

How to Calculate Column Hydraulics Considering Operational Effects

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Abstract. The hydraulic design of columns is normally based on ideal conditions. In operational reality, however, fouling, corrosion and abrasion affect the hardware of the internals and trays and thus also the hydraulics. In specific terms, this can have an impact on the size of hydraulic openings, mobility and lift height of float valves, free cross-sectional area of packings and support grids, clearance height of downcomer outlets, number of openings of liquid distributors and the resulting distribution quality. This can lead to significant deviations between calculation and reality! If these effects are properly considered in the calculation, useful conclusions can be drawn.

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1. Introduction

Columns have been used industrially as decisive devices for phase contact for more than 100 years. During this time, new equipment has constantly been developed, so that its performance (capacity, efficiency) steadily increased. Nevertheless, you will find internals of the latest design next to columns with internals from the 1950s.

The hydraulic design of columns is normally based on ideal conditions. In operational reality, however, fouling, corrosion and abrasion affect the hardware of the internals and trays and thus also the hydraulics. In specific terms, this can have an impact on the size of hydraulic openings (e.g., sieve holes and fixed valves), mobility and lift height of float valves, free cross-sectional area of packings and support grids, clearance height of downcomer outlets, openings of liquid distributors and the resulting distribution quality. This can lead to significant deviations between calculation and reality! Usually, reality makes itself apparent in the form of operational problems. Then it is a matter of interpreting them correctly and detecting the causes through variation in the calculation parameters. For this purpose, there are some publications and books dealing with all kinds of troubleshooting and operational problems [1,2].

2. Design and Rating of mass transfer equipment

A column is normally built to handle a certain separation task. This task is described in a specification data sheet and the process engineer has to find a suitable design for the column equipment. The specification is based on the classical flow data (mass flow, density, viscosity and surface tension) and additionally on the so-called system factor, which describes the degassing difficulty of the liquid as an empirical factor. With this information, in combination with relevant models and suitable software, the engineer can calculate the load limits and all relevant parameters. In a professional design, up to 40 parameters are calculated for all load conditions, taking into account the interaction of the stages [5]. The values of these parameters are checked for plausibility and functionality.

In *Fig. 1*, the operation diagram of a float valve tray with the most important load limits is shown qualitatively [4]. The limiting lines define a so-called operational window (yellow area). Within this window the trays can be operated. For operational stability the load should have a safety margin from the limits.

These limits can be seen and experienced on a test rig. However, a built column is a black box and almost none of the limits given in the diagram can be measured or recorded during operation as a numerical value. The only chance is to have capacity test runs and determine the 100% limit. It is tricky to set up the suitable test scenario to determine a certain flooding mechanism at maximum load. Sometimes it will not be easy to identify the flooding mechanism, because of the interaction of all parameters. It is good practice to perform capacity test runs in combination with assisting gamma scanning.

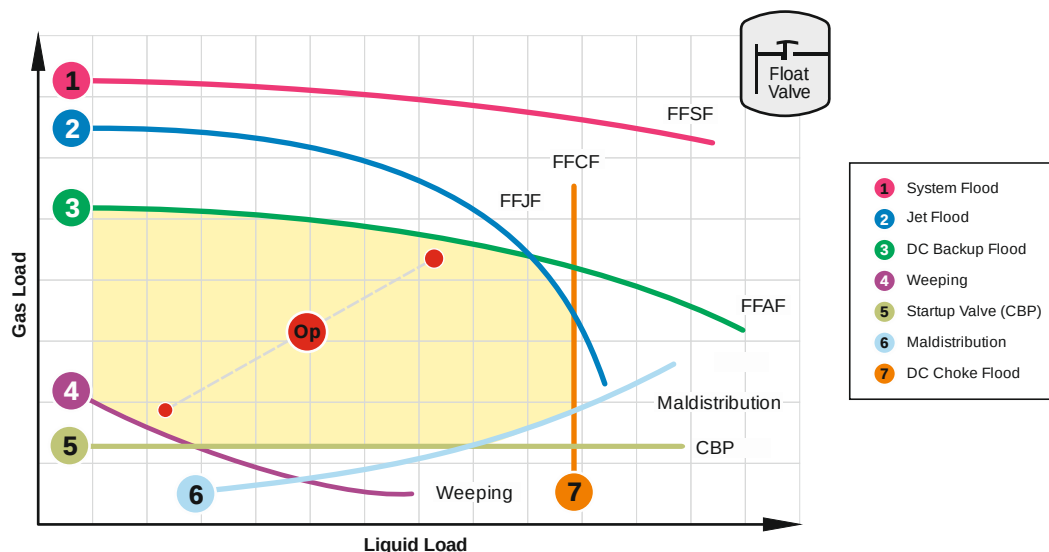


Fig. 1 Main operational limits of a float valve tray

In reality, columns usually have only very few measuring equipment inside the tower: besides the temperature sensors usually only a pressure / pressure drop measurement. This means that there are few indicators to alert to problems and deviations at an early stage.

Such problems and deviations occur in a state where the conditions in the column change and deviate from the design conditions. These can be changes in the load (internal flow data) or in the physical properties of the flow data. But it can also be that the hardware deviates from the design. This can happen due to fouling, corrosion and abrasion.

3. Operational Effects

Operational practice for mass transfer equipment often means countering effects such as corrosion, abrasion and fouling. These effects change the original design variables and the hydraulic behavior of the equipment. In the following chapters, the operational effects are described, and the calculation possibilities are discussed on the basis of adapted design calculations.

3.1 Fouling

In the case of fouling, a distinction can be made between three different mechanisms: crystallization fouling, particle fouling and polymerization fouling. In all cases, fouling is a progressive effect, the speed of which is often unknown. If fouling cannot be prevented, the central issue is the remaining column operation time until the necessary shutdown for cleaning.

Crystallization fouling occurs by super saturation. This happens at the contact of gas and liquid, i.e. at the circumference of sieve holes. Fig. 2 shows the fouling ring within the sieve holes observed in a distillation column during an inspection. In the following, such a sieve tray column will be used as an example to show the calculation procedure for crystallization fouling. This column fights against this fouling type in a certain section. Hence, a deliberately robust design was chosen (e.g., hole diameter 25mm) to achieve long service intervals.



Fig. 2 Crystallization fouling in a sieve tray tower

In the ideal design for these trays without fouling, a total pressure drop of 5.8 mbar per tray is calculated. In reality, the crystallization fouling reduces the diameter of the holes. Since the growth of the fouling ring is linear in diameter, this has a quadratic effect on the decreasing area and thus on the gas velocity. At the same time, the *dry pressure drop* increases with the square of the gas velocity! In addition to this value, the *total pressure drop* of the tray also depends on parameters such as froth height, stream property data and flow regime. For this example, *Fig. 3* shows the pressure drop characteristics versus a decreasing hole diameter. The curve starts at the ideal pressure drop of the clean holes and ends at the shutdown point. At this point, the pressure drop is so high that downcomer backup flood occurs. Instead of the hole diameter on the abscissa, one can also plot the normalized operation time for fouling applications in *Fig. 3*. Since the axis is linearly scaled, the remaining running time of the section can be extracted from the diagram for a measured pressure drop.

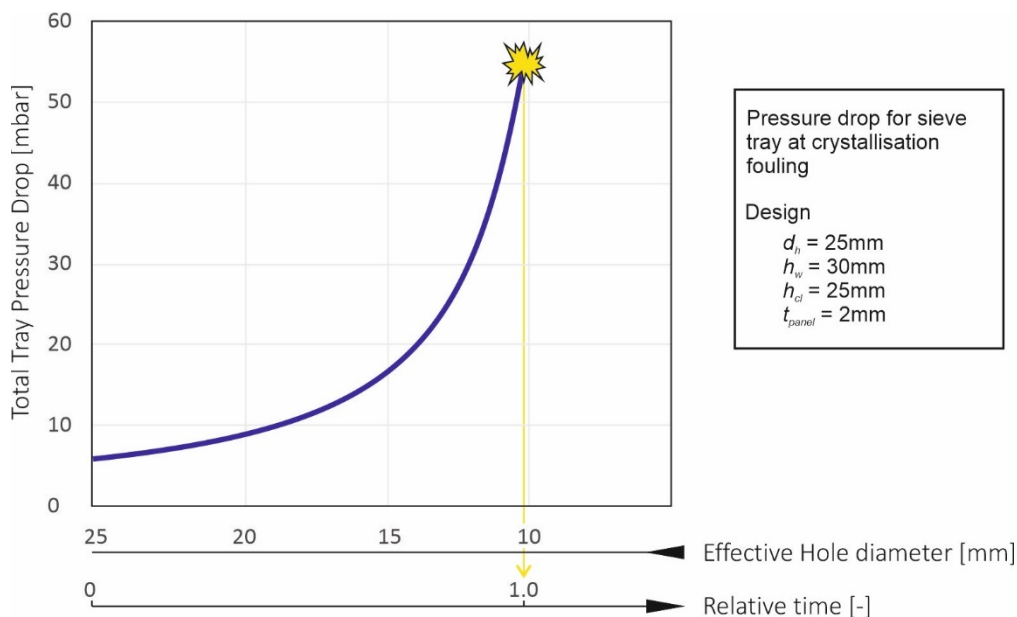


Fig. 3 Example for pressure drop development caused by crystallization fouling

Fouling can have an effect not only on sieve trays. Other types of trays it affects in a similar way: the free area for the passage of the gas decreases. This can happen through blocked float valves, bubble caps, tunnels, and even for fixed valves.

For all tray types you can calculate an individual fouling curve as shown in *Fig. 3* for the sieve tray, by determining the remaining free open area for each type. As shown in the example above, this is an easy task for sieve trays. For fixed valves, float valves, bubble cap and tunnel trays however, this is comparatively difficult, since the geometry of the curtain area is more complex.

In random and structured packing columns, the free cross-section area is reduced by fouling. In most cases the fouling forms layers on the hardware and thereby reduces the void fraction of the bed. *Fig. 4* shows pictures of crystallization fouling of a Pall ring [6].

As for the sieve tray, one can calculate fouling curves for packings, too. With the help of these curves the operators can estimate the time until next cleaning stop from the pressure drop measurement. The calculation is not as easy as for the sieve holes, where one can vary the hole diameter. For structured packings you have to vary the thickness of the corrugated sheet metal in calculation, for random packings each phase of the fouling progress leads to a new geometry of the rings. Therefore, you will only vary the void fraction in calculation.

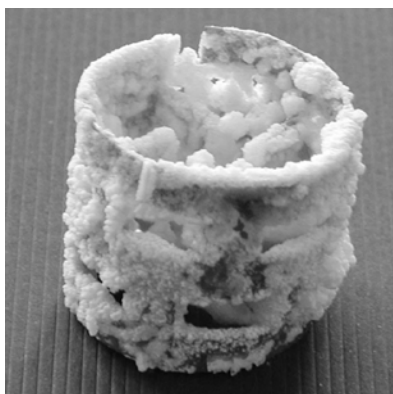


Fig. 4a: Pall ring (side view) [6]

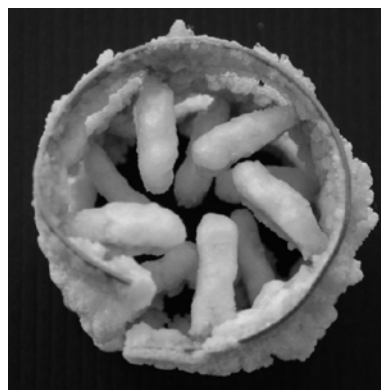


Fig. 4b: Pall ring (top view) [6]

Currently, a research project (funded by German BMWK) is carried out, which deals with the systematization of fouling effects and their hydraulic impacts [7].

3.2 Corrosion and Abrasion

Corrosion can be described as the loss of material by chemical reaction. In contrast to this, abrasion is the loss of material due to mechanical motion. Any moveable part in a column may initiate abrasion. However, it can also be caused by particles in gas flows.

Corrosion and abrasion – like fouling – also progress steadily, but the period is usually much longer (often decades). The need to act usually arises from troubleshooting: a tower no longer behaves as usual, i.e. its separation efficiency is poor, minimum and maximum loads can no longer be run or the pressure drop is noticeable.

Float valve trays are sensitive to corrosion as well as abrasion. Both effects make material disappear and lead to the loss of valves. Depending on the relative number of lost valves, this may change the characteristic of the tray dramatically. *Fig. 5* shows effects of corrosion and abrasion. In *Fig. 5a* almost all caged valves got lost due to corrosion. Vibration allowed the legs to expand the openings in the bottom plate and as a consequence, cage and valve plate disappeared. *Fig. 5b* shows a carbon steel panel deck with V1 float valves, where the movement of the valves increased the diameter of the openings and the valves got stuck or left.



Fig. 5a: Panel with lost caged valves



Fig. 5b: V1-valve tray with lost and stuck valves

Since normally the pressure drop is the only measured hydraulic parameter by the process control system, its values must be evaluated carefully. In *Fig. 6*, the pressure drop characteristic of a designed float valve tray is shown by the green line: The valves start working at the *Closed Balance Point (CBP)* and are all fully open at the *Open Balance Point (OBP)*. This characteristic curve changes, when valves are lost or get stuck in lifted position. The modified characteristic is shown in the dashed orange line in *Fig. 6*. The shape of the curve depends on the relative number of lost valves, on the physical properties of the streams, the tray regime and the dimension of the outlet weir. Hence, the curve in *Fig. 6* only gives a qualitative impression.

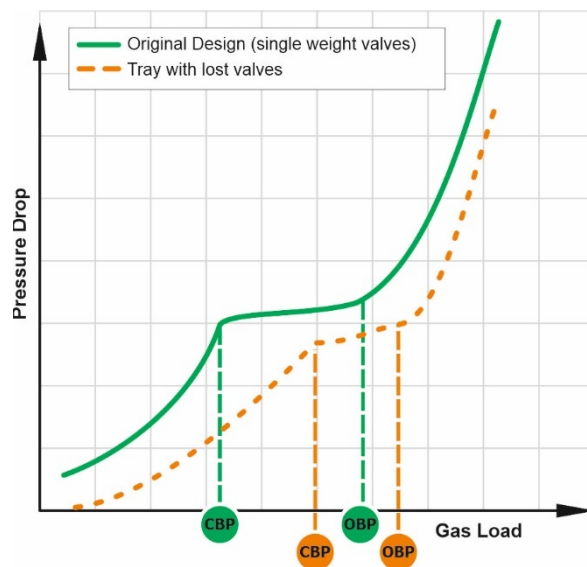


Fig. 6 Valve tray characteristic (without and with lost valves)

The curtain area of a standard round valve (V1) is about 29% less than its deck hole, for caged valves the curtain area is about 17% less than its deck opening. Therefore, in case of loss of valve elements, the open area of the tray increases. This results in loss of pressure drop. An additional effect on the pressure drop reduction is the loss of the directional change of the gas flow by the valve plate – resulting in gas channeling with effects on entrainment and *Jet Flood* [8].

Fig. 7 shows the qualitative effects of the lost valves on the "operational window" (cf. *Fig. 1*) of such a tray: The limits *Weeping* and *Maldistribution* are getting more critical and the *Jet Flood* will appear earlier (gas leaves the empty valve openings straight upwards and will expand the froth layer and additionally lead to entrainment).

As one can see, the operation of the tray may be still possible – but as an indicator the operators will detect a loss in pressure drop and – maybe – a loss in efficiency. As corrosion and abrasion increase, the operational window continues to shrink.

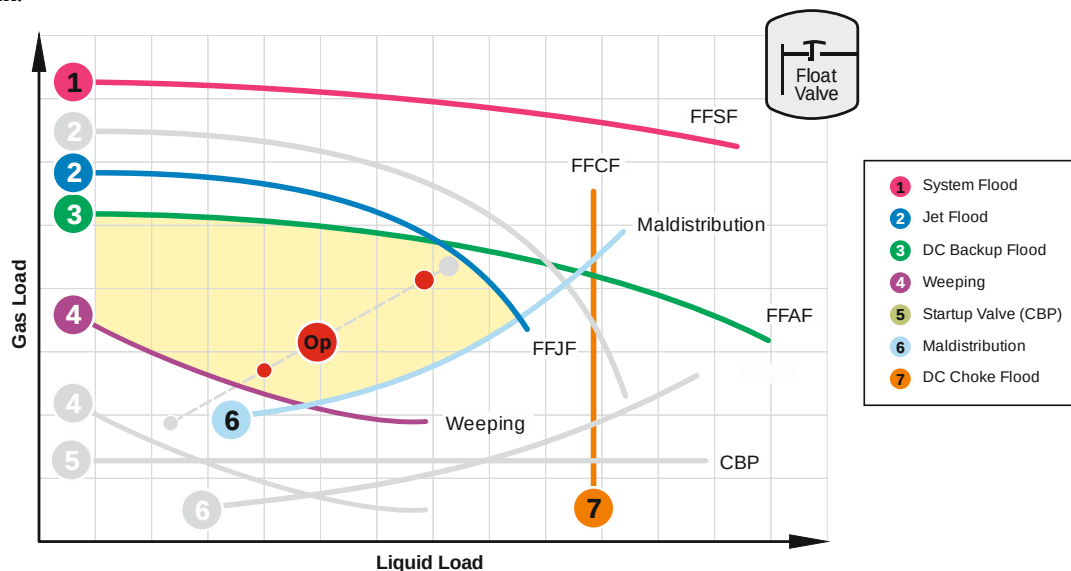


Fig. 7 Change in operational limits of a corroded valve tray

3.3 Other operational effects

There are other effects which can cause damage to the hardware and therefore change in hydraulic parameters, but these effects are in the category “incident”. There may be mechanical crashes (pressure/vacuum surges, liquid overloads, vibration faults). Those problems you may exclude by appropriate designs and correct operation. Another operational effect is foaming. Whenever there is stable foam within the tower, there is no chance for stable operation. You can detect the effect by large variations in the pressure drop measurement as well as by gamma scanning. There are little options to design foam resistant internals – you will have to minimize the effect by process conditions and foam inhibitors.

5. Summary

Operational effects can be taken into account in hydraulic calculation. Since the effects are continuous processes, it is possible to estimate the effects and thus make a prediction about the remaining operating time. Experience in dealing with the calculation of columns considering operational effects also helps the engineer to choose designs that are less vulnerable when redesigning columns. But even for running columns it is a good idea to monitor the lifetime of internals and to provide the operating staff with suitable operation diagrams for determining the best operational window.

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