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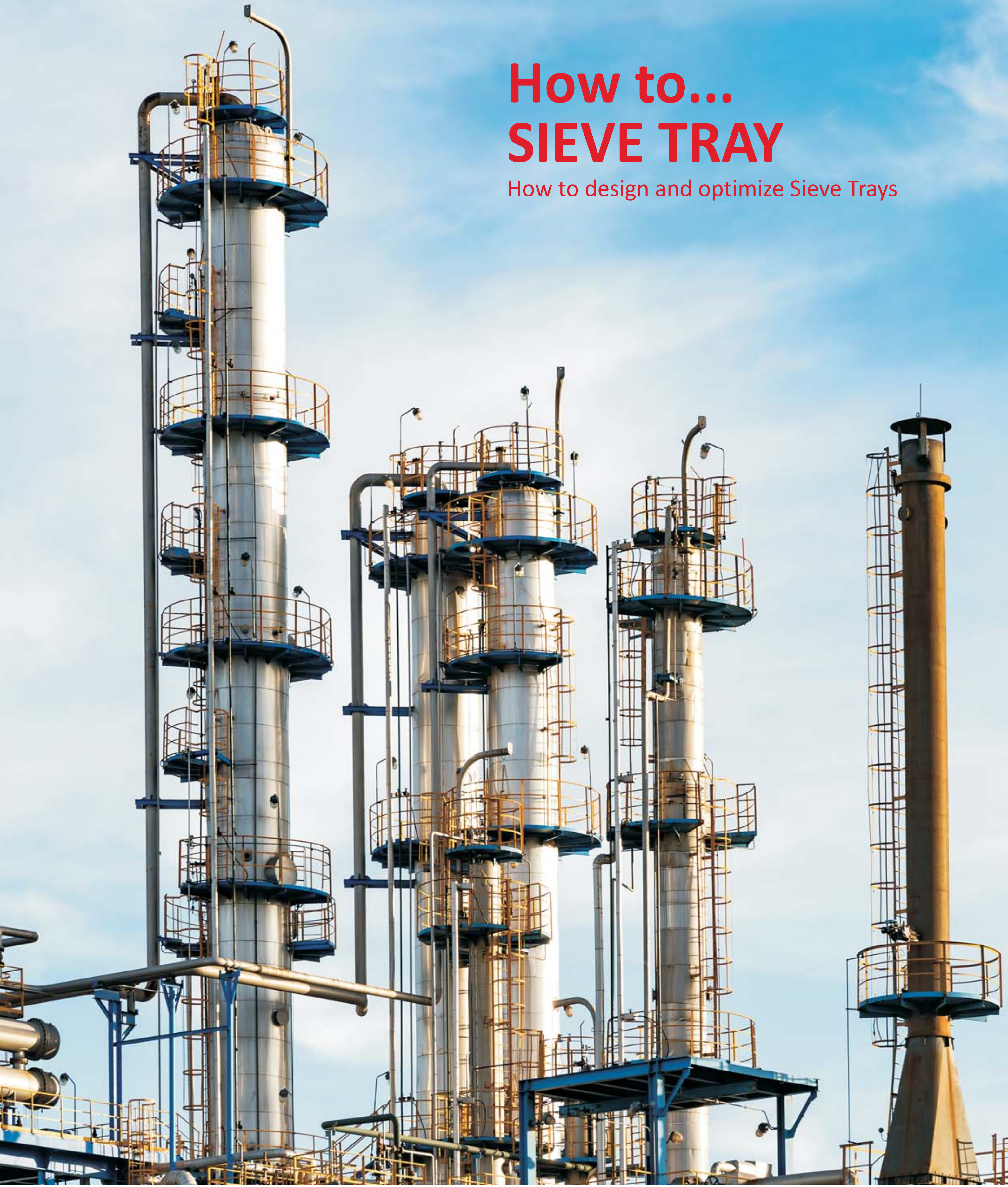

How to... SIEVE TRAY

Part 1

How to design and optimize Sieve 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 start of a series on different kinds of trays and internals.

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 gets into the liquid. For *Sieve Trays* (also called *Perforated Trays*) the vapor enters through horizontal round holes in the tray deck panels.

Sieve trays have been used for about a hundred years and are therefore one of the best studied tray type. They can be easily adapted to different design scenarios (flow rates) using different perforations, they do not require any special tool in production and thus are inexpensive to manu-facture. On the downside they are quite susceptible to bumps and non-level installation. As the gas flow passes vertically through sieve holes and froth layer, the sieve tray tends more to jet flooding compared to other tray types at the same load.

The perforation hole diameters of common sieve trays (for atmospheric applications and standard physical properties) usually reaches from 5 to 12.7mm, the relative free area (hole area per active area) is about 5 to 15% and the resulting total pressure drop per tray is advantageously low, about 5 to 8mbar. The tray spacing is usually not less than 400mm. Please note, that small holes are preferable due to hydraulic reasons, but higher in fabrication costs. Do not use hole diameters less than the material thickness, as they are difficult to punch.

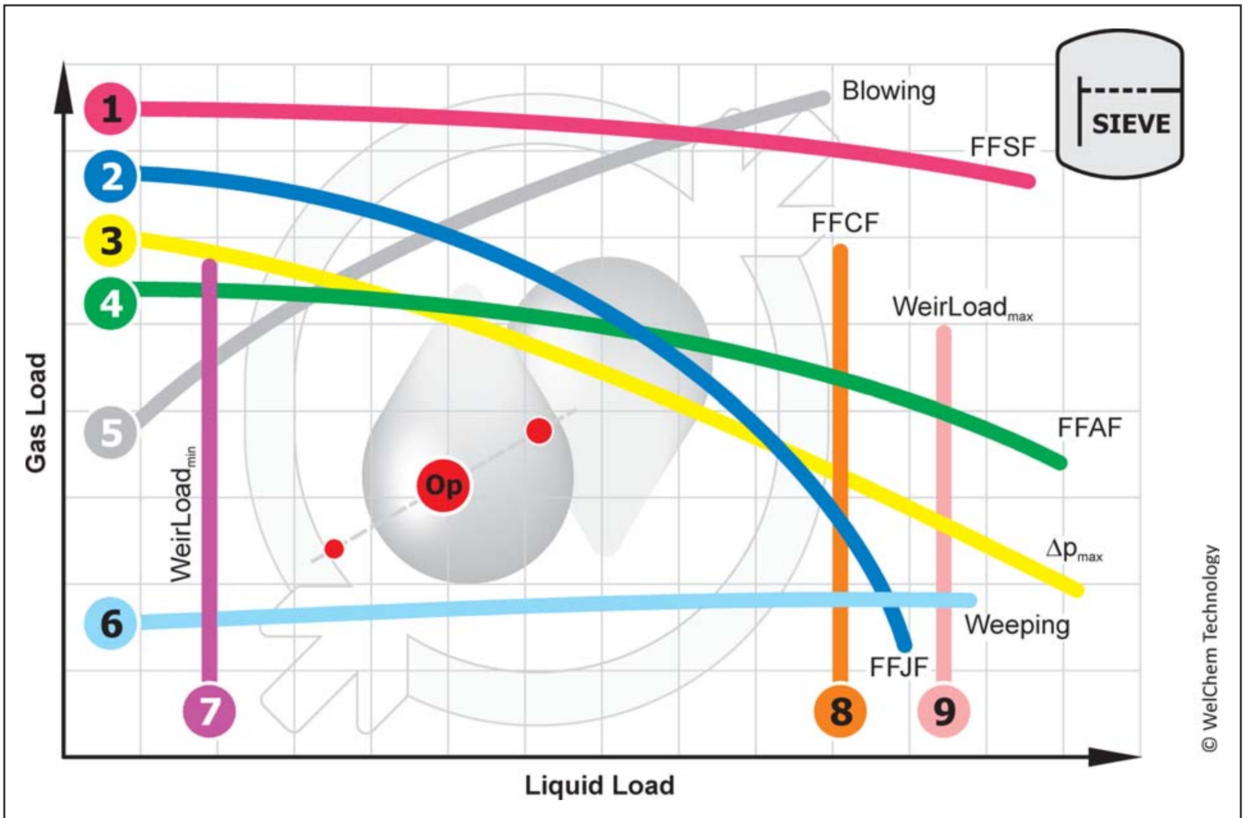

Fig. 1: Qualitative Operation Diagram for Sieve Trays

As always, there are exceptions to these rules of thumb. There are cryogenic applications with hole diameters less than 1mm, cartridge towers with tray spacings of 300mm and wash trays with a relative open area of about 3%.

The turndown of sieve trays is significant less than that of valve trays.

The *Operating Area* of a sieve tray is defined by different limits. In *Fig. 1* a qualitative operation diagram is shown. Please note, that the position and shape of all curves depend on the physical data, the tray geometry and the gas/liquid load. Each curve can be limiting!

The *Operation Point* (**Op** in *Fig. 1*) 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).

The first step for analyzing a design is – of course – calculating all relevant parameters. For a sieve tray design there are nine main parameters shown as curves in *Fig. 1*. 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, throw width over weir (anti-jump baffles), hydraulic gradients, 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! (ref. to TrayHeart of WelChem)

In the following sections, all nine parameter curves of *Fig. 1* 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 contra-dicting 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 holes, larger holes)

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

e) using push valves (there are special push valves which are used in sieve tray designs)

Pressure Drop 3

In most cases there is specified a maximum allowable pressure drop of a tower (e.g. vacuum applications). 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 hole area (the pressure drop is directly proportional to the square of the gas velocity!)

b) use smaller holes (based on the same absolute hole area, small holes have a lower pressure drop than larger ones)

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

d) enlarge the active area (for more holes) by reducing the downcomer area or sloping the downcomers

4 Aerated Downcomer Backup FFAF

This limiting curve 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:

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 Blowing

The effect of running a tray deck dry is called *Blowing*. It occurs at low froth height and/or high gas load. The Blowing effect has to be taken into account particularly at low liquid loads – at high gas load other effects are more limiting.

To visualize this effect one can imagine that the two-phase layer is separated from the panel and carried upwards.

To prevent Blowing, you can

a) enlarge the two-phase layer (by increasing outlet weir height or by using picket fence / blocked weirs)

b) reduce the flow path length

c) enlarge the hole diameter (at same absolute hole area)

Weeping 6

Weeping describes liquid raining through the sieve holes. The weeping rate tells you the ratio of liquid flow lost by weeping. Since the weeping liquid leads to an uneven distribution on the active area (danger of gas break-through, unsealing of downcomer, cross flow channeling), weeping rates should be less than 10% and should not occur on design load.

Liquid raining through the hole changes all other liquid loads on the tray (weir crest height, downcomer backup height, froth height, ...).

To reduce Weeping you have to

a) reduce the liquid head on the tray deck (by reducing outlet weir height or weir crest height)

b) reduce the hole diameter (small holes resist better)

c) enlarge the gas velocity in sieve holes (by reducing sieve hole area)

Minimum Weir Load 7

The uniform thickness of the two-phase layer is essential for the successful operation of a tray. This applies even more to a sieve tray than to other tray types. 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

8 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 9

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 sieve trays. Sieve trays can be adjusted very well to a certain design point (the pressure drop is often better than for “modern” solutions), just their operation area is not as flexible as for valve tray designs and the Jet Flood is not as good as that for valve trays.

Sieve trays are rarely suggested by suppliers, because they are no proprietary solutions.

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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