BTX Extractive Distillation Capacity Increased by Enhanced Packing Distributors

Karl Kolmetz
kkolmetz@yahoo.com

Jeff Gray
jeffngray@hotmail.com

Mel Chua
Sulzer Chemtech

Raghu Desai
Sulzer Chemtech

AIChE 2002 Spring Meeting
New Orleans, Louisiana, USA
10-14 March 2002

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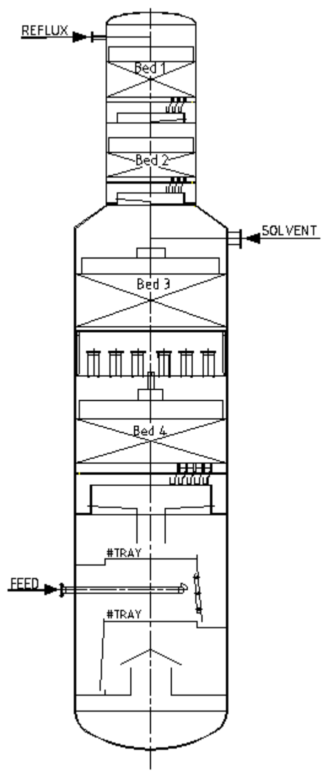
Abstract

A new grassroots BTX Extractive Distillation Unit was commissioned in February 2000. A test run was preformed in July 2000 and plant design criteria was marginally accomplished. A review of the tower internals was completed and recommendations made to improve the distributors and reduce the area of the distributor supports that obstructed the packing.

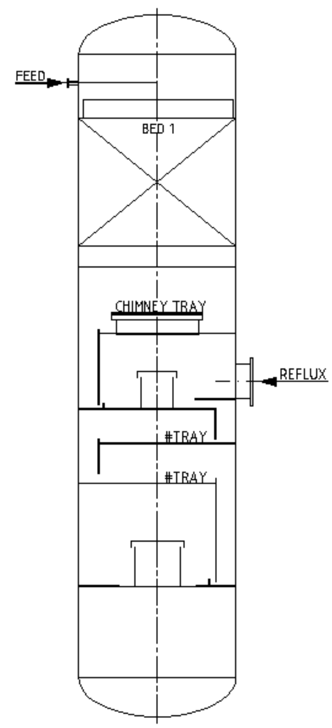
In January 2001, with the turn around of the Ethylene Cracker, the recommended modifications were installed. With the modifications to the distributors and retraying a limiting stripping section, all the plant design criteria were met. Additionally an 18% increase in aromatic production capacity was achieved while improving aromatic recoveries. Enhanced distributors can greatly improve the fractionation capacity of structured packing.

Background

A grass roots extractive distillation BTX unit was commissioned in January 2000. The unit consisted of a Reactor Pretreatment Section, an Extractive Distillation (ED) Column, a Stripper Column, and a Benzene-Toluene Distillation Column. The ED Column has four structured packed sections in the rectifying section (top of the tower) and trays in the stripping section (bottom of the tower). The Stripper Column has one structured packed bed with one tray in the rectifying section and trays in the stripping section.



ED Column



Stripper Column

After commissioning the unit failed to meet design rates and recoveries. The operation was reviewed and it was decided that new Z-Bar type trays, with small slotted valves, in the bottom of the ED Tower would meet design conditions. Z-Bar trays have additional area in the downcomer to allow more liquid traffic. Small slotted valves, which are smaller than standard valves, have higher overall efficiency. The unit was shut down in May 2000 for tray replacement.

Opportunities Found in May 2000

The team of maintenance and engineering personnel, that included some of the authors, was able to inspect the ED Column and Stripper Column in May 2000. The columns were found to be clean and well constructed. The design was similar to those that the technology licensee had utilized in the past with success. It is acceptable to utilize past designs only if they conform to basic engineering fundamentals.

The first opportunity found was at the top of the third bed of the ED Column, counting from the top down. This was the lean solvent feed point. The liquid distributor had two issues. The first issue was that four by eight inch plates on top of the packing supported the distributor. These plates covered 8% of the packing.

Packing loses its efficiency by channeling. Channeling is when the vapor and liquid travel in separate paths and fail to mix. Channeling can present itself in two phenomena; one in macro and one in micro.

The micro phenomenon is in the point flow. As the liquid travels down the length of the packing bed less and less mixing occurs leading to reduced heat and mass transfer. The liquid coalesces into large flow streams by passing the rising vapor.

A four by eight-inch plate blocks the rising vapor flow and sets up a channeling regimen, negating the effect of the distributor. The plates are blocking the gas flow underneath and the vapor below the plates is channeled to the side. A reduced separation or heat exchange efficiency is induced and column capacity may be reduced.

The macro phenomenon is in the bulk flow. One half of the liquid is on the left side of the column and one half is on the right. If the liquid is not collected and re-mixed between the beds, a bulk flow composition difference can exist between the right and left side of the column.

The second opportunity was in the distributor itself. At this point the distributor had two feeds. The first was from the second bed of packing, which was mostly hydrocarbon, and the second was from the lean solvent feed point. The distributor was essentially two distributors in parallel; no pre mixing of the feeds to the third bed was preformed. This meant that the hydrocarbon from the second bed and the lean solvent did not began to contact until several feed down the bed of the packing.

The third opportunity found was at the bottom of the third bed. The bottom of the third bed did not have a liquid collector. Liquid was allowed to freely rain down on next chimney tray, setting up the macro phenomena. A liquid collector and distributor has two functions. First is to collect, mix the liquid, and route it to the next bed.

The second is to evenly distribute the vapor across the upper bed section. In some cases without a collector, the vapor may be channeled leading to reduced packing efficiency. Vapor distribution is required; 1) if there is not sufficient height between the beds for vapor mixing, 2) at high-pressure applications where gas densities are high, and 3) where there is a small gas to liquid density ratio.

The fourth opportunity found was on the fourth bed. The fourth bed's distributor was a chimney tray. At this point there are two liquid phases, hydrocarbon and solvent. A standard chimney tray may not be the best distributor for two liquid phases with different densities.

The fifth and last opportunity found was that the fourth bed did not have a hold down grid below the chimney tray. Hold down grids maintain the levelness of the packing during a mild column upset, reducing channeling. The packing appeared to be miss-aligned under the chimney tray.

Recommendations were made to rectify each of the items mentioned, but due to time constraints decisions were made to only redistribute the upset packing and replace the bottom 37 trays with enhanced liquid and vapor capacity trays. The unit was then recommissioned.

Turn Around Time Management

In a turn around, decisions are normally made quickly in view of lost production, with the hope that the shortest most reasonable outage will result in improved tower performance. It is difficult when a unit is down and no sellable products are being produced to extend an outage. The unit manager has to balance the cost of an additional day or days of lost production versus the potential gain of improved tower performance. It is often difficult to quantify the potential gain of the improved tower performance.

It is very important for a decision-maker to have considered what some of the potential scenarios they could encounter before the turn around begins. Some of the scenarios that may cause additional time in the outage include; 1) damaged trays, 2) upset packing, 3) damaged feed / reflux nozzles, 4) improper installation, and 5) design deviating from basic principles.

Managers are group leaders that bring teams of people together for the best overall result. It is important for managers to built relationships, in advance of problems, with competent distillation engineers so that the potential gain of improved tower performance can be quantified quickly with reliability. With the ability to transfer information quickly, many decisions can be made with reliable guidance.

Tower Problem Solving

The first step in resolving any distillation problem is to understand the operating and technical fundamentals of the column. Knowledge of how a column functions, hydraulic constraints, thermodynamic and equilibrium limits, and heat and material balances are required. This knowledge needs to be accumulated in advance of formulating any resolution of a problem.

At least four types of distillation equipment problems can exist. The first problem is inappropriate design, the second is inappropriate installation, the third is inappropriate operation, and the fourth is potential damage to internal equipment. Before a process is shut down for repairs the inappropriate design and damage to internal equipment should determined, and inappropriate operation should be eliminated.

Synopsis of Tower Troubleshooting

Always do simple checks first.

1. Ensure that levels are accurate. Have operations move levels and view changes in the field.
2. Calculate column pressure drop and then measure pressure drop. Review survey pressure reading to operation’s readings.
3. Survey column temperature profile. Review survey temperature reading to operation’s readings.

Verify Tower Operations

Perform tower simulation to verify Tower Stage efficiency. Sometimes the feed compositions changes and tower is no longer able to meet desired specifications due to thermodynamic or equilibrium constraints. Parameters required to perform the simulation will be;

1. Accurate tower feed, Overhead, and Bottoms laboratory analysis
2. Accurate tower mass balance, within 2%.
3. Heating and cooling medium temperatures.

If the tower simulation confirms the limits are not beyond thermodynamic or equilibrium constraints and additional check may be to have the tower gamma scanned to look for tray damage. This type of troubleshooting method can determine internal damage, vapor liquid mal-distribution, and packed and trayed tower fouling. Because of economic constraints, scanning should be chosen only after the simple checks and the limits are confirmed. Scanning can sometimes confirm the problem that was identified by the other checks.

July 2000 Test Run

From May to July the unit was further optimized. Several other non-distillation unit issues were resolved. During July 13th thorough the 16th a unit test run was performed. The unit was able to test run design rates, but did not meet benzene recoveries. Benzene design recovery was 97.0 wt % and Toluene design recovery was 98.0 wt %.

	Test Run Design	13 July 00	14 July 00	15 July 00
Unit Feed Rate ton/hr	27.55	27.48	27.26	27.17
Benzene Recovery %	97.0	95.8	95.7	95.7
Toluene Recovery %	98.0	97.4	99.2	98.7
Benzene Product ton/hr		12.97	12.97	13.14
Toluene Product ton/hr		4.62	4.79	4.83
Non Aromatics ton/hr		6.43	6.31	6.29
Benzene in Non Aromatics		3.4	4.2	5.1
Benzene Purity %	99.90	99.96	99.96	99.95
Toluene Purity %	98.50	98.72	98.91	98.78

From July until December the unit was operated and additional optimization was performed.

November High Load Test

During November a high load test was conducted to determine the existing limits of each section of the plant. A properly planned and executed high load test can provide valuable information in unit revamps. A high load test can provide insight into the unit's current problems and under utilized equipment.

The feed was raised step wise, over a two-day period, November 10th and 11th, to test each section. The feed rate was slowly raised to 123% as a hydraulic system check neglecting product recoveries. The limiting section of the plant was found to be the Stripper Column, which had solvent carry over at 111%.

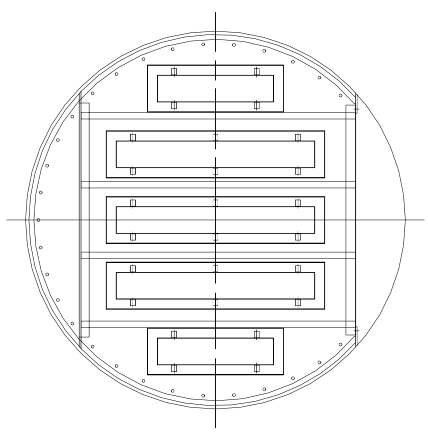
January 2001 Turn Around

During the January 2001 turn around the opportunity was taken to upgrade the BTX Unit. Simulations were conducted rate the ED and Stripper Column. The existing packing in the ED and Stripper Column was rated at 140% of design. The new trays in the bottom of the ED Column were rated at 125% of design.

The unit limits were found to be the distributors and the Stripper Column trays. An additional consideration was the solvent carry over in the Stripper Column. The Stripper Column had one tray and a large, twenty plus foot, packed bed above the feed point to reduce solvent losses. Reflux was washed down the packed bed to remove the solvent from the aromatics. One would not expect that the solvent would carry over with the overhead vapor from a large packed bed.

The Stripper Column

To reduce the solvent carry over, the top tray below the packed bed was converted to a chimney tray. A small amount of fractionation capacity was lost, but during the high load test the aromatics in the lean solvent had remained low. Chimney tray design seems straight forward, but several factors need to be considered in the design. The pressure drop of the chimney tray needs to be reviewed, and minimized if possible, as this tray does no actual fractionation. The vapor distribution needs to be reviewed and redistributed if necessary by the design of the chimney hats.



Schematic of new Chimney Tray

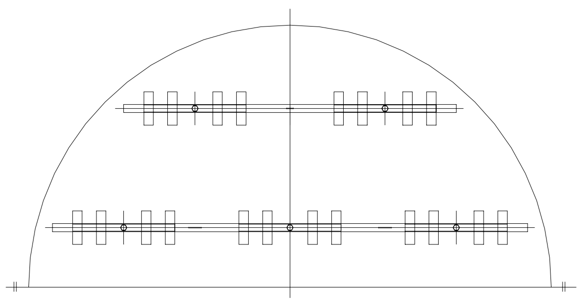
Picture of new Chimney Tray

The remaining Stripper Column trays were upgraded to the Z-Bar style with small valves to match the ED Column trays. They were rated to 140% of design. One negative of raising tower tray rates is the column down turn, or minimum rates. By increasing the design rating to 140%, the new effective column minimum-operating rate was raised.

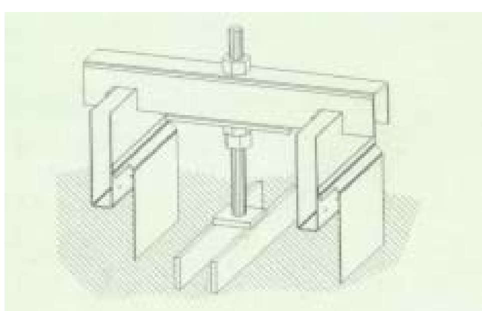
Picture of new Sulzer BDH smaller valve trays

The ED Column

Several opportunities were found in the ED Column in May 2000 and each of the opportunities was addressed in the January 2001 turn around. The first opportunity found was at the top of the third bed of the ED Column, counting from the top down. This was the lean solvent feed point. The lean solvent liquid redistributor had four by eight inch plates on top of the packing supporting the distributor. These plates covered 8% of the packing.



The liquid redistributor was redesigned using thin square bar stock to support the distributor in two parallel strips across the top of the packing. This reduced the blocked area of the packing too less than 1%. This one change greatly increases the distillation capacity of the packing.



The second opportunity was in the lean solvent distributor itself. At this point the distributor had two feeds. The first was from the second bed of packing, which was mostly hydrocarbon, and the second was from the lean solvent feed point. The distributor was essentially two distributors in parallel, no premixing of the feeds to the third bed was preformed.

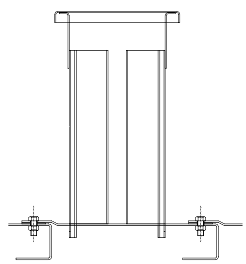
The distributor was reconfigured to allow the hydrocarbon and the lean solvent to premix as they left the distributor. Each distributor box had dual compartments that released the different phases to mix together above the packing. This enhanced the solvent’s ability to be more selective toward the aromatics.

At this point there are three phases in the packing; vapor which should be mostly non-aromatics, hydrocarbon liquid that should be a mixture of aromatics and non-aromatics, and solvent.   Improved mixing of the phases should lead to increased mass transfer.

Picture of dual compartment distributor
being tested at Sulzer Test Rig in Singapore

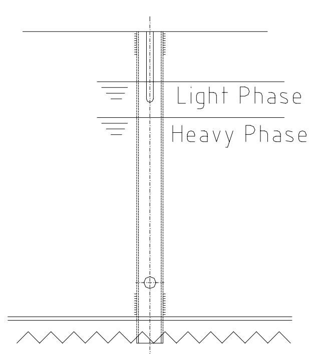
The third opportunity found was at the bottom of the third bed. The bottom of the third bed did not have a liquid collector or redistributor. Liquid was allowed to freely rain down on next chimney tray. A liquid collector and redistributor has two functions. First is to collect the liquid, mix, and route it to the next bed. The second is to evenly distribute the vapor across the upper bed section. Without a collector, the vapor may be channeled

The packing was removed from the third bed and a liquid collector was installed. The well-mixed liquid was collected and routed to the fourth bed liquid distributor, and the vapor was evenly distributed to the packing above the collector.

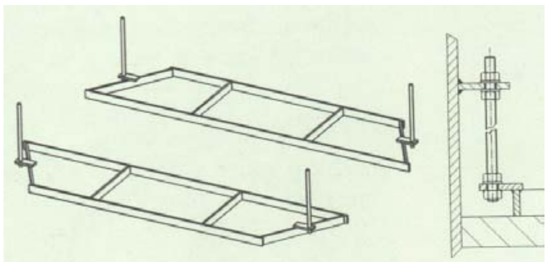


Picture of typical liquid collector

The fourth opportunity found was on the fourth bed. The fourth bed's distributor was a chimney tray. At this point there are two liquid phases, hydrocarbon and solvent. A standard chimney tray may not be the best distributor for two liquid phases with different densities. The distributor was replaced with a design that would evenly distribute the two liquid phases. Each overflow weir had two exit points, one for each density.



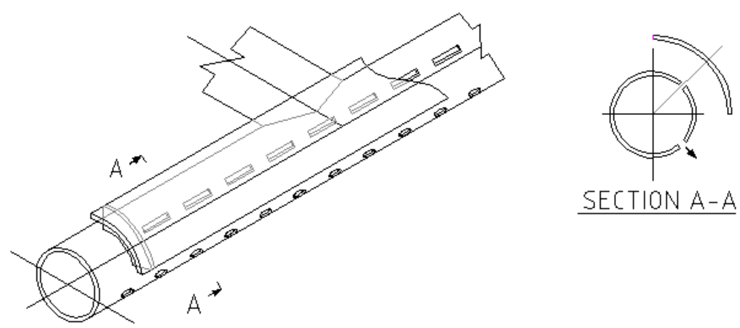
The fifth and last opportunity found was that the fourth bed did not have a hold down grid below the chimney tray. Hold down grids maintain the levelness of the packing, reducing channeling. The packing appeared to be miss-aligned under the chimney tray. The packing was removed, leveled and a hold down grid installed.



Picture of typical hold down grids

An additional finding during the January 2001 turn around was the ED Column feed nozzle. The feed nozzle had been modified during the May 2000 outage. The concern was the potential for the hydrocarbon feed to be two phases, vapor and liquid. The original design was a T-Shaped inlet feed nozzle with outlet holes only in the bottom of the T. The design was modified to include a slot for the vapor in the top of the T.

A potential problem of two-phase feeds is that the vapor leaving the nozzle can touch the bottom of the upper tray, leading to loss of efficiency. To minimize the vapor from contacting the next tray, a shroud was installed above the vapor slots.



May 2001 Test Run

The unit was commissioned in February 2001 and a high load test was preformed in May 2001. The unit has yet to reach its limit due to feedstock constraints. Below is a table comparing the July 2000 test run with the May 2001 test run.

	Test Run Design	15 July 00	15 May 01
Unit Feed Rate ton/hr	27.55	27.17	33.78
Benzene Recovery %	97.0	95.7	97.27
Toluene Recovery %	98.0	98.7	98.69
Benzene Product ton/hr	10.78	13.14	15.07
Toluene Product ton/hr	5.61	4.83	6.32
Non Aromatics ton/hr	7.25	6.29	7.12
Benzene in Non Aromatics Wt %	<5	5.1	3.1
Benzene Purity %	99.90	99.95	99.98
Toluene Purity %	98.50	98.78	98.70

Lessons Learned

In each revamp there are lessons learned that should be noted. Unfortunately, there are times when you learn the lesson only after the unit starts up. Here are some lessons learned in this revamp.

1. Review each design to conform to distillation fundamentals. Even though a design has been successful in the past, a review of each new application needs to be completed. Some small deviation could restrict the column from obtaining design goals.

2. For operating companies most distillation applications have the ability to be improved. For many existing columns a test run followed by a review of distillation equipment can lead to improved rates and recoveries. New designs are constantly being applied that can improve the efficiency of existing columns.

3. For engineering and construction companies improved column efficiency could translate into smaller equipment with lower construction cost, leading to wins in the bidding wars.

4. Building relationships with competent professionals prior to a unit outage in distillation, rotating equipment, furnaces and other areas can provide timely guidance.

Conclusions

A well planed and executed test run of existing equipment followed by a distillation fundamentals review can yield a cost effective production increase. On the existing Extractive Distillation BTX Columns the aromatic production capacity was increased over 18% while improving aromatic recoveries.

With design improvements of distributors, the efficiency and capacity of structured packing can be increased. Enhancing the mixing of the vapor and liquid phases results in improved mass transfer.

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