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WELCHEM PROCESS TECHNOLOGY

How to... DOWNCOMERS

All about Downcomers and Weirs

How to... DOWNCOMERS Part 5

All about Downcomers and Weirs

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

In almost all tray towers, the liquid flows horizontally from the inlet, gets in contact with the vertical streaming gas, generates a two-phase layer on the active area, leaves the tray at the outlet weir and degases in the downcomer while passing to the next tray below.

The main focus in tray towers is often only the active area (type of tray, pressure drop, froth height, efficiency, ...), where the mass transfer takes place. To understand all the complexity of trays, it is necessary to get an overview of the various shapes and layouts of downcomers.

DOWNCOMERS (DC)

The main function of the downcomer is to collect all liquid from the active area, degas the liquid, lead the liquid to the next tray and seal the downcomer against gas bypass (*Fig. 1*).

The size and shape of the downcomer is specified by the liquid flow rate, whereas the size of the active area is determined by the gas load.

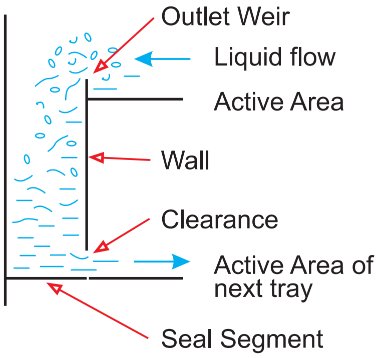

Fig. 1: Parts of a downcomer

NOTE: The downcomer belongs to the tray, where the liquid **leaves** the tray. Its numbering is therefore the same as the tray. Any downcomer above the top tray (e.g. for inlet) is called "False Downcomer" (ref. *Fig. 33*).

One of the main tasks at designing a proper tray is to choose suitable values for these two areas. This sets the tower diameter!

Flow Passes

One of the very first steps in the design of a tray is to deal with the liquid load: It shows, how many downcomers per tray are required and how the downcomer(s) have to be designed. To handle the liquid load, you have to supply the appropriate downcomer area as well as enough weir length.

To achieve this goal, there are different layouts with one or more downcomers and special downcomer shapes. (Some other designs like Dualflow trays, baffle trays, shower decks, ... have no downcomers.)

In the easiest case, there is only one downcomer (*Fig. 2*). The liquid is streaming from one side of the tower to the other. There is one active area and one flow path. This (common) design is called *1-pass* or *Single-pass tray*. The tray design is turned by 180° at each stage. It is used for tower diameters up to 3m. (For some special applications you will even find 1-pass trays up to 8m.)

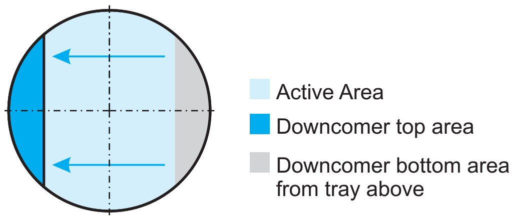

Fig. 2: 1-pass tray layout

For higher liquid loads and larger diameters, two liquid paths are needed (*Fig. 3*). This leads to two different tray designs, which are used alternately for the stages (therefore the odd tray numbers belong to one design, the even ones to the other). The so-called *inboard design* has a center downcomer, the other (*outboard design*) has two side downcomers. The liquid is streaming from the center downcomer to the side downcomers and on the next stage from the sides to the center downcomer. The active area is symmetrical on each tray. 2-pass designs are often used in practice.

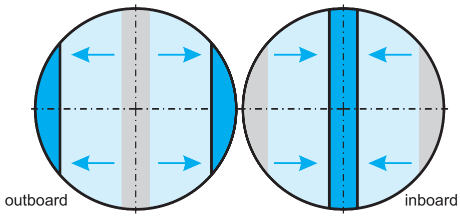

Fig. 3: 2-pass tray layout

The next logical step is the *3-pass tray* design (*Fig. 4*). There is a side downcomer and an off-center downcomer. The design is rotated by 180° per stage. There is only one design for all trays (as for the 1-pass design). This is an advantage in terms of the investment costs compared to the 2- and 4-pass tray design. On the other hand there are three different shaped active areas per stage and a very different geometry of the downcomers. Therefore it is not easy to design this 3-pass tray for a wide operation range and you will not find this type very often in practice (but you will!).

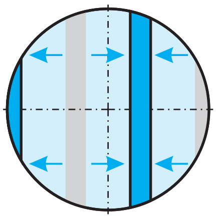

Fig. 4: 3-pass tray layout

The 4-pass tray has two tray layouts (*Fig. 5*): One stage is equipped with two side downcomers and one center downcomer (*outboard*), the other with two off-center downcomers (*inboard*). As each layout is symmetrical to the tower center line, there are only two different active area shapes. Therefore it is easier to calculate than the 3-pass-design – but as the

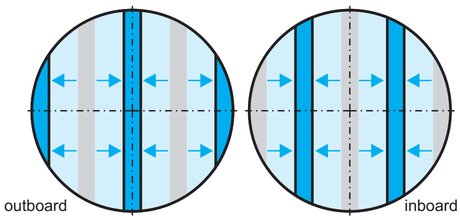

Fig. 5: 4-pass tray layout

liquid splits up in two different active areas (with different froth heights, pressure drop, ...), the calculation of 4-pass trays needs a complex iteration for the individual load of each active area for each design case (min / design / max).

The next logical number of downcomers would be the *5-pass tray*. You will find it in literature, but rarely in practice.

For large tower diameters the *6-pass tray* is used (*Fig. 6*). Since it is symmetrical to the tower center line, there are "only" three different active areas per tray and four different downcomer shapes per tray. Therefore the calculation is similar to that of the 3-pass tray. The outboard layout has two side downcomers and two off-center downcomers, the inboard layout has one center downcomer and two off-center downcomers.

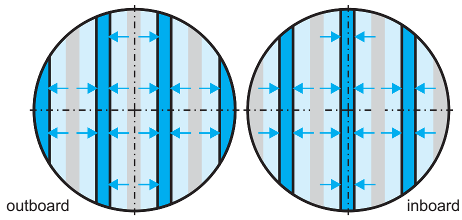

Fig. 6: 6-pass tray layout

The choice of a certain design (number of passes) and setting the width of the downcomer results in a certain length of the flow paths. This flow path length is relevant in terms of hydraulics (contact time of the gas-liquid mixture) as well as in terms of practice (the flow path length is the maximum width of one dimension of the manway). Therefore you have to check these hydraulic and security aspects, too.

Multi-Downcomers

The designs described above are called *conventional multi-pass* trays and they are "bound" to the circle geometry of towers. Instead of using the tower shell as part of the downcomer wall, you can place downcomer boxes in the active area. These designs are called *Multi-Downcomer* designs ("MD trays").

There are different principles:

You can place the downcomer boxes over the entire diameter of the tower and rotate the design by 90° per stage (*Fig. 7*). The crossing points of the boxes are blocked to have no liquid shortcuts.

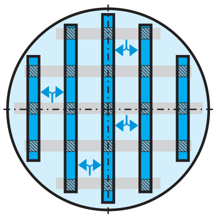

Fig. 7: MD layout (uop design)

Another option is to place the downcomer boxes only on one half of the cross section area and rotate the designs by 180° per stage (*Fig. 8*). These designs are also known as *Calming Section* trays.

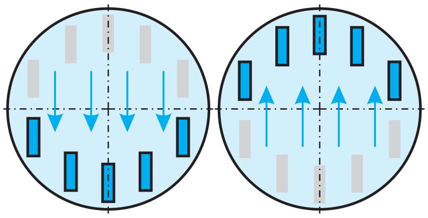

Fig. 8: MD layout ("Calming Section")

Another type is shown in *Fig. 9*. It is also known as HiFi-tray (Shell).

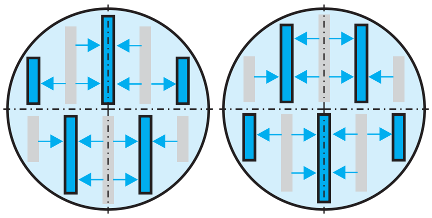

Fig. 9: MD layout ("HiFi-tray")

These MD trays are normally used for large liquid load when volumetric ratio between vapor and liquid rate is low (medium to high-pressure systems).

Reverse-Flow

Another design for the flow path is the so-called *Reverse-Flow* tray (*Fig. 10*). It is used to achieve long flow paths and long contact times between gas and liquid.

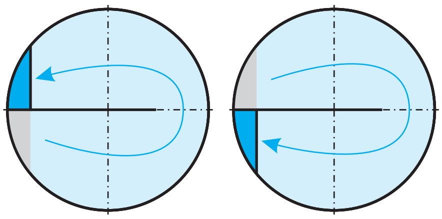

Fig. 10: Reverse-Flow layout

Downcomer Shapes

The side downcomer in a classic design is normally chordal (*Fig. 11*). This design is comparably easy in construction and fabrication for tower attachments and tray parts.

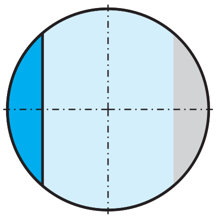

Fig. 11: Chordal downcomer

For high liquid loads you can have *multi-chordal* designs (*Fig. 12*). Especially at the side downcomers you are struggling with the geometry of round towers: changing the width of the side downcomer has great effect on the area, but small on the weir length. With a multi-chordal design you can achieve a long(er) weir length without increasing the corresponding chordal downcomer area.

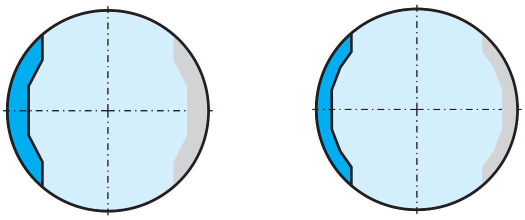

Fig. 12: Multi-chordal downcomers

At the design of multi-chordal downcomers, you have some degrees of freedom. Normally you will find 5 segments as multi-chordal, sometimes 7 segments. The construction and fabrication of a multi-chordal tray is more expensive than a chordal design.

Sloped Downcomer

The gas-liquid mixture entering the downcomer has the average density of the phases. During the degassing process, the density increases and ideally becomes the liquid density at the bottom of the downcomer. You can take benefit from this change in density (i.e. change in volume) by reducing the cross sectional area of the downcomer over its height. This adjustment is called *sloped* or *stepped* downcomer (*Fig. 13*).

It can be applied on all types of downcomers (side, center, off-center, multi-downcomers, ...). The benefit of this design is the gain of active area on the next tray.

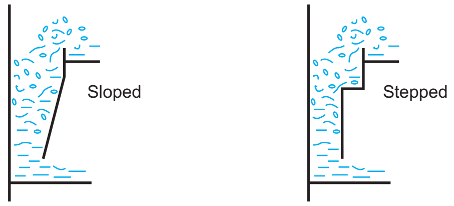

Fig. 13: Sloped and stepped downcomers

Truncated Downcomer

Another possibility to maximize the active area is to use *truncated* downcomers (*Fig. 14*). In this design the floor of the next tray is not the bottom of the downcomer – the downcomer ends above the active area. For Multi-Downcomers this design is standard. The area below the downcomer can be used (partly) as active area.

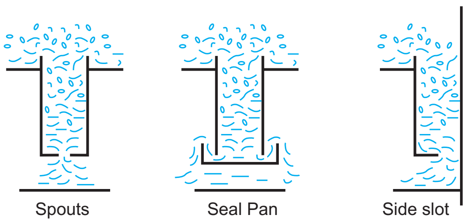

Fig. 14: Truncated downcomers

Truncated downcomers bring us to some fundamental hydraulic considerations.

Downcomer Flooding

There are two flooding effects related to downcomers. One deals with the maximum throughput, the other with the liquid level in the downcomer.

The first one is called *Choke Flood* and is related to the cross-sectional area of the downcomer and the physical properties of the liquid and the gas. If there is not enough area for the degassing (upflowing gas and downflowing liquid) the downcomer "chokes". In result, no liquid will pass trough the downcomer and the tower starts flooding.

The standard model for calculating the max. volume flow rate through a downcomer was published by Glitsch in 1993 (here in SI-units):

$$\dot{V}_{DC,Lmax,1} = 0.1698 \cdot SF \cdot A_{DC,top}$$

$$\dot{V}_{DC,Lmax,2} = 0.006955 \cdot \sqrt{\rho_L - \rho_G} \cdot SF \cdot A_{DC,top}$$

$$\dot{V}_{DC,Lmax,3} = 0.0079824 \cdot \sqrt{TS} \cdot \sqrt{\rho_L - \rho_G} \cdot SF \cdot A_{DC,top}$$

$$\dot{V}_{DC,Lmax} = \min(V_{DC,Lmax,1}, V_{DC,Lmax,2}, V_{DC,Lmax,3})$$

The equations are based on gas density ρ_G, liquid density ρ_L, tray spacing *TS* and system factor *SF*. This last parameter describes the difficulty of degassing. You can find lists of values for different applications in literature (*ref. to References at the end of article*).

The second flooding effect is the so-called *Aerated Downcomer Flood* (also called *Downcomer Backup Flood*): In this case the liquid level in the downcomer exceeds the total downcomer height. The level in the downcomer is the result of "border effects" (*Fig. 15*):

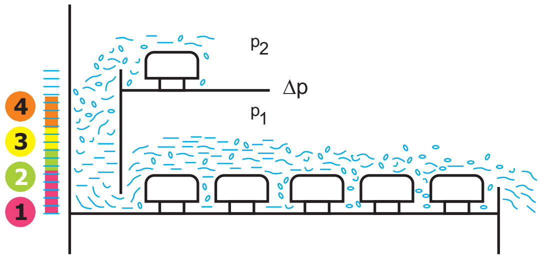

Fig. 15: Liquid level in downcomer

1 The two-phase layer on the next tray seals the downcomer. It is calculated by the physical height of the weir plus the weir crest height.

2 The hydraulic gradient of a tray produces an additional liquid head in the downcomer. (Depends on contact elements and flow path length.)

3 The liquid is accelerated by leaving through the clearance. This rise in kinetic energy is taken from potential energy and results in an additional liquid head.

4 The pressure p_1 of the gas is higher than the pressure p_2 at the tray above. This difference in pressure results in liquid head in the downcomer.

All these values are calculated as "clear liquid". In praxis the liquid in the downcomer contains gas (calculated as so-called *Aeration Factor*) and leads to a higher level in the downcomer than the clear liquid height. If this level exceeds the downcomer height plus weir height, the downcomer will not be able to handle the load and floods.

NOTE: The effect of Aerated Downcomer Flood is *not* correlated with the downcomer area. Therefore the change of downcomer area will not affect this value!

There are some calculation models for the *Aeration Factor* in literature (*ref. to References at the end of article*).

A short glance back: We started the discussion with truncated downcomers. Since the height of the downcomer is relevant for the *Aerated Downcomer Flood* (and a truncated downcomer is less in height), truncated downcomers are only applicable, if there is no problem with *Aerated Downcomer Flood*.

OUTLET WEIRS

The liquid-gas mixture enters the downcomer at the outlet weir. The standard weir is a plain bar of about 50 mm height. In liquid limited systems or on trays running in the froth regime, the weir height might be more. The specific weir load should be more than 4.5 $m^3/m/h$ (or 5 mm weir crest height). Why?

If the weir crest height is very low, any leveling issues of the tower (due to tower attachments, tower installation or even wind) can cause problems: If a part of the weir is not in use, this part of the active area is stagnant – no mass transfer will happen (*Fig. 16*).

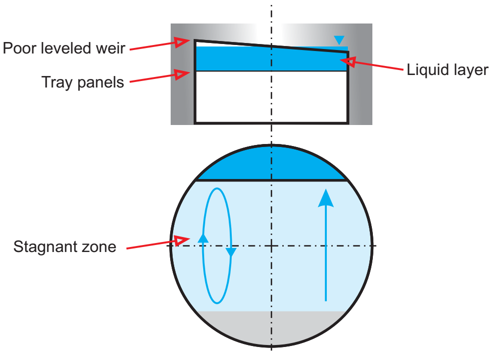

Fig. 16: Malfunction of weir

To achieve a uniform overflow at the entire length of the downcomer, you can use *Notched Weirs* (*Fig. 17*). At low loads the liquid uses the bottom parts of the notches. At higher loads the entire weir is used by the liquid.

The bottom angle of the notches is normally 90° or 60°. The height of the notches is about 30 mm. The weir height *HW* is the bottom part of the weir (without the notches).

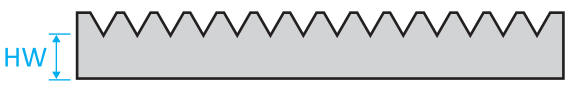

Fig. 17: Notched Weir

For safety reasons (e.g. during installation or inspection) it is strongly recommended to have plain tops at the notches.

Another possibility to adapt long weirs for small liquid loads is to *block* the weir (*Fig. 18*). The weir length is reduced to the openings. An additional effect of a blocked weir: it keeps the two-phase layer on the active area.

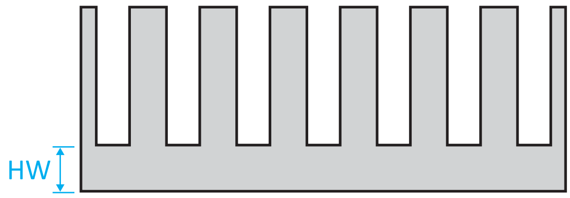

Fig. 18: Blocked Weir

The number and width of the blocks depend on the weir crest height you have to achieve. The method of blocking is not only relevant for small liquid loads, but also for balancing the different weir lengths of 2-and-more-pass layouts. The block should be at least as high as the two-phase layer of the active area.

Blocked weirs prevent workers/inspectors from climbing over the center/off-center down-comers to the other pass! If there is no manhole in each pass, there should be manways in the blocked weir.

Sometimes you will find weirs with adjustable height. These are built in when it is known that the load will change in the future.

Anti-Jump Baffles

At center, off-center and multi-downcomers, the liquid enters the downcomer from both sides. At high liquid loads and small downcomer widths, you have to install so-called *Anti-Jump Baffles (Fig. 19)*. These baffles ensure, that only half of the area is used by each side.

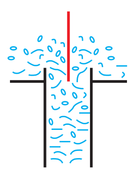

Fig. 19: Anti-Jump Baffle

Just like for the weir blocks, Anti-Jump Baffles have to be as high as the two-phase layer on the active area. Therefore they block the passage during inspections. It is good practice to have bolted manways in the baffles.

Swept-Back Weir

To achieve a long weir, you can use a so-called *Swept-back Weir* (*Fig. 20*). The downcomer stays chordal, but the weir is – similar to the shape of multi-chordal downcomers – longer than the chordal length.

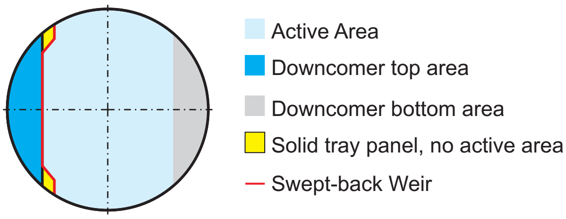

Fig. 20: Swept-back Weir

Weirs for Startup

For high capacity trays you will find so-called *Weir Spouts* (*Fig. 21*): At tray floor level, there are rectangular openings.

These holes help to fill the downcomer initially at startup of the tower. During operation they help to reduce the weir crest height. They are only used, if the tower is always running at high liquid loads and there is no minimum load issue.

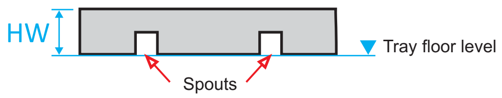

Fig. 21: Weir Spouts

CLEARANCE

The last aspect of downcomers is the design of the liquid outlet (= inlet to the next tray).

The liquid is leaving the downcomer through the so-called *Clearance*. The outlet velocity of the liquid should be less than 0.45 m/s. If it is higher, the liquid will splash and overrun the first rows of contact elements (see later).

The height of the clearance *HCL* is normally less than the outlet weir height *HW* to have a *Static Seal*

$$Seal_{static} = HW - HCL.$$

For liquid-tight trays (e.g. bubble cap or tunnel trays) this seal is present, whenever liquid is on the tray. For all other tray types (e.g. sieve, float valves, fixed valves) the seal is only working, if there is enough gas for no weeping.

If there is no *Static Seal* (due to design, poor hydraulics or at startup of the tower) there is the risk of gas bypassing the active area through the downcomer.

During operation the weir crest generates additional liquid height (*How*) (*Fig. 22*) and generates a *Dynamic Seal*

$$Seal_{dynamic} = How + HW - HCL.$$

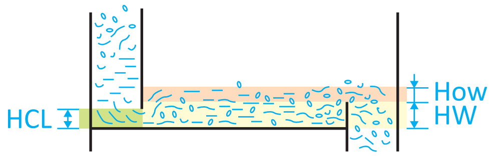

Fig. 22: Static and Dynamic Seal

So-called *high capacity designs* are often running with no static but only dynamic sealing.

Radius Lip

The acceleration of the liquid in the clearance results in liquid head (ref. to *Fig. 15*, *Aerated Downcomer Flood* **3**). To reduce this effect, you can add a *Radius Lip* (*Fig. 23*). This shape lowers the outlet orifice coefficient.

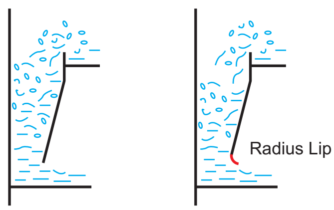

Fig. 23: Radius Lip

Inlet Weir

To ensure sealing of downcomers you can place an *Inlet Weir* in front of the clearance (*Fig. 24*). Even at a very small liquid load, there will be no gas bypass through the downcomer. The inlet weir can only function if it is higher than the clearance. It can also be notched (for low liquid loads).
The inlet weir is helpful for the startup of the tower and at low liquid load – but the downcomer tends to blocking in fouling systems.

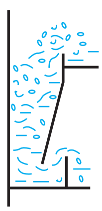

Fig. 24: Inlet Weir

As discussed at the Aerated Downcomer Flood, one part of the liquid level in the downcomer depends on the liquid level on the next tray. For part 1 (*Fig. 15*) you have to take into account the inlet weir height plus the inlet weir crest height. Therefore an inlet weir "costs" downcomer height in respect to downcomer flooding (especially at low tray spacings).

Recessed Seal Pan

The effect of sealing can also be achieved by the so-called *Recessed Seal Pan* (also called *Inlet Pot*, *Fig. 25*). The main advantage over the inlet weir is, that it "costs" no downcomer height. But of course it is more complex in construction and fabrication. It is normally combined with a sloped downcomer.

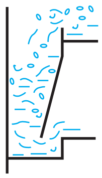

Fig. 25: Recessed Seal Pan

Interrupter Bar

At float valve trays you may sometimes find elements, that are looking similar to inlet weirs. They are not for sealing the downcomer but to keep the first valve row functional (*Fig. 26*). The bar is about 13mm high and is called *Interrupter Bar*.

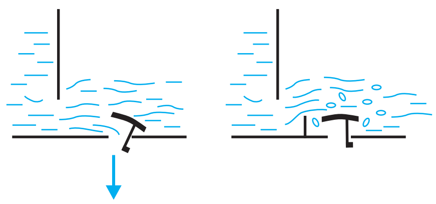

Fig. 26: Interrupter Bar

Bubbling Initiators

At high liquid outlet velocity, the liquid overruns the first rows (of fixed valves, sieve holes, ...). To break the impulse at high capacity trays there are *Bubbling Initiators* (also called *Bubbling Promoters*, *Fig. 27*). They are placed instead of the first row of "normal" contact elements. The gas outlet openings of the Bubbling Initiators are not oriented towards the downcomer (to prevent gas entry through the clearance).

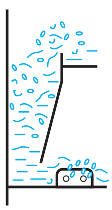

Fig. 27: Bubbling Initiator

Inlet Pusher

A special design ("NYE-tray") for the inlet is to push gas near the clearance through holes to the active area (*Fig. 28*). It also helps to initiate the two-phase layer. It is not easy to design this layout for a large operating region.

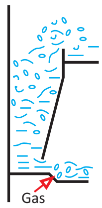

Fig. 28: Inlet Pusher ("NYE-tray")

SEAL PAN

The last downcomer of a tower/section is sealed by a special *Seal Pan* (*Fig. 29*) or submerged in the bottom liquid (*Fig. 30*).

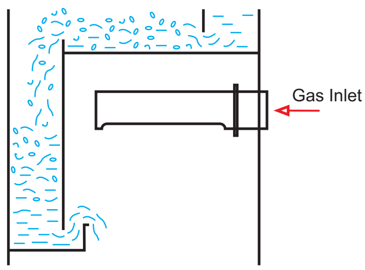

Fig. 29: Last downcomer with Seal Pan

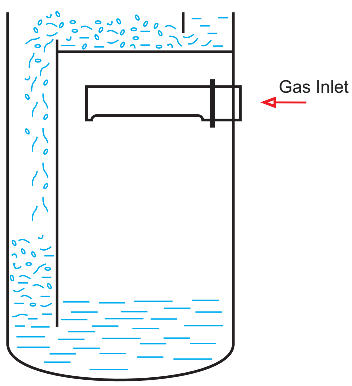

Fig. 30: Submerged downcomer

In any case, the gas inlet should not affect the outlet of the liquid. It is good practice to make the last downcomer long enough to bypass the gas inlet.

Draw-Off (Draw)

You will find seal pans not only at the very last downcomer of a tower. Whenever there is a change in flow path number and/or tray orientation ("transitions"), the liquid is transferred to the next tray (or to a liquid distributor) by pipes. *Fig. 31* shows some examples for Draw-Offs from a seal pan.

In all cases you have to ensure that the seal is not affected by the Draw-Off.

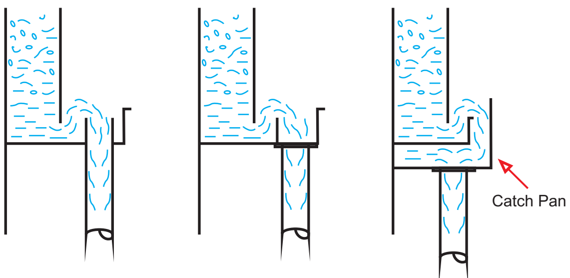

Fig. 31: Draw-Offs at Seal Pan

One of the advantages of tray towers is the possibility to draw off liquid at each stage. These intermediate Draw-Offs are normally done with the help of *Recessed Seal Pans* (*Fig. 32*).

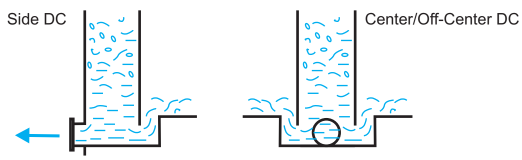

Fig. 32: Draw-Offs at Recessed Seal Pans

Feed to downcomer

As mentioned before, you will install so-called *False Downcomers (FDC)* to feed liquid on the top tray of a section (*Fig. 33*). They are designed accordingly to the downcomers of the following trays.

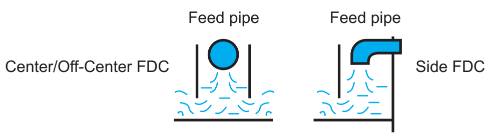

Fig. 33: False Downcomer

To feed liquid to a tray within a section, it is good practice to feed near the downcomer clearance (feed pipe with holes directed to the area above the clearance, *Fig. 34*). If there is the danger of two-phase or super-heated liquid, you will shield the downcomer wall by a so-called *Impingement Baffle*.

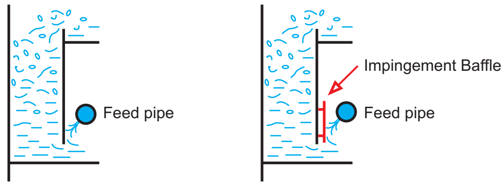

Fig. 34: Feed to tray

MECHANICAL ASPECTS

The active area is carried by the support ring, the downcomer (at the outlet weir side) and the downcomer seal segment (at the inlet). Therefore these downcomer elements have to be designed to withstand the dead load plus the liquid load.

For large tower diameters, the upper part of the downcomers (so-called *Downcomer Truss*) will be fabricated in a higher material thickness (*Fig. 35*).

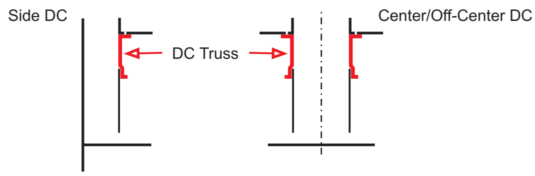

Fig. 35: Downcomer Truss

Whenever the downcomer elements would not fit through the manhole, the elements have to be divided, too. (A benefit of a downcomer wall consisting of two parts is the opportunity to adjust the clearance height during installation.)

In downcomers there are used so-called *Downcomer Brackets* (*Fig. 36*). They support the downcomer seal segment and prevent the walls from vibration. In center/off-center downcomers the brackets additionally connect the walls and keep them in place – in best case even at a pressure surge. (A well-known failure pattern is when the downcomer walls are pushed inwards after a pressure surge and the panels of the active area therefore slip and fall.)

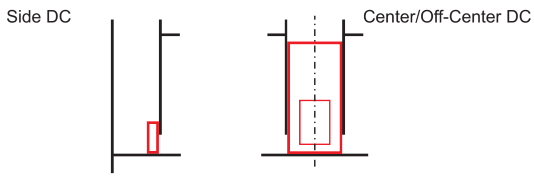

Fig. 36: Downcomer Brackets

CALCULATED PARAMETERS

The following parameters have to be calculated and checked for all downcomers at each load. This can hardly be done by hand, but with suitable software. Any software that does not show all of these parameters carries the risk of overlooking relevant values. Since the supplier's free software does not do this, commercial software (ref. *TrayHeart*) should be used.

Parameters of the downcomer:

- Residence Time
- Clear liquid level in downcomer
- Aeration Factor of downcomer
- Aerated liquid level in downcomer
- Liquid head caused by clearance
- Liquid outlet velocity
- Max. liquid volume flow through downcomer

For the outlet weir the following parameters have to be calculated:

- Specific liquid load of weir
- Weir crest height
- Throw width over weir
- Liquid ratio through spouts

If there is an inlet weir:

- Specific liquid load of weir
- Weir crest height

Conclusion

There are many layouts and designs for downcomers and weirs. The effort for the engineer is to combine the best options to achieve an optimum for the very different aspects as startup, statics, hydraulics and interaction with the active area. The hydraulic design of downcomers has to be as accurate as the design of the active area.

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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