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WELCHEM PROCESS TECHNOLOGY

How to...
TUNNEL TRAY

How to design and optimize Tunnel Trays

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How to design and optimize Tunnel trays

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Tunnel trays are more than only „trays with rectangular bubble caps“. There are two variants of orientation of the tunnels on the active area with specific features. Even though there is only few and rather old public literature of Tunnel trays, this tray type is used in many applications.

Tunnel trays have many things in common with Bubble Cap trays. On the other hand, they are also very different and have specific features that make them the first choice for some applications!

There is only few literature about Tunnel trays. Most of the research work and publications were done 60 years ago (e.g. HOPPE/MITTELSTRASS 1967, DIERY 1960).

Similar to the bubble caps is the flow path of the gas through riser and cap (*Fig. 1*): The gas ascends in the riser (a), is redirected in the top of the cap (b) (reversal area) and then flows downwards to the gap (c). Finally, the gas enters the liquid layer through the openings of the cap (d).

By this the riser and the cap form a siphon, where liquid cannot weep. Tunnel trays (like Bubble Cap trays) are therefore able to handle very small liquid rates. There is no weeping as an operational limit!

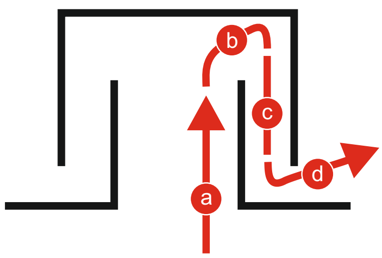

Fig. 1: Gas Flow Path

The length of a tunnel is set by the dimension of the active area or by construction issues. To handle even small gas load without having trouble with tray levelness or hydraulic gradient, the tunnel caps are slotted. This corresponds to the idea of *notched* outlet weirs distributing liquid to the entire length.

The slots at the skirt act as dynamic openings (*Fig. 2*): At a small gas load, only the top of the slots of the skirt is used by the gas. The more gas is flowing, the more the slots are opened by the gas. The pressure drop characteristic of a Tunnel tray is therefore more like that of a float valve (dynamic openings) tray than that of a sieve tray (static openings). Because of the gas flow path (with its redirections) the dry pressure drop of the Tunnel tray is slightly higher than that of Sieve or Valve trays.

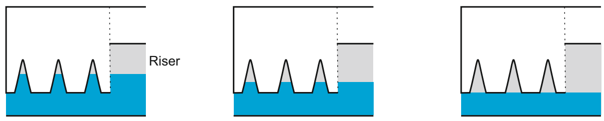

Fig. 2: Dynamic behavior of the skirt openings

The main difference to bubble caps is the shape of risers and caps. The rectangular tunnels have a length and a width. Hence, there are two principle arrangements of the tunnels on the active area.

When liquid flows through the lanes between the tunnels directly from the inlet to the outlet of the tray (Fig. 3), the configuration is called **STREUBER** design. This variant can also be used for high liquid load, as the hydraulic gradient of the straight lanes is less than the hydraulic gradient of a comparable bubble cap design.

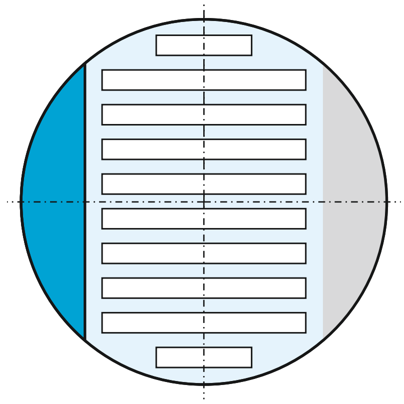

Fig. 3: Single-pass STREUBER design

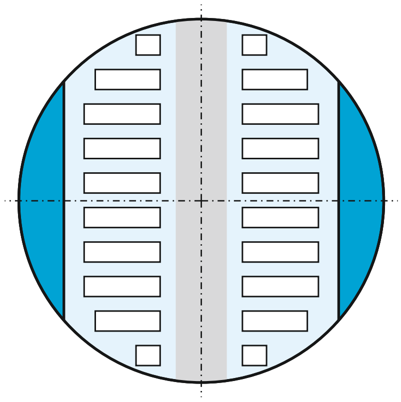

Fig. 4: Two-pass STREUBER design

Tunnel trays of type STREUBER can be designed as single or multi-pass trays. *Fig. 4* shows a two pass design.

The perpendicular orientation of the tunnels is called **THORMANN** design (*Fig. 5*). Liquid is meandering around the tunnel caps. The path of the liquid is quite long. The flow path length is about the sum of all tunnel lengths.

This type is used for applications with the need of high residence time (e.g. chemical absorption) or for small liquid load.

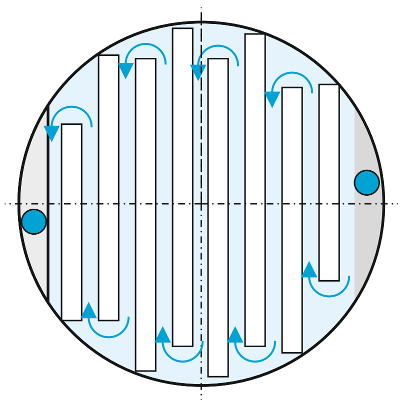

Fig. 5: Tunnel THORMANN design

The defined liquid path is a great feature of the THORMANN design. The liquid path of a Bubble Cap tray at a comparable liquid load is random. In the worst case, most of the active area is stagnant and liquid passes only few bubble caps along a favorite path. By using a Thormann type tray, liquid is guided across the entire active area and will be in contact with all gas.

At a long flow path, you normally would have to deal with a high liquid gradient. To solve this problem, the tunnel openings are acting as pushing elements (*Fig. 6*). For caps fabricated

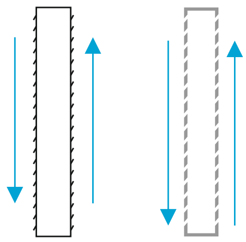

Fig. 6: Pushing effect of tunnel caps

from metal material, there are bended flaps directing the gas in flow direction of the liquid (*Fig. 6,* left). For plastics and carbon material the slots are fabricated with an inclination to the cap length achieving the same pushing effect (*Fig. 6,* right).

Since the THORMANN design is used for small liquid load, there is normally no need for multi-pass designs in meanings of having several downcomers. But at large tower diameters even for THORMANN designs there can be several flow passes (*Fig. 7*).

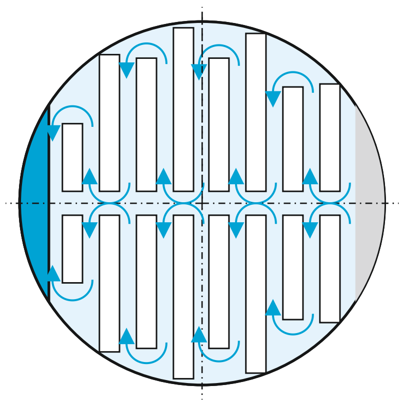

Fig. 7: Multiple flow passes at THORMANN designs

Another aspect in comparing Bubble Cap trays to Tunnel trays is fabrication. On one hand it is easier to fabricate the caps for tunnels by bending than deep drawing for bubble caps. For special materials you will therefore realize Tunnel trays, because bubble caps are no economical alternative. On the other hand the fabrication of the risers at a Tunnel tray deck has always to do with welding. This is costly.

Design of Riser, Cap and Downcomer

Fig. 8 shows a sketch of a downcomer with clearance, a tunnel cap (STREUBER-type), with its riser and an outlet weir.

As for all tray designs there should be a static sealing of outlet weir to clearance **(A)**. This sealing is important for startup (especially at low liquid load).

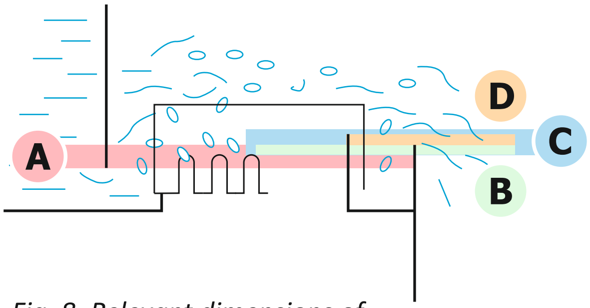

Fig. 8: Relevant dimensions of tunnel cap, riser, clearance and outlet weir

When the tray is running at low liquid and low gas load, gas will leave the cap at the top most slot area. This point should be submerged **(B)**.

The liquid level above the top of the gas outlet of the cap defines the minimum contact time for the gas. It is called „static slot submergence".

At presence of liquid flow there will be an additional weir crest height. This dynamic slot submergence **(C)** defines the contact time of the gas with the liquid at operation.

Finally the riser height should preferably be higher than the outlet weir **(D)**. Whenever there are waves on the tray or the hydraulic gradient is high, the risk of weeping should be minimized.

The *Operating Area* of a Tunnel tray is defined by different limits. In *Fig. 9*, 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 *Operating Point* (**Op** in *Fig. 9*) 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.

The first step in analyzing a design is to calculate all relevant limits and parameters. For a Tunnel tray design there are 9 main parameters shown as curves in *Fig. 9*.

There are some additional effects you will have to look at: entrainment, head loss at downcomer exit (clearance), flow regime, downcomer residence time, efficiency, hydraulic gradient, spray height, sealing, construction issues, statics, ... About 40 parameters have to be calculated and checked (e.g. software TrayHeart of WelChem).

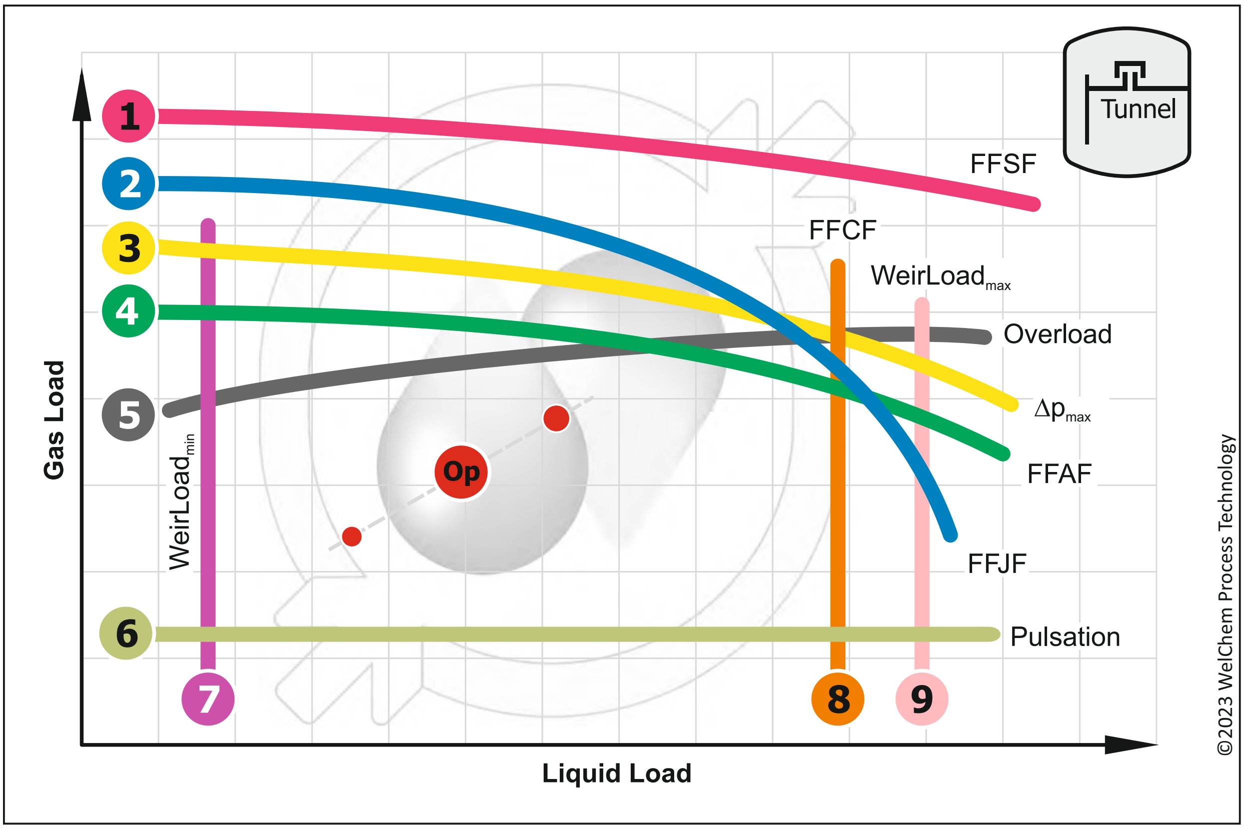

Fig. 9: Qualitative Operation Diagram for Tunnel trays

In the following sections, all 9 main limiting curves of *Fig. 9* 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 gas velocity in the tower. When the gas velocity exceeds the settling velocity of liquid droplets („Stokes Law Criterion“), gas 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 gas cross section area (e.g. enlarging tower diameter or reduce downcomer area).

For Tunnel trays you will rarely touch this limit, as Tunnel trays are used for handling small liquid rates (THORMANN).

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.

Jet Flood is only calculated for STREUBER designs. For THORMANN designs there is another limiting mechanism (see curve 5).

You can reduce Jet Flood by

a) lowering the gas velocity (higher open area, i.e. higher tunnel length, 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

3 Pressure Drop

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 length of tunnels 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 space for more tunnels) by reducing the downcomer area or sloping the downcomers

4 Aerated Downcomer Backup FFAF

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 8).

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 curve 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 tunnel caps is dried – the liquid cannot enter this region and is blown to a froth layer above the caps.

THORMANN designs are dealing with the pushing effect of the openings. By overloading the slots the lanes between the tunnels are blown free and this pushing effect is off. Thus, for THORMANN designs this limit is more relevant than the Jet flood.

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 tunnel length

6 Pulsation

The slots of tunnel 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 tunnels are pulsating.

To reduce Pulsation you have to

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

b) reduce tunnel length

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.

At small liquid loads (as typically for THORMANN designs) there are often piped downcomers with very small weir lengths.

To ensure these minimum values, you can use

a) notched weirs (for STREUBER designs)

b) blocked weirs (often used with Tunnel trays)

Choke Flood 8

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 9

The maximum liquid flow handled by a downcomer can also be limited by the weir. A high weir crest height corresponds to a high wet pressure drop. The design limit for standard trays is about 37mm.

For Tunnel Trays (especially for THORMANN designs) this limit is somehow theoretical.

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

a) larger downcomers with longer weirs (or multi-chordal downcomers)

b) more flow passes

c) swept-back weirs at the side downcomers

Conclusion

The Tunnel tray complements the field of application of the Bubble Cap tray: For very low liquid load the THORMANN design (with defined contact time and path) and for high liquid load the STREUBER design (with smaller liquid gradient) is favorable.

A Tunnel tray must be designed correctly and implemented well in terms of construction and fabrication in order to prove itself in operational practice.

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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