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Chemical Engineering Research and Design

journal homepage: www.elsevier.com/locate/cherd

Vapor/liquid parallel-flow channeling on cascade trays with moving valves

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ARTICLE INFO

Article history:
Received 13 November 2014
Accepted 11 March 2015
Available online 18 March 2015

Keywords:
Distillation
Valve tray column
Liquid channeling
Maldistribution
Multiple steady states
Vapor crossflow channeling

ABSTRACT

A hydraulic mechanism called ‘vapor/liquid parallel-flow channeling’ (VPC) is introduced, which leads to tray efficiency loss due to disengagement of vapor and liquid flows. It occurs only on cascade trays. The occurrence of VPC is shown based on model calculations and experimental results from water/air tests.

1. Introduction

Vapor crossflow channeling (VCC) is a known problem of trayed distillation columns with high liquid load and long flow path length. Here, the high liquid load generates a high hydraulic gradient on the tray, which in turn causes weeping/small gas loads at the inlet and high vapor load at the tray outlet. The weep as well as deficient vapor and liquid contact lower tray efficiency, and degrade column performance. One measure to alleviate vapor crossflow channeling is the use of cascade weirs as depicted in Fig. 1, which reduces the flow path length. However, the cascade can lead to another form of vapor–liquid maldistribution, we termed ‘vapor/liquid parallel-flow channeling’ (VPC). In contrast to VCC, it will occur even on trays with low liquid load.

2. Tray efficiency loss in a technical scale column

The work presented here is based on a real troubleshooting case of a plant distillation column just less than 3 m diameter equipped with cascade trays containing Varioflex moving valves type VV16-3L20.

While the product specifications were met in some cases, they were missed widely in others. Plant data revealed that for the same process operating conditions (feed/bottoms/distillate flow rate, pressure and reflux ratio) on-spec as well as off-spec cases were found. So, the column seemed to have two different steady states, which can run more or less stable under the same process conditions. These problems occurred particularly at small and medium loads, but not at high loads.

A column simulation showed that the number of trays installed is sufficient to achieve the desired separation. Even when decreasing the value for the expected tray efficiency considerably, product specifications could be met. It was concluded, that only an unrealistic low tray efficiency could explain the observed malfunction of the column.

Based on these findings a hydraulic phenomenon was suspected to cause the observed tray efficiency loss. But which kind of hydraulic malfunction could lead to the dramatic loss in tray efficiency? Based on literature, the first theory to be

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http://dx.doi.org/10.1016/j.cherd.2015.03.014

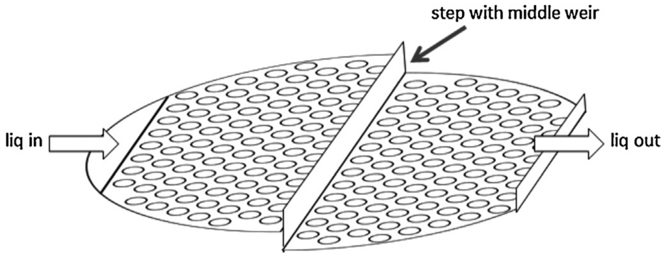

Fig. 1 – Cascade tray.

checked was ‘vapor crossflow channeling’ (VCC) (see Kister, 1993, 2006; Resetarits and Pappademos, 2001).

In case of VCC the hydraulic gradient on the tray results in a significant higher liquid level on the inlet side of the tray, as depicted in Fig. 2. Due to the higher liquid level in the inlet area, hydrostatic pressure is also higher, which results in weeping. In addition, the higher hydrostatic pressure hinders vapor rising through this area. On the other hand, there is no weeping but increased vapor traffic on the outlet side of the tray, as liquid level is smaller. As part of the vapor flows countercurrent to the liquid, it even increases the gradient in liquid level.

As in the inlet area some of the liquid is weeping and vapor traffic is small, contact between liquid and vapor is worsened, resulting in poor tray efficiency. Similarly, this is what is observed in the above mentioned case as well.

According to Kister (2006), four criteria need to be fulfilled to allow for VCC:

- A large open area of more than 15% or venturi valves.
- A high ratio (>2) of flow path length to tray spacing.
- A pressure of 4.8 bara (70 psia) or less.
- A high liquid flow rate (>45–54 m^3/m/h (5–6 gpm/in.) of outlet weir).

In our case the fourth and most important criterium is not met by a large margin (liquid flowrate at outlet was about 4 m^3/m/h). But only when liquid flowrate on the tray is high enough, a strong gradient in liquid level may build up. Thus VCC is very unlikely in our case.

In Fig. 3 the normal and intended operation of the cascade tray is shown. Using a picket-fence weir the active weir length is the same on both halves of the tray, resulting in identical overflow height and liquid level on both sides. As a result of the

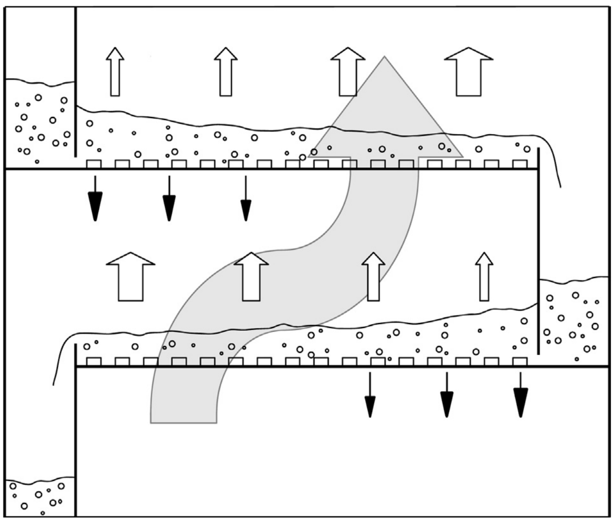

Fig. 2 – Vapor crossflow channeling.

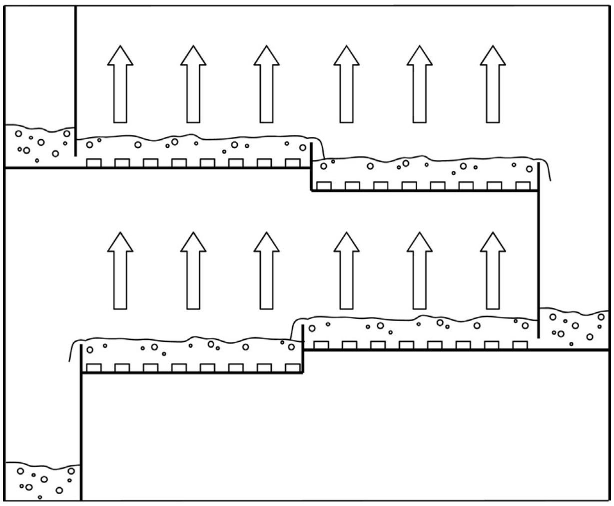

Fig. 3 – Normal operation of cascade tray.

uniform liquid level on the tray, the relation between pressure drop and vapor load is the same for all valves. Thus, vapor is equally distributed.

Based on VCC, a slightly different scenario was considered. What if all the liquid fed to the tray is weeping from the inlet half before the cascade weir (dumping) as shown in Fig. 4? If the liquid level on the inlet half is smaller than the weir height there will be no overflow over the cascade weir. Consequently the outlet half of the tray will run completely dry. However, the described state can only be stable, if pressure drop on both sides of the cascade is the same: the inlet side, which has some liquid level and only minimal vapor traffic, and the outlet side that has no liquid level but high vapor load.

The column is equipped with Varioflex valves of type VV16-3L20 which were developed by company Stahl in the 1970s. As can be seen in Fig. 5, at low vapor loads (left, closed position) only a relatively small hole is provided for the vapor. However, at high vapor loads, the caged disc is lifted and a much higher open area (5×) is available. As a result, the Varioflex provides a very wide operating range with a turndown ratio of five.

Varioflex valves have been tested extensively in the 1980s by Bayer. Hence, proprietary data on pressure drop and weeping was available for this work. The pressure drop for selected liquid levels as a function of vapor load is depicted in Fig. 6.

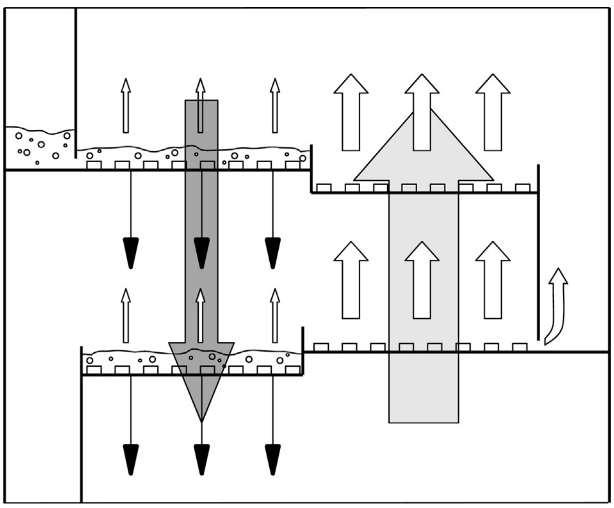

Fig. 4 – Scenario of ‘vapor/liquid parallel-flow channeling’ (VPC).