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Title: "***Modern Sieve Trays for Liquid-Liquid Extraction***"

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Abstract:

Sieve trays continue for find a role in modern liquid-liquid extractions where static devices are specified for various niches in the petroleum and chemical process industry.

There are several proven equipment features that can improve the reliability and performance of sieve extractor trays. These include: extruded orifice holes for deck perforations, downcomer restrictors, structural truss orientation and using multiple downcomers for large diameter units. Properly designed inlet devices and liquid-liquid coalescers are also important considerations for achieving good performance in these applications.

This paper provides examples of recent industrial experience involving sieve trays equipped with special features.

Sieve trays continue to fill an important niche in the extractor applications in the refinery and chemical processing industry in modern times. There are operational advantages for sieve trays compared to alternative contacting devices that result in operational benefits in these niche applications:

Sieve Tray Advantages

- The dispersed phase is collected, re-mixed, settled and re-distributed at each tray during operation.
- The sieve holes can be sized and equipped with features that resist fouling and enhance tray performance.
- Sieve trays handle a wide range of phase ratios compared to packing. Sieve trays resist the effects of axial-mixing better compared to random packing. Packings are limited to phase ratios below 10:1 due to the effects of axial-mixing, while sieve trays can be designed to handle phase ratios to 40:1 and higher.
- Sieve trays can be equipped with rag eliminators and tray manways to allow for inspection, cleaning and maintenance.
- The cost per unit vessel volume for trays is low compared to packing or other alternative contacting devices.
- There are no moving parts for these static devices.

Extractor sieve trays have some of the same equipment features used in gas-liquid contactors. They feature perforated decks and downcomers that allow for cross flow contact of fluids in the space between the trays. The perforated decks have holes that allow for dispersal of the fluid with the continuous phase fluid. The continuous phase that flows into the downcomer has the opportunity to disengage entrained droplets of the dispersed phase fluid before it is introduced to the next tray. The downcomer exit is designed to allow for distribution of the continuous phase across the tray deck.

There are some important differences for the features of liquid-liquid contacting sieve trays that differ from gas-liquid contacting trays. The dispersed phase accumulates at each tray deck and coalesces before it is re-distributed and passes through the sieve holes. If the dispersed phase is the light phase, the fluid coalesces under the tray decks and flows upwards through the sieve holes located in the deck. If the dispersed phase is the heavy phase, it coalesces on the top side of the deck and flows downward through the sieve holes.

The design of the up/downcomers is dependent on whether the continuous phase is the heavy or light phase. If the continuous phase is the heavy phase, it flows downwards

through the downcomers as shown in Figure-1. If the continuous phase is the light phase, it flows upwards through the upcomers as shown in Figure-2. Normally, extractor trays are designed to disperse the phase with the higher volumetric flow rate that contains the solute. Sometimes, however, there could be other process considerations where the selection of the dispersed phase might be opposite of this guideline.

Figure 1 – *Flow of Light Dispersed Phase Through Trays*

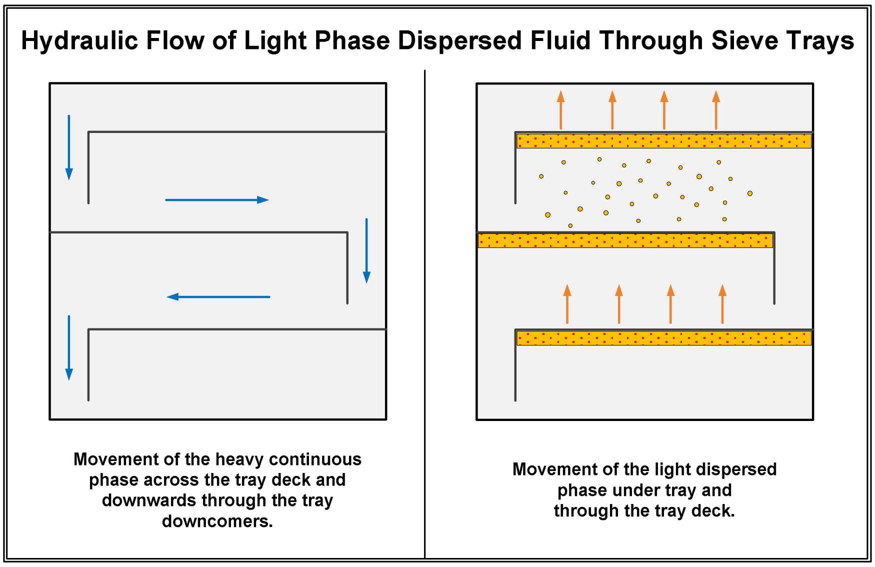
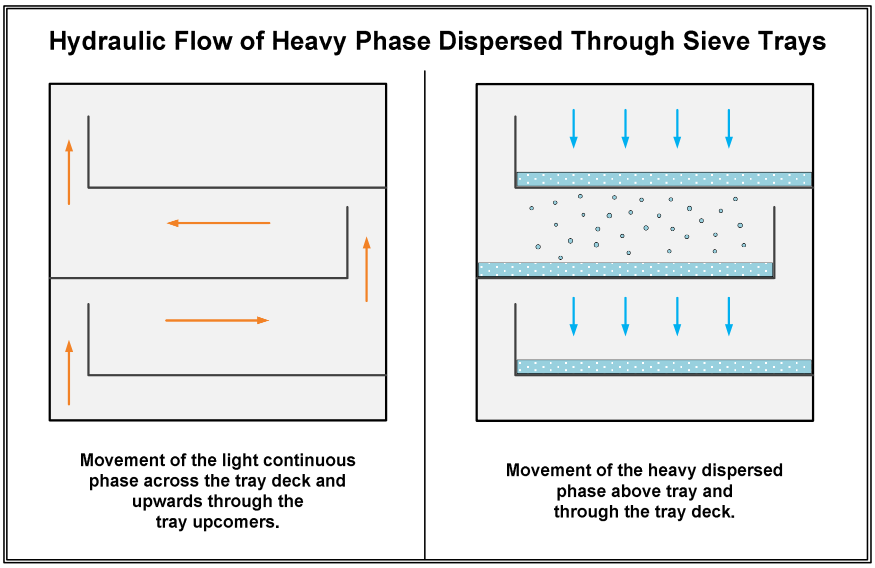


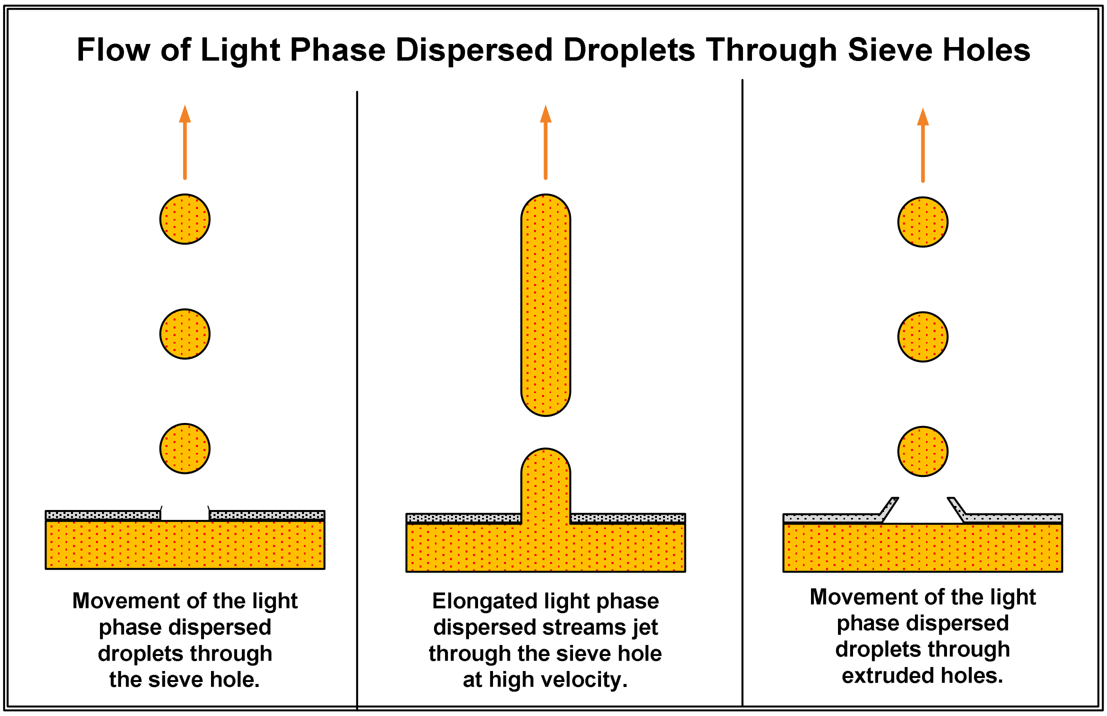
Figure 2 – *Flow of Heavy Dispersed Phase Through Trays*



Extractor sieve holes have different functions compared to those on gas-liquid contactor trays. The primary purpose of extractor sieve holes is to produce low velocity droplets that exit from the deck that imparts convection inside the droplets. At sufficiently low exit velocity and Weber number, the droplets exit the hole as spherical droplets that are nearly uniform in diameter and spaced with sufficient distance apart that they do not interfere with one another. At higher velocity, elongated jetted streams leave the sieve holes traveling at high exit velocity that break into droplets of non-uniform diameter a short distance above the deck. At high exit velocity, the holes produce continuous jetted streams of the dispersed phase. Elongated droplets or jetted streams are not desirable for most extraction applications because they have lower interfacial contact area compared to spheres. Furthermore, the high slip velocity causes the undesirable risk of emulsion formation. The droplets are shown in Figure-3 below for high and low velocities.

Modern punch presses are used by manufacturing shops to stamp the sieve holes in the tray decks. The exit side from the die punched holes has a sharp burr compared to the smoother edge where the die strikes the sheet metal. The normal practice is to have the sharp burr downstream located where the droplet exits the hole. In some extraction applications, special dies are used to produce a volcano shaped extrusion in the tray deck as shown on the right side of Figure-3.

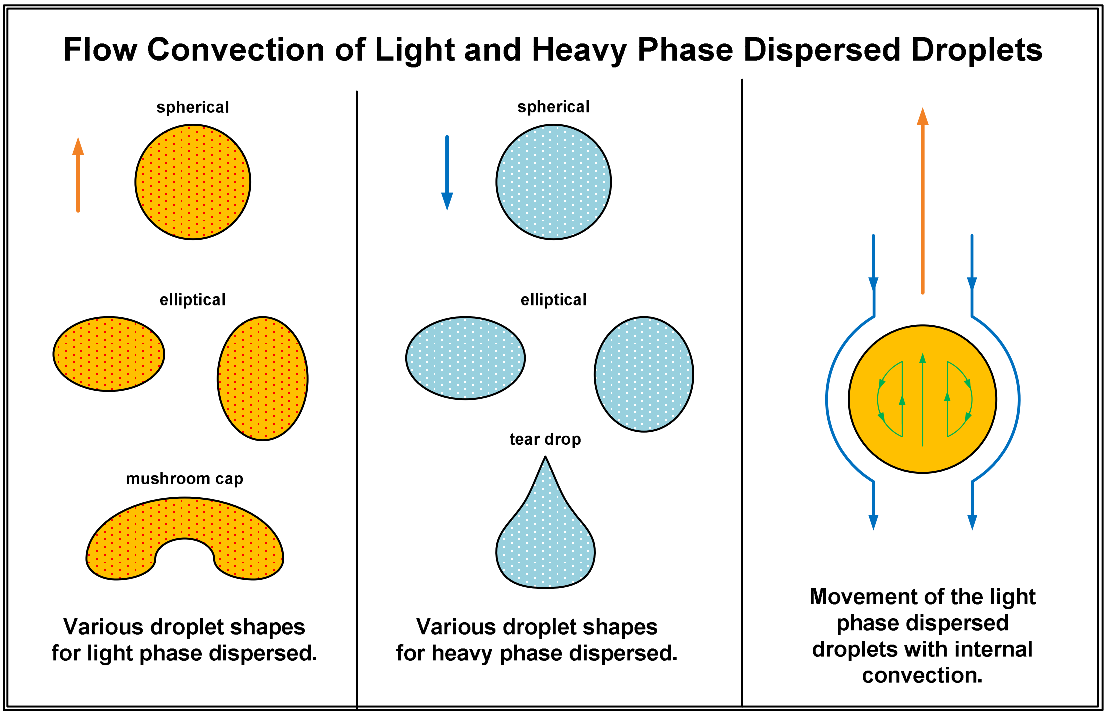
Figure 3 – *Flow of Dispersed Phase Droplets Through Sieve Holes*



Droplets from holes are mostly a function of the physical properties of the dispersed phase and the interfacial tension. Droplets below approximately 2,000 micrometer diameter are typically spheres. Larger droplets can wobble and be distorted into elliptical or other shapes depending on their velocity and physical properties. Low viscosity dispersed phase droplets can sometimes take the shape of mushroom caps. High viscosity dispersed phase droplets can sometimes take the shape of rain drops. Some of the typical shapes of droplets are shown in Figure-4 below.

It is desirable for sieve trays to produce spherical droplets to achieve good mass transfer efficiency. As spherical droplets flow upwards against the resistance of the continuous phase, the friction of drag force causes internal convection inside the droplets. This internal convection serves to expose the high concentration of solute in the droplet interior to the surface, where it can interface with the continuous phase for mass transfer. An example of droplet internal convection is shown in Figure-4.

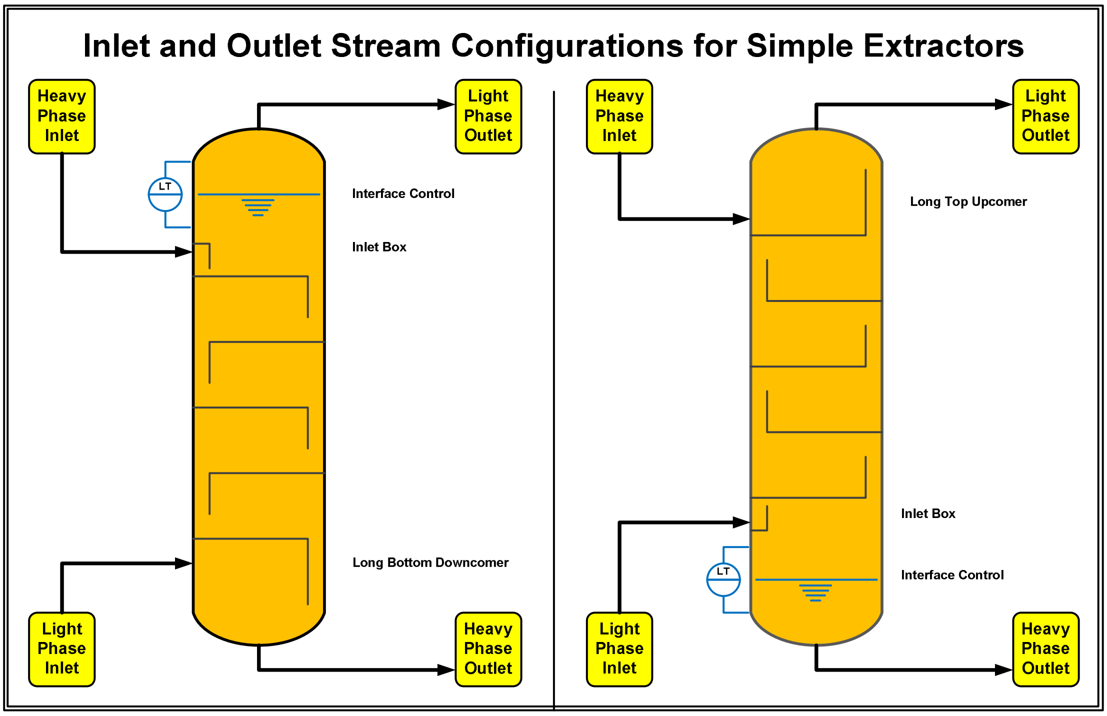
Figure 4 – *Droplets Shapes and Internal Convection*



The location of the inlet streams needs to consider the arrangement of the tray feed arrangement with up/downcomers. Trays are equipped with downcomers need an inlet baffle box for the heavy continuous phase stream and consider careful design of the

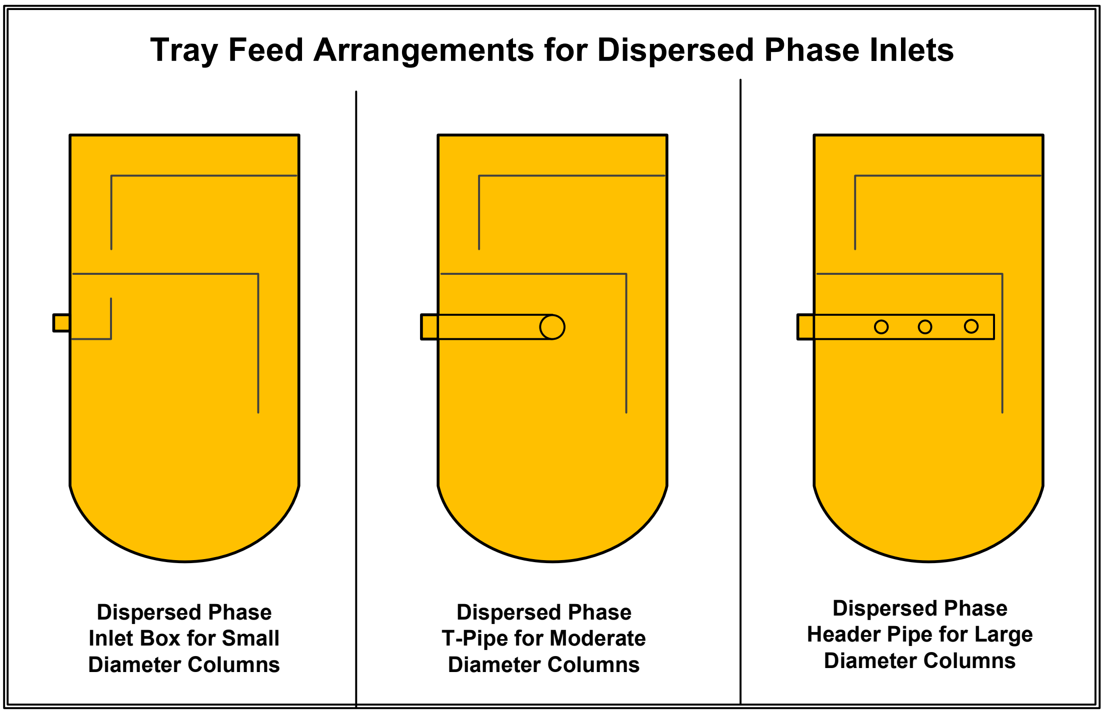
coalescing section and interface at the top section of the vessel. The bottom tray should be equipped with an elongated downcomer, and a light phase inlet device is required below the bottom tray as shown on the left side of Figure-5. Trays equipped with upcomers need a continuous phase inlet baffle box and careful design of the coalescer interface section near the bottom of the vessel. The top tray will need an elongated upcomer as shown on the right side of Figure-5. For extractors without seal pans most of the time elongated downcomers are sufficient for extractors if the feed inlet elevation is designed with sufficient elevation from the up/downcomer exit.

Figure 5 – *Tray Downcomer / Upcomer Configurations*



The design of the dispersed phase inlet is dependent on the diameter of the column. Small diameter columns can use a simple inlet baffle box. Moderate sized columns can be equipped with a T-pipe for the dispersed phase inlet. The T-arm pipe is oriented 90^{o} from the tray trusses. Arm pipes are equipped with holes pointed upwards toward the tray. Large diameter columns can be equipped with a header pipe with a large main pipe and multiple arm pipes. Arm pipes should be oriented 90^{o} relative to the tray trusses. These dispersed feed options are shown in Figure-6.

Figure 6 – *Dispersed Phase Feed Inlets*



Special Performance Features for Sieve Trays

Hole Patterns – The sieve holes are typically arranged uniformly across the active area of the tray as shown on the left side of Figure-7. The active area has an allowance for a blank zone for the width of the tray support ring under the deck, and an allowance for distance between the leading edge of the up/downcomer inlet and outlet to the nearby row of sieve holes.

There are some applications that benefit from concentrating the holes in a zone at the inlet of the tray deck. The right side of Figure-7 shows the holes concentrated in the first half of the tray. This arrangement allows for more concentrated contacting of the dispersed phase droplets at the point were the continuous phase is introduced to the tray. Rising droplets will drift sideways due to the cross flow of the continuous phase, and this allows for phase disengagement in calm space above the un-perforated tray deck as shown on the left side of Figure 8. Droplets reaching the underside of the unperforated deck shown on the right side of Figure 8 will coalesce and flow along the length of the panel to the perforated section. Partially perforated panels allow for more intense contacting above the tray, followed by a longer disengaging and coalescing time compared to the design using full coverage perforated panels.

Figure 7 – *Sieve Tray Active Area Hole Arrangements*

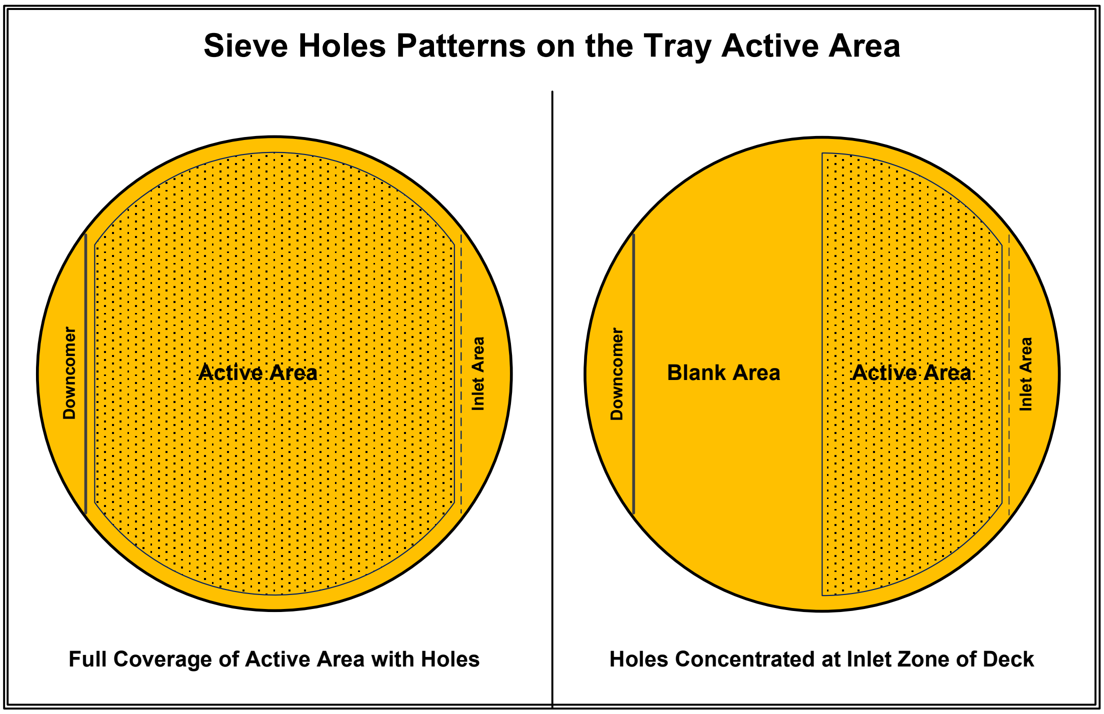
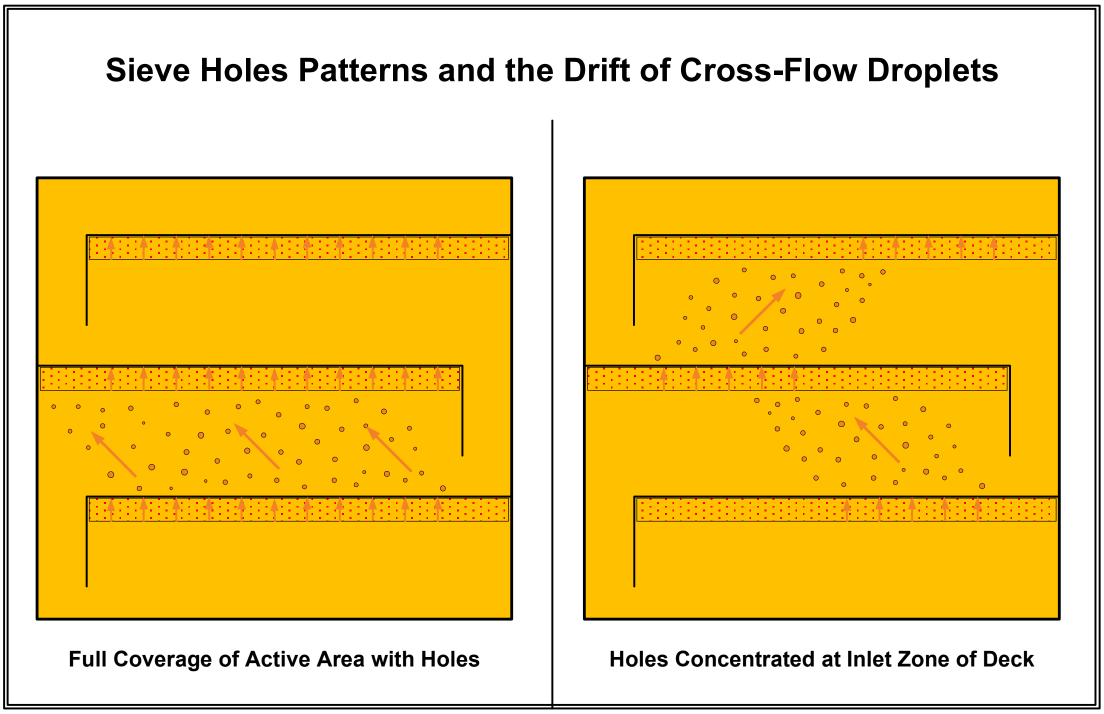


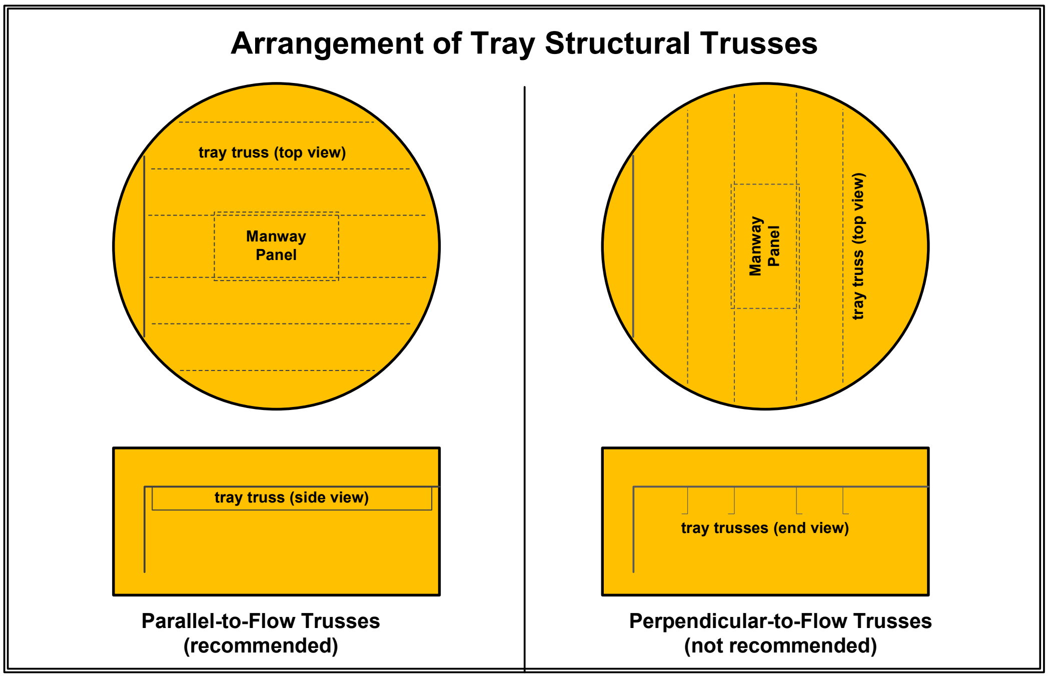
Figure 8 – *Side View of Dispersed Phase Flow and Drift of Droplets*



Truss Orientation – The direction of the tray panel and truss orientation is an important consideration in the design of extractor sieve trays with short spacing. Trusses should be oriented parallel-to-flow for the continuous phase across the tray. If orientated perpendicular-to-flow as shown on the right side of Figure-9, the trusses can impede the flow of the continuous phase across the tray. Perpendicular trusses can also impede the redistribution of the coalesced layer under the deck if the truss depth exceeds 20% of the tray spacing. A similar effect has been documented in gas-liquid contactor trays is called "cross-flow channeling" that is related to the ratio of the active panel length to the tray spacing. This effect decreases tray hydraulic performance, and is be noticed when the capacity results of small diameter pilot columns are scaled up to large diameter production columns.

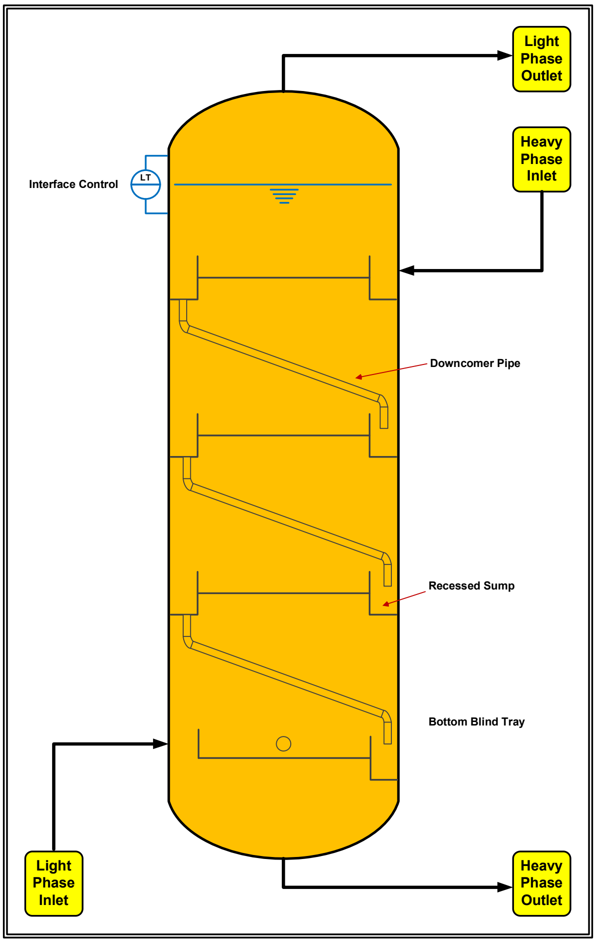
Higher capacity and better tray efficiency are achieved when extractor trays with short spacings are designed with deck panels oriented parallel-to-flow as shown on the left side of Figure-9. This arrangement minimizes the resistance to flow along the flow path.

Figure 9 – *Sieve Tray Panel Orientation*



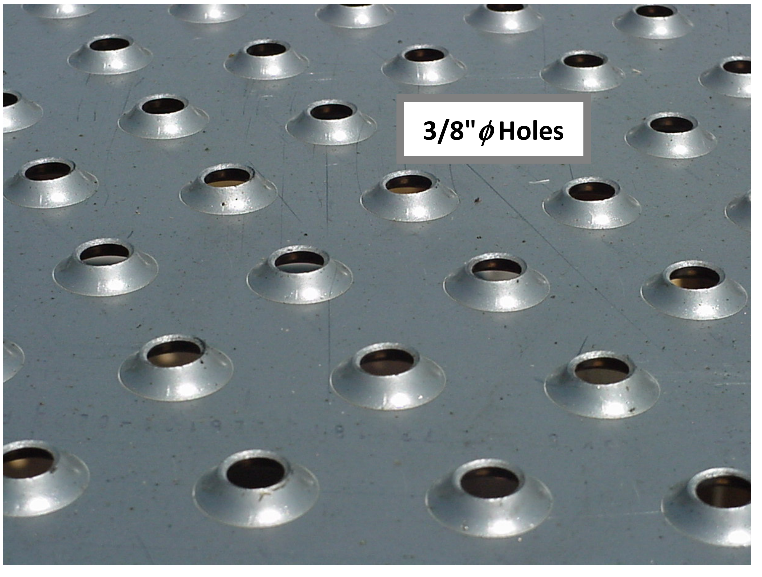
Cross-Over DC Pipes – There is a special downcomer configuration that has found a niche in the refinery industry in caustic treaters and wash units. This configuration has been used in various extractor niches since it was patented in Germany nearly ninety years ago. Figure-10 shows the cross-over pipe downcomer arrangement. The tray decks feature recessed pans that are equipped with a downcomer pipe. The pipe crosses over the tray deck with a downward angle, and all the trays have the same orientation. The bottom tray below the hydrocarbon feed is a blind tray that allows the hydrocarbon feed to be introduced in a way that minimizes the risk of emulsion. These trays have special features like high tray spacing and welded decks. High exit velocities allow these trays to handle the high phase ratios above 20:1 for the light/heavy phases.

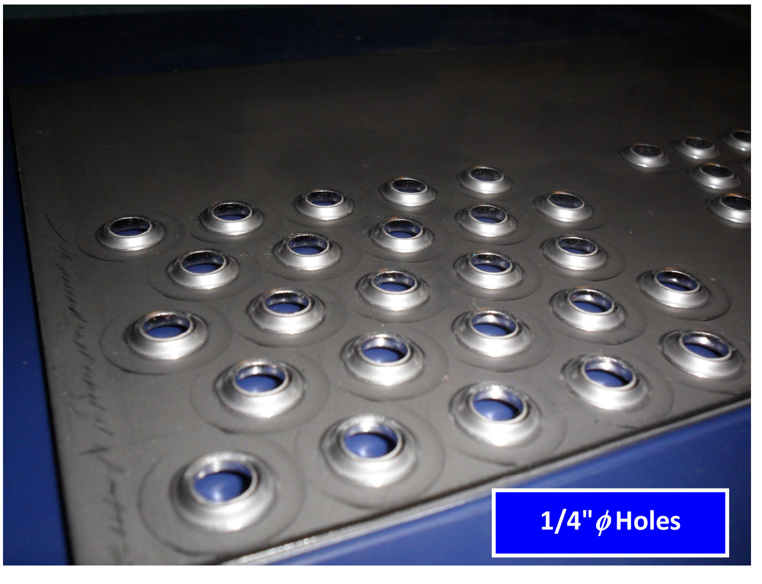
Figure 10 – *Sieve Trays with Cross-Over Pipe Downcomer*



Extruded Holes – Some high-performance extractor applications benefit from the use of extruded sieve holes as shown in Photo-11. The extruded holes provide a smooth orifice entrance effect coefficient for the flow of the dispersed phase. In some systems with polar fluids, the dispersed phase has a tendency to wet the tray metal, and this can result in globules of dispersed phase spread on the tray deck that have difficulty to release droplets when standard sieve holes are applied. Studies show that the extruded exit from the volcano shaped extruded holes allows release of spherical droplets from the deck without the tendency of the dispersed phase clinging to the deck.[1] These benefits include an enhanced resistance to fouling and an extended range of operation (maximum to minimum). The industry guideline is to design trays for a Weber number greater than 2 for the turndown case, to ensure that all holes are active and produce spherical droplets during tray operation.

Photos 11a and 11b – *Extruded Sieve Holes - 0.375"ϕ and 0.25"ϕ*





Distributor Pipes – Design considerations for inlet distribution systems are applied to ensure that the trays near the feed points have sufficient distribution quality. The configuration of the dispersed phase inlet headers should be matched to the configuration for adequate coverage of the tray active area. The size of the main and arm pipes should allow for a low pressure drop resistance of the fluid along the pipe length. The ratio of the pipe hole exit velocity and arm pipe velocity should be selected such to avoid excessive exit velocity that could result in maldistribution caused by a relatively high exit velocity. Excessively high exit velocities could also result in the

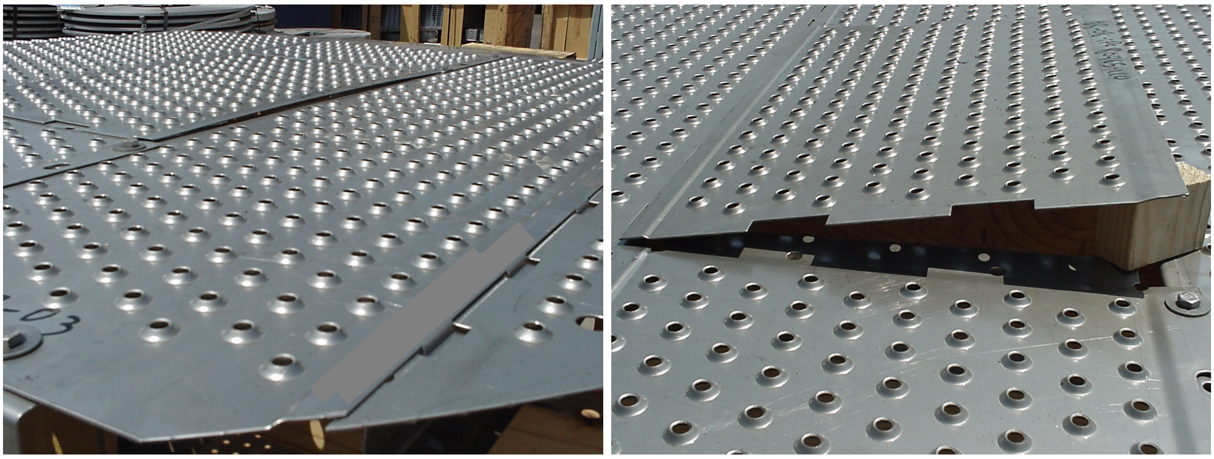
production of small droplets with the risk of emulsion formation. The elevation between the inlet distribution pipes and the up/downcomer exit should be specified such to ensure that no dispersed phase streams can interfere with the up/downcomer hydraulic operation.

Downcomer Restrictors – The bottom exits from up/downcomers can be equipped with plates that are perforated or equipped with slots. This device provides a slight pressure drop resistance to the flow of the continuous phase through the up/downcomer exit. The higher velocity at the exit prevents the flow of dispersed phase droplets up through the up/downcomer opening. For multi-pass trays, these restrictors serve to promote flow distribution of the continuous phase, and this feature resists the effects of axial-mixing for large diameter columns.

Photo 12 – *Downcomer Restrictor Plate*

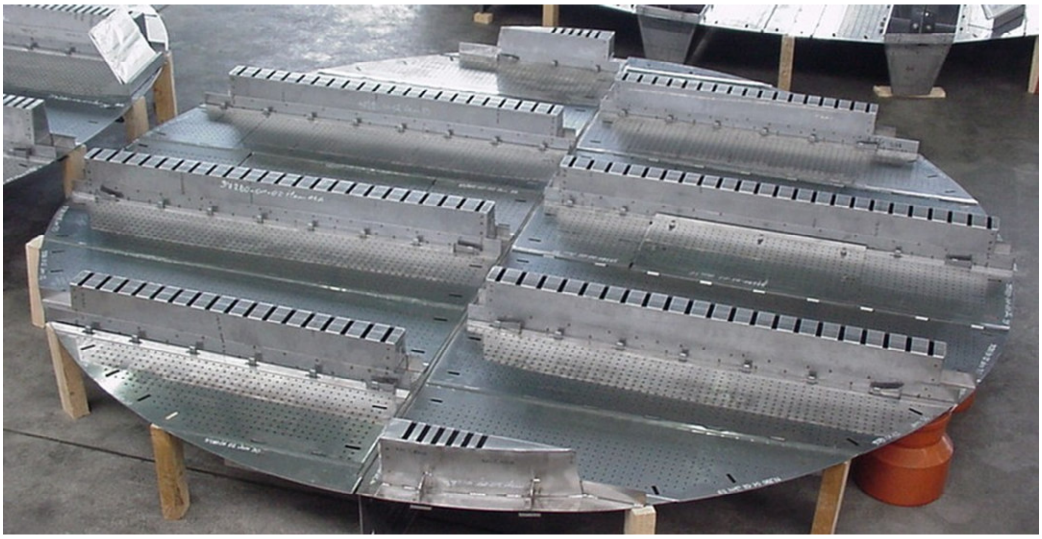
Lip-Slot Panels – The low pressure drop of extractor trays allow the use of lip-slot connections between adjacent tray panels in order to create tray manways. This feature allows for rapid installation of the tray panels. Lip-slot manway panels allow for easy inspection, maintenance and servicing of the trays, and are shown in Photo-13.

Photos 13 – *Lip-Slot Connections*



Multiple Downcomers – The HiFi™ extractor tray is supplied through the Sulzer alliance with Shell Global Solutions is shown in Photo-14.[2] This tray features multiple up/downcomers arranged between equal flow path lengths, which allows for the design of high capacity trays with short tray spacing. The use of multiple up/downcomers eliminates the risk of "cross-flow channeling" discussed earlier in this paper. HiFi extractor trays have been applied to sulfolane extraction applications to separate aromatics from petrochemical streams. These trays can be applied to butadiene wash extraction, isoprene purification, and the recovery of ECH and DCH from heavy-ends. Several existing RDC (rotating disc contactors) have been successfully revamped with HiFi trays that can use convenient stator rings to support the new trays.

Photo 14 – *SGS HiFi™ Extractor Tray*

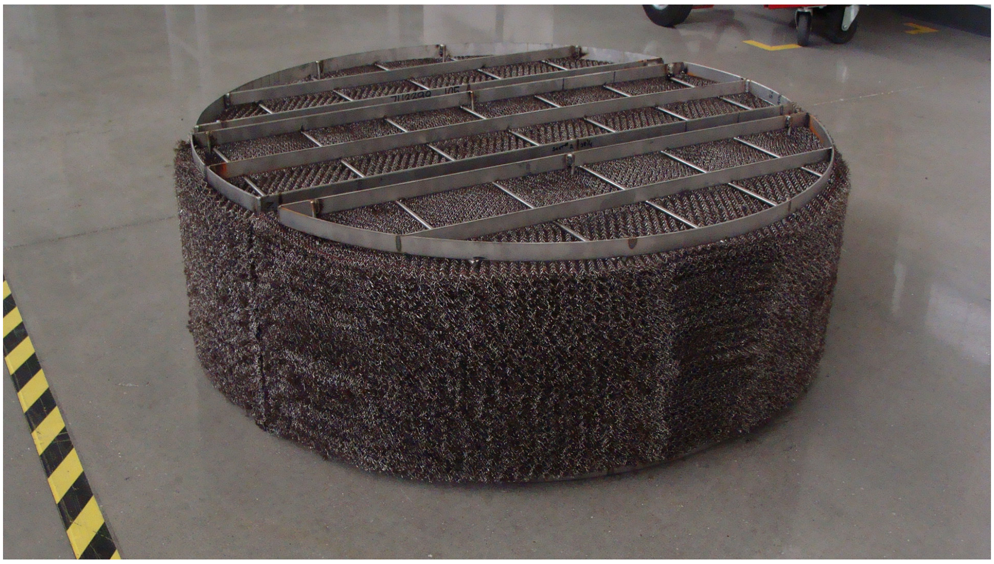


Dirty Interfaces – Industrial applications have the risk of micron sized particulates carried into the extractor by the feed or solvent. This can have the effect of accumulating particulates at the interface of droplets and in the coalescing sections during operation. Some applications with unsaturated hydrocarbons can react with acids to produce higher molecular weight components, and this can sometimes produce a rag layer between the interfaces of coalescing zones. Sieve trays can handle fouling issues associated with fine particulates better compared to packings. In some applications, it is possible to increase the diameter of sieve holes to overcome the risks for fouling fluids. In case a rag layer is present in an application, then it is necessary to design a rag eliminator device in the tray deck to allow for flushing away of rag material during a flushing operation with a high flow rate of the continuous phase.

Coalescer Sections – The retrofit of existing vessels with higher capacity mass transfer internals should consider the installation of a coalescer device to improve the removal of primary dispersions. Revamps that do not upgrade the coalescer section have the risk of suffering higher amounts of entrainment to contaminate the product. The DC Coalescer™ provides dual co-knit mesh materials that allow for wetting by hydrophilic and hydrophobic surfaces and removal of droplets by direct interception. Droplets that pass through the DC Coalescer are grown in size so they can be settled by gravity.

Various mesh densities, material combinations and pad configurations are available to meet the needs for extractor applications. The addition of a DC Coalescer pad to an extractor can improve the product purity and yield. Photo-15 shows a DC Coalescer pad.

Photo 15 – *DC Coalescer™ Mesh Pad*



Conclusion

Sieve extractor trays continue to be used by industry in various niche applications owing to the excellent benefits that derive from their low cost, design confidence, reliable performance and proven operation. As the processing industry increases the flow capacity and performance requirements for extractor columns for retrofits and new applications, there will be a continuing need to implement these reliable tray technologies to meet these demands. This paper presents the state-of-the-art equipment design considerations for trays and feed arrangements necessary for higher performance extractor trays.

References:

[1] F.D. Mayfield and W.L. Church; "*Liquid-Liquid Extractor Design*"; Industrial and Engineering Chemistry; Volume 44, N$^{o.}$ 9 ; September 1952.

[2] W. de Villers, J.L. Bravo, F. Seibert, G.H. Shiveler; "*Tray Technology Enhances Extraction*"; Petroleum Technology Quarterly; 3rd Quarter 2007; pages 25-30.

Note: Shell HiFi™ is a proprietary extraction tray technology by Shell Global Solutions.

Note: The DC Coalescer™ is a mesh pad liquid coalescer technology from Sulzer Chemtech Inc.

About the Author:

Glenn Shiveler attended Rutgers University with a bachelor degree in chemical engineering. He has been an AIChE member since 1983 and has presented many papers on various subjects for mass transfer separation technologies at AIChE meetings. Other industrial memberships include ACS and ISA. For many years he has designed mass transfer trays and packings at Nutter Engineering and Sulzer. He now is an applications specialist handling process technology at the Sulzer office located in Tulsa, Oklahoma.