

**IMPROVE EB/SM PLANT DISTILLATION**  
**WITH**  
**HIGH PERFORMANCE MASS TRANSFER EQUIPMENT**

**Randall A. Sommerfeldt**  
**John M. Einwich**

**KOCH-GLITSCH, INC.**

**Toby Darbonne**  
**Timothy M. Zygula**

**Westlake Styrene Corporation**

**Presented at the 1998 Criterion Catalyst Co.**  
**World Styrene Conference,**  
**Orlando, Florida**  
**May 3-7, 1998**

**"Unpublished"**

**KOCH-GLITSCH, INC.**

**MASS TRANSFER TECHNOLOGY**  
**P.O. BOX 8127, WICHITA, KS 67208**

## INTRODUCTION

Presented herein is a two-part discussion of mass transfer technology and its application in Ethylbenzene/Styrene service. Higher capacity limits are realized in the Ethylbenzene unit by applying high capacity tray technology. Higher capacity and efficiency limits are achieved in the Styrene distillation unit by applying high performance, high efficiency structured packing and optimized liquid distribution devices.

Case studies will be presented which demonstrate the advantages of the SUPERFRAC<sup>®</sup> Tray in the Benzene Prefractionator, Benzene Recovery column, and the Ethylbenzene Recovery column while the capacity and efficiency advantages of FLEXIPAC<sup>®</sup> and GEMPAK<sup>®</sup> structured packing are discussed for the Styrene Recovery column, Finishing column, and the Benzene/Toluene column.

### **SUPERFRAC<sup>®</sup> High Performance Trays**

Distillation tray capacity is limited by two primary phenomena. The first, entrainment, occurs when vapor velocities are sufficiently high to carry the froth on the tray up to the tray above. The second, downcomer flooding, occurs when the frothy liquid volume can not be fully accommodated by the downcomer.

Distillation tray technology now addresses the need to increase these two fundamental limits with the use of high capacity trays. The SUPERFRAC<sup>®</sup> Tray was invented to decrease entrainment and/or relieve downcomer loadings. Since 1987, over 400 installations of SUPERFRAC<sup>®</sup> trays have consistently proven to increase column capacity by as much as 20-35%, depending on existing geometry.

### CONVENTIONAL TRAY OPERATION

As is the case with most technologies, the history of conventional distillation tray development has laid the ground work for improving the current level of technology. Three common goals of the SUPERFRAC<sup>®</sup> tray are:

- Increase column capacity over conventional trays
- Maintain or improve tray efficiency
- Limit (or eliminate) tower attachment modifications during installation

The study of conventional tray operation in numerous pilot plant tests has developed into a broader level of understanding of the fluid dynamics associated with the conventional valve tray. The froth flux across a typical valve (or sieve) tray with a chordal downcomer is concentrated on that area between the downcomer exit of the tray above and the outlet weir. This velocity gradient of froth indicates that the useful active area of the tray is not fully utilized. When the downcomers are a sloped chordal design, the froth velocity gradient is even larger. When the

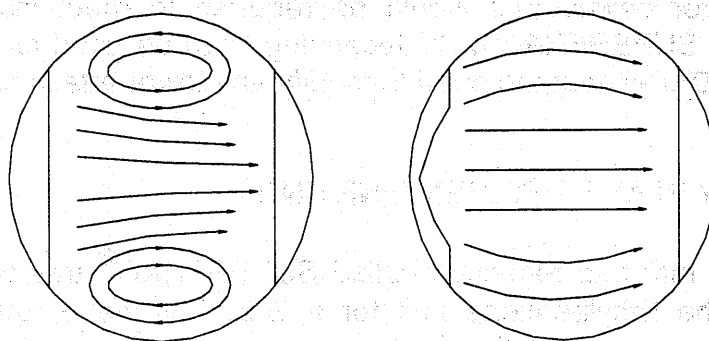
froth impacts the outlet weir, most of it will flow over the weir immediately while a portion will be deflected back onto the tray by the weir. Fluid mechanics dictate that, to an extent, this portion of the froth that remains on the tray will create eddy currents on the outer portions of the tray. Numerous pilot plant tests with dye injections have confirmed this recirculation phenomena.

This liquid recirculation results in longer liquid residence time on the tray and reduces the capacity of the tray for two reasons. First, this recirculated frothy liquid occupies space on the active area, which in turn impedes the progress of froth coming from the trays above. Second, this froth has already undergone mass-transfer with vapors from the tray below. Thus, minimal mass-transfer will occur between the vapor from the tray below and this recirculating frothy liquid. More reflux and reboiler vapors will be needed to maintain the desired column efficiency for a given feed rate.

### SUPERFRAC<sup>®</sup> TRAY OPERATION

One objective of the SUPERFRAC<sup>®</sup> Tray is to create a plug-flow velocity profile in the active area. This is initiated by a downcomer design which is chordal at the top and multichordal at the bottom. The downcomer exit design initiates liquid distribution to the active tray deck. The velocity profile is maintained by specially-designed valve units in the periphery area of the tray. The valve design maintains the plug-flow and assists in hydraulically pumping the froth over the weir. Without recirculation of froth, the entire active area is now participating in mass-transfer.

Figure 1: Active Area Velocity Profile (1-pass tray)



Conventional Tray Velocity Profile

SUPERFRAC<sup>®</sup> Tray Velocity Profile

As a result, the plug-flow characteristic of the SUPERFRAC<sup>®</sup> Tray helps to increase column capacity by limiting the residence time of liquid on the tray while maintaining optimum tray efficiency.

Other hydraulic components have been optimized for the SUPERFRAC<sup>®</sup> Tray. The use of minivalves provides many vapor injection points into the active tray deck and increases tray capacity. Also, bubble promoters are used at the downcomer exit to

initiate frothing of the liquid leaving the downcomer. Both of these devices help to lower entrainment and provide maximum mass-transfer on the tray.

The combination of these optimized tray components (plug-flow valve design, downcomer exit design, minivalve design, bubble promoter design) has produced a tray technology that has 20-35% more capacity than a conventional tray with equal or better efficiency.

The operation of high capacity trays is the primary interest of most users, but the SUPERFRAC<sup>®</sup> design also incorporates design features to minimize the installation required for these trays. The SUPERFRAC<sup>®</sup> Tray design has the added benefit that replacement of conventional trays can be made on a one-for one basis with no welding to vessel in most cases. The downcomer design can be adjusted to bolt or clamp to an existing straight or sloped downcomer bar. In the case where these trays have replaced multiple downcomer trays with 360° tray support rings, the SUPERFRAC<sup>®</sup> downcomer has been designed with envelope downcomers. This minimizes the turnaround time and in the case of high pressure columns, reduces the total installed cost by eliminating the need for welding to the vessel shell and post-weld heat treating.

The limitations of conventional downcomers can be also be expanded with the SUPERFRAC<sup>®</sup> Multi-Stage Downcomer (MSD) technology. On conventional trays, the area in front of the outlet weir is normally an inactive "disengagement" zone about three inches wide. SUPERFRAC<sup>®</sup> technology has embraced this dead area for use as a relief downcomer. The use of this area to relieve the downcomer loading does not detract from the active area used for valves. In many revamp cases, a larger downcomer would be required to meet increased liquid loads. However, the SUPERFRAC MSD technology can be used to increase downcomer capacity 15-20% without the need to modify any tower attachments.

## CASE STUDY IN AN ETHYLBENZENE UNIT

Koch-Glitsch, Inc. has recently applied SUPERFRAC<sup>®</sup> tray technology in several columns of the Ethylbenzene unit for a U.S. Styrene producer. This producer wanted to increase production in three columns while maintaining current column efficiencies. Tables 1, 2, and 3 on the next page show the before and after revamp conditions for a Benzene Prefractionator, Benzene Recovery column, and Ethylbenzene Recovery column.

For the Benzene Prefractionator (Table 1), the trays above the feed would need to handle additional vapor loading as a result of both increasing the feed rate and feed temperature. The existing valve trays were replaced with SUPERFRAC<sup>®</sup> trays to extend the vapor handling capacity of the tower.

**TABLE 1**

Benzene Prefractionator	Before Revamp	After Revamp (25% Feed Rate Increase) Guaranteed
Tray Design	2-pass valve trays; Vapor feed above tray 8	2-pass Superfrac® Trays above feed; 8 existing valve trays
Tray Capacity (Calculated)	77% of flood (97% at 125% rates)	78% of flood *
Feed Temperature	464 F	500 F
Maximum EB in Distillate	2000 ppmw spec.	2000 ppmw Guaranteed

\* Ultimate tray capacity to be determined in a future performance test

For the Benzene Recovery column (Table 2), the valve trays above the feed were revamped with minivalve trays to provide more vapor handling capacity. The valve trays below the feed were revamped to SUPERFRAC® trays to improve both liquid and vapor handling capacity.

**TABLE 2**

Benzene Recovery Column	Before Revamp	After Revamp (25% Feed Rate Increase) Guaranteed
Tray Design	2-pass valve trays; Flashing feed above #18 (10% flash)	2-pass minivalve trays above feed; 2-pass Superfrac® trays below feed
Tray Capacity (Calculated)	78% of flood (98% at 125% rates)	78% of flood *
Maximum EB in Distillate	1300 ppmw spec.	1300 ppmw Guaranteed
Maximum Benzene in Bottoms	1500 ppmw spec.	1500 ppmw Guaranteed

\* Ultimate tray capacity to be determined in a future performance test

All trays in the Ethylbenzene Recovery column (Table 3) were revamped to SUPERFRAC® trays to improve the overall tower capacity. In each of these columns, the flashing feed pipe designs were analyzed. The existing designs in all columns indicated vapor impingement to the tray above in a localized area. Therefore, the feed pipe designs were also revamped to provide proper distribution of the vapor and liquid to the feed trays.

**TABLE 3**

Ethylbenzene Recovery Column	Before Revamp	After Revamp (25% Feed Rate Increase) Guaranteed
Tray Design	2-pass valve trays; Flashing feed above tray #36 (35-45% flash)	2-pass Superfrac® Trays
Tray Capacity (Calculated)	79% of flood (99% at 125% rates)	83% of flood *
Minimum EB in Distillate	99.2 wt% spec.	99.2 wt% Guaranteed
Maximum O-xylene	200 ppmw spec.	200 ppmw Guaranteed
Maximum M-xylene + P-xylene	1650 ppmw spec.	1650 ppmw Guaranteed
Maximum Cumene	500 ppmw spec.	500 ppmw Guaranteed

\* Ultimate tray capacity to be determined in a future performance test

The new SUPERFRAC® trays were installed in these columns without any modifications to the existing tower attachments. Koch-Glitsch Field Services completed the installation of these trays a full two days ahead of schedule.

The full capacity advantage of these trays is not yet realized due to auxiliary equipment limitations that are scheduled to be debottlenecked in the near future. However, preliminary plant data indicates that the columns are in stable operation with purity levels exceeding the guaranteed minimum values.

### **FLEXIPAC® and GEMPAK® High Performance Structured Packing**

#### **STRUCTURED PACKINGS IN STYRENE SERVICE**

Structured packings are uniquely suited for the vacuum distillation columns in Styrene units. Structured packings have a low pressure drop per stage as compared to random packings or trays. Low column pressure drop results in reduced bottoms pressure and temperature that translates to less polymer formation and less inhibitor usage. The open, vertical flow channels of structured packings are more resistant to fouling than random packings. Structured packings can be utilized for trayed tower revamps to realize improvements in both capacity and product purity within the fixed tower diameter.

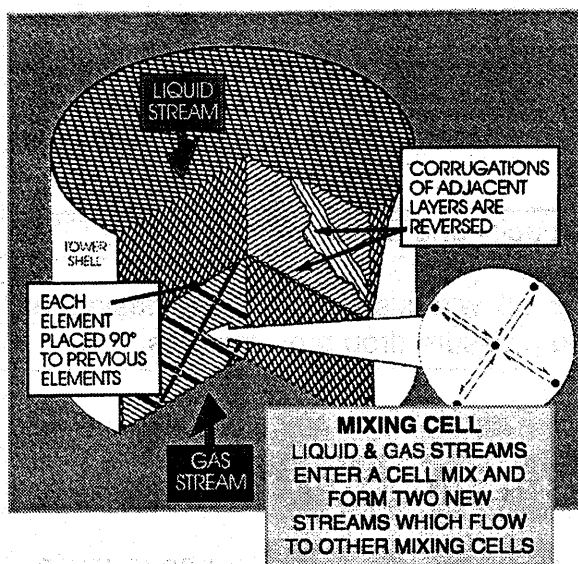
#### **BASIC DESIGN PRINCIPLES OF STRUCTURED PACKING**

FLEXIPAC® and GEMPAK® packing elements make use of a constant configuration of geometrically arranged and corrugated sheets throughout a tower.

The geometric design combined with perforations and horizontal surface texturing results in intimate mixing and radial distribution of liquid and gas streams.

An element of structured packing fills the cross section of the tower. Elements are typically comprised of smaller bricks or modules that are designed to fit through column manways. The tower is packed with a series of such elements with each successive element typically rotated 90 degrees from the element below. A typical element is composed of vertically oriented, corrugated sheets. The angled corrugations of adjacent sheets are reversed with respect to the vertical column axis. This packing design forms a mixing cell at every point where the corrugations intersect.

Figure 2: Structured Packing Operation



As shown in Figure 2, liquid and gas streams enter a cell, mix and form two new liquid and gas streams that flow to other mixing cells downstream in the element. After passing through an element, both fluids have been mixed primarily along the layers of this element. With each element rotated 90 degrees to the previous one, intimate mixing and radial distribution of both fluids occur over the tower cross section.

Structured packing effectively minimizes channeling and radially distributes the gas and liquid as a result of its geometric design. Wiper bands around each element prevent bypassing of fluids at the vessel wall. A close approach to even distribution is quickly established in the packed bed and homogeneous gas/liquid concentrations are maintained at any given tower elevation.

## PACKING SELECTION

Structured packing is selected for styrene towers based on the tower requirements for separation efficiency, throughput capacity, and pressure drop. There is a trade-off between efficiency and capacity, however, as illustrated in Figure 3. Within a given series of structured packings ( same surface treatment, angle of inclination, etc.), greater efficiency is obtained by reducing the crimp or corrugation height and

thus, increasing the specific surface area of the packing. This results in less open area, higher resistance to fluid flow, and consequently, less capacity.

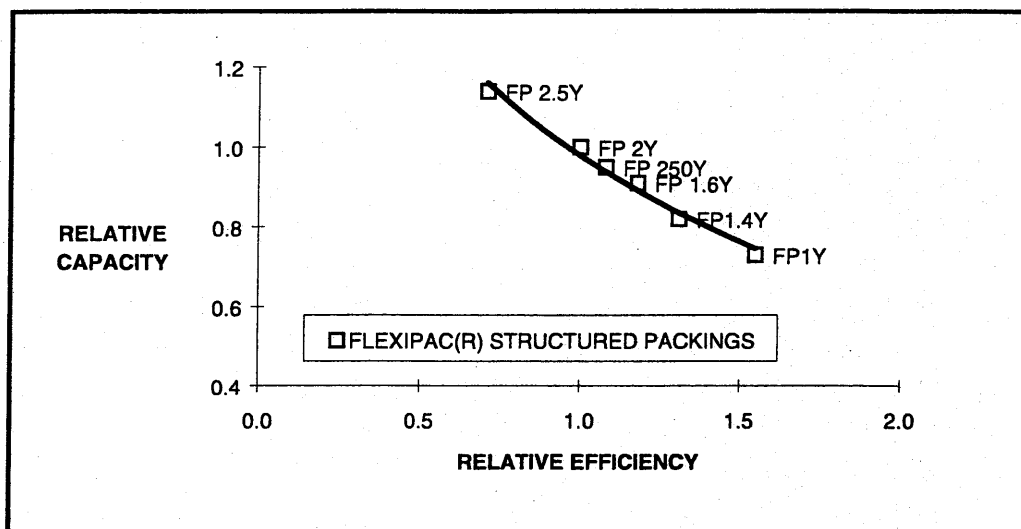


Figure 3: Relative Packing Capacity and Efficiency

A wide selection of incremental packing sizes allow a customized tower design that is optimized to meet efficiency, capacity, and pressure drop requirements.

#### CASE STUDY IN A STYRENE UNIT WITH STRUCTURED PACKING

The advantages of structured packings are illustrated in a recent, 2 phase revamp of a Styrene Finishing ( AS-203 ) and Styrene Recovery Column ( AS-205 ) for a US Styrene producer. The Recycle column bottoms contains mostly Styrene along with the heavier components generated in the process as side-products or polymer. Recycle column bottoms is fed to the Finishing column to produce high purity Styrene product for sale as the distillate. The Finishing column bottoms feeds the Recovery column where Styrene is recovered from the heavy residue bottoms. In this particular unit, the Finishing column and Recovery column use a common overhead condenser system since both columns produce high purity Styrene monomer as the distillate.

The primary revamp objective for the columns is to improve Styrene quality to meet stricter product specifications. Reduced tower bottoms pressure is also required to decrease polymer losses. High efficiency structured packing is selected to replace the conventional sieve trays in the rectification section to meet these objectives. A secondary objective is to obtain sufficient additional operating capacity such that the towers do not present a future bottleneck in the unit.

Phase I consists of the AS-205 Recovery Column revamp and was successfully completed in 1995. A bed of GEMPAK® 3AS high efficiency structured packing

and associated internals are installed above the feed point. A high performance trough-type distributor is used above the bed of packing. The distributor features elevated orifices to prevent polymer fouling and incorporates overflow slots to maintain distribution in the event fouling does occur. In addition, the distributor is carefully designed to handle the low liquid rates by balancing minimum orifice diameter ( approximately 1/8" ) with the drip point density to ensure adequate wetting of the packing. A vapor distributor is installed above the mixed phase feed to optimize vapor distribution to the packed bed and reduce liquid entrainment.

Phase II consists of the AS-203 Finishing column revamp and was successfully completed in 1998. The AS-203 revamp design is the same as the AS-205 column except that FLEXIPAC<sup>®</sup> 1.6Y high efficiency structured packing is selected for this tower. Prior to revamp, AS-203 can operate at 115% turnup and thus, another additional 10% capacity increase is desired such that the total AS-203 / AS-205 system has 125% turnup capacity relative to the original unit design.

Detailed column information is provided in Tables 4 and 5 for the Recovery column and Finishing column, respectively. A step change reduction of the alpha-methyl styrene (AMS) impurity is achieved in each phase. The AMS reduction is the result of additional theoretical stages in the rectification section, optimized internals, and reduction in tower pressure drop. Within the fixed column height available, the beds of structured packing develop more theoretical stages than the original conventional sieve trays. The careful selection and design of internals enable the packing to achieve maximum efficiency. The ease of separation is improved ( increased relative volatility ) after the revamp due to reduced top operating pressure and lower pressure drop. The bottoms temperature in AS-205 is 60 F lower due to pressure change and results in a 5-10% reduction in polymer losses. The change in tower operating pressure is achievable due to the additional capacity provided by the structured packing.

**TABLE 4: AS-205 STYRENE RECOVERY COLUMN.**

PHASE I	BEFORE REVAMP	AFTER REVAMP ( 25% FEED RATE INCREASE) ACTUAL
RECTIFICATION SECTION	1-PASS SIEVE TRAYS	GEMPAK <sup>®</sup> 3AS STRUCTURED PACKING
REFLUX : FEED RATIO	BASE	SAME
CAPACITY (CALCULATED)	79% of flood ( 98% AT REVAMP RATES)	58 % of flood
DISTILLATE STYRENE, WT%	99.9	99.9
AMS, PPMW	250	140
BOTTOMS TEMPERATURE, F	BASE	60 F REDUCTION
POLMER PRODUCTION	BASE	5% REDUCTION

**TABLE 5: AS-203 FINISHING COLUMN.**

PHASE II	BEFORE REVAMP	AFTER REVAMP ( 10% FEED RATE INCREASE) ACTUAL
RECTIFICATION SECTION	2-PASS SIEVE TRAYS	FLEXIPAC <sup>®</sup> 1.6Y STRUCTURED PACKING
CAPACITY (CALCULATED)	56% OF FLOOD ( 70% AT REVAMP RATES )	47% OF FLOOD
PRESSURE DROP	55 mmHg	9 mmHg
REFLUX : FEED RATIO	BASE	SAME
DISTILLATE STYRENE, WT%	99.9	99.92
AMS, PPMW	140	45

### FLEXIPAC<sup>®</sup> HIGH CAPACITY ( HC<sup>™</sup> ) STRUCTURED PACKING

FLEXIPAC<sup>®</sup> HC<sup>™</sup> packing is the latest advance in structured packing technology. The technology is patented ( US patent 5,632,934 ) by Praxair Technology, Inc. and is exclusively licensed to Koch-Glitsch, Inc. for commercial application except for industrial gas separations.

It is well established that, for conventional corrugated-sheet structured packing, the liquid holdup is greatest at the interface between two elements. This phenomena is caused by the high drag forces of the gas on the liquid as the liquid leaves the bottom edge of the upper element to enter the lower element. FLEXIPAC<sup>®</sup> HC<sup>™</sup> packing is designed to minimize this localized accumulation of liquid at the element interfaces. Thus, significant capacity increase is achieved with the FLEXIPAC<sup>®</sup> HC<sup>™</sup> packing by removing an inherent limitation found in all conventional structured packings.

The FLEXIPAC® HC™ packing is designed with two distinct regions: a bulk region in which the corrugated sheets are arranged in the conventional pattern, and a base region at the bottom of the element. The base region of the sheets are modified to provide less resistance to gas flow than in the bulk region. The net effect of the patented packing design is to reduce the gas velocity and permit improved draining of liquid at the interface between two stacked elements and increase ultimate usable hydraulic capacity.

The performance characteristics of FLEXIPAC® HC™ structured packing as compared to conventional packing of similar geometry are:

- Capacity increase of 10 - 40% without a loss in efficiency
- Efficiency increase of 10 - 20% without a loss in capacity
- Stable operation and excellent packing efficiency are maintained throughout the extended range of hydraulic operation

Actual capacity and / or efficiency increase varies and is a function of the bulk packing geometry, the physical properties of the specific chemical system, and the internal hydraulic loadings.

#### CASE STUDY - FLEXIPAC® HC™ STRUCTURED PACKING IN A STYRENE UNIT

FLEXIPAC® HC™ structured packing was used to solve a bottleneck in the Benzene-Toluene column ( AS-201 ) of a Styrene producer in the US. In the producer's process, the Benzene-Toluene column separates Benzene and Toluene overhead as light components from the dehydrogenation reactor effluent. In anticipation of adding a parallel Recycle column in the future, the existing Benzene-Toluene column will require modifications to process sufficient feedstock for the dual Recycle columns.

The initial process simulation study and hydraulic analysis were completed and a revamp design is proposed. The existing structured packing in the stripping section is hydraulically limited at the revamp loadings and a conventional packing with a larger crimp is proposed. New high performance liquid distributors are required to handle the increased liquid rates in the tower. In addition, optimization of the vapor distribution to the stripping bed is proposed to develop maximum packing efficiency. The addition of a vapor distributor will reduce height available for packing. Thus, the proposed revamp has potential for a loss theoretical stages.

Since the loss of stages is not desirable, FLEXIPAC® 2Y HC™ is installed in the stripping section instead of a conventional structured packing. The bed height is maximized in order to develop maximum stages and achieve the desired throughput. Detailed column information before and after the revamp is presented

in Table 6. The tower is performing as expected at reduced rates to date. A performance test for the process guarantee will be completed when the unit comes up to full rates in the near future.

**TABLE 6: AS-201 BENZENE-TOLUENE COLUMN.**

	BEFORE REVAMP	AFTER REVAMP * GUARANTEED
FEED RATE	BASE (100%)	20% INCREASE (120%)
STRIPPING SECTION	NO. 2 NOMINAL STRUCTURED PACKING	FLEXIPAC <sup>®</sup> 2Y HC <sup>™</sup> STRUCTURED PACKING
REFLUX : FEED RATIO	BASE	SAME AS BEFORE
PACKING CAPACITY ( CALCULATED )	76% OF FLOOD (91% AT 120% RATES)	83% OF FLOOD
DISTILLATE ETHYLBENZENE, WT%	0.22	0.22
BOTTOMS TOLUENE, WT%	1.28	1.0 - 1.3

\* Expected performance - Actual performance to be verified in future performance test.

This case study demonstrates how FLEXIPAC<sup>®</sup> HC<sup>™</sup> Packing can be applied in revamp situations for greater capacity while maintaining efficiency. FLEXIPAC<sup>®</sup> HC<sup>™</sup> packing can also be utilized in the following situations:

- revamps for greater efficiency at the same tower capacity ( smaller crimp )
- combination of greater capacity and efficiency for revamps
- new tower construction to reduce required vessel diameter and / or height.

## CONCLUSION

The SUPERFRAC<sup>®</sup> tray is designed to increase both the entrainment limit and downcomer flooding limit of a column by applying technologies both for the active area and downcomer area. The technology can be applied in columns that now have conventional trays or columns that have trays with 360° support rings. In most cases, very little to no tower attachment modifications are necessary, making the installation of such trays as short as possible.

FLEXIPAC<sup>®</sup> and GEMPAK<sup>®</sup> structured packing provide lower pressure drop and higher capacity than random packing or trays. The lower pressure drop results in reduced temperature and fouling. Even greater capacity or efficiency gains can be realized with the new FLEXIPAC<sup>®</sup> HC<sup>™</sup> high capacity structured packing.