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How to... BUBBLE CAP TRAY

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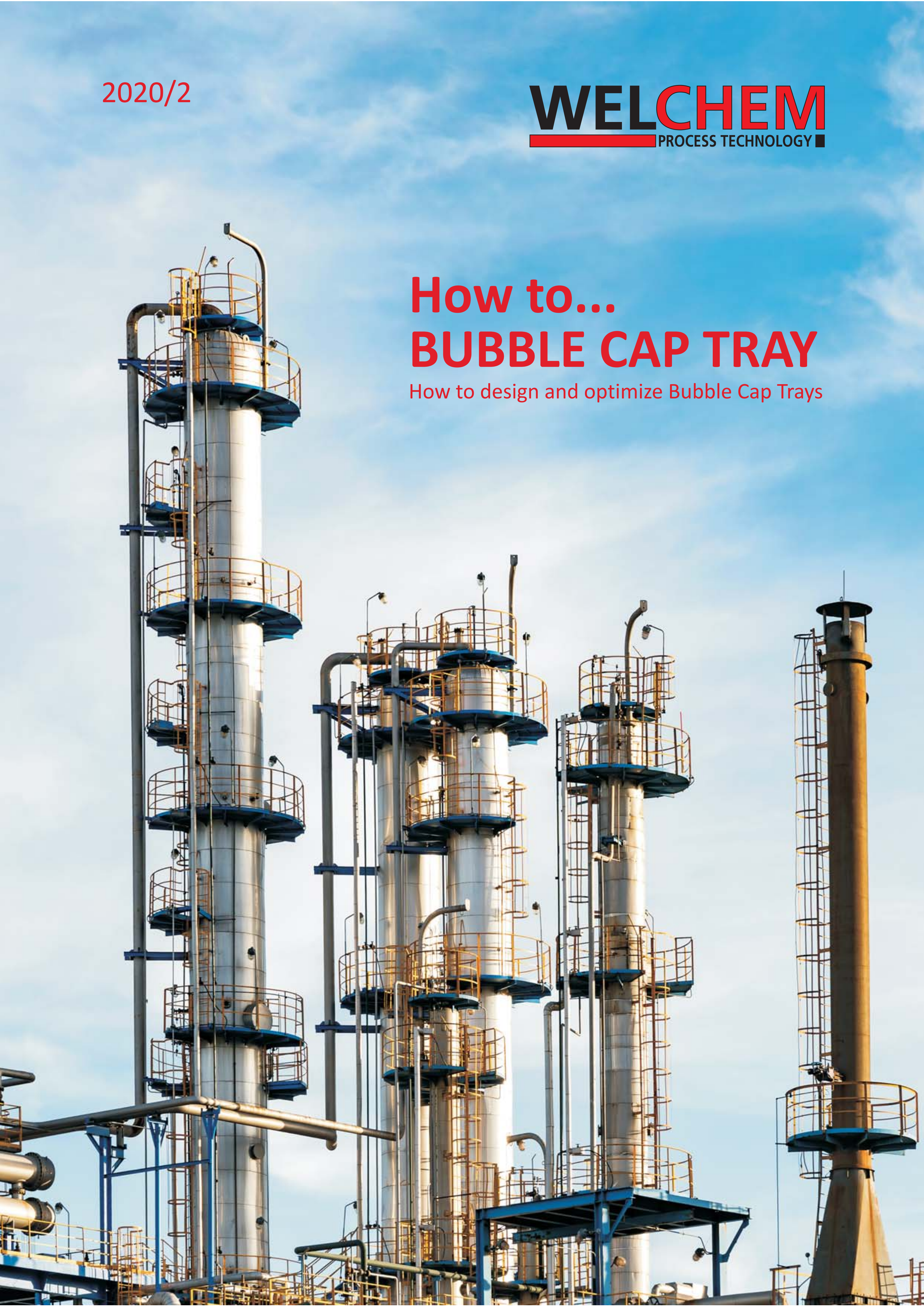

How to... BUBBLE CAP TRAY Part 2

How to design and optimize Bubble Cap Trays

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Tower trays and internals are the heart of all distillation columns. Their design is an essential part of a process engineer's task and determines the process reliability and economy.

This article is the 2nd part of a series on different kinds of trays and internals.

Bubble Cap trays have been used for about 80 years in technical applications and are a very well studied tray type. Nowadays, they are mainly used for handling low liquid loads, as for this field of application there are only few alternatives!

On a distillation tray vapor enters liquid and forms a two phase regime (bubbling, froth, spray). The tray types differ mainly in the way the vapor enters the liquid. For *Bubble Cap Trays* the gas flow path is very different compared to other tray types and is depicted in *Fig. 1*.

Before entering the liquid, the gas ascends in the riser (a), is redirected in the top of the cap (b) (reversal area) and then flows downwards in the cylindrical annular gap (c). Finally, the vapor enters the liquid layer through vertical slots, holes or the skirt of the cap (d).

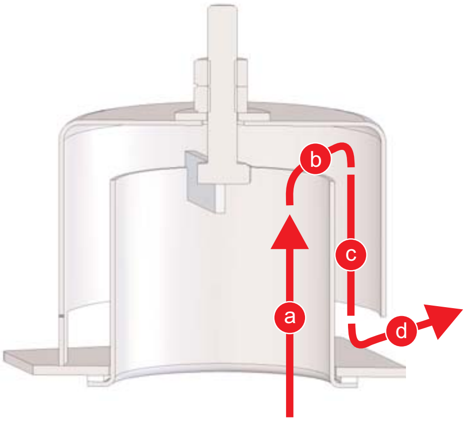

Fig. 1: Gas Flow Path

As long as the riser is higher than the outlet weir and the panels and risers are liquid-tight, the tray is able to handle very small amounts of liquid. This is the main advantage of this tray type and a typical field of application.

The main disadvantages are the relatively high costs for the equipment and a higher pressure drop compared to other tray types.

There are many different types and sizes of bubble caps. Historically, there are cast iron types (still in use!), oval, rectangular and round bubble caps.

Today, new bubble cap trays are usually equipped with bubble caps with an outer cap diameter of 2 inch, 3 inch, 4 inch or 6 inch. As the caps are fabricated by deep drawing, the material thickness is about 1mm. For special materials types or thick materials, the caps are rolled and welded.

There are several types of cap designs (*Fig. 2*).

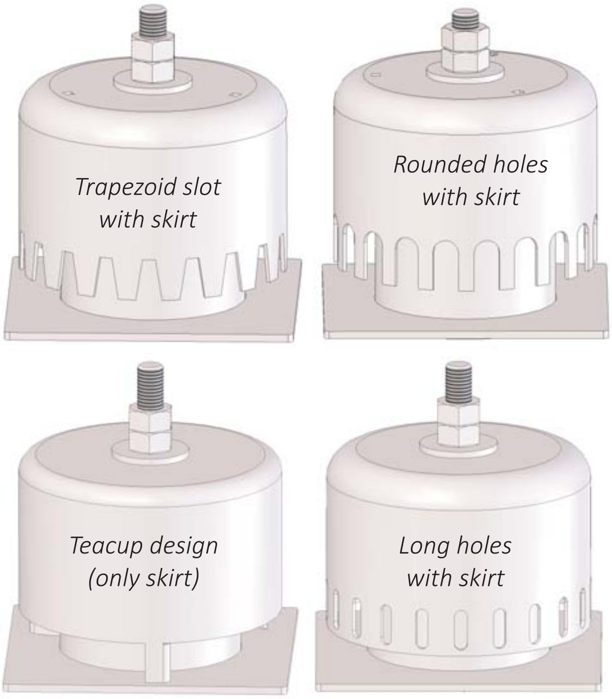

Fig. 2: Bubble Cap Designs

The cap is normally bolted (double nut!) to the riser, sometimes welded, sometimes wedged. (It is not fun to move on the top of bubble caps for maintenance or inspection duty.)

The caps are categorized by the top level of the gas opening and the area of the openings (expressed by a function of the "opened" height of the slots / skirt).

The pitch of the bubble caps is important for the function of the tray: In standard applications it is triangular and expected to be 1.25 .. 1.5 times the cap diameter [Hoppe/Mittelstrass 1967].

The risers are welded or pressed in the tray panel or gasketed by pulling the riser flange to the tray panel (*Fig. 3*).

The values of the riser area, the reversal area, the annular gap as well as the escape area of the bubble cap have to be balanced. As the fabrication possibilities are on the one hand confined by the riser dimension, which is limited by the available pipe dimensions, and on the other hand by the cap, which is restricted to the dimensions of the deep drawing tools, you will have to find a compromise to have almost equal values for all areas.

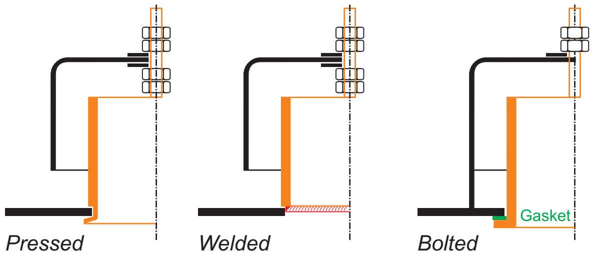

Fig. 3: Fastening of Risers

The relative free area (riser area per active area) is typically about 5 to 10% and the resulting total pressure drop per tray is about 8 to 12mbar. The tray spacing is usually not less than 500mm (for large tower diameters it should be higher due to inspection and maintenance reasons).

The *Operating Area* of a bubble cap tray is defined by different limits. In *Fig. 4*, a qualitative operation diagram is shown. Please note, that the position and shape of all curves depend on the physical data, the tray and cap geometry and the gas/liquid load. Each curve can be limiting!

The *Operation Point* (Op in *Fig. 4*) of the design case (as well as the minimum and maximum load) has to stay inside all limiting curves. For stable operation and good efficiency there is a *useful operation area* with narrower limits (e.g. 80%-FFCF and 85%-FFJF curves).

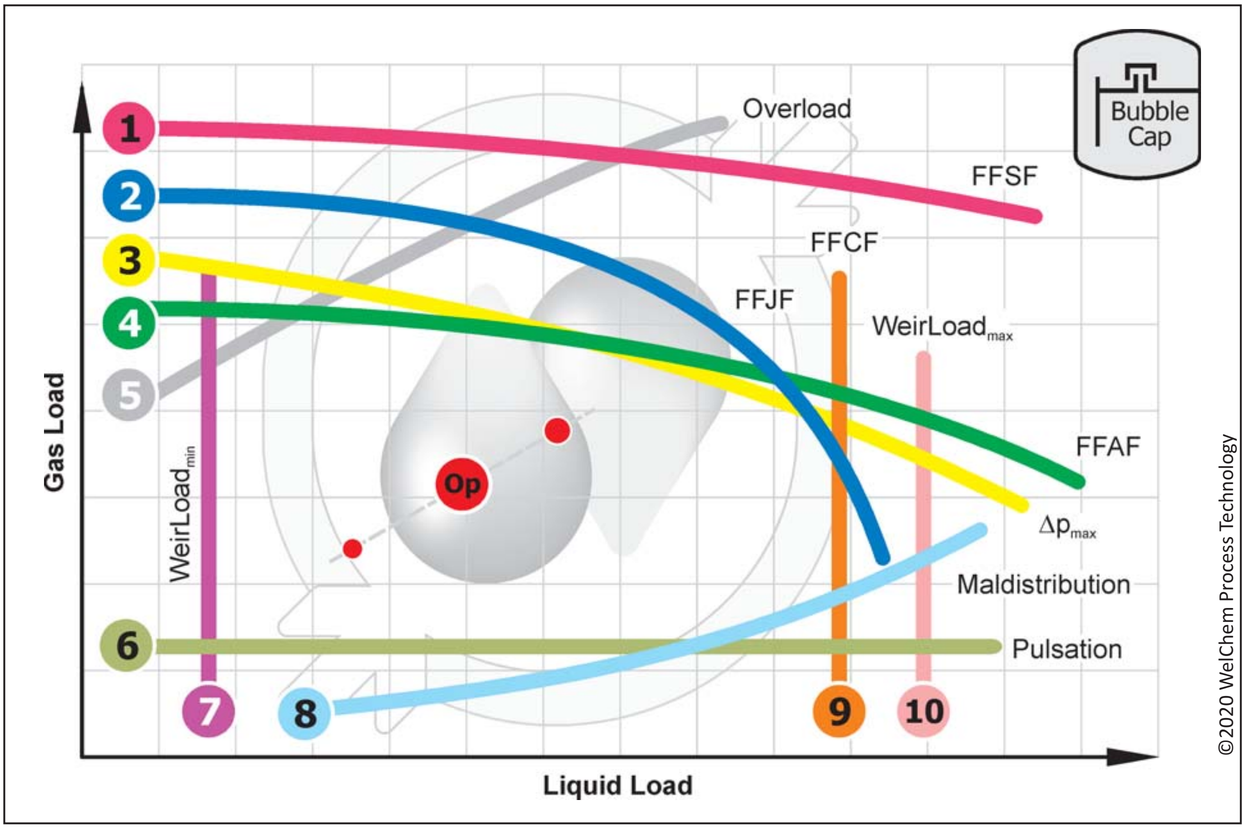

Fig. 4: Qualitative Operation Diagram for Bubble Cap Trays

The first step in analyzing a design is – of course – calculating all relevant parameters. For a bubble cap tray design there are 10 main parameters shown as curves in *Fig. 4*. These parameters are discussed in this article. There are some additional effects you will have to look at: entrainment, head loss at downcomer exit (clearance), flow regime, downcomer residence time, efficiency, sealing, construction issues, statics, ...

Please note, that all free suppliers' software only show a limited number of these parameters and therefore are not save to use for design, rating and troubleshooting of trays. For save design you should be able to calculate all parameters! (e.g. software TrayHeart of WelChem)

In the following sections, all 10 main parameter curves of *Fig. 4* are described. Each suggested action for preventing a certain effect may result in fertilizing another. The main task for designing trays is to balance these different and contradicting effects.

1 System Flood FFSF

There is a system limit set by the superficial vapor velocity in the tower. When the vapor velocity exceeds the settling velocity of liquid droplets („Stokes Law Criterion"), vapor lifts and takes much of the liquid with it. A well known model was published by Stupin and Kister 2003.

This flooding effect cannot be reduced by use of other tray types or by increasing tray spacing. The only way is to enlarge the vapor cross section area (e.g. enlarging tower diameter or reduce downcomer area).

2 Jet Flood FFJF

There are several definitions in literature for the so called *Jet Flood*. Similar definitions are *Entrainment Flood*, *Massive Entrainment*, *Two-Phase Flood* or *Priming*. For practical understanding, Jet Flood describes any liquid carried to the tray above by the gas stream. This leads to a shortcut recycling of the liquid with loss of tray efficiency, additional pressure drop and additional downcomer load. For good tray performance, the Jet Flood value should be less than 75-80%.

You can reduce Jet Flood by

a) lowering the gas velocity (higher open area, i.e. more bubble caps, higher escape area)

b) enlarging the tray spacing

c) lowering the froth height on the tray deck (by reducing weir height or weir crest height)

d) enlarging the active area (i.e. the gas flow area) by sloping the downcomers

Pressure Drop 3

In most cases there is specified a maximum allowable pressure drop of the tower. You have to ensure that the pressure drop per tray does not exceed a certain value. This leads to a limiting curve within the operation diagram.

To reduce the pressure drop of a design, you can

a) lower the gas velocity by enlarging the number of bubble caps or change their geometry

b) lower the froth height on the tray deck (by reducing weir height or weir crest height)

c) enlarge the active area (with place for more bubble caps) by reducing the downcomer area or sloping the downcomers

Aerated Downcomer Backup FFAF 4

This limiting effect is also known as *Downcomer Backup Flood*. It describes the (aerated) backup of the downcomer due to pressure drop effects. It is important to not mix this up with the Choke-Flood-effects (ref. to 9).

The level of the liquid in the downcomer is the result of (i) head loss at the clearance, (ii) the liquid height on the outlet deck, (iii) an inlet weir (if present) and (iv) the pressure drop of the tray itself. All these effects can be expressed by "hot liquid height". This resulting level in the downcomer has to compensate these effects! Taking into account the aeration of the liquid in the downcomer, the level has to be less than tray spacing plus weir height.

To reduce a high Aerated Downcomer Backup value you have to

a) reduce the pressure drop of the tray (ref. to 3)

b) reduce the head loss of the clearance (use higher clearance height or radius lips or recessed seal pans in case of insufficient sealing)

c) avoid inlet weirs

Please note, that it is no option to enlarge the downcomer area to reduce this flooding effect!

5 Overload Caps

At high gas loads, the space between the caps is dried - the liquid can't enter this region and is blown to a froth layer above the caps. This is not a recommended and stable regime! The effect is close to the *Blowing effect* of sieve trays (where the liquid layer is "disconnected" from the tray panel and blown upwards).

Therefore, the bottom skirt of the bubble cap should not be used for the gas outlet. (In a teacup design, the skirt should not be blown totally free.)

To prevent overload of caps, you can

a) adapt the design of the caps (more slots, enlarge width of slots, higher skirt)

b) enlarge the number of caps

6 Pulsation

The slots of bubble caps are opened by the gas flow. To have a stable operation, the gas has to open all slots of all bubble caps. If there is not enough gas (minimum slot velocity not reached), the bubble caps are pulsating.

To reduce Pulsating you have to

a) change cap design (less slots, reduce width of slots)

b) reduce number of bubble caps

7 Minimum Weir Load

The uniform thickness of the two-phase layer is essential for the successful operation of a tray. To achieve this uniform flow, the tray panels have to be in level and the outlet weir has to be installed accurately.

To compensate small tolerances, the weir crest should be higher than 3mm and the weir load more than 9 m³/m/h. In case of low weir loads you will normally have to consider gasketing the tray to avoid any leakage and loss of liquid.

To ensure these minimum values, you can use

a) notched weirs

b) blocked weirs

Gas Maldistribution 8

In all types of trays the liquid must have a driving force to flow from the inlet to the outlet. As long as there is no gas driven flow (as generated by fixed valves or push valves) the hydraulic gradient is the main reason for liquid flow.

Because the bubble caps are obstacles in the liquid flow pass, the hydraulic gradient is significant higher for bubble cap trays than for other trays.

Why might the hydraulic gradient be a problem? At a high hydraulic gradient, the tray will not work properly (*Fig. 5*): At the tray inlet the liquid "closes" the caps. The gas will use less liquid affected bubble caps for passage. This leads to a gas maldistribution and a bad efficiency of the tray. If the liquid head of rows with high gradient gets too high, weeping occurs!

To reduce gas maldistribution you have to

a) reduce the number of cap rows (e.g. by switching to a design with more flow passes)

b) cascade the active area

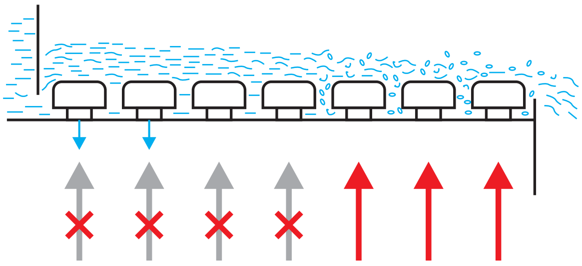

Fig. 5: Maldistribution

9 Choke Flood

The maximum liquid throughput of a downcomer is limited by the liquid velocity and the effect of overload (so called *Choke Flood*). The maximum allowable liquid velocity in the downcomer depends on the density ratio of gas to liquid, the tray spacing and the system factor. (The system factor describes the difficulty of phase separation. For common applications it is 1.0.) The most popular downcomer choke flooding calculation was published by GLITSCH 1993.

Another effect of Choke Flood at center and off-center downcomers is initiated by the mutual interference of the two liquid flows into the downcomer.

To prevent downcomer Choke Flood you have to

a) enlarge the downcomer area

b) implement more flow passes (with in sum an overall higher downcomer area)

c) enlarge the tray spacing (if limiting)

d) install anti-jump baffles for center / off-center downcomers

Maximum Weir Load 10

The maximum liquid flow handled by a downcomer can also be limited by the weir.

If the weir crest exceeds 37mm or the weir load 120 $m^3/m/h$, the liquid will not enter the downcomer properly.

To prevent overload of the weir, you have to extend the weir length by

a) larger downcomers with longer weirs (or multichordal downcomers)

b) more flow passes

c) swept back weirs at the side downcomers

Conclusion

There are multiple limiting effects that have to be considered at the design and operation of bubble cap trays. Among the “standard” limits there are bubble-cap-individual limits as pulsating, gas maldistribution and cap overload.

Even if bubble caps are sometimes considered as dinosaurs, they are still in use and often the only solution (among all types of internals!) for low liquid loads.

About the author

Volker Engel studied process engineering at the Technical University of Munich and did his Ph.D. thesis on packed columns with Prof. Johann G. Stichlmair. Since 1998 he has been the managing director of WelChem Process Technology GmbH and head of the TrayHeart software. TrayHeart has developed into a state-of-the-art design tool for trays and internals in process technology.

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WelChem Process Technology: TrayHeart Software. Tower Internals Calculation Software.
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