

Foaming in fractionation columns

By understanding the foaming process and its root causes, steps can be taken to eliminate or minimise the formation of foaming

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As long as there are fractionating columns, there will be issues with foaming in some of the different chemical applications. Foaming in columns is problematic because it hinders the hydraulic processes (the vapour and liquid flows within the tower). This is especially true with trayed internals where liquid and vapour are meant to contact intimately and then physically separate within a series of discrete stages. Conversely, packed columns tend to be more forgiving in foaming applications.

Generally, there are two competing issues with foaming: first, the tendency for the process to generate foam (foaminess); and secondly, the tendency for the process to destroy foam (foam stability). As with any dynamic balance, when production (foaming) exceeds consumption (foam breakage), an excess occurs. When a fractionating column generates stable foam, the column capacity will decrease.

This article will briefly discuss the fundamentals of foams and the different types of foam formations. The effect of foaming on various internals will be discussed along with design and operating methods used to mitigate foaming and/or the effects of foaming.

Fundamentals of foams

Foaming is essentially the encapsulation of vapour within a liquid cell. Foams can be formed with a variety of methods generally associated with mechanical agitation or vapour formation. When the wall of a bubble ruptures, the bubble collapses, destabilising the foam. The main cause of bubble rupture is

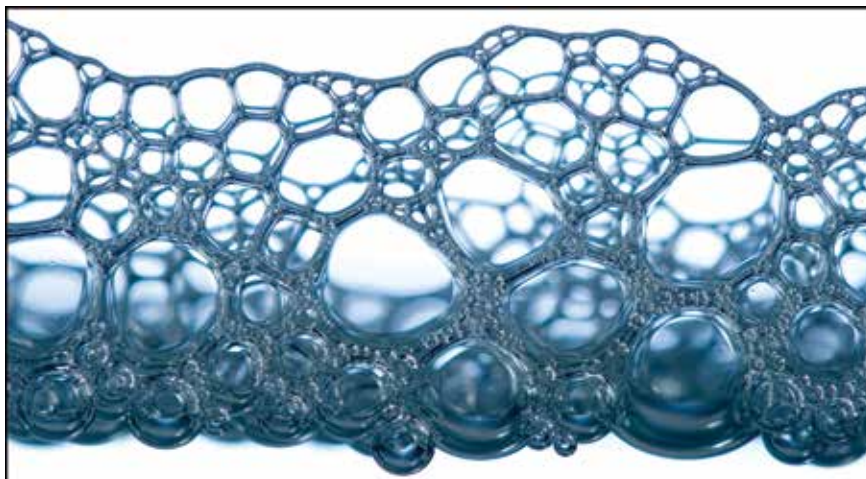


Figure 1 Bubbles draining in foam

thinning of the liquid wall. **Figure 1** shows how the liquid walls thin in the upper section of the foam as the liquid drains downward.

Foams are stabilised when liquid viscosity and surface tension oppose the natural drainage tendency of the bubble liquid. Liquid properties play a central role in foaming. Liquid drainage within foam is a natural phenomenon. Liquid always has a tendency to drain downward (or in the direction of any centrifugal forces). As the liquid drains from the bubbles, the liquid walls thin and weaken, eventually rupturing the bubbles and breaking the foam. Any condition that stabilises the bubble wall thickness will stabilise the foam.

Surface tension gradients within localised liquid create what is known as the Marangoni effect, where liquids flow from lower to higher surface tension regions. Generally, foaming tendency is proportional to this gradient. This key factor of foaming is explained well by Zuideweg and Harmans.¹

It is important to note that pure liquids will not produce a stable foam. However, when a surfactant is added to the system, stable foaming is then possible. Simply, the surfactant concentration at the liquid surface decreases as the bubble size increases. When this happens, the higher surface tension in the expansion area draws liquid from the lower surface tension region at the base of the bubble. This 'heals' the thinning bubble wall and stabilises the foam.

Types of foaming

Ross foams

As discussed by Ross², a liquid solution with an incipient formation of a second liquid phase (for instance, a hydrocarbon fluid with a high equilibrium amount of water or an aqueous fluid with a small amount of hydrocarbon) will naturally be susceptible to foaming. Since this is an equilibrium effect, Ross foams can sometimes be overcome by changing the system temperature. A good example of this in practice is

discussed by Bolles.³ In his troubleshooting endeavour, he found that sections of the tower were approaching the incipient formation of a second liquid phase, creating dramatic foaming within the column. To further support this conclusion, he raised the temperature of the column, eliminating the incipient second liquid phase and the foaming subsided.

Marangoni foams

Foaming can occur with or without the presence of mass transfer. Foams stabilised by surface tension gradients due to mass transfer are referred to as Marangoni foams. In applications where the higher volatility component has a lower surface tension, Marangoni foaming can be a problem. When a bubble forms in these systems, the lighter component evaporates from the liquid and the surface tension of the remaining liquid increases and stabilises the bubble. Without this effect, the evaporation would have caused the bubble film to thin and break. **Figure 2** shows wine ‘tears’ produced as a result of mass transfer. As the alcohol evaporates from the wine on the wall of the glass, the surface tension increases and causes the liquid to form rivulets and droplets.

Foaming from solids/particulates

It is widely known that the presence of particulates tends to stabilise foam. When solids are present in liquids, they increase the solution viscosity. Increased viscosity inhibits the drainage of foams and stabilises them. An interesting study done by Kadoi⁴ looks at the influence of particulate composition, size, and shape on both viscosity and foaming in water. Somewhat surprisingly, the increase in foam stability was



Figure 2 Marangoni effect in wine

not always directly proportional to viscosity. Instead, particulate size, shape, and composition seemed to play important parts in foam stability. It is also important to note that the particulates did not transform a non-typical foaming system (water) into a foaming system. However, when a surfactant was added to the water and foam was produced, the solids stabilised the foam.

Also important was the reinforcement of the understanding that a smaller amount (weight) of smaller size particulates creates more foam stabilisation effects than a larger amount of larger sized particles. This is an unfortunate truth for fractionation column applications where the liquid solution is filtered to remove particulates and the worst offenders (small particles) are the most difficult to remove.

All things considered, it is clear that particulates are generally detrimental additions to a foaming system. The potential for the pres-

ence of particulates should always be accounted for during the column engineering design stage. In less serious cases, the equipment can be sized to account for the foaming. Ideally, the particles need to be removed from the system with filtration or totally prevented from forming in the process or entering the column.

Processes and applications that are susceptible to foam

Amine contacting and regenerating systems are notorious for foaming tendencies, with about half of the reported industrial column foaming cases coming from acid gas treating units.⁵ Acidic amines, such as MEA, DEA, and MDEA in their pure state, are essentially non-foaming. However, amine systems tend to have a variety of potential contaminants such as:

- Liquid hydrocarbons: Ross foams
- Oil field chemical contaminants: Ross foams and surfactants
- Corrosion products (such as iron sulphide): particulate foaming
- Amine degradation products: surfactants.

Some other known foaming processes are:

- Refinery preflash towers and long residue stripping sections are also known to be susceptible to foaming.⁶ Studies show that different crude types have different foaming potential. Other contaminants and suspended particulates also affect foaming in these systems
- Refinery alkylation isostrippers also can foam near the feed. This is a Ross foam condition where aqueous hydrofluoric acid is present in the hydrocarbon.

Difference between trays, random packings, and structured packings

A wide variety of research has been done on the topic of foaming with different column internals. Generally, it is accepted that packings perform better in foaming processes than trays do. This is essentially due to the nature of the devices (see **Figures 3** and **4**). In most trayed applications, the vapour flows upward through a continuous liquid layer on the tray deck and creates bubbles. In most

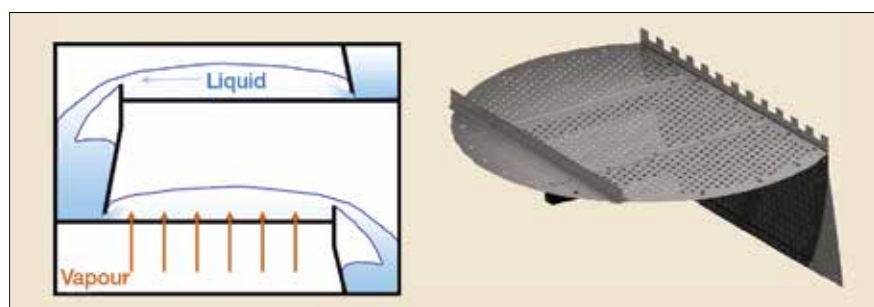


Figure 3 Vapour and liquid flows on trays

systems, the bubbles break quickly. However, in systems where the bubbles are stabilised, foaming is an issue.

When trays do foam, a foam layer develops on top of the liquid on the tray deck and then flows into the downcomer. The foam on the tray deck increases the froth height and causes entrainment. Also, the foam fills up the downcomer and eventually backs onto the tray and hydraulically floods it. In either case, foaming can substantially limit tray capacity.

Packings operate with vapour and liquid flowing past each other, with the vapour remaining in the continuous phases and liquid rivulets and droplets being in the dispersed phase. With this operation, the packings are much less likely to generate bubbles and foaming. This is why packings are preferred in foaming applications. However, when the liquid rate in a packed column is high enough to bridge gaps within the packed bed, the vapour will flow upward through the liquid and form bubbles.

Reviewing random versus structured packing, we see an interesting set of counter principles. First, due to its streamline structure, structured packing has a very high capacity and efficiency relative to random packing in high vapour rate applications. However, the more laterally open structure of random packings allows them to process high liquid rates more effectively. With foaming systems, foam acts as a volumetric liquid flow multiplier.

In cases where the liquid rates are low and the foaming tendency is moderate, the effective 'liquid' volumetric flow rate is low to moderate. In these cases, the inherent hydraulic advantages of structured packing ensure that it performs well. However, in higher liquid rate and/or highly foaming systems where the effective 'liquid' volumetric flow rate is higher, the random packing's ability to handle more liquid tends to overcome the vapour handling capabilities of the structured packing, making random packing the better choice. This effect is shown in a study by Thiele.⁷

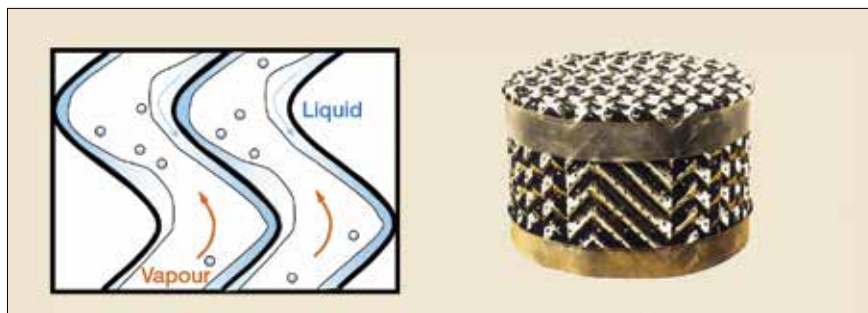


Figure 4 Vapour and liquid flows in structured packing

What internals to use in foaming applications?

Since trays are the most susceptible column internal to foaming, they are typically only used in applications where they are needed for specific purposes. For example, trays are used quite often in amine contactors, a known foaming application. They are used mainly because some amine reactions are slow and additional residence time is desired. Trays are also used in sour water strippers, another known foaming process. This is because these services are often dirty and trays provide a more robust solution. In these cases, a 'foam factor' is used that derates the capacity of the device, sometimes by as much as 50%. With this derating factor, the column diameters are larger so that the vapour flows are lower through the column and the tray downcomers are larger to have more residence time and lower liquid velocities.

When trays are not mandatory in a foaming service, packings will be the first choice. The selection between random versus structured packing should be based on previous experience, the liquid flow rate, and the expected severity of foaming. For very low liquid flux rates ($<10 \text{ m}^3/\text{m}^2\text{-hr}$) and low to moderate foaming, structured packings will be the natural choice. For very high liquid rates ($>50 \text{ m}^3/\text{m}^2\text{-hr}$) and moderate to high foaming, random packings will be the preferred choice.

The difficulty comes where the effective liquid flux rates are between these extremes. In the testing from Thiele, above a liquid rate of $20 \text{ m}^3/\text{m}^2\text{-hr}$, structured packing with a surface area of $350 \text{ m}^2/\text{m}^3$ with a 45° corrugation angle showed a significant increase in pressure

drop due to foaming. However, it should be noted that a lower surface area packing (for example, the standard $250 \text{ m}^2/\text{m}^3$ size) with a more vertical 60° corrugation angle would be much more resistant to foaming.

From these studies, it would seem that a reasonable 'rule of thumb' would be that structured packings in moderate foaming systems are typically safe at liquid flux rates below $25 \text{ m}^3/\text{m}^2\text{-hr}$. As a first pass, this is probably a useful value for an initial review, but it must be kept in mind that the degree of foaminess and the packing geometry will have a major effect in the proper packing choice. It is important to note that structured packings with appropriate corrugation angle and hydraulic diameter have been successfully used in hundreds of gas sweetening units, which are considered to be foaming systems. Liquid loads in these applications are typically high, with some structured packing units working properly at flux rates over $100 \text{ m}^3/\text{m}^2\text{-hr}$.

Similar to trays, random packings typically are also derated using a foam factor. Since they can handle foaming more effectively than trays, the foam factor for a random packed column is typically less conservative than for those used with trays. Structured packings may or may not use a foam factor.

How to avoid foaming in the process

As mentioned previously, there are a variety of contaminants that can cause excessive foaming in a fractionation process. Preventing these contaminants from entering the system is nearly always the most effective method to prevent foaming, but often not the most cost effective method. Upstream

contaminants (particularly from oil fields) need to be carefully monitored and removed. Oils, liquid hydrocarbons and greases need to be avoided. In amine systems, the amine quality must be checked and continually cleaned. Degradation products, solids, and corrosion products must be minimised.

If the contaminant cannot be removed from the feed, the next best option is to remove the contaminant in the process itself. This is commonly done with particulates or other chemical contaminants by using a recycle stream and a mechanical filter or an activated carbon bed. Although this seldom removes all the contaminants, it does serve to maintain them at an acceptable level. One thing to note is that if carbon beds are used in conjunction with anti-foams that the carbon beds may actually remove the anti-foam and mitigate its benefit.

How to deal with foaming in the process

Anti-foams are commonly used to reduce the foaming tendency of the process. They generally serve to assure a uniform surface tension on the liquid portion of the foam. This removes the surface tension gradient that stabilises the foams.

The use of anti-foam can be costly and is often empirical, with the proper formulation being dependent upon the actual foam causing contaminants. Different types of anti-foams work well in some systems and work poorly, or even promote foaming, in other systems. The same can be said for dosage rates. While the correct dosage of the proper anti-foam can work very well, the improper rate of the same chemical can even produce a detrimental effect.

As mentioned earlier, temperature variations can control incipient second liquid phases. In this case, the process components and conditions must be understood and correct temperature adjustments need to be made as possible.

Directionally, as the system temperature increases, more liquid vaporises, vapour velocity increases, the liquid rate decreases, and the

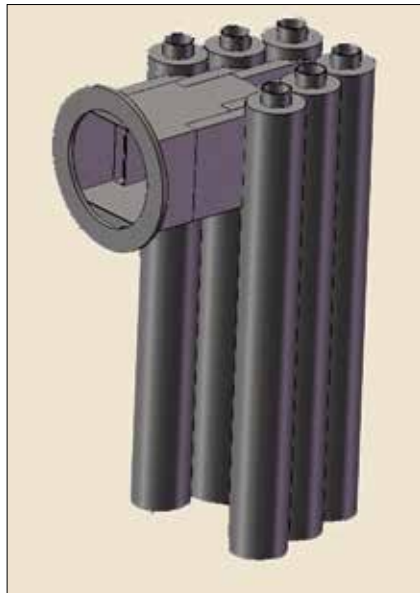


Figure 5 Sulzer GIRZ feed device

liquid viscosity decreases. All of these occurrences tend to inhibit foaming. A decrease in column pressure should have a similar effect.

For mass transfer Marangoni positive systems that promote foaming, this can generally be predicted with a review of the physical properties of the components in the process simulation. If there is a surface tension decrease of more than 1 dyne/cm per theoretical stage moving up the column, this process can be expected to have foaming issues. In this case, the internals need to be designed beforehand to allow for this. Conversely, if the system is Marangoni negative (increasing surface tension as you move up the column), foaming is not expected.

How to minimise the effects of foaming with equipment design

Packing

With packings, there are only a few design changes possible. First, the feed distribution should not create foaming. With a total liquid phase feed, this should not be an issue other than to ensure that the feed momentum is minimised and that the liquid feed is submerged in the normal distributor liquid. With a two phase feed, care needs to be taken that the vapour and liquid separate without generating foam. If it is suspected that the incoming

feed is foaming then a good solution is to use a feed device with centrifugal separators (such as a Sulzer GIRZ and HiPer inlet cyclone).

One example of a GIRZ application is for a US West Coast refiner in the preflash tower. The refiner was having issues with foaming when running different crude slates. Sulzer recommended the installation of a GIRZ in the tower feed to mitigate foaming. The unit is now on-line and the refiner can run multiple crude slates with no issues in the column, thus increasing their flexibility and profitability.

With random packing, you can mitigate foaming by using a larger size packing that is further away from flood. This is essentially just designing with a foam factor.

With structured packing, a more vertical crimp angle can be used, such as a 60° (X Style) packing corrugation. This will allow the liquid to flow more easily down the corrugations without bridging and creating a foaming opportunity. Also, using a larger crimp size (lower surface area packing) creates larger channels for fluid flow. This will also delay bridging due to higher relative liquid flux rates. Finally, using a high performance packing with an S shape (such as MellapakPlus) to minimise liquid hold-up at the packing layer interface will also delay the onset of foaming in the bed. The smooth vertical transition between the packing layers can be seen in Figure 6.

Trays

For tray designs, it is accepted that trays operating in the froth regime are clearly more susceptible to foaming than those operating in the spray regime. This is due to the balance between foam generation and foam destruction. In the froth regime, vapour bubbles through the liquid pool create foaming opportunities. In the spray regime, vapour is in the continuous phase and the liquid on the tray deck is blown into droplets above the deck, likely destroying any small bubbles that may be formed.

Unfortunately in foaming applications, most trays are designed to

operate in a froth regime. It is quite difficult to force operation in the spray regime when high liquid rates are present. Methods to shift a tray's operation from froth to spray regime include lowering the effective liquid depth on the tray deck, increasing the vapour velocity through the deck orifices, and using larger deck orifices. The most effective way to lower the liquid depth on a tray is to increase the number of liquid passes. Shell HiFi multi-pass trays (shown in **Figure 7**) are often used for this purpose. Another helpful modification can be to increase the tray's spacing, allowing the tray to more easily accommodate the foam build-up prior to flooding. A successful case study using these techniques is discussed by Resetarits.⁸

In froth regime applications, there is too much liquid on the tray deck to allow a practical transition to a spray regime and destroy the foam. As an example, froth and foam height studies were conducted at the University of Texas with a weir load of 55 m³/m-hr.⁹ At these rates, it was found that higher vapour rates created more foam. However, column designs can still be altered to control foaming.

The vapour side dry pressure drop of a tray is a common calculation that represents vapour momentum entering a tray. For trays operating in the froth regime, dry drop is a good indicator of foaming susceptibility. In amine columns where liquid rates are high, the following guidelines are proposed by Shivelor:¹⁰

For dry drops:

- <40mm H₂O (vapour hole velocity of 4.2 m/s), foaming tendency is low
- 40-50mm H₂O, (vapour hole velocity of 4.2-4.8 m/s), low to moderate tendency

Tray downcomer design is also important for foaming applications. It is recommended that the downcomer be large enough so that the clear liquid velocity does not exceed 0.10 m/s. Another more conservative recommendation is for a limit of 0.06 m/s.¹¹ Generally, it is seen that increased downcomer residence time is less beneficial than decreased

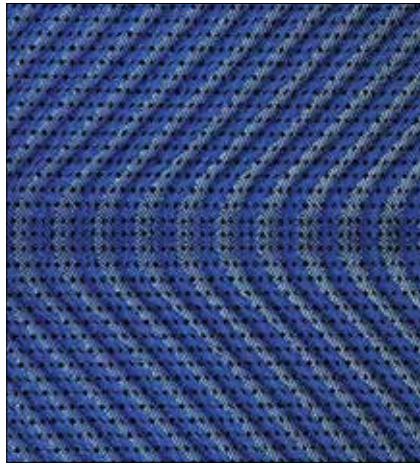


Figure 6 Sulzer MellapakPlus packing

downcomer velocity.⁶ This would indicate that large downcomers with a slope from top to bottom would be preferred.

Conclusions

Foaming in susceptible fractionation columns is a phenomenon that is essentially unavoidable. However, by understanding the foaming process and the root cause of the foaming, steps can be taken to eliminate and/or minimise the formation of foaming. When foaming cannot be avoided, process and equipment modifications can be made to successfully deal with the foaming to maintain a properly operating column with efficient operation.

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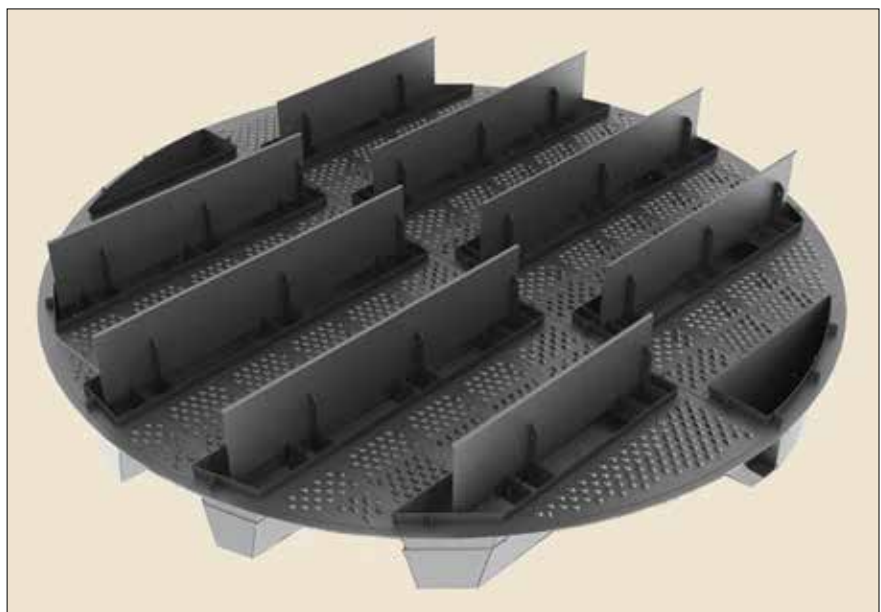


Figure 7 Shell HiFi Plus Trays

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