

HYDRAULIC MEASUREMENTS OF SIEVE PLATE

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A measurement device for sieve plates have been designed and built at Helsinki University of Technology. The unit consists of a rectangular transparent container where one plate is installed. The flow path on the plate is of constant width. The plate is easy to change and sieve plates with two different diameters of holes have already been measured. The measurements have been done with two systems: air–water and air–heat transfer oil. The adjustable variables of the unit are air flow rate, liquid flow rate, downcomer clearance, exit weir height, plate configuration including thickness of plate, diameter of holes, number of holes, area of holes, spacing of holes and fractional perforated area. The measurements carried out are: weeping (visual detection through the transparent walls), entrainment (with a dry tray above the measured tray), pressure drop (manometers), vapor/liquid dispersion (using a camera), clear liquid height and froth height using camera and measurement scale fixed on the unit, and flow patterns (camera). The measured values have been verified against published correlations and have been found to agree quite well.

KEYWORDS: sieve plate, hydraulics, measurements, pressure drop, entrainment

INTRODUCTION

The hydraulic measurements of sieve plates can be carried out in many different kinds of equipment. The objective is to obtain knowledge of pressure drop, entrainment, weeping etc. This knowledge is needed in designing new distillation equipment. When experimental data is correlated using certain features of the equipment, like weir height, hole diameter, width and length of the flow path etc, it is still uncertain to use these correlations for new plate type or large scale-up factors. This is due to the fact that the flow phenomena are not easily scaled.

Our group and the Laboratory of Chemical Engineering and Plant Design at Helsinki University of Technology has been active in modeling multicomponent mass transfer in gas-liquid and liquid-liquid reactors, see e.g. Alopaeus *et al.* [1, 2] and Laakkonen *et al.* [3, 4]. The methodology is to combine computational fluid dynamics (CFD) programs and in-house program code to describe the reactor as rigorously as required using local chemical concentrations, physical properties, reaction rates, temperatures, pressures and mass transfer. Another approach applied has been the multi-block model where the thermodynamic and reaction kinetic details can be taken into account in more rigorous way compared to the CFD approach. Both approaches require that thermodynamic and transport properties are evaluated using local values. This applies also for the mass transfer: The aim here is to separate the mass transfer coefficients and the mass transfer area. Thus the mass transfer area is to be modeled. This is done by using population balances which requires models for bubble and droplet breakage and growth. These models are functions of the physical properties and the dissipation of the turbulent kinetic energy, which can be obtained from the CFD calculations, all determined locally. This allows one to study computationally various reactor geometries and sizes with higher confidence than using average values.

Our aim in this study was to obtain information to aid modeling of distillation trays using the multi-block and CFD techniques. Once successful in modeling the measured sieve plates we hope to be able to extend our knowledge in multiphase reactor modeling to cover new geometries of distillation trays using multi-block and CFD approaches. The ultimate goal is to be able to predict the performance of new internals of distillation equipment prior to building them.

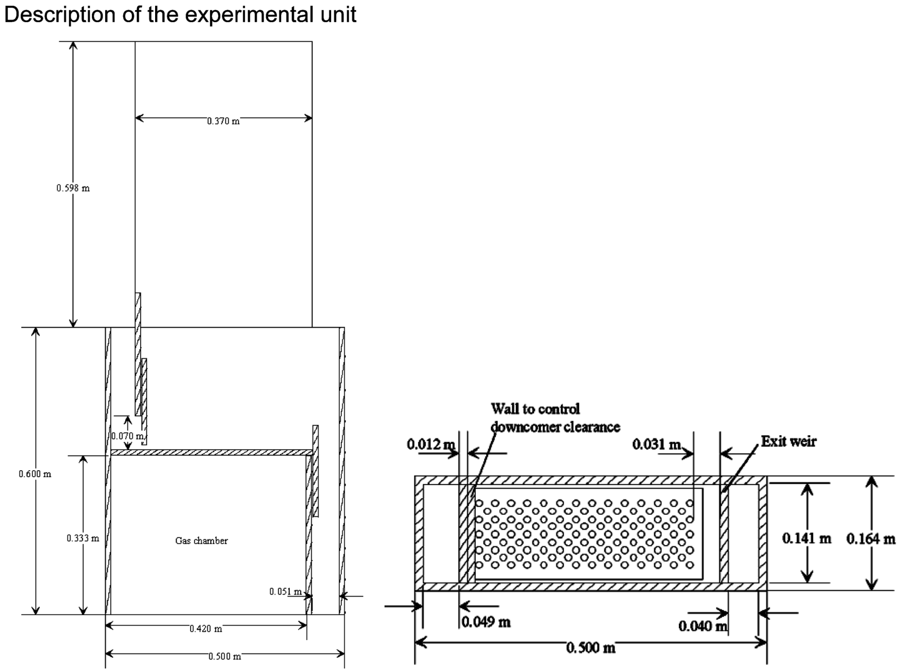

Figure 1. On left is a schematic side view of the unit and on right is shown a metal sieve plate as seen from above. The downcomer clearance can be adjusted using a wall as shown. Similarly, the exit weir height can be adjusted. The design allows easy change of the metal sieve plate itself

Table 1. Properties of the two measured sieve trays

	Tray I	Tray II	Dimension
Width	0.130	0.130	m
Length	0.337	0.337	m
Area of the tray	0.0438	0.0438	m^2
Active area	0.0237	0.0237	m^2
Thickness of plate	3.0×10^{-3}	3.0×10^{-3}	m
Diameter of holes	3.0×10^{-3}	5.0×10^{-3}	m
Number of holes	353	122	–
Area of holes	2.50×10^{-3}	2.40×10^{-3}	m^2
Fractional perforated area	10.6	10.1	%
Hole spacing	2.5	2.5	

The design of our unit is described in more detail by Makkonen [5] and is based on that of Ellenberger and Krishna [6] with some modifications. The gas flow from the blower has been directed as a bubble flow through two closed tanks in series filled with the liquid in order to saturate the gas with the liquid. When gas was saturated with liquid it was passed through liquid separator. At the same time the liquid was saturated with the gas to avoid all mass transfer when flows enter the plate. Liquid was pumped into the downcomer from which it flows across the metal plate. The gas was introduced through a distributor at the bottom of the unit and it flows through the holes of the sieve plate.

SYSTEMS MEASURED

Two chemical systems have already been measured:

- air and water
- air and heat transfer oil

There were no heating and cooling elements in the system and thus the gas and liquid temperatures were close to the ambient temperature. Physical properties for air saturated with water vapor were obtained from literature. In the air and heat transfer oil system the air was assumed to be free of oil as the vapor pressure of the heat transfer oil is very low. Density, surface tension and viscosity of the heat transfer oil were measured.

VARIABLES MEASURED AND SET

The liquid and gas flow rates were both measured using rotameters. Similarly, their temperatures were monitored. Pressure measurement on the unit was done with a set of manometers. Variables used in measurements are given in Table 2.

Table 2. Variables used in measurements

Variable	Minimum value	Maximum value	Dimension
Gas flow rate	0.48	1.17	m/s
Water flow rate/weir length	0.8	3.7	$m^3/(h\,m)$
Oil flow rate/weir length	0.7	2.6	$m^3/(h\,m)$
Exit weir height	0.031	0.05	m
Downcomer clearance	0.010	0.015	m
Orifice diameter	0.0030	0.0050	m

Entrainment was measured using dry tray method. On the tray above the sieve tray to be measured, five sponges were used to collect the entrainment. The sponges were weighted before and after each measurement. The air was almost saturated with liquid vapor prior entering the equipment. Evaporation of entrained liquid collected on sponges was negligible.

Weeping was collected from bottom of the gas chamber and weighted.

Hydrostatic pressure at the sieve tray and above froth was measured with manometers. Two manometer heads were at the height of the tray and one 135 mm above the tray floor. Hydrostatic pressure was calculated with equation $P = \rho_L gh$, where h is the height of liquid level in manometer and ρ_L is the liquid density.

Vapor liquid dispersion was examined from photographs taken with Canon EOS 300D digital camera, using shutter speed $s/3200$ and aperture value of 4.0 and 4.5 and a lot of light. Pictures were also taken with shutter speed of $s/4000$ and aperture value of 4.0 and 4.5, using two flashes. Focal length was from 40 to 45 mm and distance between lens and column wall was approximately 0.5 m.

The slip velocity between entrained oil and air was measured from pictures, taken with camera shutter speeds of $s/200$ and $s/100$.

The air was blown for 10 to 20 minutes before starting the experiments to even out its temperature and relative humidity. Simultaneously the liquid flow was recycled to eliminate the mass transfer during measurements.

RESULTS AND DISCUSSION

AIR–WATER SYSTEM

The *weep point* was visually observed and the type of weeping was easily detected. The design of the measurement equipment was not the best for determining the amount of weeping as the bottom was flat and it was slightly difficult to measure the liquid amount accurately. When exit weir height was 31 mm and the Tray I (diameter of holes 3.0 mm) was used, the weep point was visually observed when air flow rate was 0.48 m/s and water flow rate/weir length was 3.6 $m^3/(h\,m)$. When the exit

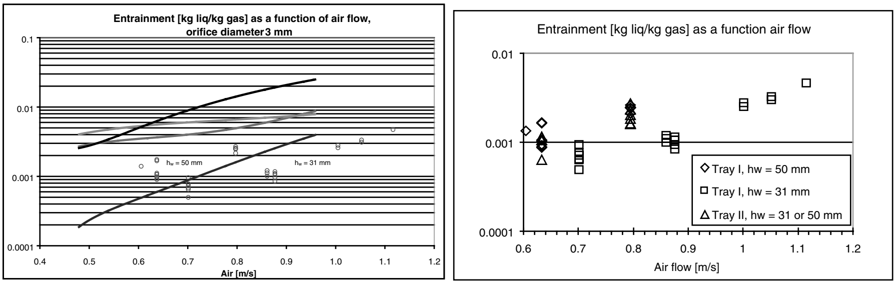

Figure 2. a) Entrainment for Tray I (diameter of holes 3.0 mm) in air–water system. Own measurements are shown with circles and two exit weir heights were used ($h_w = 31$ mm and 50 mm). The lines present the entrainment calculated from correlation of (from top to bottom order) Hunt *et al.* [10], Bennett *et al.* [9], Fell and Pinczewski [7], and Koziol and Mackowiak [8]. b) Entrainment in air–water system on Tray I (diameter of holes 3.0 mm) and Tray II (diameter of holes 5.0 mm). On Tray II the exit weir height (31 mm or 50 mm) did not made any noticeable difference on entrainment. Similarly the liquid flow rate did not have any effect on entrainment

weir height was increased to 50 mm, the weep point was observed at air flow rate 0.64 m/s and water flow rate/weir length 1.8 m^3/(h m). When exit weir height was 31 mm and the Tray II (diameter of holes 5.0 mm) was used, the weep point was visually observed when air flow rate was 0.48 m/s and water flow rate/weir length was 2.8 m^3/(h m). When the exit weir height for Tray II was increased to value 50 mm, the weep point was observed at air flow rate 0.56 m/s and water flow rate/weir length 3.6 m^3/(h m).

The *entrainment* was measured with dry plate method for both trays. Results for Tray I (diameter of holes 3.0 mm) are shown in Figure 2a. Four entrainment correlations are shown for comparison. Tray I and Tray II had almost the same open bubbling area (Table 1), but different hole diameter. Figure 2b shows the entrainment on Tray I and Tray II.

Gas holdup was calculated for various measurements. Similarly the clear *liquid heights*, needed to calculate pressure drop, were calculated with equation of Colwell [11]. *Pressure drop* was calculated for comparison with our measurements using the correlation of Stichlmair and Fair [12]. *Depth of liquid in downcomer* was also measured. *Froth height* as a function of flow rates was also measured and studied with high speed digital camera at varying conditions. Froth height is shown in Figure 3 for Tray I (diameter of holes 3.0 mm) with exit weir height 31 mm as a function of water flow rate. Rather large deviations from literature values were noticed for some of the measured variables.

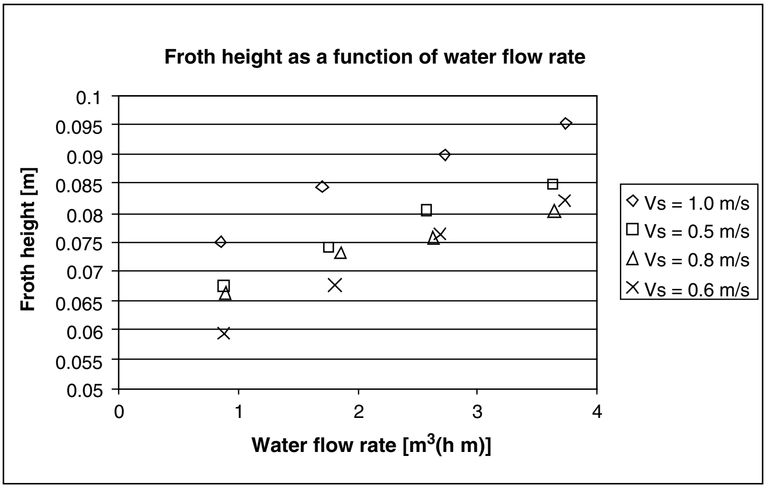

Figure 3. Froth height as a function of water flow rate for Tray I (diameter of holes 3.0 mm) with exit weir height 31 mm. V_s is the air flow rate

We were not able to measure the clear liquid height directly. This is an important variable used in many correlations.

AIR–HEAT TRANSFER OIL SYSTEM

Similar measurements for the air–heat transfer oil system was carried out as were done for the air–water system.

For the air–heat transfer oil system both trays were studied. Measured variables include weeping, entrainment, gas holdup, hydrostatic pressure and pressure drop, clear liquid height, froth height and bubble size. Figure 4 shows measurement results for the hydrostatic pressure and pressure drop as a function of air flow rate.

For the air–heat transfer oil system also the sizes, velocities and local flow directions of the entrained oil droplets could be measured by the photographs taken with the digital camera with shutter speeds $s/200$ and $s/100$.

The full results for both trays and chemical systems are presented by Makkonen [5].

CONCLUSIONS

Bennett and Ludwig [13] reported, that air–water test have some value if the aim is to: predict froth to spay transition, model density corrected entrainment or define the onset of weeping. They claimed that air–water test have little value or not at all for the industry, if the following things are studied: mass-transfer performance, downcomer flooding near

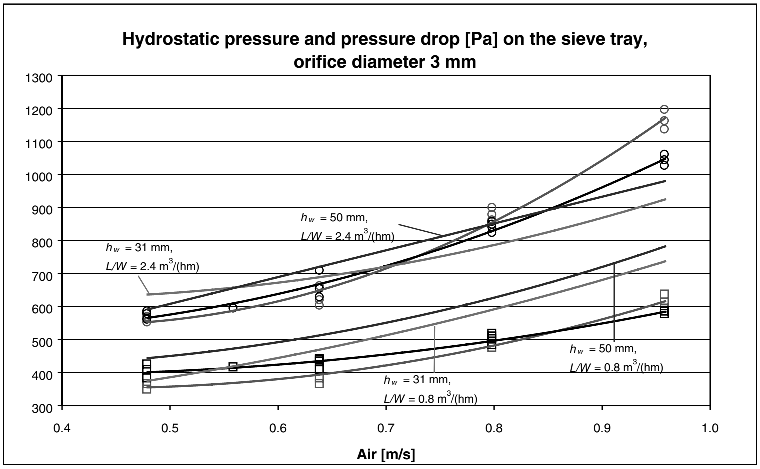

Figure 4. Hydrostatic pressure and pressure drop on Tray I (diameter of holes 3.0 mm) for the air–heat transfer oil system with the clear liquid height calculated with equation of Colwell [11]. The circles and squares represent our measured points, while the lines are calculated pressure drops by correlation of Stichlmair and Fair [12] for the corresponding exit weir heights and flow conditions

the flood point or modeling hydraulic gradient due to frictional forces near the tray deck. We were trying to eliminate the mass transfer totally by using saturated feeds to the measuring equipment and measured only the hydraulic performance related variables. Additionally, we have selected to use air–heat transfer oil system to vary system behavior from the standard air–water system.

The experimental unit built in Laboratory for Chemical Engineering and Plant Design at Helsinki University of Technology has been found to work satisfactorily. Comparison of the results obtained with literature correlations have been found favorable. Small adjustments in the experimental unit has to be done in the future, main issue is the location of the adjustable wall (for downcomer clearance) on the plate side of the liquid entrance on to the plate. This wall has to be relocated on the downcomer side. The unit is useful in teaching purposes on laboratory courses as the transparent walls allow visual inspection of the behavior of a sieve plate. Other types of plates can also be tested in the future. The number of chemical systems to be studied is limited due to the safety issues and the material of construction, i.e. the Perspex acryl plastic walls and the glue used cannot resist many organic solvents. Also, pressure and temperature ranges are limited on this experimental unit. The clear liquid height is one of the critical variables in many correlations and it would be of benefit to be able to directly measure it reliably.

Our goal of obtaining local values for bubble sizes, flow directions, clear liquid height etc. needs some development to fulfill the needs of validation data for multi-block and CFD based distillation tray performance prediction.

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