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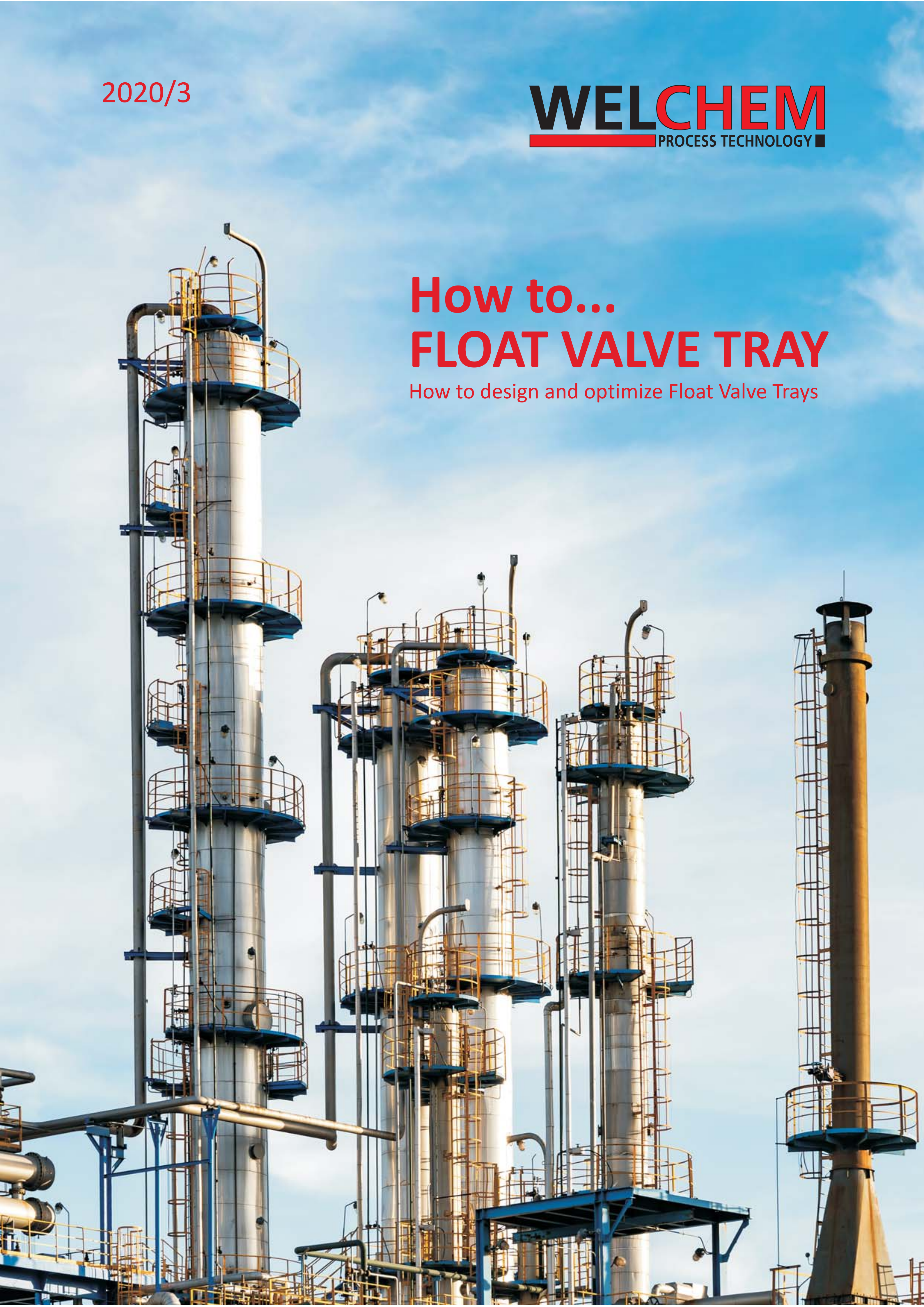
How to...
FLOAT VALVE TRAY

How to design and optimize Float Valve Trays



How to... FLOAT VALVE TRAY Part 3

How to design and optimize Float Valve 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 3rd part of a series on different kinds of trays and internals.

Float Valve Trays (also called movable valve trays or ballast trays) are the most flexible tray type among the standard trays. They have been used for about 80 years in technical applications, they are well studied and they are still the mainly used tray type in towers.

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 float valve trays, at low gas loads the valves are all closed – the gas can only enter the liquid layer by the annular gap of the valve plate's initial lift (i.e. dimples that prevent the valve plate from sticking to the tray panel). Therefore float valve trays do not tend to weep.

At increasing gas loads the float valves start to open and the gas enters the liquid layer predominantly in horizontal direction (resulting in less entrainment compared to sieve holes). The starting point for the movement of the valves is called "Closed Balance Point (CBP)". At the "Open Balance Point (OBP)" all valves are at their maximum opening (i.e. the valve plate has reached its maximum lift). The region between the CBP and OBP is called "working area", where the pressure drop is quite constant.

By increasing the gas load beyond the OBP the pressure drop characteristic behaves like a static tray: the pressure drop is proportional to the gas velocity square.

The tray spacing of float valve trays can be small (300 mm), but is normally – due to inspection and maintenance reasons – about 450 - 500 mm.

The advantage of the flexibility of this tray type is achieved in exchange for the disadvantage of movable parts within the tower. The movement includes the risk of wear of the valves in operation, getting lost in high pressure cleaning, higher effort in maintenance and higher costs in fabrication of the trays. (The acquisition costs of float valve trays are about twice of those of sieve trays.)

There are various float valve types:

The most common type is the so called **V1-valve** (see *Fig. 1*). It is a round valve plate (Ø48 mm) with three legs fitting in a Ø39 mm panel hole.

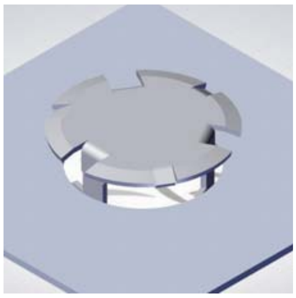

Fig. 1: Standard Round Float Valve

The standard pitch of these valves is 76mm (in flow direction) x 127 mm. The resulting relative free area is about 13%.

As the valve elements interact to create a proper two-phase layer, the standard pitch should only be varied to a small extent.

The standard V1 valve has a material thickness of 1.5mm (weight 24g/valve) and dimples for initial lift (to prevent it from sticking to the tray panel).

In corrosive applications and for increasing the operation range of a tray (see later) the material thickness can be 2.0mm (weight 30g/valve) as well.

To achieve even higher valve weights one can add ballast plates to the valve plate.

The legs of the V1 valve guide the element in the panel opening and limit the lift of the valve

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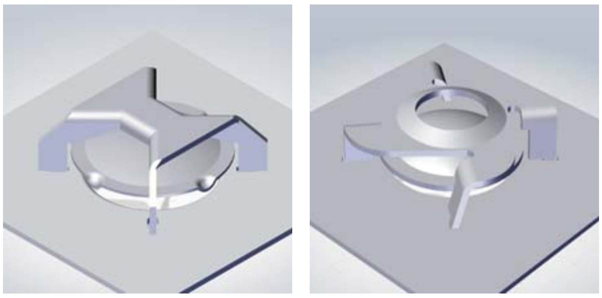
("legged valve"). Another float valve type is called **Caged valve** (see *Fig. 2*). These valves consist of two parts: The (moving) valve plate and the (static) cage. This type of float valve is used in fouling services (higher turbulence caused by the cage) and to minimize pressure drop (valve plate lighter than legged type). The panel hole diameter is Ø39mm.



Type T *Type A3*

Fig. 2: Caged Float Valves

Beside these standard types there are several other types:

Rectangular float valves (see *Fig. 3*) have two legs in flow direction. The values for panel and curtain area of the type "BDH" is very similar to the V1 valve data. The "BDP" type has twice the length of the BDH.

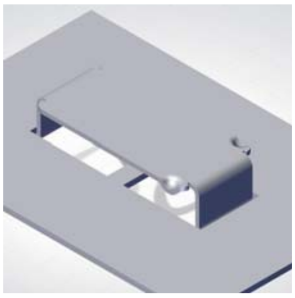


Fig. 3: Rectangular Float Valve

Venturi shaped panel openings (see *Fig. 4*) are fabricated to achieve minimum pressure drop. The length of the legs has to compensate this additional "thickness" of the tray panel. The venturi height is normally about 6.7mm. The legged valves are often called "V4", the caged units "A4" or "T0" (depending on the cage type).

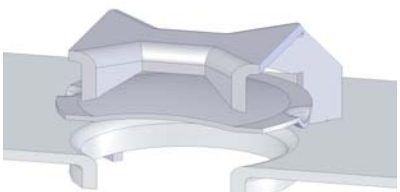


Fig. 4: Venturi Deck Opening

Mini valves (see *Fig. 5*) have a panel hole diameter of about Ø24mm and normally two legs orientated towards inlet and outlet (like the rectangular valves). Their size helps to achieve a small pressure drop (same at sieve trays: The pressure drop of the identical open area of small holes is better than that of large holes) and a good coverage of the active area (easier to achieve by small elements than by larger ones). These advantages are in competition with higher production costs.

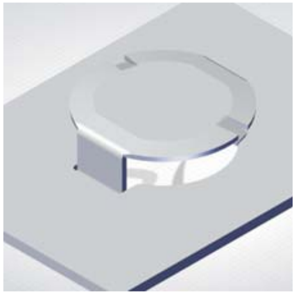


Fig. 5: Mini Valve

Moving elements cause abrasion and wear. To prevent spinning of the valves, the panel holes are equipped with **anti-spin noses**. This helps to reduce the risk of loosing valves by abrasion of the legs or of enlarging the panel holes by rotation. Nevertheless, you will find sticking valves, where the legs have worked their way into the panel deck.

Double disk valves (see *Fig. 6*) have two valve plates in their cage. The upper plate (called "ballast plate") has three small legs for static lift. The lower plate is called "orifice cover" and closes the deck hole.

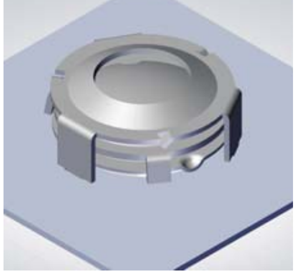


Fig. 6: Double Disk Float Valve

All valves are normally installed in the workshop of the supplier. The elements are inserted into the panel openings, the panel is turned and the valves are locked from the opposite side. In case of maintenance within a tower, you need one worker above and one below the panel to put in

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a new valve element. Because this is quite expensive (sometimes you have to add thousands of valves), repair valves have been developed (see *Fig. 7*). They can be inserted from the top side of the panel by one worker.

Fig. 7: Repair Valve

(Caution: There are so called “SnapIn-Valves”. These are not suitable for substitution of V1 valves as they are made for openings of Ø40mm.)

A special type of caged valve is the **Varioflex valve** (see *Fig. 8*). Its valve plate has (as standard) a round hole (Ø20mm).

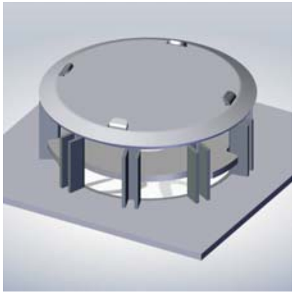

Fig. 8: Varioflex Valve

Apart from the presented float valve types, there are still several others types (e.g. cup-valves, double disk legged valves or legged valves with one shorthend leg for acting as push valve at high gas loads).

Pressure Drop Characteristic

Below the CBP the gas enters the tray by gaps or by opening single valves. At this load the tray is not safe in operation, because the liquid may use lanes to cross the tray – without getting in contact with the gas. To enlarge the operation range to low gas flow rates, you can equip the tray with light and heavy valves in alternating row blocks (parallel to weir). This design is called “multi-weight”. In *Fig. 9* the pressure drop characteristic of a single and a multi-weight design is shown.

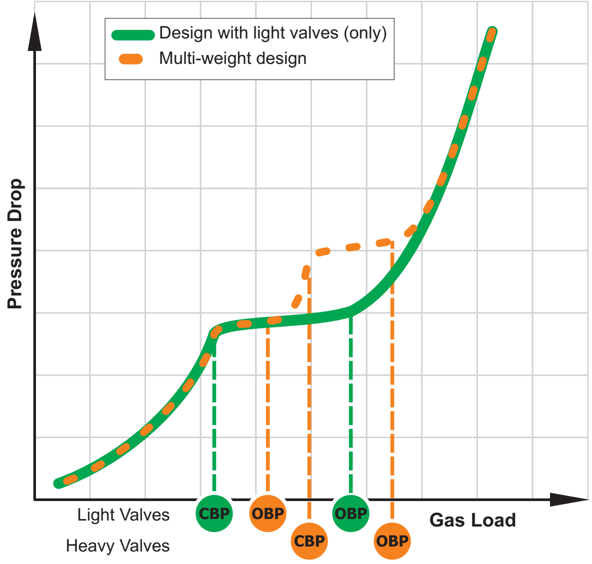

Fig. 9: Pressure Drop Characteristic

The *Operating Area* of a float valve tray is defined by different limits. In *Fig. 10*, 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 GLITSCH bulletin can be considered as the standard calculation procedure for float valve trays. As it deals only with some types of valves, there have been developed new models for calculation.

The *Operation Point* (**Op** in *Fig. 10*) of the design case (as well as the minimum and maximum load) has to stay inside all limiting curves. The *design load case* should additionally be above the OBP (not only the CBP): The movement of valves should not take place in the design load case as the abrasion is too high!

For stable operation and good efficiency there is a *useful operation area* with narrower limits (e.g. 80%-FFCF and 85%-FFJF curves).

The first step in analyzing a design is – of course – calculating all relevant parameters. For a float valve tray design there are 10 main parameters shown as curves in *Fig. 10*. 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, ...

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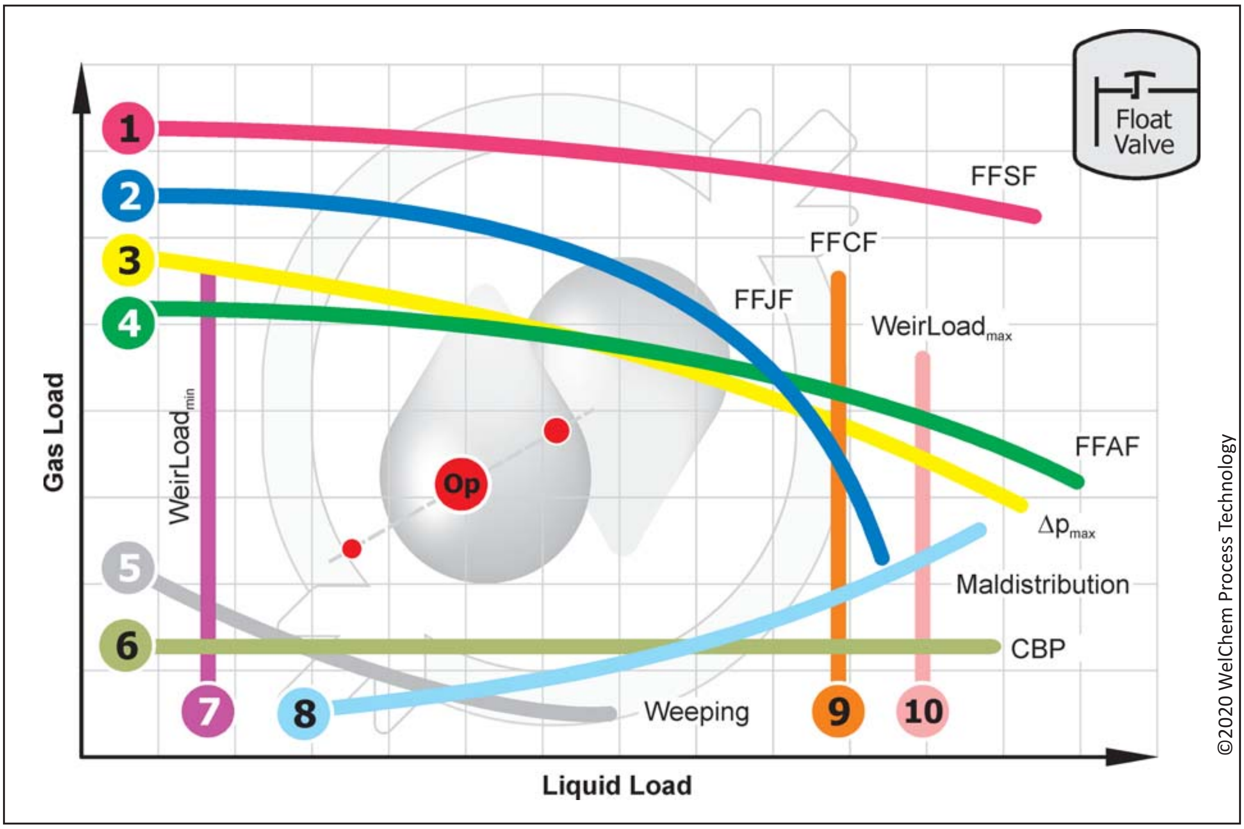

Fig. 10: Qualitative Operation Diagram for Float Valve Trays

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 safe 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. 10* 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).

Jet Flood FFJF 2

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 valve elements)

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

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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 number of valve elements. As you shouldn't vary the pitch, you have to optimize the panel dimensions to achieve the maximum number of units

b) use venturi openings in the tray deck panels

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

d) enlarge the active area (with place for more valve units) 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 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!

Weeping 5

Weeping is a minor subject of float valve trays. If you have a very low MIN load, you have to ensure, that weeping is minimized. Therefore you can

a) reduce the number of valve elements

b) use valve plates without initial lift (only in clean and non-corrosive services). As weeping occurs normally below CBP the heavy units of multi-weight designs are often build without initial lift dimple.

Closed Balance Point (CBP) 6

Below the Closed Balance Point the operation of the tray is not safe. The liquid is not getting in contact with the gas.

To lower the CBP you can reduce the number of valve elements.

Note: If you are running the tray below the OBP (not all valves completely open), you should consider using a multi-weight valve design to ensure that there are "bubbled areas" in the liquid flow path.

Minimum Weir Load 7

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 $m^3/m/h$. 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, the hydraulic gradient is the main reason for liquid flow.

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Because the valve units are obstacles in the liquid flow pass, the hydraulic gradient has to be considered for valve trays, too.

Why might the hydraulic gradient be a problem? At a high hydraulic gradient, the tray will not work properly (see *Fig. 11*): At the tray inlet the liquid "closes" the valves. The gas will use less liquid affected valves for passage. This leads to a gas maldistribution and a bad efficiency of the tray. Furthermore, if the liquid head of rows with high gradient gets too high, weeping occurs!

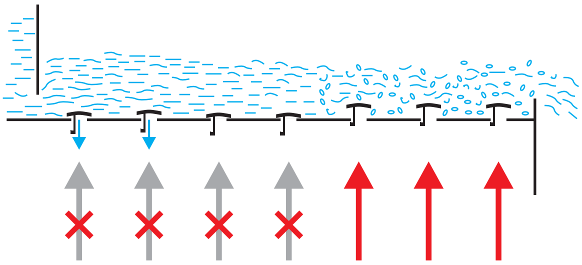

Fig. 11: Gas Maldistribution

To reduce gas maldistribution you have to

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

b) cascade the active area

At high downcomer liquid outlet velocity there is the risk of "undermining" the first valve rows: The valve plates are acting as a baffle guiding the liquid directly to the next tray. To avoid this short cut one can place so-called *interrupter bars* (see *Fig. 12*; height about 13mm). Do not confuse these bars with inlet weirs!

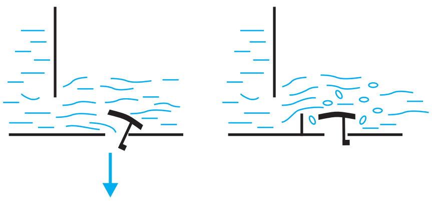

Fig. 12: Interrupter Bar

Choke Flood FFCF 9

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 m³/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 float valve trays. The float valves are still the working horses of the contact elements. Float valve trays are very flexible and their efficiency is constant over a broad load range. Due to the moving parts they are higher in costs (fabrication as well as maintenance).

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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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