Design Guidelines for Distillation Columns in Fouling Service

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Abstract

Hydrocarbon Producers are exploring avenues to extend the on-stream time between outages for maintenance. Key equipment that can determine the end of run includes: catalyst life, cyclone erosion, and compressor and tower fouling. Critical equipment that has been shown to be a limiting factor can be duplicated to extend run length: for example parallel pumps, reactors and reboilers. This is a successful method to extend on-stream time, expensive and in fact, at times cost prohibitive. Incorporating design guidelines that increase the on-stream time of the key pieces of equipment is a better economic decision for most plants.

Currently Refiners are planning four-year run lengths and Ethylene Producers greater than five-year run lengths. These targets present challenges for distillation column design. Potential problem areas include refining vacuum wash oil beds, ethylene plant quench and saturator towers, and butadiene and other polymer producing distillation columns. Each of these applications has some common characteristics. A review of successful and not so successful designs can help develop key design criteria. Design guidelines developed from successful applications can improve the on-stream time of each of the applications.

Introduction

Designing mass transfer equipment for fouling service requires first an understanding of the fouling mechanism, the process in which the fouling occurs, and behavior of the process when the fouling is present. An understanding of these items needs to be developed in advance of designing mass transfer equipment for fouling service.

The challenges of fouling columns can result in;

1. Increase energy consumption due to heat transfer and efficiency issues.
2. Reduced column capacity, which may lead to production loses.
3. Increased down time for cleaning and disposing of fouling wastes
4. Potential need for the use of chemical additives

General Guidelines

Fouling service in a distillation column is a broad term that encompasses many fouling phenomena. The fouling phenomena can be localized in either the vapor phase or liquid phase. It the fouling is localized in the liquid phase an inhibitor can be utilized. Fouling phenomena can include;

1. Vaporization of volatile components
2. Polymerization
3. Condensation
4. Sedimentation / Precipitation / Crystallization
5. Foaming
6. Chemical Reaction
7. Corrosion

Complex fouling problems are a result of a combination of two or more of these phenomena occurring at the same time, such as in an ethylene caustic tower. They are nearly always mutually reinforcing.

Factors that assist fouling phenomena can include;

1. Residence time
2. Stagnate zones
3. Sharp transitions
4. Emulsion issues

Consideration must also include the fact that fouling gets worse over time. Fouling is not static.

Fouling Mechanisms

Vaporization of Volatile Components

In many applications fouling can result if the volatile components are allowed to vaporize. This fouling is found in refinery vacuum and de-asphaltene oil towers and ethylene quench oil towers. If the process is placed on recirculation without the addition of fresh feed with volatile material, the column can foul as the volatile components are removed. In one example an ethylene quench oil tower was placed on circulation and viscosity of the bottoms product increased beyond its pour point. The unit was shut down and required several days of off-line cleaning.

Polymerization

Polymerization is the linking of double bonds to form long chain molecules. Examples of polymerization include, polyethylene, polypropylene, polystyrene, poly butadienes and poly MMA. These products are undesirable in the monomer distillation column. These products can lead to reduced capacity and unit outages.

Condensation

Condensation is a reaction where two or more small molecules combine to from large, stable structure molecules. Extreme condensation is the formation of coke at high temperature and long residence times. Coke forms when thermal cracking removes hydrogen and light material from the fluid. A layer of coke is left behind. Thermal cracking can occur in both the gas phase and the liquid phase. However, the most common situation is liquid-phase cracking when low liquid rates extend residence time in high-temperature operations.

Examples of condensation can be found in ethylene furnace transfer lines to the quench oil tower and in refinery vacuum towers.

Sedimentation / Precipitation / Crystallization

Sedimentation is the accumulation of solids that are deposited in low velocity areas in process equipment. The equipment can include heat exchangers, tower distributors, distillation trays, random packing, and structured packing. If the trays are fouled below the feed point the cause might be sedimentation.

Many processes contain suspended solids, which can settle out on the mass-transfer surface. Products of sedimentation can include salts, metal oxides, catalyst fines, fermentation products and coke fines. Precipitation and crystallization of dissolved salts can occur when process conditions become super saturated, especially at mass transfer surfaces. Ammonia salt deposition resulting from both water vaporization and direct solid deposition from the gas phase is a common refining problem.

Sometimes the deposits formed do not adhere strongly to the surface and are self limiting, the thicker a deposit becomes, the more likely is to be removed by the fluid flow and thus attain some asymptotic average value over time. Sedimentation fouling is strongly affected by velocity and less so by temperature, however a deposit can bake on a surface and become very difficult to remove.

Precipitation and supersaturation are fouling issues. Certain salts such as calcium sulfate are less soluble in warm water than cold. If such a stream encounters a wall at a temperature above that corresponding to saturation for the dissolved salt, the salt will crystallize on the surface.

Crystallization will begin at specially active points (nucleation sites) such as scratches and pits, often after a considerable induction period and then spread to cover the entire surface. The build up will continue as long as the surface in contact with the fluid has a temperature above saturation. The scale is strong, adherent and can require vigorous mechanical or chemical treatment for cleaning.

The following processes may cause super saturation:

1. Evaporation of solvent
2. Cooling below the solubility limit for solution with normal solubility, solubility increases with temperature.
3. Heat above the solubility of solutions with inverse solubility such as; $CaCO_3$, $CaSO_4$, $CA_3(PO_4)_2$, CaSiO3, $Mg(OH)_2$, $MgSiO_3$, Na_2SO_4, Li_2S0_4 and Li_2Co_3 in water.
4. Mixing of streams with different composition.
5. Variation of pH, which affects the solubility of CO_2 in water.
6. Ammonia salt deposition in refining

Additionally, solidification fouling can occur due to cooling below the solidification temperature of a dissolved component, such as solidification of wax from crude oil.

Knowing the properties of the fluid and suspended solid, flow conditions and mixing effects one can develop guidelines to predict sedimentation of solids from liquids. Petroleum fluid is a mixture of various compounds. Solubility balances among all such components make a petroleum fluid stable. Changes in that balance can cause precipitation from a petroleum fluid and result in fouling (asphaltene precipitation).

Foaming Systems

Some systems have a propensity for fouling in the form of foaming. In many systems an operating froth can be observed on the liquid phase. In distillation systems, the decrease in surface tension as equilibrium temperature rises promotes foaming. High gas velocities allow liquid to be entrained into the vapor phase. In non-foaming systems liquid disengagement from the vapor stream is relatively easy. Foaming makes liquid disengagement from vapor flow difficult. When foaming becomes severe it can lead to a reduction in capacity and loss of efficiency. To counter this effect distillation equipment that operate in foaming systems are run a lower vapor and liquid rates to reduce the amount of froth generated. Sometimes anti-foam additives are added to distillation columns to decrease the amount of foam generated in the column. There are drawbacks to using anti-foam chemicals. Sometimes they may contaminate the end product and produce product that is does not meet production specifications. (7)

Chemical Reactions

In distillation desired or undesired chemical reactions can occur. In an ethylene caustic tower there are competing chemical reactions. The caustic absorbs the CO_2 (desired) by electrostatic interactions and Van der Wall attraction. The acetaldehydes can be polymerized by the caustic (undesired) to form first a yellow oil polymer, and then a red oil polymer by aldol condensation reactions, which can then lead to emulsions.

Corrosion

When corrosion occurs the increased surface roughness may promote fouling from the other fouling mechanisms. A comprehensive theoretical discussion of the different fouling mechanism is given in [4].

Operating Conditions affect on Fouling Phenomena

Stagnant Zones

Stagnant zones are areas where fouling mechanisms can propagate: vaporization of volatile components, polymerization, condensation, sedimentation and chemical reactions. To eliminate stagnant zones a small slope can be added to collection devices and flow promoters to distillation trays. Stagnant zones increase the residence time of the process and lead to precipitation and build-up of polymer and coke. Stagnant zones can also promote unwanted chemical reactions because of high residence time and little or no movement of material.

Sharp Transitions

In the higher fouling cases sharp transitions and corners need to be avoided. Transitions and corners are areas where polymer and solids can seed and grow. Packed tower internals such as feed pipes and trough distributors can be areas for polymer and solids build-up. The fouling potential of packed tower internals can be reduced or eliminated through proper design practices.

If the fouling potential is in the vapor phase, the overhead vapor may be drawn from the side of the tower versus the tower over head to eliminate transition line length and an additional corner.

Emulsion Issues

In hydrocarbon service where water is present, as in ethylene quench and saturator towers, emulsion issues can create opportunities for fouling. If the pH of the water is allowed to depart from neutral ranges, emulsions can occur that create mixtures that can carry hydrocarbons along.

Trace contaminates like oxygen, nitrogen compounds, sulphur compounds, mercury, and chlorides have a significant effect on the performance of chemical process fouling and this need to be recognized if present in the process. Contaminates with surfactant properties should be reviewed carefully.

Measures to Mitigate Fouling Phenomena

Process Review

The first step in mitigation of fouling phenomena is to thoroughly review the process for fouling potentials. Investigations of previous applications need to be reviewed to develop the best solution to the specific process.

Equipment Selection

The most suitable mass transfer equipment for fouling service may also be the least efficient for mass transfer. Grid packing and shed decks can handle nearly every fouling service, but have low efficiencies when compared to sieve trays, random, and structured packings.

Packing

For packed towers the key fouling factors revolve around liquid distribution and packing residence time. The longer the residence times the less suitable. Low-pressure drop, smooth surface, low residence time packings perform best in fouling service. The order of preference is:

1. Grid
2. Structured packing
3. Random packing

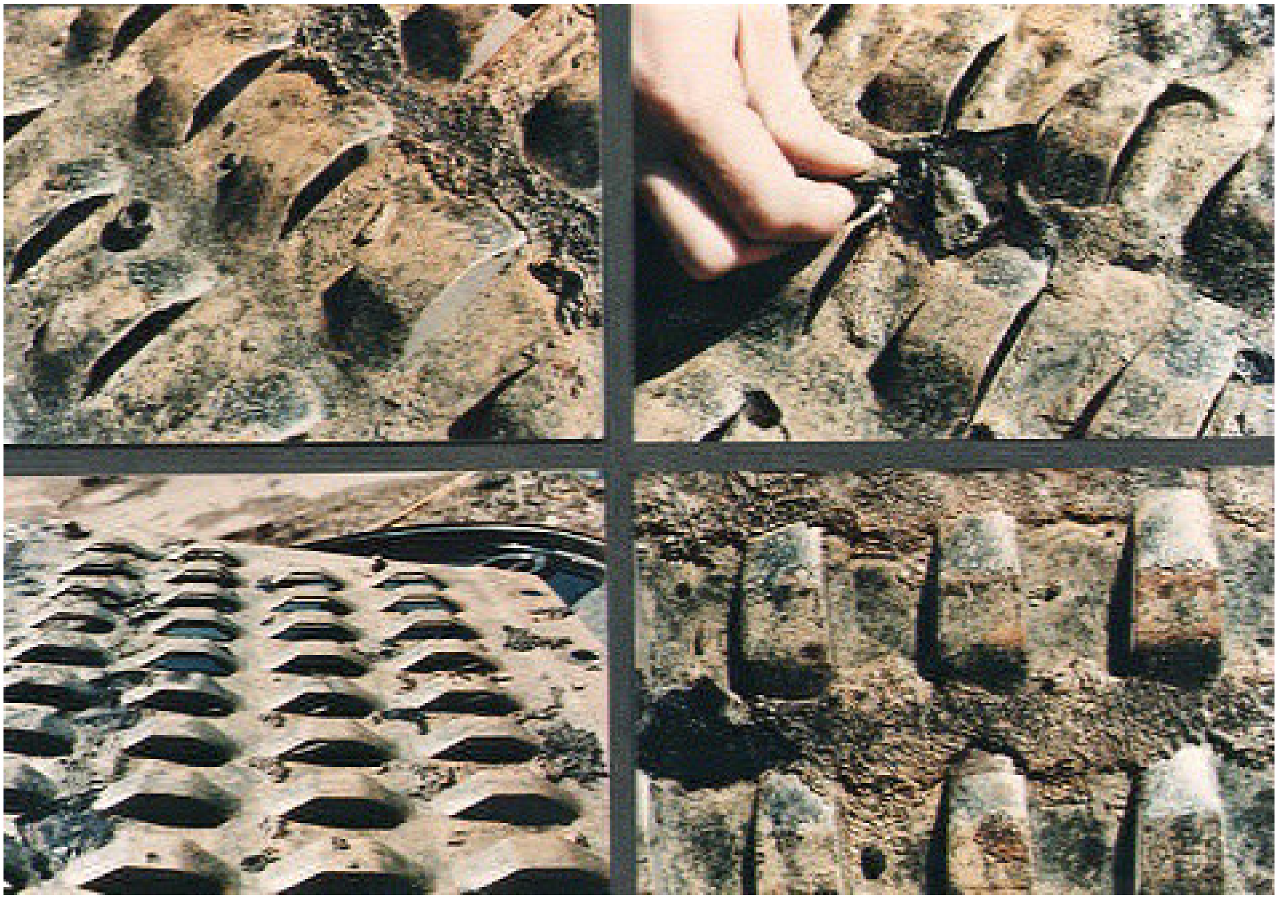
Packing Distributor Concerns

In fouling service, distributors are areas where residence time is increased and fouling phenomena can occur. In high-fouling services trough v-notch or other type of trough distributors are recommended over pan type distributors. A review of feed piping is also warranted.

Trays

The industry prefers trays in fouling service because of the long history of success trays have had in fouling service applications. The first continuous distillation column with bubble cap trays was developed in 1813 and structured packing was developed in 1964. The database and application know how is much larger with trays. The best trays to use in fouling services are sieve trays and dual flow trays. Moveable valve trays are less resistant to fouling because the valves are areas where fouling can seed and propagate. Distillation is part art and part science, as in any science, as you explore the limits you will find them

Example of Trays in Mash Service.



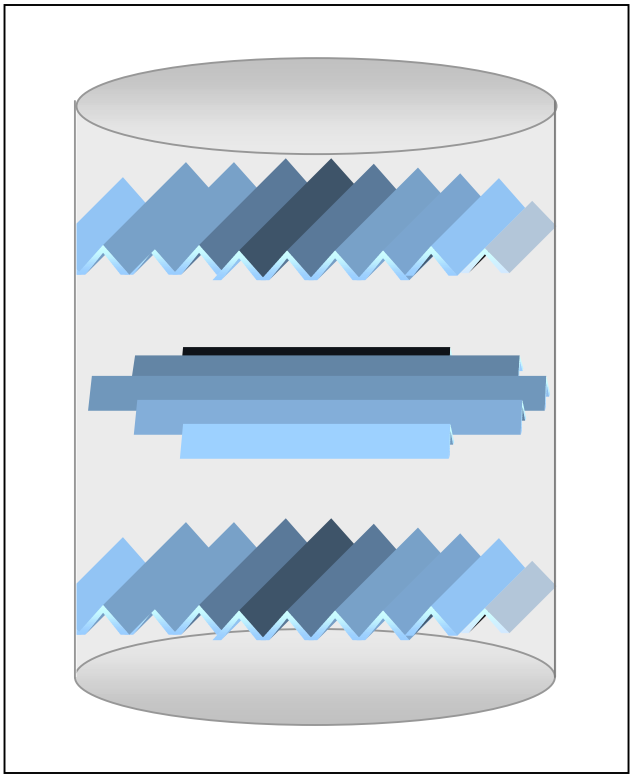
Tray Downcomer Concerns

In fouling services downcomer design requires attention to detail. A major problem with downcomers is the creation of dead spots: in areas near the tower wall, in areas opposite the downcomer outlet, areas near outlet weirs, and at the ends of the downcomer. Using modified downcomers that decrease the downcomer volume helps to reduce the dead spot by keeping more of the downcomer volume full of agitated liquid. For quick revamps of existing equipment an alternative is to install metal or ceramic shapes to modify the downcomer volume. Consider the influence of weir heights and avoid the use on inlet weirs when possible.

Baffle Trays

1. Shed Decks

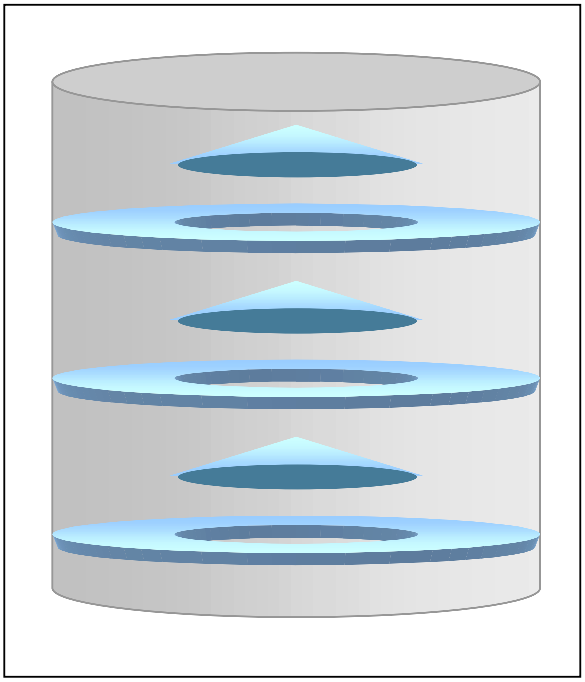
Shed decks are essentially angle iron beams of various sizes from two to ten inches that are placed in rows across the column. They typically are at on 24 inch tray spacing. They may be set in overlapping rows or rotated 90 degrees from tray to tray. The open area on the tray is typically 50%. The positives of shed deck are that the fouling potential of the decks is almost zero because there are no stagnate zones and low residence time. Unfourtunaly, the efficiency of the tray almost matches the fouling potential, particularly if wide shed decks are utilized. Shed decks work well in fouling applications where their application is essentially for heat-transfer purposes.



Shed Trays

2. Disk and donut trays

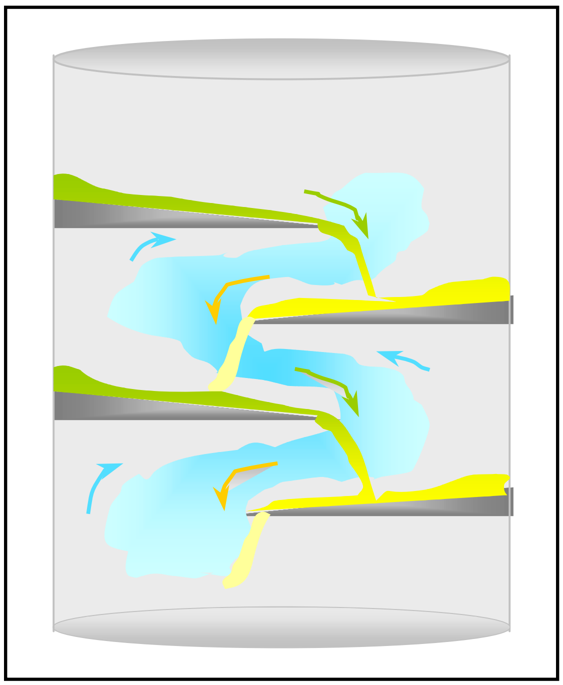
Disk and donut trays are slightly sloped trays that allow the liquid to splash from inner circle ring to outer circle ring. Fouling potential of this tray is low along with the efficiency.



Disk and Donut Trays

3. Side to side trays

Side-to-side trays are trays that allow the liquid to splash from side to side. The decks can be sloped. Fouling potential of this tray is low, as with efficiency



Side-to-Side Trays

Dual Flow Trays

Dual flow trays are the trays of preference for heavy fouling services. Dual flow trays have no downcomers, where products of fouling phenomena can accumulate or where polymer and solids can seed and propagate. Dual flow trays are designed with enough open area on the tray decks to eliminate stagnation and promote back mixing. A disadvantage to dual flow trays is that they are limited in turndown potential.

The vapor and liquid transfer up and down the column through the holes on the tray deck. This is an advantage in combating vapor-phase fouling as the underneath of the tray is washed. The continuous agitation of the liquid on the topside of the trays combined with continuous underside wetting/washing action makes this tray suitable for fouling services

The challenge of dual flow tray is mal-distribution in larger diameter towers. The top of a column will move in a typical storm as much as six inches. This movement will cause the hydrologic load to migrate in the column. If hydrologic flow instability is developed it propagates down the column. Improper feed, reflux or vapor distribution can also create mal-distribution problems,

Two types of dual flow trays are available; standard deck and rippled deck. The standard deck has a flat plate, and the rippled deck has sinusoidal waves

Spray nozzles vs. distributors

There is much discussion in the industry between the advantages and disadvantages of spray nozzles in fouling services. There are groups that advocate only spray nozzles with no packing or shed decks. There are groups that advocate only distributors with packing.

The best trough distributor will have superior distribution performance to the best spray distributor. In fractionation services, the trough distributor may be mandatory to meet separation requirements. In solids services, such as refinery FCC slurry zones, specially designed trough distributors have proven performance.

However, as long as the nozzles on a spray distributor have a large enough minimum flow passage to protect against plugging, spray distributors resist plugging. They have performed well in extremely severe services including refinery vacuum wash zones and delayed coker main fractionators.

Material of Construction / Surface Finishing

It may be possible to reduce fouling by the choice of material selection, or more importantly by surface finish. Smooth surfaces shed deposits easier than rough surfaces.

A corroded surface is more prone to other fouling mechanisms. The following guidelines on material selection can be considered on services that are very prone to fouling. (3)

1. Standard austenitic stainless steel such as 316 (18Cr 10Ni 3Mo) can be utilized for resistance to acids and reasonable resistance to pitting corrosion. Type 304L (18Cr 10Ni) stainless steel has a good resistance to nitric acid. Austenitic stainless steels have relatively low strength, poor anti erosion and abrasion properties and do not possess the ability to resist stress corrosion cracking.

2. Super austenitic stainless steels with relatively high nickel content (approximately 20 Cr 29 – 34 Ni), sometimes referred to as alloy 20 are more costly than standard austenitic steels but provide excellent resistance to acids and some acid chlorides.

3. Duplex stainless steel offer high strength, coupled with resistance to abrasion, erosion and stress corrosion cracking.

4. Nickel based alloys, such as Hastelloy, have out standing corrosion resistance in resisting acids, mixed acids, and acids at high temperatures. The principle restriction in their use is the high cost.

Use of Additives

An additive may act to resist fouling in one or more of the following ways.

1. Chemically react with the fouling species to modify it's fouling potential.

2. Change the physical interaction between the foulant and the equipment surface.

3. Modify the deposit residing on the surface, so that is can be removed by fluid flow.

It is also possible to reduce the fouling potential by pre-treating the metal with passivating solutions.

Case Studies

Case Studies can be utilized to refine design practices and standards for fouling services.

Refinery Vacuum Towers

Refinery Vacuum Towers are an excellent case study because many of the fouling phenomena are present in this application. The most challenging part of the vacuum column is the wash bed, which removes the entrained bottoms from the distillate products. Both trayed wash sections and packed wash sections have problems. The lower pressure drop of packing has overwhelming shifted the industry to packing for this service.

Liquid rates in the wash zone are very low. The low liquid rate, couple with high temperature, results in long residence times in stagnant sections of the packing. This occurs in the packing surface treatment, the interface between packing layers, on packing supports, and in dead portions of the packing (for random packing).

Asian Refinery Vacuum Tower Wash Bed

The industry average wash bed run length might approach 5 years. The average life of a wash bed is based on a variety of factors, which include;

1. Design of inlet feed system to reduce entrainment and vapour mal-distribution.
2. Design of inlet transfer line to reduce velocity and resulting entrainment
3. Design of furnace to prevent high flux areas which initiate cracking and coking
4. Design of collector tray, this can be sloped to reduce residence time
5. Rate of wash bed oil flow
6. Amount of vacuum – deep cut vacuum will result in more velocity gradients leading to more entrainment and local low-flow areas
7. Selection of packing and internals

Vacuum Tower Design Options

Baffle Trays

Baffle trays, particularly shed decks have seen excellent service factors in Refinery Vacuum Towers. The positives of shed deck are that the fouling potential of the decks is almost zero because there are no stagnate zones and low residence time. The negatives are the low stage efficiencies. Baffle trays are still in use in some older units.

Grid Equivalents

Grid Equivalents have proven service in wash zones. Capacity is high and entrainment removal is average. With sufficient liquid wetting, coking and fouling is unusual. Grids fit the design guidelines for packing in fouling service, which include low-pressure drop, smooth surface, low residence time.

Random Packing

Random packing has had successes in vacuum towers. However, due to the increased possibility of stagnant liquid pool formation, many installations have changed to structured packing or grid.

Structured Packing

Structured Packing may be used in wash beds if designed correctly. The challenge of structured packing in vacuum tower service is increased efficiency at slightly increased delta p compared to grids along with rougher surfaces and increased residence time.

If the packing is allowed to dry, by not properly designing the wash bed liquid rates with optimized liquid distributors, the packing can foul quickly causing very high-pressure drops and poor product quality and reduced capacity.

Current practice is a mixed bed of grid and structured packing combining fouling resistance at the lower sections and high separation efficiency at the higher sections. Computerized Fluid Dynamics (CFD) studies should be evaluated to optimize inlet vapor flow.

Examples

1. An Asian Refinery had a challenge maintaining wash oil rates due to plugging spray nozzles and the result is shown in the previous picture. The run length of this tower was less than one year. The spray nozzles were replaced with a liquid distributor and since the change was made there has been no sign of fouling. The same refinery had a second challenge of napthanic acid attack to the internals. The tower was revamped and metallurgy of the internals was upgraded.

2. An Asian Refinery wash bed was changed from random packing to grid packing in 1995, this tower is still in service today.

An example of the grid installed in the Asian Refinery

Lessons Learned

1. Grid equivalents may be an improved packing choice over structured packing at a reduced efficiency price in wash beds lowers sections.

2. Wash bed rates are difficult to simulate correctly and need to be carefully specified to insure long bed life with reduced fouling.

Ethylene Quench Oil Towers

Ethylene quench oil towers have the potential to encounter several of the fouling phenomena described in this paper. The distillation equipment selection needs to consider each of the fouling scenarios. The industry average Ethylene Unit run length might approach 6 years.

A challenge for quench oil towers is the formation of coke on the tower internals and fines. The tower internals must be designed, especially velocities and the residence time, to reduce the formation coke and fine accumulation on the internals.

An additional design criterion for ethylene quench oil towers is the concern for naphthalene concentrations. On heavy naphtha's the naphthalene concentration can cycle up in the tower. The naphthalene is too heavy to exit in the tower overhead, and can be stripped back into the tower from the fuel oil stripper, causing the liquid traffic in the tower to flood.

Quench Oil Tower Design Options

Baffle Trays

Baffle trays, particularly shed decks, have been used successfully in Ethylene Quench Oil Towers. The positives of shed deck are that the fouling potential of the decks is almost zero because there are no stagnate zones and low residence time. The negatives of baffle trays and shed decks are the low efficiency of the tray.

Ripple Trays

An Asian Producer has seen excellent fouling resistant service from Ripple Trays. They have been in service ten years will no issue of fouling.

Random Packing

A small negative of random packing is the horizontal area where liquid can pool. Fouling can begin to propagate from this area.

Lessons Learned

1. One on the lessons to learn is to utilize caution when commissioning quench oil towers. Normal guidelines are to purchase #2 Diesel Oil to start the circulation fluid. If the furnaces are on steam stand by to the quench oil towers, the steam can strip the light ends out of the circulation loops, increasing the viscosity of the circulation loops. If the viscosity is allow to increase above the pour point the flow from the tower can cease, requiring several days to clear the fouled lines. The vaporization of volatile components is a concern in Ethylene Quench Oil Towers.

2. The naphthalene concentration can cause high liquid loads in the bottom of the quench oil tower. Naphthalene is too light to exit with the fuel oil, and too heavy to exit the tower overhead.

Ethylene Quench Water Towers

Ethylene quench water tower in naphtha crackers that have quench oil towers can be relatively trouble free because the oil tower removes the coke fines and heavy hydrocarbons. Quench water towers for ethane crackers are a different story. There can be numerous challenges in light gas crackers. These can include;

1. Coke fines
2. Pyrolysis Tar
3. Emulsions

Quench Water Tower Design Options

Baffle Trays

Baffle trays, particularly shed decks, have seen excellent service factors in ethylene quench water towers. The positives of shed deck are that the fouling potential of the decks is almost zero because there are no stagnate zones and low residence time.

Ripple Trays

An Asian Producer has seen excellent fouling resistance service from Ripple Trays. They have been in service ten years will no issue of fouling.

Random Packing

A small negative of random packing and grid equivalents is the horizontal component, which is an area for the fouling phenomena to begin to propagate.

Examples

1. US Gas Cracker. A quench water tower was commissioned with a combination of spray nozzles, and random packing with pan distributors. The random packing was replaced in 1999 and 2000 because of high-pressure drop and loss of capacity. By February 2001 the tower was again showing signs of high-pressure drop and heat transfer losses. In July 2001 the tower was converted to v-notch liquid distributors and grid packing. The tower, which has been operating for 2 1/2 years, is now performing with higher capacity, lower pressure drop and improved heat transfer capacity than was experienced when the tower was first commissioned.

2. US Gas Cracker Quench Water Tower. The original design of the tower had random packing in the top bed and structure packing in the bottom bed. The tower was upset during start-up and the packed bed collapsed. The tower was then hot tapped and spray nozzles were inserted through ring of hot taps around the top of the tower. With the ring of hot taps and spray nozzles unit the tower was able to run at full rates, however, the tower's top temperature was higher than design, about 115 to 120 °F. The temperature in the bottom of the column was 140 to 160 °F. The plant should be commended for designing and installing a workable system in 20 days without bringing the plant down.

   In 1995 the tower was revised with random packing in the top and a draw pan for spray circulation in the tower bottom. The draw pan was upset during start up. Later inspection found hold-down clamps were not properly installed and bolts were missing. The ring of spray nozzles was reinstalled.

   In 2000 the circulation rate was suddenly reduced, as if a line plugged overnight. The tower was shut down for inspection and a loose vapor riser hat from the draw pan was found in circulation draw. The vapor riser hats were welded in place improving the previous bolting design.

   In September 2003 the tower was converted to v-notch liquid distributors and grid packing. The tower is now performing with lower pressure drop and improved heat transfer capacity.

Lessons Learned

1. The inspection of tower internals installation is important part of a successful column revamp. This is especially true of a column that has a system with hydrocarbons and water. The volumetric expansion of water is 1100:1. Any potential for water to vaporize will greatly increase the volume of vapor flow. Combine this volume increase with improperly installed equipment and severe problems are sure to follow.

2. The use of random packing and pan distributors should be limited in fouling services, especially quench towers.

3. A small injection of py gas to a quench water tower greatly improves operation.

Ethylene Saturator and Dilution Steam Generator Towers

The ethylene industry recognizes that saturator and dilution steam generator tower designs are a challenge. Many technology suppliers will provide multiple or small dual units to be utilized when the large tower is being refurbished.

Typically challenges include;

1. Corrosion due to pH issues

2. Erosion due to coke particles

3. Fouling due to polystyrene and pyrolysis tars,

4. Emulsion issues due to carry over of hydrocarbons from quench water towers and hydrocarbon removal systems, which can be a stripper tower or Dispersed Oil Extraction - DOX Unit.

Environmentally this is an important tower, which has two environmental functions. The first is water conservation. The Saturator and Dilution Steam Generators recycle the water needed in the cracking furnace, thus reducing the total amount of wastewater generated. The second is hydrocarbon losses to the wastewater treatment system, partially phenols. This tower strips the hydrocarbons from the tower bottoms that are sent to the wastewater treatment facility.

Typical Design of a DSG System

The effluent from a pyrolysis furnace can be introduced to a quench oil tower and then to a quench water tower for cooling. The effluent is a full range mixture of hydrocarbons and water.

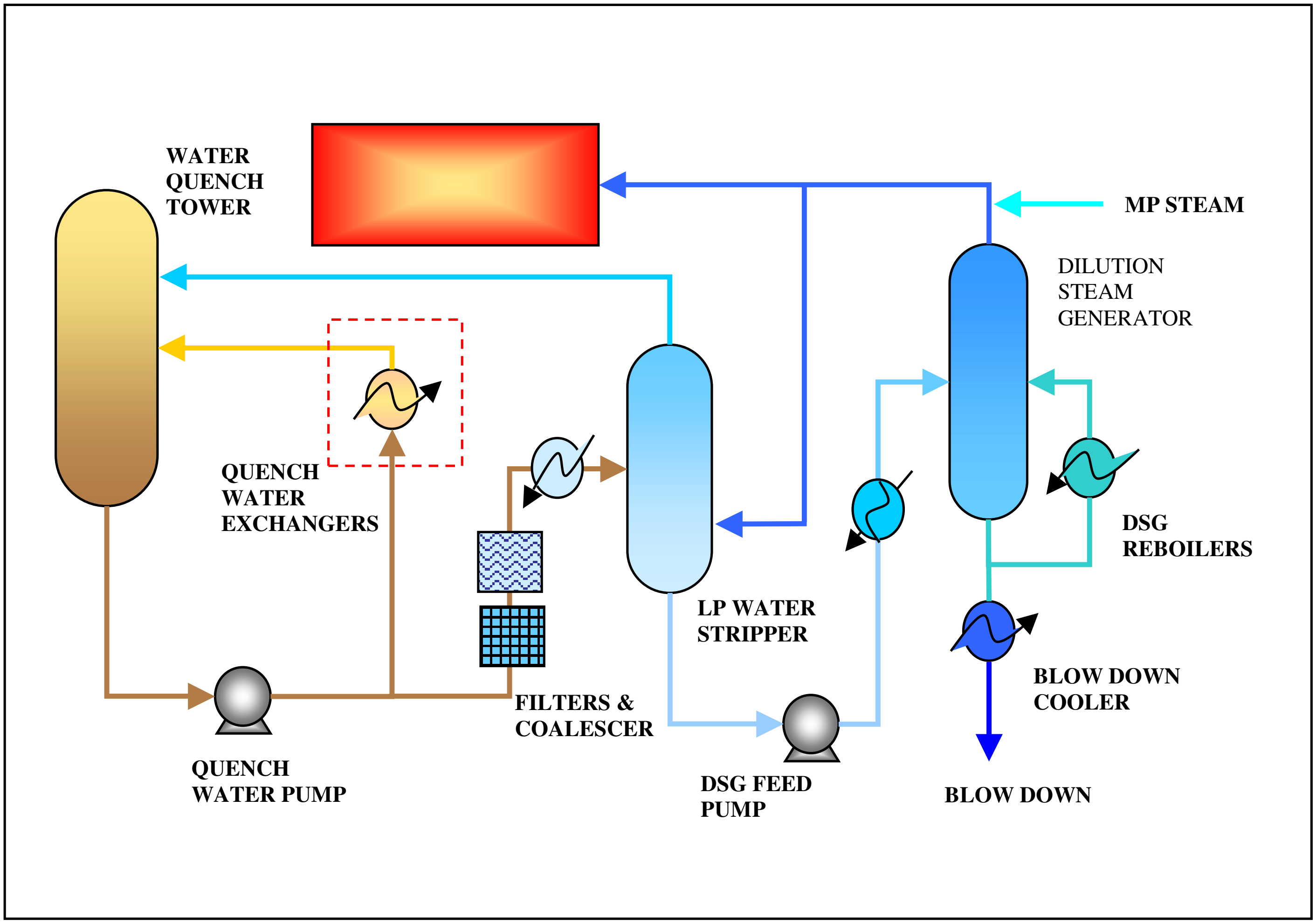
Water for the dilution steam system is withdrawn from the circulating quench water loop of the quench water tower and can be pretreated in filters and coalescers to remove most of the entrained hydrocarbons and coke fines.

The filters and coalescers can be an elaborate system utilizing anthracite and multiple coalescers sometimes called a Dispersed Oil Extraction (DOX). Some systems utilize a low pressure water stripper using steam to strip-off the volatile hydrocarbons back to the quench water tower.

The partially stripped water is introduced into the dilution steam generator tower. The water feed stream is typically introduced on the top tray and counter flow with the rising vapor, which allows the steam to leave at saturation.

Steam is added to raise dilution steam temperature to slightly above superheat, preventing condensation along the dilution steam piping from the tower to the pyrolysis furnace.

Steam is also used in the dilution steam generator reboiler as the heating medium. Blow downs from furnace steam drums and boilers can also be introduced to the DSG tower. Dual flow trays or other non-fouling distillation equipment should be utilized to providing resistance to fouling, which is typical in this service. Styrene polymers have been know to foul the top of DSG Towers. Heavy compounds leave the dilution steam system in the tower bottom blow down to the wastewater treatment.



WATER QUENCH TOWER
MP STEAM
DILUTION STEAM GENERATOR
QUENCH WATER EXCHANGERS
DSG REBOILERS
LP WATER STRIPPER
BLOW DOWN COOLER
FILTERS & COALESCER
QUENCH WATER PUMP
DSG FEED PUMP
BLOW DOWN

Typical Design of a Saturator System

The effluent from a pyrolysis furnace can be introduced to a Quench Oil Tower and then to a Quench Water tower for cooling. The effluent is a full range mixture of hydrocarbons and water.

Water for the dilution steam system is withdrawn from the circulating quench water loop of the Quench Water Tower and can be pretreated in filters and coalescers to remove most of the entrained hydrocarbons and coke fines.

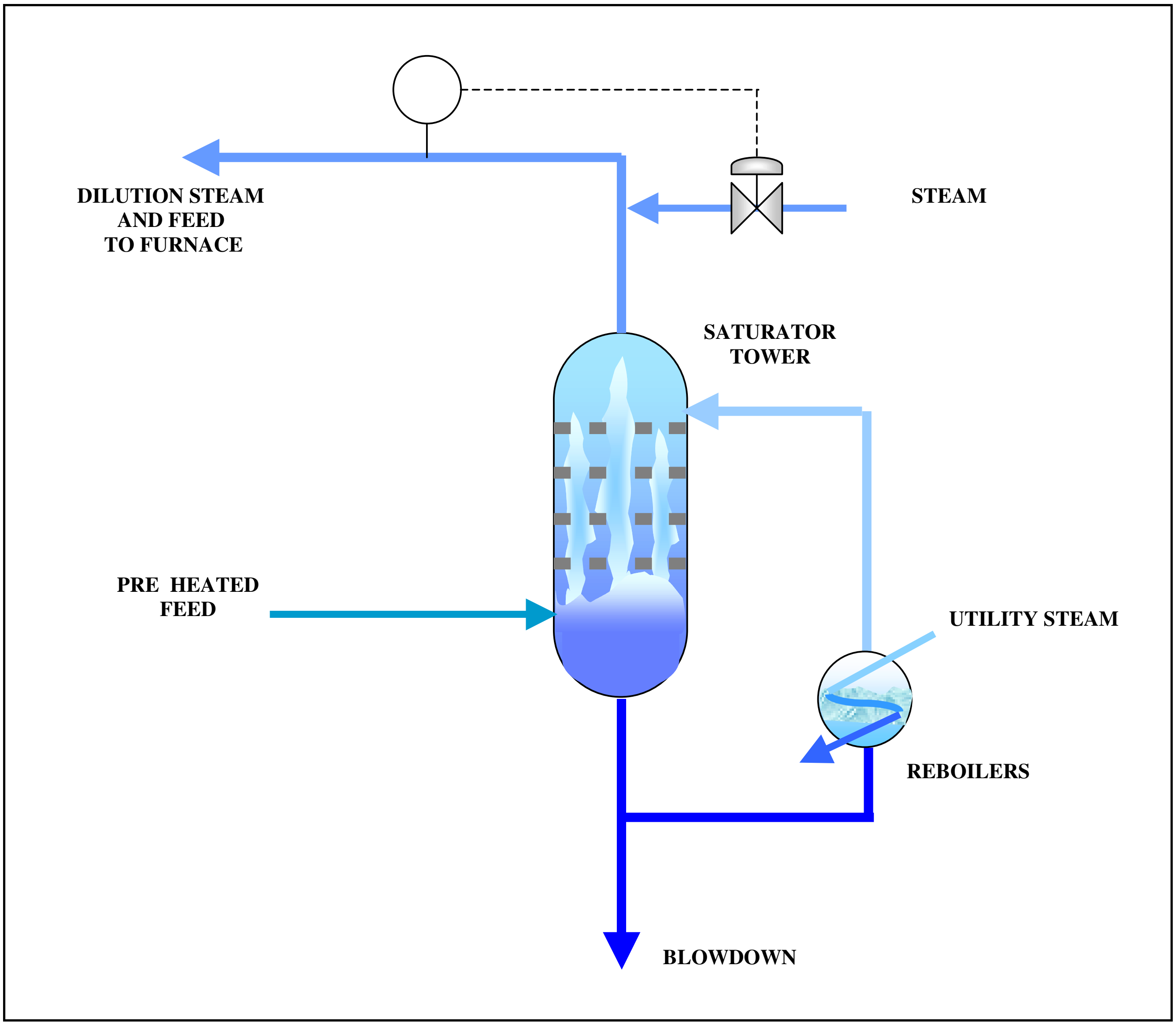
The filters and coalescers can be an elaborate system utilizing anthracite and multiple coalescers sometimes called a Dispersed Oil Extraction unit (DOX). Some systems utilize a Low Pressure Water Stripper using steam to strip-off the volatile hydrocarbons back to the Quench Water Tower.

The then partially stripped or extracted water is introduced into the Saturator Tower. The water feed steam is typically introduced on the top of the tower and the hydrocarbon vapor feed steam is typically introduced at the bottom of the tower. The counter flow of the rising vapor generated from the reboilers and the hydrocarbon allows the stream to leave at saturation.

Steam can be added to raise dilution steam temperature to slightly above superheat, preventing condensation along the dilution steam piping from the tower to the pyrolysis furnace. Knock out pots can also be utilized to remove any water that condenses. Additionally a second pass through the furnace can superheat the saturated stream to super heated conditions.

Steam is also used in the reboiler as a heating medium. Blow downs from furnace steam drums and boilers can also be introduced to the Saturator tower. Dual flow trays or other non-fouling distillation equipment should be utilized to providing resistance to fouling, which is typically in this service. Heavy compounds leave the dilution steam system in the tower bottom stream. This stream is typically blown down to the wastewater treatment system.

Design Of a Typical Saturator Tower



Saturator Tower Design Options

Baffle Trays

Baffle trays, particularly shed decks have been used successfully in saturator towers. The positives of shed deck are that the fouling potential of the decks is almost zero because there are no stagnate zones and low residence time. The negatives of baffle trays and shed decks are the low efficiency of the tray.

Random Packing

A small negative of random packing is the horizontal component, which is an area for the fouling phenomena to begin to propagate.

Grid Equivalents

Grid fits the design guide lines for packing in fouling service, which include low-pressure drop, smooth surface, low residence time.

Dilution Steam Generator Tower Design Options

Baffle Trays

Baffle trays could be utilized in DSG Tower design and might be the preferred option. The positives of baffle trays are that the fouling potential of the decks is almost zero because there are no stagnate zones and low residence time. The negatives of baffle trays are the low efficiency that can be seen if not designed properly

Ripple Trays

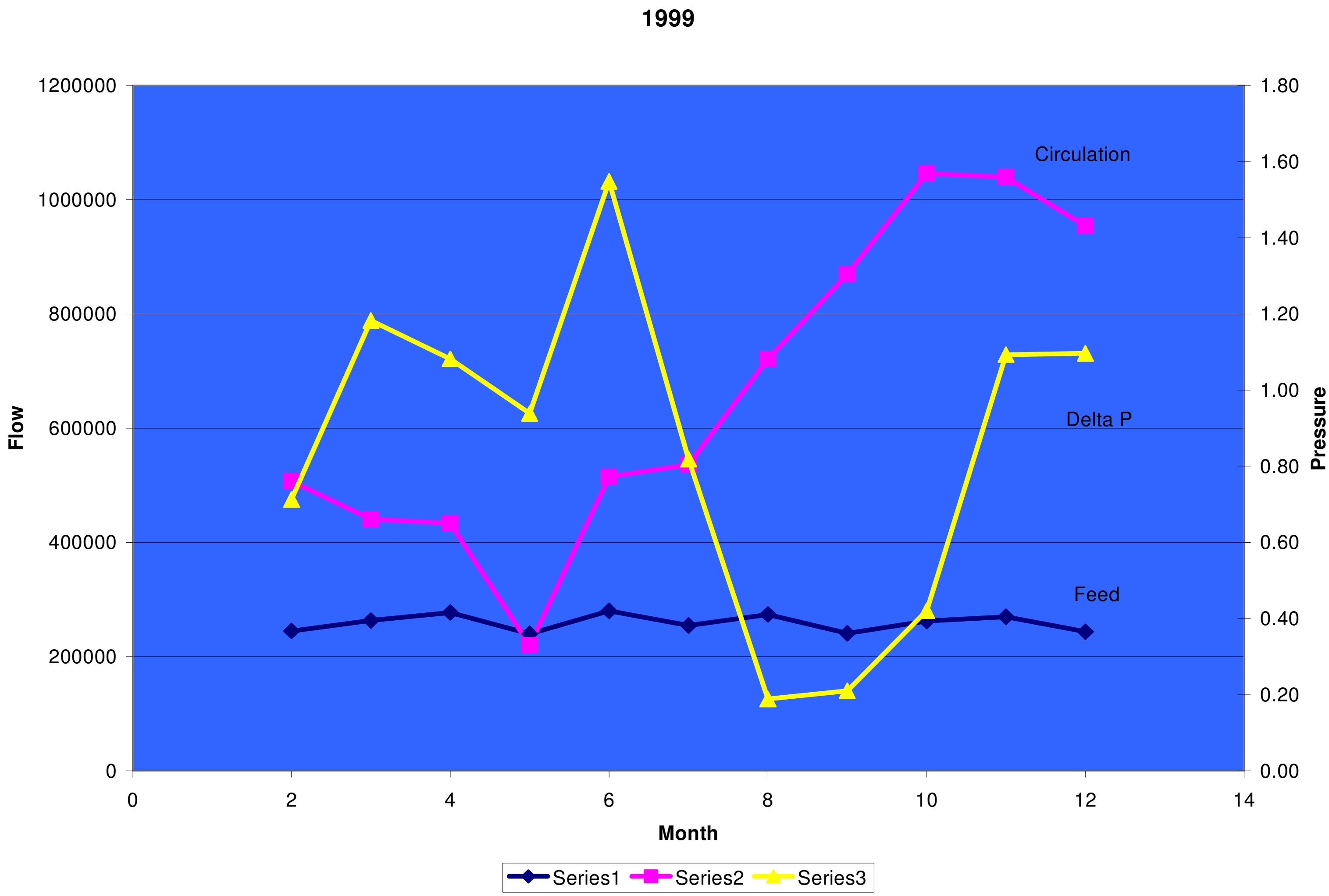
An Asian producer has seen good service from Ripple Trays except for the emulsion issues, which are related to pH control.

No Internal Distillation Devices

Several Producers have chosen to remove the distillation devices and have only a spray tower. This option is the most operationally reliable, but may not be the best environmentally.

Examples

1. US Gas Cracker. A saturator tower was commissioned with a combination of spray nozzles and random packing with pan distributors. The random packing was replaced in this tower in 1999 and 2000 because of high-pressure drop and loss of capacity. The tower was experiencing high-pressure drop and reduction in capacity only a few months after the packing was replaced. Attached is a table of pressure drop during this period of operation.



The pan distributor was replaced with a v-notch distributor without parting boxes to redistribute the flow. Because this tower is mainly for heat exchange and not mass transfer the parting boxes were not installed to reduce fouling potential.

Installed V-Notch Pan Distributor in Saturator Tower

2. Asian Ethylene Producer

During the commissioning of a furnace sulfur is added to reduce the catalytic coking of the metal based tubes. This sulfur can reduce the pH of the quench water tower and form an emulsion. Because water is polar and styrene is polar the water / styrene emulation can be difficult to break. This emulsion can carry through to the Dilution Steam Generator and form styrene polymer when introduced to the higher temp of the DSG Tower.

Ethylene Unit Caustic Towers

Ethylene caustic tower have many of the fouling phenomena: polymerization, sedimentation, precipitation, crystallization, chemical reactions, and corrosion. Caustic towers qualify as a complex fouling system with more than two fouling phenomena occurring at the same time while being mutually reinforcing.

A certain amount of polymer formation in a caustic tower is expected in most systems. Caustic tower polymer fouling is typically thought of as a function of acetaldehyde concentration and aldol condensation reactions. The acetaldehydes can be polymerized by the caustic to form first a yellow oil polymer, and then a red oil polymer by aldol condensation reactions, which can then lead to emulsions.

Caustic tower sedimentation results in the salt by-product being deposited on the underside of the tray. Over time this by-product can product a high-pressure drop resulting in reduced rates and increase energy consumption in the Cracked Gas Compressor. Some producers utilize a small continuous py gas wash, followed by a larger py gas wash when the pressure drop increases.

Caustic Tower Design Options

Standard Sieve Deck Trays

Standard sieve deck trays can be utilized in caustic tower design. The positives of sieve decks are that the chemical reaction ability of the process can be maintained over time. The negatives of trays are the higher-pressure drop as compared to packing. Caustic Towers have seen excellent service from standard sieve deck trays. Run lengths have exceeded five years.

Random Packing

Caustic Towers have seen good service from random packing. A small negative of random packing and grid equivalents is the horizontal component, which is an area for the fouling phenomena to begin to propagate. Run lengths have exceeded five years.

Lessons Learned

1. The use of random packing and pan distributors should be limited in fouling services.

2. A small injection of py gas to a caustic tower greatly improves operation.

3. Internal overflows need to be carefully considered during the design phase of a revamp. High-pressure drops can result if internal overflows are undersized.

Ethylene Unit Butadiene Fouling

An ethylene unit can experience Butadiene Polymer fouling in the deethanizer, depropanizer, and debutanizer columns. Butadiene polymerizes to poly butadiene, sometimes called popcorn polymer because it is pyrophoric and makes a popping sound when exposed to air. The polymer formation is temperature dependent and recommendations are to keep temperatures below 200 degrees F.

Example of Butadiene Polymer Fouling in a depropanizer.

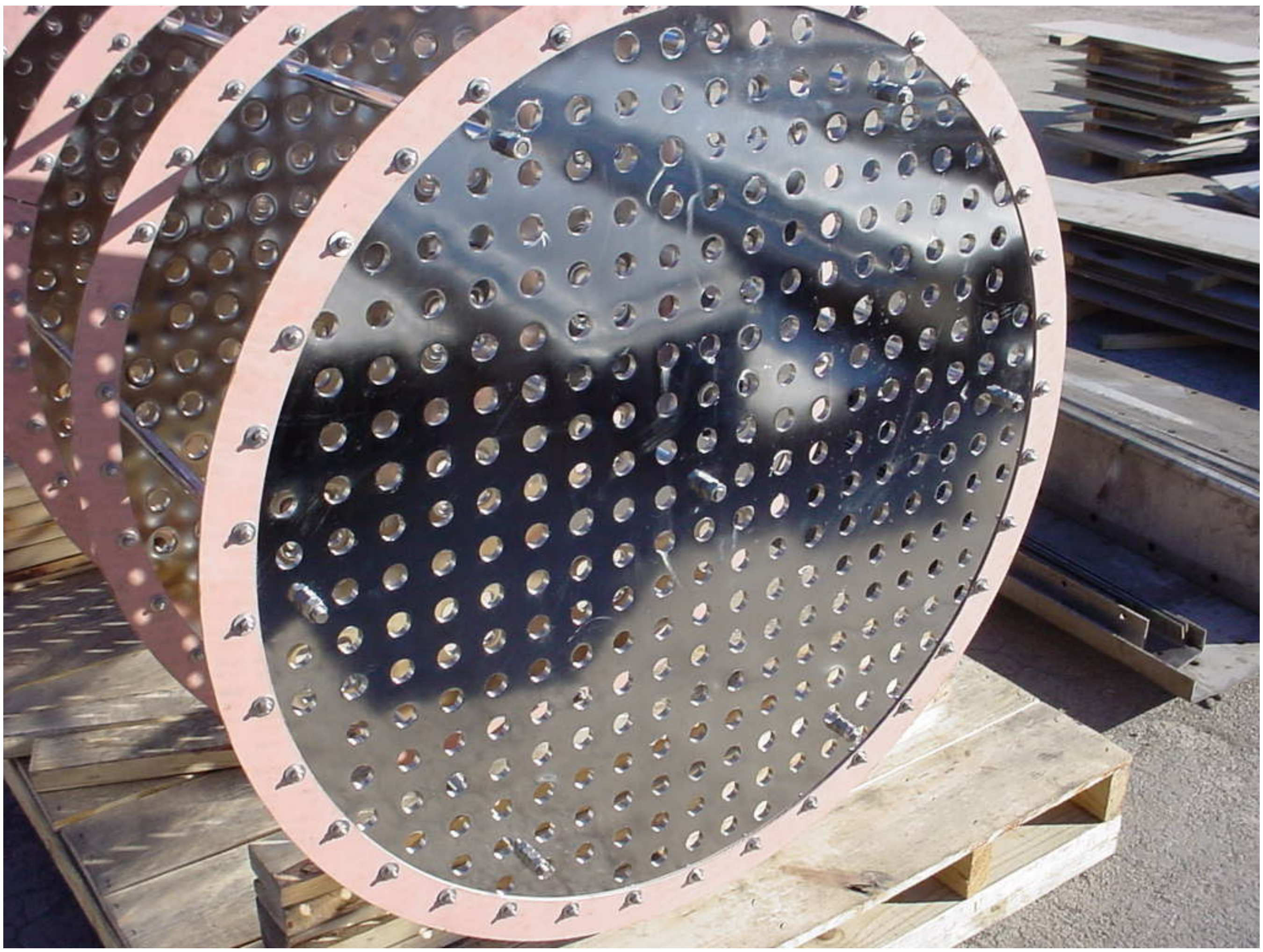
Example of depropanizer Tower Bottoms

Butadiene Polymer Tower Design Options

Standard Sieve Deck Trays

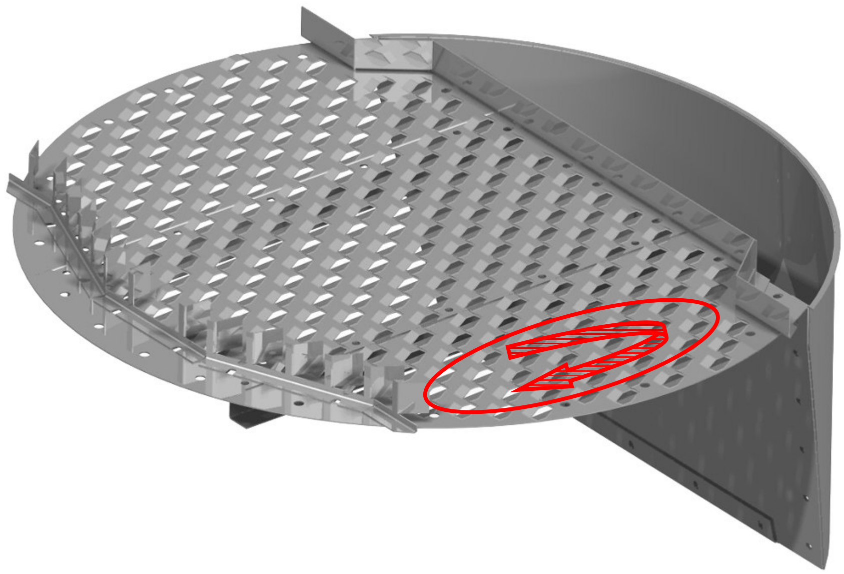
Standard sieve deck trays can be utilized in butadiene polymer tower design. Many Producers have seen excellent service from standard sieve deck trays. Run lengths have exceeded five years. Electro-polished trays have been used in this service to prevent the popcorn from sticking to the tray.

Picture of Electro-Polished Tray



High Capacity Trays

With the short residence times of high capacity trays, particularly the elimination of dead zones on the tray by flow directors, polymer production could be reduce in the tower bottoms where higher temperatures are necessary.



Conclusions

There are many different opinions on designing tower internals for use in fouling services, and because distillation is part art and part science differing opinions can be proven to be serviceable in the field. Trays and packings can both be utilized for fouling services. The key to a successful design is the proper application of internals, trays and or packings. This paper is a starting point for producers to develop, based on their operating experience, practical, serviceable columns for fouling service.

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