4).

Although we expect this device to operate at a similar efficiency as MVG trays, the efficiency of this new device will need to be to be validated in a standard hydrocarbon test system like chlorobenzene/ethylbenzene at atmospheric pressure and perhaps other test systems at higher pressures. These data will be released when available.

4. Test Data

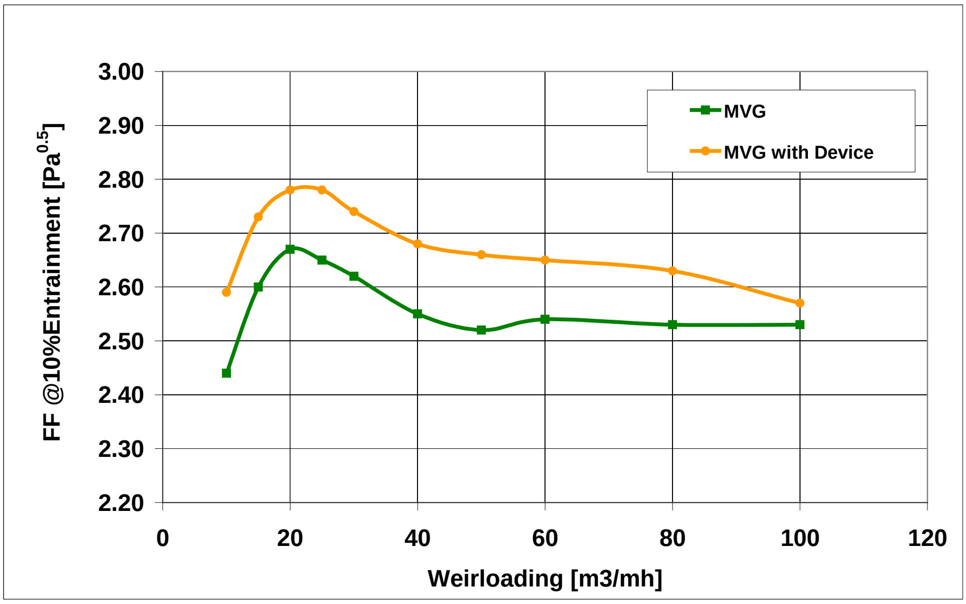

Figure 2. Improvement with De-Entrainment Devices

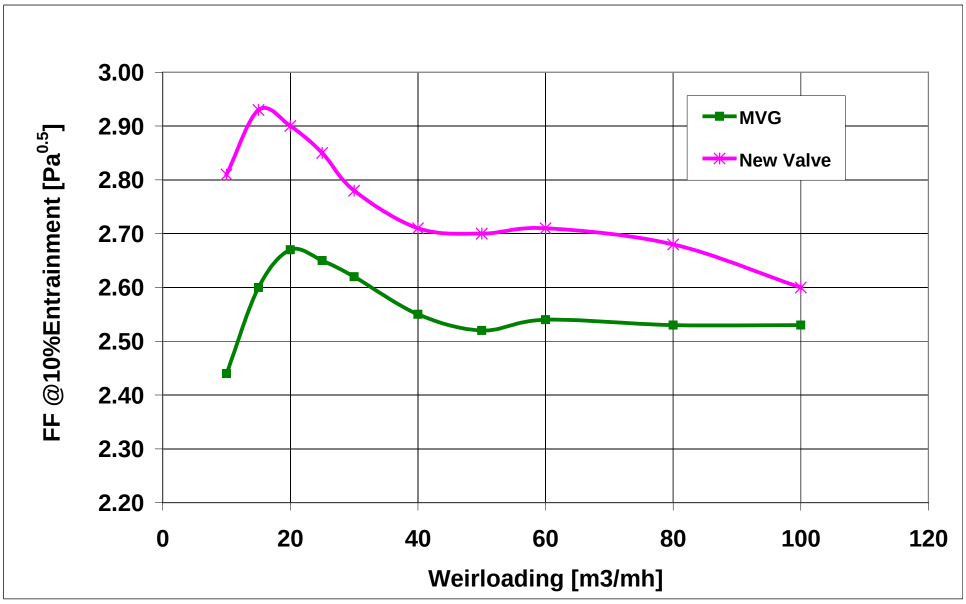

Figure 3. Improvement with New Valve Shapes

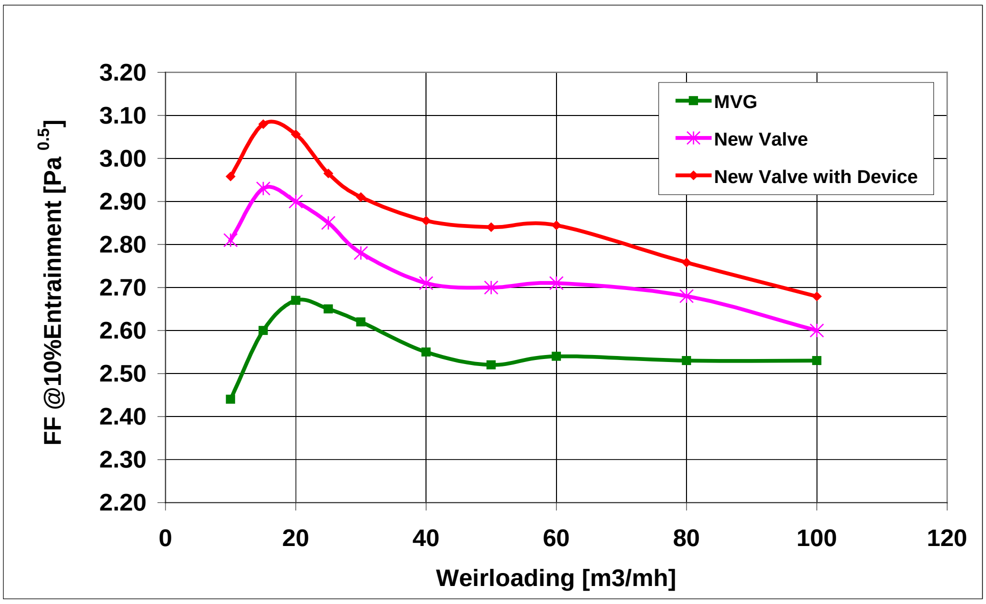

Figure 4. Improvements with Combined Valve Modifications

5. Conclusions

Although many tray orifice and valve designs have been evaluated and used during the long history of tray design, recent results show that valve and tray deck modifications can still be used to obtain significant increases in tray performance beyond what is currently considered state of the art. As would be expected, changes to valves and tray decks are more likely to affect the trays operating at moderate to lower distillation pressures since that is where the emphasis on vapor handling is the most dominant. Test results show that an increase in capacity in the order of 15% can be achieved at the lower liquid loading rates and that an increase of over 10% can be obtained at moderate to high liquid loads as well. This makes this new tray device interesting for nearly all trayed applications with the ability to improve performance across a wide variety of liquid operating ranges.

6. Bibliography

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