2020/4

WELCHEM
PROCESS TECHNOLOGY

How to... FIXED VALVE TRAY

How to design and optimize Fixed Valve Trays

How to... FIXED VALVE TRAY Part 4

How to design and optimize Fixed Valve Trays

Dr.-Ing. Volker Engel

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 4th part of a series on different kinds of trays and internals.

Fixed Valve trays were first published and patented by Nutter in 1967. After some improvements in scale and development of NC-machinery, they gained technical relevance in the 1990s. Therefore they are the most recent, technical relevant development in contact elements of trays.

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.

The combination of "Fixed" and "Valve" is somehow contradicting. In principle the naming describes a "static covered hole". The gas passes the panel openings and is directed by the cover to the vertical outlet area (so-called *curtain area*). Therefore the gas enters the liquid in horizontal direction. This feature reduces entrainment and increases the capacity of the tray type compared to sieve trays.

Some Fixed Valve types emphasize this feature by doming the Fixed Valve cover (see *Fig. 1*):

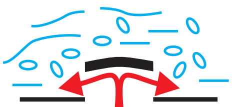

Fig. 1: Domed cover

This shape achieves an outlet vector of the gas flow of less than 90° to the vertical and helps to reduce entrainment.

Another feature is the orientation of the Fixed Valve elements. To fix the cover to the tray panel, there are normally two "legs". Both are oriented in flow direction: one is located on the upstream side of the element, one on the downstream side. At most of the Fixed Valves in the market, the width of the upstream leg is larger than the downstream one. There is a resulting pushing effect of the gas outlet to the liquid flow (see *Fig. 2*):

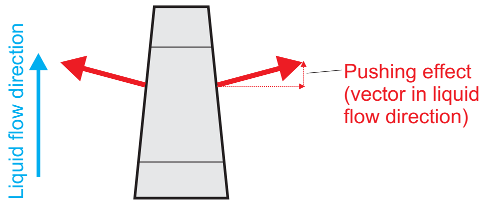

Fig. 2: Pushing effect

These two features increase gas and liquid capacity. Therefore the Fixed Valves are often used for revamps.

To support this pushing effect, there are sometimes additional, special *Push Valves* on the tray. The gas outlet direction of these Push Valves is only in flow direction of the liquid. The combination of Fixed Valves with Push Valves and special downcomers (truncated, sprouts, multichordal, sloped, ...) are often called *high performance trays*. Suppliers have special brand names for these designs (e.g. "SuperFrac", "PlusTray", ...).

The production of Fixed Valves is quite easy: A punching tool cuts and bends the element at a time. The cover is part of the panel material. The lift height can be controlled by the punching machine. Important: The length of the element depends on the lift height (see *Fig. 3*).

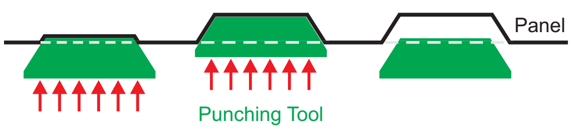

Fig. 3: Punching process of Fixed Valves

The lift of a Fixed Valve is limited by the punching tool as well as by the mechanical properties and material thickness of the panel material. The small scale valves (often called "Minivalves") with domed covers are normally limited to 2mm material thickness.

The pitch of the Fixed Valves is also limited by the punching tool. The minimum spacing is defined by the individual tool dimensions.

The tray spacing of Fixed Valve trays is normally about 450-500mm. It can be less, but due to inspection and maintenance reasons this is a typical value.

The costs of Fixed Valve trays are close to sieve trays (and significant less than float valve trays).

Most of the suppliers keep their knowhow of Fixed Valve private. Therefore there are only few publications, data and models available.

There are two Fixed Valve classes: The Round Shape (with brand names like VG0, VG10, ...) and the Trapezoid Shape (with brand names like LVG, MVG, MMVG, R-MV, ...).

Within each class there are different sizes and different lift heights. To get an overview, the following list shows the most common types.

The VG0 valve is one of the standard Fixed Valves in the market (see *Fig. 4*). Its cover is slightly domed and has a diameter of 29mm.

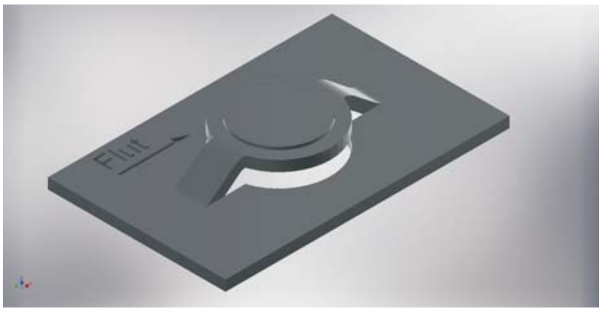

Fig. 4: Round Fixed Valve

For heavy duty applications (e.g. fouling service), there is a large variant (called e.g. VG10, see *Fig. 5*) with a cover diameter of 35mm. It is often built in 3mm material thickness, therefore the cover has no doming.

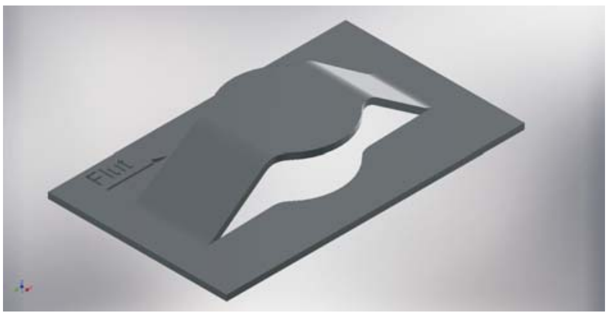

Fig. 5: Large, round Fixed Valve

At the trapezoid shaped Fixed Valves, the so-called MVG (length about 35mm, upstream width 18mm, downstream width 15mm) is the most common type (see *Fig. 6*).

Fig. 6: Trapezoid Fixed Valve

For heavy duty applications there is a trapezoid shaped Fixed Valve (SVG, see *Fig. 7*) with a length of about 44mm (upstream width 32mm, downstream width 25mm).

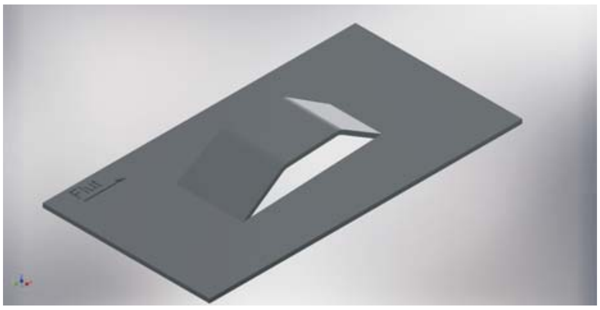

Fig. 7: Large, trapezoid Fixed Valve

In the first patent of Nutter the dimension of the Fixed Valve element was significantly larger than the newer ones (see *Fig. 8*). It is called LVG and has a length of about 116mm. As it hardly can be manufactured on standard NC-punching machines, it is quite expensive and rare.

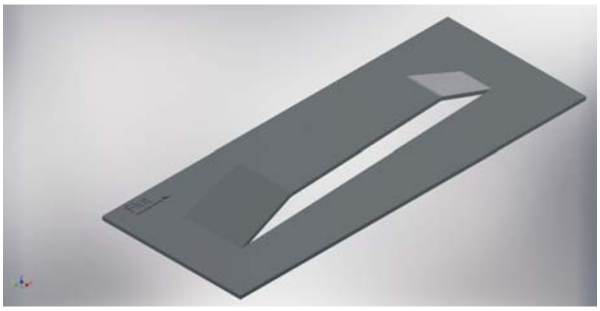

Fig. 8: Long version of trapezoid Fixed Valve

Contrary, there is a small version (brand name e.g. MMVG, see *Fig. 9*) with a length of about 34mm (upstream width 13mm, downstream width 10mm).

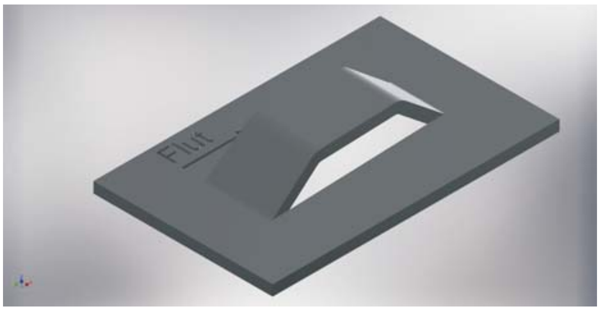

Fig. 9: Small size, trapezoid Fixed Valve

Another mini Fixed Valve is called R-MV and has a domed cover (see *Fig. 10*).

Fig. 10: Mini Fixed Valve R-MV

Another type for heavy duty is the so-called ProValve (see *Fig. 11*). Its cover is not formed from the panel material, but is mounted as an additional part. The opening in the panel has a diameter of 39mm.

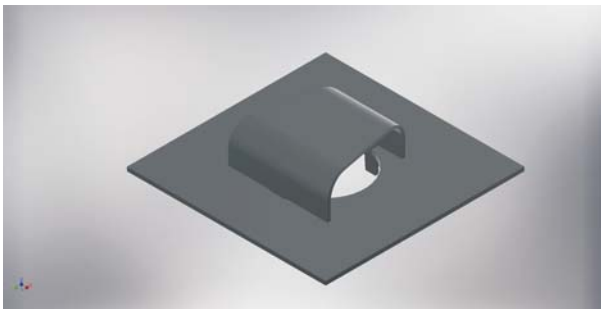

Fig. 11: Fixed Valve with extra cover

The *Operation Area* of a fixed valve tray is defined by different limits. In *Fig. 12*, a qualitative operation diagram is shown. Please note, that the position and shape of all curves depend on the physical data, the tray and downcomer geometry and the gas/liquid load. Each curve can be limiting!

The first step in analyzing a design is – of course – calculating all relevant parameters. For a Fixed Valve tray design there are 9 main parameters shown as curves in *Fig. 12*. 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, ...

The *Operation diagram* of Fixed Valves is similar to this for sieve trays. The limiting curves are almost of the same type. Only the Blowing-curve of sieve trays is normally not part of an operation diagram of Fixed Valves. The effect of Blowing at sieve trays describes the separation of the two-phase layer from the tray panel and its lift off. This effect has not this relevance for Fixed Valve trays – this is due to the different gas entry direction of a Fixed Valve tray.

The *Operation Point* (**Op** in *Fig. 12*) 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).

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 9 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.

System Flood FFSF 1

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).

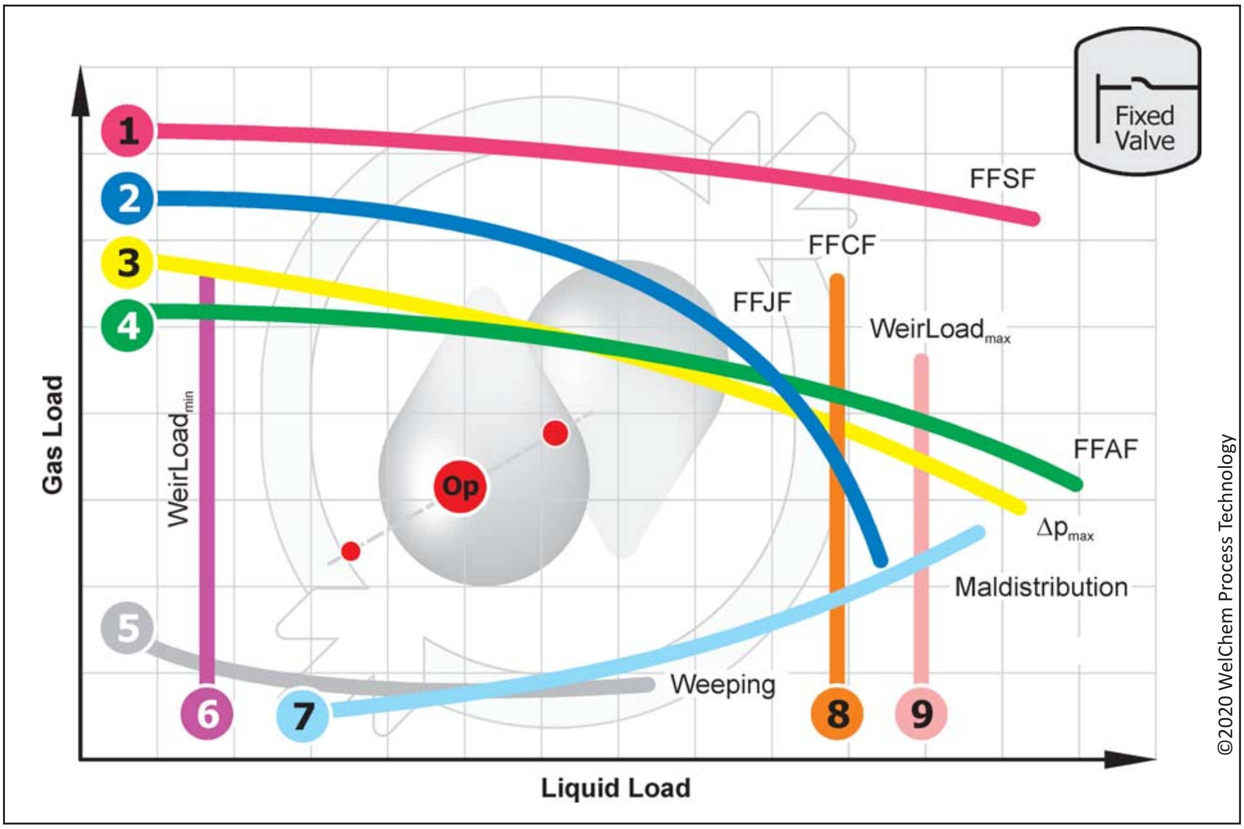

Fig. 12: Qualitative Operation Diagram for Fixed Valve trays

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 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 by sloping the downcomers

3 Pressure Drop

In most design 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

b) use small size Fixed Valves (at same or higher open area)

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

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 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 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 Weeping

Like on sieve trays, there is an operation limit by weeping. As the gas outlet area ("curtain area") for standard size Fixed Valves is significantly larger (expressed by the hydraulic diameter of the openings) than those of sieve holes, the weeping limit is similar or worse than that of sieve trays. To minimize weeping, you can

a) reduce the number of elements (to achieve a higher gas velocity)

b) use small-size ("mini") Fixed Valve types

6 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 $m^3/m/h$. 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 7

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.

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. 13*): 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!

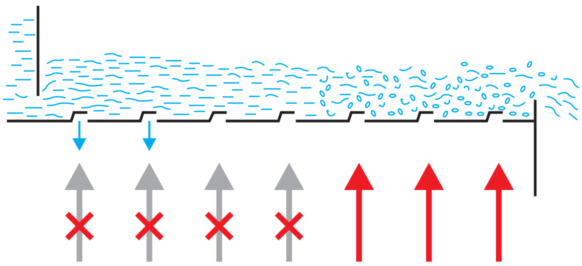

Fig. 13: Gas Maldistribution

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

Choke Flood FFCF 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

9 Maximum Weir Load

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 Fixed Valve trays. Fixed valves are comparatively new contact elements. As they can handle higher loads than sieve or float valve trays, they are often used for revamps but also for new towers. Together with special downcomer features and in combination with push valves, a classical Fixed Valve can be enhanced to a high performance tray.

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.

Contact: volker.engel@welchem.com

References

Lockett, M. J.: Distillation tray fundamentals, Cambridge University Press, New York, 1986

Nutter, D.E.: The MVG tray at FRI, Trans IChemE, Vol. 77, Part A, September 1999

Nutter, D. E.; Perry, D.: Sieve upgrade 2.0 - The MVG tray, AIChE Spring National Meeting Houston, Texas, March 1995

Stupin, W.J.; Kister, H.Z.: System Limit: The ultimate capacity of fractionators, Chem.Eng.Res.Des. 81, January (2003), p. 136-146

Summers, D. R.; van Sinderen, A.: Dry tray pressure drop of rectangular float valve and Vgrid trays, AIChE Spring National Meeting, April 2001

US-Patent 3,463,464 (Aug. 26, 1969): Irvin E. Nutter and Dale E. Nutter; Tulsa

WelChem Process Technology: TrayHeart Software. Tower Internals Calculation Software.
Internet: www.welchem.com; Info: service@welchem.com

Published in the IACPE-Magazine *Engineering Practice* October/2020 (http://www.iacpe.com)

