# APPENDIX A

## SUMMARY OF EXPERIMENTS AND EXPERIMENTAL CONDITIONS

The various experiments conducted during the present study were distinguished by run numbers. A run number consists of two parts; the first part is the batch-number for the wax used in that run, and the second part is the experiment number with the given batch of wax. For example, Run 3-2 corresponds to the second experiment with wax batch-number 3. The set of run numbers used for experiments conducted in the 0.051 m ID glass and stainless steel columns are different from the set used for experiments conducted in the 0.229 m ID glass and 0.241 m ID stainless steel columns. This is because two different wax storage tanks were used for the two different sets of columns (see Section IV-B.), each with its own set of wax batch-numbers.

A new batch of wax was used once the old wax began to turn dark yellow (i.e. FT-200 and FT-300 waxes, which originally are clear) or when experiments with a new type of wax were to be conducted. During the first two wax changes (i.e. between wax batch numbers 1a and 1b, and between 1b and 1c), the entire batch of old wax was not replaced with fresh wax. Instead, the new batch consisted of a large amount of fresh wax added to a small amount of the old wax (from the previous batch). Since the three batches of wax originated from the same batch of fresh wax, they were numbered 1a, 1b and 1c. On an average, six runs were conducted with a batch of FT-300 wax before a change was necessary. A relatively large number of runs were conducted with batch-numbers 1a to 3 in the 0.051 m ID columns because the wax during these runs was stored in the large storage tank (0.085 $m^3$ capacity) while the small storage tank (0.009 $m^3$ capacity) was used for batch-numbers 4 and higher

Three different types of solvents were used to clean the bubble column

apparatus during the present studies. Kerosene, which is relatively inexpensive, was used for series 1a runs, however, due to its dark color, kerosene was replaced by a mineral spirit (varsol) after Run 1c-5. Toluene was used in addition to varsol from Run 2-5 onwards. The use of varsol was limited to instances when the column was fairly dirty.

The column and the distributor section were cleaned with toluene between runs. Approximately 1 liter of the solvent was introduced into the column and the temperature maintained between 100 and 150°C. The toluene vapors rose through the column and condensed along the walls, stripping any wax remaining on the walls. After approximately 20 minutes the toluene was drained through the distributor, removing any wax present in that section. A small nitrogen flow was maintained during the cleaning process. For instances when the column was fairly dirty (i.e. when walls were significantly stained with wax), the toluene wash was preceded by a varsol wash. The varsol was introduced into the column up to a height of approximately 1.5 m and a relatively high flow rate of nitrogen maintained for 20 to 30 minutes, after which the solvent was drained through the distributor. When a different type of wax was to be used, the cleaning process also included the wax storage tank and the wax inlet line. The varsol was drained from the column into the storage tank, through the wax inlet line and then drained through the opening under the storage tank. This process was then repeated using toluene.

Periodically the columns were removed and cleaned manually using steel wool and a detergent. The columns were then rinsed with distilled water and dried. A similar procedure was used to clean the distributor section and the plenum chamber.

All experiments conducted during the course of this study are summarized in Tables A-1 and A-2. Table A-1 summarizes runs conducted in the 0.051 m ID glass and stainless steel columns, and Table A-2 summarizes runs conducted in the 0.229 m ID glass and the 0.241 m ID stainless steel columns.

Table A-1. Summary of experiments performed in the small bubble columns (0.051 m ID).

| Run No. | Wax Type | Column ID (m) | Temperature (°C) | Distributor | Start-up velocity (m/s) | Static height (m) |
|---|---|---|---|---|---|---|
| 1a-1 | FT-300 | 0.051 (glass) | 230-280 | 1.85 mm | 0.01 | 2.2 |
| 1a-2 | " | " | 230-265 | " | 0.03 | 2.1 |
| 1a-3 | " | " | 230,250 | " | 0.065 | 1.9 |
| 1a-4 | " | " | 265 | " | 0.055 | " |
| 1a-5 | " | " | 280 | " | 0.066 | 1.9-2.1 |
| 1a-6 | " | " | 265 | " | 0.024 | 1.7-2.2 |
| 1a-7 | " | " | 250,265 | " | 0.09 | 1.7-1.9 |
| 1a-8 | " | " | 230,250 | " | " | 1.8-2.2 |
| 1a-9 | " | " | 230 | " | 0.10 | 2.2 |
| 1a-10 | " | " | 265 | " | 0.067 | 1.8-2.2 |
| 1a-11 | " | " | 160 | " | 0.07 | 2.0 |
| 1a-12 | " | " | 280 | " | 0.045 | 1.4-1.7 |
| 1a-13 | " | " | 230 | 4.0 mm | 0.093 | 1.9 |
| 1a-14 | " | " | 265 | " | " | 1.7 |
| 1a-15 | " | " | 280 | " | " | 1.5-2.1 |
| 1b-1 | " | " | 230 | 40 $\mu$m SMP | 0.09 | 1.3-2.0 |
| 1b-2 | " | " | 265 | " | " | 0.9-2.1 |
| 1b-3 | " | " | 280 | " | " | 0.8-1.7 |
| 1b-4 | " | " | 265,280 | " | 0.02 | 1.6 |
| 1c-1 | " | " | 230 | 1.85 mm | 0.10 | 2.0 |
| 1c-2 | " | 0.051 (SS) | 265 | " | 0.01 | 2.3 |
| 1c-3 | " | " | " | 4.0 mm | " | 2.2 |
| 1c-4 | " | " | " | 40 $\mu$m SMP | " | 0.6-1.9 |
| 1c-5 | " | 0.051 (glass) | " | 1.85 mm | 0.10 | 2.0 |
| 1c-6 | " | " | " | 4.0 mm" | " | 1.9-2.0 |
| 1c-7 | " | " | " | 40 $\mu$m SMP | " | 1.2-2.0 |
| 1c-8 | " | " | " | 1.85 mm | 0.09 | 1.6-1.9 |
| 1c-9 | " | " | " | " | " | 1.8 |
| 2-1 | " | " | " | " | " | " |
| 2-2 | " | " | " | " | 0.01 | 2.2 |
| 2-3 | " | " | " | " | 0.02 | 2.1 |
| 2-4 | " | " | " | " | 0.01 | " |

Table A-1. (contd.)

| Run No. | Wax Type | Column ID (m) | Temperature (°C) | Distributor | Start-up velocity (m/s) | Static height (m) |
|---|---|---|---|---|---|---|
| 2-5 | FT-300 | 0.051 (glass) | 265 | 4.0 mm | 0.01 | 2.1 |
| 2-6 | " | " | " | " | 0.09 | " |
| 2-7 | " | " | " | 1.85 mm | 0.01 | 1.8-2.2 |
| 2-8 | " | " | " | " | 0.09 | 1.8 |
| 2-9 | " | " | " | 40 $\mu$m SMP | 0.01 | 0.6-1.7 |
| 2-10 | " | " | " | " | 0.17 | 0.7-1.8 |
| 3-1 | " | " | " | 1.85 mm | 0.01 | 2.1 |
| 3-2 | " | " | " | " | " | " |
| 3-3 | " | " | " | 40 $\mu$m SMP | " | 0.8-1.2 |
| 3-4 | " | 0.051 (SS) | " | 1.85 mm | " | 1.8 |
| 3-5 | " | " | " | " | 0.09 | " |
| 3-6 | " | " | " | 4.0 mm | 0.01 | 1.7 |
| 3-7 | " | " | " | 40 $\mu$m SMP | " | " |
| 3-8 | " | 0.051 (glass) | " | 1.85 mm | " | " |
| 4-1 | " | " | " | " | " | 1.9 |
| 4-2 | " | " | " | " | 0.12 | " |
| 4-3 | " | " | 200 | " | 0.01 | " |
| 4-4 | FT-300[a] | " | 265 | " | " | 2.0 |
| 4-5 | FT-300[b] | " | " | " | " | " |
| 4-6 | FT-300[b] | " | " | 40 $\mu$m SMP | " | 0.8-1.5 |
| 5-1 | FT-300 | " | " | " | " | 0.8-1.9 |
| 5-2 | " | " | " | " | 0.12 | 0.8-2.1 |
| 5-3 | " | " | 200 | " | 0.01 | 1.0-1.8 |
| 6-1[c] | " | " | 265 | 1.85 mm | " | 1.8-2.2 |
| 6-2 | " | " | " | 4.0 mm | " | 2.1 |
| 6-3 | " | " | " | " | 0.12 | " |
| 7-1 | " | " | " | 1.85 mm | 0.01 | " |
| 7-2 | " | " | " | 40 $\mu$m SMP | " | 0.9-1.4 |
| 7-3[c] | " | " | " | 1.85 mm | 0.12 | 2.1 |

[a] FT-300 + 5% stearyl alcohol by weight.
[b] FT-300 + 5% stearyl alcohol + 5% stearic acid by weight.
[c] Long term stability run - Duration - 4 hours per velocity

Table A-1. (contd.)

| Run No. | Wax Type | Column ID (m) | Temperature (°C) | Distributor | Start-up velocity (m/s) | Static height (m) |
|---|---|---|---|---|---|---|
| 8-1 | SASOL | 0.051 (glass) | 265 | 1.85 mm | 0.01 | 1.9 |
| 8-2 | " | " | " | " | 0.12 | " |
| 8-3 | " | " | 200 | " | 0.01 | " |
| 8-4 | " | " | 265 | " | " | " |
| 9-1 | MOBIL[d] | " | " | " | " | 2.1 |
| 9-2 | " | " | 200 | " | " | " |
| 9-3 | " | " | 265 | " | 0.12 | 2.0 |
| 9-4 | " | " | " | 40 $\mu$m SMP | 0.01 | 1.8 |
| 10-1 | SASOL | " | " | " | " | 2.1 |
| 11-1 | FT-200 | " | " | 1.85 mm | " | " |
| 11-2 | " | " | 200 | " | " | " |
| 11-3 | " | " | 265 | " | 0.12 | " |
| 11-4 | " | " | 200 | " | 0.01 | " |
| 11-5 | " | " | 265 | " | " | " |
| 12-1 | " | " | 200 | " | " | 1.8-2.1 |
| 12-2 | " | " | 265 | " | " | 2.2 |
| 13-1 | FT-300 | " | " | " | " | 2.1 |
| 13-2 | " | " | 200 | " | " | " |
| 13-3 | " | " | 265 | " | 0.12 | " |
| 14-1 | " | " | " | " | 0.01 | 2.0 |
| 14-2 | " | " | " | " | 0.12 | 2.1 |
| 15-1 | " | " | " | 1.0 mm | 0.01 | 1.9 |
| 15-2 | " | " | " | " | 0.12 | 1.8 |
| 16-1 | " | " | " | 4.0 mm | 0.01 | 2.1 |
| 16-2 | " | " | " | " | 0.12 | 1.7 |
| 17-1 | FT-200 | " | " | 1.0 mm | 0.01 | 1.5-2.0 |
| 17-2 | " | " | " | " | 0.12 | 1.4 |
| 18-1 | " | " | " | 1.85 mm | 0.01 | 1.6 |
| 18-2 | " | " | " | " | 0.12 | " |
| 19-1 | " | " | 200 | " | 0.01 | 1.9 |
| 20-1 | " | " | 265 | 40 $\mu$m SMP | " | .6-1.9 |

[d] Composite from Mobil's runs CT-256-9, -11 and -12.

Table A-1. (contd.)

| Run No. | Wax Type | Column ID (m) | Temperature (°C) | Distributor | Start-up velocity (m/s) | Static height (m) |
|---|---|---|---|---|---|---|
| 21-1 | MOBIL[e] | 0.051 (glass) | 265 | 1.85 mm | 0.01 | 1.9 |
| 21-2 | " | " | " | 40 μm SMP | " | " |
| 21-3 | " | " | " | 1 mm | " | " |
| 21-4 | " | " | 200 | 1.85 mm | " | 2.0 |
| 22-1 | MOBIL[f] | " | 265 | 40 μm SMP | " | 1.9 |
| 22-2 | " | " | " | 1 mm | " | 2.0 |
| 22-3 | " | " | " | 1.85 mm | " | 1.9 |
| 22-4 | " | " | 200 | " | " | " |
| 23-1 | MOBIL[e] +1% FT-200 | " | 265 | 40 μm SMP | " | 2.0 |
| 23-2 | MOBIL[e] +3% FT-200 | " | " | " | " | " |
| 23-3 | " | " | " | 1 mm | " | " |
| 24-1 | MOBIL[f] +1% FT-200 | " | " | " | " | 2.1 |
| 24-2 | MOBIL[f] +3% FT-200 | " | " | " | " | " |
| 24-3 | MOBIL[f] +5% FT-200 | " | " | " | " | 2.2 |

[e] Composite from Mobil's runs CT-255-4 and -7.
[f] Composite from Mobil's runs CT-256-5 and -8.

Table A-2. Summary of experiments performed in the large bubble columns (0.229 - 0.241 m ID).

| Run No. | Wax Type | Column ID (m) | Temperature (°C) | Distributor | Start-up velocity (m/s) | Static height (m) |
|---|---|---|---|---|---|---|
| 1-1 | FT-300 | 0.229 (glass) | 200 | 19 x 1.85 mm | 0.01 | 1.9 |
| 1-2 | " | " | 265 | " | " | " |
| 1-3 | " | " | " | " | " | " |
| 1-4 | " | " | " | " | 0.09 | 2.0 |
| 1-5 | " | " | " | 30 x 1.5 mm [a] | 0.01 | 1.8 |
| 1-6 | " | " | " | 19 x 1.0 mm | " | " |
| 2-1 | " | " | 200 | " | " | 2.1 |
| 2-2 | " | " | 265 | " | " | 2.0 |
| 2-3 | " | " | " | 19 x 1.85 mm | " | " |
| 2-4 | " | " | " | " | 0.12 | " |
| 2-5 | " | 0.241 (SS) | " | " | 0.01 | 1.3-2.0 |
| 2-6 | " | " | 200 | " | " | 1.8 |
| 2-7 | " | " | 265 | " | " | 2.1 |
| 2-8 | " | 0.229 (glass) | " | " | " | " |
| 2-9 | " | " | 265 | " | 0.12 | 2.0 |
| 3-1 | SASOL | 0.241 (SS) | " | " | 0.01 | " |
| 3-2 | " | 0.229 (glass) | " | " | " | 1.7 |
| 3-3 | " | " | " | " | " | 2.0 |
| 3-4 | " | " | 200 | " | " | " |
| 4-1 | FT-300 | " | 265 | 5 x 1.0 mm | " | 2.1 |
| 4-2 | " | " | 170 | " | " | 1.9 |

[a] perforated pipe distributor.