

FACTORS INFLUENCING VAPOR CROSSFLOW CHANNELING

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ABSTRACT

When distillation trays exhibit non-optimum hydraulic performance, efficiency and capacity suffer. In recent years, several excellent papers have been written describing a hydraulic maldistribution phenomenon called “vapor crossflow channeling”. Vapor crossflow channeling has been attributed to the liquid-phase hydraulic gradients which often occur on trays having high liquid rates, long flow path lengths, short outlet weirs, low dry pressure drops and excessive deck resistance. In response to this gradient, vapor flows preferentially through the tray outlet area and then flows horizontally in the direction opposite to the liquid flow. Liquid weeping occurs near the tray inlet. Ultimately, the vapor crossflow channeling further exacerbates the hydraulic gradient. There is another phenomenon, inlet inactivity, that contributes to the source and magnification of the vapor crossflow channeling.

INTRODUCTION

Distillation tray hydraulics has been the focus of industrial and academic study for decades. Those studies identified and evaluated factors affecting tray capacity, efficiency and pressure drop. Going back many years, two such factors called “inlet inactivity” and “froth gradient” have been well understood and documented, often in conjunction with the development of bubble promoters and vapor thrust devices. Only recently, in the past decade or so, has “vapor crossflow channeling” (“VCC”) been identified as a cause of poor tray hydraulic performance.

BACKGROUND

Inlet Inactivity

Inlet inactivity occurs when the vapor phase does not penetrate the liquid phase at the inlet side of a tray. Clear unaerated liquid flows across an appreciable portion of the tray and does not participate in the mass transfer process (Figure 1). Full frothing occurs downstream of the clear liquid. Obviously, inlet inactivity is deleterious to tray performance. Inactive areas on a tray can weep significantly, and vapor will preferentially flow to the outlet side of the tray.^{1,2} Video footage demonstrating inlet inactivity is owned by Koch-Glitsch, Inc.³ and UOP LLC⁴.

Inlet inactivity does not occur on all distillation trays. It has been observed often in air-water test columns. According to the literature, the following cause inlet inactivity:

1. Hydrostatic gradient
2. Large tray diameters
3. Low dry tray pressure drop
 - High hole area
 - Low vapor rate
4. Air –water type physical properties

Various methods are available to mitigate inlet inactivity and improve hydraulic performance. Figure 2 shows a tray with a bubble promotion device at the inlet. Such devices usually provide reduced resistance to vertical vapor flow. Additional inlet vapor traffic results and penetrates the liquid phase. On trays that employ light and heavy moving valves, the positioning of a row of light valves at the tray inlet can sometimes eliminate inlet inactivity. Another option is to provide decks having high dry tray pressure drop. Such trays tend to distribute vapor more evenly than trays having low pressure drop.

Liquid Gradient

On decks with conventional sieve holes or valve units, the height of clear liquid at the inlet exceeds that at the outlet (Figure 3). This gradient provides the motive force for liquid flow on the tray and occurs even when the froth gradient is not visible to the naked eye.^{5,6} Gradient is exacerbated by the following:

1. High liquid rates
2. Long flow path lengths

3. Short outlet weirs
4. Elevated deck structures (like bubble caps)
5. Low tray pressure drop

Gradient is minimized or eliminated by the following:

1. Increased number of flow passes
2. High outlet weirs
3. Use of sieve or low-rise valve decks
4. Reduced deck open areas
5. Push valves

Bubble cap trays are particularly prone to excessive gradient since the caps provide appreciable resistance to liquid flow. When operating at high liquid loads and low dry tray pressure drops, large-diameter single-pass valve and sieve trays are also particularly prone to gradient.

Vapor Crossflow Channeling

Vapor crossflow channeling, or “VCC”, has been identified for bubble cap, sieve, and valve trays and has been the subject of papers by Kister^{7,8} and Hartman⁹. Figure 3 illustrates how VCC is caused by gradient. When the liquid height at a tray’s outlet is less than at its inlet, vapor flows preferentially through the outlet region of the tray. A pressure imbalance is created above the froth and vapor then flows horizontally in the disengagement space above the froth, in the direction opposite to the liquid flow. The horizontal vapor traffic, in fact, increases the froth gradient. On towers employing single-pass trays, VCC causes the vapor to snake its way up the tower. VCC can cause efficiency and capacity problems as described in the aforementioned papers.

DISCUSSION

A reexamination of Figure 1 shows how inlet inactivity can be a precursor to VCC. When a gradient exists on a tray, the vapor passing through the inlet area is reduced. When inlet inactivity exists, however, the vapor passing through the inlet area is eliminated. This, in turn, creates a huge pressure imbalance above the froth. Vapor crossflow channeling becomes extreme.

Koch-Glitsch has video footage of an air/water test column demonstrating the hydraulic conditions described above. Careful analysis of the test runs shows how gradient, inlet inactivity, and VCC correlate to vapor and liquid rates, and to each other. The first, and most striking, conclusion is that the causes of VCC also cause inlet inactivity. When clear liquid gradient was severe in the video footage, so was inlet inactivity. As the vapor rate increased, inlet inactivity became less noticeable, while VCC developed. At very high vapor and high liquid rates, VCC worsened.

The video also showed that the elimination of clear liquid gradient resulted in the elimination of inlet inactivity and VCC. Trays with higher outlet weirs had substantially improved hydraulic performance, as did trays with lower percent open area. In addition, movable valve trays did not suffer from VCC in these test runs.

Figure 4 shows a total solution to the VCC problem. The tray of Figure 4 has inlet bubble promoters plus push devices on the tray decks. UOP possesses video footage that shows inlet inactivity as well as how inlet areas are activated by the installation of bubble promoters. Push devices can be used to overcome skin friction as froth flows across decks. Push devices can provide the motive force for horizontal liquid flow. Many different deck devices provide push, including the following:

1. Slots on UOP (Linde) Slotted Sieve and ECMD trays
2. Inlet uni-directional louvers on Bi-FRAC trays
3. Fixed and moving valve units where the upstream support leg is wider than the downstream leg
4. Fixed and moving valve units that are angled to the tray deck

The tray of Figure 4 will exhibit no inlet inactivity and no froth gradient. It will therefore experience no VCC.

CASE STUDIES

A literature search yielded three papers⁷⁻⁹ where VCC was believed to be the cause of a distillation column malperformance. In two of the cases, it is known that the distillation column trays were modified or replaced, in an effort to lessen or eliminate the VCC. The cases are summarized below:

Case 1 by H. Z. Kister "Vapor Cross-flow Channeling on Sieve Trays: Fact or Myth?" VCC was suspected on large-diameter sieve trays that were achieving a poor efficiency. The problem trays were replaced with new stainless steel trays with smaller sieve holes to reduce total hole area and decrease weeping.

Case 2 by H.Z. Kister "Can Valve Trays Experience Vapour Cross-Flow Channeling?" VCC was suspected on single pass valve trays with contoured orifices that were weeping excessively at 40-70% of flood and flooding prematurely at gas loads 10-20% lower than predicted by the correlations. No known tray retrofit was effected.

Case 3 by Edward Hartman "New Millennium, Old Problems: Vapor Crossflow Channeling on Valve Trays" VCC was suspected on two pass regular caged type valves that were prematurely flooding. The trays were replaced with SUPERFRAC trays. The trusses were rotated to be parallel to flow to prevent them from blocking vapor flow and exacerbating the VCC.

A review of these case studies with an eye on inlet inactivity issues revealed interesting possibilities. In Case 1, the initial trays had open areas of 16%. It is entirely possible that inlet inactivity was the cause of the excessive weeping and began the trend of vapor preferentially flowing through outlet portion of the tray, leading to VCC. In Case 3, push valves and bubble promoters were not present on the original trays. However, SUPERFRAC combines these technologies, and as previously mentioned, these devices lessen or eliminate inlet inactivity as well as VCC. It should be pointed out that in all of the cases, the existence of froth gradient, inlet inactivity and VCC was never proven. No eyewitness testimony or video footage exists. In general, however, there is little doubt that such hydraulic maladies sometimes exist. The UOP and Koch-Glitsch videos provide proof.

CONCLUSION AND RECOMMENDATIONS

Clear liquid gradient and inlet inactivity on distillation trays can create or amplify vapor crossflow channeling. Capacity and efficiency malperformance can result. The utilization of some form of inlet area bubble promoters fully activate the tray inlet. Many vendors automatically include bubble promoters on their trays. The inclusion of a light row of valves at the inlet of a (moving) valve tray can possibly have the same effect.

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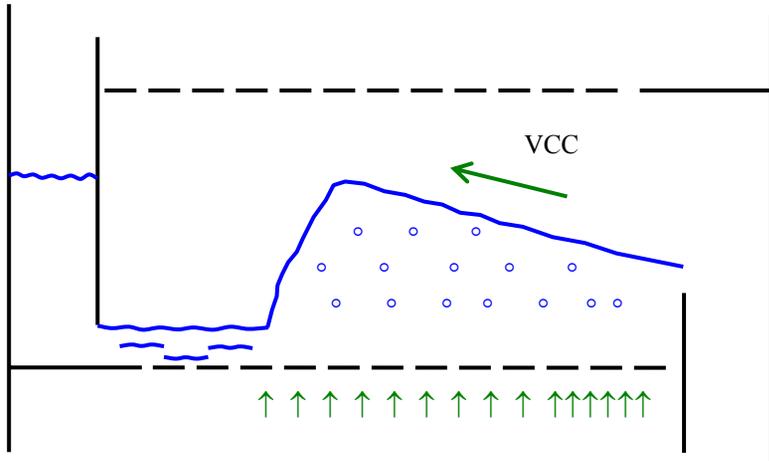


Figure 1
Inlet Inactivity

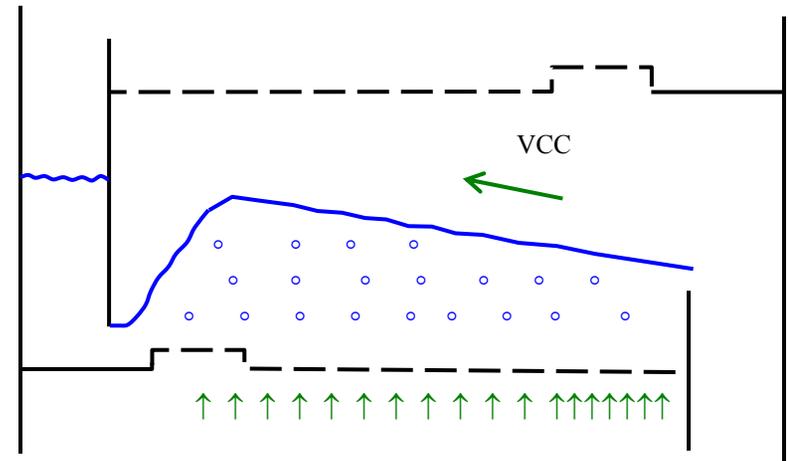


Figure 2
Inlet Bubble Promotion

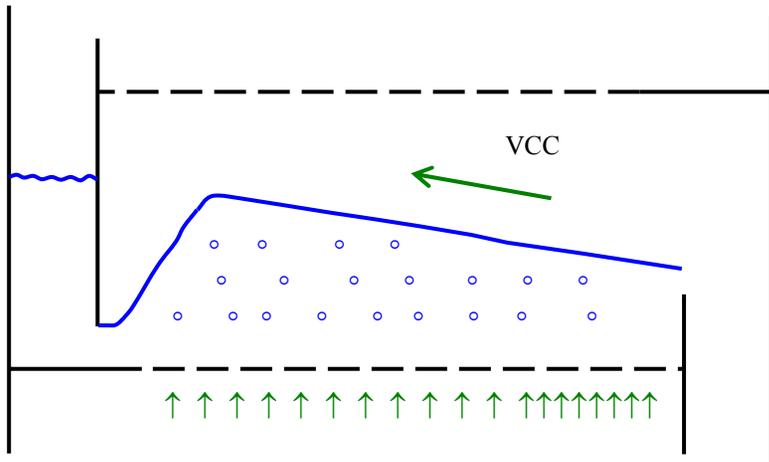


Figure 3
Froth Gradient and Vapor Crossflow Channeling

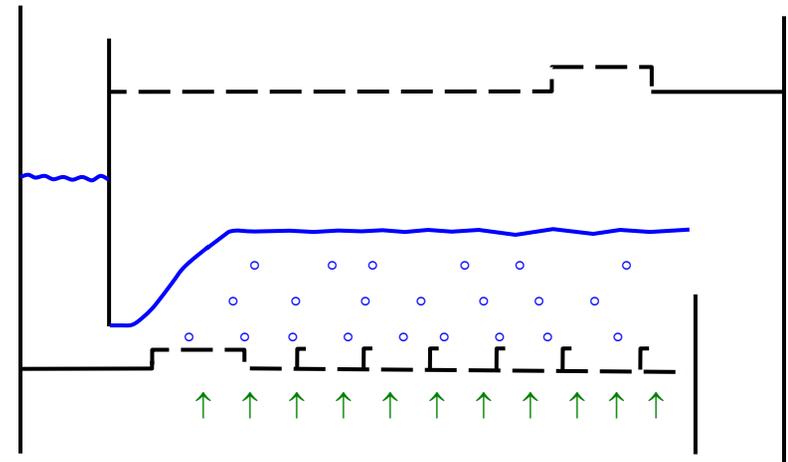


Figure 4
Inlet Bubble Promotion Plus Deck Push