# Foaming Effect on Random Packing Performance

**T. J. Cai** * **and G. X. Chen**

Fractionation Research, Inc., P.O. Box 2108, Stillwater, OK 74076 USA

**K.T. Chuang and A. Afacan**

Department of Chemical and Materials Engineering

University of Alberta, Edmonton, Canada T6G 2G6

## ABSTRACT

The effect of foaming on the performance of 16 mm Pall rings was determined in a 0.15 m distillation column with a bed depth of 1.23 m. The tests were conducted with the methanol/water system at 1.0 bar pressure. A controllable foaming inside the packed bed was generated successfully with the addition of the surfactant, Triton X-100, to the reflux stream. The performance of the packing with and without foaming was determined and compared. It was found that foaming reduces the mass transfer efficiency by about 20 percent, and lowers the capacity by approximately 30 percent. The results also show significant increase of the bed pressure drop caused by foaming.

Key Words: Distillation, packings, foaming, efficiency, capacity

## INTRODUCTION

Foaming is one of the leading causes of malfunctioning distillation towers [1, 2]. The foaming problems are often reported for gas treatment, distillation and extraction columns. Foaming may affect the capacity of a fractionator by causing excessive entrainment or by limiting the capacity of a downcomer.

Though foaming problems exist in the process industry for a long time, there are few systematic studies on foaming effects on fractionating devices. Most of the foaming studies [3,4] have been on the foaming effect on device capacity. There are no published models, fundamental or empirical, which predict the performance of foaming systems. Designers have to rely on de-rating factors from accumulated experiences to account for the effects of foaming on the performance of column internals.

Fractionation Research, Inc. (F.R.I.) has been engaged in a comprehensive program of foaming tests with different fractionating internals. Prior to studies in a commercial size distillation column of 1.22 m diameter at the F.R.I. experimental unit, an exploratory test was conducted in a 0.15 m diameter column to get the experiences how to conduct the foaming test in the commercial size column, and compare the packing performances of small and large columns. The purposes of the test program are: to determine foaming effects on efficiency, pressure drop, and capacity; to compare the performance of the random, structured packings and sieve trays in the foaming systems. The test program reported in this paper was to study the effects of foaming on the performance of 16 mm Pall rings. The studies were conducted in a 0.15 m diameter distillation column with a bed depth of 1.23 m. The test system used was the methanol/water system at 1.0 bar pressure. A controllable foaming inside the packed bed was generated successfully with the addition of the surfactant, Triton X-100, to the reflux stream.

## EXPERIMENTAL SETUP

A glass distillation column was used to allow visual observations of the flow characteristics during operations. The column was packed to a height of 1.23 m and was equipped with a total condenser and a thermosyphon partial reboiler. A schematic diagram of the experimental set-up is shown in **Figure 1**. A perforated-pipe liquid distributor with 12 irrigating points, which is equivalent to 658 points/$m^2$ pour point density, was installed at the top of the column to distribute the reflux flow. Four in-bed samples, S2, S3, S4, and S5 as

*Corresponding author. E-mail: cai@fri.org , Phone: 1-405-385-0354, Fax: 1-405-385-0357

shown in the figure, were taken during the test. The samplers were located at 1.120, 0.900, 0.448, and 0.212 m above the bottom of the support plate, respectively. Liquid samples were also withdrawn from the reboiler and condenser as shown in the figure. Two pressure taps spaced 0.89 m apart were installed along the column to measure the pressure drop across the packing.

To generate foaming in the packed bed, the surfactant, Triton X-100, was injected continuously into the reflux stream using a single-syringe infusion pump (Cole-Parmer A-X 4900). Significant foaming was observed in the reboiler during the initial operation, and foams tended to back up into the packed bed. To prevent foaming in the reboiler, Silicone oil SAG 471 was added as an anti-foaming agent into the reboiler. No visible foaming occurred in the reboiler after adding the anti-foaming agent.

## EXPERIMENTAL PROCEDURE

The test without surfactant injection (no foaming) was conducted first to establish the baseline of the packing performance. Next, the tests with surfactant injection at similar conditions were conducted. For each condition with surfactant injection, the Triton X-100 was continuously injected into the reflux stream once the hydraulic equilibrium was established for that condition.

A total of 10 runs were conducted without surfactant. The vapor flow rate (expressed by F-factor), at the middle of the column, was varied from 0.68 to 1.26 m/s $(kg/m^3)^{0.5}$. For each vapor rate setting, temperature and flow rate profiles were monitored to ensure steady state operation. Once the column reached steady state, liquid samples were taken from the condenser, reboiler, and in-bed sampling ports along the column. For each run, the packing pressure drop was recorded, and videos were taken. The runs were repeated using a similar experimental procedure with addition of Triton X-100 to the reflux flow to investigate the foaming effect. The liquid samples taken along the column (S2, S3, S4, S5) were analyzed using a Hewlett Packard 5790A gas chromatograph Series II equipped with a TCD detector. For all test runs, we obtained almost pure methanol (~99%) in the condenser (S1) and pure water (~20 ppm methanol) in the reboiler (S6). For the extreme concentrations in these samples, analyses were performed using a Varian-3400 GC equipped with an FID detector.

The operation from tests was video recorded. A copy of this video in DVD format is available on request.

## RESULTS

The efficiency was characterized by calculating the number of theoretical stages using the measured liquid compositions at S3 and S5 samples. The theoretical stages were determined from Fenske equation [5]. The number of stages between the samples S3 and S5 is divided by the averaged theoretical stages in the middle of the operating region without foaming inside the packed bed. Using this quantity, the percent change in efficiency due to foaming can be shown directly.

### Baseline Results without Surfactant

**Figure 2** shows the measured efficiency as a function of vapor rate. It can be seen that the efficiency remained nearly constant between F-factors 0.68-1.26 m/s $(kg/m^3)^{0.5}$. The measured bed pressure without surfactant is shown in **Figure 3.**

It is observed that the liquid volumetric flow rate at the top of the column was greater than at the bottom of column. This is due to the difference in mean molecular weight and density of the liquid phase. This trend is also predicted in the Aspen plus simulation results as shown in **Figure 4**.

### Results with Surfactant

#### General Observations

The surfactant, Triton X-100, was injected continuously into the reflux stream using a single-syringe infusion pump. The concentration of the surfactant was maintained at the level of 400 ppm by weight for all tests. For the methanol/water system, once the surfactant, Triton X-100, was injected into the reflux stream, foaming occurred in the packed bed within 2 minutes or less. The degree of foaming is higher at high liquid rates than at low liquid rates. When foaming occurs, the bed pressure drop increases.

For all experimental runs, the reboiler contained almost pure water. Consequently, foaming occurred at very low Triton X-100 concentrations. An antifoaming agent, silicone oil (SAG 471), was added to eliminate foaming within the reboiler. It was found that a concentration of 4 mL/L antifoaming agent in the reboiler was sufficient to prevent foaming.

**R**esults

**Figure 5** shows the measured foam height as a function of methanol concentration at sampling location S3. The foam height was measured from the bottom of the column. As the methanol concentration increased the foam height decreased. Since the surfactant concentration in the reflux line was kept constant for all tests, as methanol concentration along the column increased the foam height was expected to decrease. This was in agreement with the findings of the foaming tendency tests outside the column.

**Figure 6** shows a comparison of packing efficiencies for tests with and without surfactant. As shown in the figure, the efficiency for the tests with surfactant is lower than that without surfactant. The presence of surfactant/foaming at the liquid–vapor interface may hinder the rate of mass transfer. This figure also shows that the column capacity was greater for tests without surfactant than those with surfactant. Without Triton X-100, the column could operate up to an F-factor of 1.26 $m/s(kg/m^3)^{0.5}$, while in tests with Triton X-100 the column flooded at an F-factor of 0.90 $m/s(kg/m^3)^{0.5}$. Clearly the foaming decreases the packing capacity drastically with the addition of surfactant.

The measured pressure drops across the packed bed as a function of F-factor for tests with and without surfactant are shown in **Figure 7**. It can be seen that in the presence of surfactant the pressure drops were significantly higher than that for tests without surfactant.

## CONCLUSIONS AND DISCUSSION

A controllable foaming inside the packed bed was generated successfully with the addition of the surfactant, Triton X-100, to the reflux stream. This study shows that foaming has significant effect on the packing performances. The foaming reduces both hydraulic flood capacity and maximum useful capacity, and increases the bed pressure drop very significantly.

Followed by the small column tests with 16 mm Pall rings, F.R.I. conducted a comprehensive foaming test program using the 1.22 m diameter distillation column of the FRI experimental unit. In this program, random and structured packings and sieve tray were tested with and without foaming. The test was conducted with the steam/water and methanol/water systems at different column pressures. The performances of different internals with foaming system are measures and compared.

## REFERENCES

1. K.Z. Kister (2003), Chem. Eng. Res. Des., 80 (1), pp 5-26.
2. N.P. Lieberman and S.W. Golden (1989), Journal of Oil and gas, 87 (33), pp 45-47
3. M.R. Resetarits, J.L. Navarre, D.R. Monkelbaan, G.W.A. Hangx, R.M.A. van den Akker (1992), Hydrocarbon Processing, 71 (3), pp61-64
4. R. Thiele, H. Wiehler, J.U. Repke, H. Thielert and G. Wozny (2004), AIChE Annual Meeting Conference Proceedings, pp 3647-3655
5. C. W. Fitz, A. Shariat and J. G. Kunesh (1997), IChemE Symp. Series No. 142, pp 829-839.

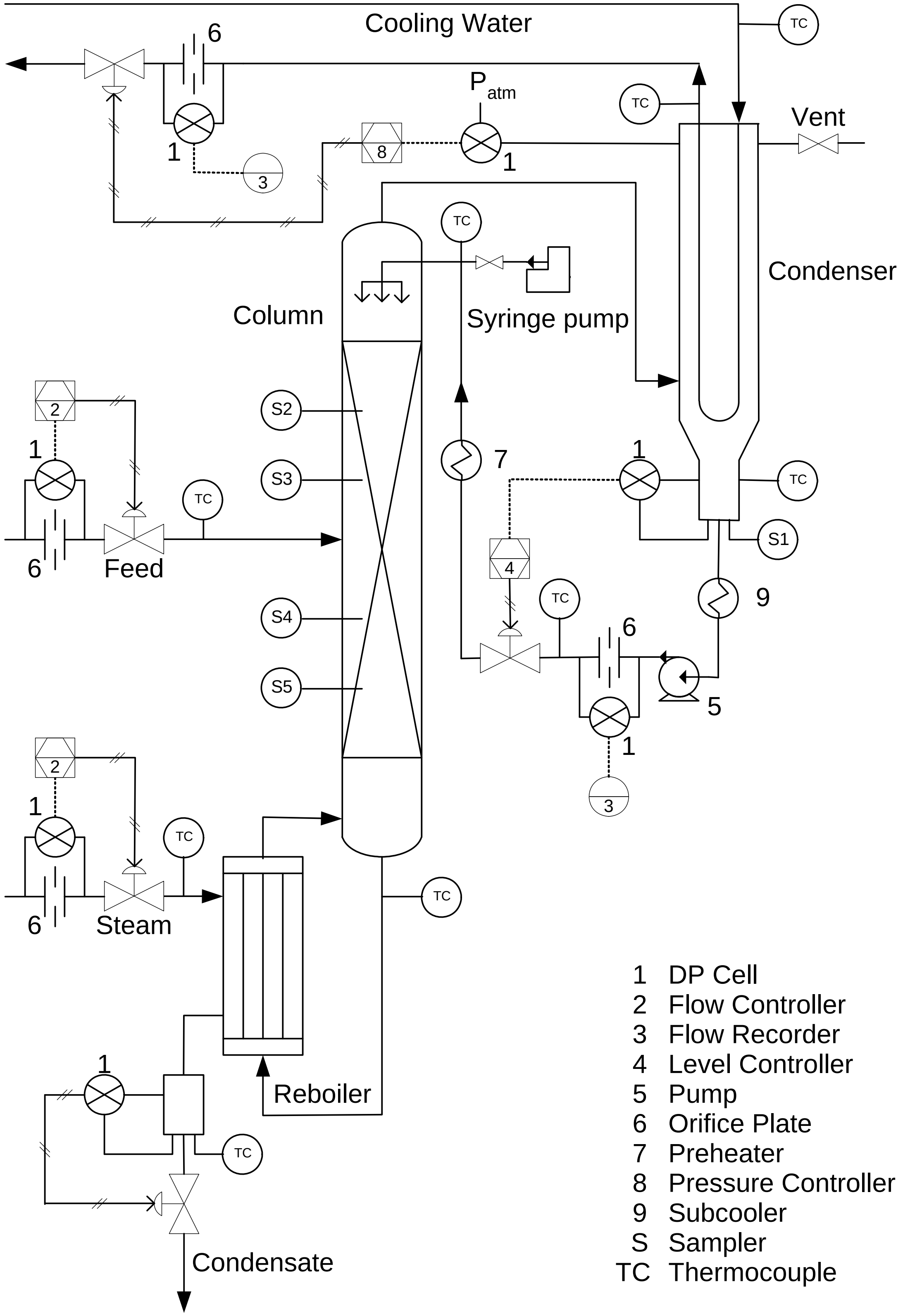

**Figure 1.** Schematic diagram of experimental setup.

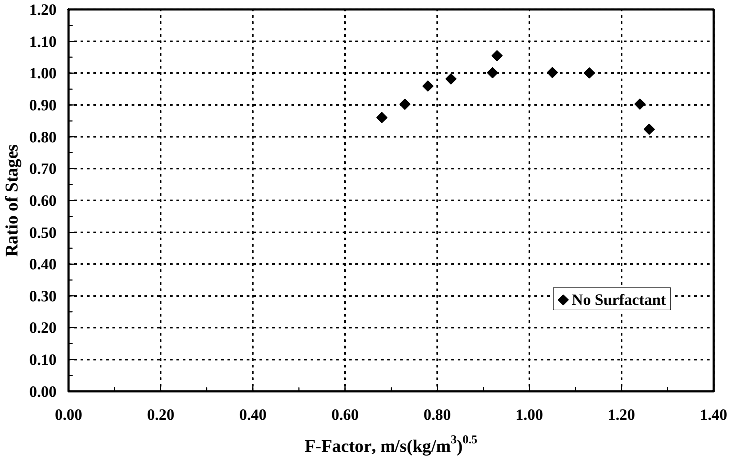

**Figure 2.** Measured Efficiency (without surfactant)

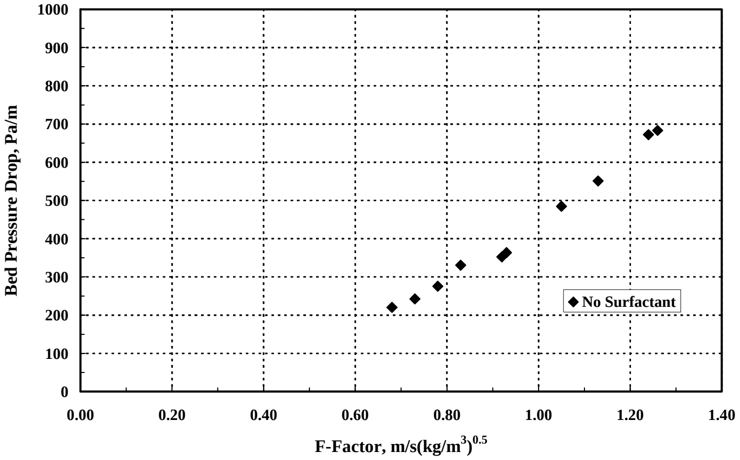

**Figure 3**. Measured Bed Pressure Drop (without surfactant)

**Figure 4.** Volumetric flow-rate profile of a methanol/water distillation column

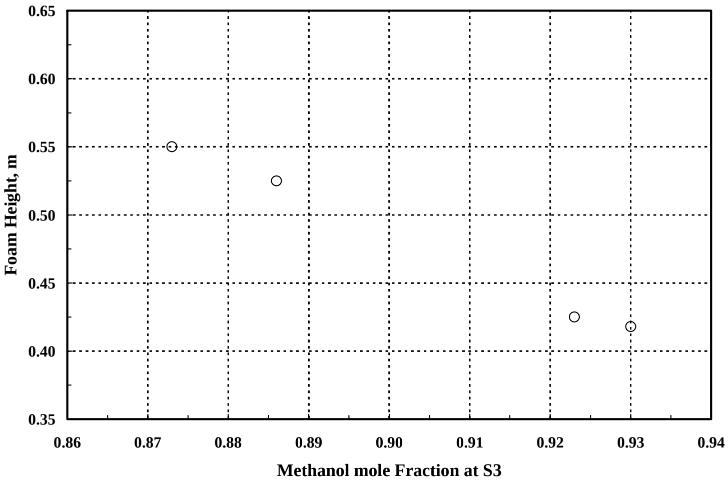

**Figure 5.** Effect of Methanol Concentration on Foam Height.

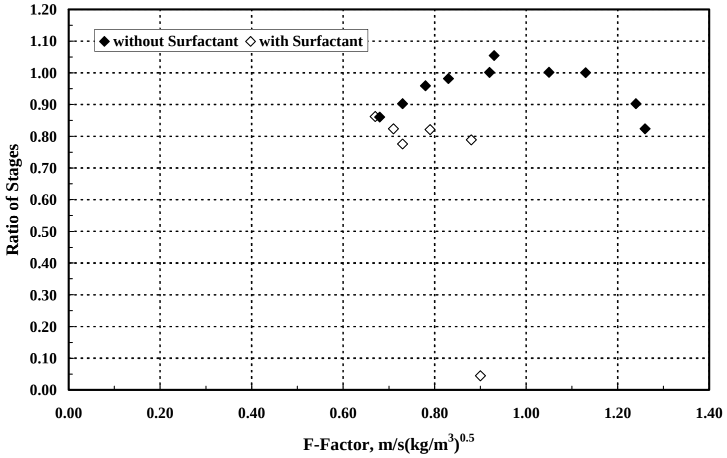

**Figure 6.** Effect of Foaming on Efficiency

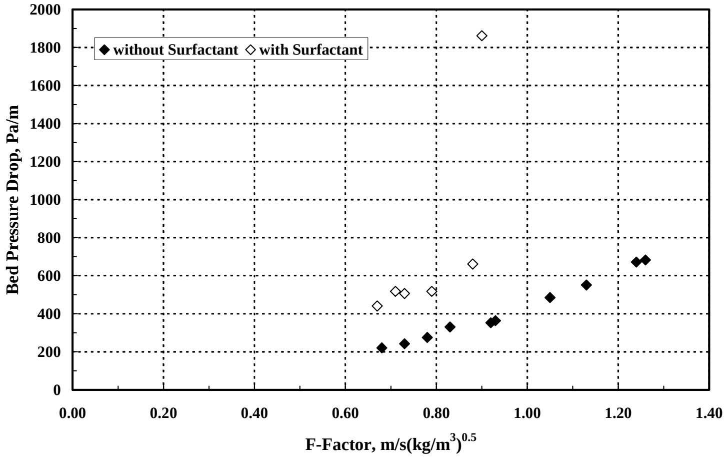

**Figure 7**. Effect of Foaming on Bed Pressure Drop