University at Buffalo *The State University of New York*

To: CE428 Students
From: Dr. T. Kofke
Date: January 22, 2004
Subject: **Bubble Cap and Sieve Plate Assignment**

Our company is modifying the process to improve the product quality of Superchem®. This is a $5 million capital improvement project that is expected to improve profits by $1.5 million/yr. A distillation column will be an integral part of the proposed process.

This distillation column will make use of either bubble cap trays or sieve trays to affect vapor-liquid contact. We have little experience in the design of distillation columns and even less experimental data. Our design is going to rely on empirical correlations available in the literature. These correlations will be used to find the pressure drop experienced by the vapor as it flows through a plate and the hydraulic gradient driving the liquid flow across a plate. These are critical factors affecting the cost and efficiency of the column. Thus, we need to check the reliability of the correlations for bubble cap trays and sieve plates before the decision is made about which will be used in the column design.

Your team has been assigned to use an air-water simulator for plate columns to collect relevant data, and to report on the suitability of the correlations that we are planning to use.

Some additional information is attached.

Background

Trays used in distillation columns have two main parts, the vapor-liquid contacting area and the downcomer area, where the vapor and liquid are separated. One factor in the classification of trays is the type of plate used in the contacting area. Sieve trays have simple perforated plates which can come with different hole shapes, various hole sizes, and several punch patterns. In a bubble cap tray, caps are mounted over risers fixed on the plate.

Bubble cap trays were developed to promote a high degree of contact between the downward flowing liquid and the upward flowing vapor within a distillation column. Although bubble cap trays are not typically used any more when new distillation columns are designed and constructed, we have access to used equipment with bubble cap trays, use of which we would like consider to minimize costs for this project. (There are many older columns in use that contain bubble cap trays.)

In this experiment you will investigate two important parameters associated with plate columns. The first parameter is the **pressure drop** of the vapor as it passes *through* a tray. This is clearly important in designing a distillation column, in order to determine the overall pressure drop through the column. The second parameter is known as the **hydraulic gradient**. Effectively the hydraulic gradient is the difference in the depth of the liquid *across* the tray; it provides the driving force for liquid to flow across the tray. If the hydraulic gradient is too large, then the depth of liquid near where it enters the tray is large, and the gas can't bubble through the liquid easily. This leads to poor vapor-liquid contact and an inefficient column. If the hydraulic gradient is too small, dry spots can form on the tray, again leading to an inefficient column. The air-water simulator of a sieve plate and bubble plate column is shown in Figure 1. It consists of a 60.0 cm diameter column 3.04 meters high constructed from transparent plastic into which have been inserted two sieve plates and a bubble cap plate. Each plate has a segmented downcomer and a 6.5 cm weir. The top plate is a sieve plate of conventional design installed to ensure gas and liquid distribution in/and on the bubble cap tray chamber immediately below. The compartments above and below the bubble cap plate contain ports for the pressure taps. One pressure point enables the pressure in the vapor space above the bubble caps to be measured; five pressure points give the pressures on "top of the risers" of five bubble caps, and finally the sixth pressure tapping gives the pressure below the bubble cap plate in the lower sieve plate compartment. In addition, provision is made for the atmospheric pressure to be obtained and the pressure below the lower sieve plate to be measured.

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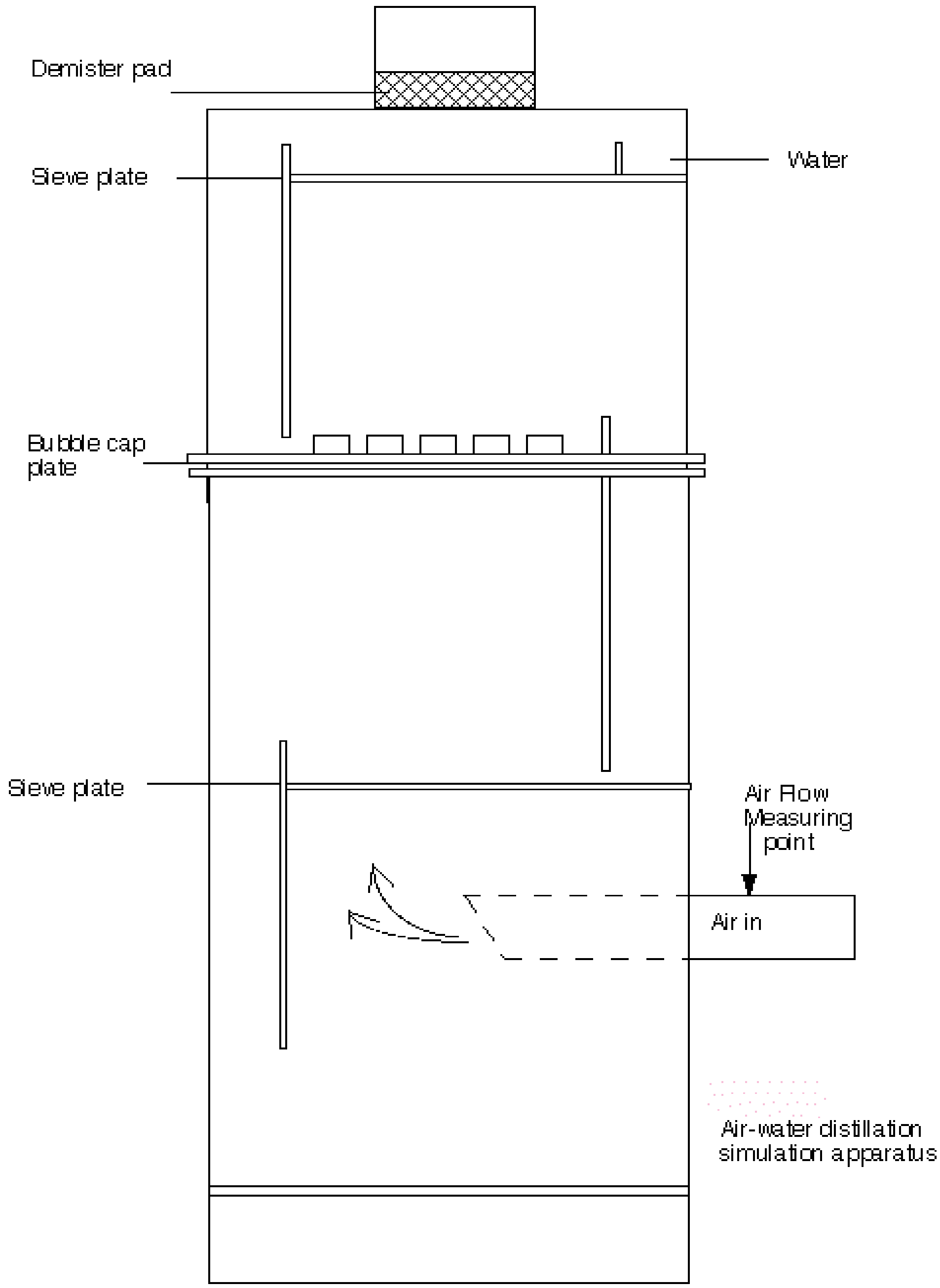

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Figure 1. Schematic of the experimental apparatus

The liquid reservoir is situated in the base of the column and is provided with a drain and a connection to a centrifugal pump that recirculates water to the top sieve tray after which it passes down the downcomers and over the bubble cap tray and then the lower sieve plate. The water flow rate is measured by the rotameter shown and the airflow admitted through the 31.4 cm port just above the water reservoir is measured by the electronic anemometer or by an alternate method.

Details of the cap plate and bubble caps are presented in Figures 2 and 3. There it will be seen that the plate contains 27 bubble caps each 59 cm diameter arranged on a 14.0 cm triangular pitch. The caps possess slots 0.3 cm wide 1.5 cm long as shown.

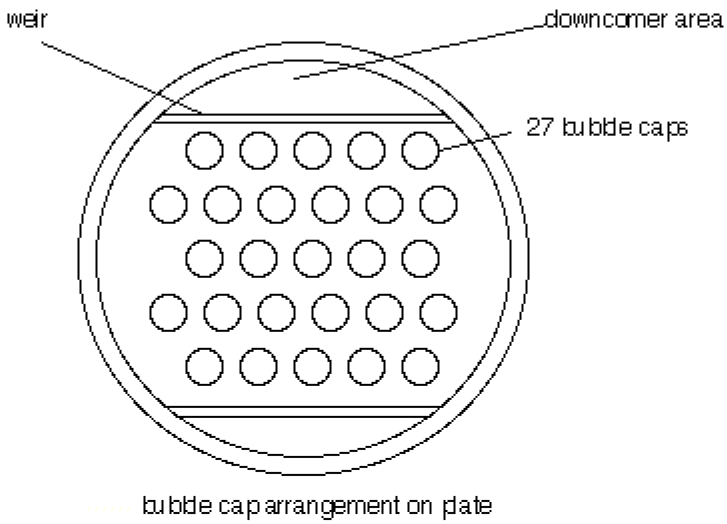

Figure 2. Bubble Cap Arrangement

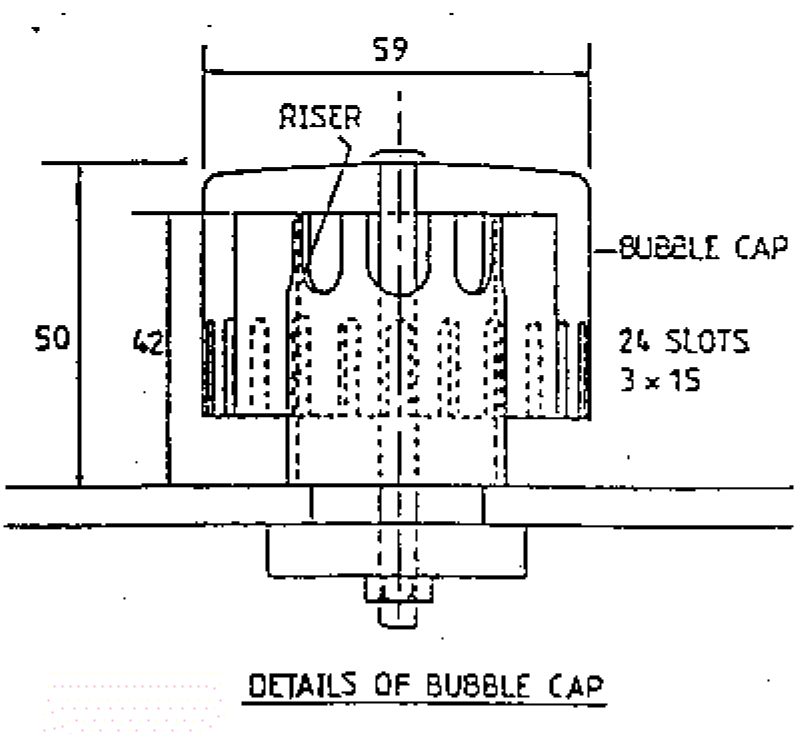

Figure 3. Schematic of a bubble cap.

Tray Hydraulics Theory

The total pressure drop for vapor flow from one tray to the next in a column is defined by the general equation

$$h_t = h_d + h_l \qquad (1)$$

where h_t =total pressure drop, in. liquid
h_d = pressure drop across the dispersion unit (dry hole for sieve plates, dry cap and slot drop for bubble caps, in. liquid
h_l = pressure drop through aerated mass over and around the disperser, in. liquid.

This pressure drop has the value that would be read from a manometer tapped to the vapor space of adjacent trays. The various terms in Eq. (1) are given for bubble cap trays by correlations listed in the Air/Water Simulator for Plate Columns manual (posted on course website). The analogous correlations for sieve plates can be found in the Perry's handbook.

Experimental Method

Fill the water reservoir at the base of the column with water, making sure that the base of the down comer from the lower sieve plate is immersed below the water level thereby preventing air being short circuited up the down comer (this should already be done). Ensure that the manometers all read '0' on the 0-20 scale. You will operate this manometer at the vertical position. If the level of all the manometers is not '0' then you can adjust the height of all the manometers simultaneously by either raising or lowering the reservoir. On the other hand, if you notice that any one particular manometer level is lower than the rest, you will need to blow air through it in order to clear out any water that may have entered the tube (Talk to either me or the TA about this).

For all the experimental runs, the airflow rate setting is set at 'med'. Start the pump and control the water flow rate at 12 cm on the rotameter scale (22.4 l/min). When the water flow has been established, switch on the air fan to admit air into the column.

Allow steady state operation for 5 minutes and then record the pressures on the column manometer. Allow the column to operate for a further 3 minutes and then repeat the pressure readings. If constant steady state operation has been reached, measure the head over the exit weir of the bubble cap and sieve plate. Also, measure the flow rate of air using the rotating vane anemometer at the top of the column. Next increase the water flow rate to 15.0 cm on the rotameter scale (27 l/min), and when steady state has been attained, again record the pressures and the head over the weir of each of the bubble cap and sieve plates. Repeat the experiment a third time with a water rotameter reading of 27.0 (49.3 l/min).

Slowly, reduce the airflow rate while keeping the water rotameter at 27.0. When do you observe weeping from the top sieve flow rate in this system? Note the airflow rate corresponding to this condition of weeping?

Analyze the results to test stability of the plates for all the experimental conditions and compare the measured pressure drop and hydraulic gradient at all conditions to those predicted using the correlations. Discuss how each varies with air and water flow rate.

For this report, you will write a business memo. Please refer to the information given on memo writing.

References

1. Smith, B. D., "Design of Equilibrium Stage Processes," McGraw-Hill, 1963.

2. Robinson, C. S. and E. R. Filliland, "Elements of Fractional Distillation," 5th ed., McGraw-Hill, 1952.

3. Perry's Chemical Engineers' Handbook, 5th edition, 1973.

Table 1. Parameters needed for the theoretical calculations
Tower diameter 60 cm
Air channel diameter 31.4 cm
Down comer area 0.026 m^2
Weir length 0.43 m
Weir height 5.0 cm
Skirt clearance 1.25 cm
Slot height 15 mm
Slot width 3 mm
Number of slots 24
Riser area 2.07 in^2/cap
Reversal area 1.914 in^2/cap
Annulus area 2.153 in^2/cap
ρ_v (air) 1.185 g/L
ρ_e (water) 1000 g/L
Static slot seal 27 mm