Hydrodynamics of Foaming Systems in Packed Towers

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Abstract

Foaming can be a serious problem in the process industry. For packed columns foaming is often reported for treatments of sour gases with alkaline solutions (e.g. amine scrubbing), but also for distillation and extractive distillation. Existing hydrodynamic prediction methods for pressure drop and flood points, but also for mass transfer efficiencies, do not consider foaminess. To build an experimental data base for modifications of the above mentioned models, this work systematically conducts experimental investigations on the influence of foaminess, geometry and flow conditions on the hydrodynamic behavior in packed towers. The aim of this study is to provide a database for the correlation of the foaminess of a solution determined in a test cell to its hydrodynamic behavior in the packed column with different geometries to enhance the predictivity of hydrodynamic and mass-transfer models. The experimental results show that existing empirical system factors developed for tray columns fail to predict the decreased loading capacity of the packings for the model solution. Whereas in non-foaming solutions flooding is especially sensitive to the gas load, for foaming solutions the capacity is strongly decreased also at high liquid loads. The influence of the geometry of the packing on the generation of foam is substantial. The contribution shows novel experimental results of foaming solutions in packed towers. These include the substantially by foaminess altered loading diagrams and different phenomena in the column. In addition different column internals are compared and design suggestions are given.

1. Introduction

Foam can reduce throughput and separation performance or can even cause contamination of products due to takeover of foam from other vessels. It can therefore be a serious problem in the process industry. For packed columns foaming problems are often reported in treatments of sour gases with alkaline solutions (e.g. amine scrubbing), but also in distillation and extractive distillation [1], [2].

Whereas the reasons (Marangoni effect, mass-transfer-induced Marangoni effect, Ross-type foaming) for increased foaminess of solutions are nearly completely understood, a literature review revealed that the hydrodynamics of foaming solutions in packed towers and the occurring phenomena are covered insufficiently. In industrial practice the foaming problem is frequently suppressed using foaming inhibitors. However, the increase in costs, product specifications or requirements of units downstream might prohibit the use of an additional substance in the process. Avoiding foam inhibitors, dimensioning of packed towers under foaming conditions is usually done using empirical system factors which are tabulated for different services for tray columns and account for foaming [3]. These system factors are mere safety factors to correlate premature flooding and cannot be derived from physical properties. A prediction of the operating conditions (pressure drop, flood points, separation efficiency) of the column using existing models is therefore not possible, since the foamability caused by surface active components is unaccounted for in these models.

2. Theoretical Models

Models for foam drainage and foam stability are readily available in the literature, however mechanisms in the geometry of a packing and the dynamics of the gas-liquid interactions are complex and exhibit chaotic behavior. A theoretical investigation alone would therefore not be target-oriented. To build an experimental data base for modifications of the above mentioned models, this work systematically conducts experimental investigations on the influence of foaminess, geometry and flow conditions on the hydrodynamic behavior in packed towers. Therefore a model system water-butanol is chosen that shows increasing foaminess close to the miscibility gap due to the so-called Ross-type foaming [7].

The aim of this study is to allow the correlation of the foaminess of a solution to its hydrodynamic behavior in the packed column with different geometries to enhance the predictivity of hydrodynamic and mass-transfer models. The applicability of test cell measurements for determining foaminess to predict the behavior in the packed column has to be investigated.

Hydrodynamic models for the prediction of pressure drop and flood points have been proposed by many authors. This study uses the models proposed by Mackoviak [4] and Engel [5] as well as the commercial program of SULPAK 3.2 from SULZER. These models take into account geometrical parameters of the packing and physical properties (density, surface tension, viscosity) of the fluids. These properties, however, do not give information about foaminess. These models can therefore not consider an increase in pressure drop and earlier flooding under foaming conditions.

3. Test cell

The foaminess behavior is determined in a test cell by a dynamic method, where nitrogen is bubbled in a cylinder through the solution of defined volume under similar conditions to the pilot plant. The experimental setup of the test cell is shown in Figure 1.

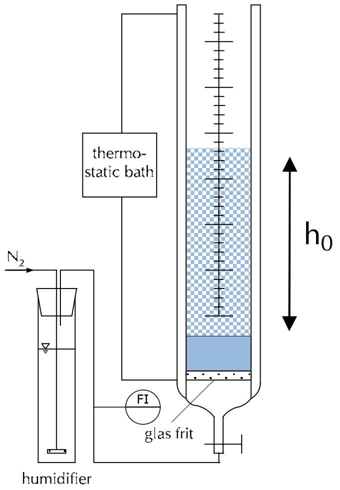

Figure 1. Test cell for the determination of foaminess

By measuring the foam height the Bikerman Index (Σ) [6] can be calculated using equation 1 with u_0 the gas velocity for the empty tube and h_0 the foam height as shown in Figure 1.

$$\Sigma = \frac{V_{foam}}{\dot{V}_{nitrogen}} = \frac{h_0}{u_0} \qquad \text{Eq. 1}$$

The results for different concentrations of water-butanol are shown in Figure 2. Measured Bikerman indices are in the range of 7 to 18 s with a local maximum between 0.35 and 0.7 wt% which has been observed more pronounced also by Ross and Suzin [8]. Foaminess rises only slowly with further increasing butanol concentrations. In the two-phase region, starting at 7.9 wt% 1-butanol, foaminess is suppressed completely due to the existence of the second liquid phase (compare [7]).

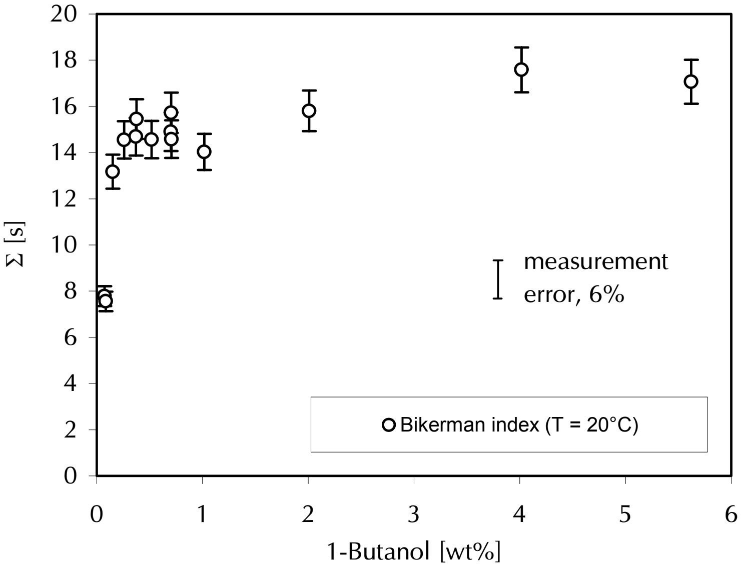

Figure 2. Bikerman index for water-butanol

4. Pilot Plant

To conduct the experiments a packed column pilot plant of 300 mm (11") is used (Figure 3). The pilot plant is equipped with controllers to feed a liquid and a gas stream with defined properties (temperature, pressure, volumetric flow, humidity, concentration) to a packed bed of 1 m height (3.3 ft). Pressure drop and flood point data can be determined for different structured and random packings (Table 1, Figure 4) to gain knowledge about the influence of the geometry on foam generation. For comparison trays (sieve and valve) can also be investigated. Foamability is varied by changing the concentration of the solution.

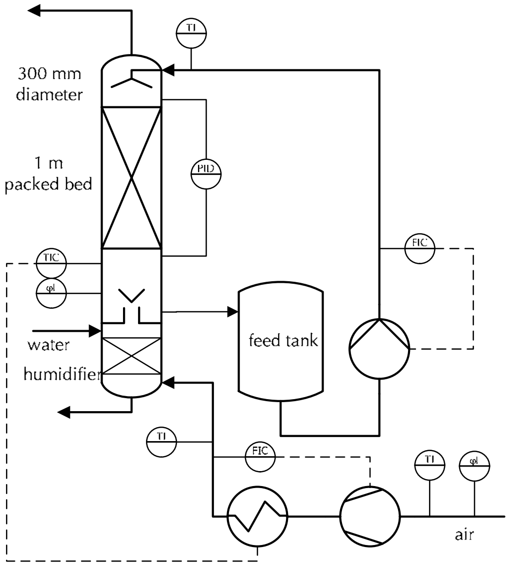

Figure 3. Scheme of the pilot plant.

The design of liquid distributors is crucial for the performance of modern packings. To determine the influence of the quality of the initial liquid distribution onto hydrodynamics, two different liquid drip point densities can be realized (160 m^{-2} and 550 m^{-2}). In additional experiments liquid is maldistributed by blocking holes in the distributor to investigate foam generation at irregular distributions.

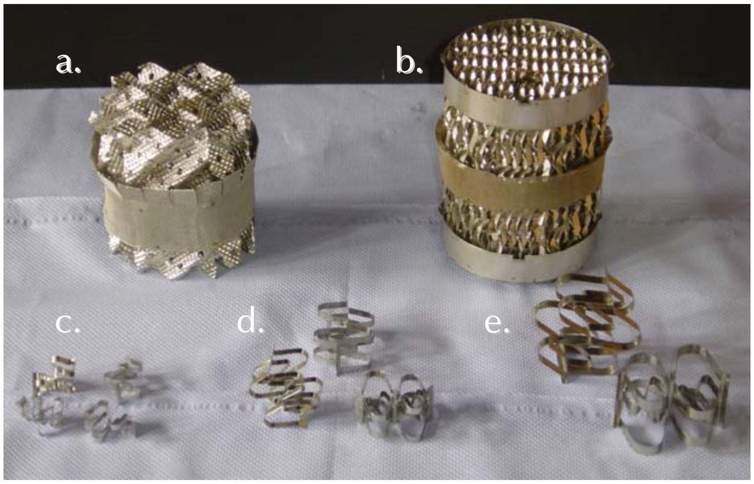

Figure 4. Packings used

Table 1. Data for the metal packings used

no. in Figure 4	packing	area [m²/m³]	ε [-]
a.	SULZER Mellapak 350.Y	350	0.93 (est.)
b.	KÜHNI Rombopak 9M	350	0.93 (est.)
c.	RASCHIG Super-Ring #0.3	315	0.960
d.	RASCHIG Super-Ring #1	160	0.980
e.	RASCHIG Super-Ring #2	97.6	0.985

5. Experimental Results

Experiments were carried out using the five packings described in Table 1 in a wide range of operating conditions with liquid loads B in the range of 7.5 … 30 m^3/m^2h (3.1 … 12.3 gpm/ft^2) and gas loads F in the range of 0.5 … 2.1 $Pa^{½}$ (0.4 … 1.7 $ft/s\ (lbs/ft^3)^{½}$) measuring the pressure drop over the height of the packing and determining the flood point. In addition, maldistribution experiments are carried out by blocking a third of the drip points over the cross-sectional area on one side of the distributor.

Figure 5. Flooded SULZER Mellapak 305.Y, B = 15 m^3/m^2h, F = 1,9 $Pa^{½}$

Figure 5 shows the flooded Mellapak 350.Y under high loading conditions. The beginning of foam build-up starts with a few bubbles at points, where high local liquid fluxes exist (compare [2]). There, bubbles accumulate blocking a part of the cross-sectional area, leading to large gas velocities in the remaining part. With larger velocities the interaction between both phases is intensified leading to large pressure drops and more foam build-up until foam is observed around the entire circumference. It was observed that bubbles and foam do not only accumulate at the collars but also within the packing over the entire cross-sectional area.

Figure 6 shows pressure drops for this packing using different solutions with different foamabilities. Whereas the pressure drop for the solution with a low foamability (Σ = 6 s) is only slightly increased compared to that of water, the pressure drop for the stronger foaming solution (Σ = 15 s) is greatly increased. The liquid load shows a strong influence on the hydrodynamics. This leads to premature flooding as indicated in Figure 7. In comparison to the flood point lines calculated by SULPAK and the model proposed by Mackowiak, the maximum loads are reduced to almost a fifth for high liquid loads.

Using the System factor (SF) approach, developed for tray columns [3], the predicted flooding line is still deviating from the real data to a large extent. Whereas for low liquid loads the influence of foam would be overestimated, dimensioning for high liquid loads would fail due to premature flooding.

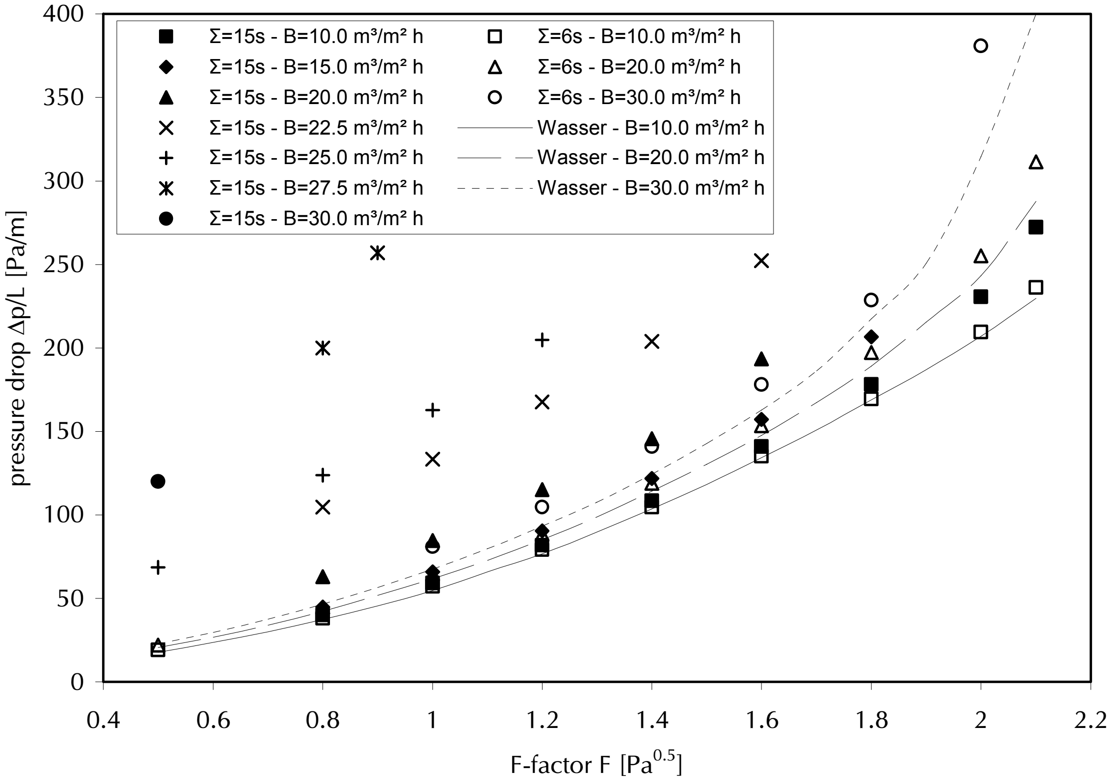

Figure 6. Pressure drop for SULZER Mellapak 350.Y for different foamabilities

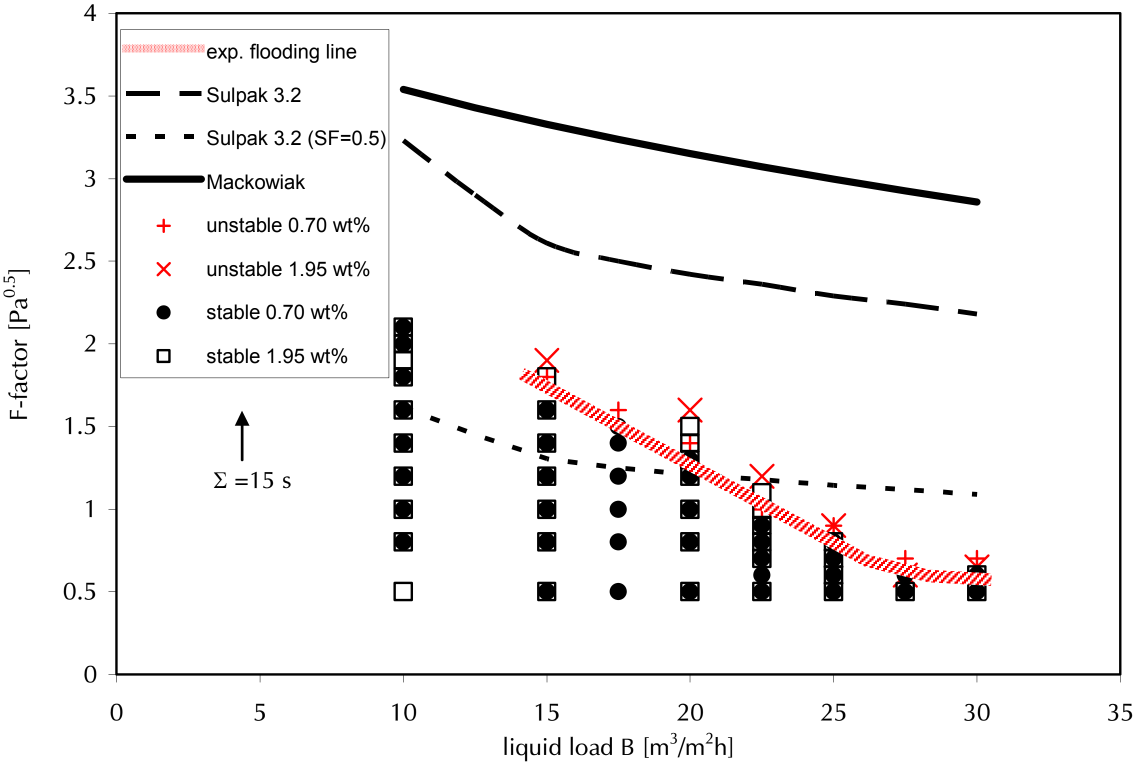

Figure 7. Loading diagram for SULZER Mellapak 350.Y

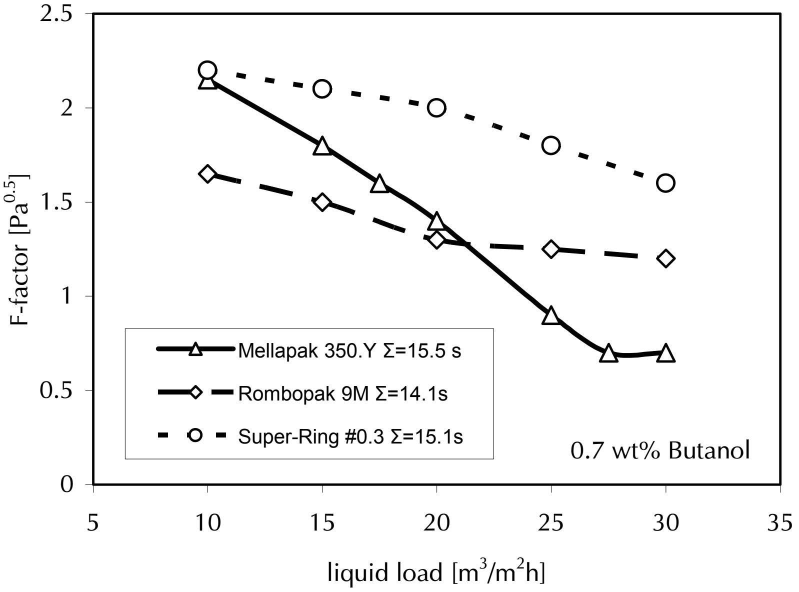

Figure 8. Flood points for three investigated packings of similar specific area

Flood points for the three packings with a similar specific area are plotted in Figure 8. The comparison of these packings showed various tendencies to promote foaming due to the different geometries. A sheet-structure like the Mellapak seems to stabilize foam under high liquid loads, whereas a packing with an open structure like the Rombopak 9M is under high liquid loads less affected. Irregular packings like the RASCHIG Super-Ring #0.3 show a surprisingly good performance under foaming conditions.

6. Conclusions

The experimental results show that the empirical system factors for the existing models fail to predict the decreased loading capacity of the packings for the model solution. Whereas in non-foaming solutions flooding is especially sensitive to the gas loading, for foaming solutions the capacity is strongly decreased especially at high liquid loads (B > 25 m^3/m^2h, 10 gpm/ft^2). In one case flooding occurred already for an F-factor of 0.5 $Pa^{0.5}$ (0.4 ft/s $(lbs/ft^3)^{0.5}$) with 30 m^3/m^2h (12 gpm/ft^2) liquid load.

The influence of the geometry of the packing on the generation of foam is substantial. Designing a packed tower, this should also be taken into consideration by choosing the appropriate packing regarding its tendency to promote foaming. Further research is required on that matter. This includes validation of the results using different test solutions.

As mentioned above, foaminess has also an influence on mass transfer due to induced convection and an increase in interfacial area [9]. Future experimental work will also focus on experimental determination of the influence on mass transfer in foaming system.

Acknowledgements

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