HIGH-PERFORMANCE TRAYS: GETTING THE BEST CAPACITY *AND* EFFICIENCY

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KEYWORDS: trays, efficiency, capacity, high-performance

INTRODUCTION

In 1815 Cellier-Blumenthal patented the bubble-cap tray. In a distillation process patented in 1832, Anneas Coffey mentions the use of sieve trays. For about 120 years bubble-cap and sieve tray technology remained unchanged. In the 1950s the performance of these cross-flow trays was improved by using large movable valves and sloped downcomers. This remained the state-of-the-art in tray technology for almost 40 years. In the 1970s and 1980s new random packing and the advent of structured packing made serious inroads on the cross-flow tray domain. Vacuum and low-pressure applications were taken over by packing. The packing products guaranteed low pressure drop, high capacity and high efficiency. However, since the 1990's trays are on the rebound. The developments that led to the renewed interest in trays are covered in this paper.

HIGH PERFORMANCE CROSS-FLOW TRAYS

Research showed that small diameter valves have a higher jet-flood capacity and higher efficiency than large diameter valves. This led to the introduction of the patented **MINIVALVE**® technology by Koch-Glitsch(1,2). The fixed-valve version is called VG-0, and the movable-valve version is called MV-1. The shape and dimensions of these valves ensure good liquid/vapor mixing without imparting excessive directionality to the froth flow. VG-0 fixed valves were recently used on the **SUPERFRAC**® high-performance tray that was tested at the Fractionation Research Institute (FRI) using the i-C4/n-C4 test system at 165 psia. This tray showed an efficiency of in excess of 105% up to close to the flood point. These test results confirm that the MINIVALVE technology by Koch-Glitsch can be used on high-performance trays to obtain good tray efficiency.

In order to maximize the capacity of a cross-flow tray, it is imperative to make the downcomer only as big as it needs to be. Over-sizing the downcomer reduces the bubbling

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area and disengagement area of the tray. Koch-Glitsch patented several "semi-conical vapor-tunnel" downcomers that are characterized by a downcomer bottom edge that consists of a multitude of straight lines[3,4]. This multitude of straight lines follows the contour of the tower wall and frees up bubbling area and disengagement area that would otherwise have been inside of the downcomer. Even more bubbling area can be freed up by truncating the vapor-tunnel downcomer, and populating the area underneath the truncation plate with bubbling devices[5,6]. However, bubbling area is only effective if bubbling actually takes place. An inlet weir and bubble promotors are used to ensure that the liquid from the downcomer starts bubbling right away, and that the active area gained by the vapor-tunnel, or truncated vapor-tunnel downcomer is fully utilized[2]. In the case of truncated downcomers, it is important to give special attention to how the liquid exits the downcomer. Koch-Glitsch has patented several downcomer outlet arrangements[5,7,8] where the liquid exits at the back of the truncation plate, between the downcomer apron and the truncation plate, or through louvers in the truncation plate. An additional benefit of the vapor-tunnel downcomer, and in particular the truncated vapor-tunnel downcomer, is that it maximizes the liquid flow path length. This maximizes the cross-flow effect, which increases the tray efficiency. The downcomer design of choice, as well as the relative dimensions will depend on the particular application.

To maximize tray efficiency, it is also very important to maximize the plug-flow effect by eliminating stagnant zones and retrograde flow. This is done by strategically placing proprietary push-valves and other proprietary directional devices on the tray deck. However, too much push will reduce the tray efficiency. This is confirmed by the fact that the VG-0 valves on the SUPERFRAC tray tested at the FRI gave a higher efficiency than the other FRI-tested trays that imparted more push on the froth.

The SUPERFRAC tray technology can also be used in fouling services. A larger version of the patented fixed valve, called VG-10, which has a larger escape area per valve, or the patented **PROVALVE**® high net rise fixed valve[9] can be used in conjunction special hardware, and special beam- and downcomer designs to deal with the fouling tendency of the system.

It is evident that the SUPERFRAC tray technology should be seen as a toolbox of:

- High capacity and high efficiency valves available in different sizes
- Vapor-tunnel or truncated vapor-tunnel downcomers with various downcomer outlet shapes to maximize the capacity and efficiency of the trays
- Inlet weir and bubble promotors
- Push valves and other directional devices
- Multi-pass arrangements
- Special features to deal with fouling
- Mechanical innovations to simplify installation

In designing an optimal SUPERFRAC tray, Koch-Glitsch chooses the features that best fits the application.

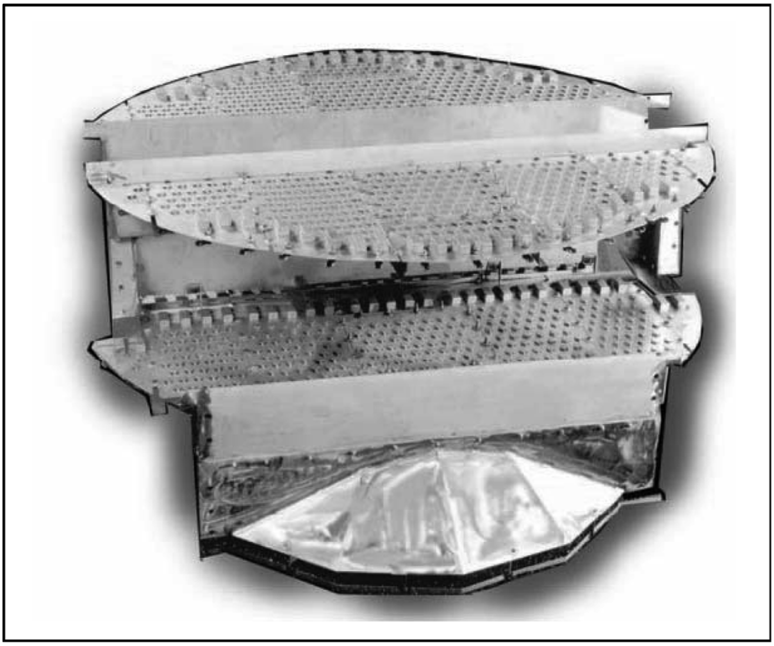

Figure 1. Photograph of a two-pass SUPERFRAC® tray showing some of the available features

The exceptional capacity and efficiency of SUPERFRAC trays are illustrated by the following case study: Single-pass SUPERFRAC trays were operated in a de-isobutanizer type service (150 psig, 24″ tray spacing) at $32\ \mathrm{gpm/ft^2}$ and $C_s = 0.303$ ft/s. At these conditions the trays still exhibited an overall efficiency of 101%.

It is estimated that the SUPERFRAC tray has a 10% efficient capacity and 5% efficiency advantage over competing high-performance trays. In light hydrocarbons processing, this translates to approximately 15% higher throughput in the same tower.

The SUPERFRAC tray was recently tested at the FRI and was found to have the highest combined efficiency and capacity of all cross-flow trays ever tested at the FRI.

ULTRA HIGH CAPACITY TRAYS

One way of increasing the capacity of a cross-flow tray is to use a multitude of downcomers. One example of such a device is the UOP ECMD tray. Due to the short flow path length, these trays exhibit efficiencies of 70–75%[(10)]. Like all other cross-flow and radial-flow trays, this tray is limited by gravity. If the vapor velocity exceeds the settling velocity of the droplets, the tray will become entrainment flooded. The only way to exceed this limit is to use a centripetal force that exceeds 1 g.

In the **ULTRA-FRAC®** tray by Koch-Glitsch centrifugal action is used to create intense mixing of the liquid and vapor. In the zone above this region of intense mixing, the centrifugal action causes very good vapor/liquid disengagement. The higher the rates, the higher the centripetal force becomes. This causes more intense mixing and more effective disengagement until the flood point of the device is eventually reached. A photograph of an ULTRA-FRAC tray assembly is shown in Figure 2.

The maximum efficiency that can be reached in a well-mixed zone is 100%. The vapor/liquid contact in the mixing zone of the ULTRA-FRAC tray is so intense that it can achieve efficiencies in the 80–90% range. In most trays the efficiency drops off close to the flood point. This is not the case with ULTRA-FRAC trays. Since the intensity of mixing increases with higher rates, the efficiency keeps on going up until the tray gets very close to its flood point.

Koch-Glitsch has access to a 5 ft diameter commercial depropanizer that is instrumented like a research tower. All process and utility flow rates are measured with Coriolis mass flow meters, samples can be drawn from trays, and temperatures and pressure drops

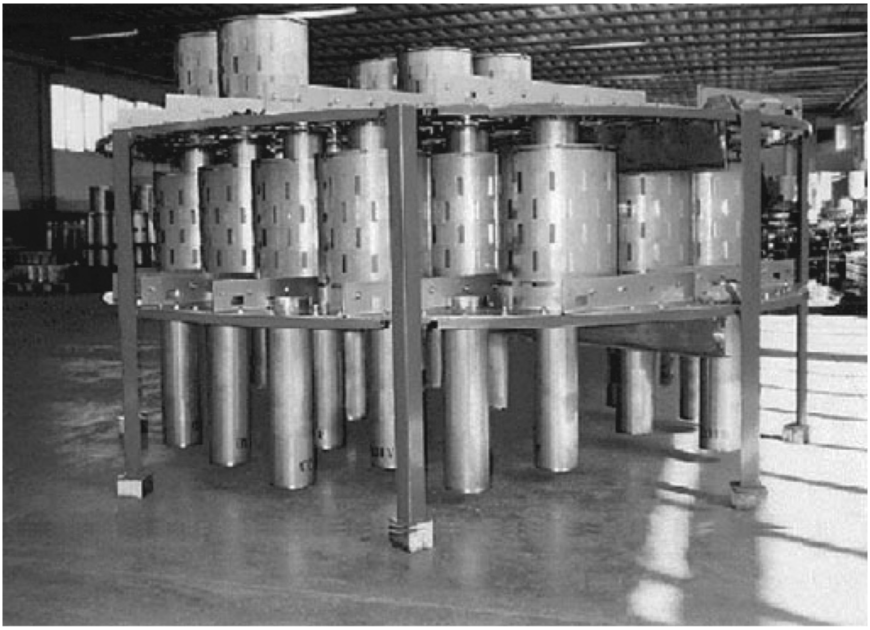

Figure 2. Photograph of an ULTRA-FRAC® tray assembly

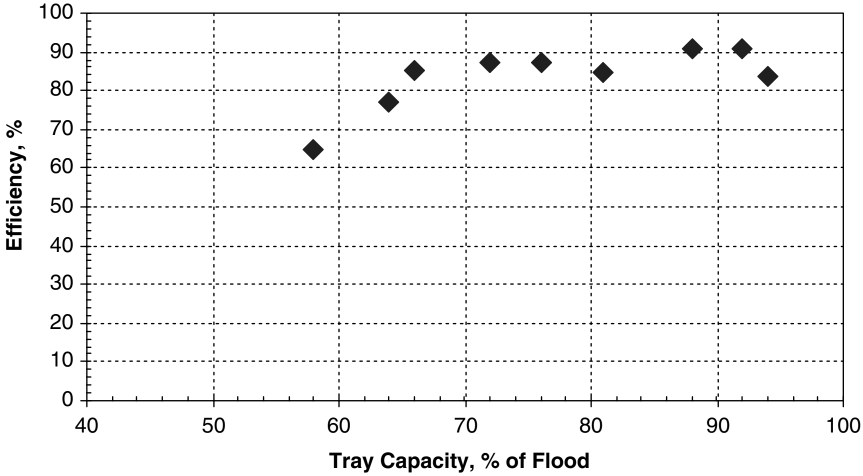

Figure 3. Efficiency of ULTRA-FRAC trays in depropanizer service

are measured in multiple locations. ULTRA-FRAC trays were installed in this tower, and the performance was carefully studied. The performance of the ULTRA-FRAC tray in this service is shown in Figure 3. In the operating range of commercial interest, the efficiency of the ULTRA-FRAC trays was 85–90%.

The exceptional capacity of the ULTRA-FRAC tray is illustrated by the following case study: ULTRA-FRAC trays were operated in a C4 service (24″ tray spacing) at 57 gpm/ft^2 and $C_s = 0.547$ ft/s. At these conditions, the efficiency was 84% and the pressure drop was 4 inches H_2O/tray. When the tray was turned down to 72% of flood, it exhibited an efficiency of 82%, and the pressure drop was 2.2 inches H_2O/tray.

The ULTRA-FRAC tray has 30% more capacity than the Shell ConSep™ tray, and the pressure drop of the ULTRA-FRAC tray is also significantly lower than that of the ConSep™ tray[(11)].

CONCLUSIONS

During the 1970s and 1980s, packing captured a significant portion of the mass transfer equipment market. In the last 15 years trays have made a comeback, mainly due to the fact that the tray capacity was increased significantly whilst maintaining good efficiency.

The high-performance SUPERFRAC tray can be used to extend the efficient capacity of towers to approximately 10% beyond the capability of other high-performance trays.

The ultra high capacity ULTRA-FRAC tray can be used to extend the capacity of towers to 30% beyond the capability of it closest competitor.

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