CHAPTER VIII

CONCLUSIONS AND RECOMMENDATIONS

From this experimental study of bubble columns using different liquid mediums, two different column diameters, different distributors, and different modes of operation, the following conclusions were derived: Paraffin waxes have a tendency to foam when heated to high temperatures (> 200 °C). The amount of foam produced increases with decrease in the orifice size of the gas distributor, also with decrease in column diameter. When experiments are conducted in decreasing order of superficial gas velocity the amount of foam produced decreases (lower hold-ups are obtained). The transition to slug flow regime or the churn-turbulent regime is characterized by the disapearance of foam. In the absence of foam the hold-ups are independent of the column geometry and operating temperature. Reactor waxes (Sasol and Mobil reactor waxes) do not have a foaming behavior and the hold-ups are independent of column geometry and operating temperature. Bubble size measurement shows that Sauter mean diameters for FT derived waxes increases in the following order FT-300 wax < Sasol reactor wax < Mobil reactor wax. The hold-ups for FT derived waxes can be predicted using the correlation developed by Bach and Pilhofer (1978).

Hydrodynamic studies with pure liquids (distilled water and n-butanol) shows that average gas hold-up for pure liquids is independent of column geometry and type of liquid medium. The hold-ups for pure liquids are similar to those obtained with reactor waxes or paraffin waxes in the absence of foam. Bubble size measurement shows that, in bubbly flow regime Sauter mean bubble diameters increase with orifice size of the gas distributor, but once in slug flow regime

Sauter mean bubble diameters are independent of distributor type. Hydrodynamic parameters for pure liquids can be predicted using the correlations developed by Akita and Yoshida, 1973 and 1974.

Addition of n-butanol to distilled water changes water into a non-coalescing medium (foaming medium) by lowering the surface tension, also the amount of foam produced increases with the concentration of n-butanol. The hold-up values for the foaming mixture increase with decrease in the orifice size of the distributor and increase with increase in column diameter (opposite to paraffin waxes). Conducting experiments in increasing or decreasing order of gas velocity has no effect on the average gas hold-up (opposite to the behavior of paraffin waxes, lower hold-ups are obtained in decreasing order of gas velocity). Bubble size measurement shows that in the presence of n-butanol smaller bubbles are formed as compared to pure liquids. Hold-ups for the aqueous solutions of alcohol can be predicted using the correlations by Kelkar *et al.*, 1983 and by Posarac and Tekic (1987). Whereas, the specific gas-liquid interfacial area can be predicted using the correlation developed by Akita and Yoshida, 1974.

Addition of CMC into the foaming mixture changes the mixture into a coalescing medium by increasing it's viscosity. With further addition of CMC it is possible to lower the hold-ups of the foaming medium close to those of the pure liquid, also the foaming behavior of the alcohol solution can be suppressed. Bubble size measurement shows that the presence of CMC results in the formation of larger bubble than those formed in the pure liquid. In bubbly flow regime, the size of the bubbles formed increases with increasing size of the orifice of the gas distributor and there was no strong effect of distributor type on bubble size in the fully developed slug flow regime or churn-turbulent flow regime. Hold-up values

for the non-Newtonian mixtures can be correlated using equation 7.18 which takes into account the physical properties of the liquid medium, column geometry, and dynamic parameters.

To understand more on the influence of physical properties on foaming systems, more experimental studies are required. Experiments should be focused on varying the surface tension of liquid medium by adding small amounts of surfactants to the pure liquid (with minimal changes in density), preferably to obtain a cold liquid mixture which has physical properties similar to those of molten paraffin waxes. Then by varying the viscosity of the liquid mixture using a miscible Newtonian liquid such as, glycerol or sucrose, more studies can be performed as to how can the values of viscosity and surface tension be manipulated to lower foaming while maintaining high values of specific gas-liquid interfacial area. The other alternative method to vary liquid viscosity is the use of inert solid particles suspended in the slurry. Varying solid concentration will vary the slurry viscosity also. This system will be of much more practical importance, because it is analogous to the slurry bubble column used in FT synthesis.

Finally, the dynamic gas disengagement technique, is not applicable for systems which tend to produce unbreakable foam at the interface. To extend this technique to these systems, a movable mechanical foam breaker can be used to disperse the foam as the level falls down. This will enable to monitor the liquid level without having to guess where is the liquid-foam interface.

NOTATIONS

a_g = specific gas-liquid interfacial area, m^2/m^3
b_i = intercept associated with the i-th line
d_B = bubbles diameter i, mm
d_{Bi} = diameter of bubbles in class i, mm
$C_{\ell,i}$ = concentration of component i in liquid phase, mol/m^3
C_i^* = equilibrium concentration of component i in liquid phase, mol/m^3
d_c = column diameter, m
d_{cat} = diameter of solid particles, m
d_o = orifice diameter, mm
d_s = Sauter mean bubble diameter, m
f_i = volume fraction of bubbles of size d_{Bi}
g = gravity constant = 9.81 m/s^2
H = expanded bed height at time t, m
H_e = expanded bed height at time 0, m
H_s = static bed height, m
K = consistency index, $Pa.s^n$
k_l = liquid side mass transfer coefficient, m/s
l = ring circumference, m
m = mass, kg
n = flow behavior index
n_i = number of bubbles of size d_{Bi}
n_o = number of holes in a perforated plate
N = number of bubble size classes from DGD technique
P = observed apparent surface tension, N/m
p = pressure, Pa
S = calculated apparent surface tension, N/m
s_i = slope associated with the i-th line
t = time, s
T = operating temperature, °C
u_{Bi} = swarm velocity associated with bubbles of size d_{Bi}, m/s
$u_{Bi\infty}$ = rise velocity for a bubbles of size d_{Bi}, m/s
u_g = superficial gas velocity, m/s
u_j = jet velocity, m/s
V = voltage, v
V_g = volume of gas in the gas-liquid dispersion, m^3
V_i = volume of gas bubbles of size d_{Bi}, m^3
V_T = total volume of gas-liquid dispersion, m^3
w_{cat} = wt. % of solid particles

Greek Letters

ϵ_g	= average gas hold-up, (%)
ϵ_{go}	= fraction average gas hold-up
ϵ_{goi}, ϵ_i	= average gas hold-up due to the presence of bubbles of size d_{B_i}
$\dot{\gamma}$	= shear rate, s^{-1}
μ, μ_l	= liquid viscosity, Pa.s
μ_a	= apparent viscosity, $K\dot{\gamma}^{n-1}$, Pa.s
ρ_g	= gas density, kg/m^3
ρ_l	= liquid density, kg/m^3
σ_l	= liquid surface tension, N/m
τ	= shear stress, $Pa.s^n$

Dimensionless Numbers

N_{Bo}	= Bond number, $d_c{}^2\rho_l g/\sigma_l$
N_F	= flow number, $g d_B{}^{3/3}(\rho_l - \rho_g)\rho_l{}^{2/3}/\mu_l{}^{4/3}\sigma_l{}^{1/3}$
N_{Fr}	= Froude number, $u_g/\sqrt{d_c g}$
N_{Ga}	= Galileo number, $d_c{}^3\rho_l{}^2 g/\mu_l{}^2$
N_V	= velocity number, $u_B d_B{}^{2/3}\rho_l{}^{2/3}/\mu_l{}^{4/3}\sigma_l{}^{1/3}$
N_{We}	= Weber number (orifice), $d_o\rho_g u_j{}^2/\sigma_l$

Acronyms

CMC	= Carboxymethyl cellulose
DGD	= dynamic gas disengagement
FT, F-T	= Fischer Tropsch
ID	= inside diameter
KW	= Krupp wax
PP	= perforated plate
PW	= product wax
SMP	= sintered metal plate
SN	= single nozzle

Subscripts

B	= bubble
g	= gas
l	= liquid
L	= large
M	= medium
o	= at time=0
S	= small

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APPENDIX A

SUMMARY OF RUNS WITH FT DERIVED WAXES

Table A.1. Summary of Run 3-3

Date: 01-17-87	Liquid: Sasol wax
Column ID: 22.9 cm	Temperature: 265°C
Distributor: 19 x 1.85 mm	Gas: Nitrogen

Gas Velocity (cm/s)	1	2	3	4	5	7	9	12
Static Height (cm)	202.6	203.2	201.0	199.4	196.9	193.7	1192.4	189.2
Gas hold-up (%)	5.81	10.03	11.70	12.8	14.44	16.67	18.02	20.81
Foam (cm)	1.6	2.2	1.3	-	-	-	-	-
Slug Frequency (1/s)	-	-	-	-	-	-	-	-
Height slugs observed (cm)	-	-	-	-	-	-	-	-
Amplitude of Oscillation (cm)	0.5	0.8	1.6	3.2	4.4	4.8	5.1	5.7

Table A.2. Summary of Run 3-4

Date: 01-20-87	Liquid: Sasol wax
Column ID: 22.9 cm	Temperature: 200°C
Distributor: 19 x 1.85 mm	Gas: Nitrogen

Gas Velocity (cm/s)	1	2	3	4	5	7	9	12
Static Height (cm)	203.2	202.9	203.2	199.4	199.1	200.7	201.3	202.6
Gas hold-up (%)	5.23	10.90	12.20	13.30	14.58	15.96	17.00	18.50
Foam (cm)	2.5	2.2	1.3	1.0	-	-	-	-
Slug Frequency (1/s)	-	-	-	-	-	-	-	-
Height slugs observed (cm)	-	-	-	-	-	-	-	-
Amplitude of Oscillation (cm)	0.5	0.8	1.0	1.6	3.2	4.1	4.1	4.8

Table A.3. Summary of Run 4-1

Date: 02-24-87				Liquid: FT-300 wax				
Column ID: 22.9 cm				Temperature: 265°C				
Distributor: 5 x 1.00 mm				Gas: Nitrogen				
Gas Velocity (cm/s)	1	2	3	4	5	7	9	12
Static Height (cm)	207.3	206.7	206.4	206.4	206.2	206.1	-	-
Gas hold-up (%)	9.81	28.14	28.73	17.62	18.00	20.00	-	-
Foam (cm)	10.2	71.1	20.3	-	-	-	-	-
Slug Frequency (1/s)	-	-	-	-	-	-	-	-
Height slugs observed (cm)	-	-	-	-	-	-	-	-
Amplitude of Oscillation (cm)	0.2	0.6	1.3	3.2	4.4	5.7	-	-

Table A.4. Summary of Run 4-2

Date: 02-26-87				Liquid: FT-300 wax				
Column ID: 22.9 cm				Temperature: 170°C				
Distributor: 5 x 1.00 mm				Gas: Nitrogen				
Gas Velocity (cm/s)	1	2	3	4	5	7	9	12
Static Height (cm)	191.8	191.8	191.5	191.3	191.1	191.1	191.0	191.0
Gas hold-up (%)	5.03	8.48	10.74	10.34	9.88	10.01	10.90	11.41
Foam (cm)	0.6	-	-	-	-	-	-	-
Slug Frequency (1/s)	-	-	-	-	-	-	-	-
Height slugs observed (cm)	-	-	-	-	-	-	-	-
Amplitude of Oscillation (cm)	0.3	1.0	1.6	1.9	2.5	3.8	5.1	6.4

Table A.5. Summary of Run 8-1

Date: 09-02-86 Column ID: 5.1 cm Distributor: 1.85 mm				Liquid: Sasol wax Temperature: 265°C Gas: Nitrogen				
Gas Velocity (cm/s)	1	2	3	4	5	7	9	12
Static Height (cm)	193.7	192.4	190.5	189.8	189.3	189.3	187.9	182.9
Gas hold-up (%)	5.08	7.06	9.09	11.01	12.86	15.34	18.23	22.47
Foam (cm)	0.6	0.6	1.1	0.6	0.6	-	-	-
Slug Frequency (1/s)	-	-	-	-	1.3	1.4	1.4	1.4
Height slugs observed (cm)	-	-	-	-	106.7	106.7	106.7	-
Amplitude of Oscillation (cm)	0.6	0.6	1.3	1.27	1.9	1.9	2.5	3.8

Table A.6. Summary of Run 8-2

Date: 09-03-86 Column ID: 5.1 cm Distributor: 1.85 mm				Liquid: Sasol wax Temperature: 265°C Gas: Nitrogen				
Gas Velocity (cm/s)	12	9	7	5	4	3	2	1
Static Height (cm)	189.2	187.3	187.9	187.9	187.9	187.6	186.7	186.7
Gas hold-up (%)	22.93	18.95	15.90	13.20	11.64	9.64	7.06	4.23
Foam (cm)	-	-	-	-	-	0.6	0.6	0.6
Slug Frequency (1/s)	1.4	1.41	1.38	1.32	1.23	1.2	-	-
Height slugs observed (cm)	106.7	106.7	106.7	106.7	106.7	193.04	-	
Amplitude of Oscillation (cm)	3.81	3.81	3.2	2.2	1.9	1.3	0.6	0.6

Table A.7. Summary of Run 8-3

Date: 09-5-86 Column ID: 5.1 cm Distributor: 1.85 mm				Liquid: Sasol wax Temperature: 200°C Gas: Nitrogen				
Gas Velocity (cm/s)	1	2	3	4	5	7	9	12
Static Height (cm)	187.9	187.6	186.7	186.0	185.4	184.8	183.5	183.5
Gas hold-up (%)	3.79	7.51	9.9	11.3	13.44	16.14	18.9	21.32
Foam (cm)	0.6	0.9	0.7	0.3	-	-	-	-
Slug Frequency (1/s)	-	-	1.5	1.6	1.8	1.6	1.9	2.7
Height slugs observed (cm)	-	-	-	-	106.7	106.7	106.7	106.7
Amplitude of Oscillation (cm)	0.3	0.6	1.2	1.6	2.5	2.5	3.8	5.1

Table A.8. Summary of Run 8-4

Date: 09-6-86 Column ID: 5.1 cm Distributor: SMP				Liquid: Sasol wax Temperature: 265°C Gas: Nitrogen				
Gas Velocity (cm/s)	1	2	3	4	5	7	9	-
Static Height (cm)	208.9	208.9	208.6	206.7	206.4	205.7	204.2	-
Gas hold-up (%)	4.91	7.41	10.2	12.26	13.33	16.7	19.28	-
Foam (cm)	0.6	1.3	1.3	1.6	0.95	-	-	-
Slug Frequency (1/s)	-	-	1.3	1.6	1.8	2.0	2.0	-
Height slugs observed (cm)	193.0	193.0	106.7	106.7	106.7	106.7	106.7	-
Amplitude of Oscillation (cm)	0.32	0.64	0.95	1.3	1.3	2.54	4.4	-

Table A.9. Summary of Run 9-1

Date: 09-10-86				Liquid: Mobil wax Composite Runs 9, 11 & 12				
Column ID: 5.1 cm Distributor: 1.85 mm				Temperature: 265°C Gas: Nitrogen				
Gas Velocity (cm/s)	1	2	3	4	5	7	9	12
Static Height (cm)	214.3	213.4	212.1	211.77	207.6	206.4	203.7	-
Gas hold-up (%)	4.07	7.03	9.44	10.87	12.80	15.36	18.59	-
Foam (cm)	0.6	0.6	0.3	-	-	-	-	-
Slug Frequency (1/s)	-	-	-	-	1.	1.7	1.4	-
Height slugs observed (cm)	-	-	-	-	106.7	106.7	106.7	-
Amplitude of Oscillation (cm)	0.3	0.3	0.95	1.27	1.9	3.8	4.44	-

Table A.10. Summary of Run 9-2

Date: 09-12-86				Liquid: Mobil wax Composite Runs 9, 11 & 12				
Column ID: 5.1 cm Distributor: 1.85 mm				Temperature: 200°C Gas: Nitrogen				
Gas Velocity (cm/s)	1	2	3	4	5	7	9	12
Static Height (cm)	214.2	213.4	211.5	209.2	207.0	206.7	206.1	205.7
Gas hold-up (%)	4.59	7.00	9.06	11.06	12.76	15.01	17.85	21.2
Foam (cm)	0.6	0.6	-	-	-	-	-	-
Slug Frequency (1/s)	-	-	-	-	1.0	1.55	1.63	2.0
Height slugs observed (cm)	-	-	-	-	106.7	106.7	106.7	106.7
Amplitude of Oscillation (cm)	0.32	0.32	0.63	1.6	1.9	2.54	3.8	5.1

Table A.11. Summary of Run 9-3

Date. 09-13-86				Liquid: Mobil wax Composite Runs 9, 11 & 12				
Column ID: 5.1 cm Distributor: 1.85 mm				Temperature: 265°C Gas: Nitrogen				
Gas Velocity (cm/s)	12	9	7	5	4	3	2	1
Static Height (cm)	204.5	201.1	200.7	200.7	200.7	200.3	199.4	198.8
Gas hold-up (%)	22.2	18.93	15.62	12.70	11.50	9.33	7.46	4.71
Foam (cm)	-	-	-	-	-	0.32	0.64	0.64
Slug Frequency (1/s)	1.6	1.3	1.2	1.16	1.0	-	-	-
Height slugs observed (cm)	101.6	101.6	101.6	101.6	101.6	-	-	-
Amplitude of Oscillation (cm)	3.8	2.54	1.9	1.6	1.58	1.22	0.32	0.32

Table A.12. Summary of Run 9-4

Date: 09-15-86				Liquid: Mobil wax Composite Runs 9, 11 & 12				
Column ID: 5.1 cm Distributor: SMP				Temperature: 265°C Gas: Nitrogen				
Gas Velocity (cm/s)	1	2	3	4	5	7	9	12
Static Height (cm)	193.0	173.4	171.7	170.6	170.6	169.7	169.2	167.9
Gas hold-up (%)	20.7	10.6	11.2	12.3	13.3	16.2	18.8	19.8
Foam (cm)	14.3	1.3	0.6	0.3	-	-	-	-
Slug Frequency (1/s)	-	-	-	1.0	1.4	1.6	1.7	2.0
Height slugs observed (cm)	-	-	-	-	101.6	101.6	101.6	101.6
Amplitude of Oscillation (cm)	0.32	0.64	0.95	1.3	1.9	2.54	3.8	6.4

Table A.13. Summary of Run 9-5

Date: 05-15-87				Liquid: Mobil wax Composite Runs 4 & 7				
Column ID: 5.1 cm				Temperature: 265°C				
Distributor: 1.85 mm				Gas: Nitrogen				
Gas Velocity (cm/s)	1	2	3	4	5	7	9	12
Static Height (cm)	194.0	191.1	189.9	188.9	187.6	188.0	187.0	184.2
Gas hold-up (%)	3.32	7.10	11.00	14.26	15.08	17.08	19.54	23.48
Foam (cm)	0.3	0.3	0.6	0.6	-	-	-	-
Slug Frequency (1/s)	-	-	-	-	-	-	-	-
Height slugs observed (cm)	-	-	-	-	-	-	-	-
Amplitude of Oscillation (cm)	0.3	0.5	0.6	1.0	1.3	1.7	2.2	3.2

Table A.14. Summary of Run 9-6

Date: 05-15-87				Liquid: Mobil wax Composite Runs 4 & 7				
Column ID: 5.1 cm				Temperature: 265°C				
Distributor: 40 μm SMP				Gas: Nitrogen				
Gas Velocity (cm/s)	1	2	3	4	5	7	9	12
Static Height (cm)	188.0	187.0	185.4	184.8	183.8	182.9	182.2	181.3
Gas hold-up (%)	8.36	12.35	14.37	15.65	15.84	17.63	19.38	22.84
Foam (cm)	3.8	2.2	1.3	-	-	-	-	-
Slug Frequency (1/s)	-	-	-	-	-	-	-	-
Height slugs observed (cm)	-	-	-	-	-	-	-	-
Amplitude of Oscillation (cm)	0.3	0.6	0.6	1.0	1.3	1.7	2.2	2.9

Table A.15. Summary of Run 9-7

Date: 05-18-87				Liquid: Mobil wax Composite Runs 4 & 7				
Column ID: 5.1 cm Distributor: 1.00 mm				Temperature: 265°C Gas: Nitrogen				
Gas Velocity (cm/s)	1	2	3	4	5	7	9	12
Static Height (cm)	192.4	191.8	189.9	188.9	188.0	186.1	182.9	177.8
Gas hold-up (%)	3.38	7.36	11.22	13.01	14.94	17.69	20.0	23.91
Foam (cm)	-	0.5	0.6	0.3	-	-	-	-
Slug Frequency (1/s)	-	-	-	-	-	-	-	-
Height slugs observed (cm)	-	-	-	-	-	-	-	-
Amplitude of Oscillation (cm)	0.3	0.3	0.6	1.3	1.7	2.2	2.5	3.5

Table A.16. Summary of Run 9-8

Date: 05-19-87				Liquid: Mobil wax Composite Runs 4 & 7				
Column ID: 5.1 cm Distributor: 1.85 mm				Temperature: 200°C Gas: Nitrogen				
Gas Velocity (cm/s)	1	2	3	4	5	7	9	12
Static Height (cm)	200.0	198.0	194.9	193.4	192.4	191.5	190.5	189.5
Gas hold-up (%)	3.37	6.66	9.44	11.09	12.43	15.42	18.03	21.45
Foam (cm)	-	-	-	-	-	-	-	-
Slug Frequency (1/s)	-	-	-	-	-	-	-	-
Height slugs observed (cm)	-	-	-	-	-	-	-	-
Amplitude of Oscillation (cm)	0.3	0.5	0.6	0.6	1.3	1.9	2.5	3.2

Table A.17. Summary of Run 9-9

Date: 05-20-87				Liquid: Mobil wax Composite Runs 5 & 8				
Column ID: 5.1 cm				Temperature: 265°C				
Distributor: 40 μm SMP				Gas: Nitrogen				
Gas Velocity (cm/s)	1	2	3	4	5	7	9	12
Static Height (cm)	195.3	194.0	193.0	191.5	189.9	188.6	188.0	186.5
Gas hold-up (%)	4.95	7.70	9.52	11.32	12.57	15.74	18.00	21.88
Foam (cm)	0.6	0.6	0.3	-	-	-	-	-
Slug Frequency (1/s)	-	-	-	-	-	-	-	-
Height slugs observed (cm)	-	-	-	-	-	-	-	-
Amplitude of Oscillation (cm)	0.2	0.3	1.0	1.3	1.9	2.5	3.2	4.4

Table A.18. Summary of Run 9-10

Date: 05-21-87				Liquid: Mobil wax Composite Runs 5 & 8				
Column ID: 5.1 cm				Temperature: 265°C				
Distributor: 1.00 mm				Gas: Nitrogen				
Gas Velocity (cm/s)	1	2	3	4	5	7	9	12
Static Height (cm)	198.8	197.8	197.5	196.2	195.6	194.3	191.8	190.5
Gas hold-up (%)	3.54	6.59	8.39	10.43	12.00	15.11	17.93	21.05
Foam (cm)	0.5	0.6	-	-	-	-	-	-
Slug Frequency (1/s)	-	-	-	-	-	-	-	-
Height slugs observed (cm)	-	-	-	-	-	-	-	-
Amplitude of Oscillation (cm)	0.2	0.3	0.6	1.3	1.7	1.9	2.5	3.8

Table A.19. Summary of Run 9-11

Date: 05-22-87 Column ID: 5.1 cm Distributor: 1.85 mm				Liquid: Mobil wax Composite Runs 5 & 8 Temperature: 265°C Gas: Nitrogen				
Gas Velocity (cm/s)	1	2	3	4	5	7	9	12
Static Height (cm)	197.6	194.5	193.0	191.8	190.8	190.5	189.5	188.3
Gas hold-up (%)	3.94	7.20	8.98	10.65	12.13	14.77	17.31	21.14
Foam (cm)	0.6	0.6	0.3	-	-	-	-	-
Slug Frequency (1/s)	-	-	-	-	-	-	-	-
Height slugs observed (cm)	-	-	-	-	-	-	-	-
Amplitude of Oscillation (cm)	0.2	0.3	0.6	1.3	1.9	2.5	3.2	3.8

Table A.20. Summary of Run 9-12

Date: 05-22-87 Column ID: 5.1 cm Distributor: 1.85 mm				Liquid: Mobil wax Composite Runs 4 & 7 Temperature: 200°C Gas: Nitrogen				
Gas Velocity (cm/s)	1	2	3	4	5	7	9	12
Static Height (cm)	196.5	195.6	194.9	194.6	194.6	194.0	193.4	193.0
Gas hold-up (%)	3.28	5.81	7.95	9.85	11.41	14.42	17.25	20.0
Foam (cm)	0.5	-	-	-	-	-	-	-
Slug Frequency (1/s)	-	-	-	-	-	-	-	-
Height slugs observed (cm)	-	-	-	-	-	-	-	-
Amplitude of Oscillation (cm)	0.2	0.6	1.0	1.3	1.9	2.5	3.2	3.8

Table A.21. Summary of Run 10-1

Date: 09-17-86				Liquid: Sasol wax				
Column ID: 5.1 cm				Temperature: 265°C				
Distributor: 40 μm SMP				Gas: Nitrogen				
Gas Velocity (cm/s)	1	2	3	4	5	7	9	12
Static Height (cm)	209.6	209.2	207.9	206.7	203.8	202.7	201.9	200.9
Gas hold-up (%)	10.08	10.74	12.40	13.08	14.55	17.43	19.56	22.55
Foam (cm)	1.6	1.3	1.0	0.6	0.6	0.3	-	-
Slug Frequency (1/s)	-	-	1.5	1.7	1.8	2.1	2.5	2.8
Height slugs observed (cm)	-	-	102.0	102.0	102.0	102.0	102.0	102.0
Amplitude of Oscillation (cm)	0.2	0.6	1.3	1.9	2.5	3.8	5.1	6.4

Table A.22. Summary of Run 11-1

Date: 08-10-86				Liquid: FT-200 wax				
Column ID: 5.1 cm				Temperature: 265°C				
Distributor: 1.85 mm				Gas: Nitrogen				
Gas Velocity (cm/s)	1	2	3	4	5	7	9	12
Static Height (cm)	208.9	208.3	207.0	206.7	206.0	206.0	203.5	202.6
Gas hold-up (%)	6.80	7.34	10.30	11.55	13.19	15.27	18.16	21.42
Foam (cm)	0.5	0.6	0.6	0.3	-	-	-	-
Slug Frequency (1/s)	-	-	-	1.2	1.7	2.0	2.1	2.2
Height slugs observed (cm)	-	-	-	102.0	102.0	102.0	102.0	102.0
Amplitude of Oscillation (cm)	0.3	0.5	0.6	1.3	1.6	2.2	3.2	6.0

Table A.23. Summary of Run 11-2

Date: 10-10-86 Column ID: 5.1 cm Distributor: 1.85 mm				Liquid: FT-200 wax Temperature: 200°C Gas: Nitrogen				
Gas Velocity (cm/s)	1	2	3	4	5	7	9	12
Static Height (cm)	212.7	212.7	212.7	212.7	213.4	213.4	214.0	214.0
Gas hold-up (%)	3.88	11.43	20.71	19.86	18.58	16.42	18.34	22.0
Foam (cm)	0.6	7.3	35.6	24.1	7.6	-	-	-
Slug Frequency (1/s)	-	-	-	1.0	1.8	2.2	2.5	2.6
Height slugs observed (cm)	-	-	-	102.0	102.0	102.0	102.0	102.0
Amplitude of Oscillation (cm)	0.3	0.4	1.0	1.6	1.6	2.2	3.2	4.4

Table A.24. Summary of Run 11-3

Date: 10-10-86 Column ID: 5.1 cm Distributor: 1.85 mm				Liquid: FT-200 wax Temperature: 265°C Gas: Nitrogen				
Gas Velocity (cm/s)	12	9	7	5	4	3	2	1
Static Height (cm)	214.0	213.7	211.8	210.2	208.9	207.9	208.3	207.6
Gas hold-up (%)	23.4	18.9	16.2	13.8	12.5	12.46	7.7	4.1
Foam (cm)	-	-	-0.3	0.6	2.3	2.3	1.0	0.3
Height slugs observed (cm)	1.9	1.7	1.6	1.5	1.3	-	-	-
Amplitude of Oscillation (cm)	102.0	102.0	102.0	102.0	102.0	-	-	-

Table A.25. Summary of Run 11-4

Date: 10-13-86
Column ID: 5.1 cm
Distributor: 1.85 mm
Liquid: FT-200 wax
Temperature: 200°C
Gas: Nitrogen

Gas Velocity (cm/s)	1	2	3	4	5	7	9	12
Static Height (cm)	209.6	211.1	211.8	213.4	213.0	213.0	213.8	214.3
Gas hold-up (%)	3.86	11.8	22.8	25.7	26.0	23.7	21.9	23.3
Foam (cm)	0.6	14.6	38.1	45.7	50.8	15.2	-	-
Slug Frequency (1/s)	-	1.0	1.4	1.5	1.5	2.0	2.3	2.4
Height slugs observed (cm)	-	230.0	234.0	234.0	102.0	102.0	102.0	102.0
Amplitude of Oscillation (cm)	0.3	0.6	1.3	2.2	2.5	3.2	3.5	5.7

Table A.26. Summary of Run 11-5

Date: 10-15-86
Column ID: 5.1 cm
Distributor: 1.85 mm
Liquid: FT-200 wax
Temperature: 265°C
Gas: Nitrogen

Gas Velocity (cm/s)	1	2	3	4	5	7	9	12
Static Height (cm)	212.7	214.0	214.0	214.0	213.4	213.0	212.7	-
Gas hold-up (%)	4.42	12.54	22.47	23.1	28.8	27.7	24.7	-
Foam (cm)	1.3	10.2	34.3	31.0	33.8	17.8	0.6	-
Slug Frequency (1/s)	-	0.8	1.2	1.4	1.4	1.3	1.5	-
Height slugs observed (cm)	-	231.0	183.0	63.5	63.5	45.7	30.5	-
Amplitude of Oscillation (cm)	0.3	0.6	0.8	1.6	1.6	2.8	3.8	-

Table A.27. Summary of Run 12-1

Date: 10-18-86				Liquid: FT-200 wax				
Column ID: 5.1 cm				Temperature: 200°C				
Distributor: 1.85 mm				Gas: Nitrogen				
Gas Velocity (cm/s)	1	2	3	4	5	7	9	12
Static Height (cm)	210.2	209.6	209.2	208.6	207.6	207.8	206.4	176.84
Gas hold-up (%)	4.52	8.92	17.35	23.25	27.33	31.1	31.1	42.0
Foam (cm)	0.3	1.0	17.8	33.0	33.0	33.0	5.0	2.5
Slug Frequency (1/s)	-	1.3	1.3	1.2	1.2	1.2	1.2	1.1
Height slugs observed (cm)	-	213.0	175.0	94.0	58.0	30.0	30.0	30.0
Amplitude of Oscillation (cm)	0.3	0.6	0.8	1.6	3.2	4.4	5.7	7.6

Table A.28. Summary of Run 12-2

Date: 10-20-86				Liquid: FT-200 wax				
Column ID: 5.1 cm				Temperature: 265°C				
Distributor: 1.85 mm				Gas: Nitrogen				
Gas Velocity (cm/s)	1	2	3	4	5	7	9	12
Static Height (cm)	215.6	215.6	214.5	214.0	213.4	-	114.6	-
Gas hold-up (%)	4.50	12.56	19.60	21.80	32.60	-	51.10	-
Foam (cm)	0.3	9.1	7.6	16.0	50.0	-	102.0	-
Slug Frequency (1/s)	-	0.5	1.3	1.2	1.1	-	1.3	-
Height slugs observed (cm)	-	234.0	152.4	84.0	84.0	-	30.0	-
Amplitude of Oscillation (cm)	0.3	0.4	0.9	1.6	3.2	-	3.2	-

Table A.29. Summary of Run 13-1

Date: 10-25-86					Liquid: FT-300 wax			
Column ID: 5.1 cm					Temperature: 265°C			
Distributor: 1.85 mm					Gas: Nitrogen			
Gas Velocity (cm/s)	1	2	3	4	5	7	9	12
Static Height (cm)	208.8	207.3	206.0	205.1	204.4	204.4	204.0	202.6
Gas hold-up (%)	4.42	19.60	29.46	32.3	27.30	18.90	19.75	23.68
Foam (cm)	0.9	37.7	86.4	83.8	35.1	-	-	-
Slug Frequency (1/s)	-	1.4	1.5	1.6	1.7	1.4	1.5	1.7
Height slugs observed (cm)	-	218.4	182.8	147.3	53.3	45.7	45.7	30.0
Amplitude of Oscillation (cm)	0.3	0.5	0.5	1.6	2.1	3.2	4.1	5.7

Table A.30. Summary of Run 13-2

Date: 10-27-86					Liquid: FT-300 wax			
Column ID: 5.1 cm					Temperature: 200°C			
Distributor: 1.85 mm					Gas: Nitrogen			
Gas Velocity (cm/s)	1	2	3	4	5	7	9	12
Static Height (cm)	210.5	210.2	209.6	209.2	209.2	208.9	208.3	208.3
Gas hold-up (%)	5.2	14.3	18.8	19.2	18.4	18.6	21.0	23.9
Foam (cm)	0.9	20.3	17.8	10.1	-	-	-	-
Slug Frequency (1/s)	-	1.0	1.4	1.4	1.5	1.6	1.8	2.0
Height slugs observed (cm)	-	216.0	122.0	76.0	66.0	46.0	30.0	30.0
Amplitude of Oscillation (cm)	0.3	0.5	0.8	0.8	1.6	3.2	4.5	5.7

Table A.31. Summary of Run 13-3

Date: 10-27-86				Liquid: FT-300 wax				
Column ID: 5.1 cm				Temperature: 265°C				
Distributor: 1.85 mm				Gas: Nitrogen				
Gas Velocity (cm/s)	12	9	7	5	4	3	2	1
Static Height (cm)	211.1	209.9	208.6	207.6	207.0	206.0	205.1	205.1
Gas hold-up (%)	25.8	22.7	22.4	25.2	28.1	25.3	20.8	5.9
Foam (cm)	-	-	-	33.0	61.0	46.0	33.0	3.8
Slug Frequency (1/s)	2.0	1.8	1.5	1.3	1.1	1.0	1.0	-
Height slugs observed (cm)	30.0	46.0	81.0	102.0	130.0	180.0	220.0	-
Amplitude of Oscillation (cm)	5.7	4.7	4.4	2.0	1.3	0.9	0.6	0.3

Table A.32. Summary of Run 14-1

Date: 01-23-87				Liquid: FT-300 wax				
Column ID: 5.1 cm				Temperature: 265°C				
Distributor: 1.85 mm				Gas: Nitrogen				
Gas Velocity (cm/s)	1	2	3	4	5	7	9	12
Static Height (cm)	200.0	199.4	198.0	196.5	195.6	195.0	193.7	193.0
Gas hold-up (%)	4.74	20.7	31.83	33.00	19.30	19.21	22.60	26.40
Foam (cm)	0.6	36.0	76.0	81.3	9.0	-	-	-
Slug Frequency (1/s)	-	1.0	1.6	1.8	1.5	1.7	1.6	1.6
Height slugs observed (cm)	-	210.0	210.0	120.0	120.0	120.0	30.0	30.0
Amplitude of Oscillation (cm)	0.2	0.9	1.6	2.2	2.2	3.2	4.1	4.4

Table A.33. Summary of Run 14-2

Date: 01-26-87				Liquid: FT-300 wax				
Column ID: 5.1 cm				Temperature: 265°C				
Distributor: 1.85 mm				Gas: Nitrogen				
Gas Velocity (cm/s)	12	9	7	5	4	3	2	1
Static Height (cm)	212.0	211.0	210.5	209.0	209.0	207.6	207.0	206.4
Gas hold-up (%)	27.55	24.60	23.97	29.10	29.70	30.13	18.30	6.20
Foam (cm)	-	-	2.5	48.0	66.0	76.0	22.8	2.5
Slug Frequency (1/s)	1.6	1.6	1.8	1.5	1.7	1.3	1.0	-
Height slugs observed (cm)	30.0	120.0	120.0	120.0	120.0	120.0	210.0	210.0
Amplitude of Oscillation (cm)	4.8	4.1	3.2	2.2	2.2	1.6	0.5	0.2

Table A.34. Summary of Run 15-1

Date: 01-28-87				Liquid: FT-300 wax				
Column ID: 5.1 cm				Temperature: 265°C				
Distributor: 1.00 mm				Gas: Nitrogen				
Gas Velocity (cm/s)	1	2	3	4	5	7	9	12
Static Height (cm)	193.0	192.4	192.0	191.5	190.8	190.8	190.5	190.0
Gas hold-up (%)	5.74	18.55	34.94	35.57	35.6	29.80	27.40	29.50
Foam (cm)	2.5	28.0	102.0	103.0	76.2	38.1	-	-
Slug Frequency (1/s)	-	1.0	1.7	1.6	1.6	1.8	1.6	1.7
Height slugs observed (cm)	-	210.0	120.0	120.0	120.0	120.0	30.0	30.0
Amplitude of Oscillation (cm)	0.2	0.2	0.8	1.6	2.2	2.2	3.5	4.4

Table A.35. Summary of Run 15-2

Date: 01-29-87 Column ID: 5.1 cm Distributor: 1.00 mm				Liquid: FT-300 wax Temperature: 265°C Gas: Nitrogen				
Gas Velocity (cm/s)	12	9	7	5	4	3	2	1
Static Height (cm)	176.5	176.2	175.9	175.1	174.3	173.7	173.7	173.4
Gas hold-up (%)	29.08	26.13	23.90	40.10	41.35	41.06	18.84	6.5
Foam (cm)	-	-	-	76.2	95.3	106.7	20.3	2.5
Slug Frequency (1/s)	1.3	1.5	1.5	1.4	1.2	1.7	1.6	-
Height slugs observed (cm)	30.0	30.0	120.0	120.0	210.0	210.0	210.0	-
Amplitude of Oscillation (cm)	3.8	3.5	2.2	2.0	1.9	1.3	1.0	0.2

Table A.36. Summary of Run 16-1

Date: 02-11-87 Column ID: 5.1 cm Distributor: 4.0 mm				Liquid: FT-300 wax Temperature: 265°C Gas: Nitrogen				
Gas Velocity (cm/s)	1	2	3	4	5	7	9	12
Static Height (cm)	212.0	21.0	210.9	209.7	208.6	205.0	203.6	165.9
Gas hold-up (%)	6.02	16.31	21.86	30.32	32.24	35.60	36.36	47.95
Foam (cm)	0.6	20.3	27.0	55.0	75.0	57.0	23.0	6.4
Slug Frequency (1/s)	-	0.8	1.2	1.3	1.3	1.4	1.2	1.3
Height slugs observed (cm)	-	210.0	210.0	120.0	120.0	120.0	30.0	30.0
Amplitude of Oscillation (cm)	0.3	0.5	0.9	1.7	3.2	6.3	7.0	8.0

Table A.37. Summary of Run 16-2

Date: 02-12-87				Liquid: FT-300 wax				
Column ID: 5.1 cm				Temperature: 265°C				
Distributor: 4.0 mm				Gas: Nitrogen				
Gas Velocity (cm/s)	12	9	7	5	4	3	2	1
Static Height (cm)	165.0	165.2	166.7	167.8	167.0	165.9	165.6	165.2
Gas hold-up (%)	45.80	43.44	43.05	35.53	30.76	26.18	17.47	5.06
Foam (cm)	7.6	93.0	57.0	61.0	61.0	36.8	23.0	-
Slug Frequency (1/s)	1.3	1.2	1.1	1.3	1.2	1.3	0.8	-
Height slugs observed (cm)	30.0	120.0	120.0	120.0	120.0	210.0	210.0	210.0
Amplitude of Oscillation (cm)	7.6	6.4	5.7	3.8	2.5	1.6	0.6	0.3

Table A.38. Summary of Run 17-1

Date: 02-14-87				Liquid: FT-200 wax				
Column ID: 5.1 cm				Temperature: 265°C				
Distributor: 1.00 mm				Gas: Nitrogen				
Gas Velocity (cm/s)	1	2	3	4	5	7	9	12
Static Height (cm)	199.4	198.6	152.4	151.8	150.5	149.5	147.9	144.8
Gas hold-up (%)	4.85	19.18	30.83	35.58	37.47	48.22	51.46	54.22
Foam (cm)	0.6	25.4	44.5	59.7	67.31	120.7	120.7	107.0
Slug Frequency (1/s)	-	0.7	1.1	1.3	1.4	1.1	1.3	1.5
Height slugs observed (cm)	-	210.0	210.0	120.0	120.0	120.0	120.0	120.0
Amplitude of Oscillation (cm)	0.3	0.4	1.0	1.6	3.2	5.4	7.0	7.3

Table A.39. Summary of Run 17-2

Date: 02-15-87				Liquid: FT-200 wax				
Column ID: 5.1 cm				Temperature: 265°C				
Distributor: 1.00 mm				Gas: Nitrogen				
Gas Velocity (cm/s)	12	9	7	5	4	3	2	1
Static Height (cm)	143.5	140.3	138.4	136.3	135.3	134.6	134.0	-
Gas hold-up (%)	52.6	53.6	53.5	53.3	47.5	32.3	13.9	-
Foam (cm)	114.3	114.3	105.0	93.2	111.8	51.6	9.7	-
Slug Frequency (1/s)	1.7	2.071.9	1.6	1.4	1.2	-	-	
Height slugs observed (cm)	30.0	30.0	30.0	120.0	120.0	200.0	-	-
Amplitude of Oscillation (cm)	5.7	5.7	5.1	3.2	2.0	1.2	0.6	-

Table A.40. Summary of Run 18-1

Date: 02-16-87				Liquid: FT-200 wax				
Column ID: 5.1 cm				Temperature: 265°C				
Distributor: 1.85 mm				Gas: Nitrogen				
Gas Velocity (cm/s)	1	2	3	4	5	7	9	12
Static Height (cm)	163.8	161.9	161.3	159.7	158.8	156.8	154.9	152.4
Gas hold-up (%)	4.79	17.5	32.71	33.11	32.06	32.88	33.97	34.78
Foam (cm)	-	17.8	56.0	62.2	45.7	43.2	22.9	25.4
Slug Frequency (1/s)	-	0.8	1.3	1.4	1.3	1.3	1.5	1.3
Height slugs observed (cm)	-	210.0	210.0	120.0	120.0	120.0	120.0	30.0
Amplitude of Oscillation (cm)	0.2	0.3	1.0	1.6	2.2	3.2	4.4	5.1

Table A.41. Summary of Run 18-2

Date: 02-17-87				Liquid: FT-200 wax				
Column ID: 5.1 cm				Temperature: 265°C				
Distributor: 1.85 mm				Gas: Nitrogen				
Gas Velocity (cm/s)	12	9	7	5	4	3	2	1
Static Height (cm)	160.7	158.1	157.5	156.5	156.7	156.2	155.6	-
Gas hold-up (%)	38.5	37.9	37.9	34.1	23.8	22.4	11.23	-
Foam (cm)	3.8	22.9	47.8	48.3	22.8	17.8	5.1	-
Slug Frequency (1/s)	1.3	1.3	1.3	1.4	1.3	1.2	0.8	-
Height slugs observed (cm)	30.0	120.0	120.0	120.0	120.0	210.0	210.0	-
Amplitude of Oscillation (cm)	5.4	5.1	4.4	2.2	2.5	1.6	0.32	-

Table A.42. Summary of Run 19-1

Date: 02-18-87				Liquid: FT-200 wax				
Column ID: 5.1 cm				Temperature: 200°C				
Distributor: 1.85 mm				Gas: Nitrogen				
Gas Velocity (cm/s)	1	2	3	4	5	7	9	12
Static Height (cm)	191.5	185.1	185.9	186.4	186.7	186.9	187.3	187.3
Gas hold-up (%)	4.46	11.35	22.76	26.26	27.85	29.77	23.57	28.4
Foam (cm)	-	5.1	41.9	53.3	48.3	25.4	-	-
Slug Frequency (1/s)	-	0.7	1.2	1.2	1.2	1.3	1.4	1.3
Height slugs observed (cm)	-	210.0	210.0	120.0	120.0	120.0	120.0	30.0
Amplitude of Oscillation (cm)	0.3	0.6	1.0	1.6	2.2	3.2	3.2	5.1

Table A.43. Summary of Run 20-1

Date: 02-23-87				Liquid: FT-200 wax				
Column ID: 5.1 cm				Temperature: 265°C				
Distributor: 40 μm SMP				Gas: Nitrogen				
Gas Velocity (cm/s)	1	2	3	4	5	7	9	12
Static Height (cm)	186.4	135.9	80.6	80.3	79.4	63.5	62.2	59.7
Gas hold-up (%)	17.32	57.8	74.2	74.8	75.2	80.16	79.6	58.4
Foam (cm)	96.5	102.0	211.0	214.0	214.0	214.0	214.0	214.0
Slug Frequency (1/s)	-	-	1.1	1.0	1.0	1.2	1.21	1.2
Height slugs observed (cm)	-	-	210.0	120.0	120.0	120.0	120.0	30.0
Amplitude of Oscillation (cm)	0.2	0.3	0.8	1.9	3.2	3.8	4.4	5.7