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APPENDICES

Appendix A Physical Properties of Liquids Used in The Experiment

Table A1 Determination the density of surfactant (SDS) solution by pycnometer (volume = 25.499 cm^3)

Procedure to determine the density of SDS solution:

1. Weigh the empty dry pycnometer and record the mass.
2. Fill the pycnometer with SDS solution and take the mass of the filled pycnometer.
3. The difference between the mass of the empty pycnometer and the pycnometer when it is full yields the mass of the SDS solution that is within the pycnometer.
4. Knowing the mass of the SDS solution and the volume of the pycnometer, the density of the SDS solution can be calculated using the equation:

$$\rho = \frac{M}{V} \tag{A1}$$

Note: system temperature, T = 31±0.3 °C

Conc. (g/L)	Empty bottle (g)			Average (g)	Empty bottle + SDS solution (g)			Average (g)	SDS solution weight(g)			Average SDS solution weight (g)	SDS density (ρ_{SDS}), kg/m^3			Average ρ_{SDS}, (kg/m^3)
	1	2	3		1	2	3		1	2	3		1	2	3	
0	32.193	32.204	32.197	32.1986	57.583	57.544	57.563	57.5635	25.389	25.339	25.365	25.3649	995.7	993.7	994.8	994.7
0.2423	32.200	32.201	32.201	32.2014	57.574	57.570	57.556	57.5671	25.374	25.368	25.354	25.3657	995.1	994.9	994.3	994.8
1.9381	32.198	32.201	32.198	32.1993	57.571	57.560	57.568	57.5664	25.373	25.359	25.369	25.3672	995.1	994.5	994.9	994.8
20	32.199	32.202	32.201	32.2010	57.678	57.668	57.668	57.6717	25.479	25.466	25.466	25.4707	999.2	998.7	998.7	998.9
27	32.206	32.203	32.203	32.2043	57.701	57.697	57.697	57.6988	25.495	25.494	25.494	25.4946	999.8	999.8	999.8	999.8
31.009	32.208	32.2	32.201	32.2033	57.690	57.711	57.7	57.7010	25.481	25.511	25.499	25.4977	999.3	1000.5	1000	999.9

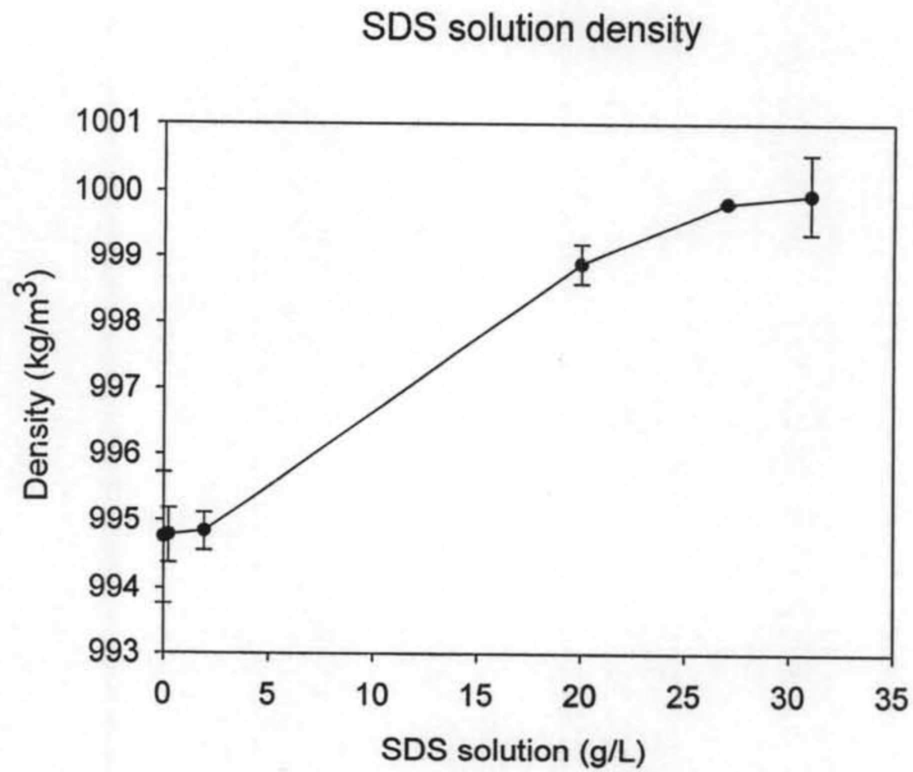

Figure A1 SDS solution density.

Table A2 Determination the viscosity of surfactant (SDS) solution by Cannon-Ubbelohe viscometer

Procedure to determine the viscosity of SDS solution:

1. Use the Cannon-Ubbelohde viscometer size no. 50 which has the approximate constant equal to 0.004 (Figure A2).
2. Fill the SDS solution into Cannon-Ubbelohde viscometer.
3. Mount the Cannon-Ubbelohde viscometer in the constant-temperature (31±0.3 °C) bath and keeping the tube vertical.
4. Apply vacuum to tube N and closing tube M by a finger or rubber stopper to make the SDS solution filling upper bulb D.
5. Let the SDS solution flow by gravitation and timing the level of SDS solution from mark E to mark F. Use the time average value for calculating the kinematic viscosity.
6. Calculate the kinematic viscosity (v) by using equation:

$$\text{Kinematic viscosity } (v),\ mm^2/s = \text{Time(s)} \times \text{approximate constant } ((mm^2/s)/s) \qquad (A2)$$

7. Calculate the viscosity (μ) by using equation:

$$\mu = \upsilon\rho \qquad (A3)$$

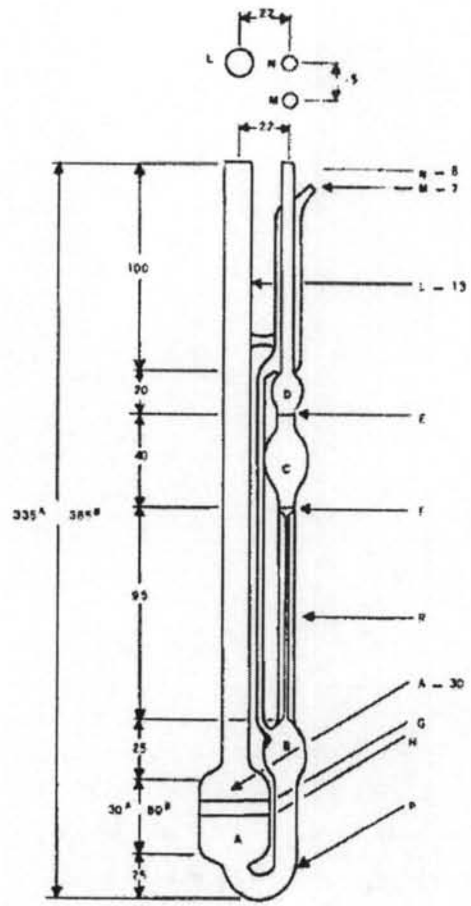

Figure A2 Cannon-Ubbelohde (ASTM D 446-04).

Conc. (g/L)	CMC	Time (sec)			Time average (sec)	Kinematic viscosity (ν), m^2/s			Average kinematic viscosity (ν), m^2/s	SDS solution viscosity (μ_{SDS}), Pa.s			Average SDS solution viscosity (μ_{SDS}), Pa.s
		1	2	3		1	2	3		1	2	3	
0	0	214	214	214	214.0	8.56E-07	8.56E-07	8.56E-07	8.6E-07	8.51E-04	8.51E-04	8.51E-04	8.51E-04
0.2423	0.09	216	215	215	215.3	8.64E-07	8.6E-07	8.6E-07	8.6E-07	8.60E-04	8.56E-04	8.56E-04	8.57E-04
0.4845	0.18	219	219	219	219.0	8.76E-07	8.76E-07	8.76E-07	8.8E-07	8.71E-04	8.71E-04	8.71E-04	8.71E-04
0.969	0.35	224	224	225	224.3	8.96E-07	8.96E-07	9E-07	9E-07	8.91E-04	8.91E-04	8.95E-04	8.93E-04
1.9381	0.7	246	246	246	246.0	9.84E-07	9.84E-07	9.84E-07	9.8E-07	9.79E-04	9.79E-04	9.79E-04	9.79E-04
3.8762	1.41	265	266	265	265.3	1.06E-06	1.06E-06	1.06E-06	1.1E-06	1.05E-03	1.06E-03	1.05E-03	1.06E-03
7.7523	2.82	285	285	285	285.0	1.14E-06	1.14E-06	1.14E-06	1.1E-06	1.14E-03	1.14E-03	1.14E-03	1.14E-03
15.5046	5.64	348	347	348	347.7	1.39E-06	1.39E-06	1.39E-06	1.4E-06	1.39E-03	1.39E-03	1.39E-03	1.39E-03
20	7.27	442	441	440	441.0	1.77E-06	1.76E-06	1.76E-06	1.8E-06	1.77E-03	1.76E-03	1.76E-03	1.76E-03
27	9.82	556	556	556	556.0	2.22E-06	2.22E-06	2.22E-06	2.2E-06	2.22E-03	2.22E-03	2.22E-03	2.22E-03
31.0093	11.28	737	739	736	737.3	2.95E-06	2.96E-06	2.94E-06	2.9E-06	2.95E-03	2.96E-03	2.94E-03	2.95E-03

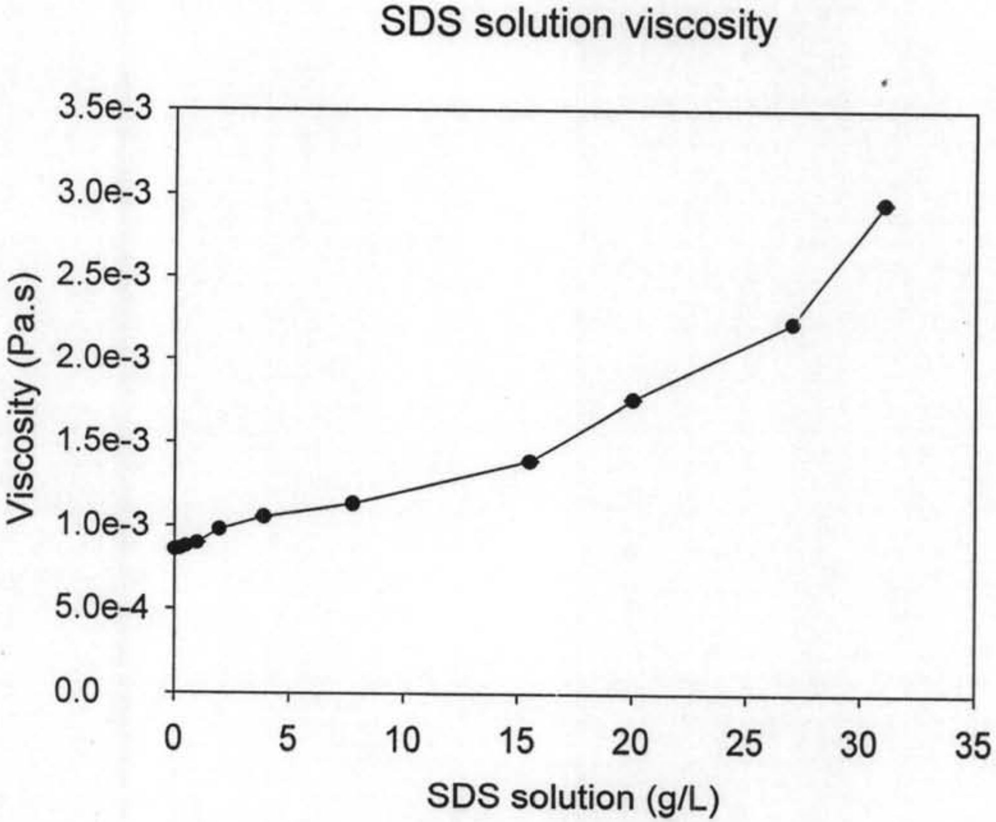

Figure A3 SDS solution viscosity.

Table A3 Determination the electrical conductivity of surfactant (SDS) solution by TDS meter

Procedure to determine the electrical conductivity of SDS solution:

1. Fill the empty dry beaker with the SDS solution.
2. Put the probe of the TDS meter (ORION model 124) in the SDS solution to measure the electrical conductivity.
3. Read the value from the monitor.

g/L	conductivity (µS/cm)			Average conductivity (µS/cm)
	1	2	3	
0	1.7	1.8	1.7	1.7
0.2423	247	247	246	246.7
0.4845	428	427	428	427.7
0.969	790	793	792	791.7
1.8	1251	1252	1251	1251.3
2	1402	1404	1405	1403.7
2.1	1498	1497	1496	1497.0
2.2	1524	1526	1526	1525.3
2.3	1647	1649	1648	1648.0
2.4	1655	1656	1654	1655.0
2.5	1708	1707	1706	1707.0
2.6	1764	1765	1767	1765.3
2.7	1928	1926	1924	1926.0
3	2010	2000	2010	2006.7
3.2	2070	2070	2070	2070.0
3.8762	2220	2240	2230	2230.0
7.7523	3330	3340	3330	3333.3

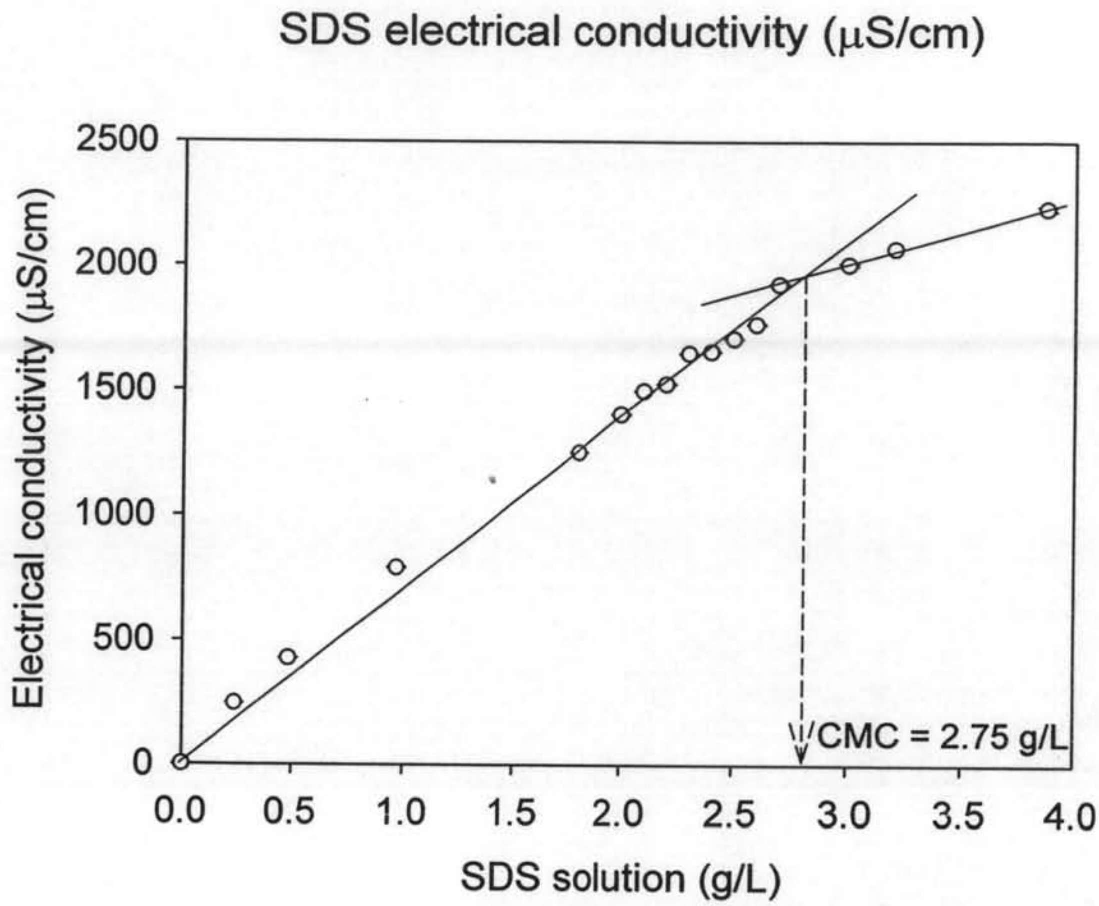

Figure A4 SDS solution electrical conductivity.

Table A4 Determination the surface tension of surfactant (SDS) solution by Tensiometer

Procedure to determine the surface tension of SDS solution:

1. Fill the empty dry beaker with the SDS solution.
2. Put the beaker with the SDS solution into Tensiometer (Dataphysics, Germany, model DCAT 11, Serial G01 Bogo 2 F97c)
3. Read the value from the monitor.

SDS solution (CMC)	surface tension (mN/m)
0	71.272
0.5	22.02
1	21.813
2	21.606
3	21.556

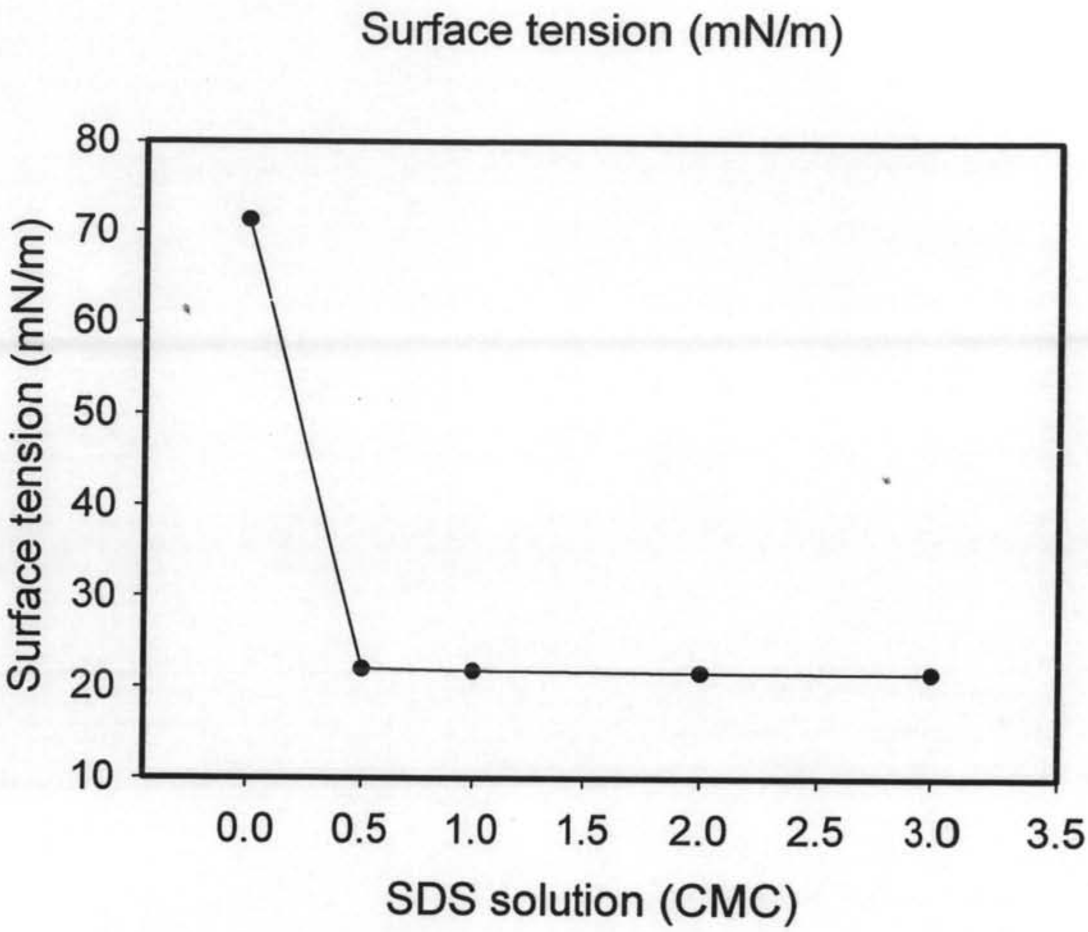

Figure A5 SDS solution surface tension.

Appendix B Determination of Pressure Gradient From Wilkes and Sylvester Theory

Table B1 Determination of pressure gradient for the bubble flow regime from Wilkes theory (Pure water)

Physical properties of air and water used in experiment:

density of water, ρ_{water} = 994.7 kg/m^3; viscosity of water, $\mu_{water} = 8.51 \times 10^{-4}$ Pa.s

density of air, ρ_{air} = 1.18 kg/m^3; viscosity of air, $\mu_{air} = 1.85 \times 10^{-5}$ Pa.s

temperature, T = 31 °C (± 1 °C); inner pipe diameter, D = 0.019 m; cross-sectional area of pipe, A = 0.00028 m^2

Superficial liquid velocity, $j_{liquid} = \dfrac{Q_{liquid}}{A}$ (B1)

Superficial air velocity, $j_{air} = \dfrac{Q_{air}}{A}$ (B2)

Reynolds number of liquid, $\mathrm{Re}_{liquid} = \dfrac{\rho\, j_{liquid} D}{\mu_{liquid}}$ (B3)

Reynolds number of air, $\mathrm{Re}_{air} = \dfrac{\rho\, j_{air} D}{\mu_{air}}$ (B4)

Bubble velocity rising in stagnant liquid, $u_b = 1.00\sqrt{g R_b}$ (B5)

where R_b is equivalent radius of the bubble which defined as the radius of a sphere that has the same volume as the bubble

Void fraction, $\varepsilon = \dfrac{Q_{air}}{Q_{air} + Q_{liquid} + u_b A}$ (B6)

Pressure gradient for bubble flow regime, $\frac{dp}{dz} = -\rho_l g(1-\varepsilon)$ (B7)

Water				Air				Flow regime	U_b (m/s)	void fraction	$(dp/dz)_{tp}$ from theory (kPa/m)
Q_{water} (ml/min)	Sup. water velocity j_{water} (m/s)	Q_{water} (m^3/sec)	Re_{water}	Q_{air} (L/min)	Sup. Air velocity j_{air} (m/s)	Q_{air} (m^3/sec)	Re_{air}				
0	0	0	0	0.0444	0.0026	7.406E-07	3.17	bubble	0.2730	0.0095	9.6684
0	0	0	0	0.0792	0.0047	1.319E-06	5.64	bubble	0.2730	0.0168	9.5973
0	0	0	0	0.1139	0.0067	1.898E-06	8.12	bubble	0.2730	0.0239	9.5273
263	0.0154	4.376E-06	344	0.0444	0.0026	7.406E-07	3.17	bubble	0.2730	0.0090	9.6733
263	0.0154	4.376E-06	344	0.0792	0.0047	1.319E-06	5.64	bubble	0.2730	0.0159	9.6059
263	0.0154	4.376E-06	344	0.1139	0.0067	1.898E-06	8.12	bubble	0.2730	0.0227	9.5395
263	0.0154	4.376E-06	344	0.1486	0.0087	2.477E-06	10.59	bubble	0.2730	0.0294	9.4740
263	0.0154	4.376E-06	344	0.1833	0.0108	3.055E-06	13.06	bubble	0.2730	0.0360	9.4093
364	0.0214	6.069E-06	477	0.0444	0.0026	7.406E-07	3.17	bubble	0.2730	0.0088	9.6751
364	0.0214	6.069E-06	477	0.0792	0.0047	1.319E-06	5.64	bubble	0.2730	0.0156	9.6090
364	0.0214	6.069E-06	477	0.1139	0.0067	1.898E-06	8.12	bubble	0.2730	0.0222	9.5439
364	0.0214	6.069E-06	477	0.1486	0.0087	2.477E-06	10.59	bubble	0.2730	0.0288	9.4796
364	0.0214	6.069E-06	477	0.1833	0.0108	3.055E-06	13.06	bubble	0.2730	0.0353	9.4162
465	0.0274	7.758E-06	610	0.0444	0.0026	7.406E-07	3.17	bubble	0.2730	0.0086	9.6768
465	0.0274	7.758E-06	610	0.0792	0.0047	1.319E-06	5.64	bubble	0.2730	0.0153	9.6120
465	0.0274	7.758E-06	610	0.1139	0.0067	1.898E-06	8.12	bubble	0.2730	0.0218	9.5481
465	0.0274	7.758E-06	610	0.1486	0.0087	2.477E-06	10.59	bubble	0.2730	0.0283	9.4850
465	0.0274	7.758E-06	610	0.1833	0.0108	3.055E-06	13.06	bubble	0.2730	0.0346	9.4228
567	0.0334	9.456E-06	744	0.0444	0.0026	7.406E-07	3.17	bubble	0.2730	0.0085	9.6784
567	0.0334	9.456E-06	744	0.0792	0.0047	1.319E-06	5.64	bubble	0.2730	0.0150	9.6149

567	0.0334	9.456E-06	744	0.1139	0.0067	1.898E-06	8.12	bubble	0.2730	0.0214	9.5522
567	0.0334	9.456E-06	744	0.1486	0.0087	2.477E-06	10.59	bubble	0.2730	0.0277	9.4903
567	0.0334	9.456E-06	744	0.1833	0.0108	3.055E-06	13.06	bubble	0.2730	0.0340	9.4292
771	0.0453	1.284E-05	1010	0.0444	0.0026	7.406E-07	3.17	bubble	0.2730	0.0081	9.6815
771	0.0453	1.284E-05	1010	0.0792	0.0047	1.319E-06	5.64	bubble	0.2730	0.0144	9.6203
771	0.0453	1.284E-05	1010	0.1139	0.0067	1.898E-06	8.12	bubble	0.2730	0.0206	9.5598
771	0.0453	1.284E-05	1010	0.1486	0.0087	2.477E-06	10.59	bubble	0.2730	0.0267	9.5002
771	0.0453	1.284E-05	1010	0.1833	0.0108	3.055E-06	13.06	bubble	0.2730	0.0328	9.4413
974	0.0573	1.623E-05	1277	0.0444	0.0026	7.406E-07	3.17	bubble	0.2730	0.0078	9.6843
974	0.0573	1.623E-05	1277	0.0792	0.0047	1.319E-06	5.64	bubble	0.2730	0.0139	9.6253
974	0.0573	1.623E-05	1277	0.1139	0.0067	1.898E-06	8.12	bubble	0.2730	0.0199	9.5670
974	0.0573	1.623E-05	1277	0.1486	0.0087	2.477E-06	10.59	bubble	0.2730	0.0258	9.5094
974	0.0573	1.623E-05	1277	0.1833	0.0108	3.055E-06	13.06	bubble	0.2730	0.0316	9.4525
1278	0.0752	2.131E-05	1676	0.0444	0.0026	7.406E-07	3.17	bubble	0.2730	0.0074	9.6882
1278	0.0752	2.131E-05	1676	0.0792	0.0047	1.319E-06	5.64	bubble	0.2730	0.0132	9.6322
1278	0.0752	2.131E-05	1676	0.1139	0.0067	1.898E-06	8.12	bubble	0.2730	0.0189	9.5768
1278	0.0752	2.131E-05	1676	0.1486	0.0087	2.477E-06	10.59	bubble	0.2730	0.0245	9.5220
1278	0.0752	2.131E-05	1676	0.1833	0.0108	3.055E-06	13.06	bubble	0.2730	0.0300	9.4679
2091	0.1230	3.485E-05	2742	0.0444	0.0026	7.406E-07	3.17	bubble	0.2730	0.0066	9.6970
2091	0.1230	3.485E-05	2742	0.0792	0.0047	1.319E-06	5.64	bubble	0.2730	0.0116	9.6475
2091	0.1230	3.485E-05	2742	0.1139	0.0067	1.898E-06	8.12	bubble	0.2730	0.0166	9.5986
2091	0.1230	3.485E-05	2742	0.1486	0.0087	2.477E-06	10.59	bubble	0.2730	0.0216	9.5502
2091	0.1230	3.485E-05	2742	0.1833	0.0108	3.055E-06	13.06	bubble	0.2730	0.0265	9.5023
2091	0.1230	3.485E-05	2742	0.2180	0.0128	3.634E-06	15.54	bubble	0.2730	0.0314	9.4548
2091	0.1230	3.485E-05	2742	0.2528	0.0149	4.213E-06	18.02	bubble	0.2730	0.0362	9.4078
2091	0.1230	3.485E-05	2742	0.2875	0.0169	4.791E-06	20.49	bubble	0.2730	0.0409	9.3613

Table B2 Determination of pressure gradient for the bubble flow regime from Wilkes theory (SDS solution at 1 CMC)

Physical properties of air and SDS solution (1 CMC) used in experiment:

density of SDS solution, $\rho_{SDS\ solution}$ = 994.97 kg/m^3; viscosity of SDS solution, $\mu_{SDS\ solution}$ = 1.01 × 10^{-3} Pa.s

density of air, ρ_{air} = 1.18 kg/m^3; viscosity of air, μ_{air} = 1.85 × 10^{-5} Pa.s

temperature, T = 31 °C (± 1 °C); inner pipe diameter, D = 0.019 m; cross-sectional area of pipe, A = 0.00028 m^2

SDS solution (1 CMC)				Air							
$Q_{solution}$ (ml/min)	Sup. SDS solution velocity $j_{SDS\ solution}$ (m/s)	$Q_{solution}$ (m^3/sec)	$Re_{solution}$	Q_{air} (L/min)	Sup. Air velocity j_{air} (m/s)	Q_{air} (m^3/sec)	Re_{air}	Flow regime	U_b (m/s)	void fraction	$(-dp/dz)_{cal}$ from theory (kPa/m)
0	0	0	0	0.0444	0.0026	7.406E-07	3.17	bubble	0.2466	0.0105	9.6583
0	0	0	0	0.0792	0.0047	1.319E-06	5.64	bubble	0.2466	0.0185	9.5798
350	0.0206	5.831E-06	385	0.0444	0.0026	7.406E-07	3.17	bubble	0.2466	0.0097	9.6661
350	0.0206	5.831E-06	385	0.0792	0.0047	1.319E-06	5.64	bubble	0.2466	0.0171	9.5935
350	0.0206	5.831E-06	385	0.1139	0.0067	1.898E-06	8.12	bubble	0.2466	0.0245	9.5220
350	0.0206	5.831E-06	385	0.1486	0.0087	2.477E-06	10.59	bubble	0.2466	0.0317	9.4515
453	0.0266	7.551E-06	500	0.0444	0.0026	7.41E-07	3.17	bubble	0.2466	0.0095	9.6682
453	0.0266	7.551E-06	500	0.0792	0.0047	1.32E-06	5.64	bubble	0.2466	0.0168	9.5972
453	0.0266	7.551E-06	500	0.1139	0.0067	1.9E-06	8.12	bubble	0.2466	0.0239	9.5272
453	0.0266	7.551E-06	500	0.1486	0.0087	2.48E-06	10.59	bubble	0.2466	0.0310	9.4582
556	0.0327	9.271E-06	610	0.0444	0.0026	7.41E-07	3.17	bubble	0.2466	0.0093	9.6702
556	0.0327	9.271E-06	610	0.0792	0.0047	1.32E-06	5.64	bubble	0.2466	0.0164	9.6007
556	0.0327	9.271E-06	610	0.1139	0.0067	1.9E-06	8.12	bubble	0.2466	0.0234	9.5321
556	0.0327	9.271E-06	610	0.1486	0.0087	2.48E-06	10.59	bubble	0.2466	0.0303	9.4645

660	0.0388	1.099E-05	725	0.0444	0.0026	7.41E-07	3.17	bubble	0.2466	0.0091	9.6721
660	0.0388	1.099E-05	725	0.0792	0.0047	1.32E-06	5.64	bubble	0.2466	0.0160	9.6040
660	0.0388	1.099E-05	725	0.1139	0.0067	1.9E-06	8.12	bubble	0.2466	0.0229	9.5369
660	0.0388	1.099E-05	725	0.1486	0.0087	2.48E-06	10.59	bubble	0.2466	0.0297	9.4707
970	0.0570	1.615E-05	1065	0.0444	0.0026	7.41E-07	3.17	bubble	0.2466	0.0085	9.6774
970	0.0570	1.615E-05	1065	0.0792	0.0047	1.32E-06	5.64	bubble	0.2466	0.0151	9.6133
970	0.0570	1.615E-05	1065	0.1139	0.0067	1.9E-06	8.12	bubble	0.2466	0.0216	9.5500
970	0.0570	1.615E-05	1065	0.1486	0.0087	2.48E-06	10.59	bubble	0.2466	0.0280	9.4876
1175	0.0691	1.959E-05	1290	0.0444	0.0026	7.41E-07	3.17	bubble	0.2466	0.0082	9.6805
1175	0.0691	1.959E-05	1290	0.0792	0.0047	1.32E-06	5.64	bubble	0.2466	0.0145	9.6188
1175	0.0691	1.959E-05	1290	0.1139	0.0067	1.9E-06	8.12	bubble	0.2466	0.0208	9.5579
1175	0.0691	1.959E-05	1290	0.1486	0.0087	2.48E-06	10.59	bubble	0.2466	0.0269	9.4978
1485	0.0873	2.475E-05	1635	0.0444	0.0026	7.41E-07	3.17	bubble	0.2466	0.0078	9.6849
1485	0.0873	2.475E-05	1635	0.0792	0.0047	1.32E-06	5.64	bubble	0.2466	0.0137	9.6265
1485	0.0873	2.475E-05	1635	0.1139	0.0067	1.9E-06	8.12	bubble	0.2466	0.0197	9.5688
1485	0.0873	2.475E-05	1635	0.1486	0.0087	2.48E-06	10.59	bubble	0.2466	0.0255	9.5117
2310	0.1359	3.851E-05	2540	0.0444	0.0026	7.41E-07	3.17	bubble	0.2466	0.0068	9.6944
2310	0.1359	3.851E-05	2540	0.0792	0.0047	1.32E-06	5.64	bubble	0.2466	0.0120	9.6433
2310	0.1359	3.851E-05	2540	0.1139	0.0067	1.9E-06	8.12	bubble	0.2466	0.0172	9.5927
2310	0.1359	3.851E-05	2540	0.1486	0.0087	2.48E-06	10.59	bubble	0.2466	0.0223	9.5426
2310	0.1359	3.851E-05	2540	0.1833	0.0108	3.06E-06	13.06	bubble	0.2466	0.0274	9.4931
2310	0.1359	3.851E-05	2540	0.2180	0.0128	3.63E-06	15.54	bubble	0.2466	0.0324	9.4441

Table B3 Determination of pressure gradient for the slug flow regime from Wilkes theory (Pure water)

Physical properties of air and water used in experiment:

density of water, ρ_{water} = 994.7 kg/m^3; viscosity of water, μ_{water} = 8.51 × 10^{-4} Pa.s

density of air, ρ_{air} = 1.18 kg/m^3; viscosity of air, μ_{air} = 1.85 × 10^{-5} Pa.s

temperature, T = 31 °C (± 1 °C); inner pipe diameter = 0.019 m; cross-sectional area of pipe, A = 0.00028 m^2

Mean liquid velocity, $u_l = \dfrac{Q_{air} + Q_{liquid}}{A}$ (B8)

Reynolds number of the liquid slug, $\mathrm{Re}_{slug} = \dfrac{\rho_{liquid} u_l D}{\mu_{liquid}}$ (B9)

Fanning friction factor, $f_F = \dfrac{16}{\mathrm{Re}_{slug}}$ for laminar flow ($\mathrm{Re}_{slug} < 2000$) (B10)

$f_F = 0.079\,\mathrm{Re}_{slug}^{-1/4}$ for turbulent flow ($\mathrm{Re}_{slug} > 4000$) (B11)

Single-phase frictional pressure gradient for liquid only, $\left(\dfrac{dp}{dz}\right)_{sp} = \dfrac{2 f_F \rho_{liquid} u_l}{D}$ (B12)

Void fraction, $\varepsilon = \dfrac{Q_{air}}{1.2\left(Q_{air} + Q_{liquid}\right) + 0.35 A\sqrt{gD}}$ (B13)

Pressure gradient for slug flow regime, $\dfrac{dp}{dz} = (1-\varepsilon)\left[-\rho_{liquid}\, g + \left(\dfrac{dp}{dz}\right)_{sp}\right]$ (B14)

Q_{water} (m^3/sec)	Re_{water}	Q_{air} (m^3/sec)	Re_{air}	Flow regime	mean liq velocity U_l(m/s)	Re_{slug}	f_F	$(-dp/dz)_{sp}$	void fraction	$(dp/dz)_{tp}$ from theory (kPa/m)
0	0	4.21E-06	18.02	slug	0.0149	331	0.0483	1.1174	0.0880	8.9030
0	0	4.79E-06	20.49	slug	0.0169	377	0.0424	1.2709	0.0987	8.7991
0	0	5.37E-06	22.95	slug	0.0189	422	0.0379	1.4235	0.1089	8.6988
0	0	6.57E-06	28.08	slug	0.0232	517	0.0310	1.7416	0.1295	8.4983
0	0	7.76E-06	33.21	slug	0.0274	611	0.0262	2.0597	0.1489	8.3090
0	0	8.96E-06	38.33	slug	0.0316	705	0.0227	2.3777	0.1673	8.1298
0	0	1.02E-05	43.46	slug	0.0359	800	0.0200	2.6958	0.1847	7.9599
0	0	1.14E-05	48.59	slug	0.0401	894	0.0179	3.0139	0.2013	7.7988
0	0	1.38E-05	58.85	slug	0.0486	1083	0.0148	3.6501	0.2319	7.4999
0	0	1.62E-05	69.10	slug	0.0570	1271	0.0126	4.2862	0.2598	7.2287
0	0	1.86E-05	79.36	slug	0.0655	1460	0.0110	4.9224	0.2851	6.9815
0	0	2.1E-05	89.62	slug	0.0739	1649	0.0097	5.5586	0.3083	6.7552
0	0	2.34E-05	99.87	slug	0.0824	1837	0.0121	8.5833	0.3297	6.5489
4.38E-06	344	6.57E-06	28.08	slug	0.0386	861	0.0186	2.9023	0.1174	8.6180
4.38E-06	344	7.76E-06	33.21	slug	0.0428	955	0.0168	3.2204	0.1353	8.4430
4.38E-06	344	8.96E-06	38.33	slug	0.0471	1049	0.0152	3.5385	0.1524	8.2766
4.38E-06	344	1.02E-05	43.46	slug	0.0513	1144	0.0140	3.8566	0.1686	8.1181
4.38E-06	344	1.14E-05	48.59	slug	0.0555	1238	0.0129	4.1747	0.1841	7.9670
4.38E-06	344	1.38E-05	58.85	slug	0.0640	1427	0.0112	4.8108	0.2131	7.6849
4.38E-06	344	1.62E-05	69.10	slug	0.0725	1615	0.0099	5.4470	0.2395	7.4270
4.38E-06	344	1.86E-05	79.36	slug	0.0809	1804	0.0089	6.0832	0.2638	7.1902
4.38E-06	344	2.1E-05	89.62	slug	0.0894	1993	0.0080	6.7193	0.2862	6.9720
4.38E-06	344	2.34E-05	99.87	slug	0.0979	2181	0.0116	11.593	0.3069	6.7733
4.38E-06	344	4.13E-05	177	slug	0.1614	3597	0.0102	27.817	0.4233	5.6454
4.38E-06	344	6.67E-05	285	slug	0.2507	5589	0.0091	60.142	0.5206	4.7087
4.38E-06	344	8.33E-05	356	slug-churn	0.3095	6900	0.0087	86.967	0.5628	4.3055

4.38E-06	344	0.000117	499	slug-churn	0.4271	9522	0.0080	152.81	0.6203	3.7639
4.38E-06	344	0.000167	713	slug-churn	0.6036	13456	0.0073	279.87	0.6719	3.2948
4.38E-06	344	0.000333	1425	slug-churn	1.1917	26567	0.0062	920.39	0.7439	2.7351
6.07E-06	477	6.57E-06	28.08	slug	0.0446	994	0.0161	3.3515	0.1132	8.6586
6.07E-06	477	7.76E-06	33.21	slug	0.0488	1088	0.0147	3.6696	0.1307	8.4886
6.07E-06	477	8.96E-06	38.33	slug	0.0530	1183	0.0135	3.9876	0.1473	8.3266
6.07E-06	477	1.02E-05	43.46	slug	0.0573	1277	0.0125	4.3057	0.1631	8.1721
6.07E-06	477	1.14E-05	48.59	slug	0.0615	1371	0.0117	4.6238	0.1783	8.0246
6.07E-06	477	1.38E-05	58.85	slug	0.0700	1560	0.0103	5.2600	0.2066	7.7488
6.07E-06	477	1.62E-05	69.10	slug	0.0784	1749	0.0091	5.8961	0.2325	7.4958
6.07E-06	477	1.86E-05	79.36	slug	0.0869	1937	0.0083	6.5323	0.2564	7.2629
6.07E-06	477	2.1E-05	89.62	slug	0.0954	2126	0.0075	7.1685	0.2785	7.0478
6.07E-06	477	2.34E-05	99.87	slug	0.1038	2315	0.0114	12.860	0.2989	6.8522
6.07E-06	477	4.13E-05	177	slug	0.1673	3730	0.0101	29.644	0.4147	5.7309
6.07E-06	477	6.67E-05	285	slug	0.2567	5722	0.0091	62.673	0.5124	4.7898
6.07E-06	477	8.33E-05	356	slug-churn	0.3155	7033	0.0086	89.926	0.5552	4.3819
6.07E-06	477	0.000117	499	slug-churn	0.4331	9656	0.0080	156.58	0.6137	3.8311
6.07E-06	477	0.000167	713	slug-churn	0.6095	13589	0.0073	284.74	0.6664	3.3513
6.07E-06	477	0.000333	1425	slug-churn	1.1977	26700	0.0062	928.48	0.7406	2.7731
7.76E-06	611	6.57E-06	28.08	slug	0.0506	1127	0.0142	3.8006	0.1094	8.6964
7.76E-06	611	7.76E-06	33.21	slug	0.0548	1222	0.0131	4.1187	0.1264	8.5312
7.76E-06	611	8.96E-06	38.33	slug	0.0590	1316	0.0122	4.4368	0.1425	8.3735
7.76E-06	611	1.02E-05	43.46	slug	0.0633	1410	0.0113	4.7548	0.1580	8.2228
7.76E-06	611	1.14E-05	48.59	slug	0.0675	1505	0.0106	5.0729	0.1728	8.0788
7.76E-06	611	1.38E-05	58.85	slug	0.0760	1693	0.0094	5.7091	0.2005	7.8088
7.76E-06	611	1.62E-05	69.10	slug	0.0844	1882	0.0085	6.3453	0.2259	7.5606
7.76E-06	611	1.86E-05	79.36	slug	0.0929	2071	0.0077	6.9814	0.2494	7.3316
7.76E-06	611	2.1E-05	89.62	slug	0.1013	2259	0.0071	7.6176	0.2712	7.1197
7.76E-06	611	2.34E-05	99.87	slug	0.1098	2448	0.0112	14.183	0.2914	6.9271
7.76E-06	611	4.13E-05	177	slug	0.1733	3864	0.0100	31.521	0.4064	5.8131
7.76E-06	611	6.67E-05	285	slug	0.2626	5855	0.0090	65.249	0.5045	4.8685

7.76E-06	611	8.33E-05	356	slug-churn	0.3215	7166	0.0086	92.927	0.5478	4.4563
7.76E-06	611	0.000117	499	slug-churn	0.4391	9789	0.0079	160.37	0.6072	3.8969
7.76E-06	611	0.000167	713	slug-churn	0.6155	13722	0.0073	289.64	0.6610	3.4069
7.76E-06	611	0.000333	1425	slug-churn	1.2036	26834	0.0062	936.60	0.7372	2.8108
9.46E-06	744	6.57E-06	28.08	slug	0.0565	1260	0.0127	4.2497	0.1058	8.7318
9.46E-06	744	7.76E-06	33.21	slug	0.0608	1355	0.0118	4.5678	0.1223	8.5711
9.46E-06	744	8.96E-06	38.33	slug	0.0650	1449	0.0110	4.8859	0.1381	8.4174
9.46E-06	744	1.02E-05	43.46	slug	0.0692	1543	0.0104	5.2040	0.1532	8.2705
9.46E-06	744	1.14E-05	48.59	slug	0.0735	1638	0.0098	5.5220	0.1676	8.1297
9.46E-06	744	1.38E-05	58.85	slug	0.0819	1826	0.0088	6.1582	0.1947	7.8655
9.46E-06	744	1.62E-05	69.10	slug	0.0904	2015	0.0079	6.7944	0.2197	7.6219
9.46E-06	744	1.86E-05	79.36	slug	0.0989	2204	0.0073	7.4305	0.2428	7.3967
9.46E-06	744	2.1E-05	89.62	slug	0.1073	2392	0.0067	8.0667	0.2642	7.1879
9.46E-06	744	2.34E-05	99.87	slug	0.1158	2581	0.0111	15.561	0.2841	6.9985
9.46E-06	744	4.13E-05	177	slug	0.1793	3997	0.0099	33.448	0.3984	5.8921
9.46E-06	744	6.67E-05	285	slug	0.2686	5988	0.0090	67.868	0.4969	4.9449
9.46E-06	744	8.33E-05	356	slug-churn	0.3274	7300	0.0085	95.971	0.5405	4.5288
9.46E-06	744	0.000117	499	slug-churn	0.4451	9922	0.0079	164.21	0.6009	3.9615
9.46E-06	744	0.000167	713	slug-churn	0.6215	13855	0.0073	294.58	0.6557	3.4617
9.46E-06	744	0.000333	1425	slug-churn	1.2096	26967	0.0062	944.75	0.7339	2.8483
1.28E-05	1010	7.76E-06	33.21	slug	0.0727	1621	0.0099	5.4660	0.1150	8.6437
1.28E-05	1010	8.96E-06	38.33	slug	0.0769	1715	0.0093	5.7841	0.1299	8.4976
1.28E-05	1010	1.02E-05	43.46	slug	0.0812	1810	0.0088	6.1022	0.1443	8.3575
1.28E-05	1010	1.14E-05	48.59	slug	0.0854	1904	0.0084	6.4203	0.1581	8.2230
1.28E-05	1010	1.38E-05	58.85	slug	0.0939	2093	0.0076	7.0564	0.1841	7.9696
1.28E-05	1010	1.62E-05	69.10	slug	0.1023	2281	0.0070	7.6926	0.2082	7.7350
1.28E-05	1010	1.86E-05	79.36	slug	0.1108	2470	0.0065	8.3288	0.2305	7.5171
1.28E-05	1010	2.1E-05	89.62	slug	0.1193	2659	0.0060	8.9649	0.2513	7.3143
1.28E-05	1010	2.34E-05	99.87	slug	0.1277	2847	0.0108	18.479	0.2708	7.1315
1.28E-05	1010	4.13E-05	177	slug	0.1912	4263	0.0098	37.446	0.3834	6.0416
1.28E-05	1010	6.67E-05	285	slug	0.2806	6255	0.0089	73.240	0.4823	5.0912

1.28E-05	1010	8.33E-05	356	slug-churn	0.3394	7566	0.0085	102.18	0.5267	4.6686
1.28E-05	1010	0.000117	499	slug-churn	0.4570	10188	0.0079	172.01	0.5885	4.0869
1.28E-05	1010	0.000167	713	slug-churn	0.6334	14122	0.0072	304.56	0.6454	3.5690
1.28E-05	1010	0.000333	1425	slug-churn	1.2216	27233	0.0061	961.15	0.7274	2.9224
1.62E-05	1277	7.76E-06	33.21	slug	0.0847	1888	0.0085	6.3643	0.1084	8.7082
1.62E-05	1277	8.96E-06	38.33	slug	0.0889	1982	0.0081	6.6824	0.1227	8.5690
1.62E-05	1277	1.02E-05	43.46	slug	0.0931	2076	0.0077	7.0004	0.1364	8.4352
1.62E-05	1277	1.14E-05	48.59	slug	0.0974	2171	0.0074	7.3185	0.1496	8.3065
1.62E-05	1277	1.38E-05	58.85	slug	0.1058	2359	0.0068	7.9547	0.1746	8.0631
1.62E-05	1277	1.62E-05	69.10	slug	0.1143	2548	0.0063	8.5909	0.1978	7.8369
1.62E-05	1277	1.86E-05	79.36	slug	0.1228	2737	0.0058	9.2270	0.2195	7.6261
1.62E-05	1277	2.1E-05	89.62	slug	0.1312	2925	0.0055	9.8632	0.2397	7.4291
1.62E-05	1277	2.34E-05	99.87	slug	0.1397	3114	0.0106	21.610	0.2586	7.2530
1.62E-05	1277	4.13E-05	177	slug	0.2032	4530	0.0096	41.636	0.3695	6.1807
1.62E-05	1277	6.67E-05	285	slug	0.2925	6521	0.0088	78.785	0.4685	5.2296
1.62E-05	1277	8.33E-05	356	slug-churn	0.3513	7832	0.0084	108.56	0.5135	4.8017
1.62E-05	1277	0.000117	499	slug-churn	0.4690	10455	0.0078	179.95	0.5767	4.2077
1.62E-05	1277	0.000167	713	slug-churn	0.6454	14388	0.0072	314.68	0.6354	3.6733
1.62E-05	1277	0.000333	1425	slug-churn	1.2335	27500	0.0061	977.66	0.7210	2.9956
2.13E-05	1676	7.76E-06	33.21	slug	0.1026	2287	0.0070	7.7116	0.0999	8.7925
2.13E-05	1676	8.96E-06	38.33	slug	0.1068	2381	0.0067	8.0297	0.1133	8.6625
2.13E-05	1676	1.02E-05	43.46	slug	0.1111	2476	0.0065	8.3478	0.1261	8.5372
2.13E-05	1676	1.14E-05	48.59	slug	0.1153	2570	0.0062	8.6659	0.1385	8.4163
2.13E-05	1676	1.38E-05	58.85	slug	0.1237	2759	0.0058	9.3020	0.1621	8.1867
2.13E-05	1676	1.62E-05	69.10	slug	0.1322	2947	0.0054	9.9382	0.1841	7.9722
2.13E-05	1676	1.86E-05	79.36	slug	0.1407	3136	0.0051	10.574	0.2047	7.7713
2.13E-05	1676	2.1E-05	89.62	slug	0.1491	3325	0.0048	11.211	0.2240	7.5828
2.13E-05	1676	2.34E-05	99.87	slug	0.1576	3514	0.0103	26.694	0.2422	7.4168
2.13E-05	1676	4.13E-05	177	slug	0.2211	4929	0.0094	48.275	0.3504	6.3721
2.13E-05	1676	6.67E-05	285	slug	0.3104	6921	0.0087	87.427	0.4493	5.4238
2.13E-05	1676	8.33E-05	356	slug-churn	0.3693	8232	0.0083	118.44	0.4949	4.9902

2.13E-05	1676	0.000117	499	slug-churn	0.4869	10854	0.0077	192.16	0.5599	4.3808
2.13E-05	1676	0.000167	713	slug-churn	0.6633	14788	0.0072	330.14	0.6210	3.8246
2.13E-05	1676	0.000333	1425	slug-churn	1.2514	27899	0.0061	1002.66	0.7117	3.1036
3.49E-05	2742	1.02E-05	43.46	slug	0.1589	3541	0.0045	11.941	0.1050	8.7472
3.49E-05	2742	1.14E-05	48.59	slug	0.1631	3636	0.0044	12.259	0.1156	8.6433
3.49E-05	2742	1.38E-05	58.85	slug	0.1715	3824	0.0042	12.895	0.1360	8.4443
3.49E-05	2742	1.62E-05	69.10	slug	0.1800	4013	0.004	13.531	0.1553	8.2562
3.49E-05	2742	1.86E-05	79.36	slug	0.1885	4202	0.0038	14.167	0.1736	8.0784
3.49E-05	2742	2.1E-05	89.62	slug	0.1969	4390	0.0036	14.803	0.1909	7.9098
3.49E-05	2742	2.34E-05	99.87	slug	0.2054	4579	0.0096	42.436	0.2073	7.7713
3.49E-05	2742	4.13E-05	177	slug	0.2689	5995	0.009	67.994	0.3080	6.8018
3.49E-05	2742	6.67E-05	285	slug	0.3582	7986	0.0084	112.33	0.4049	5.8754
3.49E-05	2742	8.33E-05	356	slug	0.4171	9298	0.008	146.56	0.4513	5.4360
3.49E-05	2742	0.000117	499	slug-churn	0.5347	11920	0.0076	226.38	0.5193	4.8005
3.49E-05	2742	0.000167	713	slug-churn	0.7111	15853	0.007	372.89	0.5855	4.2002
3.49E-05	2742	0.000333	1425	slug-churn	1.2992	28965	0.0061	1070.63	0.6878	3.3817
3.49E-05	2742	0.000667	2851	slug-churn	2.4755	55188	0.0052	3308.20	0.7536	3.2202

Table B4 Determination of pressure gradient for the slug flow regime from Wilkes theory (SDS solution at 1 CMC)

Physical properties of air and SDS solution (1 CMC) used in experiment:

density of SDS solution, $\rho_{SDS\ solution}$ = 994.97 kg/m^3; viscosity of SDS solution, $\mu_{SDS\ solution} = 1.01 \times 10^{-3}$ Pa.s

density of air, ρ_{air} = 1.18 kg/m^3; viscosity of air, $\mu_{air} = 1.85 \times 10^{-5}$ Pa.s

temperature, T = 31 °C (± 1 °C); inner pipe diameter = 0.019 m; cross-sectional area of pipe, A = 0.00028 m^2

$Q_{solution}$ (m^3/sec)	$Re_{solution}$	Q_{air} (m^3/sec)	Re_{air}	Flow regime	mean liq velocity U_l(m/s)	Re_{slug}	f_F	$(-dp/dz)_{sp}$	void fraction	$(dp/dz)_{tp}$ from theory (kPa/m)
0	0	3.06E-06	13.06	slug	0.0108	202	0.0793	0.9652	0.0657	9.1201
0	0	3.63E-06	15.54	slug	0.0128	240	0.0667	1.1481	0.0770	9.0099
0	0	4.21E-06	18.02	slug	0.0149	278	0.0575	1.3309	0.0880	8.9030
0	0	4.79E-06	20.49	slug	0.0169	316	0.0506	1.5137	0.0987	8.7991
0	0	5.37E-06	22.95	slug	0.0189	354	0.0451	1.6954	0.1089	8.6988
0	0	6.57E-06	28.08	slug	0.0232	434	0.0369	2.0743	0.1295	8.4984
0	0	7.76E-06	33.21	slug	0.0274	513	0.0312	2.4531	0.1489	8.3090
0	0	8.96E-06	38.33	slug	0.0316	592	0.0270	2.8320	0.1673	8.1299
0	0	1.02E-05	43.46	slug	0.0359	671	0.0238	3.2108	0.1847	7.9601
0	0	1.14E-05	48.59	slug	0.0401	750	0.0213	3.5897	0.2013	7.7990
0	0	1.38E-05	58.85	slug	0.0486	909	0.0176	4.3474	0.2319	7.5002
0	0	1.62E-05	69.10	slug	0.0570	1067	0.0150	5.1051	0.2598	7.2291
0	0	1.86E-05	79.36	slug	0.0655	1226	0.0131	5.8628	0.2851	6.9819
0	0	2.10E-05	89.62	slug	0.0739	1384	0.0116	6.6205	0.3083	6.7557
0	0	2.34E-05	99.87	slug	0.0824	1543	0.0104	7.3782	0.3297	6.5479
5.8E-06	385	4.79E-06	20.49	slug	0.0375	702	0.0228	3.3559	0.0862	8.9221
5.8E-06	385	5.37E-06	22.95	slug	0.0395	740	0.0216	3.5376	0.0954	8.8327

5.8E-06	385	6.57E-06	28.08	slug	0.0437	819	0.0195	3.9164	0.1138	8.6533
5.8E-06	385	7.76E-06	33.21	slug	0.0480	898	0.0178	4.2953	0.1313	8.4827
5.8E-06	385	8.96E-06	38.33	slug	0.0522	977	0.0164	4.6741	0.1480	8.3202
5.8E-06	385	1.02E-05	43.46	slug	0.0564	1056	0.0151	5.0530	0.1639	8.1652
5.8E-06	385	1.14E-05	48.59	slug	0.0607	1136	0.0141	5.4318	0.1791	8.0172
5.8E-06	385	1.38E-05	58.85	slug	0.0691	1294	0.0124	6.1895	0.2075	7.7406
5.8E-06	385	1.62E-05	69.10	slug	0.0776	1452	0.0110	6.9472	0.2335	7.4870
5.8E-06	385	1.86E-05	79.36	slug	0.0861	1611	0.0099	7.7049	0.2574	7.2536
5.8E-06	385	2.10E-05	89.62	slug	0.0945	1769	0.0090	8.4620	0.2796	7.0382
5.8E-06	385	2.34E-05	99.87	slug	0.1030	1928	0.0119	13.244	0.3000	6.8415
5.8E-06	385	4.13E-05	177	slug	0.1665	3116	0.0106	30.696	0.4158	5.7196
5.8E-06	385	6.67E-05	285	slug	0.2558	4788	0.0095	65.097	0.5136	4.7797
5.8E-06	385	8.33E-05	356	slug-churn	0.3146	5889	0.0090	93.503	0.5562	4.3729
5.8E-06	385	1.17E-04	499	slug-churn	0.4323	8091	0.0083	163.01	0.6146	3.8243
5.8E-06	385	1.67E-04	713	slug-churn	0.6087	11393	0.0076	296.73	0.6672	3.3475
5.8E-06	385	3.33E-04	1425	slug-churn	1.1968	22401	0.0065	968.75	0.7410	2.7784
7.6E-06	500	4.79E-06	20.49	slug	0.0436	815	0.0196	3.90	0.0831	8.9527
7.6E-06	500	5.37E-06	22.95	slug	0.0456	853	0.0188	4.08	0.0920	8.8662
7.6E-06	500	6.57E-06	28.08	slug	0.0498	932	0.0172	4.4598	0.1099	8.6922
7.6E-06	500	7.76E-06	33.21	slug	0.0540	1012	0.0158	4.8387	0.1269	8.5264
7.6E-06	500	8.96E-06	38.33	slug	0.0583	1091	0.0147	5.2175	0.1431	8.3683
7.6E-06	500	1.02E-05	43.46	slug	0.0625	1170	0.0137	5.5964	0.1586	8.2172
7.6E-06	500	1.14E-05	48.59	slug	0.0667	1249	0.0128	5.9752	0.1734	8.0728
7.6E-06	500	1.38E-05	58.85	slug	0.0752	1408	0.0114	6.7329	0.2012	7.8022
7.6E-06	500	1.62E-05	69.10	slug	0.0837	1566	0.0102	7.4906	0.2267	7.5534
7.6E-06	500	1.86E-05	79.36	slug	0.0921	1724	0.0093	8.2483	0.2503	7.3240
7.6E-06	500	2.10E-05	89.62	slug	0.1006	1883	0.0085	9.0060	0.2721	7.1117
7.6E-06	500	2.34E-05	99.87	slug	0.1091	2041	0.0118	14.640	0.2923	6.9182
7.6E-06	500	4.13E-05	177	slug	0.1726	3230	0.0105	32.681	0.4074	5.8036
7.6E-06	500	6.67E-05	285	slug	0.2619	4902	0.0094	67.824	0.5055	4.8601
7.6E-06	500	8.33E-05	356	slug-churn	0.3207	6003	0.0090	96.683	0.5487	4.4488
7.6E-06	500	1.17E-04	499	slug-churn	0.4383	8204	0.0083	167.04	0.6080	3.8914

7.6E-06	500	1.67E-04	713	slug-churn	0.6148	11507	0.0076	301.93	0.6617	3.4042
7.6E-06	500	3.33E-04	1425	slug-churn	1.2029	22515	0.0064	977.36	0.7377	2.8170
9.3E-06	610	4.79E-06	20.49	slug	0.0496	929	0.0172	4.44	0.0803	8.9813
9.3E-06	610	5.37E-06	22.95	slug	0.0517	967	0.0165	4.62	0.0889	8.8974
9.3E-06	610	6.57E-06	28.08	slug	0.0559	1046	0.0153	5.0032	0.1062	8.7285
9.3E-06	610	7.76E-06	33.21	slug	0.0601	1125	0.0142	5.3821	0.1227	8.5673
9.3E-06	610	8.96E-06	38.33	slug	0.0643	1204	0.0133	5.7609	0.1385	8.4133
9.3E-06	610	1.02E-05	43.46	slug	0.0686	1284	0.0125	6.1398	0.1537	8.2660
9.3E-06	610	1.14E-05	48.59	slug	0.0728	1363	0.0117	6.5186	0.1681	8.1250
9.3E-06	610	1.38E-05	58.85	slug	0.0813	1521	0.0105	7.2763	0.1953	7.8602
9.3E-06	610	1.62E-05	69.10	slug	0.0897	1680	0.0095	8.0340	0.2203	7.6162
9.3E-06	610	1.86E-05	79.36	slug	0.0982	1838	0.0087	8.7917	0.2435	7.3906
9.3E-06	610	2.10E-05	89.62	slug	0.1067	1996	0.0080	9.5494	0.2650	7.1815
9.3E-06	610	2.34E-05	99.87	slug	0.1151	2155	0.0116	16.096	0.2849	6.9912
9.3E-06	610	4.13E-05	177	slug	0.1786	3343	0.0104	34.719	0.3993	5.8844
9.3E-06	610	6.67E-05	285	slug	0.2680	5016	0.0094	70.598	0.4977	4.9380
9.3E-06	610	8.33E-05	356	slug-churn	0.3268	6116	0.0089	99.907	0.5413	4.5228
9.3E-06	610	1.17E-04	499	slug-churn	0.4444	8318	0.0083	171.11	0.6016	3.9573
9.3E-06	610	1.67E-04	713	slug-churn	0.6208	11620	0.0076	307.16	0.6563	3.4602
9.3E-06	610	3.33E-04	1425	slug-churn	1.2090	22629	0.0064	986.01	0.7343	2.8553
1.1E-05	725	4.79E-06	20.49	slug	0.0557	1042	0.0153	4.99	0.0776	9.0080
1.1E-05	725	5.37E-06	22.95	slug	0.0577	1080	0.0148	5.17	0.0859	8.9266
1.1E-05	725	6.57E-06	28.08	slug	0.0620	1160	0.0138	5.5466	0.1028	8.7625
1.1E-05	725	7.76E-06	33.21	slug	0.0662	1239	0.0129	5.9255	0.1189	8.6057
1.1E-05	725	8.96E-06	38.33	slug	0.0704	1318	0.0121	6.3043	0.1343	8.4556
1.1E-05	725	1.02E-05	43.46	slug	0.0746	1397	0.0115	6.6832	0.1490	8.3119
1.1E-05	725	1.14E-05	48.59	slug	0.0789	1476	0.0108	7.0620	0.1632	8.1741
1.1E-05	725	1.38E-05	58.85	slug	0.0873	1635	0.0098	7.8197	0.1897	7.9149
1.1E-05	725	1.62E-05	69.10	slug	0.0958	1793	0.0089	8.5774	0.2143	7.6755
1.1E-05	725	1.86E-05	79.36	slug	0.1043	1952	0.0082	9.3351	0.2371	7.4538
1.1E-05	725	2.10E-05	89.62	slug	0.1127	2110	0.0076	10.0928	0.2582	7.2477

1.1E-05	725	2.34E-05	99.87	slug	0.1212	2268	0.0114	17.610	0.2779	7.0607
1.1E-05	725	4.13E-05	177	slug	0.1847	3457	0.0103	36.810	0.3915	5.9620
1.1E-05	725	6.67E-05	285	slug	0.2740	5129	0.0093	73.420	0.4902	5.0137
1.1E-05	725	8.33E-05	356	slug-churn	0.3328	6230	0.0089	103.177	0.5342	4.5949
1.1E-05	725	1.17E-04	499	slug-churn	0.4505	8432	0.0082	175.22	0.5952	4.0219
1.1E-05	725	1.67E-04	713	slug-churn	0.6269	11734	0.0076	312.44	0.6510	3.5153
1.1E-05	725	3.33E-04	1425	slug-churn	1.2150	22742	0.0064	994.69	0.7310	2.8934
1.6E-05	1065	5.37E-06	22.95	slug	0.0759	1421	0.0113	6.80	0.0782	9.0038
1.6E-05	1065	6.57E-06	28.08	slug	0.0802	1500	0.0107	7.18	0.0937	8.8527
1.6E-05	1065	7.76E-06	33.21	slug	0.0844	1580	0.0101	7.5557	0.1086	8.7076
1.6E-05	1065	8.96E-06	38.33	slug	0.0886	1659	0.0096	7.9345	0.1229	8.5683
1.6E-05	1065	1.02E-05	43.46	slug	0.0929	1738	0.0092	8.3134	0.1366	8.4344
1.6E-05	1065	1.14E-05	48.59	slug	0.0971	1817	0.0088	8.6922	0.1498	8.3056
1.6E-05	1065	1.38E-05	58.85	slug	0.1056	1976	0.0081	9.4499	0.1748	8.0621
1.6E-05	1065	1.62E-05	69.10	slug	0.1140	2134	0.0075	10.2076	0.1981	7.8357
1.6E-05	1065	1.86E-05	79.36	slug	0.1225	2292	0.0070	10.9653	0.2197	7.6248
1.6E-05	1065	2.10E-05	89.62	slug	0.1309	2451	0.0065	11.7230	0.2399	7.4278
1.6E-05	1065	2.34E-05	99.87	slug	0.1394	2609	0.0111	22.497	0.2588	7.2508
1.6E-05	1065	4.13E-05	177	slug	0.2029	3798	0.0101	43.393	0.3698	6.1786
1.6E-05	1065	6.67E-05	285	slug	0.2922	5470	0.0092	82.169	0.4688	5.2283
1.6E-05	1065	8.33E-05	356	slug-churn	0.3511	6571	0.0088	113.26	0.5138	4.8010
1.6E-05	1065	1.17E-04	499	slug-churn	0.4687	8772	0.0082	187.80	0.5770	4.2083
1.6E-05	1065	1.67E-04	713	slug-churn	0.6451	12075	0.0075	328.49	0.6356	3.6760
1.6E-05	1065	3.33E-04	1425	slug-churn	1.2332	23083	0.0064	1020.92	0.7212	3.0060
2E-05	1295	5.37E-06	22.95	slug	0.0881	1648	0.0097	7.88	0.0737	9.0481
2E-05	1295	6.57E-06	28.08	slug	0.0923	1728	0.0093	8.26	0.0885	8.9046
2E-05	1295	7.76E-06	33.21	slug	0.0965	1807	0.0089	8.6424	0.1026	8.7665
2E-05	1295	8.96E-06	38.33	slug	0.1008	1886	0.0085	9.0213	0.1163	8.6336
2E-05	1295	1.02E-05	43.46	slug	0.1050	1965	0.0081	9.4001	0.1294	8.5055
2E-05	1295	1.14E-05	48.59	slug	0.1092	2044	0.0078	9.7790	0.1421	8.3821
2E-05	1295	1.38E-05	58.85	slug	0.1177	2203	0.0073	10.5367	0.1661	8.1481

2E-05	1295	1.62E-05	69.10	slug	0.1262	2361	0.0068	11.2944	0.1885	7.9298
2E-05	1295	1.86E-05	79.36	slug	0.1346	2520	0.0064	12.0521	0.2095	7.7257
2E-05	1295	2.10E-05	89.62	slug	0.1431	2678	0.0060	12.8098	0.2291	7.5345
2E-05	1295	2.34E-05	99.87	slug	0.1515	2836	0.0108	26.037	0.2475	7.3643
2E-05	1295	4.13E-05	177	slug	0.2150	4025	0.0099	48.038	0.3566	6.3106
2E-05	1295	6.67E-05	285	slug	0.3044	5697	0.0091	88.235	0.4556	5.3617
2E-05	1295	8.33E-05	356	slug-churn	0.3632	6798	0.0087	120.20	0.5010	4.9303
2E-05	1295	1.17E-04	499	slug-churn	0.4808	9000	0.0081	196.39	0.5654	4.3269
2E-05	1295	1.67E-04	713	slug-churn	0.6573	12302	0.0075	339.39	0.6258	3.7795
2E-05	1295	3.33E-04	1425	slug-churn	1.2454	23310	0.0064	1038.57	0.7148	3.0799
2.5E-05	1635	5.37E-06	22.95	slug	0.1063	1989	0.0080	9.51	0.0680	9.1061
2.5E-05	1635	6.57E-06	28.08	slug	0.1105	2068	0.0077	9.89	0.0817	8.9726
2.5E-05	1635	7.76E-06	33.21	slug	0.1147	2148	0.0075	10.2726	0.0949	8.8438
2.5E-05	1635	8.96E-06	38.33	slug	0.1190	2227	0.00719	10.6515	0.1076	8.7195
2.5E-05	1635	1.02E-05	43.46	slug	0.1232	2306	0.00694	11.0303	0.1200	8.5994
2.5E-05	1635	1.14E-05	48.59	slug	0.1274	2385	0.00671	11.4092	0.1319	8.4833
2.5E-05	1635	1.38E-05	58.85	slug	0.1359	2544	0.00629	12.1669	0.1546	8.2623
2.5E-05	1635	1.62E-05	69.10	slug	0.1444	2702	0.00592	12.9246	0.1758	8.0553
2.5E-05	1635	1.86E-05	79.36	slug	0.1528	2860	0.00559	13.682	0.1958	7.8607
2.5E-05	1635	2.10E-05	89.62	slug	0.1613	3019	0.0053	14.440	0.2146	7.6777
2.5E-05	1635	2.34E-05	99.87	slug	0.1698	3177	0.01052	31.756	0.2323	7.5179
2.5E-05	1635	4.13E-05	177	slug	0.2333	4366	0.00972	55.380	0.3385	6.4928
2.5E-05	1635	6.67E-05	285	slug	0.3226	6038	0.00896	97.678	0.4371	5.5492
2.5E-05	1635	8.33E-05	356	slug-churn	0.3814	7139	0.00859	130.94	0.4830	5.1136
2.5E-05	1635	1.17E-04	499	slug-churn	0.4990	9340	0.00804	209.59	0.5490	4.4969
2.5E-05	1635	1.67E-04	713	slug-churn	0.6755	12643	0.00745	356.01	0.6116	3.9295
2.5E-05	1635	3.33E-04	1425	slug-churn	1.2636	23651	0.00637	1065.29	0.7054	3.1889
3.9E-05	2544	7.76E-06	33.21	slug	0.1633	3056	0.00523	14.62	0.0790	9.0035
3.9E-05	2544	8.96E-06	38.33	slug	0.1675	3136	0.0051	15.00	0.0898	8.8975
3.9E-05	2544	1.02E-05	43.46	slug	0.1718	3215	0.00498	15.377	0.1004	8.7945
3.9E-05	2544	1.14E-05	48.59	slug	0.1760	3294	0.00486	15.756	0.1107	8.6944

3.9E-05	2544	1.38E-05	58.85	slug	0.1845	3452	0.00463	16.514	0.1304	8.5024
3.9E-05	2544	1.62E-05	69.10	slug	0.1929	3611	0.00443	17.272	0.1490	8.3206
3.9E-05	2544	1.86E-05	79.36	slug	0.2014	3769	0.00424	18.029	0.1667	8.1483
3.9E-05	2544	2.10E-05	89.62	slug	0.2098	3928	0.00407	18.787	0.1835	7.9846
3.9E-05	2544	2.34E-05	99.87	slug	0.2183	4086	0.00988	49.320	0.1995	7.8528
3.9E-05	2544	4.13E-05	177	slug	0.2818	5275	0.00927	77.104	0.2982	6.9038
3.9E-05	2544	6.67E-05	285	slug	0.3711	6947	0.00865	124.84	0.3944	5.9866
3.9E-05	2544	8.33E-05	356	slug-churn	0.4300	8048	0.00834	161.49	0.4408	5.5480
3.9E-05	2544	1.17E-04	499	slug-churn	0.5476	10249	0.00785	246.57	0.5094	4.9096
3.9E-05	2544	1.67E-04	713	slug-churn	0.7240	13552	0.00732	402.00	0.5766	4.3025
3.9E-05	2544	3.33E-04	1425	slug-churn	1.3122	24560	0.00631	1137.96	0.6816	3.4699

Table B5 Determination of pressure gradient for the slug flow regime from Sylvester theory (Pure water)

Physical properties of air and water used in experiment:

density of water, $\rho_{water} = 994.7$ kg/m^3; viscosity of water, $\mu_{water} = 8.51 \times 10^{-4}$ Pa.s

density of air, $\rho_{air} = 1.18$ kg/m^3; viscosity of air, $\mu_{air} = 1.85 \times 10^{-5}$ Pa.s

temperature, T = 31 °C (± 1 °C); inner pipe diameter = 0.019 m; cross-sectional area of pipe, A = 0.00028 m^2

$$\beta = L_{TB}/L_{SU} \tag{B15}$$

where: L_{TB} is length of the Taylor bubble

L_{SU} is length of the slug unit

Friction factor associated with the Taylor bubble, $$f_{TB} = \frac{1}{\left[-2.0\log\left\{\frac{\left(1-\alpha_{TB}^{1/2}\right)}{7.4}\right\}\right]^2} \tag{B16}$$

Reynolds number of the liquid slug, $$\mathrm{Re}_{LS} = \frac{\rho_L U_{LLS} D}{\mu_L} \tag{B17}$$

where: velocity of the liquid in the liquid slug, $$U_{LLS} = U_{SG} + U_{SL} \tag{B18}$$

Friction factor associated with the liquid slug, $$f_{LS} = \frac{1}{\left[-2.0\log\left\{\frac{\varepsilon/D}{3.7} - \left(\frac{5.02}{\mathrm{Re}_{LS}}\right)\log\left(\frac{\varepsilon/D}{3.7} + \frac{13}{\mathrm{Re}_{LS}}\right)\right\}\right]^2} \tag{B19}$$

where: ε is the pipe roughness

Acceleration pressure drop, $$(\Delta P)_A = \rho_L(U_{LTB} + U_{TB})(1-\alpha_{TB})(U_{LTB} + U_{TB} + U_{LLS}) \tag{B20}$$

where: velocity of the liquid film around the Taylor bubble, $$U_{LTB} = 9.916\left[gD\left(1-\sqrt{\alpha_{TB}}\right)\right]^{1/2} \tag{B21}$$

velocity of the Taylor bubble, $U_{TB} = 1.2(U_{SG} + U_{SL}) + 0.35\left[\frac{gD(\rho_L - \rho_G)}{\rho_L}\right]^{1/2}$ (B22)

area average void fraction of the Taylor bubble, $\alpha_{TB} = \frac{\text{Average all area at Taylor bubble region}}{\text{Average area in Taylor bubble}}$ (B23)

Hydrostatic pressure drop, $(\Delta P)_H = \rho_L(1-\alpha_{LS})gL_{LS}$ (B24)

where: void fraction of the liquid slug, $\alpha_{LS} = \frac{U_{SG}}{0.425 + 2.65(U_{SG} + U_{SL})}$ (B25)

length of the liquid slug, L_{LS}

Frictional pressure drop of slug unit, $(\Delta P)_F = \frac{L_{LS}}{2D}\left[\frac{\rho_G \beta f_{TB} U_{TB}^2}{(1-\beta)\left[1-(1-\alpha_{TB}^{1/2}\right]} + U_{LLS}^2 \rho_L (1-\alpha_{LS}) f_{LS} (1-\beta)\right]$ (B26)

Total pressure drop in the slug unit, $(\Delta P)_T = (\Delta P)_A + (\Delta P)_H + (\Delta P)_F$ (B27)

Re_{water}	Re_{air}	Flow regime	β	f_{TB}	Re_{LS}	f_{LS}	Acceleration pressure drop $(\Delta P)_A$,Pa	Hydrostatic pressure drop $(\Delta P)_H$,Pa	Frictional pressure drop $(\Delta P)_F$,Pa	Total pressure drop in slug unit $(\Delta P)_T$, Pa	Total pressure drop in slug unit $(\Delta P)_T$, kPa	Pressure gradient (dp/dz), kPa/m
0	18.02	slug	0.2136	0.0633	331	0.0895	268	1100	0.0478	1368.7	1.3687	9.2423
0	20.49	slug	0.2431	0.0575	377	0.0854	179	965	0.0497	1144.3	1.1443	9.0610
0	22.95	slug	0.2630	0.0594	422	0.0821	207	949	0.0574	1156.8	1.1568	8.4159
0	28.08	slug	0.2660	0.0533	517	0.0764	130	1093	0.0907	1223.2	1.2232	8.2979
0	33.21	slug	0.2829	0.0477	611	0.0721	79	1125	0.1197	1204.7	1.2047	7.9737
0	38.33	slug	0.3057	0.0476	705	0.0686	80	1231	0.1607	1311.0	1.3110	7.7036
0	43.46	slug	0.2708	0.0565	800	0.0658	175	1073	0.1806	1247.4	1.2474	7.5283
0	48.59	slug	0.3266	0.0535	894	0.0634	139	1069	0.2007	1208.7	1.2087	7.4562
0	58.85	slug	0.3382	0.0460	1083	0.0595	71	1150	0.2906	1221.7	1.2217	7.2589
0	69.10	slug	0.3312	0.0665	1271	0.0564	364	999	0.3350	1363.6	1.3636	7.0037
0	79.36	slug	0.4286	0.0601	1460	0.0540	246	936	0.3407	1182.6	1.1826	6.3575
0	89.62	slug	0.4737	0.0611	1649	0.0520	268	865	0.3576	1133.8	1.1338	5.9319
0	99.87	slug	0.4474	0.0461	1837	0.0502	80	1022	0.5260	1102.9	1.1029	5.7481
344	28.08	slug	0.2461	0.0695	861	0.0642	416	1028	0.2022	1444.2	1.4442	9.1963
344	33.21	slug	0.2294	0.0690	955	0.0620	409	1575	0.3754	1985.1	1.9851	8.6748
344	38.33	slug	0.2844	0.0664	1049	0.0601	353	1433	0.3724	1786.8	1.7868	8.4061
344	43.46	slug	0.3295	0.0690	1144	0.0584	416	908	0.2562	1323.9	1.3239	7.9601
344	48.59	slug	0.3545	0.0551	1238	0.0569	165	987	0.3052	1152.6	1.1526	7.5224
344	58.85	slug	0.4198	0.0670	1427	0.0544	380	760	0.2707	1139.5	1.1395	7.4761
344	69.10	slug	0.3993	0.0611	1615	0.0523	267	933	0.4209	1200.0	1.2000	6.8448
344	79.36	slug	0.3928	0.0529	1804	0.0505	148	1102	0.6022	1250.7	1.2507	6.7198
344	89.62	slug	0.4752	0.0632	1993	0.0490	319	781	0.4419	1100.7	1.1007	6.3616
344	99.87	slug	0.5347	0.0540	2181	0.0476	170	736	0.4318	906.2	0.9062	5.6871
344	177	slug	0.5245	0.0546	3597	0.0411	208	882	1.2280	1091.1	1.0911	5.0647
477	28.08	slug	0.2707	0.0650	994	0.0612	322	1025	0.2476	1347.1	1.3471	8.9542
477	33.21	slug	0.3176	0.0693	1088	0.0594	421	776	0.2050	1197.0	1.1970	8.6935

477	38.33	slug	0.2672	0.0596	1183	0.0578	229	1153	0.3726	1382.4	1.3824	8.2501
477	43.46	slug	0.3054	0.0623	1277	0.0564	279	964	0.3369	1244.1	1.2441	8.0251
477	48.59	slug	0.3158	0.0616	1371	0.0551	270	1236	0.4795	1506.4	1.5064	7.9974
477	58.85	slug	0.3748	0.0582	1560	0.0529	216	858	0.3784	1074.2	1.0742	7.3496
477	69.10	slug	0.4625	0.0501	1749	0.0510	116	854	0.3943	969.9	0.9699	7.0033
477	79.36	slug	0.4479	0.0572	1937	0.0494	210	803	0.4526	1013.1	1.0131	6.6129
477	89.62	slug	0.4649	0.0515	2126	0.0480	137	854	0.5451	991.1	0.9911	6.2431
477	99.87	slug	0.4627	0.0469	2315	0.0468	92	968	0.7147	1060.8	1.0608	5.9590
477	177	slug	0.5960	0.0403	3730	0.0406	56	774	0.9767	831.4	0.8314	4.7667
611	28.08	slug	0.2600	0.0692	1127	0.0587	421	1110	0.3350	1531.1	1.5311	8.9668
611	33.21	slug	0.2506	0.0701	1222	0.0572	447	1146	0.4002	1593.3	1.5933	8.8077
611	38.33	slug	0.2957	0.0620	1316	0.0558	276	962	0.3580	1238.2	1.2382	8.3642
611	43.46	slug	0.3052	0.0538	1410	0.0546	152	1044	0.4297	1197.2	1.1972	8.1357
611	48.59	slug	0.3319	0.0636	1505	0.0535	312	955	0.4228	1267.1	1.2671	7.9153
611	58.85	slug	0.3619	0.0516	1693	0.0515	131	1059	0.5452	1190.1	1.1901	7.5996
611	69.10	slug	0.3973	0.0499	1882	0.0499	116	924	0.5380	1040.5	1.0405	7.1206
611	79.36	slug	0.4514	0.0560	2071	0.0484	195	779	0.4882	975.0	0.9750	6.9130
611	89.62	slug	0.4729	0.0499	2259	0.0471	122	804	0.5601	925.9	0.9259	6.2636
611	99.87	slug	0.4648	0.0524	2448	0.0460	154	833	0.6749	987.8	0.9878	6.1787
611	177	slug	0.5429	0.0429	3864	0.0402	76	893	1.3452	970.1	0.9701	4.8392
744	28.08	slug	0.2525	0.0626	1260	0.0566	285	928	0.3400	1213.3	1.2133	9.1533
744	33.21	slug	0.2340	0.0632	1355	0.0553	299	1360	0.5754	1659.2	1.6592	8.6948
744	38.33	slug	0.3255	0.0635	1449	0.0541	307	894	0.3750	1201.6	1.2016	8.3808
744	43.46	slug	0.3191	0.0624	1543	0.0530	290	964	0.4532	1254.3	1.2543	8.1389
744	48.59	slug	0.3517	0.0635	1638	0.0521	314	898	0.4455	1212.6	1.2126	7.9884
744	58.85	slug	0.3274	0.0618	1826	0.0503	286	1005	0.6194	1291.5	1.2915	7.7991
744	69.10	slug	0.3282	0.0614	2015	0.0488	284	1118	0.8117	1402.2	1.4022	7.5210
744	79.36	slug	0.3763	0.0629	2204	0.0475	320	1096	0.8623	1416.5	1.4165	7.1202
744	89.62	slug	0.3744	0.0625	2392	0.0463	317	1174	1.0645	1492.3	1.4923	6.9515
744	99.87	slug	0.3602	0.0595	2581	0.0453	265	1385	1.4580	1652.2	1.6522	6.6085
744	177	slug	0.4760	0.0580	3997	0.0398	277	1145	2.0940	1424.6	1.4246	5.3299

1010	33.21	slug	0.2402	0.0619	1621	0.0522	282	1332	0.7549	1614.2	1.6142	8.5918
1010	38.33	slug	0.2393	0.0617	1715	0.0513	282	1468	0.9164	1751.4	1.7514	8.4114
1010	43.46	slug	0.2887	0.0627	1810	0.0505	302	1136	0.7272	1438.9	1.4389	8.3038
1010	48.59	slug	0.3369	0.0622	1904	0.0497	297	933	0.6084	1231.0	1.2310	8.0130
1010	58.85	slug	0.3245	0.0628	2093	0.0482	314	1148	0.8937	1463.2	1.4632	7.7945
1010	69.10	slug	0.3668	0.0616	2281	0.0470	296	982	0.8312	1279.0	1.2790	7.3877
1010	79.36	slug	0.3839	0.0596	2470	0.0459	264	1115	1.0503	1380.2	1.3802	6.7677
1010	89.62	slug	0.3888	0.0587	2659	0.0449	253	1101	1.1662	1356.0	1.3560	6.6113
1010	99.87	slug	0.3970	0.0566	2847	0.0440	223	1096	1.2861	1320.5	1.3205	6.3247
1010	177	slug	0.5794	0.0560	4263	0.0391	247	720	1.1938	968.5	0.9685	4.6587
1277	33.21	slug	0.2786	0.0637	1888	0.0498	326	1032	0.7187	1358.8	1.3588	8.8825
1277	38.33	slug	0.2741	0.0639	1982	0.0491	334	1127	0.8573	1461.8	1.4618	8.7513
1277	43.46	slug	0.2932	0.0612	2076	0.0484	282	999	0.8007	1281.3	1.2813	8.3793
1277	48.59	slug	0.3040	0.0615	2171	0.0477	291	1033	0.8794	1324.6	1.3246	8.2008
1277	58.85	slug	0.2952	0.0625	2359	0.0465	317	1352	1.3414	1670.1	1.6701	7.9158
1277	69.10	slug	0.3249	0.0616	2548	0.0455	305	1258	1.3639	1564.5	1.5645	7.5532
1277	79.36	slug	0.3619	0.0621	2737	0.0445	320	1155	1.3389	1476.2	1.4762	7.2656
1277	89.62	slug	0.3645	0.0594	2925	0.0436	274	1148	1.4836	1423.1	1.4231	6.9543
1277	99.87	slug	0.4234	0.0610	3114	0.0428	310	1046	1.3701	1357.7	1.3577	6.5465
1277	177	slug	0.5097	0.0582	4530	0.0384	295	983	2.0881	1279.4	1.2794	5.2869
1676	33.21	slug	0.2347	0.0632	2287	0.0470	329	1291	1.3167	1621.7	1.6217	9.0154
1676	38.33	slug	0.2772	0.0635	2381	0.0464	338	1100	1.1370	1439.4	1.4394	8.8159
1676	43.46	slug	0.2816	0.0628	2476	0.0458	326	1114	1.2224	1441.8	1.4418	8.6196
1676	48.59	slug	0.2863	0.0622	2570	0.0453	317	1237	1.4361	1555.5	1.5555	8.2804
1676	58.85	slug	0.3127	0.0614	2759	0.0444	306	1097	1.3849	1404.7	1.4047	8.0360
1676	69.10	slug	0.3419	0.0605	2947	0.0435	295	997	1.3504	1293.1	1.2931	7.7176
1676	79.36	slug	0.3015	0.0586	3136	0.0427	265	1241	1.9781	1507.5	1.5075	7.6027
1676	89.62	slug	0.3275	0.0595	3325	0.0420	287	1271	2.1568	1559.3	1.5593	7.3298
1676	99.87	slug	0.3492	0.0599	3514	0.0413	300	1214	2.1925	1515.5	1.5155	7.1566
1676	177	slug	0.5075	0.0624	4929	0.0375	403	1177	2.9069	1582.6	1.5826	5.5304
2742	43.46	slug	0.2521	0.0626	3541	0.0412	359	1205	2.5273	1566.4	1.5664	9.0851

2742	48.59	slug	0.3158	0.0613	3636	0.0409	333	873	1.7549	1208.1	1.2081	8.8111
2742	58.85	slug	0.3318	0.0607	3824	0.0403	325	927	1.9866	1255.0	1.2550	8.3380
2742	69.10	slug	0.3273	0.0590	4013	0.0398	298	924	2.1618	1223.3	1.2233	8.1473
2742	79.36	slug	0.3348	0.0598	4202	0.0393	318	966	2.4205	1286.9	1.2869	8.0350
2742	89.62	slug	0.3510	0.0606	4390	0.0388	342	1030	2.7160	1374.5	1.3745	7.7947
2742	99.87	slug	0.3380	0.0598	4579	0.0383	330	1163	3.3604	1496.2	1.4962	7.6051
2742	177	slug	0.4699	0.0590	5995	0.0356	356	1031	3.8155	1390.7	1.3907	6.0864

Table B6 Determination of pressure gradient for the slug flow regime from Sylvester theory (SDS solution at 1 CMC)

Physical properties of air and SDS solution (1 CMC) used in experiment:

density of SDS solution, $\rho_{SDS\ solution}$ = 994.97 kg/m^3; viscosity of SDS solution, $\mu_{SDS\ solution}$ = 1.01 × 10^{-3} Pa.s

density of air, ρ_{air} = 1.18 kg/m^3; viscosity of air, μ_{air} = 1.85 × 10^{-5} Pa.s

temperature, T = 31 °C (± 1 °C); inner pipe diameter = 0.019 m; cross-sectional area of pipe, A = 0.00028 m^2

$Re_{solution}$	Re_{air}	β	f_{TB}	Re_{LS}	f_{LS}	Acceleration pressure drop (dp/dz),Pa/m	Hydrostatic pressure drop (dp/dz),Pa/m	Frictional pressure drop (dp/dz),Pa/m	Total pressure drop in slug unit (ΔP), Pa	Total pressure drop in slug unit (ΔP), kPa	Pressure gradient (dp/dz), kPa/m
0	13.06	0.1734	0.0662	202	0.1070	321	1151	0.0333	1472.5	1.4726	10.0750
0	15.54	0.1823	0.0671	240	0.1005	341	1228	0.0464	1569.4	1.5694	9.9141
0	18.02	0.2122	0.0682	278	0.0953	366	1113	0.0517	1479.2	1.4792	9.8908
0	20.49	0.2331	0.0648	316	0.0910	299	1060	0.0589	1359.2	1.3592	9.2501
0	22.95	0.2378	0.0632	354	0.0873	270	1090	0.0722	1360.6	1.3606	8.9122
0	28.08	0.2448	0.0618	434	0.0813	249	1095	0.0993	1344.3	1.3443	8.6176
0	33.21	0.2580	0.0610	513	0.0766	238	1097	0.1284	1334.7	1.3347	8.3293
0	38.33	0.2772	0.0602	592	0.0729	227	1106	0.1597	1333.3	1.3333	7.9778
0	43.46	0.3069	0.0614	671	0.0698	249	1159	0.1979	1408.6	1.4086	7.6524
0	48.59	0.3106	0.0592	750	0.0672	216	1171	0.2384	1387.3	1.3873	7.3732
0	58.85	0.3298	0.0569	909	0.0630	186	1290	0.3503	1476.2	1.4762	6.8317
0	69.10	0.3835	0.0599	1067	0.0597	238	1101	0.3613	1339.5	1.3395	6.5940
0	79.36	0.3873	0.0581	1226	0.0571	213	1202	0.4928	1415.4	1.4154	6.2708

0	89.62	0.3980	0.0584	1384	0.0549	222	1179	0.5820	1401.9	1.4019	6.1525
0	99.87	0.3814	0.0577	1543	0.0531	216	1586	0.9622	1803.7	1.8037	5.9855
385	20.49	0.1990	0.0673	702	0.0688	366	1116	0.2343	1482.2	1.4822	10.0495
385	22.95	0.2398	0.0655	740	0.0675	328	1131	0.2465	1458.9	1.4589	9.2291
385	28.08	0.2490	0.0644	819	0.0653	311	1119	0.2849	1429.4	1.4294	8.9661
385	33.21	0.2651	0.0661	898	0.0633	348	1115	0.3243	1463.3	1.4633	8.9478
385	38.33	0.2684	0.0644	977	0.0615	316	1160	0.3863	1476.3	1.4763	8.5775
385	43.46	0.2850	0.0635	1056	0.0599	301	1360	0.5043	1662.1	1.6621	7.9939
385	48.59	0.2977	0.0634	1136	0.0585	302	1398	0.5748	1701.0	1.7010	7.7675
385	58.85	0.3144	0.0626	1294	0.0561	294	1368	0.6829	1662.2	1.6622	7.4830
385	69.10	0.3108	0.0592	1452	0.0541	237	1548	0.9411	1785.8	1.7858	7.0597
385	79.36	0.3426	0.0586	1611	0.0523	233	1481	1.0234	1714.6	1.7146	6.6839
385	89.62	0.3594	0.0565	1769	0.0508	203	1437	1.1330	1641.0	1.6410	6.3602
385	99.87	0.3791	0.0550	1928	0.0495	186	1364	1.2055	1550.8	1.5508	6.0773
385	177	0.4505	0.0527	3116	0.0428	182	1603	2.8385	1787.5	1.7875	4.9732
500	20.49	0.2212	0.0661	815	0.0653	344	1235	0.3232	1578.8	1.5788	9.4157
500	22.95	0.2205	0.0665	853	0.0644	355	1312	0.3705	1667.1	1.6671	9.3331
500	28.08	0.2606	0.0655	932	0.0625	337	1128	0.3510	1464.9	1.4649	8.9838
500	33.21	0.2689	0.0663	1012	0.0608	357	1153	0.4064	1510.0	1.5100	8.8964
500	38.33	0.2655	0.0633	1091	0.0593	299	1235	0.4954	1534.8	1.5348	8.4209
500	43.46	0.2704	0.0613	1170	0.0580	265	1323	0.5924	1588.7	1.5887	8.0300
500	48.59	0.3128	0.0617	1249	0.0568	275	1197	0.5646	1473.1	1.4731	7.7036
500	58.85	0.3182	0.0609	1408	0.0546	265	1307	0.7467	1573.0	1.5730	7.3836
500	69.10	0.2873	0.0608	1566	0.0528	269	1575	1.1223	1845.8	1.8458	7.4322
500	79.36	0.2926	0.0584	1724	0.0512	233	1745	1.4507	1979.4	1.9794	7.0669
500	89.62	0.3401	0.0570	1883	0.0498	215	1429	1.2879	1645.7	1.6457	6.6238
500	99.87	0.3446	0.0567	2041	0.0486	214	1717	1.7614	1933.2	1.9332	6.3713
500	177	0.4052	0.0553	3230	0.0424	225	1427	2.9006	1655.0	1.6550	5.6196
610	20.49	0.2225	0.0674	929	0.0626	378	1072	0.3477	1450.5	1.4505	9.9566
610	22.95	0.2168	0.0684	967	0.0617	402	1166	0.4072	1569.0	1.5690	9.9361
610	28.08	0.2457	0.0657	1046	0.0601	347	1206	0.4627	1552.9	1.5529	9.0990

610	33.21	0.2414	0.0652	1125	0.0587	339	1259	0.5486	1598.9	1.5989	8.9583
610	38.33	0.2568	0.0662	1204	0.0574	362	1302	0.6228	1664.4	1.6644	8.7830
610	43.46	0.2695	0.0658	1284	0.0563	357	1376	0.7204	1734.4	1.7344	8.4541
610	48.59	0.2800	0.0648	1363	0.0552	340	1373	0.7830	1713.7	1.7137	8.2036
610	58.85	0.2978	0.0636	1521	0.0533	322	1410	0.9440	1733.6	1.7336	7.7861
610	69.10	0.3256	0.0645	1680	0.0517	347	1344	1.0218	1692.2	1.6922	7.5768
610	79.36	0.3029	0.0617	1838	0.0502	295	1636	1.4932	1932.2	1.9322	7.2699
610	89.62	0.3166	0.0604	1996	0.0490	276	1641	1.6896	1918.9	1.9189	6.9837
610	99.87	0.3444	0.0572	2155	0.0478	225	1649	1.8536	1875.4	1.8754	6.4573
610	177	0.4387	0.0561	3343	0.0419	241	1448	2.9517	1692.1	1.6921	5.3624
725	20.49	0.2176	0.0681	1042	0.0602	399	1215	0.4803	1614.8	1.6148	9.8488
725	22.95	0.2105	0.0663	1080	0.0595	361	1377	0.5827	1738.7	1.7387	9.4086
725	28.08	0.2593	0.0655	1160	0.0581	346	1185	0.5307	1532.3	1.5323	8.9787
725	33.21	0.2456	0.0633	1239	0.0569	305	1399	0.7112	1704.0	1.7040	8.5622
725	38.33	0.2847	0.0642	1318	0.0558	326	1263	0.6769	1589.5	1.5895	8.3313
725	43.46	0.2985	0.0635	1397	0.0548	315	1255	0.7277	1570.4	1.5704	8.0748
725	48.59	0.3399	0.0645	1476	0.0538	338	1159	0.6957	1497.8	1.4978	7.7977
725	58.85	0.3405	0.0611	1635	0.0521	277	1291	0.9177	1569.2	1.5692	7.2451
725	69.10	0.3281	0.0613	1793	0.0506	285	1425	1.2041	1711.2	1.7112	7.2162
725	79.36	0.3235	0.0591	1952	0.0493	251	1613	1.5822	1866.0	1.8660	6.9243
725	89.62	0.3532	0.0602	2110	0.0481	277	1504	1.6120	1782.7	1.7827	6.7173
725	99.87	0.3699	0.0583	2268	0.0471	248	1500	1.7707	1749.6	1.7496	6.3800
725	177	0.4789	0.0551	3457	0.0415	228	1398	2.8081	1628.7	1.6287	4.9812
1065	22.95	0.2565	0.0686	1421	0.0545	429	1080	0.6820	1510.4	1.5104	9.8392
1065	28.08	0.2722	0.0678	1500	0.0535	413	1079	0.7304	1492.7	1.4927	9.4739
1065	33.21	0.2857	0.0662	1580	0.0527	380	1063	0.7703	1443.3	1.4433	9.0675
1065	38.33	0.2714	0.0663	1659	0.0519	386	1251	1.0033	1637.8	1.6378	8.8661
1065	43.46	0.2725	0.0642	1738	0.0511	342	1331	1.1526	1674.6	1.6746	8.4557
1065	48.59	0.2966	0.0641	1817	0.0504	344	1229	1.1104	1573.9	1.5739	8.2759
1065	58.85	0.3068	0.0647	1976	0.0491	362	1301	1.3349	1665.3	1.6653	8.0612
1065	69.10	0.3167	0.0632	2134	0.0480	337	1369	1.5766	1707.1	1.7071	7.6673

1065	79.36	0.3280	0.0619	2292	0.0469	317	1430	1.8289	1748.2	1.7482	7.3192
1065	89.62	0.3297	0.0607	2451	0.0460	298	1470	2.0992	1769.6	1.7696	7.1234
1065	99.87	0.3651	0.0577	2609	0.0451	247	1392	2.0978	1641.7	1.6417	6.5489
1065	177	0.4403	0.0548	3798	0.0404	232	1392	3.5157	1628.1	1.6281	5.4199
1290	22.95	0.2518	0.0696	1648	0.0520	464	1016	0.8274	1480.8	1.4808	10.3390
1290	28.08	0.2552	0.0676	1728	0.0512	418	1169	1.0258	1588.6	1.5886	9.5354
1290	33.21	0.2500	0.0657	1807	0.0505	379	1267	1.2067	1647.7	1.6477	9.1339
1290	38.33	0.2798	0.0653	1886	0.0498	372	1208	1.1890	1581.8	1.5818	8.7835
1290	43.46	0.2612	0.0645	1965	0.0492	359	1598	1.7274	1958.6	1.9586	8.3885
1290	48.59	0.3424	0.0632	2044	0.0486	334	1090	1.1251	1425.5	1.4255	7.9235
1290	58.85	0.3285	0.0638	2203	0.0475	353	1266	1.5123	1620.5	1.6205	7.8398
1290	69.10	0.3649	0.0623	2361	0.0465	328	1170	1.4900	1499.9	1.4999	7.3475
1290	79.36	0.3758	0.0605	2520	0.0456	296	1164	1.6263	1461.8	1.4618	7.0102
1290	89.62	0.3503	0.0589	2678	0.0448	271	1338	2.1542	1611.3	1.6113	6.9345
1290	99.87	0.3398	0.0577	2836	0.0440	254	1653	2.9809	1910.7	1.9107	6.7039
1290	177	0.4148	0.0564	4025	0.0398	268	1538	4.4807	1811.0	1.8110	5.7377
1635	22.95	0.2450	0.0677	1989	0.0490	435	986	1.1115	1421.9	1.4219	10.3430
1635	28.08	0.2287	0.0669	2068	0.0484	419	1240	1.5244	1660.2	1.6602	9.7544
1635	33.21	0.2642	0.0660	2148	0.0479	402	1176	1.4707	1578.6	1.5786	9.2811
1635	38.33	0.2749	0.0658	2227	0.0473	399	1192	1.5623	1592.6	1.5926	9.0547
1635	43.46	0.3226	0.0640	2306	0.0468	362	1108	1.4431	1471.6	1.4716	8.3605
1635	48.59	0.2958	0.0634	2385	0.0464	353	1305	1.8675	1659.1	1.6591	8.2823
1635	58.85	0.2812	0.0632	2544	0.0455	353	1624	2.6444	1979.6	1.9796	8.0248
1635	69.10	0.3237	0.0633	2702	0.0447	363	1423	2.4201	1788.4	1.7884	7.7080
1635	79.36	0.3312	0.0621	2860	0.0439	341	1494	2.7691	1838.7	1.8387	7.3982
1635	89.62	0.3176	0.0597	3019	0.0432	299	1650	3.4164	1952.7	1.9527	7.1991
1635	99.87	0.3411	0.0571	3177	0.0426	255	1778	3.8806	2036.9	2.0369	6.6724
1635	177	0.4135	0.0570	4366	0.0388	289	1811	6.0761	2106.9	2.1069	5.7268
2540	33.21	0.2440	0.0686	3056	0.0431	512	1188	2.7775	1702.8	1.7028	10.2399
2540	38.33	0.2564	0.0685	3136	0.0427	515	1239	2.9787	1757.1	1.7571	9.9142
2540	43.46	0.2605	0.0657	3215	0.0424	444	1278	3.1880	1725.3	1.7253	9.3449

2540	48.59	0.2680	0.0635	3294	0.0421	392	1289	3.3163	1683.9	1.6839	8.9143
2540	58.85	0.2860	0.0635	3452	0.0416	399	1234	3.3574	1636.0	1.6360	8.7477
2540	69.10	0.2891	0.0645	3611	0.0410	431	1321	3.8627	1755.7	1.7557	8.6628
2540	79.36	0.2770	0.0619	3769	0.0405	374	1584	5.0687	1963.3	1.9633	8.1483
2540	89.62	0.3058	0.0616	3928	0.0400	374	1524	5.0284	1902.7	1.9027	7.8215
2540	99.87	0.2882	0.0599	4086	0.0396	340	1701	6.1538	2047.5	2.0475	7.6760
2540	177	0.3658	0.0577	5275	0.0368	336	1982	9.9263	2328.2	2.3282	6.3647

Table B7 Determination of slug size and void fraction for Sylvester theory (Pure water)

Physical properties of air and water used in experiment:

density of water, $\rho_{water} = 994.7$ kg/m^3; viscosity of water, $\mu_{water} = 8.51 \times 10^{-4}$ Pa.s

density of air, $\rho_{air} = 1.18$ kg/m^3; viscosity of air, $\mu_{air} = 1.85 \times 10^{-5}$ Pa.s

temperature, T = 31 °C (± 1 °C); inner pipe diameter, D = 0.019 m; cross-sectional area of pipe, A = 0.00028 m^2

Procedure to determine the slug size and void fraction for Sylvester theory:

1. Make a movie of the slug flow regime by video camera.
2. Capture the picture from movie by Win DVD software program.
3. Measure the slug size and void fraction of slug unit by Scion Image software program.

Re_{water}	Re_{air}	Average all area in Taylor bubble region (mm^2)	Average area only in Taylor bubble (mm^2)	Area average void fraction of Taylor bubble (α_{TB})	Average length of Taylor bubble (L_{TB}), m	Average length of liquid slug (L_{LS}), m	Average length of slug unit (L_{SU}), m
0	18.02	601.16	513.14	0.85	0.0316	0.1165	0.1481
0	20.49	626.18	552.41	0.88	0.0330	0.1026	0.1356
0	22.95	686.85	599.56	0.87	0.0362	0.1013	0.1375
0	28.08	809.78	730.16	0.90	0.0426	0.1176	0.1602
0	33.21	914.41	846.06	0.93	0.0481	0.1220	0.1701
0	38.33	1125.18	1041.60	0.93	0.0592	0.1345	0.1937
0	43.46	832.58	738.37	0.89	0.0438	0.1180	0.1618
0	48.59	1091.61	983.01	0.90	0.0575	0.1185	0.1759
0	58.85	1254.19	1169.23	0.93	0.0660	0.1292	0.1952
0	69.10	1068.56	894.13	0.84	0.0562	0.1136	0.1698
0	79.36	1534.19	1333.55	0.87	0.0807	0.1077	0.1884
0	89.62	1720.32	1487.12	0.86	0.0905	0.1006	0.1911
0	99.87	1848.13	1722.34	0.93	0.0973	0.1201	0.2174
344	28.08	682.92	560.65	0.82	0.0359	0.1101	0.1461
344	33.21	961.84	792.02	0.82	0.0506	0.1701	0.2207
344	38.33	1176.42	985.31	0.84	0.0619	0.1558	0.2177
344	43.46	927.52	763.92	0.82	0.0488	0.0993	0.1481
344	48.59	1134.68	1013.55	0.89	0.0597	0.1087	0.1684
344	58.85	1165.14	972.35	0.83	0.0613	0.0848	0.1461
344	69.10	1329.94	1150.01	0.86	0.0700	0.1053	0.1753
344	79.36	1545.59	1395.97	0.90	0.0813	0.1257	0.2071
344	89.62	1550.08	1323.68	0.85	0.0816	0.0901	0.1717
344	99.87	1872.32	1681.98	0.90	0.0985	0.0858	0.1843
344	177	2284.24	2045.59	0.90	0.1202	0.1090	0.2292

477	28.08	773.62	653.65	0.84	0.0407	0.1097	0.1504
477	33.21	739.29	607.72	0.82	0.0389	0.0836	0.1225
477	38.33	866.84	755.98	0.87	0.0456	0.1251	0.1707
477	43.46	879.83	755.28	0.86	0.0463	0.1053	0.1516
477	48.59	1192.06	1027.46	0.86	0.0627	0.1359	0.1987
477	58.85	1086.93	955.30	0.88	0.0572	0.0954	0.1527
477	69.10	1571.49	1438.57	0.92	0.0827	0.0961	0.1788
477	79.36	1408.03	1244.09	0.88	0.0741	0.0914	0.1655
477	89.62	1620.19	1473.54	0.91	0.0853	0.0982	0.1834
477	99.87	1838.44	1707.51	0.93	0.0968	0.1124	0.2091
477	177	2670.89	2544.53	0.95	0.1406	0.0953	0.2359
611	28.08	791.92	651.30	0.82	0.0417	0.1186	0.1603
611	33.21	783.75	640.80	0.82	0.0413	0.1234	0.1646
611	38.33	831.76	715.17	0.86	0.0438	0.1043	0.1480
611	43.46	950.44	854.56	0.90	0.0500	0.1139	0.1639
611	48.59	988.89	842.31	0.85	0.0520	0.1048	0.1568
611	58.85	1267.17	1152.03	0.91	0.0667	0.1176	0.1843
611	69.10	1300.36	1191.67	0.92	0.0684	0.1038	0.1723
611	79.36	1383.20	1229.93	0.89	0.0728	0.0885	0.1613
611	89.62	1571.49	1439.86	0.92	0.0827	0.0922	0.1749
611	99.87	1591.19	1440.61	0.91	0.0837	0.0964	0.1802
611	177	2471.08	2331.84	0.94	0.1301	0.1095	0.2396
744	28.08	636.06	545.00	0.86	0.0335	0.0991	0.1326
744	33.21	848.41	724.51	0.85	0.0447	0.1462	0.1908
744	38.33	886.79	755.96	0.85	0.0467	0.0967	0.1434
744	43.46	934.48	801.58	0.86	0.0492	0.1049	0.1541
744	48.59	1014.41	864.65	0.85	0.0534	0.0984	0.1518
744	58.85	1029.99	886.99	0.86	0.0542	0.1114	0.1656
744	69.10	1162.61	1003.58	0.86	0.0612	0.1252	0.1864
744	79.36	1422.40	1216.77	0.86	0.0749	0.1241	0.1989
744	89.62	1526.97	1309.67	0.86	0.0804	0.1343	0.2147

744	99.87	1711.27	1493.02	0.87	0.0901	0.1600	0.2500
744	177	2417.43	2126.24	0.88	0.1272	0.1400	0.2673
1010	33.21	857.41	737.87	0.86	0.0451	0.1428	0.1879
1010	38.33	946.64	815.31	0.86	0.0498	0.1584	0.2082
1010	43.46	950.51	814.28	0.86	0.0500	0.1233	0.1733
1010	48.59	983.50	844.61	0.86	0.0518	0.1019	0.1536
1010	58.85	1157.54	990.94	0.86	0.0609	0.1268	0.1877
1010	69.10	1206.50	1040.21	0.86	0.0635	0.1096	0.1731
1010	79.36	1487.45	1296.88	0.87	0.0783	0.1257	0.2039
1010	89.62	1515.31	1327.84	0.88	0.0798	0.1254	0.2051
1010	99.87	1574.97	1395.69	0.89	0.0829	0.1259	0.2088
1010	177	2288.42	2034.32	0.89	0.1204	0.0874	0.2079
1277	33.21	809.65	689.24	0.85	0.0426	0.1104	0.1530
1277	38.33	870.01	739.63	0.85	0.0458	0.1212	0.1670
1277	43.46	851.71	736.06	0.86	0.0448	0.1081	0.1529
1277	48.59	932.96	804.75	0.86	0.0491	0.1124	0.1615
1277	58.85	1183.32	1014.54	0.86	0.0623	0.1487	0.2110
1277	69.10	1278.70	1102.05	0.86	0.0673	0.1398	0.2071
1277	79.36	1397.20	1201.13	0.86	0.0735	0.1296	0.2032
1277	89.62	1417.40	1237.06	0.87	0.0746	0.1300	0.2046
1277	99.87	1668.64	1443.30	0.86	0.0878	0.1196	0.2074
1277	177	2343.78	2059.87	0.88	0.1234	0.1186	0.2420
1676	33.21	801.99	684.72	0.85	0.0422	0.1377	0.1799
1676	38.33	859.88	733.06	0.85	0.0453	0.1180	0.1633
1676	43.46	895.03	766.22	0.86	0.0471	0.1202	0.1673
1676	48.59	1021.95	877.87	0.86	0.0538	0.1341	0.1879
1676	58.85	1038.48	896.44	0.86	0.0547	0.1201	0.1748
1676	69.10	1088.32	944.21	0.87	0.0573	0.1103	0.1676
1676	79.36	1136.01	995.95	0.88	0.0598	0.1385	0.1983
1676	89.62	1323.73	1154.81	0.87	0.0697	0.1431	0.2127
1676	99.87	1405.18	1223.18	0.87	0.0740	0.1378	0.2118

1676	177	2759.18	2366.77	0.86	0.1452	0.1409	0.2862
2742	43.46	825.99	707.71	0.86	0.0435	0.1289	0.1724
2742	48.59	822.64	710.18	0.86	0.0433	0.0938	0.1371
2742	58.85	948.80	822.19	0.87	0.0499	0.1006	0.1505
2742	69.10	933.66	816.58	0.87	0.0491	0.1010	0.1501
2742	79.36	1018.78	887.35	0.87	0.0536	0.1065	0.1602
2742	89.62	1175.91	1019.39	0.87	0.0619	0.1145	0.1763
2742	99.87	1263.56	1100.56	0.87	0.0665	0.1302	0.1967
2742	177	2040.09	1784.78	0.87	0.1074	0.1211	0.2285

Table B8 Determination of slug size and void fraction for Sylvester theory (SDS solution at 1 CMC)

Physical properties of air and SDS solution (1 CMC) used in experiment:

density of water, $\rho_{SDS\ solution} = 994.97$ kg/m^3; viscosity of water, $\mu_{SDS\ solution} = 1.01 \times 10^{-3}$ Pa.s

density of air, $\rho_{air} = 1.18$ kg/m^3; viscosity of air, $\mu_{air} = 1.85 \times 10^{-5}$ Pa.s

temperature, T = 31 °C (± 1 °C); inner pipe diameter, D = 0.019 m; cross-sectional area of pipe, A = 0.00028 m^2

$Re_{solution}$	Re_{air}	Average all area in Taylor bubble region (mm^2)	Average area only in Taylor bubble (mm^2)	Area average void fraction of Taylor bubble (α_{TB})	Average length of Taylor bubble (L_{TB}), m	Average length of liquid slug (L_{LS}), m	Average lengh of slug unit (L_{SU}), m
0	13.06	481.59	403.71	0.84	0.0253	0.1208	0.1462
0	15.54	548.21	456.98	0.83	0.0289	0.1295	0.1583
0	18.02	602.87	499.08	0.83	0.0317	0.1178	0.1496
0	20.49	650.69	550.17	0.85	0.0342	0.1127	0.1469
0	22.95	689.89	589.08	0.85	0.0363	0.1164	0.1527
0	28.08	725.48	624.48	0.86	0.0382	0.1178	0.1560
0	33.21	785.59	679.42	0.86	0.0413	0.1189	0.1602
0	38.33	880.27	764.82	0.87	0.0463	0.1208	0.1671
0	43.46	1073.25	926.37	0.86	0.0565	0.1276	0.1841
0	48.59	1110.30	970.10	0.87	0.0584	0.1297	0.1882
0	58.85	1354.07	1198.26	0.88	0.0713	0.1448	0.2161
0	69.10	1480.35	1288.21	0.87	0.0779	0.1252	0.2031
0	79.36	1660.98	1460.40	0.88	0.0874	0.1383	0.2257
0	89.62	1723.30	1512.77	0.88	0.0907	0.1372	0.2279
0	99.87	2183.92	1923.87	0.88	0.1149	0.1864	0.3013
385	20.49	557.52	464.12	0.83	0.0293	0.1181	0.1475
385	22.95	720.29	606.75	0.84	0.0379	0.1202	0.1581
385	28.08	754.24	639.29	0.85	0.0397	0.1197	0.1594
385	33.21	823.78	691.07	0.84	0.0434	0.1202	0.1635
385	38.33	877.61	744.08	0.85	0.0462	0.1259	0.1721
385	43.46	1125.94	959.84	0.85	0.0593	0.1487	0.2079
385	48.59	1238.55	1056.54	0.85	0.0652	0.1538	0.2190
385	58.85	1326.77	1136.77	0.86	0.0698	0.1523	0.2221
385	69.10	1493.65	1305.43	0.87	0.0786	0.1743	0.2530

385	79.36	1669.97	1464.04	0.88	0.0879	0.1686	0.2565
385	89.62	1762.12	1562.81	0.89	0.0927	0.1653	0.2580
385	99.87	1838.06	1642.79	0.89	0.0967	0.1584	0.2552
385	177	3076.61	2781.78	0.90	0.1619	0.1975	0.3594
500	20.49	704.65	591.29	0.84	0.0371	0.1306	0.1677
500	22.95	748.47	626.30	0.84	0.0394	0.1392	0.1786
500	28.08	807.50	679.98	0.84	0.0425	0.1206	0.1631
500	33.21	867.10	726.62	0.84	0.0456	0.1241	0.1697
500	38.33	919.35	784.57	0.85	0.0484	0.1339	0.1823
500	43.46	1016.37	877.60	0.86	0.0535	0.1444	0.1978
500	48.59	1136.45	978.80	0.86	0.0598	0.1314	0.1912
500	58.85	1288.14	1115.10	0.87	0.0678	0.1452	0.2130
500	69.10	1355.90	1174.05	0.87	0.0714	0.1770	0.2484
500	79.36	1556.99	1366.32	0.88	0.0819	0.1982	0.2801
500	89.62	1605.56	1419.66	0.88	0.0845	0.1640	0.2485
500	99.87	1986.39	1759.61	0.89	0.1045	0.1989	0.3034
500	177	2267.27	2023.10	0.89	0.1193	0.1752	0.2945
610	20.49	615.73	512.29	0.83	0.0324	0.1133	0.1457
610	22.95	650.50	537.86	0.83	0.0342	0.1237	0.1579
610	28.08	796.61	669.80	0.84	0.0419	0.1287	0.1707
610	33.21	818.77	690.68	0.84	0.0431	0.1354	0.1785
610	38.33	924.67	775.53	0.84	0.0487	0.1408	0.1895
610	43.46	1050.32	883.00	0.84	0.0553	0.1499	0.2052
610	48.59	1111.44	939.88	0.85	0.0585	0.1504	0.2089
610	58.85	1259.76	1072.88	0.85	0.0663	0.1564	0.2227
610	69.10	1381.62	1170.30	0.85	0.0727	0.1506	0.2233
610	79.36	1529.63	1317.93	0.86	0.0805	0.1853	0.2658
610	89.62	1652.62	1434.69	0.87	0.0870	0.1878	0.2748
610	99.87	1900.32	1679.30	0.88	0.1000	0.1904	0.2904
610	177	2630.30	2337.73	0.89	0.1384	0.1771	0.3155
725	20.49	677.86	561.50	0.83	0.0357	0.1283	0.1640

725	22.95	739.10	619.19	0.84	0.0389	0.1459	0.1848
725	28.08	840.69	707.90	0.84	0.0442	0.1264	0.1707
725	33.21	928.66	792.47	0.85	0.0489	0.1501	0.1990
725	38.33	1032.14	876.05	0.85	0.0543	0.1365	0.1908
725	43.46	1102.95	940.10	0.85	0.0581	0.1364	0.1945
725	48.59	1240.57	1051.22	0.85	0.0653	0.1268	0.1921
725	58.85	1401.19	1211.23	0.86	0.0737	0.1428	0.2166
725	69.10	1478.14	1276.72	0.86	0.0778	0.1593	0.2371
725	79.36	1656.42	1448.43	0.87	0.0872	0.1823	0.2695
725	89.62	1780.81	1547.37	0.87	0.0937	0.1717	0.2654
725	99.87	1927.30	1692.56	0.88	0.1014	0.1728	0.2742
725	177	2974.89	2657.20	0.89	0.1566	0.1704	0.3270
1065	22.95	748.09	617.69	0.83	0.0394	0.1141	0.1535
1065	28.08	814.85	676.35	0.83	0.0429	0.1147	0.1576
1065	33.21	864.12	724.54	0.84	0.0455	0.1137	0.1592
1065	38.33	952.47	798.01	0.84	0.0501	0.1346	0.1847
1065	43.46	1025.56	870.54	0.85	0.0540	0.1441	0.1980
1065	48.59	1071.66	910.16	0.85	0.0564	0.1338	0.1902
1065	58.85	1204.09	1019.19	0.85	0.0634	0.1432	0.2066
1065	69.10	1339.56	1143.99	0.85	0.0705	0.1521	0.2227
1065	79.36	1488.52	1280.79	0.86	0.0783	0.1605	0.2389
1065	89.62	1556.42	1348.65	0.87	0.0819	0.1665	0.2484
1065	99.87	1738.75	1532.20	0.88	0.0915	0.1592	0.2507
1065	177	2513.19	2248.39	0.89	0.1323	0.1681	0.3004
1290	22.95	685.14	562.32	0.82	0.0361	0.1072	0.1432
1290	28.08	807.75	671.51	0.83	0.0425	0.1241	0.1666
1290	33.21	857.03	720.68	0.84	0.0451	0.1353	0.1804
1290	38.33	957.28	807.21	0.84	0.0504	0.1297	0.1801
1290	43.46	1158.81	981.67	0.85	0.0610	0.1725	0.2335
1290	48.59	1170.46	999.28	0.85	0.0616	0.1183	0.1799
1290	58.85	1290.04	1097.51	0.85	0.0679	0.1388	0.2067

1290	69.10	1415.37	1214.80	0.86	0.0745	0.1296	0.2041
1290	79.36	1488.97	1291.80	0.87	0.0784	0.1302	0.2085
1290	89.62	1546.73	1353.94	0.88	0.0814	0.1510	0.2324
1290	99.87	1840.15	1621.51	0.88	0.0969	0.1882	0.2850
1290	177	2487.61	2206.81	0.89	0.1309	0.1847	0.3156
1635	22.95	639.92	531.45	0.83	0.0337	0.1038	0.1375
1635	28.08	739.42	617.25	0.83	0.0389	0.1313	0.1702
1635	33.21	853.86	716.66	0.84	0.0449	0.1251	0.1701
1635	38.33	918.84	772.34	0.84	0.0484	0.1275	0.1759
1635	43.46	1078.76	916.73	0.85	0.0568	0.1192	0.1760
1635	48.59	1125.69	959.85	0.85	0.0592	0.1411	0.2003
1635	58.85	1317.78	1125.47	0.85	0.0694	0.1773	0.2467
1635	69.10	1427.15	1217.91	0.85	0.0751	0.1569	0.2320
1635	79.36	1563.76	1344.38	0.86	0.0823	0.1662	0.2485
1635	89.62	1636.60	1425.78	0.87	0.0861	0.1851	0.2712
1635	99.87	1978.53	1748.73	0.88	0.1041	0.2011	0.3053
1635	177	2890.53	2556.90	0.88	0.1521	0.2158	0.3679
2540	33.21	770.89	636.69	0.83	0.0406	0.1257	0.1663
2540	38.33	863.42	713.40	0.83	0.0454	0.1318	0.1772
2540	43.46	913.71	768.32	0.84	0.0481	0.1365	0.1846
2540	48.59	961.91	820.00	0.85	0.0506	0.1383	0.1889
2540	58.85	1016.37	866.41	0.85	0.0535	0.1335	0.1870
2540	69.10	1113.46	943.27	0.85	0.0586	0.1441	0.2027
2540	79.36	1268.12	1091.26	0.86	0.0667	0.1742	0.2409
2540	89.62	1413.41	1218.38	0.86	0.0744	0.1689	0.2433
2540	99.87	1460.40	1271.49	0.87	0.0769	0.1899	0.2667
2540	177	2542.52	2240.04	0.88	0.1338	0.2320	0.3658

Table B9 Determination of pressure gradient for the annular and mist flow regime from Wilkes theory (Pure water)

Physical properties of air and water used in experiment:

density of water, $\rho_{water} = 994.7$ kg/m^3; viscosity of water, $\mu_{water} = 8.51 \times 10^{-4}$ PA.s

density of air, $\rho_{air} = 1.18$ kg/m^3; viscosity of air, $\mu_{air} = 1.85 \times 10^{-5}$ Pa.s

temperature, T = 31 °C (± 1 °C); inner pipe diameter = 0.019 m; cross-sectional area of pipe, A = 0.00028 m^2

Fanning friction factor, $f_F = \dfrac{16}{\mathrm{Re}}$ for laminar flow (Re < 2000) (B28)

$f_F = 0.079\,\mathrm{Re}^{-1/4}$ for turbulent flow (Re > 4000) (B29)

Pressure gradient for air, $\left(\dfrac{dp}{dz}\right)_{air} = \dfrac{2 f_F \rho_{air} j_{air}}{D}$ (B30)

Pressure gradient for liquid, $\left(\dfrac{dp}{dz}\right)_{liquid} = \dfrac{2 f_F \rho_{liquid} j_{liquid}}{D}$ (B31)

Martinelli parameter, X from $\left(1+X^{2/3.61}\right)^{3.61}\left((dp/dz)_{air} - \dfrac{(dp/dz)_{liquid}}{X^2}\right) = 9749\left(1 - \dfrac{1}{\left(\left(1+0.0904X^{0.548}\right)^{2.82}\right)}\right)$ (B32)

Void fraction, $\varepsilon = \dfrac{1}{\left(1+0.0904X^{0.548}\right)^{2.82}}$ (B33)

Gas two-phase flow multiplier, $\phi_g = \left(1+X^{2/3.61}\right)^{3.61/2}$ (B34)

Pressure gradient for two-phase flow, $\left(\dfrac{dp}{dz}\right) = \phi_g^2\left(\dfrac{dp}{dz}\right)_{air} - \rho_{air} g$ (B35)

Water			Air											
Q_{water} (ml/min)	j_{water} (m/sec)	Re_{water}	Q_{air} (L/min)	j_{air} (m/sec)	Re_{air}	Flow regime	f_F of water	f_F of air	$(dp/dz)_{air}$ (kPa/m)	$(dp/dz)_{water}$ (kPa/m)	Martinelli parameter X	void fraction ε	ϕ_g^2	Pressure gradient for two phase flow $(dp/dz)_{tp}$, kPa/m
263	0.0154	344	200	11.76	14255	annular	0.0465	0.0072	124	1.1608	1.7200	0.7234	21.871	2.7059
263	0.0154	344	300	17.64	21382	annular	0.0465	0.0065	253	1.1608	0.4081	0.8591	5.563	1.3937
263	0.0154	344	400	23.53	28510	annular	0.0465	0.0061	418	1.1608	0.0887	0.9354	2.312	0.9546
263	0.0154	344	500	29.41	35637	annular	0.0465	0.0057	618	1.1608	0.0564	0.9491	1.951	1.1931
263	0.0154	344	600	35.29	42765	annular	0.0465	0.0055	850	1.1608	0.0436	0.9556	1.797	1.5155
263	0.0154	344	700	41.17	49892	annular	0.0465	0.0053	1113	1.1608	0.0362	0.9598	1.704	1.8848
263	0.0154	344	800	47.05	57020	mist	0.0465	0.0051	1406	1.1608	0.0313	0.9628	1.639	2.2926
263	0.0154	344	900	52.93	64147	mist	0.0465	0.005	1728	1.1608	0.0277	0.9651	1.590	2.7351
263	0.0154	344	1000	58.81	71275	mist	0.0465	0.0048	2077	1.1608	0.0249	0.9671	1.551	3.2102
364	0.0214	477	200	11.76	14255	annular	0.0335	0.0072	124	1.6099	1.7231	0.7232	21.916	2.7115
364	0.0214	477	300	17.64	21382	annular	0.0335	0.0065	253	1.6099	0.4216	0.8568	5.703	1.4290
364	0.0214	477	400	23.53	28510	annular	0.0335	0.0061	418	1.6099	0.1061	0.9290	2.497	1.0322
364	0.0214	477	500	29.41	35637	annular	0.0335	0.0057	618	1.6099	0.0671	0.9442	2.074	1.2693
364	0.0214	477	600	35.29	42765	annular	0.0335	0.0055	850	1.6099	0.0517	0.9514	1.896	1.5992
364	0.0214	477	700	41.17	49892	annular	0.0335	0.0053	1113	1.6099	0.0429	0.9560	1.789	1.9787
364	0.0214	477	800	47.05	57020	mist	0.0335	0.0051	1406	1.6099	0.0370	0.9593	1.714	2.3979
364	0.0214	477	900	52.93	64147	mist	0.0335	0.005	1728	1.6099	0.0327	0.9619	1.658	2.8527
364	0.0214	477	1000	58.81	71275	mist	0.0335	0.0048	2077	1.6099	0.0294	0.9640	1.614	3.3406
466	0.0274	611	200	11.76	14255	annular	0.0262	0.0072	124	2.0590	1.7260	0.7230	21.959	2.7169
466	0.0274	611	300	17.64	21382	annular	0.0262	0.0065	253	2.0590	0.4338	0.8548	5.829	1.4609
466	0.0274	611	400	23.53	28510	annular	0.0262	0.0061	418	2.0590	0.1209	0.9241	2.652	1.0969
466	0.0274	611	500	29.41	35637	annular	0.0262	0.0057	618	2.0590	0.0765	0.9402	2.178	1.3338

466	0.0274	611	600	35.29	42765	annular	0.0262	0.0055	850	2.0590	0.0588	0.9479	1.979	1.6698
466	0.0274	611	700	41.17	49892	annular	0.0262	0.0053	1113	2.0590	0.0487	0.9529	1.860	2.0577
466	0.0274	611	800	47.05	57020	mist	0.0262	0.0051	1406	2.0590	0.0420	0.9565	1.777	2.4863
466	0.0274	611	900	52.93	64147	mist	0.0262	0.005	1728	2.0590	0.0371	0.9593	1.715	2.9512
466	0.0274	611	1000	58.81	71275	mist	0.0262	0.0048	2077	2.0590	0.0333	0.9615	1.666	3.4497
567	0.0334	744	200	11.76	14255	annular	0.0215	0.0072	124	2.5081	1.7290	0.7227	22.002	2.7222
567	0.0334	744	300	17.64	21382	annular	0.0215	0.0065	253	2.5081	0.4450	0.8530	5.946	1.4904
567	0.0334	744	400	23.53	28510	annular	0.0215	0.0061	418	2.5081	0.1339	0.9199	2.787	1.1531
567	0.0334	744	500	29.41	35637	annular	0.0215	0.0057	618	2.5081	0.0848	0.9369	2.270	1.3903
567	0.0334	744	600	35.29	42765	annular	0.0215	0.0055	850	2.5081	0.0652	0.9451	2.052	1.7318
567	0.0334	744	700	41.17	49892	annular	0.0215	0.0053	1113	2.5081	0.0539	0.9503	1.922	2.1268
567	0.0334	744	800	47.05	57020	mist	0.0215	0.0051	1406	2.5081	0.0464	0.9541	1.832	2.5636
567	0.0334	744	900	52.93	64147	mist	0.0215	0.005	1728	2.5081	0.0410	0.9570	1.765	3.0372
567	0.0334	744	1000	58.81	71275	mist	0.0215	0.0048	2077	2.5081	0.0368	0.9594	1.712	3.5447
771	0.0453	1010	200	11.76	14255	annular	0.0158	0.0072	124	3.4064	1.7348	0.7223	22.088	2.7329
771	0.0453	1010	300	17.64	21382	annular	0.0158	0.0065	253	3.4064	0.4653	0.8497	6.157	1.5438
771	0.0453	1010	400	23.53	28510	annular	0.0158	0.0061	418	3.4064	0.1563	0.9133	3.015	1.2484
771	0.0453	1010	500	29.41	35637	annular	0.0158	0.0057	618	3.4064	0.0995	0.9314	2.428	1.4876
771	0.0453	1010	600	35.29	42765	annular	0.0158	0.0055	850	3.4064	0.0764	0.9403	2.177	1.8383
771	0.0453	1010	700	41.17	49892	annular	0.0158	0.0053	1113	3.4064	0.0631	0.9460	2.028	2.2455
771	0.0453	1010	800	47.05	57020	mist	0.0158	0.0051	1406	3.4064	0.0543	0.9501	1.926	2.6960
771	0.0453	1010	900	52.93	64147	mist	0.0158	0.005	1728	3.4064	0.0479	0.9533	1.850	3.1842
771	0.0453	1010	1000	58.81	71275	mist	0.0158	0.0048	2077	3.4064	0.0430	0.9559	1.790	3.7071
974	0.0573	1277	200	11.76	14255	annular	0.0125	0.0072	124	4.3046	1.7290	0.7227	22.002	2.7222
974	0.0573	1277	300	17.64	21382	annular	0.0125	0.0065	253	4.3046	0.4450	0.8530	5.946	1.4904
974	0.0573	1277	400	23.53	28510	annular	0.0125	0.0061	418	4.3046	0.1339	0.9199	2.787	1.1531
974	0.0573	1277	500	29.41	35637	annular	0.0125	0.0057	618	4.3046	0.0848	0.9369	2.270	1.3903
974	0.0573	1277	600	35.29	42765	annular	0.0125	0.0055	850	4.3046	0.0652	0.9451	2.052	1.7318
974	0.0573	1277	700	41.17	49892	annular	0.0125	0.0053	1113	4.3046	0.0539	0.9503	1.922	2.1268
974	0.0573	1277	800	47.05	57020	mist	0.0125	0.0051	1406	4.3046	0.0464	0.9541	1.832	2.5636
974	0.0573	1277	900	52.93	64147	mist	0.0125	0.005	1728	4.3046	0.0410	0.9570	1.765	3.0372

974	0.0573	1277	1000	58.81	71275	mist	0.0125	0.0048	2077	4.3046	0.0368	0.9594	1.712	3.5447
1278	0.0752	1676	200	11.76	14255	annular	0.0095	0.0072	124	5.6520	1.7290	0.7227	22.002	2.7222
1278	0.0752	1676	300	17.64	21382	annular	0.0095	0.0065	253	5.6520	0.4450	0.8530	5.946	1.4904
1278	0.0752	1676	400	23.53	28510	annular	0.0095	0.0061	418	5.6520	0.1339	0.9199	2.787	1.1531
1278	0.0752	1676	500	29.41	35637	annular	0.0095	0.0057	618	5.6520	0.0848	0.9369	2.270	1.3903
1278	0.0752	1676	600	35.29	42765	annular	0.0095	0.0055	850	5.6520	0.0652	0.9451	2.052	1.7318
1278	0.0752	1676	700	41.17	49892	annular	0.0095	0.0053	1113	5.6520	0.0539	0.9503	1.922	2.1268
1278	0.0752	1676	800	47.05	57020	mist	0.0095	0.0051	1406	5.6520	0.0464	0.9541	1.832	2.5636
1278	0.0752	1676	900	52.93	64147	mist	0.0095	0.005	1728	5.6520	0.0410	0.9570	1.765	3.0372
1278	0.0752	1676	1000	58.81	71275	mist	0.0095	0.0048	2077	5.6520	0.0368	0.9594	1.712	3.5447
2091	0.1230	2742	200	11.76	14255	annular	0.0058	0.0072	124	9.2449	1.7290	0.7227	22.002	2.7222
2091	0.1230	2742	300	17.64	21382	annular	0.0058	0.0065	253	9.2449	0.4450	0.8530	5.946	1.4904
2091	0.1230	2742	400	23.53	28510	annular	0.0058	0.0061	418	9.2449	0.1339	0.9199	2.787	1.1531
2091	0.1230	2742	500	29.41	35637	annular	0.0058	0.0057	618	9.2449	0.0848	0.9369	2.270	1.3903
2091	0.1230	2742	600	35.29	42765	annular	0.0058	0.0055	850	9.2449	0.0652	0.9451	2.052	1.7318
2091	0.1230	2742	700	41.17	49892	annular	0.0058	0.0053	1113	9.2449	0.0539	0.9503	1.922	2.1268
2091	0.1230	2742	800	47.05	57020	mist	0.0058	0.0051	1406	9.2449	0.0464	0.9541	1.832	2.5636
2091	0.1230	2742	900	52.93	64147	mist	0.0058	0.005	1728	9.2449	0.0410	0.9570	1.765	3.0372
2091	0.1230	2742	1000	58.81	71275	mist	0.0058	0.0048	2077	9.2449	0.0368	0.9594	1.712	3.5447

Table B10 Determination of pressure gradient for the annular and mist flow regime from Wilkes theory (SDS solution at 1 CMC)

Physical properties of air and SDS solution (1 CMC) used in experiment:

density of SDS solution, $\rho_{SDS\ solution}$ = 994.97 kg/m^3; viscosity of SDS solution, $\mu_{SDS\ solution}$ = 1.01 × 10^{-3} Pa.s

density of air, ρ_{air} = 1.18 kg/m^3; viscosity of air, μ_{air} = 1.85 × 10^{-5} Pa.s

temperature, T = 31 °C (± 1 °C); inner pipe diameter = 0.019 m; cross-sectional area of pipe, A = 0.00028 m^2

SDS solution (1 CMC)			Air			Flow regime	f_F of SDS solution	f_F of air	$(-dp/dz)_{air}$ (kPa/m)	$(-dp/dz)_{solution}$ (kPa/m)	X	ε	ϕ_g^2	Pressure gradient for two phase flow $(dp/dz)_{tp}$ (kPa/m)
$Q_{solution}$ (ml/min)	$j_{solution}$ (m/sec)	$Re_{solution}$	Q_{air} (L/min)	j_{air} (m/sec)	Re_{air}									
350	0.0206	385	200	11.76	14255	annular	0.041	0.0072	124	1.8422	1.720	0.723	21.87	2.7059
350	0.0206	385	300	17.64	21382	annular	0.041	0.0065	253	1.8422	0.408	0.859	5.563	1.3937
350	0.0206	385	400	23.53	28510	annular	0.041	0.0061	418	1.8422	0.088	0.935	2.312	0.9546
350	0.0206	385	500	29.41	35637	annular	0.041	0.0057	618	1.8422	0.056	0.949	1.951	1.1931
350	0.0206	385	600	35.29	42765	annular	0.041	0.0055	850	1.8422	0.043	0.955	1.797	1.5155
350	0.0206	385	700	41.17	49892	annular	0.041	0.0053	1113	1.8422	0.036	0.959	1.704	1.8848
350	0.0206	385	800	47.05	57020	mist	0.041	0.0051	1406	1.8422	0.031	0.962	1.639	2.2926
350	0.0206	385	900	52.93	64147	mist	0.041	0.0050	1728	1.8422	0.027	0.965	1.590	2.7351
350	0.0206	385	1000	58.81	71275	mist	0.041	0.0048	2077	1.8422	0.024	0.967	1.551	3.2102
453	0.0266	500	200	11.76	14255	annular	0.032	0.0072	124	2.3856	1.723	0.723	21.91	2.7115
453	0.0266	500	300	17.64	21382	annular	0.032	0.0065	253	2.3856	0.421	0.856	5.703	1.4290
453	0.0266	500	400	23.53	28510	annular	0.032	0.0061	418	2.3856	0.106	0.929	2.497	1.0322
453	0.0266	500	500	29.41	35637	annular	0.032	0.0057	618	2.3856	0.067	0.944	2.074	1.2693
453	0.0266	500	600	35.29	42765	annular	0.032	0.0055	850	2.3856	0.051	0.951	1.896	1.5992
453	0.0266	500	700	41.17	49892	annular	0.032	0.0053	1113	2.3856	0.042	0.956	1.789	1.9787
453	0.0266	500	800	47.05	57020	mist	0.032	0.0051	1406	2.3856	0.037	0.959	1.714	2.3979
453	0.0266	500	900	52.93	64147	mist	0.032	0.0050	1728	2.3856	0.032	0.961	1.658	2.8527

453	0.0266	500	1000	58.81	71275	mist	0.032	0.0048	2077	2.3856	0.029	0.964	1.614	3.3406
556	0.0327	610	200	11.76	14255	annular	0.026	0.0072	124	2.9290	1.726	0.723	21.95	2.7169
556	0.0327	610	300	17.64	21382	annular	0.026	0.0065	253	2.9290	0.433	0.854	5.829	1.4609
556	0.0327	610	400	23.53	28510	annular	0.026	0.0061	418	2.9290	0.120	0.924	2.652	1.0969
556	0.0327	610	500	29.41	35637	annular	0.026	0.0057	618	2.9290	0.076	0.940	2.178	1.3338
556	0.0327	610	600	35.29	42765	annular	0.026	0.0055	850	2.9290	0.058	0.947	1.979	1.6698
556	0.0327	610	700	41.17	49892	annular	0.026	0.0053	1113	2.9290	0.048	0.952	1.860	2.0577
556	0.0327	610	800	47.05	57020	mist	0.026	0.0051	1406	2.9290	0.042	0.956	1.777	2.4863
556	0.0327	610	900	52.93	64147	mist	0.026	0.0050	1728	2.9290	0.037	0.959	1.715	2.9512
556	0.0327	610	1000	58.81	71275	mist	0.026	0.0048	2077	2.9290	0.033	0.961	1.666	3.4497
660	0.0388	725	200	11.76	14255	annular	0.022	0.0072	124	3.4723	1.729	0.722	22.00	2.7222
660	0.0388	725	300	17.64	21382	annular	0.022	0.0065	253	3.4723	0.445	0.853	5.946	1.4904
660	0.0388	725	400	23.53	28510	annular	0.022	0.0061	418	3.4723	0.133	0.919	2.787	1.1531
660	0.0388	725	500	29.41	35637	annular	0.022	0.0057	618	3.4723	0.084	0.936	2.270	1.3903
660	0.0388	725	600	35.29	42765	annular	0.022	0.0055	850	3.4723	0.065	0.945	2.052	1.7318
660	0.0388	725	700	41.17	49892	annular	0.022	0.0053	1113	3.4723	0.053	0.950	1.922	2.1268
660	0.0388	725	800	47.05	57020	mist	0.022	0.0051	1406	3.4723	0.046	0.954	1.832	2.5636
660	0.0388	725	900	52.93	64147	mist	0.022	0.0050	1728	3.4723	0.041	0.957	1.765	3.0372
660	0.0388	725	1000	58.81	71275	mist	0.022	0.0048	2077	3.4723	0.036	0.959	1.712	3.5447
970	0.0570	1065	200	11.76	14255	annular	0.015	0.0072	124	5.1025	1.734	0.722	22.08	2.7329
970	0.0570	1065	300	17.64	21382	annular	0.015	0.0065	253	5.1025	0.465	0.849	6.157	1.5438
970	0.0570	1065	400	23.53	28510	annular	0.015	0.0061	418	5.1025	0.156	0.913	3.015	1.2484
970	0.0570	1065	500	29.41	35637	annular	0.015	0.0057	618	5.1025	0.099	0.931	2.428	1.4876
970	0.0570	1065	600	35.29	42765	annular	0.015	0.0055	850	5.1025	0.076	0.940	2.177	1.8383
970	0.0570	1065	700	41.17	49892	annular	0.015	0.0053	1113	5.1025	0.063	0.946	2.028	2.2455
970	0.0570	1065	800	47.05	57020	mist	0.015	0.0051	1406	5.1025	0.054	0.950	1.926	2.6960
970	0.0570	1065	900	52.93	64147	mist	0.015	0.0050	1728	5.1025	0.047	0.953	1.850	3.1842
970	0.0570	1065	1000	58.81	71275	mist	0.015	0.0048	2077	5.1025	0.043	0.955	1.790	3.7071
1175	0.0691	1290	200	11.76	14255	annular	0.012	0.0072	124	6.1893	1.729	0.722	22.00	2.7222
1175	0.0691	1290	300	17.64	21382	annular	0.012	0.0065	253	6.1893	0.445	0.853	5.946	1.4904
1175	0.0691	1290	400	23.53	28510	annular	0.012	0.0061	418	6.1893	0.133	0.919	2.787	1.1531

1175	0.0691	1290	500	29.41	35637	annular	0.012	0.0057	618	6.1893	0.084	0.936	2.270	1.3903
1175	0.0691	1290	600	35.29	42765	annular	0.012	0.0055	850	6.1893	0.065	0.945	2.052	1.7318
1175	0.0691	1290	700	41.17	49892	annular	0.012	0.0053	1113	6.1893	0.053	0.950	1.922	2.1268
1175	0.0691	1290	800	47.05	57020	mist	0.012	0.0051	1406	6.1893	0.046	0.954	1.832	2.5636
1175	0.0691	1290	900	52.93	64147	mist	0.012	0.0050	1728	6.1893	0.041	0.957	1.765	3.0372
1175	0.0691	1290	1000	58.81	71275	mist	0.012	0.0048	2077	6.1893	0.036	0.959	1.712	3.5447
1485	0.0873	1635	200	11.76	14255	annular	0.009	0.0072	124	7.8195	1.729	0.722	22.00	2.7222
1485	0.0873	1635	300	17.64	21382	annular	0.009	0.0065	253	7.8195	0.445	0.853	5.946	1.4904
1485	0.0873	1635	400	23.53	28510	annular	0.009	0.0061	418	7.8195	0.133	0.919	2.787	1.1531
1485	0.0873	1635	500	29.41	35637	annular	0.009	0.0057	618	7.8195	0.084	0.936	2.270	1.3903
1485	0.0873	1635	600	35.29	42765	annular	0.009	0.0055	850	7.8195	0.065	0.945	2.052	1.7318
1485	0.0873	1635	700	41.17	49892	annular	0.009	0.0053	1113	7.8195	0.053	0.950	1.922	2.1268
1485	0.0873	1635	800	47.05	57020	mist	0.009	0.0051	1406	7.8195	0.046	0.954	1.832	2.5636
1485	0.0873	1635	900	52.93	64147	mist	0.009	0.0050	1728	7.8195	0.041	0.957	1.765	3.0372
1485	0.0873	1635	1000	58.81	71275	mist	0.009	0.0048	2077	7.8195	0.036	0.959	1.712	3.5447
2310	0.1359	2540	200	11.76	14255	annular	0.006	0.0072	124	12.1667	1.729	0.722	22.00	2.7222
2310	0.1359	2540	300	17.64	21382	annular	0.006	0.0065	253	12.1667	0.445	0.853	5.946	1.4904
2310	0.1359	2540	400	23.53	28510	annular	0.006	0.0061	418	12.1667	0.133	0.919	2.787	1.1531
2310	0.1359	2540	500	29.41	35637	annular	0.006	0.0057	618	12.1667	0.084	0.936	2.270	1.3903
2310	0.1359	2540	600	35.29	42765	annular	0.006	0.0055	850	12.1667	0.065	0.945	2.052	1.7318
2310	0.1359	2540	700	41.17	49892	annular	0.006	0.0053	1113	12.1667	0.053	0.950	1.922	2.1268
2310	0.1359	2540	800	47.05	57020	mist	0.006	0.0051	1406	12.1667	0.046	0.954	1.832	2.5636
2310	0.1359	2540	900	52.93	64147	mist	0.006	0.0050	1728	12.1667	0.041	0.957	1.765	3.0372
2310	0.1359	2540	1000	58.81	71275	mist	0.006	0.0048	2077	12.1667	0.036	0.959	1.712	3.5447

Appendix C Experimental Data For Pressure Gradient

Table C1 Determination of pressure gradient from experiment for pure water with opening the whole valve at pressure tab

Physical properties of air and water used in experiment:

density of water, ρ_{water} = 994.7 kg/m^3; viscosity of water, $\mu_{water} = 8.51 \times 10^{-4}$ Pa.s

density of air, ρ_{air} = 1.18 kg/m^3; viscosity of air, $\mu_{air} = 1.85 \times 10^{-5}$ Pa.s

temperature, T = 31 °C (± 1 °C); inner pipe diameter, D = 0.019 m; cross-sectional area of pipe, A = 0.00028 m^2

pressure taps difference = 0.4 m

Procedure to determine of pressure gradient from experiment:

1. Read the highest and lowest difference level from manometer.
2. Put the value of difference level (h) in $\frac{dp}{dz} = \frac{\rho g h}{dz}$ (C1)

Note; For highest difference level, it will give the maximum pressure gradient. For lowest difference level, it will give the minimum pressure gradient.

Re_{water}	Re_{air}	(dp/dz) from experiment	
		maximum (kPa/m)	minimum (kPa/m)
0	3.17	9.6877	9.6145
0	5.64	9.6389	9.5169
0	8.12	9.5657	9.3705
0	10.59	9.5657	9.1021
0	13.06	9.4779	8.7556
0	15.54	9.4047	8.6580
0	18.02	9.1655	8.1894
0	20.49	9.2485	7.7844
0	22.95	9.2485	7.3695
0	28.08	9.1265	7.2719
0	33.21	8.8581	6.8327
0	38.33	8.7605	6.5398
0	43.46	8.5408	6.5154
0	48.59	8.4920	6.3690
0	58.85	8.4188	5.5637
0	69.10	8.0772	5.2953
0	79.36	7.7112	5.1245
0	89.62	7.9796	3.9776

0	99.87	7.8332	4.4412
344	3.17	9.6877	9.5901
344	5.64	9.6389	9.5413
344	8.12	9.5413	9.4437
344	10.59	9.4925	9.3705
344	13.06	9.4925	9.0533
344	15.54	9.3705	8.7116
344	18.02	9.3266	8.4920
344	20.49	9.1362	8.1602
344	22.95	9.1021	7.9845
344	28.08	9.0240	7.4671
344	33.21	9.1021	7.0523
344	38.33	8.9801	6.7351
344	43.46	9.0045	6.3202
344	48.59	8.8337	6.1494
344	58.85	8.5896	5.8322
344	69.10	8.4920	5.6125
344	79.36	8.5408	4.7341
344	89.62	8.4920	4.7341
344	99.87	8.2480	4.4412
344	177	8.4920	2.1474
344	285	8.1016	-0.4880
344	356	7.4183	-1.6106
344	499	8.0528	-1.3177
344	713	6.6374	-1.3177
344	1425	5.1733	-1.0249
344	2851	3.6604	0.0488
344	4276	2.5134	0.2440
344	4989	2.1962	0.3416
344	5702	1.9278	0.6833
344	7127	1.7570	0.8443
344	14255	0.6101	0.5369
344	21382	0.6833	0.6101
344	28510	0.7809	0.6833
344	35637	1.0737	1.0493
344	42765	1.4641	1.2689
344	49892	1.9034	1.5862
344	57020	2.1230	2.0742
344	64147	2.5622	2.5134
344	71275	3.1235	3.1235
477	3.17	9.7365	9.6389
477	5.64	9.7121	9.5657
477	8.12	9.6633	9.4925
477	10.59	9.5169	9.1997
477	13.06	9.4681	8.9801
477	15.54	9.4681	8.7605
477	18.02	9.4730	8.4969
477	20.49	9.2631	8.1162
477	22.95	9.2339	7.8673
477	28.08	9.2095	7.7160
477	33.21	9.0777	7.3695
477	38.33	9.0533	7.1743
477	43.46	8.6140	6.9059
477	48.59	9.0045	6.5398

477	58.85	9.1021	6.3934
477	69.10	8.9313	5.9786
477	79.36	8.4920	5.5637
477	89.62	8.2236	5.1489
477	99.87	8.8825	4.7585
477	177	7.9308	1.6106
477	285	8.5408	-0.3904
477	356	8.0040	-1.2689
477	499	7.1743	-1.2689
477	713	7.9552	-1.2201
477	1425	4.8317	-1.0249
477	2851	3.3187	0.3904
477	4276	2.2938	0.5369
477	4989	2.4158	0.6101
477	5702	2.0742	0.6491
477	7127	1.5618	0.7077
477	14255	0.9175	0.6003
477	21382	0.8980	0.6784
477	28510	1.1176	0.9419
477	35637	1.4007	1.2396
477	42765	2.0352	1.7814
477	49892	2.4402	2.1913
477	57020	2.9673	2.6696
477	64147	3.5871	3.2065
477	71275	4.3290	3.9825
611	3.17	9.7610	9.7121
611	5.64	9.7121	9.6145
611	8.12	9.6877	9.4681
611	10.59	9.6145	9.2973
611	13.06	9.5657	9.1265
611	15.54	9.5169	8.8337
611	18.02	9.5462	8.5896
611	20.49	9.3949	8.0040
611	22.95	9.2827	8.0186
611	28.08	9.0582	7.6282
611	33.21	9.0874	7.4671
611	38.33	9.0045	7.2475
611	43.46	8.8581	6.9059
611	48.59	8.7361	6.8083
611	58.85	8.9069	6.3690
611	69.10	8.4432	5.8322
611	79.36	8.2724	5.5149
611	89.62	8.4188	5.2221
611	99.87	7.9308	5.2953
611	177	7.2231	2.8307
611	285	8.5896	-0.6833
611	356	8.4432	-1.1713
611	499	7.5647	-1.2201
611	713	7.4671	-1.7082
611	1425	4.6365	-0.4392
611	2851	3.4651	0.0000
611	4276	2.3426	0.7077
611	4989	2.1474	0.8053
611	5702	2.0742	0.9029

611	7127	1.8058	0.9273
611	14255	1.4885	0.8541
611	21382	1.3421	1.0005
611	28510	1.3909	1.2201
611	35637	1.7326	1.6106
611	42765	2.0742	2.0010
611	49892	2.5867	2.3670
611	57020	3.0015	2.9283
611	64147	3.6116	3.4163
611	71275	4.1728	3.9776
744	3.17	9.9074	9.7854
744	5.64	9.8098	9.6633
744	8.12	9.7365	9.5657
744	10.59	9.7854	9.4681
744	13.06	9.5657	9.1753
744	15.54	9.6145	8.9801
744	18.02	9.5364	8.7409
744	20.49	9.4144	8.4774
744	22.95	9.2534	8.0528
744	28.08	8.9361	7.7990
744	33.21	9.0533	7.5891
744	38.33	8.5311	7.2719
744	43.46	8.8581	7.0523
744	48.59	8.7849	7.2963
744	58.85	8.3700	6.8327
744	69.10	8.2968	6.3690
744	79.36	7.8820	6.1494
744	89.62	8.0772	5.3197
744	99.87	8.5164	5.0513
744	177	8.7849	3.0747
744	285	8.3944	-0.7321
744	356	9.1265	-1.2689
744	499	7.3695	-1.8546
744	713	6.5886	-1.0737
744	1425	4.9293	-0.6833
744	2851	3.4651	0.3172
744	4276	2.3670	0.9029
744	4989	2.3182	1.2689
744	5702	2.1474	1.2445
744	7127	2.2938	1.0493
744	14255	1.1079	0.8687
744	21382	1.1567	1.0054
744	28510	1.4690	1.2787
744	35637	1.8448	1.7179
744	42765	2.4012	2.1572
744	49892	3.0454	2.8258
744	57020	3.6604	3.3870
744	64147	4.5291	3.9727
744	71275	5.2904	4.7829
1010	3.17	9.8098	9.7121
1010	5.64	9.7854	9.6633
1010	8.12	9.7121	9.5657
1010	10.59	9.6389	9.3949
1010	13.06	9.5901	9.2485

1010	15.54	9.3949	9.0777
1010	18.02	9.3217	8.8093
1010	20.49	9.1899	8.5799
1010	22.95	9.0923	8.4530
1010	28.08	8.9703	8.0723
1010	33.21	8.8239	7.7844
1010	38.33	8.8141	7.5452
1010	43.46	8.9215	7.3354
1010	48.59	8.7263	7.4183
1010	58.85	8.5896	6.9791
1010	69.10	8.1992	6.4910
1010	79.36	8.1992	6.3202
1010	89.62	7.9796	5.7004
1010	99.87	7.8820	5.6858
1010	177	7.2719	3.5383
1010	285	8.3456	-0.3904
1010	356	7.5159	-0.4880
1010	499	7.0767	-0.6345
1010	713	6.7839	-0.8785
1010	1425	5.0269	-0.0488
1010	2851	2.8551	0.7321
1010	4276	2.4646	1.0249
1010	4989	2.2206	1.2201
1010	5702	2.2206	1.3421
1010	7127	1.9034	1.1225
1010	14255	1.2543	0.9615
1010	21382	1.3763	1.1567
1010	28510	1.7374	1.5666
1010	35637	2.2694	2.0742
1010	42765	2.8648	2.6403
1010	49892	3.2699	3.1967
1010	57020	4.1874	3.9044
1010	64147	4.5144	4.1972
1010	71275	4.7829	4.7097
1277	3.17	9.8830	9.8342
1277	5.64	9.8342	9.7365
1277	8.12	9.7610	9.5657
1277	10.59	9.6145	9.4437
1277	13.06	9.5413	9.2973
1277	15.54	9.5413	9.0777
1277	18.02	9.3852	8.8093
1277	20.49	9.1314	8.6726
1277	22.95	9.1167	8.5164
1277	28.08	8.9703	8.2334
1277	33.21	8.9020	8.0040
1277	38.33	8.6726	7.9112
1277	43.46	8.6384	7.6623
1277	48.59	8.5652	7.5159
1277	58.85	8.2236	7.2231
1277	69.10	8.3700	6.9547
1277	79.36	8.2724	6.4910
1277	89.62	8.0284	6.3934
1277	99.87	8.0284	5.8322
1277	177	7.4183	4.1240

1277	285	8.4920	0.2928
1277	356	7.6135	0.2928
1277	499	6.5886	-0.2928
1277	713	5.0757	-0.0488
1277	1425	4.9781	-0.5369
1277	2851	3.3431	0.3660
1277	4276	2.7575	1.2445
1277	4989	2.4402	1.3909
1277	5702	2.2694	1.2445
1277	7127	1.8546	1.1713
1277	14255	1.3958	1.0591
1277	21382	1.5373	1.3275
1277	28510	1.9717	1.7911
1277	35637	2.6599	2.4695
1277	42765	3.2358	3.0601
1277	49892	3.9239	3.6848
1277	57020	4.5327	4.0671
1277	64147	5.2026	5.1489
1277	71275	6.1006	5.8566
1676	3.17	9.7365	9.6877
1676	5.64	9.7121	9.6389
1676	8.12	9.6389	9.5657
1676	10.59	9.6145	9.4925
1676	13.06	9.5413	9.3949
1676	15.54	9.5169	9.2729
1676	18.02	9.3949	9.0289
1676	20.49	9.3461	8.8629
1676	22.95	9.3608	8.7605
1676	28.08	9.1411	8.5408
1676	33.21	9.0874	8.2236
1676	38.33	8.9313	8.0528
1676	43.46	8.7849	7.7795
1676	48.59	8.6628	7.6379
1676	58.85	8.4432	7.2719
1676	69.10	8.4676	6.9059
1676	79.36	8.9801	6.5154
1676	89.62	8.6140	6.3934
1676	99.87	8.3700	5.9542
1676	177	7.8576	4.1972
1676	285	6.9547	2.6843
1676	356	6.1006	1.7082
1676	499	6.3446	0.0000
1676	713	5.6939	0.0000
1676	1425	5.2709	-0.7321
1676	2851	3.0015	1.0737
1676	4276	2.7331	1.6594
1676	4989	2.4646	1.4885
1676	5702	2.2938	1.5373
1676	7127	2.0254	1.3421
1676	14255	1.7130	1.4007
1676	21382	1.9668	1.7716
1676	28510	2.6208	2.4207
1676	35637	3.2699	3.0405
1676	42765	4.0850	3.9141

1676	49892	4.5388	4.6218
1676	57020	5.7150	5.5735
1676	64147	6.5008	6.2714
1676	71275	6.9449	6.6960
2742	3.17	9.8342	9.7854
2742	5.64	9.8098	9.7365
2742	8.12	9.7610	9.6877
2742	10.59	9.7121	9.6389
2742	13.06	9.6389	9.5413
2742	15.54	9.5901	9.3705
2742	18.02	9.4925	9.2241
2742	20.49	9.3852	9.1216
2742	22.95	9.3022	8.8971
2742	28.08	9.2387	8.7751
2742	33.21	9.0142	8.7116
2742	38.33	8.9508	8.3798
2742	43.46	8.8825	8.2724
2742	48.59	8.8629	7.9796
2742	58.85	8.6775	7.9064
2742	69.10	8.5652	7.5647
2742	79.36	8.7849	7.3207
2742	89.62	8.4432	6.8571
2742	99.87	8.9069	6.5154
2742	177	7.8576	6.5642
2742	285	7.0767	3.6604
2742	356	6.1006	2.6029
2742	499	5.7102	2.0498
2742	713	5.1733	1.1225
2742	1425	4.1972	0.2684
2742	2851	3.7092	0.8053
2742	4276	3.4407	1.5373
2742	4989	3.2943	1.6838
2742	5702	2.9527	1.8790
2742	7127	2.4402	1.7082
2742	14255	2.3426	1.8448
2742	21382	2.8795	2.7087
2742	28510	3.6750	3.4993
2742	35637	4.4852	4.2899
2742	42765	5.1879	5.0855
2742	49892	5.8566	5.5833
2742	57020	6.5838	6.1494
2742	64147	8.0040	7.4330
2742	71275	8.0528	7.9064

Table C2 Determination of pressure gradient from experiment for pure water with nearly closing valve at pressure tab

Physical properties of air and water used in experiment:

density of water, ρ_{water} = 994.7 kg/m^3; viscosity of water, $\mu_{water} = 8.51 \times 10^{-4}$ Pa.s

density of air, ρ_{air} = 1.18 kg/m^3; viscosity of air, $\mu_{air} = 1.85 \times 10^{-5}$ Pa.s

temperature, T = 31 °C (± 1 °C); inner pipe diameter, D = 0.019 m; cross-sectional area of pipe, A = 0.00028 m^2

pressure taps difference = 0.4 m

Re_{water}	Re_{air}	(dp/dz) from experiment	
		maximum (kPa/m)	minimum (kPa/m)
0	3.17	9.6848	9.6116
0	5.64	9.6360	9.5141
0	8.12	9.5628	9.3677
0	10.59	9.3482	9.2945
0	13.06	9.2896	9.1969
0	15.54	9.0408	8.9432
0	18.02	8.9871	8.8603
0	20.49	8.9432	8.5968
0	22.95	8.7139	8.4358
0	28.08	8.5383	8.3089
0	33.21	8.5041	8.0211
0	38.33	8.2260	7.7430
0	43.46	8.2553	7.4795
0	48.59	7.9918	7.2502
0	58.85	7.7479	6.8160
0	69.10	7.6454	6.4891
0	79.36	7.3429	6.1329
0	89.62	7.0404	5.8841
0	99.87	6.7086	5.7133
477	3.17	9.7336	9.6360
477	5.64	9.7092	9.5628
477	8.12	9.6604	9.4897
477	10.59	9.5628	9.5141
477	13.06	9.5628	9.4409
477	15.54	9.5141	9.2750
477	18.02	9.2701	8.9579
477	20.49	8.9774	8.7334
477	22.95	8.7920	8.5431
477	28.08	8.6456	8.3577
477	33.21	8.5627	8.2504
477	38.33	8.4456	8.1431
477	43.46	8.3236	7.9186
477	48.59	8.1723	7.6844

477	58.85	7.9479	7.3575
477	69.10	7.4649	6.7574
477	79.36	7.3380	6.7818
477	89.62	7.0990	6.4208
477	99.87	6.9526	6.2207
477	177	5.7328	4.8839
477	285	4.5131	3.3665
477	356	3.9764	2.6835
477	499	3.2689	1.8052
477	713	2.5371	1.3173
477	1425	2.1956	0.8538
477	2851	2.4395	1.3173
477	4276	2.3175	1.3661
477	4989	1.9516	1.4247
477	5702	1.9418	1.3612
477	7127	1.4637	1.2246
477	14255	0.9173	0.6001
477	21382	0.8977	0.6782
477	28510	1.1173	0.9416
477	35637	1.4003	1.2393
477	42765	2.0345	1.7808
477	49892	2.4395	2.1907
477	57020	2.9664	2.6688
477	64147	3.5861	3.2055
477	71275	4.3277	3.9813
1010	3.17	9.8068	9.7092
1010	5.64	9.7824	9.6604
1010	8.12	9.7092	9.5628
1010	10.59	9.6360	9.3921
1010	13.06	9.5141	9.4653
1010	15.54	9.4165	9.2457
1010	18.02	9.3433	9.1481
1010	20.49	9.2701	9.0262
1010	22.95	9.2213	8.8554
1010	28.08	9.0262	8.5870
1010	33.21	8.9042	8.5627
1010	38.33	8.7968	8.1821
1010	43.46	8.5919	7.9772
1010	48.59	8.4651	7.6405
1010	58.85	8.3626	7.5137
1010	69.10	8.1333	7.4063
1010	79.36	8.0504	6.9575
1010	89.62	7.5625	6.6110
1010	99.87	7.3331	6.3915
1010	177	6.2451	5.3181
1010	285	4.8058	3.4885
1010	356	4.5375	2.9274
1010	499	3.6836	2.2443
1010	713	3.2689	1.3905
1010	1425	2.4395	1.3661
1010	2851	2.5615	1.6247
1010	4276	2.1956	1.4637
1010	4989	2.0736	1.4637
1010	5702	1.9516	1.3417

1010	7127	1.7808	1.2685
1010	14255	1.2539	0.9612
1010	21382	1.3759	1.1563
1010	28510	1.7369	1.5662
1010	35637	2.2687	2.0736
1010	42765	2.8640	2.6395
1010	49892	3.2689	3.1957
1010	57020	4.1862	3.9032
1010	64147	4.5131	4.1959
1010	71275	4.7814	4.7082
1676	3.17	9.7336	9.6848
1676	5.64	9.7092	9.6360
1676	8.12	9.6360	9.5628
1676	10.59	9.6116	9.4897
1676	13.06	9.5385	9.3921
1676	15.54	9.5141	9.4165
1676	18.02	9.5141	9.3677
1676	20.49	9.4897	9.3189
1676	22.95	9.3921	9.2213
1676	28.08	9.2701	9.0262
1676	33.21	9.0993	8.8798
1676	38.33	8.9530	8.7334
1676	43.46	8.6212	8.4553
1676	48.59	8.5431	8.2845
1676	58.85	8.4065	8.1528
1676	69.10	8.2260	7.9381
1676	79.36	8.0601	7.8064
1676	89.62	7.9528	7.5722
1676	99.87	7.7235	7.3819
1676	177	6.8794	5.9036
1676	285	5.3913	4.2935
1676	356	4.6838	3.5861
1676	499	3.7812	2.7078
1676	713	3.6349	1.8052
1676	1425	2.6591	1.8296
1676	2851	2.8542	1.9028
1676	4276	2.8786	1.9516
1676	4989	2.6835	2.0297
1676	5702	2.4395	1.8540
1676	7127	2.1565	1.7174
1676	14255	1.7125	1.4003
1676	21382	1.9662	1.7711
1676	28510	2.6200	2.4200
1676	35637	3.2689	3.0396
1676	42765	4.0837	3.9130
1676	49892	4.5375	4.6204
1676	57020	5.7133	5.5718
1676	64147	6.4988	6.2695
1676	71275	6.9428	6.6940
2742	3.17	9.8312	9.7824
2742	5.64	9.8068	9.7336
2742	8.12	9.7580	9.6848
2742	10.59	9.7092	9.6360
2742	13.06	9.6360	9.5385

2742	15.54	9.5872	9.5385
2742	18.02	9.5628	9.5141
2742	20.49	9.5385	9.5141
2742	22.95	9.5385	9.4409
2742	28.08	9.3921	9.2945
2742	33.21	9.2701	9.1481
2742	38.33	9.0603	8.9774
2742	43.46	8.9822	8.7578
2742	48.59	8.8408	8.5383
2742	58.85	8.7090	8.3626
2742	69.10	8.5870	8.1284
2742	79.36	8.3333	7.9430
2742	89.62	8.2211	7.7332
2742	99.87	8.0894	7.5088
2742	177	7.1477	6.2110
2742	285	5.7328	4.8790
2742	356	5.1230	4.1472
2742	499	4.6351	3.2787
2742	713	3.9520	2.5127
2742	1425	3.2445	2.1224
2742	2851	3.2933	2.1468
2742	4276	3.1714	2.1956
2742	4989	3.1957	2.2687
2742	5702	2.9274	1.9760
2742	7127	2.5908	2.0004
2742	14255	2.3419	1.8589
2742	21382	2.8786	2.7078
2742	28510	3.6739	3.4982
2742	35637	4.4838	4.2886
2742	42765	5.1864	5.0839
2742	49892	5.8548	5.5816
2742	57020	6.5818	6.1475
2742	64147	8.0016	7.4307
2742	71275	8.0650	7.9333

Table C3 Determination of pressure gradient from experiment for SDS solution with opening the whole valve at pressure tab

Physical properties of air and SDS solution (1 CMC) used in experiment:

density of SDS solution, $\rho_{SDS\ solution}$ = 994.97 kg/m^3; viscosity of SDS solution, $\mu_{SDS\ solution}$ = 1.01 × 10^{-3} Pa.s

density of air, ρ_{air} = 1.18 kg/m^3; viscosity of air, μ_{air} = 1.85 × 10^{-5} Pa.s

temperature, T = 31 °C (± 1 °C); inner pipe diameter, D = 0.019 m; cross-sectional area of pipe, A = 0.00028 m^2

pressure taps difference = 0.4 m

$Re_{solution}$	Re_{air}	(dp/dz) from experiment	
		maximum (kPa/m)	minimum (kPa/m)
0	3.17	9.7444	9.7119
0	5.64	9.5736	9.5410
0	8.12	9.5085	9.4922
0	10.59	9.5085	9.4353
0	13.06	9.2580	9.1457
0	15.54	9.1213	9.0237
0	18.02	9.0335	8.8334
0	20.49	8.8578	8.6187
0	22.95	8.5113	8.3844
0	28.08	8.2380	8.0037
0	33.21	7.9305	7.6133
0	38.33	7.7402	7.4767
0	43.46	7.5059	7.1009
0	48.59	7.4181	6.7349
0	58.85	7.0358	6.1411
0	69.10	6.7105	5.2870
0	79.36	6.5478	4.6363
0	89.62	6.2631	3.4976
385	3.17	9.6875	9.6142
385	5.64	9.5898	9.5166
385	8.12	9.4272	9.3133
385	10.59	9.3946	9.2726
385	13.06	9.2889	9.0286
385	15.54	9.0969	8.7846
385	18.02	9.0872	8.7651
385	20.49	8.9310	8.7114
385	22.95	8.7846	8.3063
385	28.08	8.7602	8.4918
385	33.21	8.3454	7.9061
385	38.33	8.1648	7.7109

385	43.46	8.1257	7.4913
385	48.59	7.9549	7.2473
385	58.85	7.7109	6.9789
385	69.10	7.6377	6.5396
385	79.36	7.2229	6.0516
385	89.62	7.1253	5.7100
385	99.87	6.9545	5.8076
385	177	6.2468	2.5866
385	285	4.2703	1.7569
385	356	2.6354	1.3665
385	499	2.5622	0.8541
385	713	1.9521	0.5368
385	1425	0.8785	0.4148
385	2851	1.3274	1.1176
385	4276	1.3372	1.1225
385	4989	1.4446	1.2786
385	5702	1.3958	1.2835
385	7127	1.4836	1.3665
385	14255	1.0574	0.9517
385	21382	0.9435	0.8459
385	28510	0.9679	0.9761
385	35637	1.3014	1.3421
385	42765	1.8139	1.8301
385	49892	2.2938	2.3182
385	57020	2.6272	2.8713
385	64147	2.9851	2.9851
385	71275	3.4406	3.3837
500	3.17	9.7607	9.7363
500	5.64	9.7363	9.6630
500	8.12	9.4922	9.3214
500	10.59	9.5085	9.3214
500	13.06	9.3165	9.0286
500	15.54	9.4922	8.9798
500	18.02	9.1750	8.7602
500	20.49	9.0774	8.5650
500	22.95	8.9066	8.2722
500	28.08	8.9066	8.0769
500	33.21	8.5162	7.8085
500	38.33	8.4918	7.6865
500	43.46	8.1013	7.3937
500	48.59	8.0769	7.1985
500	58.85	7.9061	7.1009
500	69.10	7.3937	6.4908
500	79.36	7.5645	5.4416
500	89.62	6.7349	5.4172
500	99.87	7.4425	5.9296
500	177	6.4908	3.4650
500	285	4.7095	0.9761
500	356	3.2942	0.4392
500	499	2.8794	0.4880
500	713	2.3670	0.5612

500	1425	1.6593	0.4636
500	2851	1.5666	1.1664
500	4276	1.5324	1.2738
500	4989	1.5861	1.3665
500	5702	1.5812	1.3714
500	7127	1.5763	1.4543
500	14255	1.4478	1.3584
500	21382	1.2770	1.1143
500	28510	1.6105	1.3258
500	35637	1.5617	1.5780
500	42765	1.9359	2.0172
500	49892	2.6842	2.6842
500	57020	3.4162	3.4162
500	64147	3.7823	3.7823
500	71275	4.7095	4.7421
610	3.17	9.7607	9.7607
610	5.64	9.6630	9.6142
610	8.12	9.5898	9.4678
610	10.59	9.5329	9.3946
610	13.06	9.4922	9.2482
610	15.54	9.3409	9.1165
610	18.02	9.4678	8.9212
610	20.49	9.1506	8.7846
610	22.95	8.9066	8.5406
610	28.08	8.9066	8.3454
610	33.21	8.6870	8.2478
610	38.33	8.5650	8.0037
610	43.46	8.5894	7.7841
610	48.59	8.3210	7.5889
610	58.85	7.8329	7.1009
610	69.10	7.7597	6.8325
610	79.36	7.5645	6.6128
610	89.62	7.1009	6.0272
610	99.87	7.1741	5.9784
610	177	6.9301	3.1234
610	285	5.3684	0.4880
610	356	4.2947	0.2440
610	499	3.5870	0.2196
610	713	1.4885	0.4880
610	1425	0.9761	0.2440
610	2851	1.3030	1.0688
610	4276	1.3177	1.2250
610	4989	1.4251	1.2445
610	5702	1.4348	1.3470
610	7127	1.4446	1.3665
610	14255	1.3584	1.2445
610	21382	1.3584	1.1631
610	28510	1.5617	1.3177
610	35637	1.7488	1.5780
610	42765	2.0741	2.0741
610	49892	2.7737	2.7086

610	57020	3.5708	3.5220
610	64147	3.9124	3.9043
610	71275	4.7421	4.5631
725	3.17	9.7607	9.7607
725	5.64	9.7119	9.6142
725	8.12	9.6142	9.4109
725	10.59	9.5166	9.4109
725	13.06	9.5020	9.2287
725	15.54	9.3751	9.1311
725	18.02	9.2141	8.9212
725	20.49	9.0286	8.6479
725	22.95	8.9066	8.5162
725	28.08	8.8578	8.4186
725	33.21	8.7114	8.2722
725	38.33	8.4674	7.8817
725	43.46	8.3454	7.9061
725	48.59	8.1990	7.5645
725	58.85	8.1990	7.2961
725	69.10	7.4679	6.9789
725	79.36	7.1741	6.6128
725	89.62	6.8813	6.0516
725	99.87	6.3932	5.5880
725	177	4.7827	3.1478
725	285	5.4660	0.6344
725	356	3.8067	0.2196
725	499	4.0507	0.0488
725	713	2.6354	0.4148
725	1425	1.9033	0.3904
725	2851	1.7325	1.2445
725	4276	1.7179	1.4983
725	4989	1.7081	1.5227
725	5702	1.7618	1.5373
725	7127	1.7081	1.6105
725	14255	1.5861	1.4478
725	21382	1.4641	1.3584
725	28510	1.0167	1.4641
725	35637	2.0741	1.6512
725	42765	2.4402	2.4402
725	49892	2.9851	3.0014
725	57020	3.5626	3.5382
725	64147	4.2947	4.2459
725	71275	4.9698	5.0105
1065	3.17	9.7932	9.7851
1065	5.64	9.7119	9.6386
1065	8.12	9.7119	9.5166
1065	10.59	9.5166	9.2726
1065	13.06	9.3653	9.1750
1065	15.54	9.3019	8.9993
1065	18.02	9.0579	8.9310
1065	20.49	9.0481	8.7846
1065	22.95	9.0042	8.5894

1065	28.08	8.8090	8.4430
1065	33.21	8.7602	8.1501
1065	38.33	8.6626	8.1013
1065	43.46	8.5406	7.8085
1065	48.59	8.3210	7.6865
1065	58.85	8.1745	7.3449
1065	69.10	7.9793	6.9545
1065	79.36	7.6621	6.8325
1065	89.62	7.4913	6.4176
1065	99.87	7.6133	6.0760
1065	177	7.1253	4.4899
1065	285	5.1731	1.1713
1065	356	4.8315	0.9273
1065	499	2.8306	0.8541
1065	713	2.8550	0.3416
1065	1425	2.4646	0.5612
1065	2851	2.0009	1.5129
1065	4276	2.0253	1.7081
1065	4989	1.9228	1.7764
1065	5702	1.8838	1.6788
1065	7127	1.8984	1.7667
1065	14255	1.6837	1.6186
1065	21382	1.5292	1.4316
1065	28510	2.2368	1.6918
1065	35637	2.1311	2.0741
1065	42765	2.6760	2.5459
1065	49892	3.2536	3.2780
1065	57020	4.0263	4.0263
1065	64147	4.3923	4.3923
1065	71275	5.3928	5.3684
1290	3.17	9.7607	9.7607
1290	5.64	9.6630	9.6793
1290	8.12	9.4678	9.4678
1290	10.59	9.3946	9.4109
1290	13.06	9.2726	9.2482
1290	15.54	9.2433	9.1897
1290	18.02	9.1506	9.0969
1290	20.49	8.9652	8.9164
1290	22.95	8.8871	8.8383
1290	28.08	8.6919	8.6431
1290	33.21	8.5406	8.4283
1290	38.33	8.3942	8.3014
1290	43.46	8.3063	8.1697
1290	48.59	8.2526	8.0233
1290	58.85	7.8817	7.4767
1290	69.10	7.8085	7.2229
1290	79.36	7.6377	6.8569
1290	89.62	7.2717	6.5640
1290	99.87	6.8569	6.4420
1290	177	5.9540	1.4153
1290	285	3.8067	0.4392

1290	356	3.3430	0.4880
1290	499	2.9038	0.4636
1290	713	3.0258	0.2684
1290	1425	2.5622	0.3660
1290	2851	2.2938	1.6105
1290	4276	2.1961	1.9424
1290	4989	2.2401	1.9424
1290	5702	2.1669	1.9570
1290	7127	2.1571	2.0253
1290	14255	1.9928	1.8464
1290	21382	1.6268	1.5373
1290	28510	1.9196	1.8871
1290	35637	2.2531	2.2287
1290	42765	2.8143	2.7574
1290	49892	3.3024	3.3186
1290	57020	3.7823	3.7823
1290	64147	4.8722	4.8885
1290	71275	5.5717	5.5961
1635	3.17	9.7607	9.7607
1635	5.64	9.7444	9.7525
1635	8.12	9.6630	9.6386
1635	10.59	9.5654	9.5329
1635	13.06	9.4678	9.4760
1635	15.54	9.4516	9.3702
1635	18.02	9.3458	9.2677
1635	20.49	9.2726	9.1213
1635	22.95	9.1555	9.0823
1635	28.08	9.0091	8.8871
1635	33.21	8.9700	8.7797
1635	38.33	8.7992	8.5991
1635	43.46	8.7211	8.4771
1635	48.59	8.5308	8.3014
1635	58.85	8.2526	7.9110
1635	69.10	8.0721	7.7841
1635	79.36	7.8573	7.4425
1635	89.62	7.6280	7.1497
1635	99.87	7.4425	6.8325
1635	177	6.8325	4.6363
1635	285	5.6124	2.8794
1635	356	4.8315	2.3914
1635	499	4.8071	1.3421
1635	713	3.6114	0.9517
1635	1425	2.3914	0.6344
1635	2851	2.4402	1.9765
1635	4276	2.3621	2.1181
1635	4989	2.4890	2.1571
1635	5702	2.4890	2.2450
1635	7127	2.5231	2.2401
1635	14255	2.3751	2.1717
1635	21382	2.3832	2.3263
1635	28510	2.4076	2.4564

1635	35637	2.8306	2.7655
1635	42765	3.3024	3.3430
1635	49892	3.8555	3.8717
1635	57020	4.8722	4.5143
1635	64147	5.1975	5.1243
1635	71275	5.8564	5.8564
2540	3.17	9.7607	9.7607
2540	5.64	9.6875	9.6630
2540	8.12	9.5898	9.5898
2540	10.59	9.5166	9.5085
2540	13.06	9.4678	9.4597
2540	15.54	9.3409	9.3214
2540	18.02	9.3214	9.3507
2540	20.49	9.2238	9.1994
2540	22.95	8.9993	8.9798
2540	28.08	9.0530	9.0384
2540	33.21	8.7846	8.7846
2540	38.33	8.8188	8.7895
2540	43.46	8.6528	8.5747
2540	48.59	8.5113	8.4478
2540	58.85	8.3893	8.3014
2540	69.10	8.2722	8.0428
2540	79.36	8.0233	7.8378
2540	89.62	7.7890	7.5889
2540	99.87	7.5791	7.4913
2540	177	6.5640	5.7344
2540	285	5.3196	4.6851
2540	356	4.9535	3.2210
2540	499	4.3435	1.3421
2540	713	3.8067	1.1713
2540	1425	3.0258	1.3665
2540	2851	2.8794	2.0985
2540	4276	2.7183	2.3426
2540	4989	2.7867	2.5963
2540	5702	2.7867	2.5427
2540	7127	2.6110	2.4808
2540	14255	3.0014	2.9770
2540	21382	3.2780	3.1885
2540	28510	3.3918	3.3674
2540	35637	3.8880	3.8555
2540	42765	4.2947	4.2703
2540	49892	5.3684	5.3684
2540	57020	5.7832	5.6856
2540	64147	6.3444	6.2956
2540	71275	7.1985	7.1009

Table C4 Determination of pressure gradient from experiment for SDS solution with nearly closing valve at pressure tab

Physical properties of air and SDS solution (1 CMC) used in experiment:

density of SDS solution, $\rho_{SDS\ solution}$ = 994.97 kg/m^3; viscosity of SDS solution, $\mu_{SDS\ solution}$ = 1.01 × 10^{-3} Pa.s

density of air, ρ_{air} = 1.18 kg/m^3; viscosity of air, μ_{air} = 1.85 × 10^{-5} Pa.s

temperature, T = 31 °C (± 1 °C); inner pipe diameter, D = 0.019 m; cross-sectional area of pipe, A = 0.00028 m^2

pressure taps difference = 0.4 m

$Re_{solution}$	Re_{air}	(dp/dz) from experiment	
		maximum (kPa/m)	minimum (kPa/m)
0	3.17	9.8339	9.8013
0	5.64	9.7119	9.7119
0	8.12	9.7037	9.5492
0	10.59	9.4678	9.3702
0	13.06	9.3946	9.2564
0	15.54	9.0237	8.9798
0	18.02	8.8773	8.7504
0	20.49	8.8090	8.7504
0	22.95	8.8090	8.5162
0	28.08	8.5211	8.3063
0	33.21	8.2722	7.9549
0	38.33	7.9110	7.5743
0	43.46	7.8085	7.1253
0	48.59	7.4425	7.1009
0	58.85	7.1985	6.8325
0	69.10	6.9545	6.4664
0	79.36	6.8081	6.0516
0	89.62	6.7495	5.4904
0	99.87	6.2468	5.0023
500	3.17	9.7607	9.7363
500	5.64	9.7363	9.6630
500	8.12	9.4922	9.3214
500	10.59	9.5085	9.3214
500	13.06	9.3605	9.3702
500	15.54	9.0823	9.0676
500	18.02	9.0530	8.8432
500	20.49	8.9700	8.7846
500	22.95	8.7895	8.7651
500	28.08	8.6382	8.5406
500	33.21	8.5162	8.4625
500	38.33	8.3063	8.2282
500	43.46	8.1404	8.0184
500	48.59	8.0233	7.8476

500	58.85	7.6719	7.5206
500	69.10	7.3205	7.1302
500	79.36	7.0374	6.6372
500	89.62	6.5836	6.2224
500	99.87	6.2468	5.8808
500	177	4.6607	4.3435
500	285	2.7574	2.0985
500	356	2.1864	1.3421
500	499	1.5959	1.2201
500	713	1.4885	0.8589
500	1425	1.2201	0.5368
500	2851	1.3079	1.1957
500	4276	1.3177	1.2591
500	4989	1.4007	1.2982
500	5702	1.3909	1.3177
500	7127	1.4104	1.3860
500	14255	1.4478	1.3584
500	21382	1.2770	1.1143
500	28510	1.6105	1.3258
500	35637	1.5617	1.5780
500	42765	1.9359	2.0172
500	49892	2.6842	2.6842
500	57020	3.4162	3.4162
500	64147	3.7823	3.7823
500	71275	4.7095	4.7421
1065	3.17	9.7932	9.7851
1065	5.64	9.7119	9.6386
1065	8.12	9.7119	9.5166
1065	10.59	9.5166	9.2726
1065	13.06	9.3653	9.1750
1065	15.54	9.3019	8.9993
1065	18.02	9.0579	8.9310
1065	20.49	9.0481	8.7846
1065	22.95	8.8920	8.6382
1065	28.08	8.5015	8.3698
1065	33.21	8.1697	8.1550
1065	38.33	7.8866	7.8232
1065	43.46	7.8524	7.8768
1065	48.59	7.7012	7.6865
1065	58.85	7.4669	7.4425
1065	69.10	7.3351	7.1985
1065	79.36	7.3693	7.0765
1065	89.62	7.0667	6.7056
1065	99.87	6.8227	6.7593
1065	177	5.4660	5.0755
1065	285	3.6017	2.9282
1065	356	2.8794	2.4060
1065	499	2.3426	1.7325
1065	713	1.8301	1.1713
1065	1425	1.5861	0.7320
1065	2851	1.9131	1.5275
1065	4276	1.8887	1.6740
1065	4989	1.8301	1.7179
1065	5702	1.8594	1.7520

1065	7127	1.8789	1.7276
1065	14255	1.6837	1.6186
1065	21382	1.5292	1.4316
1065	28510	1.9928	1.9359
1065	35637	2.1311	2.0741
1065	42765	2.6760	2.5459
1065	49892	3.2536	3.2780
1065	57020	4.0263	4.0263
1065	64147	4.3923	4.3923
1065	71275	5.3928	5.3684
1635	3.17	9.7607	9.7607
1635	5.64	9.7444	9.7525
1635	8.12	9.6630	9.6386
1635	10.59	9.5654	9.5329
1635	13.06	9.4678	9.4760
1635	15.54	9.4516	9.3702
1635	18.02	9.3458	9.2677
1635	20.49	9.2726	9.1213
1635	22.95	9.1555	9.0823
1635	28.08	9.0091	8.8871
1635	33.21	8.9700	8.7797
1635	38.33	8.7992	8.5991
1635	43.46	8.7211	8.4771
1635	48.59	8.5308	8.3014
1635	58.85	8.2624	8.0965
1635	69.10	7.7744	7.7988
1635	79.36	7.5938	7.5108
1635	89.62	7.4230	7.3254
1635	99.87	7.1985	7.0765
1635	177	5.8515	5.5880
1635	285	4.2703	3.6114
1635	356	3.6602	3.0746
1635	499	3.0404	2.2938
1635	713	1.8789	1.1713
1635	1425	1.4397	0.8053
1635	2851	1.9912	1.8252
1635	4276	2.0741	2.0253
1635	4989	2.0937	2.0302
1635	5702	2.4450	2.2205
1635	7127	2.3962	2.1864
1635	14255	2.3751	2.1717
1635	21382	2.3832	2.3263
1635	28510	2.4076	2.4564
1635	35637	2.8306	2.7655
1635	42765	3.3024	3.3430
1635	49892	3.8555	3.8717
1635	57020	4.8722	4.5143
1635	64147	5.1975	5.1243
1635	71275	5.8564	5.8564
2540	3.17	9.7607	9.7607
2540	5.64	9.6875	9.6630
2540	8.12	9.5898	9.5898
2540	10.59	9.5166	9.5085
2540	13.06	9.4678	9.4597

2540	15.54	9.3409	9.3214
2540	18.02	9.3214	9.3507
2540	20.49	9.2238	9.1994
2540	22.95	8.9993	8.9798
2540	28.08	9.0530	9.0384
2540	33.21	8.7846	8.7846
2540	38.33	8.8188	8.7895
2540	43.46	8.6528	8.5747
2540	48.59	8.5113	8.4478
2540	58.85	8.3893	8.3014
2540	69.10	8.2722	8.0428
2540	79.36	8.0233	7.8378
2540	89.62	7.7890	7.5889
2540	99.87	7.5791	7.4913
2540	177	6.7349	6.5982
2540	285	5.2903	4.8754
2540	356	4.6363	4.2703
2540	499	3.6358	2.8696
2540	713	2.4255	1.9180
2540	1425	2.5866	1.5861
2540	2851	2.7818	2.0741
2540	4276	2.9282	2.5622
2540	4989	2.9136	2.6159
2540	5702	2.8794	2.4646
2540	7127	2.9136	2.5768
2540	14255	3.0014	2.9770
2540	21382	3.2780	3.1885
2540	28510	3.3918	3.3674
2540	35637	3.8880	3.8555
2540	42765	4.2947	4.2703
2540	49892	5.3684	5.3684
2540	57020	5.7832	5.6856
2540	64147	6.3444	6.2956
2540	71275	7.1985	7.1009

Appendix D Comparison Between Wilkes Theory, Sylvester Theory and Experimental Data for Pressure Gradient

Table D1 Comparison between Wilkes theory, Sylvester theory and experimental pressure gradient by opening the whole valve at pressure tab for pure water

Physical properties of air and water used in experiment:

density of water, $\rho_{water} = 995$ kg/m^3; viscosity of water, $\mu_{water} = 8.51 \times 10^{-4}$ kg/m.s

density of air, $\rho_{air} = 1.18$ kg/m^3; viscosity of air, $\mu_{air} = 1.85 \times 10^{-5}$ kg/m.s

temperature, T = 31 °C (± 1 °C); inner pipe diameter, D = 0.019 m; cross-sectional area of pipe, A = 0.00028 m^2

pressure taps difference = 0.4 m

Water				Air				Flow regime	(dp/dz) from experiment		$(dp/dz)_{tp}$ from Wilkes theory (kPa/m)	$(dp/dz)_{tp}$ from Sylvester theory (kPa/m)
Q_{water} (ml/min)	Sup. water velocity j_{water} (m/s)	Q_{water} (m^3/sec)	Re_{water}	Q_{air} (L/min)	Sup. Air velocity j_{air} (m/s)	Q_{air} (m^3/sec)	Re_{air}		maximum (kPa/m)	minimum (kPa/m)		
0	0	0	0	0.0444	0.0026	7.40E-07	3.17	bubble	9.6877	9.6145	9.6552	-
0	0	0	0	0.0792	0.0047	1.32E-06	5.64	bubble	9.6389	9.5169	9.5741	-
0	0	0	0	0.1139	0.0067	1.90E-06	8.12	bubble	9.5657	9.3705	9.4944	-
0	0	0	0	0.253	0.0149	4.21E-06	18.02	slug	9.1655	8.1894	8.9030	9.2423
0	0	0	0	0.287	0.0169	4.79E-06	20.49	slug	9.2485	7.7844	8.7991	9.0610
0	0	0	0	0.322	0.0189	5.37E-06	22.95	slug	9.2485	7.3695	8.6988	8.4159
0	0	0	0	0.394	0.0232	6.57E-06	28.08	slug	9.1265	7.2719	8.4983	8.2979
0	0	0	0	0.466	0.0274	7.76E-06	33.21	slug	8.8581	6.8327	8.3090	7.9737

0	0	0	0	0.538	0.0316	8.96E-06	38.33	slug	8.7605	6.5398	8.1298	7.7036
0	0	0	0	0.610	0.0359	1.02E-05	43.46	slug	8.5408	6.5154	7.9599	7.5283
0	0	0	0	0.682	0.0401	1.14E-05	48.59	slug	8.4920	6.3690	7.7988	7.4562
0	0	0	0	0.826	0.0486	1.38E-05	58.85	slug	8.4188	5.5637	7.4999	7.2589
0	0	0	0	0.970	0.0570	1.62E-05	69.10	slug	8.0772	5.2953	7.2287	7.0037
0	0	0	0	1.113	0.0655	1.86E-05	79.36	slug	7.7112	5.1245	6.9815	6.3575
0	0	0	0	1.257	0.0739	2.1E-05	89.62	slug	7.9796	3.9776	6.7552	5.9319
0	0	0	0	1.401	0.0824	2.34E-05	99.87	slug	7.8332	4.4412	6.5489	5.7481
263	0.0154	4.38E-06	344	0.0444	0.0026	7.406E-07	3.17	bubble	9.6877	9.5901	9.6615	-
263	0.0154	4.38E-06	344	0.0792	0.0047	1.319E-06	5.64	bubble	9.6389	9.5413	9.5853	-
263	0.0154	4.38E-06	344	0.1139	0.0067	1.898E-06	8.12	bubble	9.5413	9.4437	9.5102	-
263	0.0154	4.38E-06	344	0.1486	0.0087	2.477E-06	10.59	bubble	9.4925	9.3705	9.4362	-
263	0.0154	4.38E-06	344	0.1833	0.0108	3.055E-06	13.06	bubble	9.4925	9.0533	9.3635	-
263	0.0154	4.38E-06	344	0.394	0.0232	6.57E-06	28.08	slug	9.0240	7.4671	8.6180	9.1963
263	0.0154	4.38E-06	344	0.466	0.0274	7.76E-06	33.21	slug	9.1021	7.0523	8.4430	8.6748
263	0.0154	4.38E-06	344	0.538	0.0316	8.96E-06	38.33	slug	8.9801	6.7351	8.2766	8.4061
263	0.0154	4.38E-06	344	0.610	0.0359	1.02E-05	43.46	slug	9.0045	6.3202	8.1181	7.9601
263	0.0154	4.38E-06	344	0.682	0.0401	1.14E-05	48.59	slug	8.8337	6.1494	7.9670	7.5224
263	0.0154	4.38E-06	344	0.826	0.0486	1.38E-05	58.85	slug	8.5896	5.8322	7.6849	7.4761
263	0.0154	4.38E-06	344	0.970	0.0570	1.62E-05	69.10	slug	8.4920	5.6125	7.4270	6.8448
263	0.0154	4.38E-06	344	1.113	0.0655	1.86E-05	79.36	slug	8.5408	4.7341	7.1902	6.7198
263	0.0154	4.38E-06	344	1.257	0.0739	2.1E-05	89.62	slug	8.4920	4.7341	6.9720	6.3616
263	0.0154	4.38E-06	344	1.401	0.0824	2.34E-05	99.87	slug	8.2480	4.4412	6.7733	5.6871
263	0.0154	4.38E-06	344	2.481	0.1459	4.13E-05	177	slug	8.4920	2.1474	5.6454	5.0647
263	0.0154	4.38E-06	344	4.000	0.2353	6.67E-05	285	slug	8.1016	-0.4880	4.7087	-
263	0.0154	4.38E-06	344	5.000	0.2941	8.33E-05	356	slug-churn	7.4183	-1.6106	4.3055	-
263	0.0154	4.38E-06	344	7.000	0.4117	0.000117	499	slug-churn	8.0528	-1.3177	3.7639	-
263	0.0154	4.38E-06	344	10.000	0.5881	0.000167	713	slug-churn	6.6374	-1.3177	3.2948	-

263	0.0154	4.38E-06	344	20.000	1.1763	0.000333	1425	slug-churn	5.1733	-1.0249	2.7351	-
263	0.0154	4.38E-06	344	200	11.76	0.0033	14255	annular	0.6101	0.5369	2.7059	-
263	0.0154	4.38E-06	344	300	17.64	0.0050	21382	annular	0.6833	0.6101	1.3937	-
263	0.0154	4.38E-06	344	400	23.53	0.0067	28510	annular	0.7809	0.6833	0.9546	-
263	0.0154	4.38E-06	344	500	29.41	0.0083	35637	annular	1.0737	1.0493	1.1931	-
263	0.0154	4.38E-06	344	600	35.29	0.0100	42765	annular	1.4641	1.2689	1.5155	-
263	0.0154	4.38E-06	344	700	41.17	0.0117	49892	annular	1.9034	1.5862	1.8848	-
263	0.0154	4.38E-06	344	800	47.05	0.0133	57020	mist	2.1230	2.0742	2.2926	-
263	0.0154	4.38E-06	344	900	52.93	0.0150	64147	mist	2.5622	2.5134	2.7351	-
263	0.0154	4.38E-06	344	1000	58.81	0.0167	71275	mist	3.1235	3.1235	3.2102	-
364	0.0214	6.07E-06	477	0.0444	0.0026	7.41E-07	3.17	bubble	9.7365	9.6389	9.6638	-
364	0.0214	6.07E-06	477	0.0792	0.0047	1.32E-06	5.64	bubble	9.7121	9.5657	9.5892	-
364	0.0214	6.07E-06	477	0.1139	0.0067	1.9E-06	8.12	bubble	9.6633	9.4925	9.5158	-
364	0.0214	6.07E-06	477	0.1486	0.0087	2.48E-06	10.59	bubble	9.5169	9.1997	9.4435	-
364	0.0214	6.07E-06	477	0.1833	0.0108	3.06E-06	13.06	bubble	9.4681	8.9801	9.3723	-
364	0.0214	6.07E-06	477	0.394	0.0232	6.57E-06	28.08	slug	9.2095	7.7160	8.6586	8.9542
364	0.0214	6.07E-06	477	0.466	0.0274	7.76E-06	33.21	slug	9.0777	7.3695	8.4886	8.6935
364	0.0214	6.07E-06	477	0.538	0.0316	8.96E-06	38.33	slug	9.0533	7.1743	8.3266	8.2501
364	0.0214	6.07E-06	477	0.610	0.0359	1.02E-05	43.46	slug	8.6140	6.9059	8.1721	8.0251
364	0.0214	6.07E-06	477	0.682	0.0401	1.14E-05	48.59	slug	9.0045	6.5398	8.0246	7.9974
364	0.0214	6.07E-06	477	0.826	0.0486	1.38E-05	58.85	slug	9.1021	6.3934	7.7488	7.3496
364	0.0214	6.07E-06	477	0.970	0.0570	1.62E-05	69.10	slug	8.9313	5.9786	7.4958	7.0033
364	0.0214	6.07E-06	477	1.113	0.0655	1.86E-05	79.36	slug	8.4920	5.5637	7.2629	6.6129
364	0.0214	6.07E-06	477	1.257	0.0739	2.1E-05	89.62	slug	8.2236	5.1489	7.0478	6.2431
364	0.0214	6.07E-06	477	1.401	0.0824	2.34E-05	99.87	slug	8.8825	4.7585	6.8522	5.9590
364	0.0214	6.07E-06	477	2.481	0.1459	4.13E-05	177	slug	7.9308	1.6106	5.7309	4.7667
364	0.0214	6.07E-06	477	4.000	0.2353	6.67E-05	285	slug	8.5408	-0.3904	4.7898	-
364	0.0214	6.07E-06	477	5.000	0.2941	8.33E-05	356	slug-churn	8.0040	-1.2689	4.3819	-
364	0.0214	6.07E-06	477	7.000	0.4117	0.000117	499	slug-churn	7.1743	-1.2689	3.8311	-

364	0.0214	6.07E-06	477	10.000	0.5881	0.000167	713	slug-churn	7.9552	-1.2201	3.3513	-
364	0.0214	6.07E-06	477	20.000	1.1763	0.000333	1425	slug-churn	4.8317	-1.0249	2.7731	-
364	0.0214	6.07E-06	477	200	11.76	0.0033	14255	annular	0.9175	0.6003	2.7115	-
364	0.0214	6.07E-06	477	300	17.64	0.0050	21382	annular	0.8980	0.6784	1.4290	-
364	0.0214	6.07E-06	477	400	23.53	0.0067	28510	annular	1.1176	0.9419	1.0322	-
364	0.0214	6.07E-06	477	500	29.41	0.0083	35637	annular	1.4007	1.2396	1.2693	-
364	0.0214	6.07E-06	477	600	35.29	0.0100	42765	annular	2.0352	1.7814	1.5992	-
364	0.0214	6.07E-06	477	700	41.17	0.0117	49892	annular	2.4402	2.1913	1.9787	-
364	0.0214	6.07E-06	477	800	47.05	0.0133	57020	mist	2.9673	2.6696	2.3979	-
364	0.0214	6.07E-06	477	900	52.93	0.0150	64147	mist	3.5871	3.2065	2.8527	-
364	0.0214	6.07E-06	477	1000	58.81	0.0167	71275	mist	4.3290	3.9825	3.3406	-
465	0.0274	7.76E-06	611	0.0444	0.0026	7.41E-07	3.17	bubble	9.7610	9.7121	9.6660	-
465	0.0274	7.76E-06	611	0.0792	0.0047	1.32E-06	5.64	bubble	9.7121	9.6145	9.5930	-
465	0.0274	7.76E-06	611	0.1139	0.0067	1.9E-06	8.12	bubble	9.6877	9.4681	9.5211	-
465	0.0274	7.76E-06	611	0.1486	0.0087	2.48E-06	10.59	bubble	9.6145	9.2973	9.4504	-
465	0.0274	7.76E-06	611	0.1833	0.0108	3.06E-06	13.06	bubble	9.5657	9.1265	9.3806	-
466	0.0274	7.76E-06	611	0.394	0.0232	6.57E-06	28.08	slug	9.0582	7.6282	8.6964	8.9668
466	0.0274	7.76E-06	611	0.466	0.0274	7.76E-06	33.21	slug	9.0874	7.4671	8.5312	8.8077
466	0.0274	7.76E-06	611	0.538	0.0316	8.96E-06	38.33	slug	9.0045	7.2475	8.3735	8.3642
466	0.0274	7.76E-06	611	0.610	0.0359	1.02E-05	43.46	slug	8.8581	6.9059	8.2228	8.1357
466	0.0274	7.76E-06	611	0.682	0.0401	1.14E-05	48.59	slug	8.7361	6.8083	8.0788	7.9153
466	0.0274	7.76E-06	611	0.826	0.0486	1.38E-05	58.85	slug	8.9069	6.3690	7.8088	7.5996
466	0.0274	7.76E-06	611	0.970	0.0570	1.62E-05	69.10	slug	8.4432	5.8322	7.5606	7.1206
466	0.0274	7.76E-06	611	1.113	0.0655	1.86E-05	79.36	slug	8.2724	5.5149	7.3316	6.9130
466	0.0274	7.76E-06	611	1.257	0.0739	2.1E-05	89.62	slug	8.4188	5.2221	7.1197	6.2636
466	0.0274	7.76E-06	611	1.401	0.0824	2.34E-05	99.87	slug	7.9308	5.2953	6.9271	6.1787
466	0.0274	7.76E-06	611	2.481	0.1459	4.13E-05	177	slug	7.2231	2.8307	5.8131	4.8392
466	0.0274	7.76E-06	611	4.000	0.2353	6.67E-05	285	slug	8.5896	-0.6833	4.8685	-
466	0.0274	7.76E-06	611	5.000	0.2941	8.33E-05	356	slug-churn	8.4432	-1.1713	4.4563	-

466	0.0274	7.76E-06	611	7.000	0.4117	0.000117	499	slug-churn	7.5647	-1.2201	3.8969	-
466	0.0274	7.76E-06	611	10.000	0.5881	0.000167	713	slug-churn	7.4671	-1.7082	3.4069	-
466	0.0274	7.76E-06	611	20.000	1.1763	0.000333	1425	slug-churn	4.6365	-0.4392	2.8108	-
466	0.0274	7.76E-06	611	200	11.76	0.0033	14255	annular	1.4885	0.8541	2.7169	-
466	0.0274	7.76E-06	611	300	17.64	0.0050	21382	annular	1.3421	1.0005	1.4609	-
466	0.0274	7.76E-06	611	400	23.53	0.0067	28510	annular	1.3909	1.2201	1.0969	-
466	0.0274	7.76E-06	611	500	29.41	0.0083	35637	annular	1.7326	1.6106	1.3338	-
466	0.0274	7.76E-06	611	600	35.29	0.0100	42765	annular	2.0742	2.0010	1.6698	-
466	0.0274	7.76E-06	611	700	41.17	0.0117	49892	annular	2.5867	2.3670	2.0577	-
466	0.0274	7.76E-06	611	800	47.05	0.0133	57020	mist	3.0015	2.9283	2.4863	-
466	0.0274	7.76E-06	611	900	52.93	0.0150	64147	mist	3.6116	3.4163	2.9512	-
466	0.0274	7.76E-06	611	1000	58.81	0.0167	71275	mist	4.1728	3.9776	3.4497	-
567	0.0334	9.46E-06	744	0.0444	0.0026	7.41E-07	3.17	bubble	9.9074	9.7854	9.6680	-
567	0.0334	9.46E-06	744	0.0792	0.0047	1.32E-06	5.64	bubble	9.8098	9.6633	9.5966	-
567	0.0334	9.46E-06	744	0.1139	0.0067	1.9E-06	8.12	bubble	9.7365	9.5657	9.5263	-
567	0.0334	9.46E-06	744	0.1486	0.0087	2.48E-06	10.59	bubble	9.7854	9.4681	9.4570	-
567	0.0334	9.46E-06	744	0.1833	0.0108	3.06E-06	13.06	bubble	9.5657	9.1753	9.3887	-
567	0.0334	9.46E-06	744	0.394	0.0232	6.57E-06	28.08	slug	8.9361	7.7990	8.7318	9.1533
567	0.0334	9.46E-06	744	0.466	0.0274	7.76E-06	33.21	slug	9.0533	7.5891	8.5711	8.6948
567	0.0334	9.46E-06	744	0.538	0.0316	8.96E-06	38.33	slug	8.5311	7.2719	8.4174	8.3808
567	0.0334	9.46E-06	744	0.610	0.0359	1.02E-05	43.46	slug	8.8581	7.0523	8.2705	8.1389
567	0.0334	9.46E-06	744	0.682	0.0401	1.14E-05	48.59	slug	8.7849	7.2963	8.1297	7.9884
567	0.0334	9.46E-06	744	0.826	0.0486	1.38E-05	58.85	slug	8.3700	6.8327	7.8655	7.7991
567	0.0334	9.46E-06	744	0.970	0.0570	1.62E-05	69.10	slug	8.2968	6.3690	7.6219	7.5210
567	0.0334	9.46E-06	744	1.113	0.0655	1.86E-05	79.36	slug	7.8820	6.1494	7.3967	7.1202
567	0.0334	9.46E-06	744	1.257	0.0739	2.1E-05	89.62	slug	8.0772	5.3197	7.1879	6.9515
567	0.0334	9.46E-06	744	1.401	0.0824	2.34E-05	99.87	slug	8.5164	5.0513	6.9985	6.6085
567	0.0334	9.46E-06	744	2.481	0.1459	4.13E-05	177	slug	8.7849	3.0747	5.8921	5.3299
567	0.0334	9.46E-06	744	4.000	0.2353	6.67E-05	285	slug	8.3944	-0.7321	4.9449	-

567	0.0334	9.46E-06	744	5.000	0.2941	8.33E-05	356	slug-churn	9.1265	-1.2689	4.5288	-
567	0.0334	9.46E-06	744	7.000	0.4117	0.000117	499	slug-churn	7.3695	-1.8546	3.9615	-
567	0.0334	9.46E-06	744	10.000	0.5881	0.000167	713	slug-churn	6.5886	-1.0737	3.4617	-
567	0.0334	9.46E-06	744	20.000	1.1763	0.000333	1425	slug-churn	4.9293	-0.6833	2.8483	-
567	0.0334	9.46E-06	744	200	11.76	0.0033	14255	annular	1.1079	0.8687	2.7222	-
567	0.0334	9.46E-06	744	300	17.64	0.0050	21382	annular	1.1567	1.0054	1.4904	-
567	0.0334	9.46E-06	744	400	23.53	0.0067	28510	annular	1.4690	1.2787	1.1531	-
567	0.0334	9.46E-06	744	500	29.41	0.0083	35637	annular	1.8448	1.7179	1.3903	-
567	0.0334	9.46E-06	744	600	35.29	0.0100	42765	annular	2.4012	2.1572	1.7318	-
567	0.0334	9.46E-06	744	700	41.17	0.0117	49892	annular	3.0454	2.8258	2.1268	-
567	0.0334	9.46E-06	744	800	47.05	0.0133	57020	mist	3.6604	3.3870	2.5636	-
567	0.0334	9.46E-06	744	900	52.93	0.0150	64147	mist	4.5291	3.9727	3.0372	-
567	0.0334	9.46E-06	744	1000	58.81	0.0167	71275	mist	5.2904	4.7829	3.5447	-
771	0.0453	1.28E-05	1010	0.0444	0.0026	7.41E-07	3.17	bubble	9.8098	9.7121	9.6719	-
771	0.0453	1.28E-05	1010	0.0792	0.0047	1.32E-06	5.64	bubble	9.7854	9.6633	9.6034	-
771	0.0453	1.28E-05	1010	0.1139	0.0067	1.9E-06	8.12	bubble	9.7121	9.5657	9.5360	-
771	0.0453	1.28E-05	1010	0.1486	0.0087	2.48E-06	10.59	bubble	9.6389	9.3949	9.4694	-
771	0.0453	1.28E-05	1010	0.1833	0.0108	3.06E-06	13.06	bubble	9.5901	9.2485	9.4038	-
771	0.0453	1.28E-05	1010	0.466	0.0274	7.76E-06	33.21	slug	8.8239	7.7844	8.6437	8.5918
771	0.0453	1.28E-05	1010	0.538	0.0316	8.96E-06	38.33	slug	8.8141	7.5452	8.4976	8.4114
771	0.0453	1.28E-05	1010	0.610	0.0359	1.02E-05	43.46	slug	8.9215	7.3354	8.3575	8.3038
771	0.0453	1.28E-05	1010	0.682	0.0401	1.14E-05	48.59	slug	8.7263	7.4183	8.2230	8.0130
771	0.0453	1.28E-05	1010	0.826	0.0486	1.38E-05	58.85	slug	8.5896	6.9791	7.9696	7.7945
771	0.0453	1.28E-05	1010	0.970	0.0570	1.62E-05	69.10	slug	8.1992	6.4910	7.7350	7.3877
771	0.0453	1.28E-05	1010	1.113	0.0655	1.86E-05	79.36	slug	8.1992	6.3202	7.5171	6.7677
771	0.0453	1.28E-05	1010	1.257	0.0739	2.1E-05	89.62	slug	7.9796	5.7004	7.3143	6.6113
771	0.0453	1.28E-05	1010	1.401	0.0824	2.34E-05	99.87	slug	7.8820	5.6858	7.1315	6.3247
771	0.0453	1.28E-05	1010	2.481	0.1459	4.13E-05	177	slug	7.2719	3.5383	6.0416	4.6587

771	0.0453	1.28E-05	1010	4.000	0.2353	6.67E-05	285	slug	8.3456	-0.3904	5.0912	-
771	0.0453	1.28E-05	1010	5.000	0.2941	8.33E-05	356	slug-churn	7.5159	-0.4880	4.6686	-
771	0.0453	1.28E-05	1010	7.000	0.4117	0.000117	499	slug-churn	7.0767	-0.6345	4.0869	-
771	0.0453	1.28E-05	1010	10.000	0.5881	0.000167	713	slug-churn	6.7839	-0.8785	3.5690	-
771	0.0453	1.28E-05	1010	20.000	1.1763	0.000333	1425	slug-churn	5.0269	-0.0488	2.9224	-
771	0.0453	1.28E-05	1010	200	11.76	0.0033	14255	annular	1.2543	0.9615	2.7329	-
771	0.0453	1.28E-05	1010	300	17.64	0.0050	21382	annular	1.3763	1.1567	1.5438	-
771	0.0453	1.28E-05	1010	400	23.53	0.0067	28510	annular	1.7374	1.5666	1.2484	-
771	0.0453	1.28E-05	1010	500	29.41	0.0083	35637	annular	2.2694	2.0742	1.4876	-
771	0.0453	1.28E-05	1010	600	35.29	0.0100	42765	annular	2.8648	2.6403	1.8383	-
771	0.0453	1.28E-05	1010	700	41.17	0.0117	49892	annular	3.2699	3.1967	2.2455	-
771	0.0453	1.28E-05	1010	800	47.05	0.0133	57020	mist	4.1874	3.9044	2.6960	-
771	0.0453	1.28E-05	1010	900	52.93	0.0150	64147	mist	4.5144	4.1972	3.1842	-
771	0.0453	1.28E-05	1010	1000	58.81	0.0167	71275	mist	4.7829	4.7097	3.7071	-
974	0.0573	1.62E-05	1277	0.0444	0.0026	7.41E-07	3.17	bubble	9.8830	9.8342	9.6755	-
974	0.0573	1.62E-05	1277	0.0792	0.0047	1.32E-06	5.64	bubble	9.8342	9.7365	9.6097	-
974	0.0573	1.62E-05	1277	0.1139	0.0067	1.9E-06	8.12	bubble	9.7610	9.5657	9.5448	-
974	0.0573	1.62E-05	1277	0.1486	0.0087	2.48E-06	10.59	bubble	9.6145	9.4437	9.4808	-
974	0.0573	1.62E-05	1277	0.1833	0.0108	3.06E-06	13.06	bubble	9.5413	9.2973	9.4177	-
974	0.0573	1.62E-05	1277	0.466	0.0274	7.76E-06	33.21	slug	8.9020	8.0040	8.7082	8.8825
974	0.0573	1.62E-05	1277	0.538	0.0316	8.96E-06	38.33	slug	8.6726	7.9112	8.5690	8.7513
974	0.0573	1.62E-05	1277	0.610	0.0359	1.02E-05	43.46	slug	8.6384	7.6623	8.4352	8.3793
974	0.0573	1.62E-05	1277	0.682	0.0401	1.14E-05	48.59	slug	8.5652	7.5159	8.3065	8.2008
974	0.0573	1.62E-05	1277	0.826	0.0486	1.38E-05	58.85	slug	8.2236	7.2231	8.0631	7.9158
974	0.0573	1.62E-05	1277	0.970	0.0570	1.62E-05	69.10	slug	8.3700	6.9547	7.8369	7.5532
974	0.0573	1.62E-05	1277	1.113	0.0655	1.86E-05	79.36	slug	8.2724	6.4910	7.6261	7.2656
974	0.0573	1.62E-05	1277	1.257	0.0739	2.1E-05	89.62	slug	8.0284	6.3934	7.4291	6.9543
974	0.0573	1.62E-05	1277	1.401	0.0824	2.34E-05	99.87	slug	8.0284	5.8322	7.2530	6.5465

974	0.0573	1.62E-05	1277	2.481	0.1459	4.13E-05	177	slug	7.4183	4.1240	6.1807	5.2869
974	0.0573	1.62E-05	1277	4.000	0.2353	6.67E-05	285	slug	8.4920	0.2928	5.2296	-
974	0.0573	1.62E-05	1277	5.000	0.2941	8.33E-05	356	slug-churn	7.6135	0.2928	4.8017	-
974	0.0573	1.62E-05	1277	7.000	0.4117	0.000117	499	slug-churn	6.5886	-0.2928	4.2077	-
974	0.0573	1.62E-05	1277	10.000	0.5881	0.000167	713	slug-churn	5.0757	-0.0488	3.6733	-
974	0.0573	1.62E-05	1277	20.000	1.1763	0.000333	1425	slug-churn	4.9781	-0.5369	2.9956	-
974	0.0573	1.62E-05	1277	200	11.76	0.0033	14255	annular	1.3958	1.0591	2.7222	-
974	0.0573	1.62E-05	1277	300	17.64	0.0050	21382	annular	1.5373	1.3275	1.4904	-
974	0.0573	1.62E-05	1277	400	23.53	0.0067	28510	annular	1.9717	1.7911	1.1531	-
974	0.0573	1.62E-05	1277	500	29.41	0.0083	35637	annular	2.6599	2.4695	1.3903	-
974	0.0573	1.62E-05	1277	600	35.29	0.0100	42765	annular	3.2358	3.0601	1.7318	-
974	0.0573	1.62E-05	1277	700	41.17	0.0117	49892	annular	3.9239	3.6848	2.1268	-
974	0.0573	1.62E-05	1277	800	47.05	0.0133	57020	mist	4.5327	4.0671	2.5636	-
974	0.0573	1.62E-05	1277	900	52.93	0.0150	64147	mist	5.2026	5.1489	3.0372	-
974	0.0573	1.62E-05	1277	1000	58.81	0.0167	71275	mist	6.1006	5.8566	3.5447	-
1278	0.0752	2.13E-05	1676	0.0444	0.0026	7.41E-07	3.17	bubble	9.7365	9.6877	9.6803	-
1278	0.0752	2.13E-05	1676	0.0792	0.0047	1.32E-06	5.64	bubble	9.7121	9.6389	9.6182	-
1278	0.0752	2.13E-05	1676	0.1139	0.0067	1.9E-06	8.12	bubble	9.6389	9.5657	9.5569	-
1278	0.0752	2.13E-05	1676	0.1486	0.0087	2.48E-06	10.59	bubble	9.6145	9.4925	9.4964	-
1278	0.0752	2.13E-05	1676	0.1833	0.0108	3.06E-06	13.06	bubble	9.5413	9.3949	9.4367	-
1278	0.0752	2.13E-05	1676	0.466	0.0274	7.76E-06	33.21	slug	9.0874	8.2236	8.7925	9.0154
1278	0.0752	2.13E-05	1676	0.538	0.0316	8.96E-06	38.33	slug	8.9313	8.0528	8.6625	8.8159
1278	0.0752	2.13E-05	1676	0.610	0.0359	1.02E-05	43.46	slug	8.7849	7.7795	8.5372	8.6196
1278	0.0752	2.13E-05	1676	0.682	0.0401	1.14E-05	48.59	slug	8.6628	7.6379	8.4163	8.2804
1278	0.0752	2.13E-05	1676	0.826	0.0486	1.38E-05	58.85	slug	8.4432	7.2719	8.1867	8.0360
1278	0.0752	2.13E-05	1676	0.970	0.0570	1.62E-05	69.10	slug	8.4676	6.9059	7.9722	7.7176
1278	0.0752	2.13E-05	1676	1.113	0.0655	1.86E-05	79.36	slug	8.9801	6.5154	7.7713	7.6027
1278	0.0752	2.13E-05	1676	1.257	0.0739	2.1E-05	89.62	slug	8.6140	6.3934	7.5828	7.3298

1278	0.0752	2.13E-05	1676	1.401	0.0824	2.34E-05	99.87	slug	8.3700	5.9542	7.4168	7.1566
1278	0.0752	2.13E-05	1676	2.481	0.1459	4.13E-05	177	slug	7.8576	4.1972	6.3721	5.5304
1278	0.0752	2.13E-05	1676	4.000	0.2353	6.67E-05	285	slug	6.9547	2.6843	5.4238	-
1278	0.0752	2.13E-05	1676	5.000	0.2941	8.33E-05	356	slug-churn	6.1006	1.7082	4.9902	-
1278	0.0752	2.13E-05	1676	7.000	0.4117	0.000117	499	slug-churn	6.3446	0.0000	4.3808	-
1278	0.0752	2.13E-05	1676	10.000	0.5881	0.000167	713	slug-churn	5.6939	0.0000	3.8246	-
1278	0.0752	2.13E-05	1676	20.000	1.1763	0.000333	1425	slug-churn	5.2709	-0.7321	3.1036	-
1278	0.0752	2.13E-05	1676	200	11.76	0.0033	14255	annular	1.7130	1.4007	2.7222	-
1278	0.0752	2.13E-05	1676	300	17.64	0.0050	21382	annular	1.9668	1.7716	1.4904	-
1278	0.0752	2.13E-05	1676	400	23.53	0.0067	28510	annular	2.6208	2.4207	1.1531	-
1278	0.0752	2.13E-05	1676	500	29.41	0.0083	35637	annular	3.2699	3.0405	1.3903	-
1278	0.0752	2.13E-05	1676	600	35.29	0.0100	42765	annular	4.0850	3.9141	1.7318	-
1278	0.0752	2.13E-05	1676	700	41.17	0.0117	49892	annular	4.5388	4.6218	2.1268	-
1278	0.0752	2.13E-05	1676	800	47.05	0.0133	57020	mist	5.7150	5.5735	2.5636	-
1278	0.0752	2.13E-05	1676	900	52.93	0.0150	64147	mist	6.5008	6.2714	3.0372	-
1278	0.0752	2.13E-05	1676	1000	58.81	0.0167	71275	mist	6.9449	6.6960	3.5447	-
2091	0.1230	3.49E-05	2742	0.0444	0.0026	7.41E-07	3.17	bubble	9.8342	9.7854	9.6909	-
2091	0.1230	3.49E-05	2742	0.0792	0.0047	1.32E-06	5.64	bubble	9.8098	9.7365	9.6369	-
2091	0.1230	3.49E-05	2742	0.1139	0.0067	1.9E-06	8.12	bubble	9.7610	9.6877	9.5834	-
2091	0.1230	3.49E-05	2742	0.1486	0.0087	2.48E-06	10.59	bubble	9.7121	9.6389	9.5306	-
2091	0.1230	3.49E-05	2742	0.1833	0.0108	3.06E-06	13.06	bubble	9.6389	9.5413	9.4783	-
2091	0.1230	3.49E-05	2742	0.2180	0.0128	3.63E-06	15.54	bubble	9.5901	9.3705	9.4266	-
2091	0.1230	3.49E-05	2742	0.2528	0.0149	4.21E-06	18.02	bubble	9.4925	9.2241	9.3754	-
2091	0.1230	3.49E-05	2742	0.2875	0.0169	4.79E-06	20.49	bubble	9.3852	9.1216	9.3248	-
2091	0.1230	3.49E-05	2742	0.610	0.0359	1.02E-05	43.46	slug	8.8825	8.2724	8.7472	9.0851
2091	0.1230	3.49E-05	2742	0.682	0.0401	1.14E-05	48.59	slug	8.8629	7.9796	8.6433	8.8111
2091	0.1230	3.49E-05	2742	0.826	0.0486	1.38E-05	58.85	slug	8.6775	7.9064	8.4443	8.3380
2091	0.1230	3.49E-05	2742	0.970	0.0570	1.62E-05	69.10	slug	8.5652	7.5647	8.2562	8.1473

2091	0.1230	3.49E-05	2742	1.113	0.0655	1.86E-05	79.36	slug	8.7849	7.3207	8.0784	8.0350
2091	0.1230	3.49E-05	2742	1.257	0.0739	2.1E-05	89.62	slug	8.4432	6.8571	7.9098	7.7947
2091	0.1230	3.49E-05	2742	1.401	0.0824	2.34E-05	99.87	slug	8.9069	6.5154	7.7713	7.6051
2091	0.1230	3.49E-05	2742	2.481	0.1459	4.13E-05	177	slug	7.8576	6.5642	6.8018	6.0864
2091	0.1230	3.49E-05	2742	4.000	0.2353	6.67E-05	285	slug	7.0767	3.6604	5.8754	-
2091	0.1230	3.49E-05	2742	5.000	0.2941	8.33E-05	356	slug	6.1006	2.6029	5.4360	-
2091	0.1230	3.49E-05	2742	7.000	0.4117	0.000117	499	slug-churn	5.7102	2.0498	4.8005	-
2091	0.1230	3.49E-05	2742	10.000	0.5881	0.000167	713	slug-churn	5.1733	1.1225	4.2002	-
2091	0.1230	3.49E-05	2742	20.000	1.1763	0.000333	1425	slug-churn	4.1972	0.2684	3.3817	-
2091	0.1230	3.49E-05	2742	40.000	2.3525	0.000667	2851	slug-churn	3.7092	0.8053	3.2202	-
2091	0.1230	3.49E-05	2742	200	11.76	0.0033	14255	annular	2.3426	1.8448	2.7222	-
2091	0.1230	3.49E-05	2742	300	17.64	0.0050	21382	annular	2.8795	2.7087	1.4904	-
2091	0.1230	3.49E-05	2742	400	23.53	0.0067	28510	annular	3.6750	3.4993	1.1531	-
2091	0.1230	3.49E-05	2742	500	29.41	0.0083	35637	annular	4.4852	4.2899	1.3903	-
2091	0.1230	3.49E-05	2742	600	35.29	0.0100	42765	annular	5.1879	5.0855	1.7318	-
2091	0.1230	3.49E-05	2742	700	41.17	0.0117	49892	annular	5.8566	5.5833	2.1268	-
2091	0.1230	3.49E-05	2742	800	47.05	0.0133	57020	mist	6.5838	6.1494	2.5636	-
2091	0.1230	3.49E-05	2742	900	52.93	0.0150	64147	mist	8.0040	7.4330	3.0372	-
2091	0.1230	3.49E-05	2742	1000	58.81	0.0167	71275	mist	8.0528	7.9064	3.5447	-

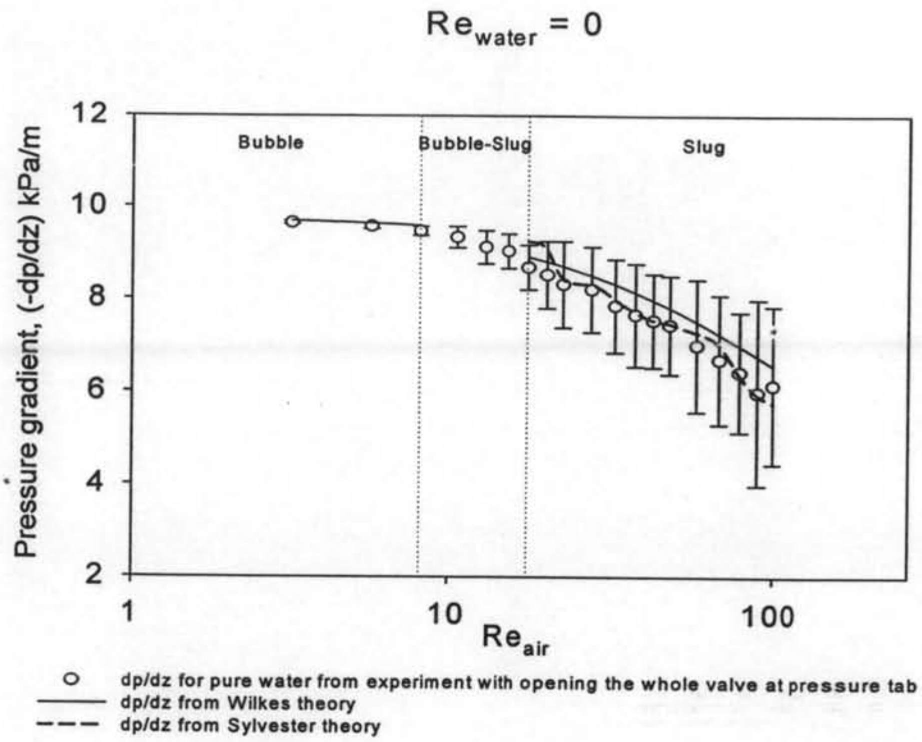

Figure D1 Comparison between Wilkes theory, Sylvester theory and experimental pressure gradient with opening the whole valve at pressure tab vs. air Reynolds number of pure water at $Re_{water} = 0$.

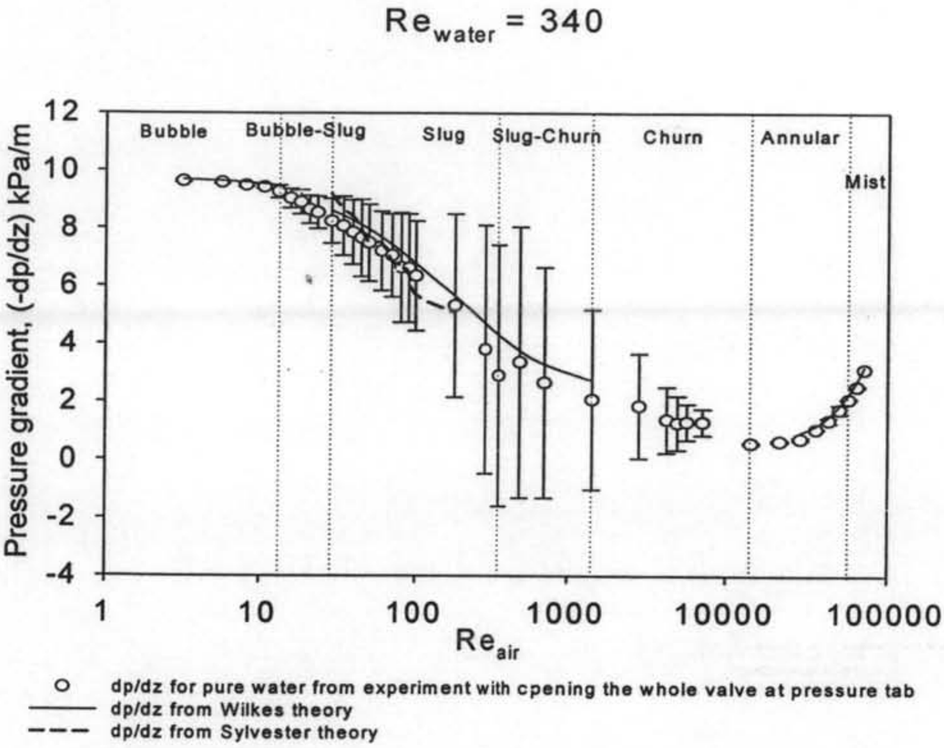

Figure D2 Comparison between Wilkes theory, Sylvester theory and experimental pressure gradient with opening the whole valve at pressure tab vs. air Reynolds number of pure water at $Re_{water} = 340$.

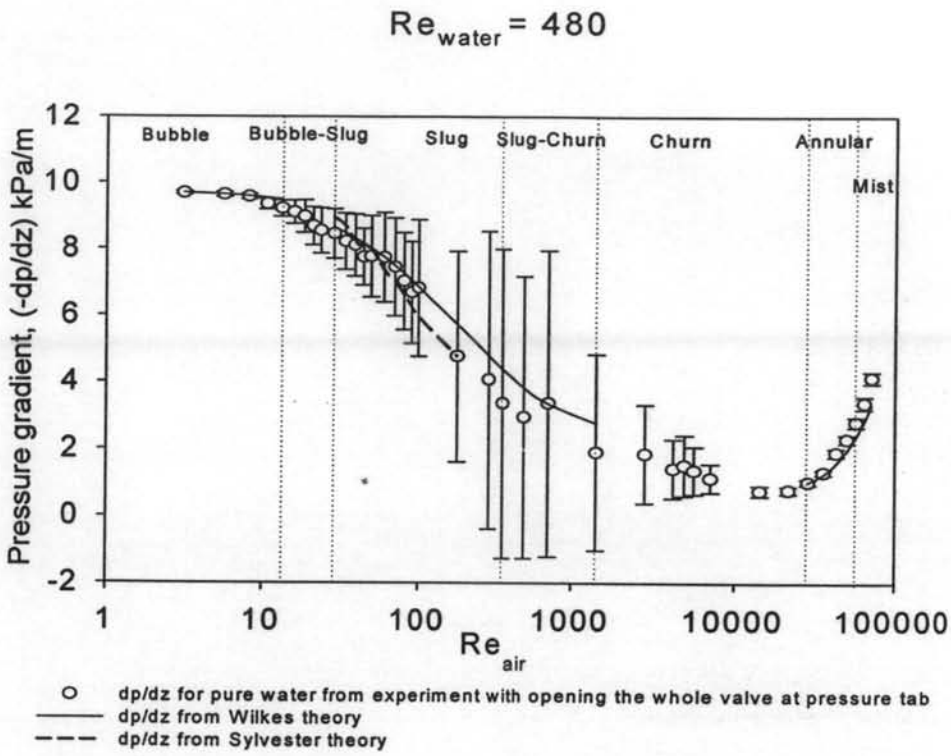

Figure D3 Comparison between Wilkes theory, Sylvester theory and experimental pressure gradient with opening the whole valve at pressure tab vs. air Reynolds number of pure water at $Re_{water} = 480$.

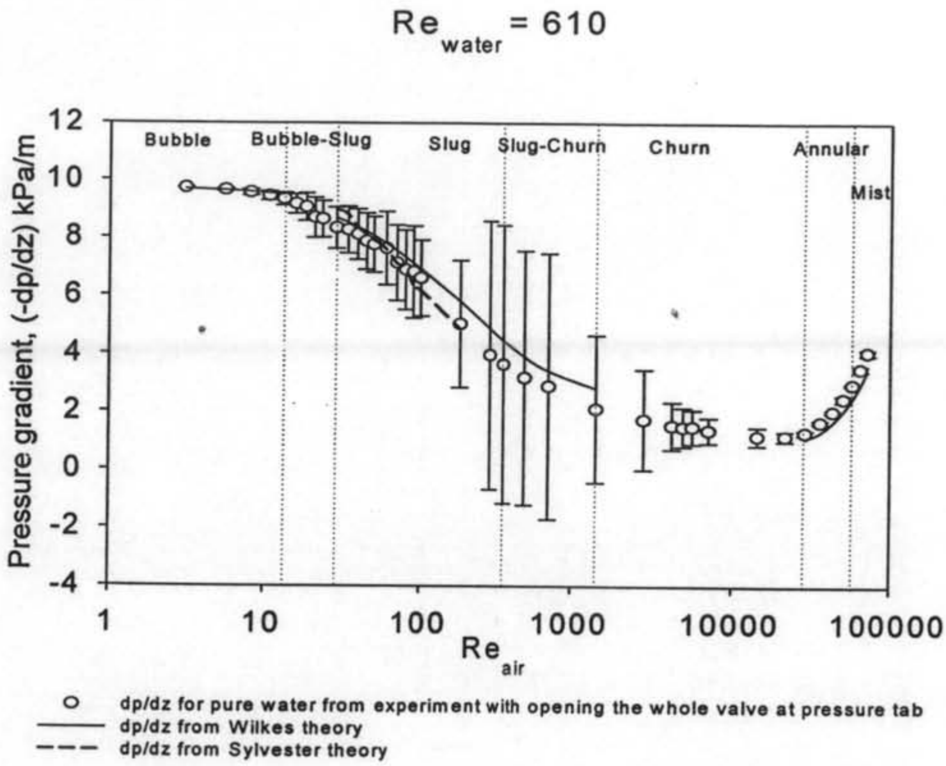

Figure D4 Comparison between Wilkes theory, Sylvester theory and experimental pressure gradient with opening the whole valve at pressure tab vs. air Reynolds number of pure water at $Re_{water} = 610$.

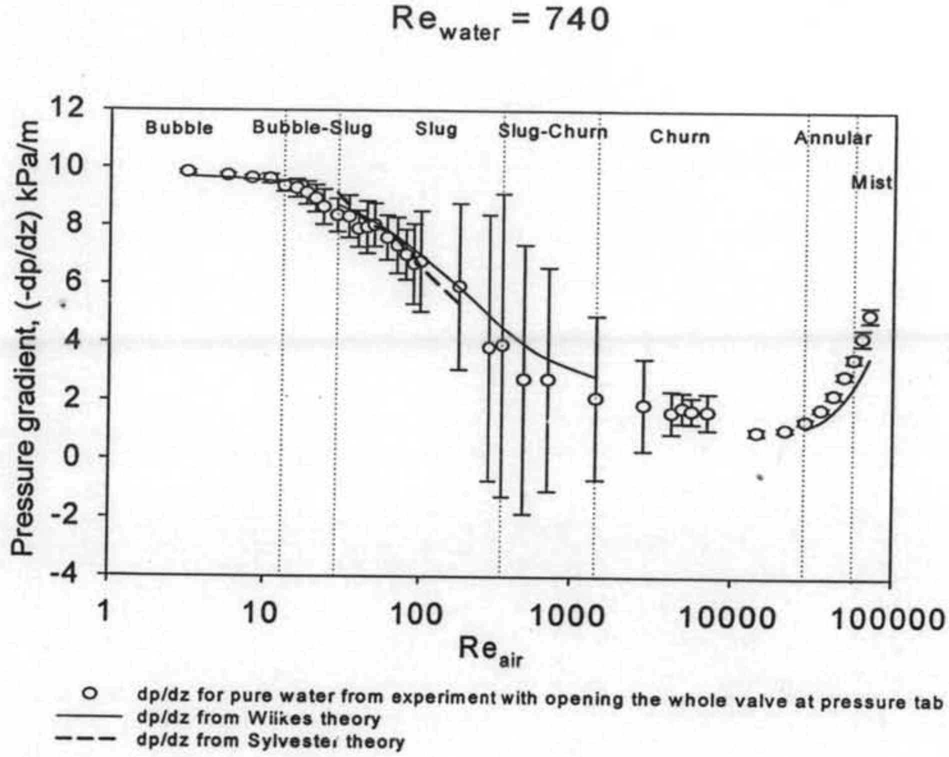

Figure D5 Comparison between Wilkes theory, Sylvester theory and experimental pressure gradient with opening the whole valve at pressure tab vs. air Reynolds number of pure water at $Re_{water} = 740$.

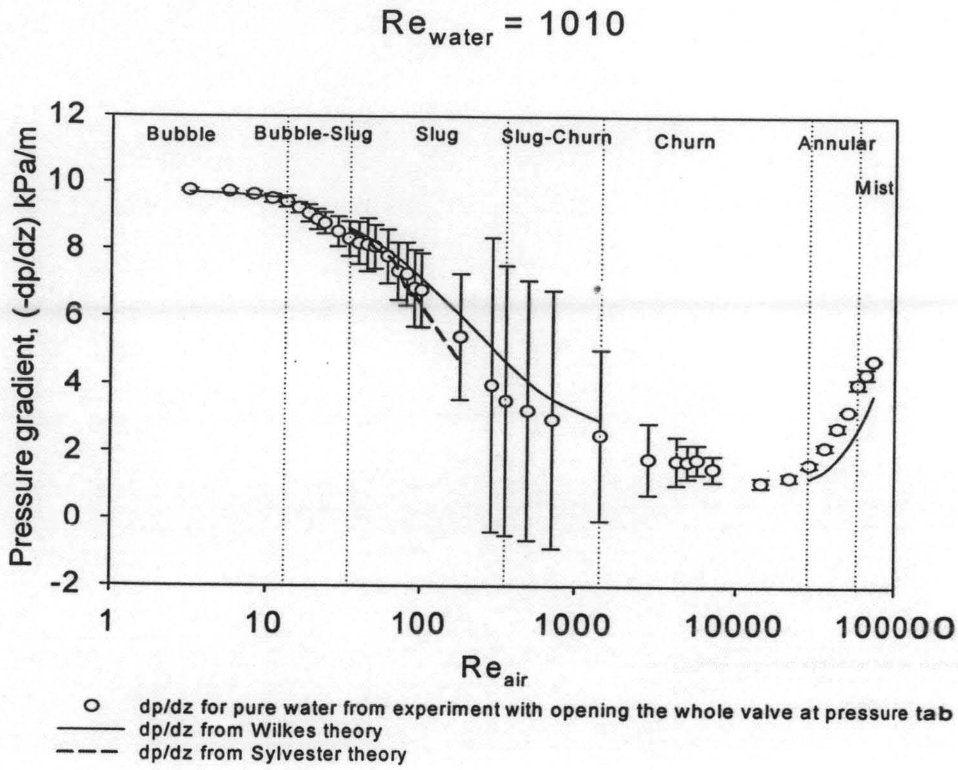

Figure D6 Comparison between Wilkes theory, Sylvester theory and experimental pressure gradient with opening the whole valve at pressure tab vs. air Reynolds number of pure water at $Re_{water} = 1010$.

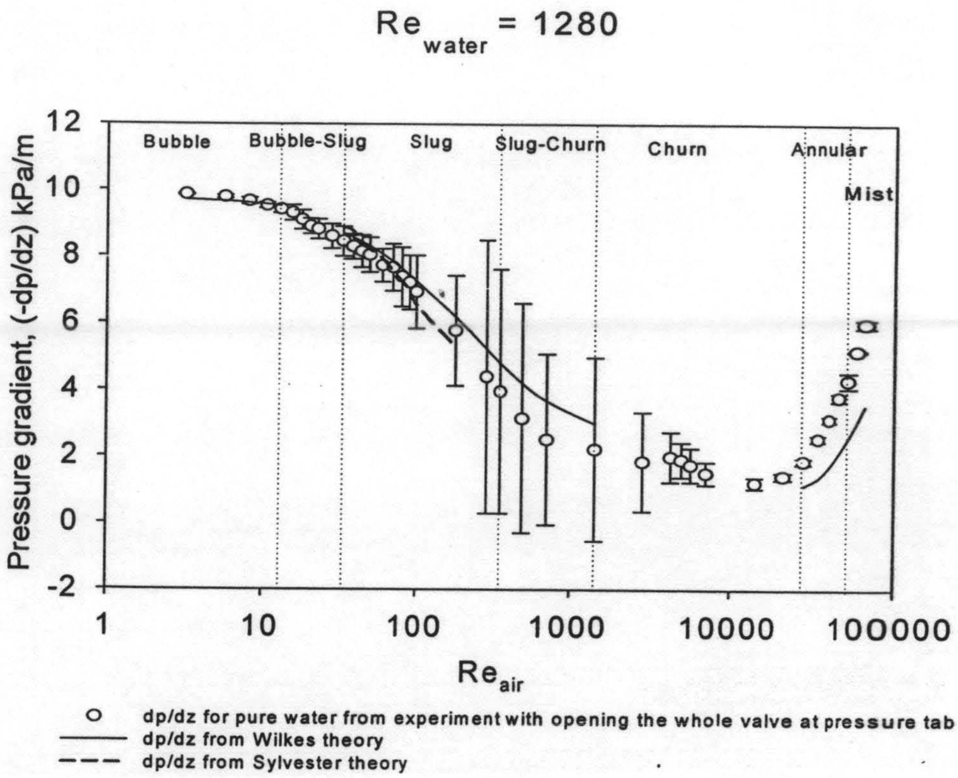

Figure D7 Comparison between Wilkes theory, Sylvester theory and experimental pressure gradient with opening the whole valve at pressure tab vs. air Reynolds number of pure water at $Re_{water} = 1280$.

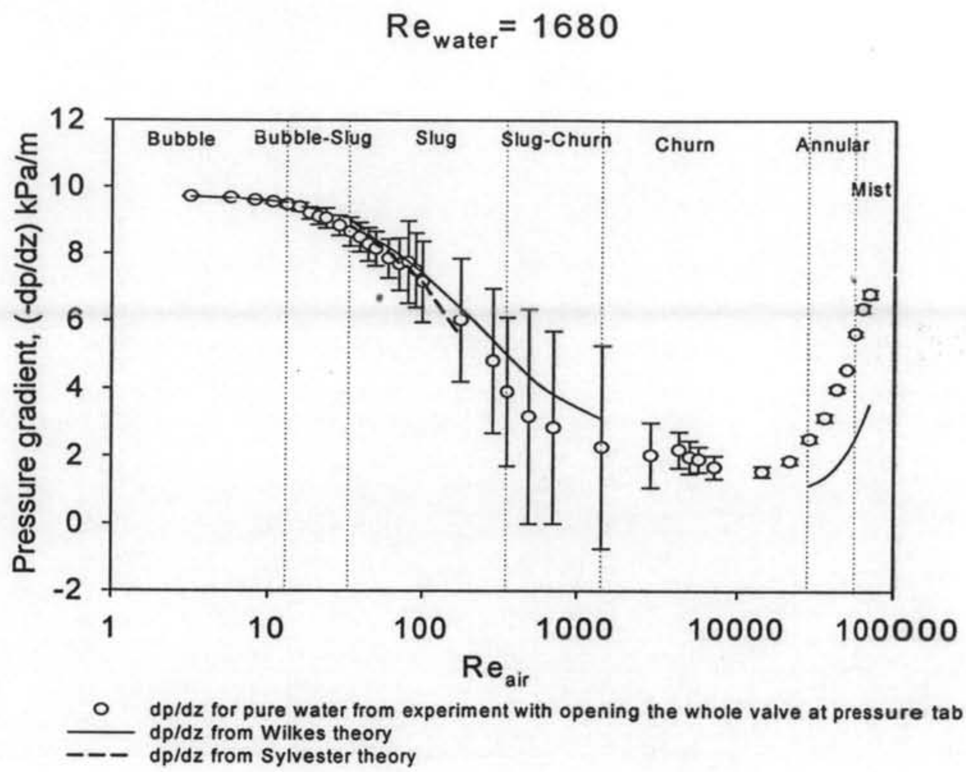

Figure D8 Comparison between Wilkes theory, Sylvester theory and experimental pressure gradient with opening the whole valve at pressure tab vs. air Reynolds number of pure water at $Re_{water} = 1680$.

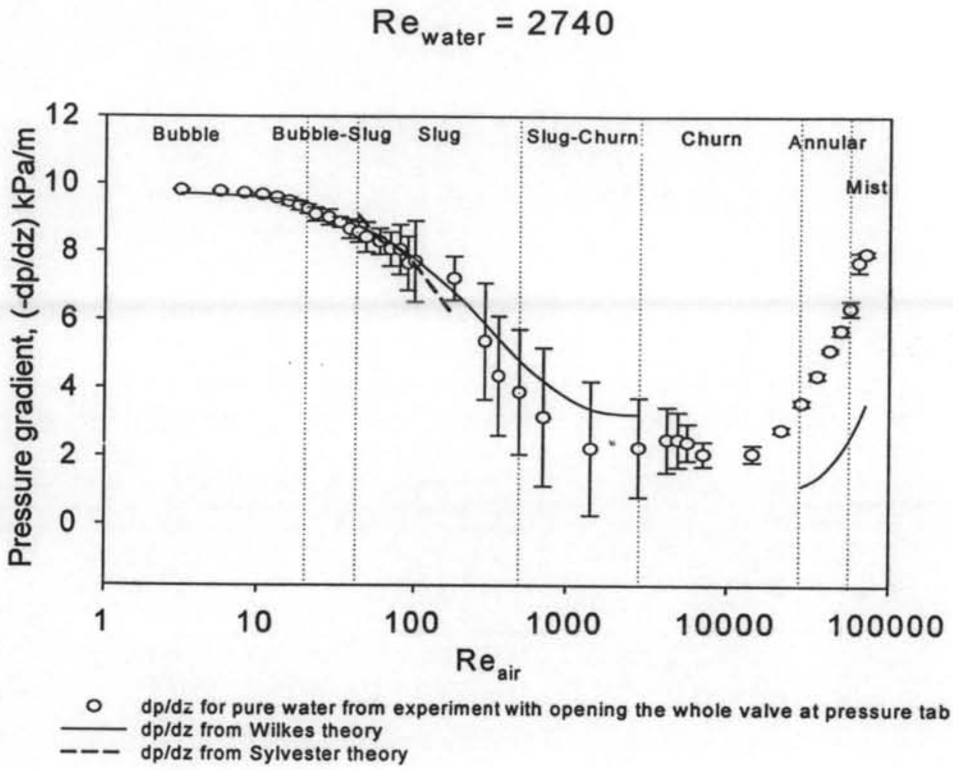

Figure D9 Comparison between Wilkes theory, Sylvester theory and experimental pressure gradient with opening the whole valve at pressure tab vs. air Reynolds number of pure water at $Re_{water} = 2740$.

Table D2 Comparison between Wilkes theory, Sylvester theory and experimental pressure gradient by nearly closing valve at pressure tab for pure water

Physical properties of air and water used in experiment:

density of water, ρ_{water} = 994.7 kg/m^3; viscosity of water, $\mu_{water} = 8.51 \times 10^{-4}$ Pa.s

density of air, ρ_{air} = 1.18 kg/m^3; viscosity of air, $\mu_{air} = 1.85 \times 10^{-5}$ Pa.s

temperature, T = 31 °C (± 1 °C); inner pipe diameter, D = 0.019 m; cross-sectional area of pipe, A = 0.00028 m^2

pressure taps difference = 0.4 m

Water				Air				Flow regime	(dp/dz) from experiment		$(dp/dz)_{tp}$ from Wilkes theory (kPa/m)	$(dp/dz)_{tp}$ from Sylvester theory (kPa/m)
Q_{water} (ml/min)	Sup. water velocity j_{water} (m/s)	Q_{water} (m^3/sec)	Re_{water}	Q_{air} (L/min)	Sup. Air velocity j_{air} (m/s)	Q_{air} (m^3/sec)	Re_{air}		maximum (kPa/m)	minimum (kPa/m)		
0	0	0	0	0.0444	0.0026	7.41E-07	3.17	bubble	9.6848	9.6116	9.6552	-
0	0	0	0	0.0792	0.0047	1.32E-06	5.64	bubble	9.6360	9.5141	9.5741	-
0	0	0	0	0.1139	0.0067	1.90E-06	8.12	bubble	9.5628	9.3677	9.4944	-
0	0	0	0	0.253	0.0149	4.21E-06	18.02	slug	8.9871	8.8603	8.9030	9.2423
0	0	0	0	0.287	0.0169	4.79E-06	20.49	slug	8.9432	8.5968	8.7991	9.0610
0	0	0	0	0.322	0.0189	5.37E-06	22.95	slug	8.7139	8.4358	8.6988	8.4159
0	0	0	0	0.394	0.0232	6.57E-06	28.08	slug	8.5383	8.3089	8.4983	8.2979
0	0	0	0	0.466	0.0274	7.76E-06	33.21	slug	8.5041	8.0211	8.3090	7.9737
0	0	0	0	0.538	0.0316	8.96E-06	38.33	slug	8.2260	7.7430	8.1298	7.7036
0	0	0	0	0.610	0.0359	1.02E-05	43.46	slug	8.2553	7.4795	7.9599	7.5283
0	0	0	0	0.682	0.0401	1.14E-05	48.59	slug	7.9918	7.2502	7.7988	7.4562

0	0	0	0	0.826	0.0486	1.38E-05	58.85	slug	7.7479	6.8160	7.4999	7.2589
0	0	0	0	0.970	0.0570	1.62E-05	69.10	slug	7.6454	6.4891	7.2287	7.0037
0	0	0	0	1.113	0.0655	1.86E-05	79.36	slug	7.3429	6.1329	6.9815	6.3575
0	0	0	0	1.257	0.0739	2.10E-05	89.62	slug	7.0404	5.8841	6.7552	5.9319
0	0	0	0	1.401	0.0824	2.34E-05	99.87	slug	6.7086	5.7133	6.5489	5.7481
364	0.0214	6.07E-06	477	0.0444	0.0026	7.41E-07	3.17	bubble	9.7336	9.6360	9.6638	-
364	0.0214	6.07E-06	477	0.0792	0.0047	1.32E-06	5.64	bubble	9.7092	9.5628	9.5892	-
364	0.0214	6.07E-06	477	0.1139	0.0067	1.90E-06	8.12	bubble	9.6604	9.4897	9.5158	-
364	0.0214	6.07E-06	477	0.1486	0.0087	2.48E-06	10.59	bubble	9.5628	9.5141	9.4435	-
364	0.0214	6.07E-06	477	0.1833	0.0108	3.06E-06	13.06	bubble	9.5628	9.4409	9.3723	-
364	0.0214	6.07E-06	477	0.394	0.0232	6.57E-06	28.08	slug	8.6456	8.3577	8.6586	8.9542
364	0.0214	6.07E-06	477	0.466	0.0274	7.76E-06	33.21	slug	8.5627	8.2504	8.4886	8.6935
364	0.0214	6.07E-06	477	0.538	0.0316	8.96E-06	38.33	slug	8.4456	8.1431	8.3266	8.2501
364	0.0214	6.07E-06	477	0.610	0.0359	1.02E-05	43.46	slug	8.3236	7.9186	8.1721	8.0251
364	0.0214	6.07E-06	477	0.682	0.0401	1.14E-05	48.59	slug	8.1723	7.6844	8.0246	7.9974
364	0.0214	6.07E-06	477	0.826	0.0486	1.38E-05	58.85	slug	7.9479	7.3575	7.7488	7.3496
364	0.0214	6.07E-06	477	0.970	0.0570	1.62E-05	69.10	slug	7.4649	6.7574	7.4958	7.0033
364	0.0214	6.07E-06	477	1.113	0.0655	1.86E-05	79.36	slug	7.3380	6.7818	7.2629	6.6129
364	0.0214	6.07E-06	477	1.257	0.0739	2.10E-05	89.62	slug	7.0990	6.4208	7.0478	6.2431
364	0.0214	6.07E-06	477	1.401	0.0824	2.34E-05	99.87	slug	6.9526	6.2207	6.8522	5.9590
364	0.0214	6.07E-06	477	2.481	0.1459	4.13E-05	177	slug	5.7328	4.8839	5.7309	4.7667
364	0.0214	6.07E-06	477	4.000	0.2353	6.67E-05	285	slug	4.5131	3.3665	4.7898	-
364	0.0214	6.07E-06	477	5.000	0.2941	8.33E-05	356	slug-churn	3.9764	2.6835	4.3819	-
364	0.0214	6.07E-06	477	7.000	0.4117	1.17E-04	499	slug-churn	3.2689	1.8052	3.8311	-
364	0.0214	6.07E-06	477	10.000	0.5881	1.67E-04	713	slug-churn	2.5371	1.3173	3.3513	-
364	0.0214	6.07E-06	477	20.000	1.1763	3.33E-04	1425	slug-churn	2.1956	0.8538	2.7731	-
364	0.0214	6.07E-06	477	200	11.76	3.33E-03	14255	annular	0.9173	0.6001	2.7115	-
364	0.0214	6.07E-06	477	300	17.64	5.00E-03	21382	annular	0.8977	0.6782	1.4290	-

364	0.0214	6.07E-06	477	400	23.53	6.67E-03	28510	annular	1.1173	0.9416	1.0322	-
364	0.0214	6.07E-06	477	500	29.41	8.33E-03	35637	annular	1.4003	1.2393	1.2693	-
364	0.0214	6.07E-06	477	600	35.29	1.00E-02	42765	annular	2.0345	1.7808	1.5992	-
364	0.0214	6.07E-06	477	700	41.17	1.17E-02	49892	annular	2.4395	2.1907	1.9787	-
364	0.0214	6.07E-06	477	800	47.05	1.33E-02	57020	mist	2.9664	2.6688	2.3979	-
364	0.0214	6.07E-06	477	900	52.93	1.50E-02	64147	mist	3.5861	3.2055	2.8527	-
364	0.0214	6.07E-06	477	1000	58.81	1.67E-02	71275	mist	4.3277	3.9813	3.3406	-
771	0.0453	1.28E-05	1010	0.0444	0.0026	7.41E-07	3.17	bubble	9.8068	9.7092	9.6719	-
771	0.0453	1.28E-05	1010	0.0792	0.0047	1.32E-06	5.64	bubble	9.7824	9.6604	9.6034	-
771	0.0453	1.28E-05	1010	0.1139	0.0067	1.90E-06	8.12	bubble	9.7092	9.5628	9.5360	-
771	0.0453	1.28E-05	1010	0.1486	0.0087	2.48E-06	10.59	bubble	9.6360	9.3921	9.4694	-
771	0.0453	1.28E-05	1010	0.1833	0.0108	3.06E-06	13.06	bubble	9.5141	9.4653	9.4038	-
771	0.0453	1.28E-05	1010	0.466	0.0274	7.76E-06	33.21	slug	8.9042	8.5627	8.6437	8.5918
771	0.0453	1.28E-05	1010	0.538	0.0316	8.96E-06	38.33	slug	8.7968	8.1821	8.4976	8.4114
771	0.0453	1.28E-05	1010	0.610	0.0359	1.02E-05	43.46	slug	8.5919	7.9772	8.3575	8.3038
771	0.0453	1.28E-05	1010	0.682	0.0401	1.14E-05	48.59	slug	8.4651	7.6405	8.2230	8.0130
771	0.0453	1.28E-05	1010	0.826	0.0486	1.38E-05	58.85	slug	8.3626	7.5137	7.9696	7.7945
771	0.0453	1.28E-05	1010	0.970	0.0570	1.62E-05	69.10	slug	8.1333	7.4063	7.7350	7.3877
771	0.0453	1.28E-05	1010	1.113	0.0655	1.86E-05	79.36	slug	8.0504	6.9575	7.5171	6.7677
771	0.0453	1.28E-05	1010	1.257	0.0739	2.10E-05	89.62	slug	7.5625	6.6110	7.3143	6.6113
771	0.0453	1.28E-05	1010	1.401	0.0824	2.34E-05	99.87	slug	7.3331	6.3915	7.1315	6.3247
771	0.0453	1.28E-05	1010	2.481	0.1459	4.13E-05	177	slug	6.2451	5.3181	6.0416	4.6587
771	0.0453	1.28E-05	1010	4.000	0.2353	6.67E-05	285	slug	4.8058	3.4885	5.0912	-
771	0.0453	1.28E-05	1010	5.000	0.2941	8.33E-05	356	slug-churn	4.5375	2.9274	4.6686	-
771	0.0453	1.28E-05	1010	7.000	0.4117	1.17E-04	499	slug-churn	3.6836	2.2443	4.0869	-
771	0.0453	1.28E-05	1010	10.000	0.5881	1.67E-04	713	slug-churn	3.2689	1.3905	3.5690	-
771	0.0453	1.28E-05	1010	20.000	1.1763	3.33E-04	1425	slug-churn	2.4395	1.3661	2.9224	-
771	0.0453	1.28E-05	1010	200	11.76	3.33E-03	14255	annular	1.2539	0.9612	2.7329	-

771	0.0453	1.28E-05	1010	300	17.64	5.00E-03	21382	annular	1.3759	1.1563	1.5438	-
771	0.0453	1.28E-05	1010	400	23.53	6.67E-03	28510	annular	1.7369	1.5662	1.2484	-
771	0.0453	1.28E-05	1010	500	29.41	8.33E-03	35637	annular	2.2687	2.0736	1.4876	-
771	0.0453	1.28E-05	1010	600	35.29	1.00E-02	42765	annular	2.8640	2.6395	1.8383	-
771	0.0453	1.28E-05	1010	700	41.17	1.17E-02	49892	annular	3.2689	3.1957	2.2455	-
771	0.0453	1.28E-05	1010	800	47.05	1.33E-02	57020	mist	4.1862	3.9032	2.6960	-
771	0.0453	1.28E-05	1010	900	52.93	1.50E-02	64147	mist	4.5131	4.1959	3.1842	-
771	0.0453	1.28E-05	1010	1000	58.81	1.67E-02	71275	mist	4.7814	4.7082	3.7071	-
1278	0.0752	2.13E-05	1676	0.0444	0.0026	7.41E-07	3.17	bubble	9.7336	9.6848	9.6803	-
1278	0.0752	2.13E-05	1676	0.0792	0.0047	1.32E-06	5.64	bubble	9.7092	9.6360	9.6182	-
1278	0.0752	2.13E-05	1676	0.1139	0.0067	1.90E-06	8.12	bubble	9.6360	9.5628	9.5569	-
1278	0.0752	2.13E-05	1676	0.1486	0.0087	2.48E-06	10.59	bubble	9.6116	9.4897	9.4964	-
1278	0.0752	2.13E-05	1676	0.1833	0.0108	3.06E-06	13.06	bubble	9.5385	9.3921	9.4367	-
1278	0.0752	2.13E-05	1676	0.466	0.0274	7.76E-06	33.21	slug	9.0993	8.8798	8.7925	9.0154
1278	0.0752	2.13E-05	1676	0.538	0.0316	8.96E-06	38.33	slug	8.9530	8.7334	8.6625	8.8159
1278	0.0752	2.13E-05	1676	0.610	0.0359	1.02E-05	43.46	slug	8.6212	8.4553	8.5372	8.6196
1278	0.0752	2.13E-05	1676	0.682	0.0401	1.14E-05	48.59	slug	8.5431	8.2845	8.4163	8.2804
1278	0.0752	2.13E-05	1676	0.826	0.0486	1.38E-05	58.85	slug	8.4065	8.1528	8.1867	8.0360
1278	0.0752	2.13E-05	1676	0.970	0.0570	1.62E-05	69.10	slug	8.2260	7.9381	7.9722	7.7176
1278	0.0752	2.13E-05	1676	1.113	0.0655	1.86E-05	79.36	slug	8.0601	7.8064	7.7713	7.6027
1278	0.0752	2.13E-05	1676	1.257	0.0739	2.10E-05	89.62	slug	7.9528	7.5722	7.5828	7.3298
1278	0.0752	2.13E-05	1676	1.401	0.0824	2.34E-05	99.87	slug	7.7235	7.3819	7.4168	7.1566
1278	0.0752	2.13E-05	1676	2.481	0.1459	4.13E-05	177	slug	6.8794	5.9036	6.3721	5.5304
1278	0.0752	2.13E-05	1676	4.000	0.2353	6.67E-05	285	slug	5.3913	4.2935	5.4238	-
1278	0.0752	2.13E-05	1676	5.000	0.2941	8.33E-05	356	slug-churn	4.6838	3.5861	4.9902	-
1278	0.0752	2.13E-05	1676	7.000	0.4117	1.17E-04	499	slug-churn	3.7812	2.7078	4.3808	-
1278	0.0752	2.13E-05	1676	10.000	0.5881	1.67E-04	713	slug-churn	3.6349	1.8052	3.8246	-
1278	0.0752	2.13E-05	1676	20.000	1.1763	3.33E-04	1425	slug-churn	2.6591	1.8296	3.1036	-

1278	0.0752	2.13E-05	1676	200	11.76	3.33E-03	14255	annular	1.7125	1.4003	2.7222	-
1278	0.0752	2.13E-05	1676	300	17.64	5.00E-03	21382	annular	1.9662	1.7711	1.4904	-
1278	0.0752	2.13E-05	1676	400	23.53	6.67E-03	28510	annular	2.6200	2.4200	1.1531	-
1278	0.0752	2.13E-05	1676	500	29.41	8.33E-03	35637	annular	3.2689	3.0396	1.3903	-
1278	0.0752	2.13E-05	1676	600	35.29	1.00E-02	42765	annular	4.0837	3.9130	1.7318	-
1278	0.0752	2.13E-05	1676	700	41.17	1.17E-02	49892	annular	4.5375	4.6204	2.1268	-
1278	0.0752	2.13E-05	1676	800	47.05	1.33E-02	57020	mist	5.7133	5.5718	2.5636	-
1278	0.0752	2.13E-05	1676	900	52.93	1.50E-02	64147	mist	6.4988	6.2695	3.0372	-
1278	0.0752	2.13E-05	1676	1000	58.81	1.67E-02	71275	mist	6.9428	6.6940	3.5447	-
2091	0.1230	3.49E-05	2742	0.0444	0.0026	7.41E-07	3.17	bubble	9.8312	9.7824	9.6909	-
2091	0.1230	3.49E-05	2742	0.0792	0.0047	1.32E-06	5.64	bubble	9.8068	9.7336	9.6369	-
2091	0.1230	3.49E-05	2742	0.1139	0.0067	1.90E-06	8.12	bubble	9.7580	9.6848	9.5834	-
2091	0.1230	3.49E-05	2742	0.1486	0.0087	2.48E-06	10.59	bubble	9.7092	9.6360	9.5306	-
2091	0.1230	3.49E-05	2742	0.1833	0.0108	3.06E-06	13.06	bubble	9.6360	9.5385	9.4783	-
2091	0.1230	3.49E-05	2742	0.2180	0.0128	3.63E-06	15.54	bubble	9.5872	9.5385	9.4266	-
2091	0.1230	3.49E-05	2742	0.2528	0.0149	4.21E-06	18.02	bubble	9.5628	9.5141	9.3754	-
2091	0.1230	3.49E-05	2742	0.2875	0.0169	4.79E-06	20.49	bubble	9.5385	9.5141	9.3248	-
2091	0.1230	3.49E-05	2742	0.610	0.0359	1.02E-05	43.46	slug	8.9822	8.7578	8.7472	9.0851
2091	0.1230	3.49E-05	2742	0.682	0.0401	1.14E-05	48.59	slug	8.8408	8.5383	8.6433	8.8111
2091	0.1230	3.49E-05	2742	0.826	0.0486	1.38E-05	58.85	slug	8.7090	8.3626	8.4443	8.3380
2091	0.1230	3.49E-05	2742	0.970	0.0570	1.62E-05	69.10	slug	8.5870	8.1284	8.2562	8.1473
2091	0.1230	3.49E-05	2742	1.113	0.0655	1.86E-05	79.36	slug	8.3333	7.9430	8.0784	8.0350
2091	0.1230	3.49E-05	2742	1.257	0.0739	2.10E-05	89.62	slug	8.2211	7.7332	7.9098	7.7947
2091	0.1230	3.49E-05	2742	1.401	0.0824	2.34E-05	99.87	slug	8.0894	7.5088	7.7713	7.6051
2091	0.1230	3.49E-05	2742	2.481	0.1459	4.13E-05	177	slug	7.1477	6.2110	6.8018	6.0864
2091	0.1230	3.49E-05	2742	4.000	0.2353	6.67E-05	285	slug	5.7328	4.8790	5.8754	-
2091	0.1230	3.49E-05	2742	5.000	0.2941	8.33E-05	356	slug	5.1230	4.1472	5.4360	-
2091	0.1230	3.49E-05	2742	7.000	0.4117	1.17E-04	499	slug-churn	4.6351	3.2787	4.8005	-
2091	0.1230	3.49E-05	2742	10.000	0.5881	1.67E-04	713	slug-churn	3.9520	2.5127	4.2002	-

2091	0.1230	3.49E-05	2742	20.000	1.1763	3.33E-04	1425	slug-churn	3.2445	2.1224	3.3817	-
2091	0.1230	3.49E-05	2742	40.000	2.3525	6.67E-04	2851	slug-churn	3.2933	2.1468	3.2202	-
2091	0.1230	3.49E-05	2742	200	11.76	3.33E-03	14255	annular	2.3419	1.8589	2.7222	-
2091	0.1230	3.49E-05	2742	300	17.64	5.00E-03	21382	annular	2.8786	2.7078	1.4904	-
2091	0.1230	3.49E-05	2742	400	23.53	6.67E-03	28510	annular	3.6739	3.4982	1.1531	-
2091	0.1230	3.49E-05	2742	500	29.41	8.33E-03	35637	annular	4.4838	4.2886	1.3903	-
2091	0.1230	3.49E-05	2742	600	35.29	1.00E-02	42765	annular	5.1864	5.0839	1.7318	-
2091	0.1230	3.49E-05	2742	700	41.17	1.17E-02	49892	annular	5.8548	5.5816	2.1268	-
2091	0.1230	3.49E-05	2742	800	47.05	1.33E-02	57020	mist	6.5818	6.1475	2.5636	-
2091	0.1230	3.49E-05	2742	900	52.93	1.50E-02	64147	mist	8.0016	7.4307	3.0372	-
2091	0.1230	3.49E-05	2742	1000	58.81	1.67E-02	71275	mist	8.0650	7.9333	3.5447	-

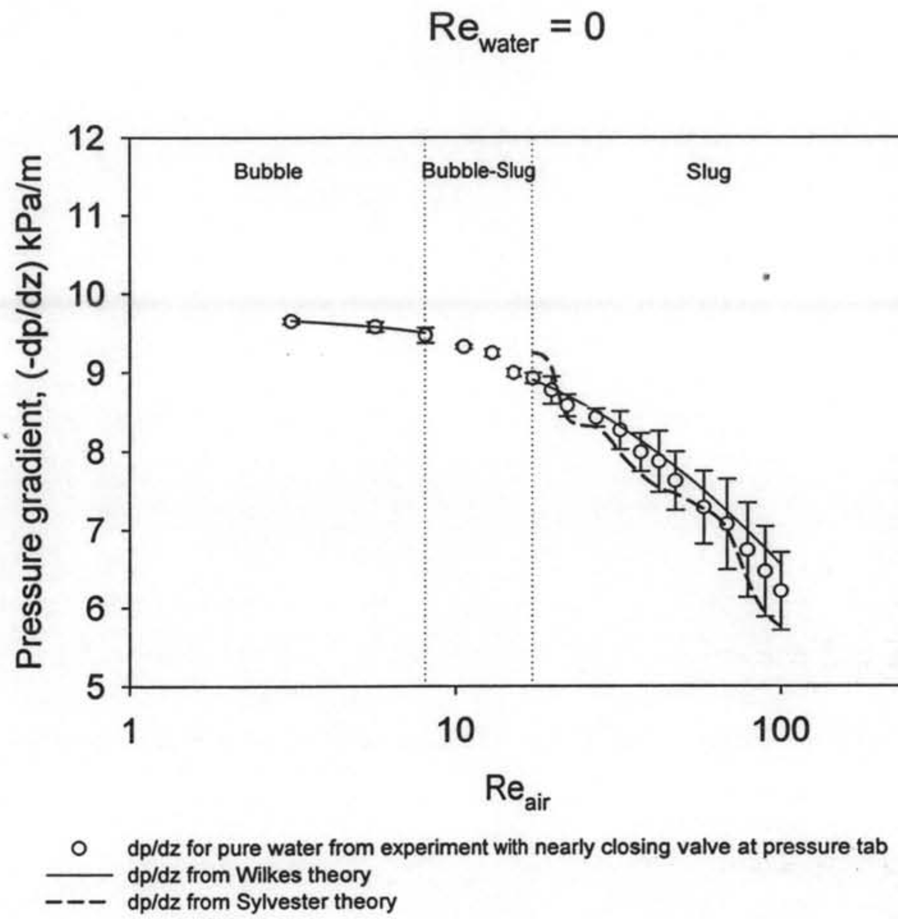

Figure D10 Comparison between Wilkes theory, Sylvester theory and experimental pressure gradient with nearly closing valve at pressure tab vs. air Reynolds number of pure water at $Re_{water} = 0$.

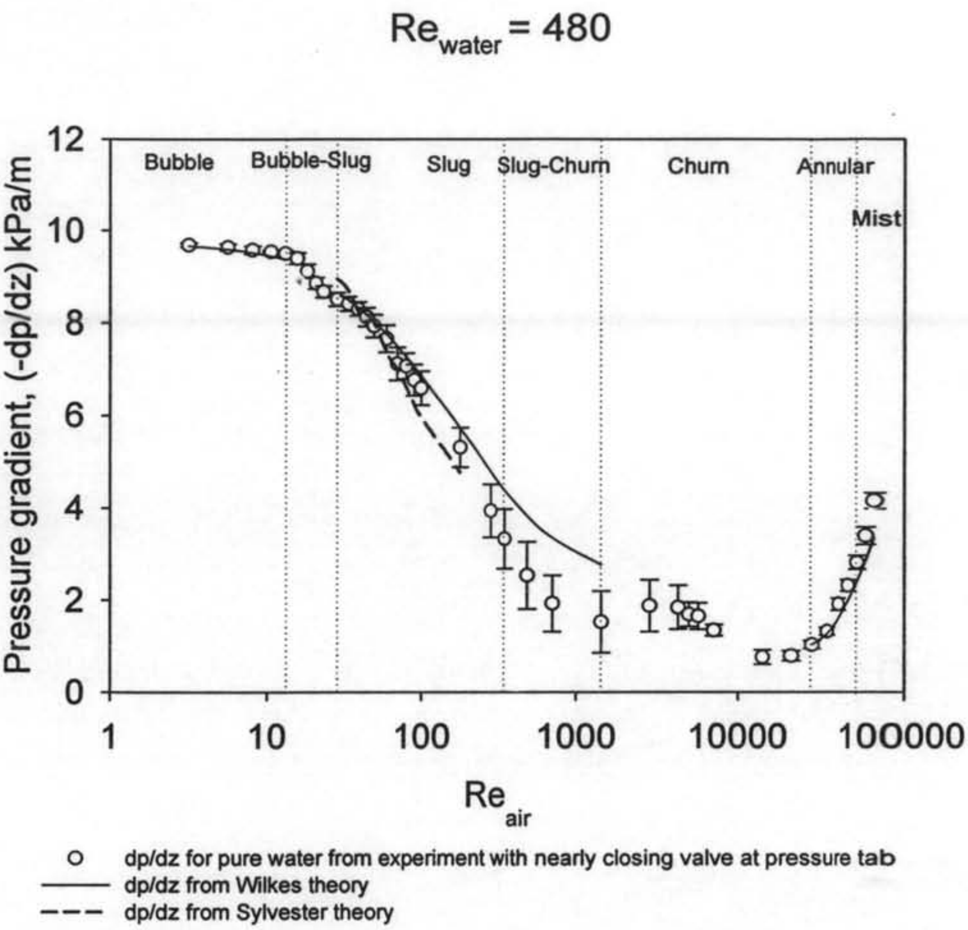

Figure D11 Comparison between Wilkes theory, Sylvester theory and experimental pressure gradient with nearly closing valve at pressure tab vs. air Reynolds number of pure water at $Re_{water} = 480$.

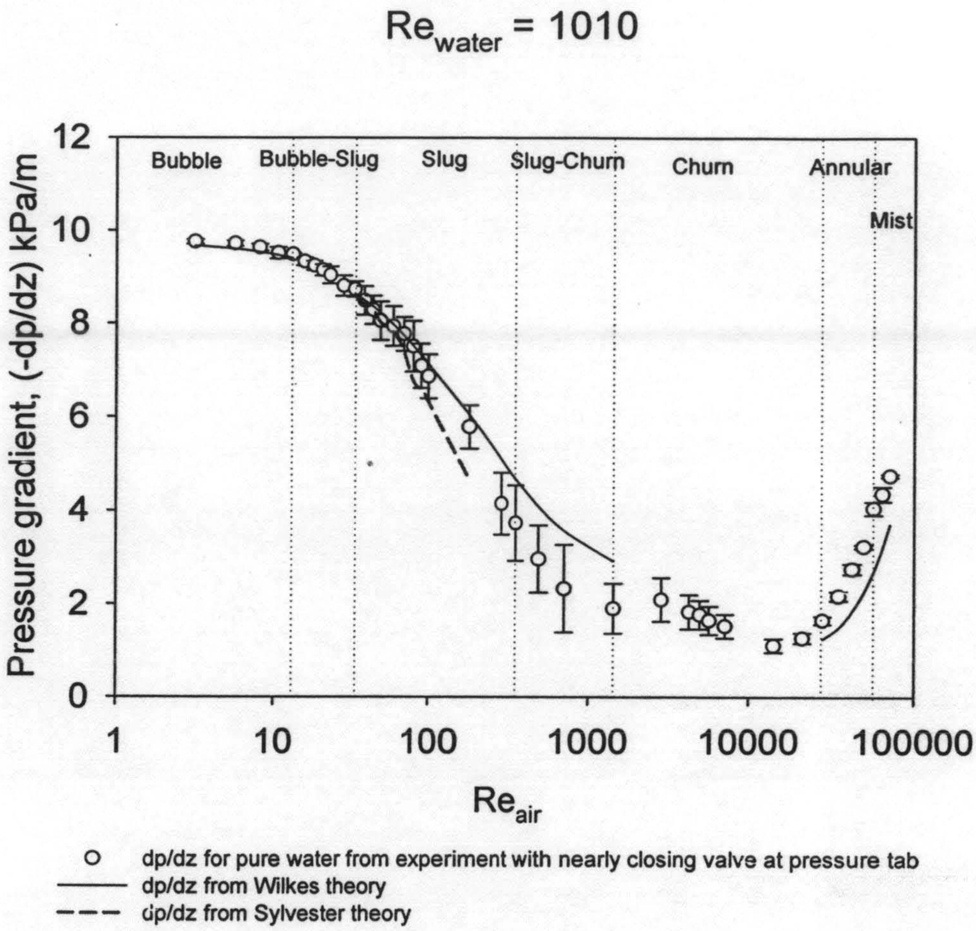

Figure D12 Comparison between Wilkes theory, Sylvester theory and experimental pressure gradient with nearly closing valve at pressure tab vs. air Reynolds number of pure water at Re_{water} = 1010.

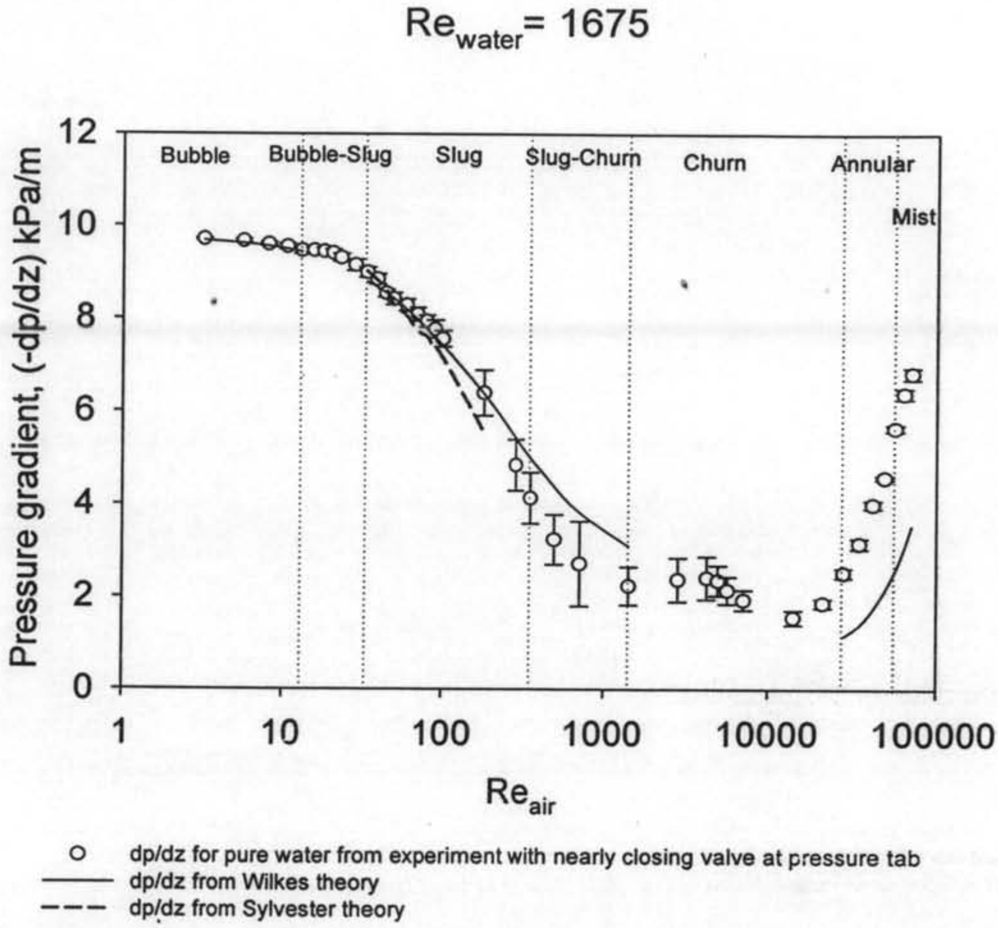

Figure D13 Comparison between Wilkes theory, Sylvester theory and experimental pressure gradient with nearly closing valve at pressure tab vs. air Reynolds number of pure water at Re_{water} = 1675.

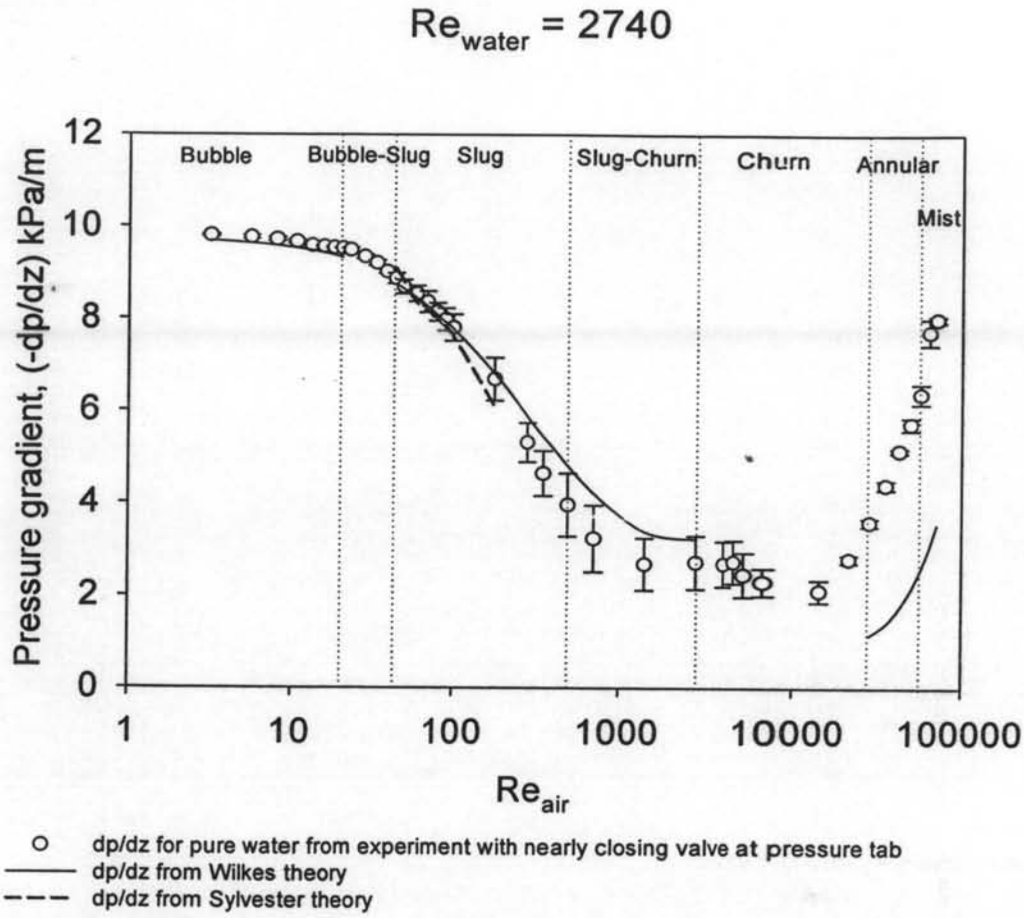

Figure D14 Comparison between Wilkes theory, Sylvester theory and experimental pressure gradient with nearly closing valve at pressure tab vs. air Reynolds number of pure water at $Re_{water} = 2740$.

Table D3 Comparison between Wilkes theory, Sylvester theory and experimental pressure gradient by opening the whole valve at pressure tab for SDS solution (1 CMC)

Physical properties of air and SDS solution (1 CMC) used in experiment:

density of SDS solution, $\rho_{SDS\ solution}$ = 994..97 kg/m^3; viscosity of SDS solution, $\mu_{SDS\ solution} = 1.01 \times 10^{-3}$ Pa.s

density of air, ρ_{air} = 1.18 kg/m^3; viscosity of air, $\mu_{air} = 1.85 \times 10^{-5}$ Pa.s

temperature, T = 31 °C (± 1 °C); inner pipe diameter, D = 0.019 m; cross-sectional area of pipe, A = 0.00028 m^2

pressure taps difference = 0.4 m

SDS solution (1 CMC)				Air				Flow regime	(dp/dz) from experiment		$(dp/dz)_{tp}$ from Wilkes theory (kPa/m)	$(dp/dz)_{tp}$ from Sylvester theory (kPa/m)
$Q_{solution}$ (ml/min)	Sup. solution velocity $j_{solution}$ (m/s)	$Q_{solution}$ (m^3/sec)	$Re_{solution}$	Q_{air} (L/min)	Sup. Air velocity j_{air} (m/s)	Q_{air} (m^3/sec)	Re_{air}		maximum (kPa/m)	minimum (kPa/m)		
0	0	0	0	0.0444	0.0026	7.41E-07	3.17	bubble	9.7444	9.7119	9.6583	-
0	0	0	0	0.0792	0.0047	1.32E-06	5.64	bubble	9.5736	9.5410	9.5798	-
0	0	0	0	0.1833	0.0108	3.06E-06	13.06	slug	9.2580	9.1457	9.1201	10.075
0	0	0	0	0.218	0.0128	3.63E-06	15.54	slug	9.1213	9.0237	9.0099	9.9141
0	0	0	0	0.253	0.0149	4.21E-06	18.02	slug	9.0335	8.8334	8.9030	9.8908
0	0	0	0	0.287	0.0169	4.79E-06	20.49	slug	8.8578	8.6187	8.7991	9.2501
0	0	0	0	0.322	0.0189	5.37E-06	22.95	slug	8.5113	8.3844	8.6988	8.9122
0	0	0	0	0.394	0.0232	6.57E-06	28.08	slug	8.2380	8.0037	8.4984	8.6176
0	0	0	0	0.466	0.0274	7.76E-06	33.21	slug	7.9305	7.6133	8.3090	8.3293
0	0	0	0	0.538	0.0316	8.96E-06	38.33	slug	7.7402	7.4767	8.1299	7.9778
0	0	0	0	0.610	0.0359	1.02E-05	43.46	slug	7.5059	7.1009	7.9601	7.6524
0	0	0	0	0.682	0.0401	1.14E-05	48.59	slug	7.4181	6.7349	7.7990	7.3732

0	0	0	0	0.826	0.0486	1.38E-05	58.85	slug	7.0358	6.14[illegible]1	7.5002	6.8317
0	0	0	0	0.970	0.0570	1.62E-05	69.10	slug	6.7105	5.2870	7.2291	6.5940
0	0	0	0	1.113	0.0655	1.86E-05	79.36	slug	6.5478	4.6363	6.9819	6.2708
0	0	0	0	1.257	0.0739	2.10E-05	89.62	slug	6.2631	3.4976	6.7557	6.1525
350	0.0206	5.83E-06	385	0.0444	0.0026	7.41E-07	3.17	bubble	9.6875	9.6142	9.6661	-
350	0.0206	5.83E-06	385	0.0792	0.0047	1.32E-06	5.64	bubble	9.5898	9.5166	9.5935	-
350	0.0206	5.83E-06	385	0.1139	0.0067	1.90E-06	8.12	bubble	9.4272	9.3133	9.5220	-
350	0.0206	5.83E-06	385	0.1486	0.0087	2.48E-06	10.59	bubble	9.3946	9.2726	9.4515	-
350	0.0206	5.83E-06	385	0.287	0.0169	4.79E-06	20.49	slug	8.9310	8.7114	8.9221	10.0495
350	0.0206	5.83E-06	385	0.322	0.0189	5.37E-06	22.95	slug	8.7846	8.3063	8.8327	9.2291
350	0.0206	5.83E-06	385	0.394	0.0232	6.57E-06	28.08	slug	8.7602	8.4918	8.6533	8.9661
350	0.0206	5.83E-06	385	0.466	0.0274	7.76E-06	33.21	slug	8.3454	7.9061	8.4827	8.9478
350	0.0206	5.83E-06	385	0.538	0.0316	8.96E-06	38.33	slug	8.1648	7.7109	8.3202	8.5775
350	0.0206	5.83E-06	385	0.610	0.0359	1.02E-05	43.46	slug	8.1257	7.4913	8.1652	7.9939
350	0.0206	5.83E-06	385	0.682	0.0401	1.14E-05	48.59	slug	7.9549	7.2473	8.0172	7.7675
350	0.0206	5.83E-06	385	0.826	0.0486	1.38E-05	58.85	slug	7.7109	6.9789	7.7406	7.4830
350	0.0206	5.83E-06	385	0.970	0.0570	1.62E-05	69.10	slug	7.6377	6.5396	7.4870	7.0597
350	0.0206	5.83E-06	385	1.113	0.0655	1.86E-05	79.36	slug	7.2229	6.0516	7.2536	6.6839
350	0.0206	5.83E-06	385	1.257	0.0739	2.10E-05	90	slug	7.1253	5.7100	7.0382	6.3602
350	0.0206	5.83E-06	385	1.401	0.0824	2.34E-05	100	slug	6.9545	5.8076	6.8415	6.0772
350	0.0206	5.83E-06	385	2.481	0.1459	4.13E-05	177	slug	6.2468	2.5866	5.7196	4.9731
350	0.0206	5.83E-06	385	4.000	0.2353	6.67E-05	285	slug	4.2703	1.7569	4.7797	-
350	0.0206	5.83E-06	385	5.000	0.2941	8.33E-05	356	slug-churn	2.6354	1.3665	4.3729	-
350	0.0206	5.83E-06	385	7.000	0.4117	1.17E-04	499	slug-churn	2.5622	0.8541	3.8243	-
350	0.0206	5.83E-06	385	10	0.59	1.67E-04	713	slug-churn	1.9521	0.5368	3.3475	-
350	0.0206	5.83E-06	385	20	1.18	3.33E-04	1425	slug-churn	0.8785	0.4148	2.7784	-
350	0.0206	5.83E-06	385	200	11.76	3.33E-03	14255	annular	1.0574	0.9517	2.7059	-
350	0.0206	5.83E-06	385	300	17.64	5.00E-03	21382	annular	0.9435	0.8459	1.3937	-

350	0.0206	5.83E-06	385	400	23.53	6.67E-03	28510	annular	0.9679	0.9761	0.9546	-
350	0.0206	5.83E-06	385	500	29.41	8.33E-03	35637	annular	1.3014	1.3421	1.1931	-
350	0.0206	5.83E-06	385	600	35.29	1.00E-02	42765	annular	1.8139	1.8301	1.5155	-
350	0.0206	5.83E-06	385	700	41.17	1.17E-02	49892	annular	2.2938	2.3182	1.8848	-
350	0.0206	5.83E-06	385	800	47.05	1.33E-02	57020	mist	2.6272	2.8713	2.2926	-
350	0.0206	5.83E-06	385	900	52.93	1.50E-02	64147	mist	2.9851	2.9851	2.7351	-
350	0.0206	5.83E-06	385	1000	58.81	1.67E-02	71275	mist	3.4406	3.3837	3.2102	-
453	0.0266	7.55E-06	500	0.0444	0.0026	7.41E-07	3.17	bubble	9.7607	9.7363	9.6682	-
453	0.0266	7.55E-06	500	0.0792	0.0047	1.32E-06	5.64	bubble	9.7363	9.6630	9.5972	-
453	0.0266	7.55E-06	500	0.1139	0.0067	1.90E-06	8.12	bubble	9.4922	9.3214	9.5272	-
453	0.0266	7.55E-06	500	0.149	0.0087	2.48E-06	10.59	bubble	9.5085	9.3214	9.4582	-
453	0.0266	7.55E-06	500	0.287	0.0169	4.79E-06	20.49	slug	9.0774	8.5650	8.9527	9.4157
453	0.0266	7.55E-06	500	0.322	0.0189	5.37E-06	22.95	slug	8.9066	8.2722	8.8662	9.3331
453	0.0266	7.55E-06	500	0.394	0.0232	6.57E-06	28.08	slug	8.9066	8.0769	8.6922	8.9838
453	0.0266	7.55E-06	500	0.466	0.0274	7.76E-06	33.21	slug	8.5162	7.8085	8.5264	8.8964
453	0.0266	7.55E-06	500	0.538	0.0316	8.96E-06	38.33	slug	8.4918	7.6865	8.3683	8.4209
453	0.0266	7.55E-06	500	0.610	0.0359	1.02E-05	43.46	slug	8.1013	7.3937	8.2172	8.0300
453	0.0266	7.55E-06	500	0.682	0.0401	1.14E-05	48.59	slug	8.0769	7.1985	8.0728	7.7036
453	0.0266	7.55E-06	500	0.826	0.0486	1.38E-05	58.85	slug	7.9061	7.1009	7.8022	7.3836
453	0.0266	7.55E-06	500	0.970	0.0570	1.62E-05	69.10	slug	7.3937	6.4908	7.5534	7.4322
453	0.0266	7.55E-06	500	1.113	0.0655	1.86E-05	79	slug	7.5645	5.4416	7.3240	7.0669
453	0.0266	7.55E-06	500	1.257	0.0739	2.10E-05	90	slug	6.7349	5.4172	7.1117	6.6237
453	0.0266	7.55E-06	500	1.401	0.0824	2.34E-05	100	slug	7.4425	5.9296	6.9182	6.3712
453	0.0266	7.55E-06	500	2.481	0.1459	4.13E-05	177	slug	6.4908	3.4650	5.8036	5.6196
453	0.0266	7.55E-06	500	4.000	0.2353	6.67E-05	285	slug	4.7095	0.9761	4.8601	-
453	0.0266	7.55E-06	500	5.000	0.2941	8.33E-05	356	slug-churn	3.2942	0.4392	4.4488	-
453	0.0266	7.55E-06	500	7	0.41	1.17E-04	499	slug-churn	2.8794	0.4880	3.8914	-
453	0.0266	7.55E-06	500	10	0.59	1.67E-04	713	slug-churn	2.3670	0.5612	3.4042	-
453	0.0266	7.55E-06	500	20	1.18	3.33E-04	1425	slug-	1.6593	0.4636	2.8170	-

453	0.0266	7.55E-06	500	200	11.76	3.33E-03	14255	churn annular	1.4478	1.3584	2.7115	-
453	0.0266	7.55E-06	500	300	17.64	5.00E-03	21382	annular	1.2770	1.1143	1.4290	-
453	0.0266	7.55E-06	500	400	23.53	6.67E-03	28510	annular	1.6105	1.3258	1.0322	-
453	0.0266	7.55E-06	500	500	29.41	8.33E-03	35637	annular	1.5617	1.5780	1.2693	-
453	0.0266	7.55E-06	500	600	35.29	1.00E-02	42765	annular	1.9359	2.0172	1.5992	-
453	0.0266	7.55E-06	500	700	41.17	1.17E-02	49892	annular	2.6842	2.6842	1.9787	-
453	0.0266	7.55E-06	500	800	47.05	1.33E-02	57020	mist	3.4162	3.4162	2.3979	-
453	0.0266	7.55E-06	500	900	52.93	1.50E-02	64147	mist	3.7823	3.7823	2.8527	-
453	0.0266	7.55E-06	500	1000	58.81	1.67E-02	71275	mist	4.7095	4.7421	3.3406	-
556	0.0327	9.27E-06	610	0.0444	0.0026	7.41E-07	3.17	bubble	9.7607	9.7607	9.6702	-
556	0.0327	9.27E-06	610	0.0792	0.0047	1.32E-06	5.64	bubble	9.6630	9.6142	9.6007	-
556	0.0327	9.27E-06	610	0.114	0.0067	1.90E-06	8.12	bubble	9.5898	9.4678	9.5321	-
556	0.0327	9.27E-06	610	0.149	0.0087	2.48E-06	10.59	bubble	9.5329	9.3946	9.4645	-
556	0.0327	9.27E-06	610	0.287	0.0169	4.79E-06	20.49	slug	9.1506	8.7846	8.9813	9.9566
556	0.0327	9.27E-06	610	0.322	0.0189	5.37E-06	22.95	slug	8.9066	8.5406	8.8974	9.9361
556	0.0327	9.27E-06	610	0.394	0.0232	6.57E-06	28.08	slug	8.9066	8.3454	8.7285	9.0990
556	0.0327	9.27E-06	610	0.466	0.0274	7.76E-06	33.21	slug	8.6870	8.2478	8.5673	8.9583
556	0.0327	9.27E-06	610	0.538	0.0316	8.96E-06	38.33	slug	8.5650	8.0037	8.4133	8.7830
556	0.0327	9.27E-06	610	0.610	0.0359	1.02E-05	43.46	slug	8.5894	7.7841	8.2660	8.4541
556	0.0327	9.27E-06	610	0.682	0.0401	1.14E-05	48.59	slug	8.3210	7.5889	8.1250	8.2036
556	0.0327	9.27E-06	610	0.826	0.0486	1.38E-05	58.85	slug	7.8329	7.1009	7.8602	7.7861
556	0.0327	9.27E-06	610	0.970	0.0570	1.62E-05	69	slug	7.7597	6.8325	7.6162	7.5768
556	0.0327	9.27E-06	610	1.113	0.0655	1.86E-05	79	slug	7.5645	6.6128	7.3906	7.2699
556	0.0327	9.27E-06	610	1.257	0.0739	2.10E-05	90	slug	7.1009	6.0272	7.1815	6.9836
556	0.0327	9.27E-06	610	1.401	0.0824	2.34E-05	100	slug	7.1741	5.978[illegible]	6.9912	6.457
556	0.0327	9.27E-06	610	2.481	0.1459	4.13E-05	177	slug	6.9301	3.1234	5.8844	5.3624
556	0.0327	9.27E-06	610	4.000	0.2353	6.67E-05	285	slug	5.3684	0.4880	4.9380	-
556	0.0327	9.27E-06	610	5	0.29	8.33E-05	356	slug-churn	4.2947	0.2440	4.5228	-
556	0.0327	9.27E-06	610	7	0.41	1.17E-04	499	slug-churn	3.5870	0.2196	3.9573	-

556	0.0327	9.27E-06	610	10	0.59	1.67E-04	713	slug-churn	1.4885	0.4880	3.4602	-
556	0.0327	9.27E-06	610	20	1.18	3.33E-04	1425	slug-churn	0.9761	0.2440	2.8553	-
556	0.0327	9.27E-06	610	200	11.76	3.33E-03	14255	annular	1.3584	1.2445	2.7169	-
556	0.0327	9.27E-06	610	300	17.64	5.00E-03	21382	annular	1.3584	1.1631	1.4609	-
556	0.0327	9.27E-06	610	400	23.53	6.67E-03	28510	annular	1.5617	1.3177	1.0969	-
556	0.0327	9.27E-06	610	500	29.41	8.33E-03	35637	annular	1.7488	1.5780	1.3338	-
556	0.0327	9.27E-06	610	600	35.29	1.00E-02	42765	annular	2.0741	2.0741	1.6698	-
556	0.0327	9.27E-06	610	700	41.17	1.17E-02	49892	annular	2.7737	2.7086	2.0577	-
556	0.0327	9.27E-06	610	800	47.05	1.33E-02	57020	mist	3.5708	3.5220	2.4863	-
556	0.0327	9.27E-06	610	900	52.93	1.50E-02	64147	mist	3.9124	3.9043	2.9512	-
556	0.0327	9.27E-06	610	1000	58.81	1.67E-02	71275	mist	4.7421	4.5631	3.4497	-
660	0.0388	1.1E-05	725	0.0444	0.0026	7.41E-07	3.17	bubble	9.7607	9.7607	9.6721	-
660	0.0388	1.1E-05	725	0.079	0.0047	1.32E-06	5.64	bubble	9.7119	9.6142	9.6040	-
660	0.0388	1.1E-05	725	0.114	0.0067	1.90E-06	8.12	bubble	9.6142	9.4109	9.5369	-
660	0.0388	1.1E-05	725	0.149	0.0087	2.48E-06	10.59	bubble	9.5166	9.4109	9.4707	-
660	0.0388	1.1E-05	725	0.287	0.0169	4.79E-06	20.49	slug	9.0286	8.6479	9.0080	9.8488
660	0.0388	1.1E-05	725	0.322	0.0189	5.37E-06	22.95	slug	8.9066	8.5162	8.9266	9.4086
660	0.0388	1.1E-05	725	0.394	0.0232	6.57E-06	28.08	slug	8.8578	8.4186	8.7625	8.9787
660	0.0388	1.1E-05	725	0.466	0.0274	7.76E-06	33.21	slug	8.7114	8.2722	8.6057	8.5622
660	0.0388	1.1E-05	725	0.538	0.0316	8.96E-06	38.33	slug	8.4674	7.8817	8.4556	8.3313
660	0.0388	1.1E-05	725	0.610	0.0359	1.02E-05	43.46	slug	8.3454	7.9061	8.3119	8.0748
660	0.0388	1.1E-05	725	0.682	0.0401	1.14E-05	48.59	slug	8.1990	7.5645	8.1741	7.7977
660	0.0388	1.1E-05	725	0.826	0.0486	1.38E-05	59	slug	8.1990	7.2961	7.9149	7.2451
660	0.0388	1.1E-05	725	0.970	0.0570	1.62E-05	69	slug	7.4679	6.9789	7.6755	7.2161
660	0.0388	1.1E-05	725	1.113	0.0655	1.86E-05	79	slug	7.1741	6.6128	7.4538	6.9243
660	0.0388	1.1E-05	725	1.257	0.0739	2.10E-05	90	slug	6.8813	6.0516	7.2477	6.7173
660	0.0388	1.1E-05	725	1.401	0.0824	2.34E-05	100	slug	6.3932	5.5880	7.0607	6.38
660	0.0388	1.1E-05	725	2.481	0.1459	4.13E-05	177	slug	4.7827	3.1478	5.9620	4.9811
660	0.0388	1.1E-05	725	4	0.24	6.67E-05	285	slug	5.4660	0.6344	5.0137	-
660	0.0388	1.1E-05	725	5	0.29	8.33E-05	356	slug-churn	3.8067	0.2196	4.5949	-

660	0.0388	1.1E-05	725	7	0.41	1.17E-04	499	slug-churn	4.0507	0.0488	4.0219	-
660	0.0388	1.1E-05	725	10	0.59	1.67E-04	713	slug-churn	2.6354	0.4148	3.5153	-
660	0.0388	1.1E-05	725	20	1.18	3.33E-04	1425	slug-churn	1.9033	0.3904	2.8934	-
660	0.0388	1.1E-05	725	200	11.76	3.33E-03	14255	annular	1.5861	1.4478	2.7222	-
660	0.0388	1.1E-05	725	300	17.64	5.00E-03	21382	annular	1.4641	1.3584	1.4904	-
660	0.0388	1.1E-05	725	400	23.53	6.67E-03	28510	annular	1.0167	1.4641	1.1531	-
660	0.0388	1.1E-05	725	500	29.41	8.33E-03	35637	annular	2.0741	1.6512	1.3903	-
660	0.0388	1.1E-05	725	600	35.29	1.00E-02	42765	annular	2.4402	2.4402	1.7318	-
660	0.0388	1.1E-05	725	700	41.17	1.17E-02	49892	annular	2.9851	3.0014	2.1268	-
660	0.0388	1.1E-05	725	800	47.05	1.33E-02	57020	mist	3.5626	3.5382	2.5636	-
660	0.0388	1.1E-05	725	900	52.93	1.50E-02	64147	mist	4.2947	4.2459	3.0372	-
660	0.0388	1.1E-05	725	1000	58.81	1.67E-02	71275	mist	4.9698	5.0105	3.5447	-
970	0.0570	1.62E-05	1065	0.044	0.0026	7.41E-07	3.17	bubble	9.7932	9.7851	9.6774	-
970	0.0570	1.62E-05	1065	0.079	0.0047	1.32E-06	5.64	bubble	9.7119	9.6386	9.6133	-
970	0.0570	1.62E-05	1065	0.114	0.0067	1.90E-06	8.12	bubble	9.7119	9.5166	9.5500	-
970	0.0570	1.62E-05	1065	0.149	0.0087	2.48E-06	10.59	bubble	9.5166	9.2726	9.4876	-
970	0.0570	1.62E-05	1065	0.322	0.0189	5.37E-06	22.95	slug	9.0042	8.5894	9.0038	9.8392
970	0.0570	1.62E-05	1065	0.394	0.0232	6.57E-06	28.08	slug	8.8090	8.4430	8.8527	9.4739
970	0.0570	1.62E-05	1065	0.466	0.0274	7.76E-06	33.21	slug	8.7602	8.1501	8.7076	9.0675
970	0.0570	1.62E-05	1065	0.538	0.0316	8.96E-06	38.33	slug	8.6626	8.1013	8.5683	8.8661
970	0.0570	1.62E-05	1065	0.610	0.0359	1.02E-05	43.46	slug	8.5406	7.8085	8.4344	8.4557
970	0.0570	1.62E-05	1065	0.682	0.0401	1.14E-05	49	slug	8.3210	7.6865	8.3056	8.2759
970	0.0570	1.62E-05	1065	0.826	0.0486	1.38E-05	59	slug	8.1745	7.3449	8.0621	8.0611
970	0.0570	1.62E-05	1065	0.970	0.0570	1.62E-05	69	slug	7.9793	6.9545	7.8357	7.6673
970	0.0570	1.62E-05	1065	1.113	0.0655	1.86E-05	79	slug	7.6621	6.8325	7.6248	7.3191
970	0.0570	1.62E-05	1065	1.257	0.0739	2.10E-05	90	slug	7.4913	6.4176	7.4278	7.1233
970	0.0570	1.62E-05	1065	1.401	0.0824	2.34E-05	100	slug	7.6133	6.0760	7.2508	6.5488
970	0.0570	1.62E-05	1065	2.481	0.15	4.13E-05	177	slug	7.1253	4.4899	6.1786	5.4199
970	0.0570	1.62E-05	1065	4	0.24	6.67E-05	285	slug	5.1731	1.1713	5.2283	-
970	0.0570	1.62E-05	1065	5	0.29	8.33E-05	356	slug-	4.8315	0.9273	4.8010	-

								churn				
970	0.0570	1.62E-05	1065	7	0.41	1.17E-04	499	slug-churn	2.8306	0.8541	4.2083	-
970	0.0570	1.62E-05	1065	10	0.59	1.67E-04	713	slug-churn	2.8550	0.3416	3.6760	-
970	0.0570	1.62E-05	1065	20	1.18	3.33E-04	1425	slug-churn	2.4646	0.5612	3.0060	-
970	0.0570	1.62E-05	1065	200	11.76	3.33E-03	14255	annular	1.6837	1.6186	2.7329	-
970	0.0570	1.62E-05	1065	300	17.64	5.00E-03	21382	annular	1.5292	1.4316	1.5438	-
970	0.0570	1.62E-05	1065	400	23.53	6.67E-03	28510	annular	2.2368	1.6913	1.2484	-
970	0.0570	1.62E-05	1065	500	29.41	8.33E-03	35637	annular	2.1311	2.0741	1.4876	-
970	0.0570	1.62E-05	1065	600	35.29	1.00E-02	42765	annular	2.6760	2.5459	1.8383	-
970	0.0570	1.62E-05	1065	700	41.17	1.17E-02	49892	annular	3.2536	3.2780	2.2455	-
970	0.0570	1.62E-05	1065	800	47.05	1.33E-02	57020	mist	4.0263	4.0263	2.6960	-
970	0.0570	1.62E-05	1065	900	52.93	1.50E-02	64147	mist	4.3923	4.3923	3.1842	-
970	0.0570	1.62E-05	1065	1000	58.81	1.67E-02	71275	mist	5.3928	5.3684	3.7071	-
1175	0.0691	2E-05	1290	0.044	0.0026	7.41E-07	3.17	bubble	9.7607	9.7607	9.6805	-
1175	0.0691	1.96E-05	1290	0.079	0.0047	1.32E-06	5.64	bubble	9.6630	9.6793	9.6188	-
1175	0.0691	1.96E-05	1290	0.114	0.0067	1.90E-06	8.12	bubble	9.4678	9.4678	9.5579	-
1175	0.0691	1.96E-05	1290	0.149	0.0087	2.48E-06	10.59	bubble	9.3946	9.4109	9.4978	-
1175	0.0691	1.96E-05	1290	0.322	0.0189	5.37E-06	22.95	slug	8.8871	8.8383	9.0481	10.339
1175	0.0691	1.96E-05	1290	0.394	0.0232	6.57E-06	28.08	slug	8.6919	8.6431	8.9046	9.5354
1175	0.0691	1.96E-05	1290	0.466	0.0274	7.76E-06	33.21	slug	8.5406	8.4283	8.7665	9.1339
1175	0.0691	1.96E-05	1290	0.538	0.0316	8.96E-06	38.33	slug	8.3942	8.3014	8.6336	8.7835
1175	0.0691	1.96E-05	1290	0.610	0.0359	1.02E-05	43	slug	8.3063	8.1697	8.5055	8.3885
1175	0.0691	1.96E-05	1290	0.682	0.0401	1.14E-05	49	slug	8.2526	8.0233	8.3821	7.9234
1175	0.0691	1.96E-05	1290	0.826	0.0486	1.38E-05	59	slug	7.8817	7.4767	8.1481	7.8398
1175	0.0691	1.96E-05	1290	0.970	0.0570	1.62E-05	69	slug	7.8085	7.2229	7.9298	7.3475
1175	0.0691	1.96E-05	1290	1.113	0.0655	1.86E-05	79	slug	7.6377	6.8569	7.7257	7.0101
1175	0.0691	1.96E-05	1290	1.257	0.0739	2.10E-05	90	slug	7.2717	6.5640	7.5345	6.9345
1175	0.0691	1.96E-05	1290	1.40124	0.08	2.34E-05	100	slug	6.8569	6.4420	7.3643	6.7039
1175	0.0691	1.96E-05	1290	2.48099	0.15	4.13E-05	177	slug	5.9540	1.4153	6.3106	5.7377

1175	0.0691	1.96E-05	1290	4	0.24	6.67E-05	285	slug	3.8067	0.4392	5.3617	-
1175	0.0691	1.96E-05	1290	5	0.29	8.33E-05	356	slug-churn	3.3430	0.4880	4.9303	-
1175	0.0691	1.96E-05	1290	7	0.41	1.17E-04	499	slug-churn	2.9038	0.4636	4.3269	-
1175	0.0691	1.96E-05	1290	10	0.59	1.67E-04	713	slug-churn	3.0258	0.2684	3.7795	-
1175	0.0691	1.96E-05	1290	20	1.18	3.33E-04	1425	slug-churn	2.5622	0.3660	3.0799	-
1175	0.0691	1.96E-05	1290	200	11.76	3.33E-03	14255	annular	1.9928	1.8464	2.7222	-
1175	0.0691	1.96E-05	1290	300	17.64	5.00E-03	21382	annular	1.6268	1.5373	1.4904	-
1175	0.0691	1.96E-05	1290	400	23.53	6.67E-03	28510	annular	1.9196	1.8871	1.1531	-
1175	0.0691	1.96E-05	1290	500	29.41	8.33E-03	35637	annular	2.2531	2.2287	1.3903	-
1175	0.0691	1.96E-05	1290	600	35.29	1.00E-02	42765	annular	2.8143	2.7574	1.7318	-
1175	0.0691	1.96E-05	1290	700	41.17	1.17E-02	49892	annular	3.3024	3.3186	2.1268	-
1175	0.0691	1.96E-05	1290	800	47.05	1.33E-02	57020	mist	3.7823	3.7823	2.5636	-
1175	0.0691	1.96E-05	1290	900	52.93	1.50E-02	64147	mist	4.8722	4.8885	3.0372	-
1175	0.0691	1.96E-05	1290	1000	58.81	1.67E-02	71275	mist	5.5717	5.5961	3.5447	-
1485	0.0873	2.48E-05	1635	0.044	0.0026	7.41E-07	3.17	bubble	9.7607	9.7607	9.6849	-
1485	0.0873	2.48E-05	1635	0.079	0.0047	1.32E-06	5.64	bubble	9.7444	9.7525	9.6265	-
1485	0.0873	2.48E-05	1635	0.114	0.0067	1.90E-06	8.12	bubble	9.6630	9.6386	9.5688	-
1485	0.0873	2.48E-05	1635	0.149	0.0087	2.48E-06	10.59	bubble	9.5654	9.5329	9.5117	-
1485	0.0873	2.48E-05	1635	0.322	0.0189	5.37E-06	22.95	slug	9.1555	9.0823	9.1061	10.343
1485	0.0873	2.48E-05	1635	0.394	0.0232	6.57E-06	28.08	slug	9.0091	8.8871	8.9726	9.7544
1485	0.0873	2.48E-05	1635	0.466	0.0274	7.76E-06	33.21	slug	8.9700	8.7797	8.8438	9.2811
1485	0.0873	2.48E-05	1635	0.538	0.0316	8.96E-06	38	slug	8.7992	8.5991	8.7195	9.0547
1485	0.0873	2.48E-05	1635	0.610	0.0359	1.02E-05	43	slug	8.7211	8.4771	8.5994	8.3605
1485	0.0873	2.48E-05	1635	0.682	0.0401	1.14E-05	49	slug	8.5308	8.3014	8.4833	8.2823
1485	0.0873	2.48E-05	1635	0.826	0.0486	1.38E-05	59	slug	8.2526	7.9110	8.2623	8.0247
1485	0.0873	2.48E-05	1635	0.970	0.0570	1.62E-05	69	slug	8.0721	7.7841	8.0553	7.708
1485	0.0873	2.48E-05	1635	1.113	0.0655	1.86E-05	79	slug	7.8573	7.4425	7.8607	7.3981
1485	0.0873	2.48E-05	1635	1.25734	0.07	2.10E-05	90	slug	7.6280	7.1497	7.6777	7.1991

1485	0.0873	2.48E-05	1635	1.40124	0.08	2.34E-05	100	slug	7.4425	6.8325	7.5179	6.6724
1485	0.0873	2.48E-05	1635	2.48099	0.15	4.13E-05	177	slug	6.8325	4.6363	6.4928	5.7267
1485	0.0873	2.48E-05	1635	4	0.24	6.67E-05	285	slug	5.6124	2.8794	5.5492	-
1485	0.0873	2.48E-05	1635	5	0.29	8.33E-05	356	slug-churn	4.8315	2.3914	5.1136	-
1485	0.0873	2.48E-05	1635	7	0.41	1.17E-04	499	slug-churn	4.8071	1.3421	4.4969	-
1485	0.0873	2.48E-05	1635	10	0.59	1.67E-04	713	slug-churn	3.6114	0.9517	3.9295	-
1485	0.0873	2.48E-05	1635	20	1.18	3.33E-04	1425	slug-churn	2.3914	0.6344	3.1889	-
1485	0.0873	2.48E-05	1635	200	11.76	3.33E-03	14255	annular	2.3751	2.1717	2.7222	-
1485	0.0873	2.48E-05	1635	300	17.64	5.00E-03	21382	annular	2.3832	2.3263	1.4904	-
1485	0.0873	2.48E-05	1635	400	23.53	6.67E-03	28510	annular	2.4076	2.4564	1.1531	-
1485	0.0873	2.48E-05	1635	500	29.41	8.33E-03	35637	annular	2.8306	2.7655	1.3903	-
1485	0.0873	2.48E-05	1635	600	35.29	1.00E-02	42765	annular	3.3024	3.3430	1.7318	-
1485	0.0873	2.48E-05	1635	700	41.17	1.17E-02	49892	annular	3.8555	3.8717	2.1268	-
1485	0.0873	2.48E-05	1635	800	47.05	1.33E-02	57020	mist	4.8722	4.5143	2.5636	-
1485	0.0873	2.48E-05	1635	900	52.93	1.50E-02	64147	mist	5.1975	5.1243	3.0372	-
1485	0.0873	2.48E-05	1635	1000	58.81	1.67E-02	71275	mist	5.8564	5.8564	3.5447	-
2310	0.1359	3.85E-05	2540	0.044	0.0026	7.41E-07	3.17	bubble	9.7607	9.7607	9.6944	-
2310	0.1359	3.85E-05	2540	0.079	0.0047	1.32E-06	5.64	bubble	9.6875	9.6630	9.6433	-
2310	0.1359	3.85E-05	2540	0.114	0.0067	1.90E-06	8.12	bubble	9.5898	9.5898	9.5927	-
2310	0.1359	3.85E-05	2540	0.149	0.0087	2.48E-06	10.59	bubble	9.5166	9.5085	9.5426	-
2310	0.1359	3.85E-05	2540	0.183	0.0108	3.06E-06	13.06	bubble	9.4678	9.4597	9.4931	-
2310	0.1359	3.85E-05	2540	0.218	0.0128	3.63E-06	15.54	bubble	9.3409	9.3214	9.4441	-
2310	0.1359	3.85E-05	2540	0.466	0.0274	7.76E-06	33.21	slug	8.7846	8.7846	9.0035	10.2399
2310	0.1359	3.85E-05	2540	0.538	0.0316	8.96E-06	38	slug	8.8188	8.7895	8.8975	9.9142
2310	0.1359	3.85E-05	2540	0.610	0.0359	1.02E-05	43	slug	8.6528	8.5747	8.7945	9.3448
2310	0.1359	3.85E-05	2540	0.682	0.0401	1.14E-05	49	slug	8.5113	8.4478	8.6944	8.9142
2310	0.1359	3.85E-05	2540	0.826	0.0486	1.38E-05	59	slug	8.3893	8.3014	8.5024	8.7477
2310	0.1359	3.85E-05	2540	0.970	0.0570	1.62E-05	69	slug	8.2722	8.0428	8.3206	8.6627

2310	0.1359	3.85E-05	2540	1.113	0.0655	1.86E-05	79	slug	8.0233	7.8378	8.1483	8.1483
2310	0.1359	3.85E-05	2540	1.257	0.0739	2.10E-05	90	slug	7.7890	7.5889	7.9846	7.8214
2310	0.1359	3.85E-05	2540	1.40124	0.08	2.34E-05	100	slug	7.5791	7.4913	7.8528	7.676
2310	0.1359	3.85E-05	2540	2.48099	0.15	4.13E-05	177	slug	6.5640	5.7344	6.9038	6.3647
2310	0.1359	3.85E-05	2540	4	0.24	6.67E-05	285	slug	5.3196	4.6851	5.9866	-
2310	0.1359	3.85E-05	2540	5	0.29	8.33E-05	356	slug-churn	4.9535	3.2210	5.5480	-
2310	0.1359	3.85E-05	2540	7	0.41	1.17E-04	499	slug-churn	4.3435	1.3421	4.9096	-
2310	0.1359	3.85E-05	2540	10	0.59	1.67E-04	713	slug-churn	3.8067	1.1713	4.3025	-
2310	0.1359	3.85E-05	2540	20	1.18	3.33E-04	1425	slug-churn	3.0258	1.3665	3.4699	-
2310	0.1359	3.85E-05	2540	200	11.76	3.33E-03	14255	annular	3.0014	2.9770	2.7222	-
2310	0.1359	3.85E-05	2540	300	17.64	5.00E-03	21382	annular	3.2780	3.1885	1.4904	-
2310	0.1359	3.85E-05	2540	400	23.53	6.67E-03	28510	annular	3.3918	3.3674	1.1531	-
2310	0.1359	3.85E-05	2540	500	29.41	8.33E-03	35637	annular	3.8880	3.8555	1.3903	-
2310	0.1359	3.85E-05	2540	600	35.29	1.00E-02	42765	annular	4.2947	4.2703	1.7317	-
2310	0.1359	3.85E-05	2540	700	41.17	1.17E-02	49892	annular	5.3684	5.3684	2.1268	-
2310	0.1359	3.85E-05	2540	800	47.05	1.33E-02	57020	mist	5.7832	5.6856	2.5636	-
2310	0.1359	3.85E-05	2540	900	52.93	1.50E-02	64147	mist	6.3444	6.2956	3.0371	-
2310	0.1359	3.85E-05	2540	1000	58.81	1.67E-02	71275	mist	7.1985	7.1009	3.5447	-

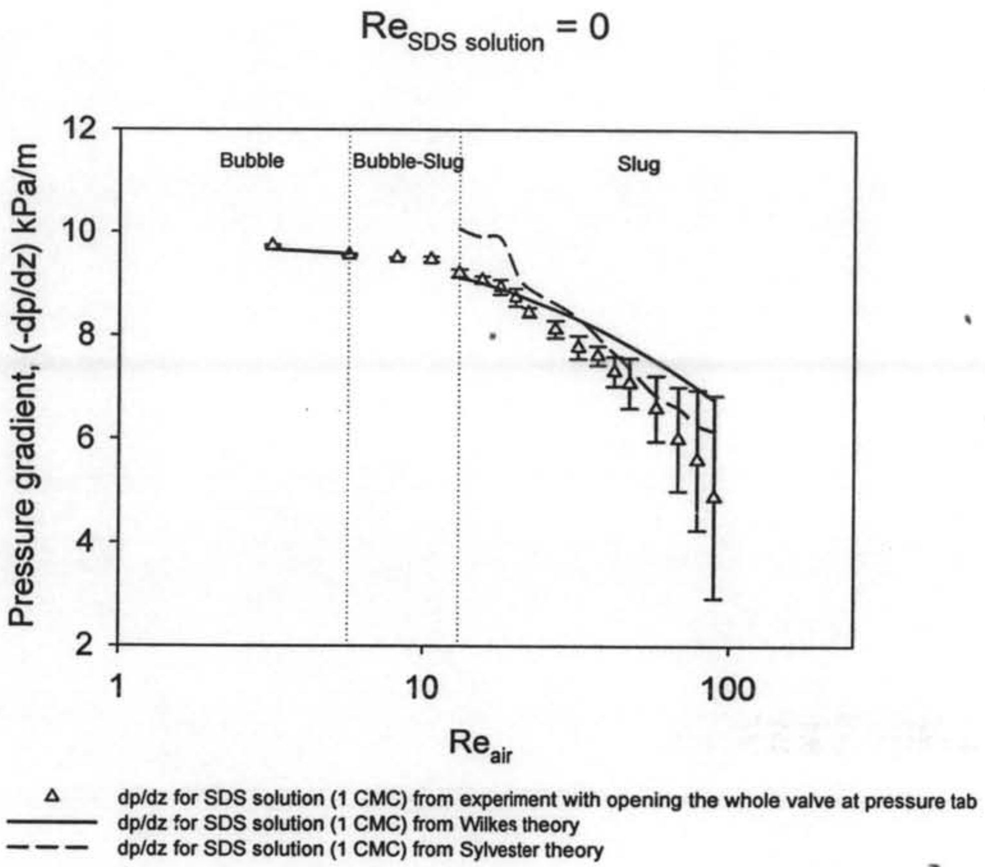

Figure D15 Comparison between Wilkes theory, Sylvester theory and experimental pressure gradient with opening the whole valve at pressure tab vs. air Reynolds number of SDS solution (1 CMC) at $Re_{SDS\ solution} = 0$.

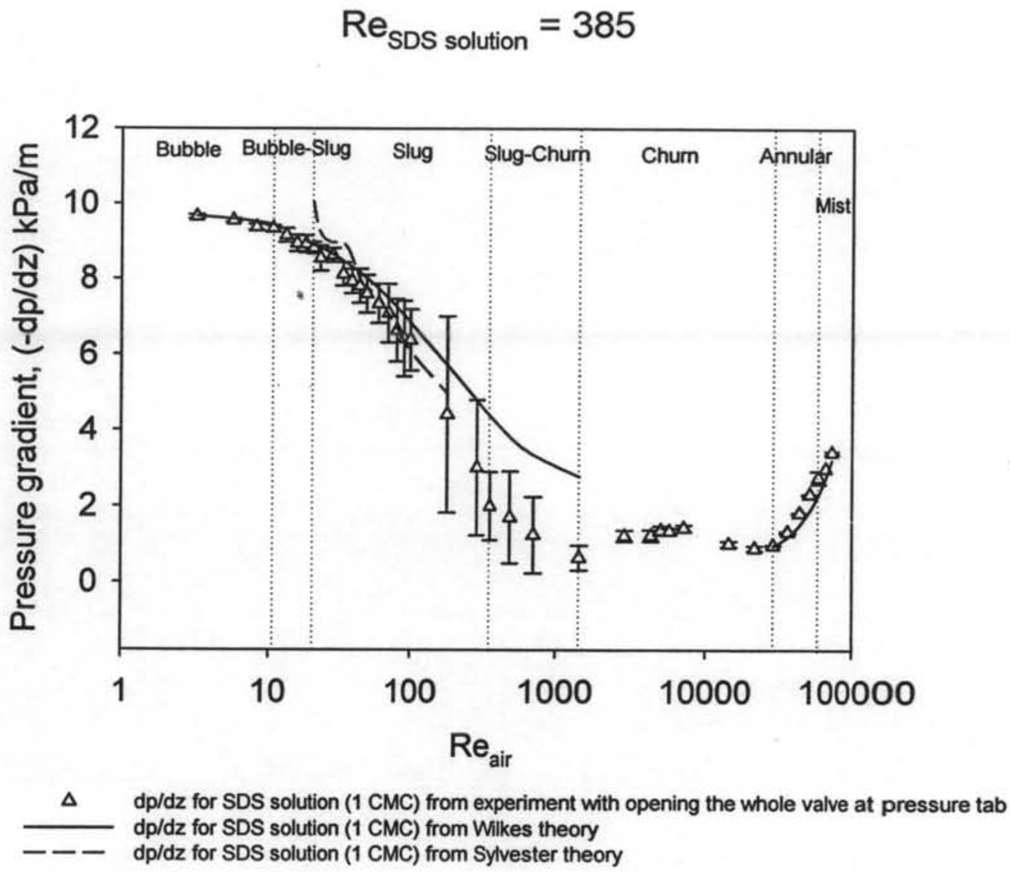

Figure D16 Comparison between Wilkes theory, Sylvester theory and experimental pressure gradient with opening the whole valve at pressure tab vs. air Reynolds number of SDS solution (1 CMC) at $Re_{SDS\ solution} = 385$.

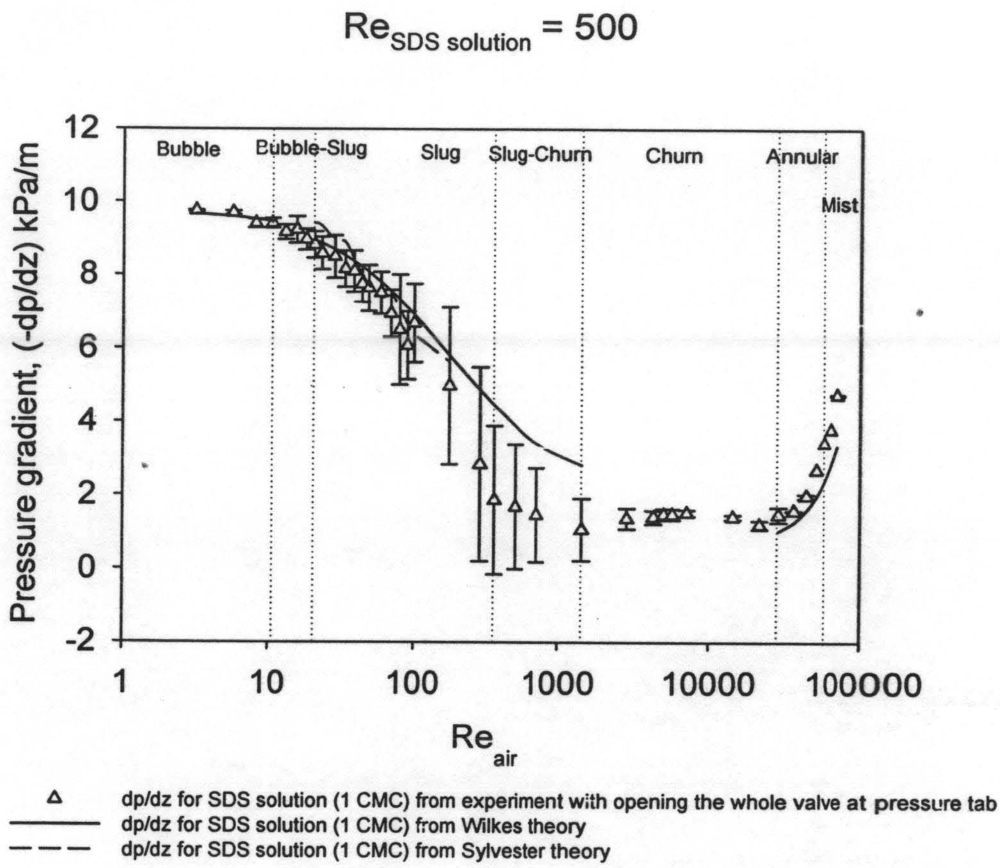

Figure D17 Comparison between Wilkes theory, Sylvester theory and experimental pressure gradient with opening the whole valve at pressure tab vs. air Reynolds number of SDS solution (1 CMC) at $Re_{SDS\ solution} = 500$.

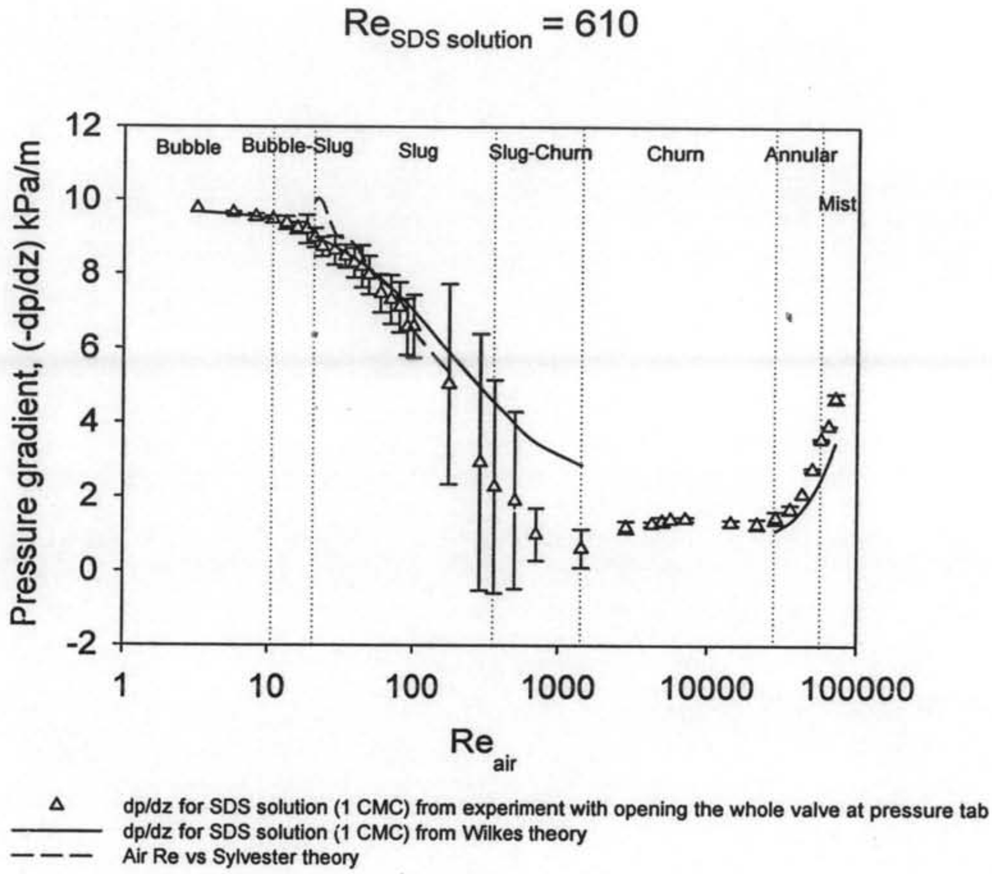

Figure D18 Comparison between Wilkes theory, Sylvester theory and experimental pressure gradient with opening the whole valve at pressure tab vs. air Reynolds number of SDS solution (1 CMC) at $Re_{SDS\ solution} = 610$.

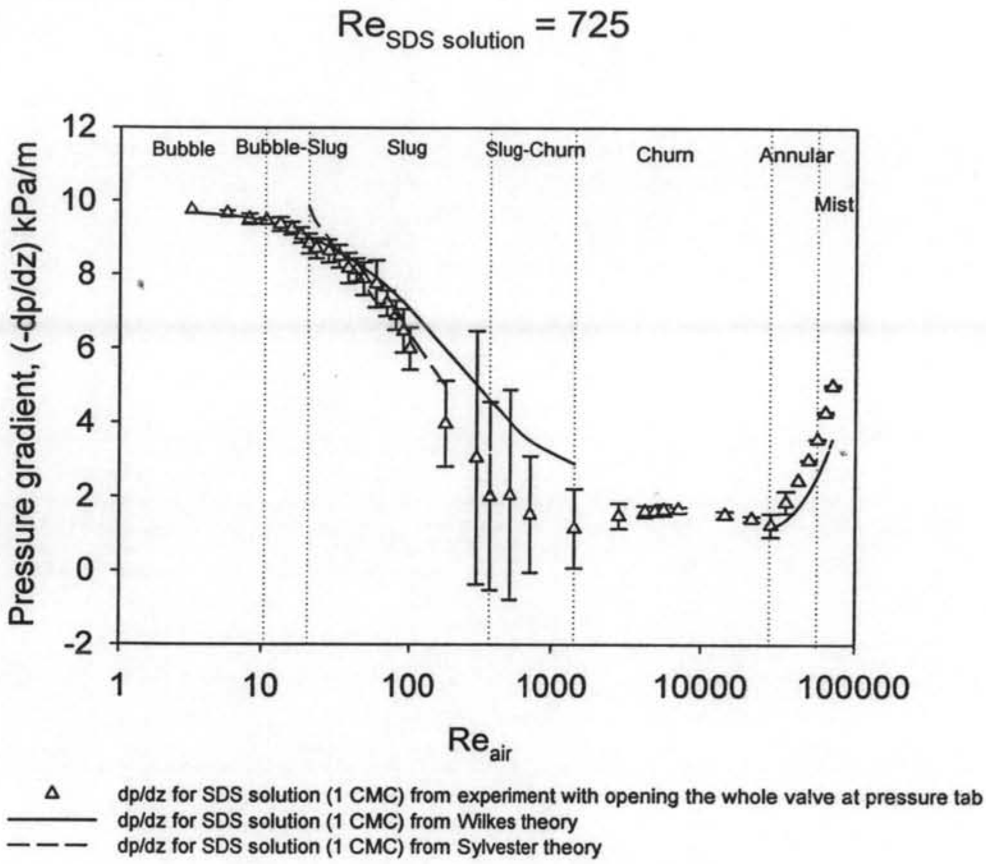

Figure D19 Comparison between Wilkes theory, Sylvester theory and experimental pressure gradient with opening the whole valve at pressure tab vs. air Reynolds number of SDS solution (1 CMC) at $Re_{SDS\ solution} = 725$.

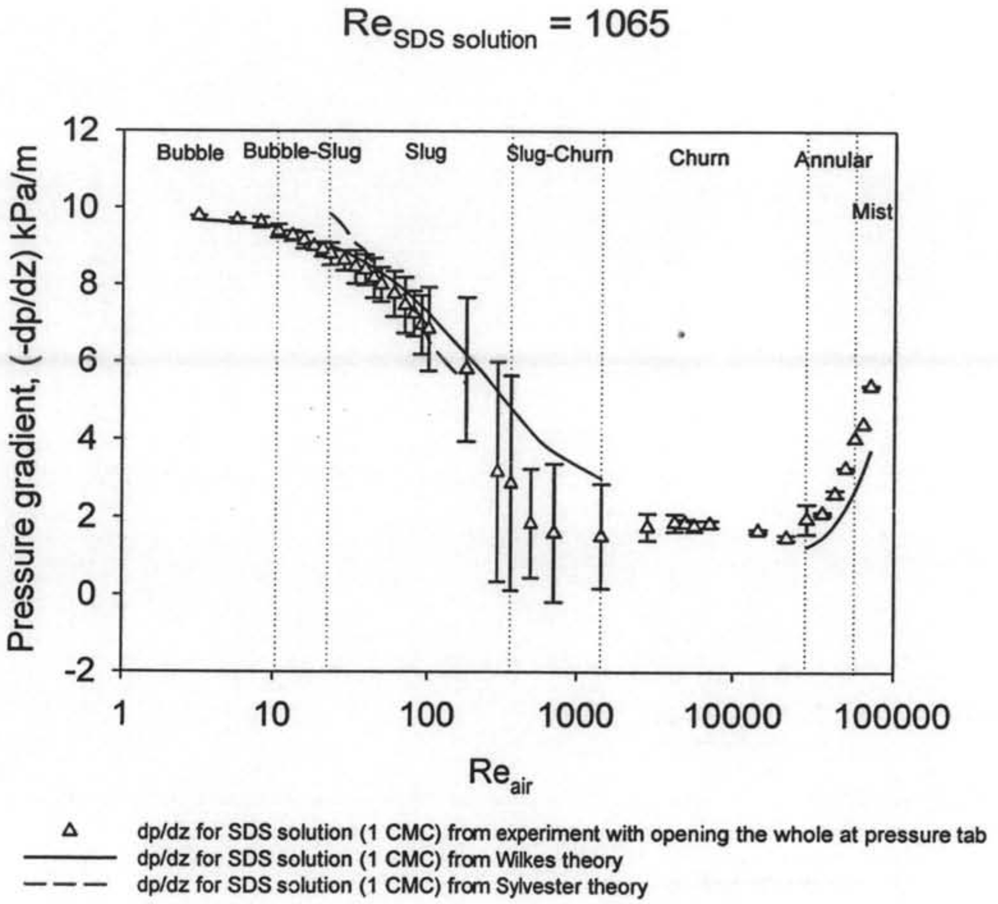

Figure D20 Comparison between Wilkes theory, Sylvester theory and experimental pressure gradient with opening the whole valve at pressure tab vs. air Reynolds number of SDS solution (1 CMC) at $Re_{SDS\ solution} = 1065$.

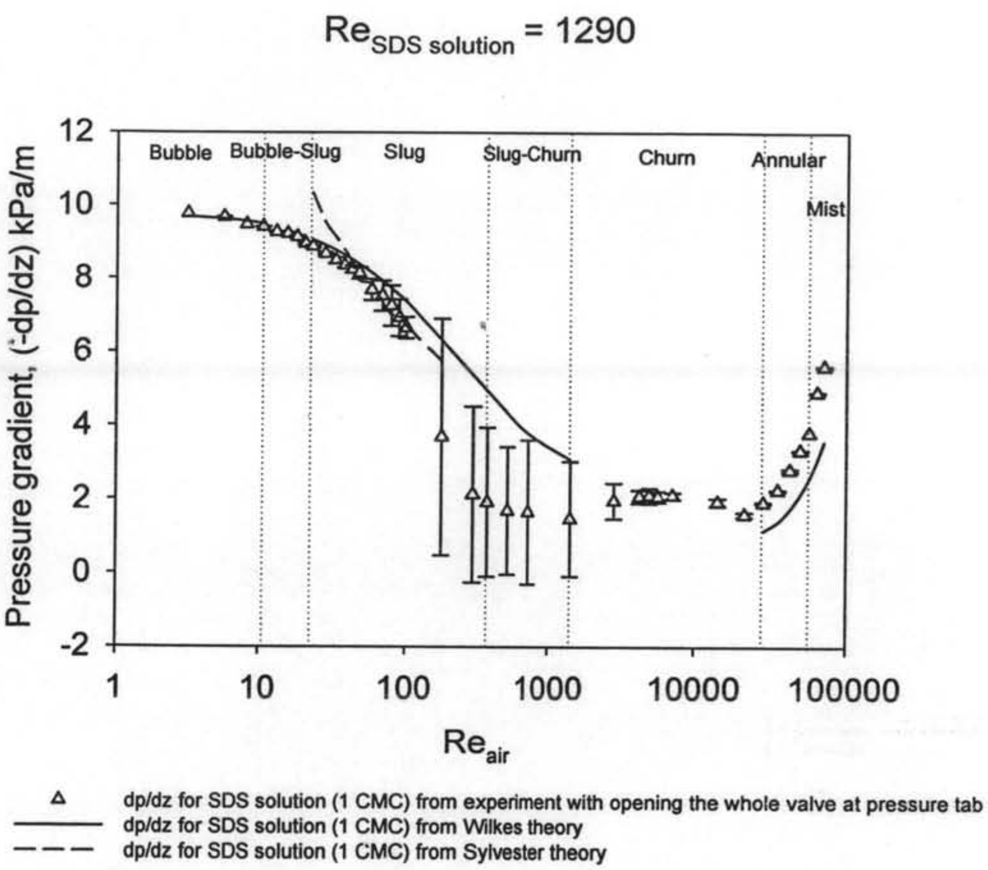

Figure D21 Comparison between Wilkes theory, Sylvester theory and experimental pressure gradient with opening the whole valve at pressure tab vs. air Reynolds number of SDS solution (1 CMC) at $Re_{SDS\ solution}$ = 1290.

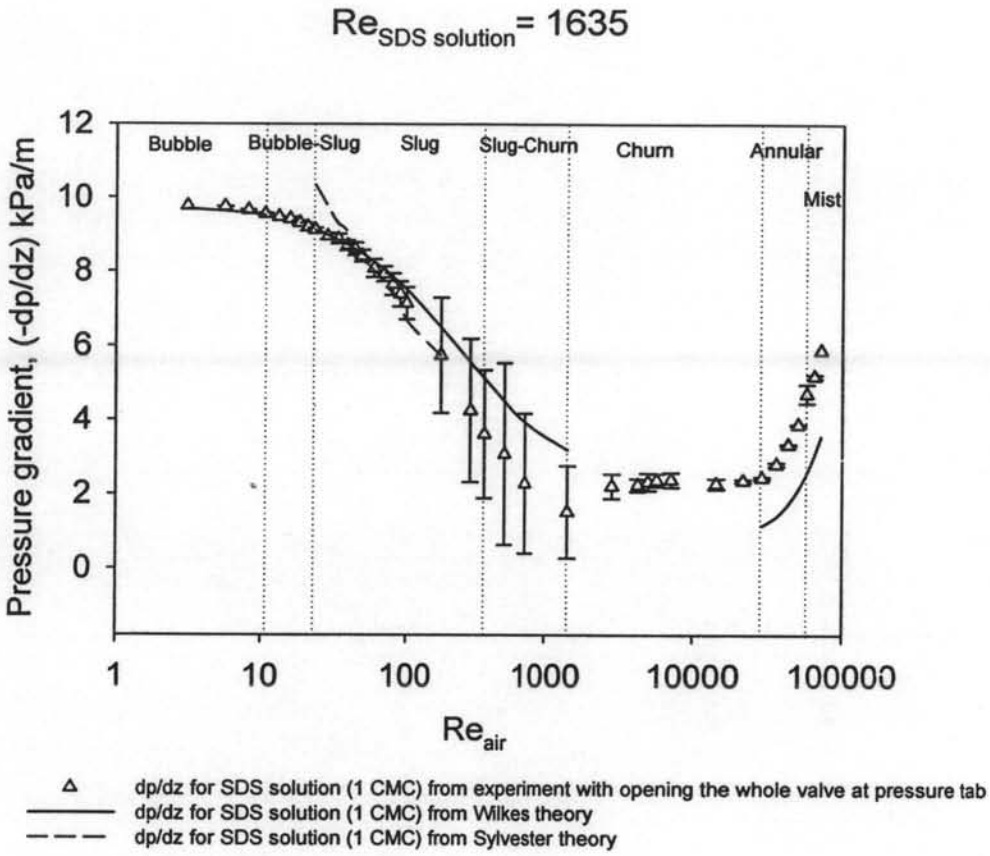

Figure D22 Comparison between Wilkes theory, Sylvester theory and experimental pressure gradient with opening the whole valve at pressure tab vs. air Reynolds number of SDS solution (1 CMC) at $Re_{SDS\ solution} = 1635$.

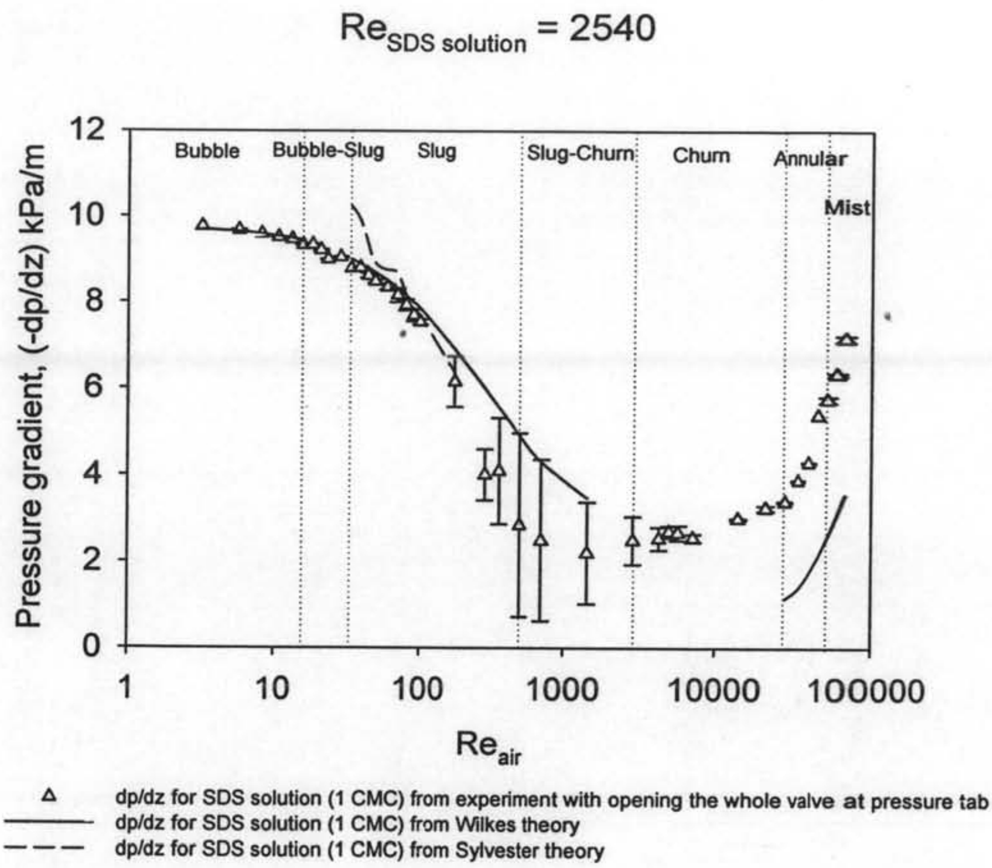

Figure D23 Comparison between Wilkes theory, Sylvester theory and experimental pressure gradient with opening the whole valve at pressure tab vs. air Reynolds number of SDS solution (1 CMC) at $Re_{SDS\ solution}$ = 2540.

Table D4 Comparison between Wilkes theory, Sylvester theory and experimental pressure gradient by nearly closing valve at pressure tab for SDS solution (1 CMC)

Physical properties of air and SDS solution (1 CMC) used in experiment:

density of SDS solution, $\rho_{SDS\ solution}$ = 994..97 kg/m^3; viscosity of SDS solution, $\mu_{SDS\ solution} = 1.01 \times 10^{-3}$ Pa.s

density of air, ρ_{air} = 1.18 kg/m^3; viscosity of air, $\mu_{air} = 1.85 \times 10^{-5}$ Pa.s

temperature, T = 31 °C (± 1 °C); inner pipe diameter, D = 0.019 m; cross-sectional area of pipe, A = 0.00028 m^2

pressure taps difference = 0.4 m

SDS solution (1 CMC)				Air				Flow regime	(dp/dz) from experiment		$(dp/dz)_{tp}$ from Wilkes theory (kPa/m)	$(dp/dz)_{tp}$ from Sylvester theory (kPa/m)
$Q_{solution}$ (ml/min)	Sup. solution velocity $j_{solution}$ (m/s)	$Q_{solution}$ (m^3/sec)	$Re_{solution}$	Q_{air} (L/min)	Sup. Air velocity j_{air} (m/s)	Q_{air} (m^3/sec)	Re_{air}		maximum (kPa/m)	minimum (kPa/m)		
0	0	0	0	0.0444	0.0026	7.41E-07	3.17	bubble	9.8339	9.8013	9.6583	-
0	0	0	0	0.0792	0.0047	1.32E-06	5.64	bubble	9.7119	9.7119	9.5798	-
0	0	0	0	0.1833	0.0108	3.06E-06	13.06	slug	9.3946	9.2564	9.1201	10.075
0	0	0	0	0.218	0.0128	3.63E-06	15.54	slug	9.0237	8.9798	9.0099	9.9141
0	0	0	0	0.253	0.0149	4.21E-06	18.02	slug	8.8773	8.7504	8.9030	9.8908
0	0	0	0	0.287	0.0169	4.79E-06	20.49	slug	8.8090	8.7504	8.7991	9.2501
0	0	0	0	0.322	0.0189	5.37E-06	22.95	slug	8.8090	8.5162	8.6988	8.9122
0	0	0	0	0.394	0.0232	6.57E-06	28.08	slug	8.5211	8.3063	8.4984	8.6176
0	0	0	0	0.466	0.0274	7.76E-06	33.21	slug	8.2722	7.9549	8.3090	8.3293
0	0	0	0	0.538	0.0316	8.96E-06	38.33	slug	7.9110	7.5743	8.1299	7.9778
0	0	0	0	0.610	0.0359	1.02E-05	43.46	slug	7.8085	7.1253	7.9601	7.6524

0	0	0	0	0.682	0.0401	1.14E-05	48.59	slug	7.4425	7.1009	7.7990	7.3732
0	0	0	0	0.826	0.0486	1.38E-05	58.85	slug	7.1985	6.8325	7.5002	6.8317
0	0	0	0	0.970	0.0570	1.62E-05	69.10	slug	6.9545	6.4664	7.2291	6.5940
0	0	0	0	1.113	0.0655	1.86E-05	79.36	slug	6.8081	6.0516	6.9819	6.2708
0	0	0	0	1.257	0.0739	2.10E-05	89.62	slug	6.7495	5.4904	6.7557	6.1525
0	0	0	0	1.401	0.0824	2.34E-05	99.87	slug	6.2468	5.0023	6.5479	5.9855
453	0.0266	7.55E-06	500	0.0444	0.0026	7.41E-07	3.17	bubble	9.7607	9.7363	9.6682	-
453	0.0266	7.55E-06	500	0.0792	0.0047	1.32E-06	5.64	bubble	9.7363	9.6630	9.5972	-
453	0.0266	7.55E-06	500	0.1139	0.0067	1.90E-06	8.12	bubble	9.4922	9.3214	9.5272	-
453	0.0266	7.55E-06	500	0.149	0.0087	2.48E-06	10.59	bubble	9.5085	9.3214	9.4582	-
453	0.0266	7.55E-06	500	0.287	0.0169	4.79E-06	20.49	slug	8.9700	8.7846	8.9527	9.4157
453	0.0266	7.55E-06	500	0.322	0.0189	5.37E-06	22.95	slug	8.7895	8.7651	8.8662	9.3331
453	0.0266	7.55E-06	500	0.394	0.0232	6.57E-06	28.08	slug	8.6382	8.5406	8.6922	8.9838
453	0.0266	7.55E-06	500	0.466	0.0274	7.76E-06	33.21	slug	8.5162	8.4625	8.5264	8.8964
453	0.0266	7.55E-06	500	0.538	0.0316	8.96E-06	38.33	slug	8.3063	8.2282	8.3683	8.4209
453	0.0266	7.55E-06	500	0.610	0.0359	1.02E-05	43.46	slug	8.1404	8.0184	8.2172	8.0300
453	0.0266	7.55E-06	500	0.682	0.0401	1.14E-05	48.59	slug	8.0233	7.8476	8.0728	7.7036
453	0.0266	7.55E-06	500	0.826	0.0486	1.38E-05	58.85	slug	7.6719	7.5206	7.8022	7.3836
453	0.0266	7.55E-06	500	0.970	0.0570	1.62E-05	69.10	slug	7.3205	7.1302	7.5534	7.4322
453	0.0266	7.55E-06	500	1.113	0.0655	1.86E-05	79	slug	7.0374	6.6372	7.3240	7.0669
453	0.0266	7.55E-06	500	1.257	0.0739	2.10E-05	90	slug	6.5836	6.2224	7.1117	6.6237
453	0.0266	7.55E-06	500	1.401	0.0824	2.34E-05	100	slug	6.2468	5.8808	6.9182	6.3712
453	0.0266	7.55E-06	500	2.481	0.1459	4.13E-05	177	slug	4.6607	4.3435	5.8036	5.6196
453	0.0266	7.55E-06	500	4.000	0.2353	6.67E-05	285	slug	2.7574	2.0985	4.8601	-
453	0.0266	7.55E-06	500	5.000	0.2941	8.33E-05	356	slug-churn	2.1864	1.3421	4.4488	-
453	0.0266	7.55E-06	500	7	0.41	1.17E-04	499	slug-churn	1.5959	1.2201	3.8914	-
453	0.0266	7.55E-06	500	10	0.59	1.67E-04	713	slug-churn	1.4885	0.8589	3.4042	-
453	0.0266	7.55E-06	500	20	1.18	3.33E-04	1425	slug-churn	1.2201	0.5368	2.8170	-
453	0.0266	7.55E-06	500	200	11.76	3.33E-03	14255	annular	1.4478	1.3584	2.7115	-
453	0.0266	7.55E-06	500	300	17.64	5.00E-03	21382	annular	1.2770	1.1143	1.4290	-
453	0.0266	7.55E-06	500	400	23.53	6.67E-03	28510	annular	1.6105	1.3258	1.0322	-
453	0.0266	7.55E-06	500	500	29.41	8.33E-03	35637	annular	1.5617	1.5780	1.2693	-

453	0.0266	7.55E-06	500	600	35.29	1.00E-02	42765	annular	1.9359	2.0172	1.5992	-
453	0.0266	7.55E-06	500	700	41.17	1.17E-02	49892	annular	2.6842	2.6842	1.9787	-
453	0.0266	7.55E-06	500	800	47.05	1.33E-02	57020	mist	3.4162	3.4162	2.3979	-
453	0.0266	7.55E-06	500	900	52.93	1.50E-02	64147	mist	3.7823	3.7823	2.8527	-
453	0.0266	7.55E-06	500	1000	58.81	1.67E-02	71275	mist	4.7095	4.7421	3.3406	-
970	0.0570	1.62E-05	1065	0.044	0.0026	7.41E-07	3.17	bubble	9.7932	9.7851	9.6774	-
970	0.0570	1.62E-05	1065	0.079	0.0047	1.32E-06	5.64	bubble	9.7119	9.6386	9.6133	-
970	0.0570	1.62E-05	1065	0.114	0.0067	1.90E-06	8.12	bubble	9.7119	9.5166	9.5500	-
970	0.0570	1.62E-05	1065	0.149	0.0087	2.48E-06	10.59	bubble	9.5166	9.2726	9.4876	-
970	0.0570	1.62E-05	1065	0.322	0.0189	5.37E-06	22.95	slug	8.8920	8.6382	9.0038	9.8392
970	0.0570	1.62E-05	1065	0.394	0.0232	6.57E-06	28.08	slug	8.5015	8.3698	8.8527	9.4739
970	0.0570	1.62E-05	1065	0.466	0.0274	7.76E-06	33.21	slug	8.1697	8.1550	8.7076	9.0675
970	0.0570	1.62E-05	1065	0.538	0.0316	8.96E-06	38.33	slug	7.8866	7.8232	8.5683	8.8661
970	0.0570	1.62E-05	1065	0.610	0.0359	1.02E-05	43.46	slug	7.8524	7.8768	8.4344	8.4557
970	0.0570	1.62E-05	1065	0.682	0.0401	1.14E-05	49	slug	7.7012	7.6865	8.3056	8.2759
970	0.0570	1.62E-05	1065	0.826	0.0486	1.38E-05	59	slug	7.4669	7.4425	8.0621	8.0612
970	0.0570	1.62E-05	1065	0.970	0.0570	1.62E-05	69	slug	7.3351	7.1985	7.8357	7.6673
970	0.0570	1.62E-05	1065	1.113	0.0655	1.86E-05	79	slug	7.3693	7.0765	7.6248	7.3191
970	0.0570	1.62E-05	1065	1.257	0.0739	2.10E-05	90	slug	7.0667	6.7056	7.4278	7.1233
970	0.0570	1.62E-05	1065	1.401	0.0824	2.34E-05	100	slug	6.8227	6.7593	7.2508	6.5489
970	0.0570	1.62E-05	1065	2.481	0.15	4.13E-05	177	slug	5.4660	5.0755	6.1786	5.4199
970	0.0570	1.62E-05	1065	4	0.24	6.67E-05	285	slug	3.6017	2.9282	5.2283	-
970	0.0570	1.62E-05	1065	5	0.29	8.33E-05	356	slug-churn	2.8794	2.4060	4.8010	-
970	0.0570	1.62E-05	1065	7	0.41	1.17E-04	499	slug-churn	2.3426	1.7325	4.2083	-
970	0.0570	1.62E-05	1065	10	0.59	1.67E-04	713	slug-churn	1.8301	1.1713	3.6760	-
970	0.0570	1.62E-05	1065	20	1.18	3.33E-04	1425	slug-churn	1.5861	0.7320	3.0060	-
970	0.0570	1.62E-05	1065	200	11.76	3.33E-03	14255	annular	1.6837	1.6186	2.7329	-
970	0.0570	1.62E-05	1065	300	17.64	5.00E-03	21382	annular	1.5292	1.4316	1.5438	-
970	0.0570	1.62E-05	1065	400	23.53	6.67E-03	28510	annular	1.9928	1.9359	1.2484	-
970	0.0570	1.62E-05	1065	500	29.41	8.33E-03	35637	annular	2.1311	2.0741	1.4876	-
970	0.0570	1.62E-05	1065	600	35.29	1.00E-02	42765	annular	2.6760	2.5459	1.8383	-
970	0.0570	1.62E-05	1065	700	41.17	1.17E-02	49892	annular	3.2536	3.2780	2.2455	-

970	0.0570	1.62E-05	1065	800	47.05	1.33E-02	57020	mist	4.0263	4.0263	2.6960	-
970	0.0570	1.62E-05	1065	900	52.93	1.50E-02	64147	mist	4.3923	4.3923	3.1842	-
970	0.0570	1.62E-05	1065	1000	58.81	1.67E-02	71275	mist	5.3928	5.3684	3.7071	-
1485	0.0873	2.48E-05	1635	0.044	0.0026	7.41E-07	3.17	bubble	9.7607	9.7607	9.6849	-
1485	0.0873	2.48E-05	1635	0.079	0.0047	1.32E-06	5.64	bubble	9.7444	9.7525	9.6265	-
1485	0.0873	2.48E-05	1635	0.114	0.0067	1.90E-06	8.12	bubble	9.6630	9.6386	9.5688	-
1485	0.0873	2.48E-05	1635	0.149	0.0087	2.48E-06	10.59	bubble	9.5654	9.5329	9.5117	-
1485	0.0873	2.48E-05	1635	0.322	0.0189	5.37E-06	22.95	slug	9.1555	9.0823	9.1061	10.343
1485	0.0873	2.48E-05	1635	0.394	0.0232	6.57E-06	28.08	slug	9.0091	8.8871	8.9726	9.7544
1485	0.0873	2.48E-05	1635	0.466	0.0274	7.76E-06	33.21	slug	8.9700	8.7797	8.8438	9.2811
1485	0.0873	2.48E-05	1635	0.538	0.0316	8.96E-06	38	slug	8.7992	8.5991	8.7195	9.0547
1485	0.0873	2.48E-05	1635	0.610	0.0359	1.02E-05	43	slug	8.7211	8.4771	8.5994	8.3605
1485	0.0873	2.48E-05	1635	0.682	0.0401	1.14E-05	49	slug	8.5308	8.3014	8.4833	8.2823
1485	0.0873	2.48E-05	1635	0.826	0.0486	1.38E-05	59	slug	8.2624	8.0965	8.2623	8.0247
1485	0.0873	2.48E-05	1635	0.970	0.0570	1.62E-05	69	slug	7.7744	7.7988	8.0553	7.7080
1485	0.0873	2.48E-05	1635	1.113	0.0655	1.86E-05	79	slug	7.5938	7.5108	7.8607	7.3981
1485	0.0873	2.48E-05	1635	1.25734	0.07	2.10E-05	90	slug	7.4230	7.3254	7.6777	7.1991
1485	0.0873	2.48E-05	1635	1.40124	0.08	2.34E-05	100	slug	7.1985	7.0765	7.5179	6.6724
1485	0.0873	2.48E-05	1635	2.48099	0.15	4.13E-05	177	slug	5.8515	5.5880	6.4928	5.7267
1485	0.0873	2.48E-05	1635	4	0.24	6.67E-05	285	slug	4.2703	3.6114	5.5492	-
1485	0.0873	2.48E-05	1635	5	0.29	8.33E-05	356	slug-churn	3.6602	3.0746	5.1136	-
1485	0.0873	2.48E-05	1635	7	0.41	1.17E-04	499	slug-churn	3.0404	2.2938	4.4969	-
1485	0.0873	2.48E-05	1635	10	0.59	1.67E-04	713	slug-churn	1.8789	1.1713	3.9295	-
1485	0.0873	2.48E-05	1635	20	1.18	3.33E-04	1425	slug-churn	1.4397	0.8053	3.1889	-
1485	0.0873	2.48E-05	1635	200	11.76	3.33E-03	14255	annular	2.3751	2.1717	2.7222	-
1485	0.0873	2.48E-05	1635	300	17.64	5.00E-03	21382	annular	2.3832	2.3263	1.4904	-
1485	0.0873	2.48E-05	1635	400	23.53	6.67E-03	28510	annular	2.4076	2.4564	1.1531	-
1485	0.0873	2.48E-05	1635	500	29.41	8.33E-03	35637	annular	2.8306	2.7655	1.3903	-
1485	0.0873	2.48E-05	1635	600	35.29	1.00E-02	42765	annular	3.3024	3.3430	1.7318	-
1485	0.0873	2.48E-05	1635	700	41.17	1.17E-02	49892	annular	3.8555	3.8717	2.1268	-
1485	0.0873	2.48E-05	1635	800	47.05	1.33E-02	57020	mist	4.8722	4.5143	2.5636	-
1485	0.0873	2.48E-05	1635	900	52.93	1.50E-02	64147	mist	5.1975	5.1243	3.0372	-

1485	0.0873	2.48E-05	1635	1000	58.81	1.67E-02	71275	mist	5.8564	5.8564	3.5447	-
2310	0.1359	3.85E-05	2540	0.044	0.0026	7.41E-07	3.17	bubble	9.7607	9.7607	9.6944	-
2310	0.1359	3.85E-05	2540	0.079	0.0047	1.32E-06	5.64	bubble	9.6875	9.6630	9.6433	-
2310	0.1359	3.85E-05	2540	0.114	0.0067	1.90E-06	8.12	bubble	9.5898	9.5898	9.5927	-
2310	0.1359	3.85E-05	2540	0.149	0.0087	2.48E-06	10.59	bubble	9.5166	9.5085	9.5426	-
2310	0.1359	3.85E-05	2540	0.183	0.0108	3.06E-06	13.06	bubble	9.4678	9.4597	9.4931	-
2310	0.1359	3.85E-05	2540	0.218	0.0128	3.63E-06	15.54	bubble	9.3409	9.3214	9.4441	-
2310	0.1359	3.85E-05	2540	0.466	0.0274	7.76E-06	33.21	slug	8.7846	8.7846	9.0035	10.2399
2310	0.1359	3.85E-05	2540	0.538	0.0316	8.96E-06	38	slug	8.8188	8.7895	8.8975	9.9142
2310	0.1359	3.85E-05	2540	0.610	0.0359	1.02E-05	43	slug	8.6528	8.5747	8.7945	9.3449
2310	0.1359	3.85E-05	2540	0.682	0.0401	1.14E-05	49	slug	8.5113	8.4478	8.6944	8.9143
2310	0.1359	3.85E-05	2540	0.826	0.0486	1.38E-05	59	slug	8.3893	8.3014	8.5024	8.7477
2310	0.1359	3.85E-05	2540	0.970	0.0570	1.62E-05	69	slug	8.2722	8.0428	8.3206	8.6628
2310	0.1359	3.85E-05	2540	1.113	0.0655	1.86E-05	79	slug	8.0233	7.8378	8.1483	8.1483
2310	0.1359	3.85E-05	2540	1.257	0.0739	2.10E-05	90	slug	7.7890	7.5889	7.9846	7.8215
2310	0.1359	3.85E-05	2540	1.40124	0.08	2.34E-05	100	slug	7.5791	7.4913	7.8528	7.6760
2310	0.1359	3.85E-05	2540	2.48099	0.15	4.13E-05	177	slug	6.7349	6.5982	6.9038	6.3647
2310	0.1359	3.85E-05	2540	4	0.24	6.67E-05	285	slug	5.2903	4.8754	5.9866	-
2310	0.1359	3.85E-05	2540	5	0.29	8.33E-05	356	slug-churn	4.6363	4.2703	5.5480	-
2310	0.1359	3.85E-05	2540	7	0.41	1.17E-04	499	slug-churn	3.6358	2.8696	4.9096	-
2310	0.1359	3.85E-05	2540	10	0.59	1.67E-04	713	slug-churn	2.4255	1.9180	4.3025	-
2310	0.1359	3.85E-05	2540	20	1.18	3.33E-04	1425	slug-churn	2.5866	1.5861	3.4699	-
2310	0.1359	3.85E-05	2540	200	11.76	3.33E-03	14255	annular	3.0014	2.9770	2.7222	-
2310	0.1359	3.85E-05	2540	300	17.64	5.00E-03	21382	annular	3.2780	3.1885	1.4904	-
2310	0.1359	3.85E-05	2540	400	23.53	6.67E-03	28510	annular	3.3918	3.3674	1.153131	-
2310	0.1359	3.85E-05	2540	500	29.41	8.33E-03	35637	annular	3.8880	3.8555	1.390314	-
2310	0.1359	3.85E-05	2540	600	35.29	1.00E-02	42765	annular	4.2947	4.2703	1.731765	-
2310	0.1359	3.85E-05	2540	700	41.17	1.17E-02	49892	annular	5.3684	5.3684	2.12685	-
2310	0.1359	3.85E-05	2540	800	47.05	1.33E-02	57020	mist	5.7832	5.6856	2.563616	-
2310	0.1359	3.85E-05	2540	900	52.93	1.50E-02	64147	mist	6.3444	6.2956	3.037153	-
2310	0.1359	3.85E-05	2540	1000	58.81	1.67E-02	71275	mist	7.1985	7.1009	3.544743	-

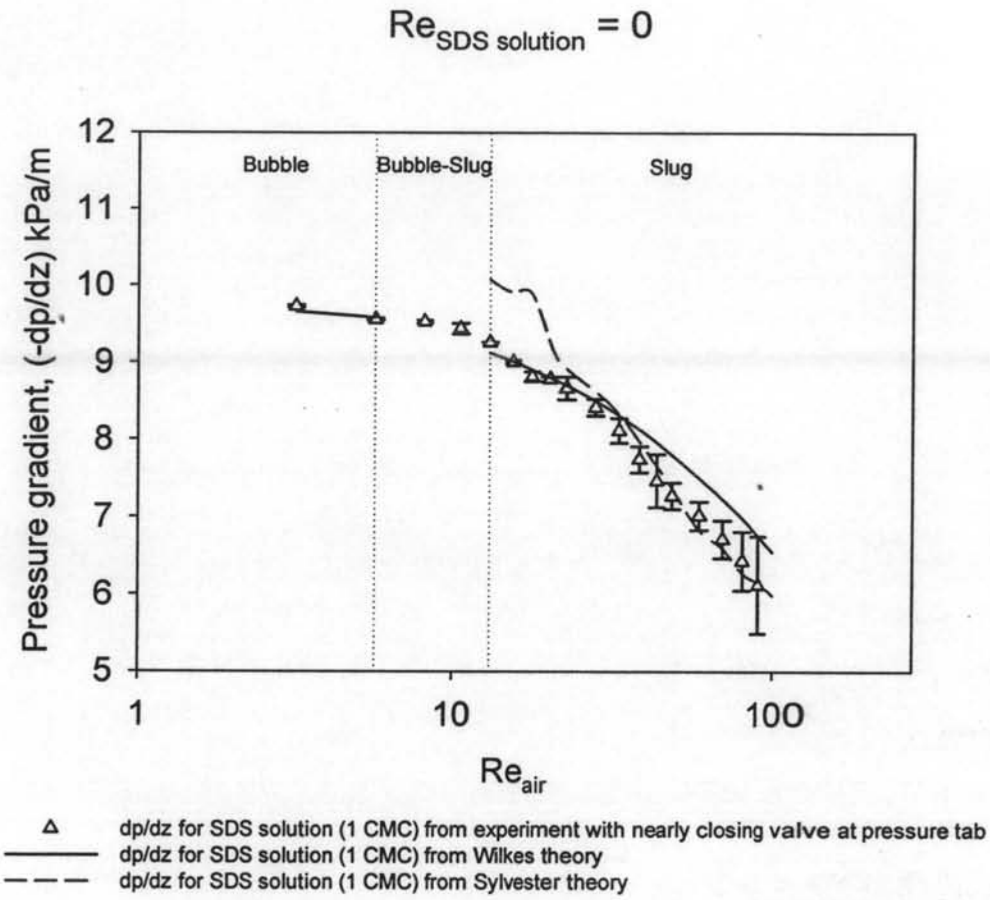

Figure D24 Comparison between Wilkes theory, Sylvester theory and experimental pressure gradient with nearly closing valve at pressure tab vs. air Reynolds number of SDS solution (1 CMC) at $Re_{SDS\ solution} = 0$.

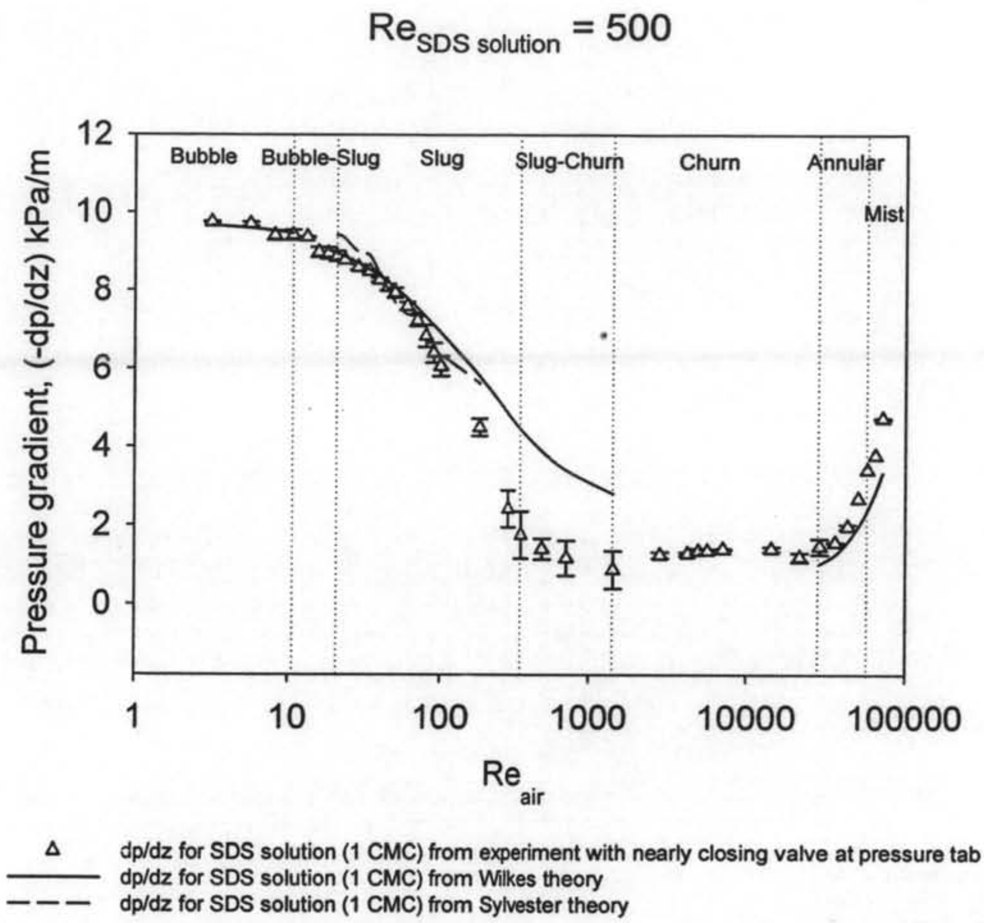

Figure D25 Comparison between Wilkes theory, Sylvester theory and experimental pressure gradient with nearly closing valve at pressure tab vs. air Reynolds number of SDS solution (1 CMC) at $Re_{SDS\ solution} = 500$.

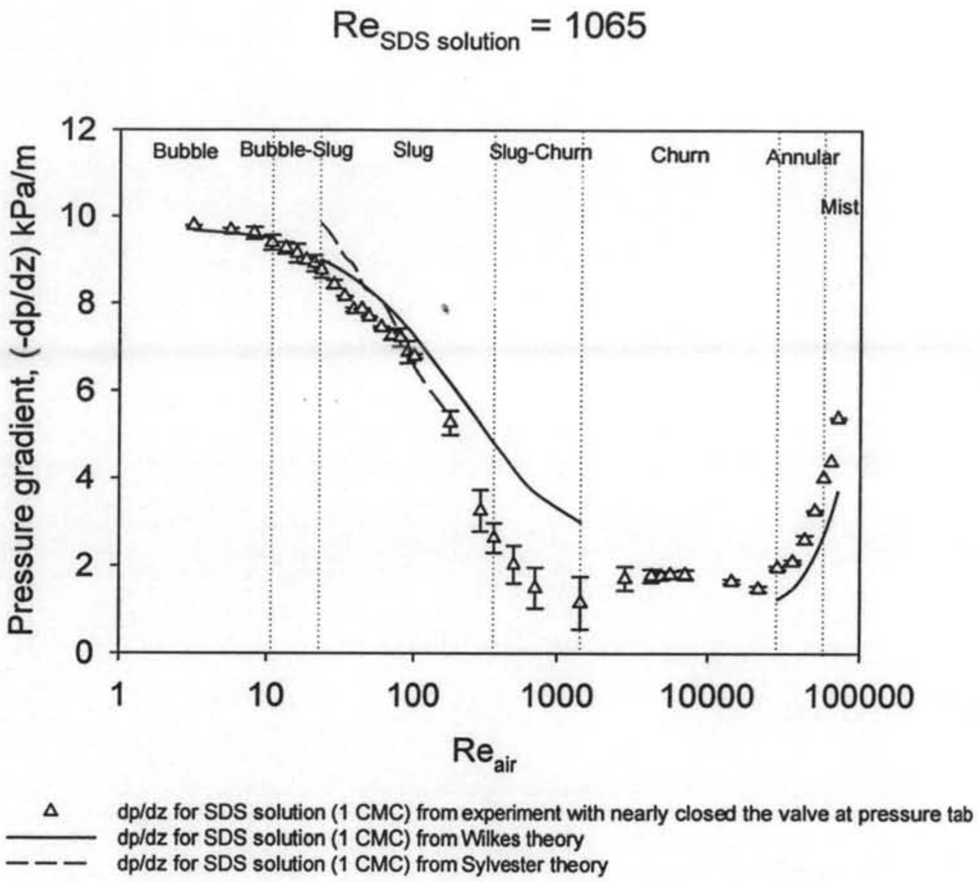

Figure D26 Comparison between Wilkes theory, Sylvester theory and experimental pressure gradient with nearly closing valve at pressure tab vs. air Reynolds number of SDS solution (1 CMC) at $Re_{SDS\ solution} = 1065$.

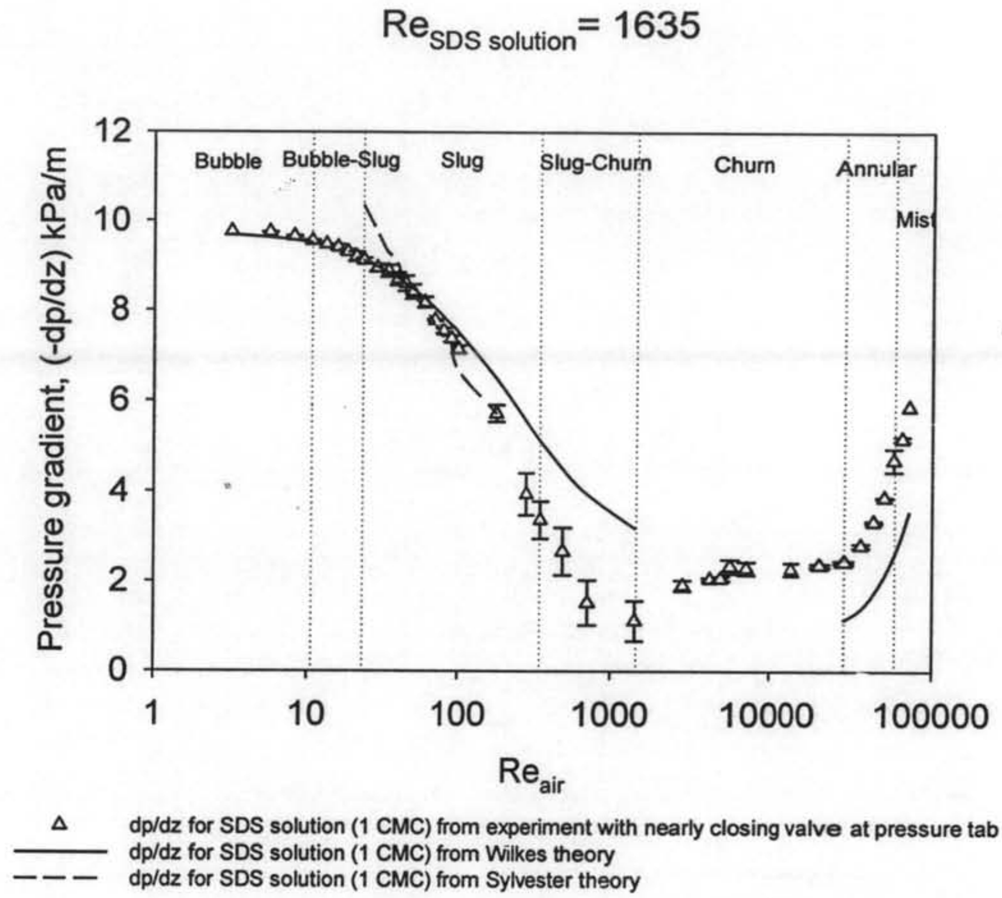

Figure D27 Comparison between Wilkes theory, Sylvester theory and experimental pressure gradient with nearly closing valve at pressure tab vs. air Reynolds number of SDS solution (1 CMC) at $Re_{SDS\ solution} = 1635$.

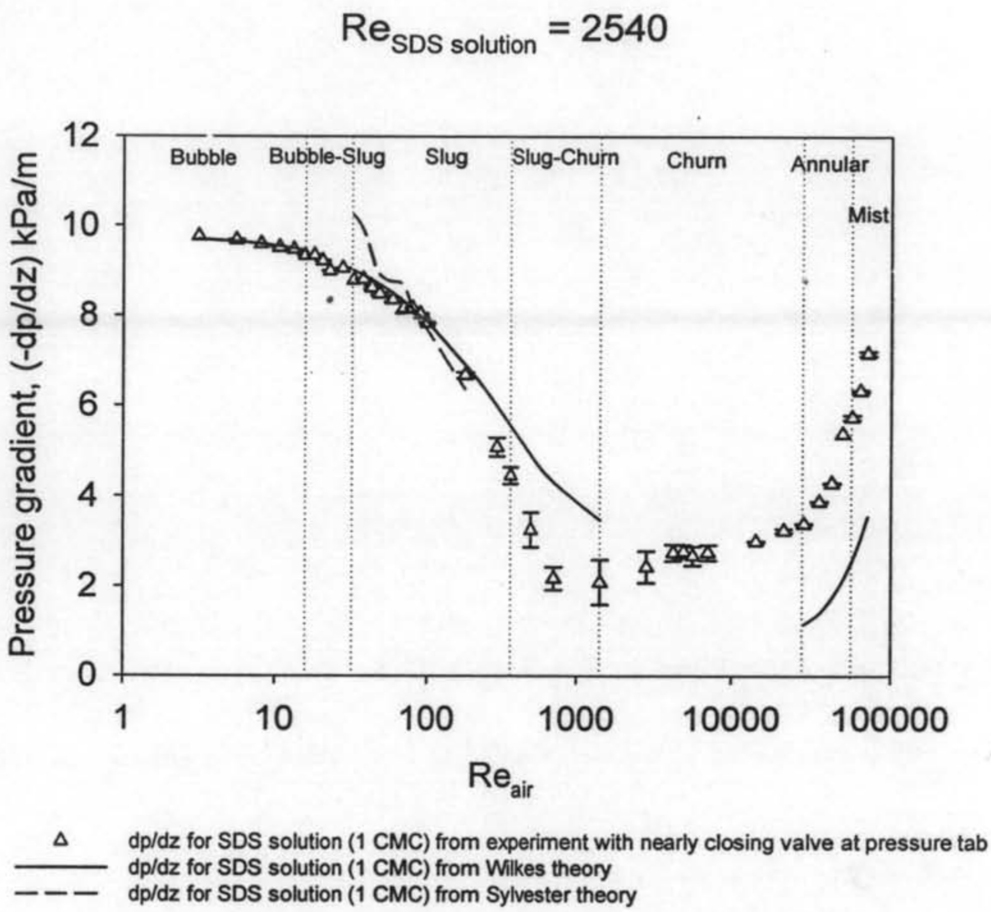

Figure D28 Comparison between Wilkes theory, Sylvester theory and experimental pressure gradient with nearly closing valve at pressure tab vs. air Reynolds number of SDS solution (1 CMC) at $Re_{SDS\ solution} = 2540$.

Appendix E Determination of Bubble Size from Experiment

Table E1 Determination of bubble size for pure water from experiment

Physical properties of air and water used in experiment:

density of water, $\rho_{water} = 995$ kg/m^3; viscosity of water, $\mu_{water} = 8.51 \times 10^{-4}$ Pa.s

density of air, $\rho_{air} = 1.18$ kg/m^3; viscosity of air, $\mu_{air} = 1.85 \times 10^{-5}$ Pa.s

temperature, T = 31 °C (± 1 °C); inner pipe diameter = 0.019 m; cross-sectional area of pipe, A = 0.00028 m^2

Procedure to determine the bubble size:

1. Make a movie of the bubble flow regime by video camera.
2. Capture the picture from movie by Win DVD software program.
3. Measure the bubble size by Scion Image software program.

Equivalent diameter (D_e) of the bubble is defined as the diameter of a sphere that has the same volume as the bubble.

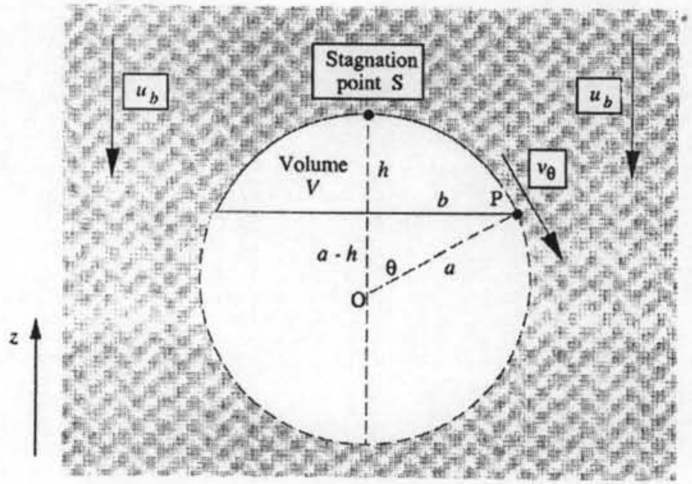

Figure E1 Flow around a spherical cap bubble (Wilkes, 1999).

$$\text{Equivalent diameter } (D_e) = \sqrt[3]{3.94h\left[\frac{h^2+b^2}{2h}\right]^2 - 1.94b^2\left[\left(\frac{h^2+b^2}{2h}\right)-h\right]} \tag{E1}$$

Re_{water}	Re_{air}	Bubble width, (mm)			Average bubble width(mm)	Bubble height, R_h (mm)			Average, R_h (mm)	Equivalent diameter, D_e (mm)			Average equivalent diameter, D_e (mm)
		1	2	3		1	2	3		1	2	3	
0	3.17	13.5	14.7	15.5	14.6	6.9	6.7	6.5	6.7	10.8	11.1	11.3	11.0
0	5.64	13.3	16.0	14.5	14.6	6.6	7.4	7.2	7.1	10.5	12.2	11.4	11.4
0	8.12	16.3	15.5	17.5	16.4	7.9	8.1	7.4	7.8	12.7	12.5	12.7	12.6
344	3.17	15.3	15.3	14.7	15.1	6.5	7.9	7.0	7.1	11.1	12.3	11.3	11.6
344	5.64	14.6	16.2	13.7	14.8	7.3	6.0	7.1	6.8	11.5	11.1	11.0	11.2
344	8.12	12.1	15.8	17.1	15.0	6.8	6.8	8.9	7.5	10.1	11.6	13.8	11.9
344	10.59	17.1	15.0	15.5	15.9	8.3	9.3	8.9	8.8	13.3	13.2	13.2	13.2
344	13.06	16.8	16.8	15.5	16.4	9.4	8.2	9.4	9.0	14.1	13.1	13.5	13.6
477	3.17	14.9	16.2	15.9	15.7	6.6	6.8	7.2	6.9	11.1	11.7	12.0	11.6
477	5.64	14.6	14.6	16.4	15.2	6.9	7.7	7.2	7.3	11.2	11.8	12.2	11.7
477	8.12	14.1	15.4	17.5	15.7	9.0	7.6	6.9	7.8	12.7	12.0	12.3	12.4
477	10.59	17.6	17.4	16.6	17.2	9.6	10.4	9.4	9.8	14.5	15.1	13.9	14.5
477	13.06	17.9	16.9	18.5	17.8	11.5	10.3	11.4	11.0	16.1	14.8	16.3	15.7
610	3.17	14.2	13.4	15.8	14.5	7.5	6.1	7.3	7.0	11.6	10.1	12.0	11.2
610	5.64	16.2	15.9	14.8	15.6	8.4	8.4	7.5	8.1	13.0	12.9	11.8	12.6
610	8.12	16.5	15.0	16.7	16.0	6.4	7.9	8.1	7.5	11.6	12.1	13.0	12.2
610	10.59	15.0	17.9	17.8	16.9	8.2	7.8	9.3	8.4	12.4	13.2	14.4	13.3
610	13.06	17.3	18.3	17.5	17.7	8.7	11.0	10.2	9.9	13.7	15.9	14.9	14.8
743	3.17	16.4	16.1	16.5	16.3	6.5	7.6	7.5	7.2	11.6	12.4	12.4	12.1
743	5.64	17.2	17.9	16.1	17.0	7.1	8.7	7.9	7.9	12.4	13.9	12.6	12.9
743	8.12	16.1	17.5	16.5	16.7	6.7	8.7	9.2	8.2	11.6	13.7	13.8	13.0
743	10.59	16.5	15.3	18.4	16.7	8.7	9.0	10.3	9.4	13.4	13.2	15.4	14.0
743	13.06	17.3	17.6	18.1	17.7	11.4	9.8	9.8	10.3	15.9	14.6	14.9	15.1
1010	3.17	16.8	17.6	15.9	16.8	7.5	8.4	8.7	8.2	12.5	13.5	13.1	13.1
1010	5.64	16.2	17.2	17.6	17.0	7.3	7.6	8.7	7.8	12.1	12.8	13.8	12.9
1010	8.12	16.2	17.3	17.6	17.0	7.5	9.5	8.4	8.5	12.3	14.3	13.5	13.4
1010	10.59	17.6	17.9	18.4	18.0	8.7	8.6	9.2	8.8	13.8	13.8	14.5	14.0

1010	13.06	18.1	17.5	18.7	18.1	10.7	10.4	11.7	11.0	15.6	15.1	16.6	15.8
1276	3.17	17.4	17.4	16.7	17.2	7.2	7.2	7.5	7.3	12.5	12.5	12.6	12.5
1276	5.64	17.6	17.9	18.4	17.9	10.0	8.4	8.7	9.0	14.9	13.7	14.1	14.2
1276	8.12	18.3	17.2	17.5	17.6	10.0	10.4	8.7	9.7	15.1	15.0	13.8	14.6
1276	10.59	17.8	18.1	17.0	17.6	9.0	9.3	11.2	9.8	14.1	14.5	15.5	14.7
1276	13.06	17.3	17.6	19.0	17.9	10.9	11.7	15.1	12.6	15.4	16.2	19.4	17.0
1676	3.17	17.0	17.2	17.2	17.1	7.0	8.5	7.9	7.8	12.2	13.5	13.0	12.9
1676	5.64	18.3	16.8	18.0	17.7	7.9	9.1	9.4	8.8	13.5	13.9	14.5	14.0
1676	8.12	18.6	17.6	18.3	18.2	9.3	10.0	10.7	10.0	14.7	14.9	15.7	15.1
1676	10.59	17.1	18.3	17.8	17.7	9.7	9.9	10.7	10.1	14.4	15.0	15.5	15.0
1676	13.06	18.3	18.5	17.8	18.2	12.3	14.3	11.0	12.5	16.9	18.6	15.7	17.1
2741	3.17	17.8	18.1	18.5	18.1	7.3	10.7	9.7	9.3	12.8	15.6	15.0	14.5
2741	5.64	18.3	18.3	18.1	18.2	11.1	10.6	10.7	10.8	16.0	15.5	15.6	15.7
2741	8.12	18.1	18.6	17.6	18.1	11.0	10.4	11.2	10.9	15.8	15.6	15.8	15.7
2741	10.59	18.1	17.2	17.6	17.6	10.6	10.1	12.0	10.9	15.5	14.8	16.4	15.6
2741	13.06	18.3	18.6	17.8	18.2	11.3	11.8	11.0	11.4	16.1	16.7	15.7	16.2
2741	15.54	18.4	17.9	18.4	18.2	10.0	12.0	11.2	11.1	15.2	16.5	16.1	15.9
2741	18.02	17.7	18.1	18.5	18.1	11.0	11.7	16.9	13.2	15.7	16.4	20.8	17.6
2741	20.49	18.8	18.5	18.1	18.5	17.4	17.4	16.6	17.1	17.1	18.7	19.3	18.4

Table E2 Determination of bubble size for SDS solution (1 CMC) from experiment

Physical properties of air and SDS solution (1 CMC) used in experiment:

density of SDS solution, $\rho_{SDS\ solution}$ = 994.97 kg/m^3; viscosity of SDS solution, $\mu_{SDS\ solution}$ = 1.01 × 10^{-3} Pa.s

density of air, ρ_{air} = 1.18 kg/m^3; viscosity of air, μ_{air} = 1.85 × 10^{-5} Pa.s

temperature, T = 31 °C (± 1 °C); inner pipe diameter = 0.019 m; cross-sectional area of pipe, A = 0.00028 m^2

$Re_{SDS\ solution}$	Re_{air}	Bubble width, (mm)			Average bubble width(mm)	Bubble height, R_h (mm)			Average, R_h (mm)	Equivalent diameter, D_e (mm)			Average equivalent diameter, D_e (mm)
		1	2	3		1	2	3		1	2	3	
0	3.17	12.5	15.3	14.9	14.2	8.3	7.9	8.1	8.1	11.5	12.3	12.3	12.0
0	5.64	14.5	15.0	14.3	14.6	8.7	8.2	8.4	8.5	12.6	12.4	12.3	12.4
385	3.17	14.4	14.9	14.6	14.6	8.2	7.9	8.2	8.1	12.1	12.1	12.2	12.2
385	5.64	16.7	15.2	15.1	15.7	8.6	8.0	7.4	8.0	13.4	12.3	11.8	12.5
385	8.12	14.2	14.8	15.7	14.9	8.1	7.9	8.2	8.1	12.0	12.1	12.7	12.3
385	10.59	16.0	15.7	15.5	15.8	9.1	8.4	7.9	8.5	13.5	12.9	12.4	12.9
500	3.17	13.8	13.4	13.8	13.7	6.8	7.0	6.6	6.8	10.8	10.8	10.7	10.8
500	5.64	14.9	14.5	14.3	14.5	6.9	7.8	7.1	7.3	11.3	11.8	11.2	11.5
500	8.12	15.5	14.9	15.2	15.2	8.7	7.8	7.8	8.1	13.0	12.0	12.2	12.4
500	10.59	15.7	16.6	17.0	16.5	8.3	8.2	9.0	8.5	12.7	13.0	13.8	13.2
610	3.17	14.6	14.0	14.0	14.2	8.5	6.4	6.4	7.1	12.4	10.6	10.6	11.2
610	5.64	15.3	15.0	15.5	15.2	7.5	8.2	7.7	7.8	12.0	12.4	12.2	12.2
610	8.12	16.6	15.0	16.4	16.0	8.2	7.5	8.4	8.0	13.0	11.8	13.1	12.7
610	10.59	17.8	16.7	17.2	17.3	9.4	7.8	9.7	8.9	14.4	12.7	14.4	13.9
725	3.17	14.7	14.7	13.9	14.5	7.4	7.4	7.6	7.5	11.6	11.6	11.5	11.6
725	5.64	14.6	15.2	14.8	14.9	8.0	9.0	7.8	8.3	12.1	13.1	12.0	12.4

725	8.12	16.1	16.9	15.9	16.3	8.7	8.2	8.9	8.6	13.2	13.1	13.3	13.2
725	10.59	17.4	17.2	17.1	17.2	11.2	10.8	10.1	10.7	15.7	15.3	14.7	15.3
1065	3.17	15.0	15.0	14.7	14.9	6.6	7.1	7.2	7.0	11.2	11.5	11.5	11.4
1065	5.64	15.0	15.6	15.3	15.3	7.5	7.8	7.8	7.7	11.8	12.3	12.2	12.1
1065	8.12	15.4	16.1	15.3	15.6	9.5	8.3	8.7	8.8	13.5	12.9	12.9	13.1
1065	10.59	16.1	16.8	17.5	16.8	10.2	9.7	11.8	10.6	14.4	14.3	16.3	15.0
1290	3.17	13.9	14.1	13.9	13.9	7.5	8.1	7.5	7.7	11.4	12.0	11.4	11.6
1290	5.64	14.8	15.3	15.3	15.1	8.0	8.4	8.1	8.1	12.2	12.6	12.4	12.4
1290	8.12	15.5	16.4	16.5	16.1	8.3	9.0	8.6	8.6	12.6	13.6	13.3	13.2
1290	10.59	17.1	17.5	17.5	17.4	11.5	10.3	11.6	11.1	15.8	15.0	16.1	15.7
1635	3.17	14.0	14.5	14.1	14.2	8.3	8.5	8.5	8.4	12.1	12.4	12.2	12.2
1635	5.64	16.7	15.9	16.2	16.3	8.6	8.9	9.2	8.9	13.4	13.3	13.6	13.4
1635	8.12	16.2	16.3	16.7	16.4	8.9	9.4	9.0	9.1	13.4	13.8	13.7	13.7
1635	10.59	18.2	17.1	17.1	17.4	11.7	13.3	13.5	12.8	16.4	17.3	17.5	17.0
2540	3.17	14.6	15.9	15.0	15.2	7.5	7.6	9.4	8.1	11.7	12.3	13.4	12.4
2540	5.64	15.0	15.6	15.6	15.4	9.5	9.6	8.3	9.1	13.4	13.7	12.7	13.3
2540	8.12	15.6	15.7	16.5	16.0	9.2	10.2	10.3	9.9	13.4	14.2	14.6	14.1
2540	10.59	16.4	16.3	16.2	16.3	10.4	9.7	10.0	10.0	14.7	14.1	14.3	14.4
2540	13.06	16.4	17.1	17.3	16.9	12.2	12.4	12.7	12.4	16.2	16.5	16.9	16.5
2540	15.54	17.3	17.8	17.3	17.5	13.1	13.6	13.9	13.5	17.2	17.8	17.9	17.6

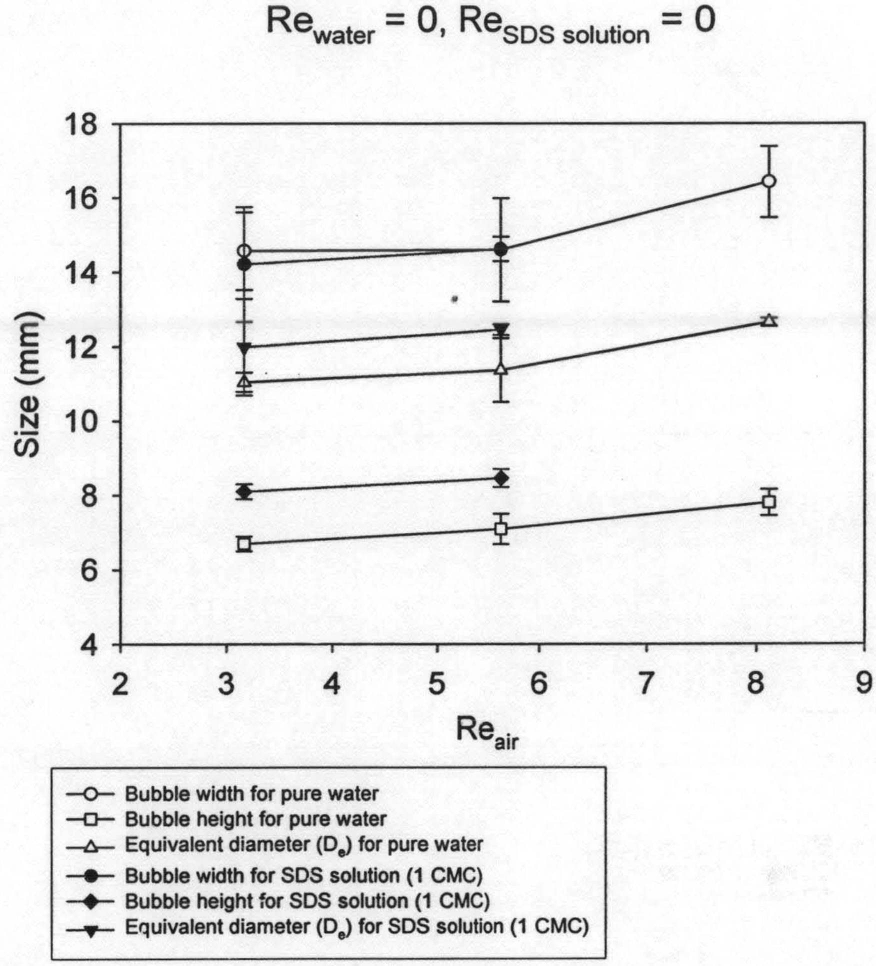

Figure E1 Bubble width, bubble height and equivalent diameter vs. air Reynolds number of pure water at $Re_{water} = 0$ and SDS solution (1 CMC) at $Re_{SDS\ solution} = 0$.

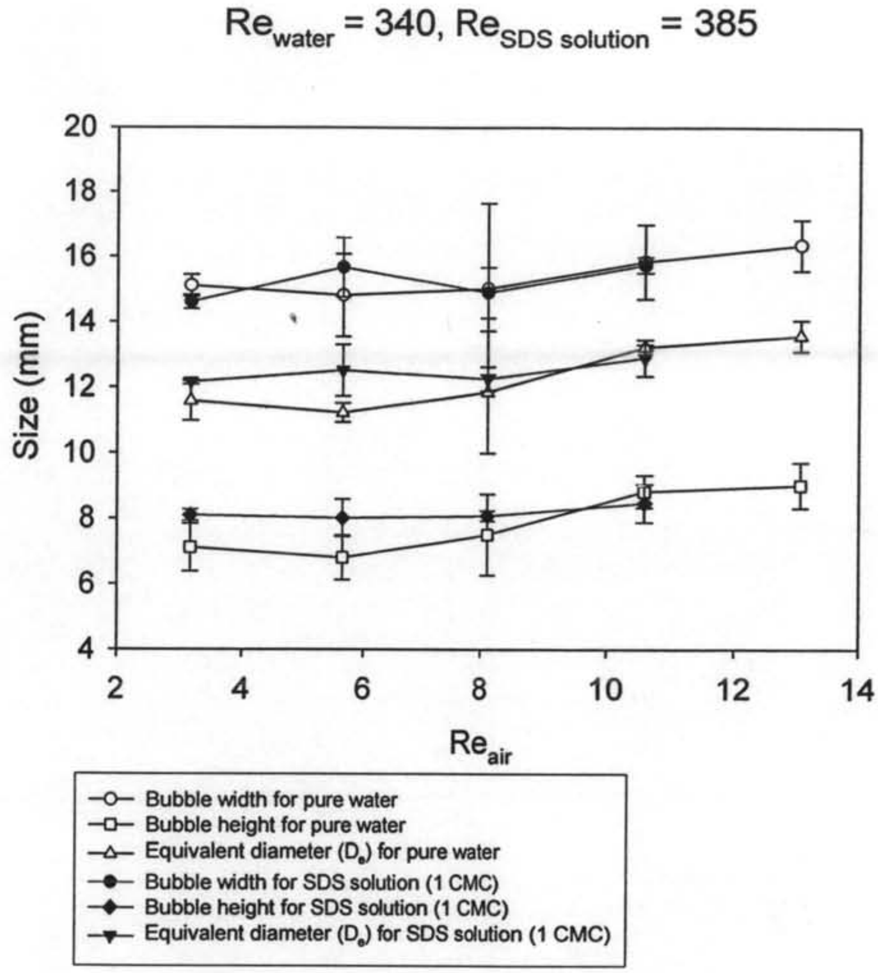

Figure E2 Bubble width, bubble height and equivalent diameter vs. air Reynolds number of pure water at $Re_{water} = 340$ and SDS solution (1 CMC) at $Re_{SDS\ solution} = 385$.

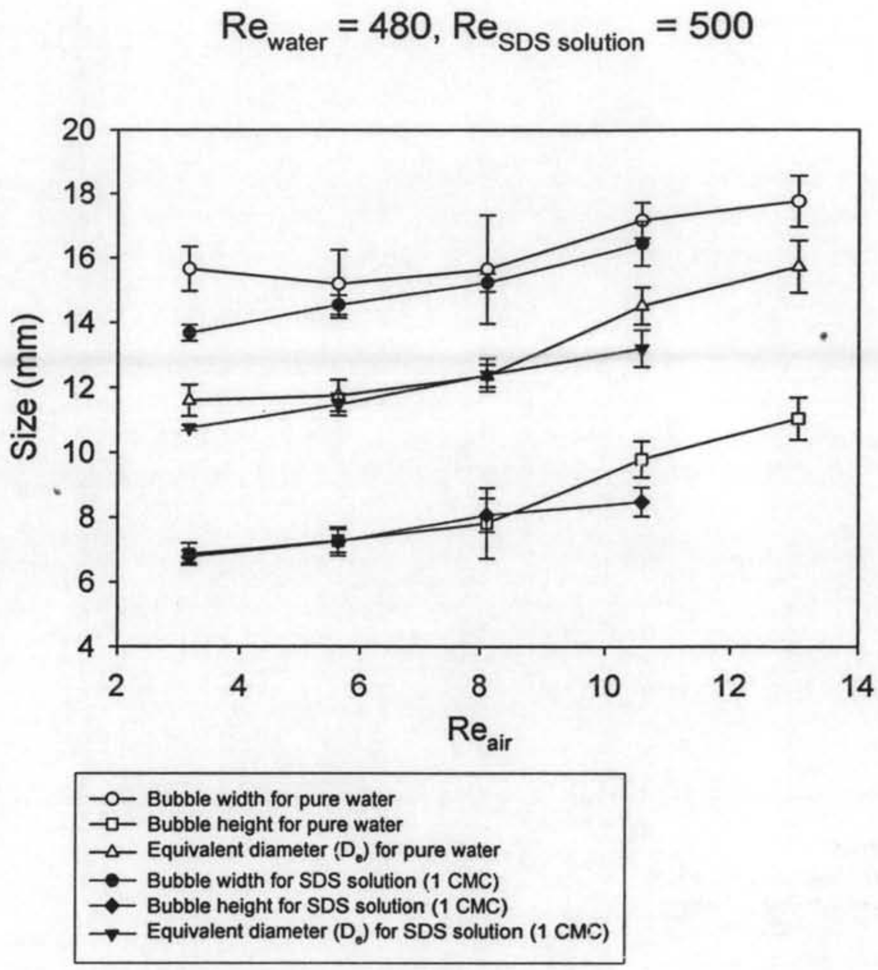

Figure E3 Bubble width, bubble height and equivalent diameter vs. air Reynolds number of pure water at $Re_{water} = 480$ and SDS solution (1 CMC) at $Re_{SDS\ solution} =$ 5000.

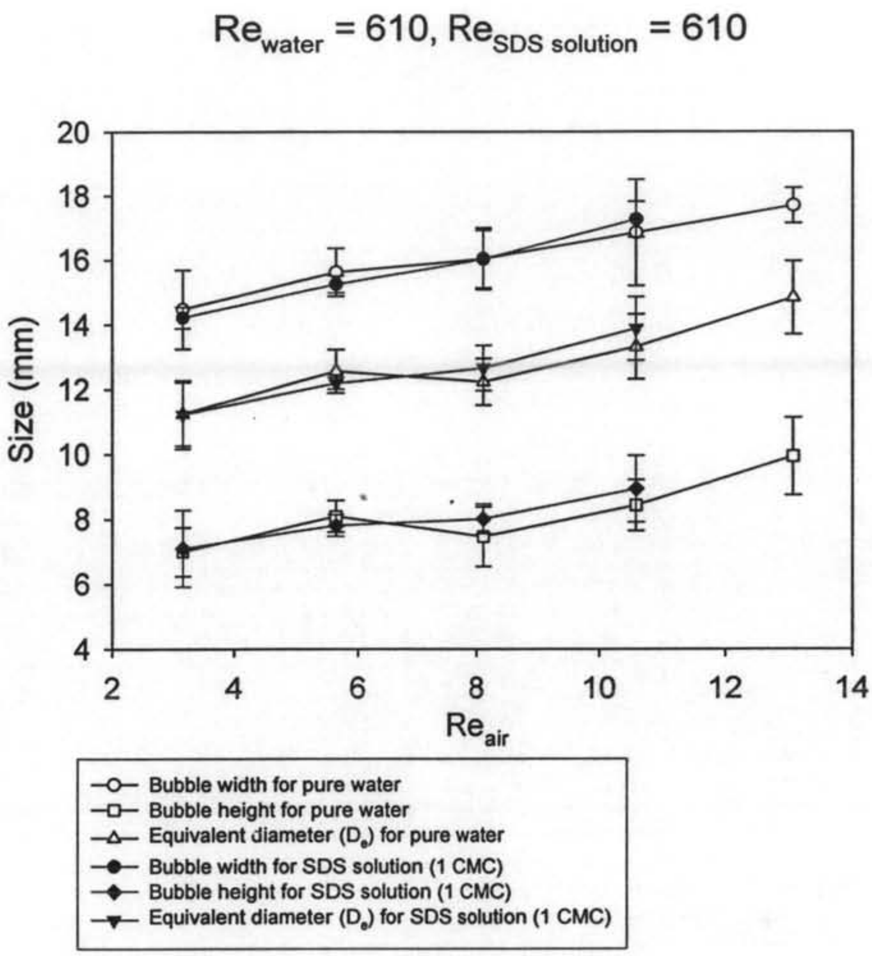

Figure E4 Bubble width, bubble height and equivalent diameter vs. air Reynolds number of pure water at $Re_{water} = 610$ and SDS solution (1 CMC) at $Re_{SDS\ solution} = 610$.

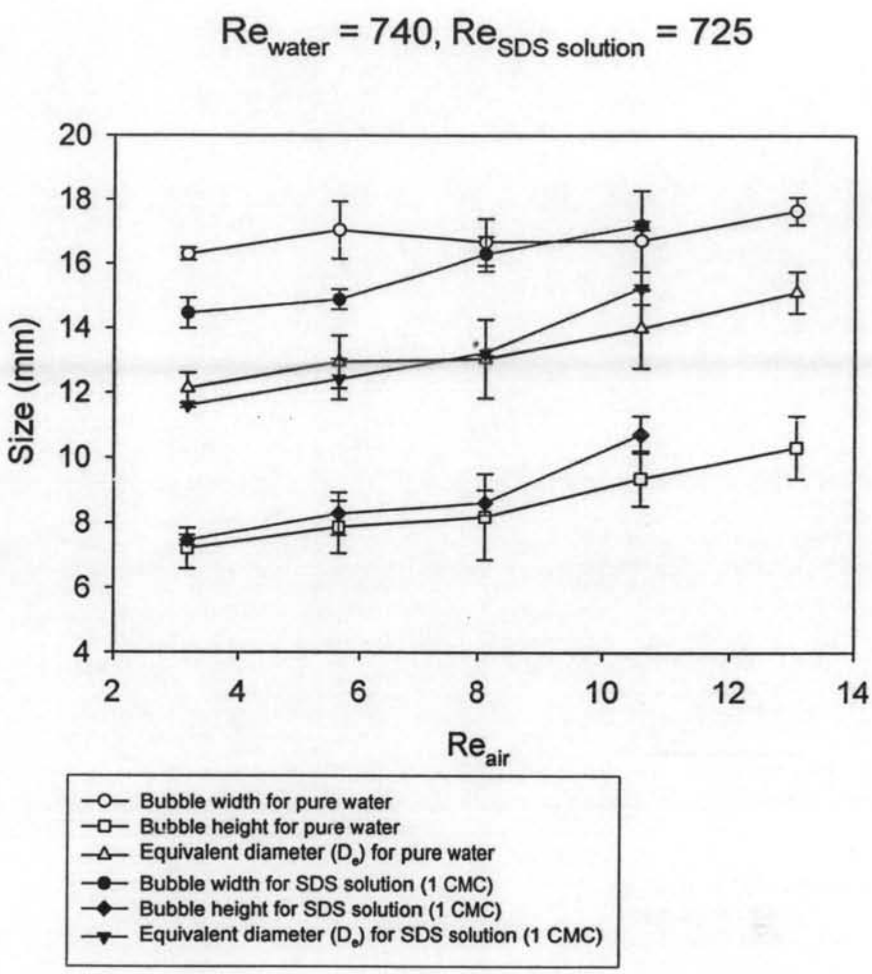

Figure E5 Bubble width, bubble height and equivalent diameter vs. air Reynolds number of pure water at Re_{water} = 740 and SDS solution (1 CMC) at $Re_{SDS\ solution}$ = 725.

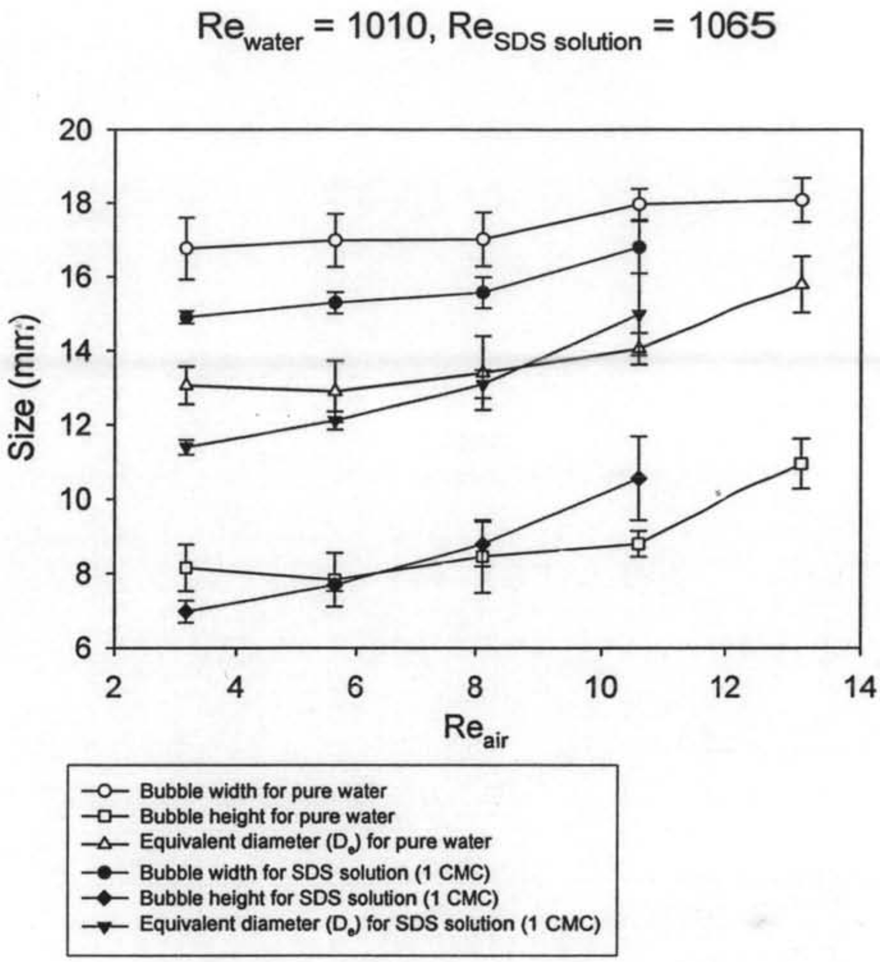

Figure E6 Bubble width, bubble height and equivalent diameter vs. air Reynolds number of pure water at Re_{water} = 1010 and SDS solution (1 CMC) at $Re_{SDS\ solution}$ = 1065.

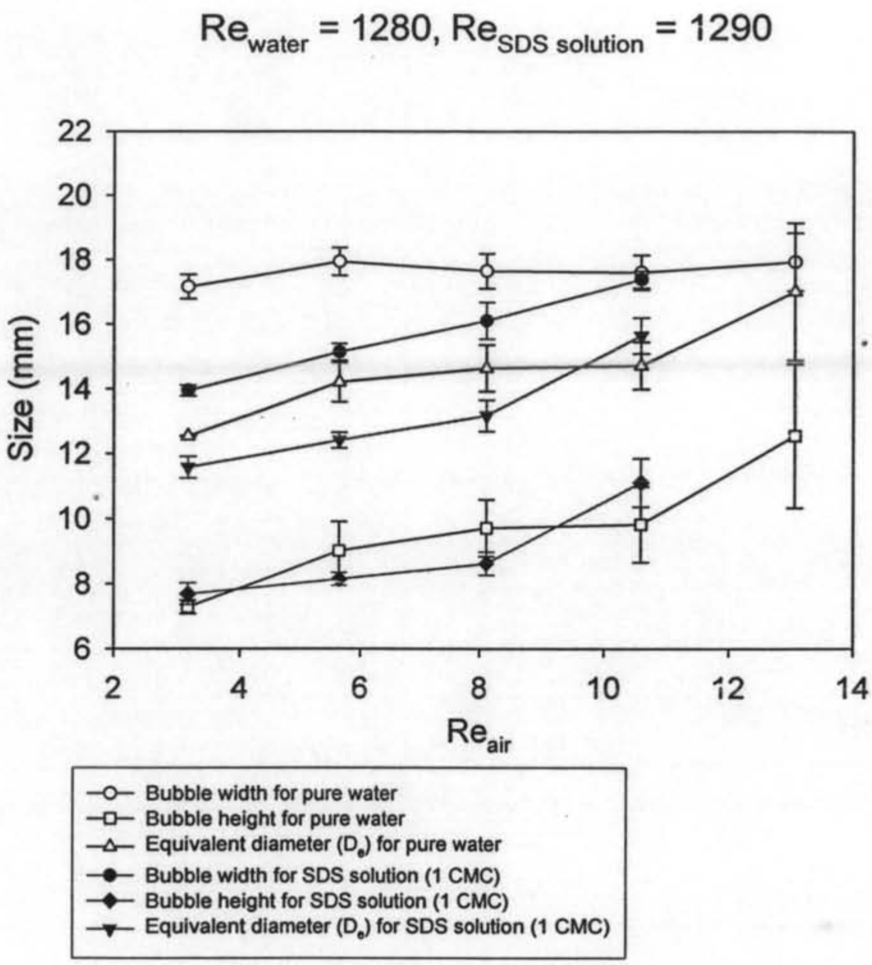

Figure E7 Bubble width, bubble height and equivalent diameter vs. air Reynolds number of pure water at $Re_{water} = 1280$ and SDS solution (1 CMC) at $Re_{SDS\ solution} = 1290$.

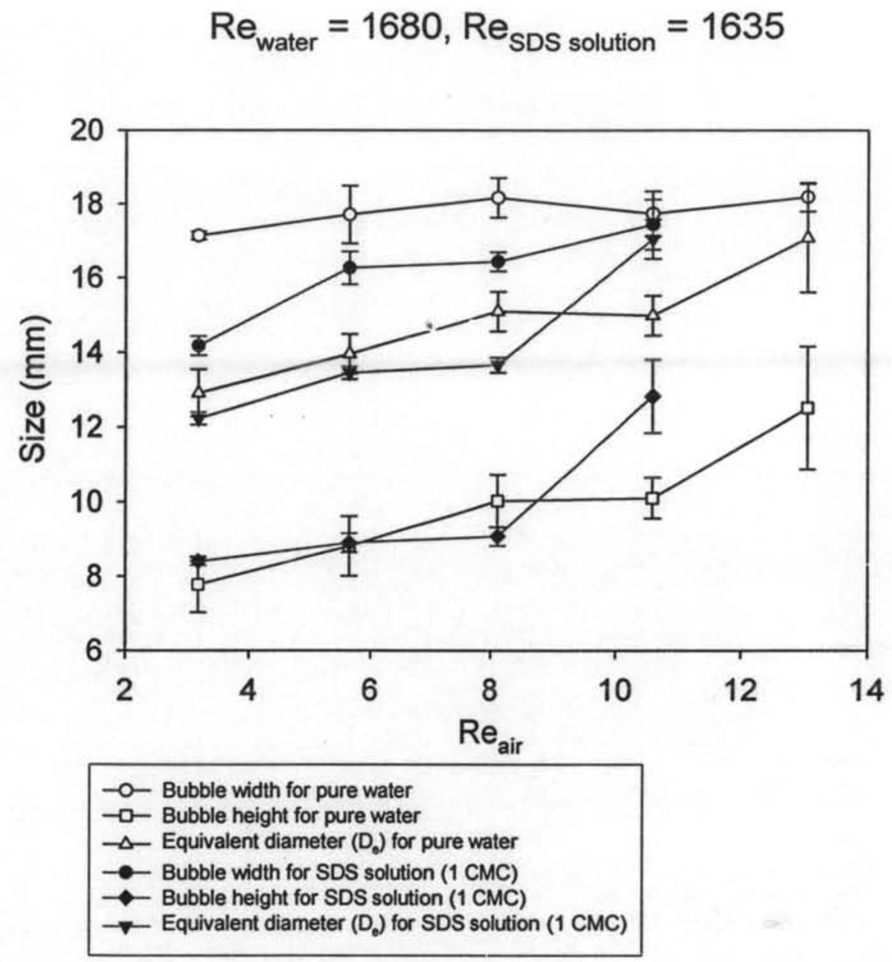

Figure E8 Bubble width, bubble height and equivalent diameter vs. air Reynolds number of pure water at $Re_{water} = 1680$ and SDS solution (1 CMC) at $Re_{SDS\ solution} = 1635$.

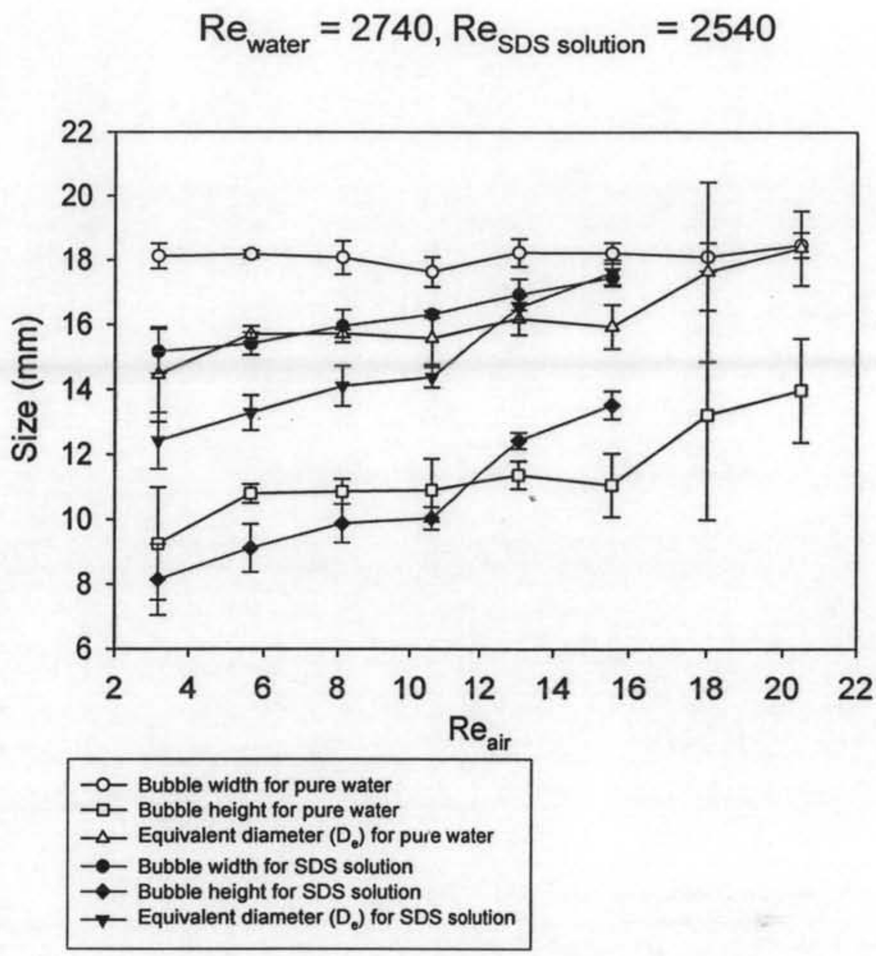

Figure E9 Bubble width, bubble height and equivalent diameter vs. air Reynolds number of pure water at $Re_{water} = 2740$ and SDS solution (1 CMC) at $Re_{SDS\ solution} = 2540$.

Appendix F Determination of Bubble Velocity from Wilkes Theory and Experiment

Table F1 Determination of bubble velocity for pure water from Wilkes theory and experiment

Physical properties of air and water used in experiment:

density of water, $\rho_{water} = 994.7$ kg/m^3; viscosity of water, $\mu_{water} = 8.51 \times 10^{-4}$ Pa.s

density of air, $\rho_{air} = 1.18$ kg/m^3; viscosity of air, $\mu_{air} = 1.85 \times 10^{-5}$ Pa.s

temperature, T = 31 °C (± 1 °C); inner pipe diameter = 0.019 m; cross-sectional area of pipe, A = 0.00028 m^2

Bubble velocity from theory, $$v_g = \frac{Q_{qir} + Q_{liquid}}{A} + u_b \quad \text{(F1)}$$

Bubble velocity rising in stagnant liquid, $$u_b = 1.00\sqrt{g R_b} \quad \text{(F2)}$$

where R_b is equivalent radius of the bubble which defined as the radius of a sphere that has the same volume as the bubble

Determination of bubble velocity from experiment by timing the bubble at known distance (0.7m)

Q_{water} (m^3/sec)	Re_{water}	Q_{air} (m^3/sec)	Re_{air}	Time of bubble travel (sec)/0.7m					average (sec/0.7m)	Bubble velocity (m/s)					Average bubble velocity from experiment (m/s)	Bubble velocity from theory (m/s)
				1	2	3	4	5		1	2	3	4	5		
0	0	7.4E-07	3.17	4.48	4.45	4.5	4.53	4.57	4.51	0.16	0.16	0.16	0.15	0.15	0.16	0.27
0	0	1.3E-06	5.64	4.56	4.61	4.63	4.54	4.54	4.58	0.15	0.15	0.15	0.15	0.15	0.15	0.27
0	0	1.9E-06	8.12	4.54	4.48	4.47	4.37	4.4	4.45	0.15	0.16	0.16	0.16	0.16	0.16	0.28
4.4E-06	340	7.4E-07	3.17	4.11	4.13	4.03	4.04	4.1	4.08	0.17	0.17	0.17	0.17	0.17	0.17	0.29
4.4E-06	340	1.3E-06	5.64	4.18	4.18	4.16	4.26	4.33	4.22	0.17	0.17	0.17	0.16	0.16	0.17	0.29
4.4E-06	340	1.9E-06	8.12	4.09	4.2	4.05	4.16	4.13	4.13	0.17	0.17	0.17	0.17	0.17	0.17	0.29
4.4E-06	340	2.5E-06	10.59	4.18	4.09	4.07	4.11	4.03	4.10	0.17	0.17	0.17	0.17	0.17	0.17	0.29
4.4E-06	340	3.1E-06	13.06	4.01	4.09	3.95	3.99	3.99	4.01	0.17	0.17	0.18	0.18	0.18	0.17	0.30
6.1E-06	480	7.4E-07	3.17	3.79	3.87	3.86	3.87	3.88	3.85	0.18	0.18	0.18	0.18	0.18	0.18	0.29
6.1E-06	480	1.3E-06	5.64	3.97	3.97	3.97	3.93	3.93	3.95	0.18	0.18	0.18	0.18	0.18	0.18	0.30
6.1E-06	480	1.9E-06	8.12	3.87	3.93	3.87	3.95	3.94	3.91	0.18	0.18	0.18	0.18	0.18	0.18	0.30
6.1E-06	480	2.5E-06	10.59	3.89	3.87	3.8	3.73	3.94	3.85	0.18	0.18	0.18	0.19	0.18	0.18	0.30
6.1E-06	480	3.1E-06	13.06	3.61	3.76	3.71	3.89	3.73	3.74	0.19	0.19	0.19	0.18	0.19	0.19	0.30
7.8E-06	610	7.4E-07	3.17	3.85	3.67	3.66	3.64	3.83	3.73	0.18	0.19	0.19	0.19	0.18	0.19	0.30
7.8E-06	610	1.3E-06	5.64	3.72	3.88	3.86	3.74	3.89	3.82	0.19	0.18	0.18	0.19	0.18	0.18	0.30
7.8E-06	610	1.9E-06	8.12	3.75	3.76	3.8	3.79	3.68	3.76	0.19	0.19	0.18	0.18	0.19	0.19	0.30
7.8E-06	610	2.5E-06	10.59	3.79	3.75	3.84	3.71	3.71	3.76	0.18	0.19	0.18	0.19	0.19	0.19	0.31
7.8E-06	610	3.1E-06	13.06	3.64	3.75	3.73	3.69	3.69	3.70	0.19	0.19	0.19	0.19	0.19	0.19	0.31
9.5E-06	740	7.4E-07	3.17	3.6	3.69	3.62	3.58	3.59	3.62	0.19	0.19	0.19	0.20	0.19	0.19	0.31
9.5E-06	740	1.3E-06	5.64	3.73	3.72	3.58	3.62	3.58	3.65	0.19	0.19	0.20	0.19	0.20	0.19	0.31
9.5E-06	740	1.9E-06	8.12	3.71	3.74	3.77	3.68	3.66	3.71	0.19	0.19	0.19	0.19	0.19	0.19	0.31
9.5E-06	740	2.5E-06	10.59	3.62	3.6	3.73	3.57	3.65	3.63	0.19	0.19	0.19	0.20	0.19	0.19	0.31
9.5E-06	740	3.1E-06	13.06	3.67	3.55	3.56	3.61	3.56	3.59	0.19	0.20	0.20	0.19	0.20	0.20	0.31
1.3E-05	1010	7.4E-07	3.17	3.47	3.39	3.42	3.37	3.42	3.41	0.20	0.21	0.20	0.21	0.20	0.21	0.32
1.3E-05	1010	1.3E-06	5.64	3.47	3.51	3.46	3.49	3.47	3.48	0.20	0.20	0.20	0.20	0.20	0.20	0.32
1.3E-05	1010	1.9E-06	8.12	3.5	3.41	3.41	3.49	3.43	3.45	0.20	0.21	0.21	0.20	0.20	0.20	0.32

1.3E-05	1010	2.5E-06	10.59	3.35	3.36	3.41	3.43	3.43	3.40	0.21	0.21	0.21	0.20	0.20	0.21	0.32
1.3E-05	1010	3.1E-06	13.06	3.37	3.29	3.34	3.25	3.38	3.33	0.21	0.21	0.21	0.22	0.21	0.21	0.33
1.6E-05	1280	7.4E-07	3.17	3.24	3.18	3.16	3.24	3.22	3.21	0.22	0.22	0.22	0.22	0.22	0.22	0.33
1.6E-05	1280	1.3E-06	5.64	3.19	3.23	3.16	3.19	3.19	3.19	0.22	0.22	0.22	0.22	0.22	0.22	0.33
1.6E-05	1280	1.9E-06	8.12	3.23	3.25	3.28	3.26	3.21	3.25	0.22	0.22	0.21	0.21	0.22	0.22	0.33
1.6E-05	1280	2.5E-06	10.59	3.22	3.16	3.17	3.13	3.25	3.19	0.22	0.22	0.22	0.22	0.22	0.22	0.34
1.6E-05	1280	3.1E-06	13.06	3.17	3.11	3.22	3.23	3.11	3.17	0.22	0.23	0.22	0.22	0.23	0.22	0.34
2.1E-05	1680	7.4E-07	3.17	2.97	2.9	2.93	2.93	2.96	2.94	0.24	0.24	0.24	0.24	0.24	0.24	0.35
2.1E-05	1680	1.3E-06	5.64	2.99	3.04	3.02	2.96	3.07	3.02	0.23	0.23	0.23	0.24	0.23	0.23	0.35
2.1E-05	1680	1.9E-06	8.12	2.99	2.97	3	2.98	3.02	2.99	0.23	0.24	0.23	0.23	0.23	0.23	0.35
2.1E-05	1680	2.5E-06	10.59	3.01	2.94	2.98	2.94	2.93	2.96	0.23	0.24	0.23	0.24	0.24	0.24	0.35
2.1E-05	1680	3.1E-06	13.06	2.86	2.88	2.9	2.95	2.93	2.90	0.24	0.24	0.24	0.24	0.24	0.24	0.36
3.5E-05	2740	7.4E-07	3.17	2.43	2.45	2.42	2.37	2.43	2.42	0.29	0.29	0.29	0.30	0.29	0.29	0.40
3.5E-05	2740	1.3E-06	5.64	2.38	2.41	2.46	2.38	2.4	2.41	0.29	0.29	0.28	0.29	0.29	0.29	0.40
3.5E-05	2740	1.9E-06	8.12	2.41	2.42	2.43	2.49	2.45	2.44	0.29	0.29	0.29	0.28	0.29	0.29	0.40
3.5E-05	2740	2.5E-06	10.59	2.41	2.39	2.45	2.42	2.42	2.42	0.29	0.29	0.29	0.29	0.29	0.29	0.40
3.5E-05	2740	3.1E-06	13.06	2.37	2.43	2.41	2.43	2.4	2.41	0.30	0.29	0.29	0.29	0.29	0.29	0.40
3.5E-05	2740	3.6E-06	15.54	2.36	2.35	2.34	2.36	2.37	2.36	0.30	0.30	0.30	0.30	0.30	0.30	0.41
3.5E-05	2740	4.2E-06	18.02	2.3	2.3	2.33	2.34	2.35	2.32	0.30	0.30	0.30	0.30	0.30	0.30	0.41
3.5E-05	2740	4.8E-06	20.49	2.35	2.27	2.27	2.29	2.27	2.29	0.30	0.31	0.31	0.31	0.31	0.31	0.41

Table F2 Determination of bubble velocity for SDS solution (1 CMC) from Wilkes theory and experiment

Physical properties of air and SDS solution (1 CMC) used in experiment:

density of SDS solution, $\rho_{SDS\ solution}$ = 994.97 kg/m^3; viscosity of SDS solution, $\mu_{SDS\ solution}$ = 1.01 × 10^{-3} Pa.s

density of air, ρ_{air} = 1.18 kg/m^3; viscosity of air, μ_{air} = 1.85 × 10^{-5} Pa.s

temperature, T = 31 °C (± 1 °C); inner pipe diameter = 0.019 m; cross-sectional area of pipe, A = 0.00028 m^2

$Q_{solution}$ (m^3/sec)	$Re_{solution}$	Qair (m^3/sec)	Re_{air}	Time of bubble travel (sec)/0.7m					average (sec/0.7m)	Bubble velocity (m/s)					Average bubble velocity from experiment (m/s)	Bubble velocity from theory (m/s)
				1	2	3	4	5		1	2	3	4	5		
0	0	7.4E-07	3.17	4.26	4.45	4.51	4.46	4.62	4.46	0.16	0.16	0.16	0.16	0.15	0.16	0.24
0	0	1.3E-06	5.64	4.57	4.3	4.29	4.36	4.33	4.37	0.15	0.16	0.16	0.16	0.16	0.16	0.25
5.8E-06	385	7.4E-07	3.17	3.87	3.77	3.85	3.78	3.83	3.82	0.18	0.19	0.18	0.19	0.18	0.18	0.27
5.8E-06	385	1.3E-06	5.64	3.81	3.89	3.89	3.87	3.8	3.85	0.18	0.18	0.18	0.18	0.18	0.18	0.28
5.8E-06	385	1.9E-06	8.12	3.89	3.83	3.81	3.81	3.82	3.83	0.18	0.18	0.18	0.18	0.18	0.18	0.28
5.8E-06	385	2.5E-06	10.59	3.75	3.8	3.69	3.83	3.76	3.77	0.19	0.18	0.19	0.18	0.19	0.19	0.28
7.6E-06	500	7.4E-07	3.17	3.59	3.6	3.61	3.67	3.57	3.61	0.19	0.19	0.19	0.19	0.20	0.19	0.28
7.6E-06	500	1.3E-06	5.64	3.63	3.64	3.7	3.64	3.72	3.67	0.19	0.19	0.19	0.19	0.19	0.19	0.28
7.6E-06	500	1.9E-06	8.12	3.65	3.65	3.63	3.63	3.62	3.64	0.19	0.19	0.19	0.19	0.19	0.19	0.28
7.6E-06	500	2.5E-06	10.59	3.57	3.55	3.61	3.56	3.65	3.59	0.20	0.20	0.19	0.20	0.19	0.20	0.29
9.3E-06	610	7.4E-07	3.17	3.55	3.53	3.56	3.53	3.46	3.53	0.20	0.20	0.20	0.20	0.20	0.20	0.29
9.3E-06	610	1.3E-06	5.64	3.55	3.47	3.48	3.47	3.53	3.50	0.20	0.20	0.20	0.20	0.20	0.20	0.29
9.3E-06	610	1.9E-06	8.12	3.42	3.42	3.48	3.47	3.47	3.45	0.20	0.20	0.20	0.20	0.20	0.20	0.29
9.3E-06	610	2.5E-06	10.59	3.37	3.4	3.39	3.38	3.41	3.39	0.21	0.21	0.21	0.21	0.21	0.21	0.29
1.1E-05	725	7.4E-07	3.17	3.37	3.53	3.36	3.43	3.39	3.42	0.21	0.20	0.21	0.20	0.21	0.20	0.29
1.1E-05	725	1.3E-06	5.64	3.43	3.37	3.39	3.49	3.39	3.41	0.20	0.21	0.21	0.20	0.21	0.21	0.29

1.1E-05	725	1.9E-06	8.12	3.29	3.47	3.34	3.33	3.38	3.36	0.21	0.20	0.21	0.21	0.21	0.21	0.30
1.1E-05	725	2.5E-06	10.59	3.33	3.36	3.27	3.28	3.32	3.31	0.21	0.21	0.21	0.21	0.21	0.21	0.30
1.6E-05	1065	7.4E-07	3.17	3.07	3.11	3.13	3.09	3.08	3.10	0.23	0.23	0.22	0.23	0.23	0.23	0.31
1.6E-05	1065	1.3E-06	5.64	3.02	3.04	3.03	3.07	3.1	3.05	0.23	0.23	0.23	0.23	0.23	0.23	0.31
1.6E-05	1065	1.9E-06	8.12	3.03	3.06	3.06	3.05	2.99	3.04	0.23	0.23	0.23	0.23	0.23	0.23	0.31
1.6E-05	1065	2.5E-06	10.59	3.02	3.06	3	3	3.01	3.02	0.23	0.23	0.23	0.23	0.23	0.23	0.32
2.0E-05	1290	7.4E-07	3.17	2.86	2.99	2.94	2.94	2.95	2.94	0.24	0.23	0.24	0.24	0.24	0.24	0.32
2.0E-05	1290	1.3E-06	5.64	2.92	2.98	2.86	2.88	2.87	2.90	0.24	0.23	0.24	0.24	0.24	0.24	0.32
2.0E-05	1290	1.9E-06	8.12	2.88	2.88	2.84	2.83	2.87	2.86	0.24	0.24	0.25	0.25	0.24	0.24	0.33
2.0E-05	1290	2.5E-06	10.59	2.84	2.82	2.82	2.9	2.88	2.85	0.25	0.25	0.25	0.24	0.24	0.25	0.33
2.5E-05	1635	7.4E-07	3.17	2.67	2.69	2.72	2.67	2.71	2.69	0.26	0.26	0.26	0.26	0.26	0.26	0.34
2.5E-05	1635	1.3E-06	5.64	2.67	2.69	2.66	2.63	2.74	2.68	0.26	0.26	0.26	0.27	0.26	0.26	0.34
2.5E-05	1635	1.9E-06	8.12	2.64	2.63	2.59	2.66	2.63	2.63	0.27	0.27	0.27	0.26	0.27	0.27	0.34
2.5E-05	1635	2.5E-06	10.59	2.61	2.67	2.62	2.58	2.57	2.61	0.27	0.26	0.27	0.27	0.27	0.27	0.35
3.9E-05	2540	7.4E-07	3.17	2.19	2.2	2.14	2.15	2.17	2.17	0.32	0.32	0.33	0.33	0.32	0.32	0.39
3.9E-05	2540	1.3E-06	5.64	2.19	2.13	2.16	2.13	2.16	2.15	0.32	0.33	0.32	0.33	0.32	0.33	0.39
3.9E-05	2540	1.9E-06	8.12	2.19	2.13	2.16	2.17	2.11	2.15	0.32	0.33	0.32	0.32	0.33	0.33	0.39
3.9E-05	2540	2.5E-06	10.59	2.13	2.12	2.17	2.11	2.14	2.13	0.33	0.33	0.32	0.33	0.33	0.33	0.39
3.9E-05	2540	3.1E-06	13.06	2.09	2.11	2.1	2.12	2.12	2.11	0.33	0.33	0.33	0.33	0.33	0.33	0.40
3.9E-05	2540	3.6E-06	15.54	2.12	2.11	2.03	2.07	2.09	2.08	0.33	0.33	0.34	0.34	0.33	0.34	0.40

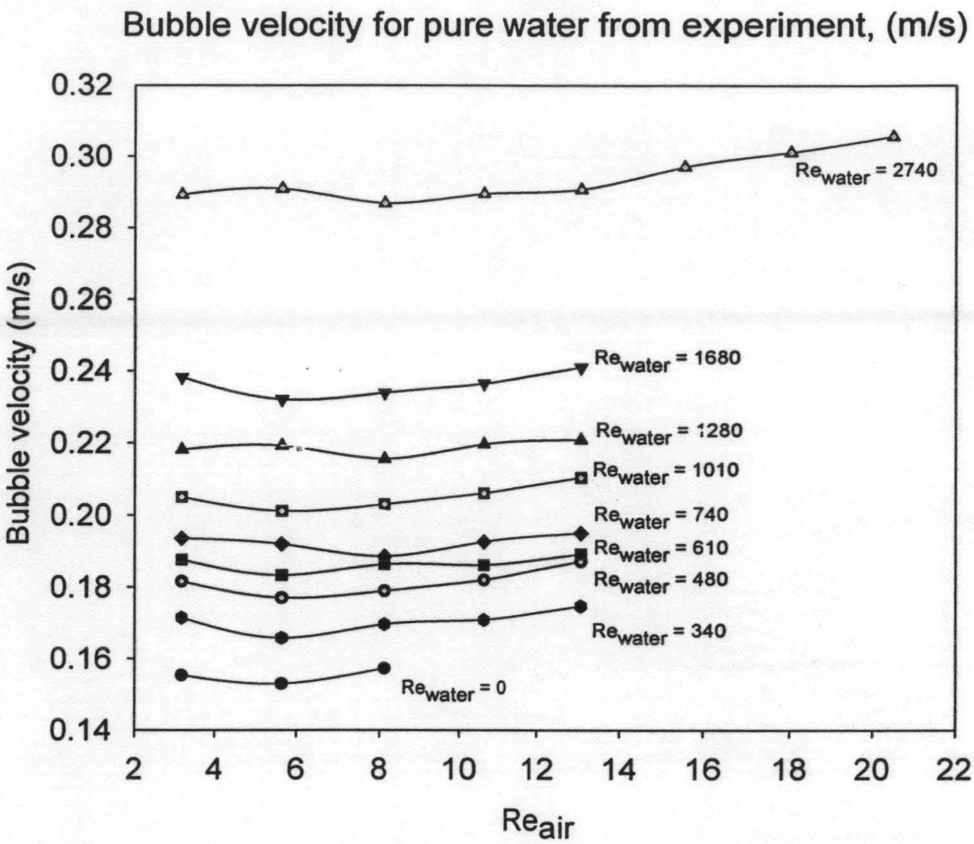

Figure F1 Bubble velocity from experiment vs. air Reynolds number of pure water.

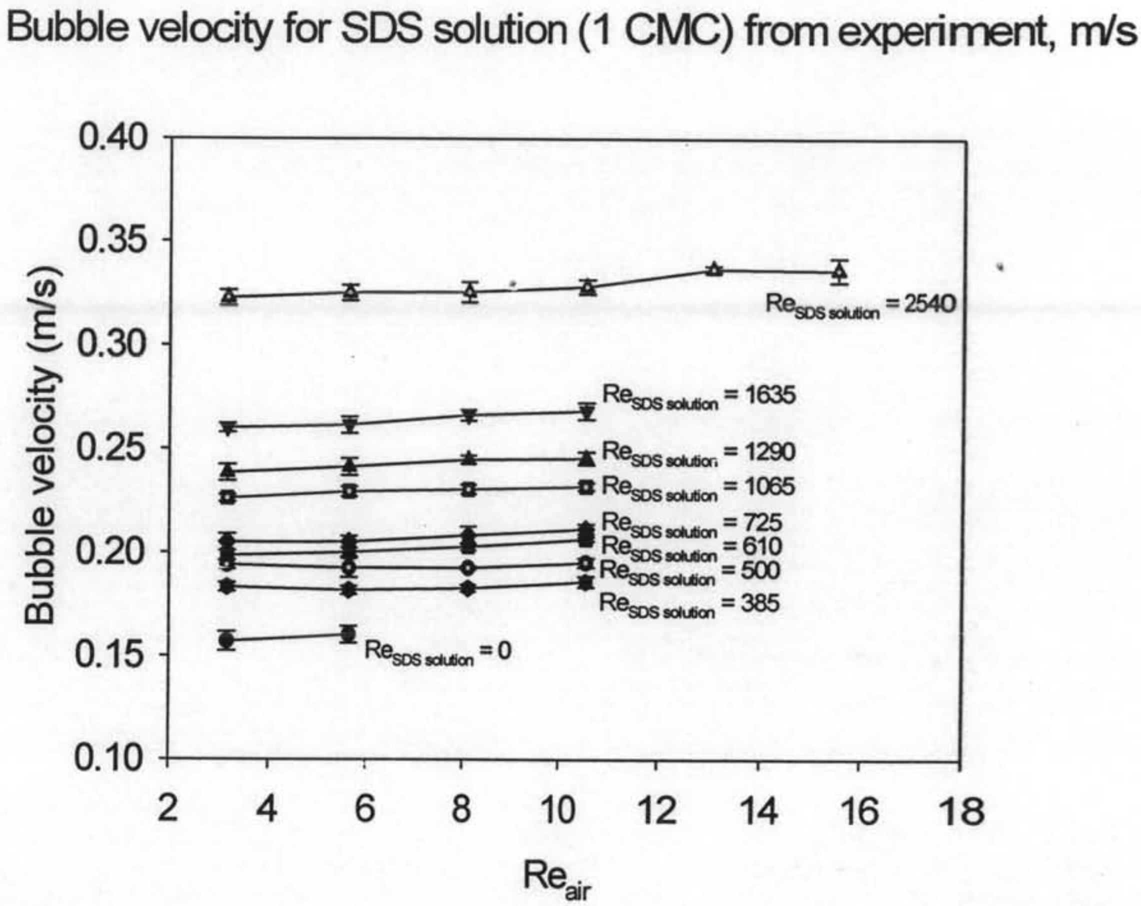

Figure F2 Bubble velocity from experiment vs. air Reynolds number of SDS solution (1 CMC).

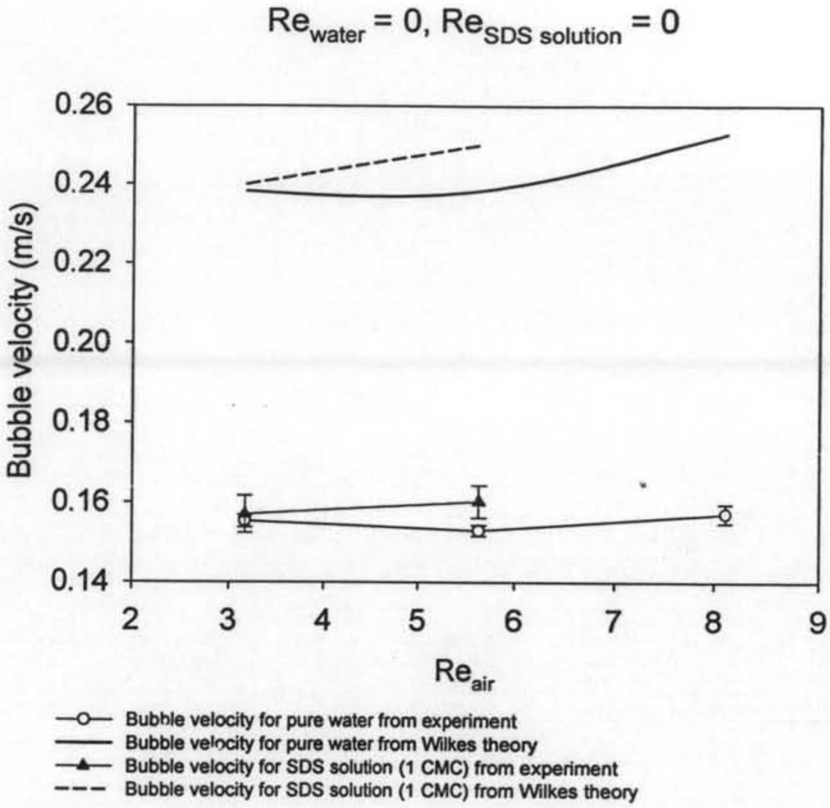

Figure F3 Comparison between Wilkes theory and experimental bubble velocity vs. air Reynolds number of pure water at $Re_{water} = 0$ and SDS solution (1 CMC) at $Re_{SDS\ solution} = 0$.

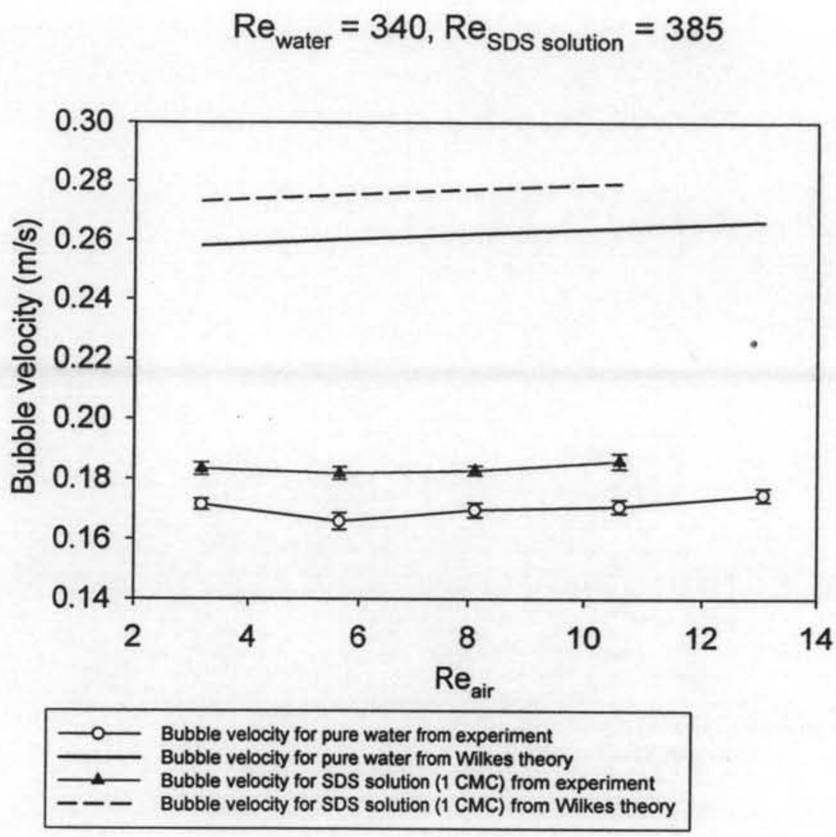

Figure F4 Comparison between Wilkes theory and experimental bubble velocity vs. air Reynolds number of pure water at $Re_{water} = 340$ and SDS solution (1 CMC) at $Re_{SDS\ solution} = 385$.

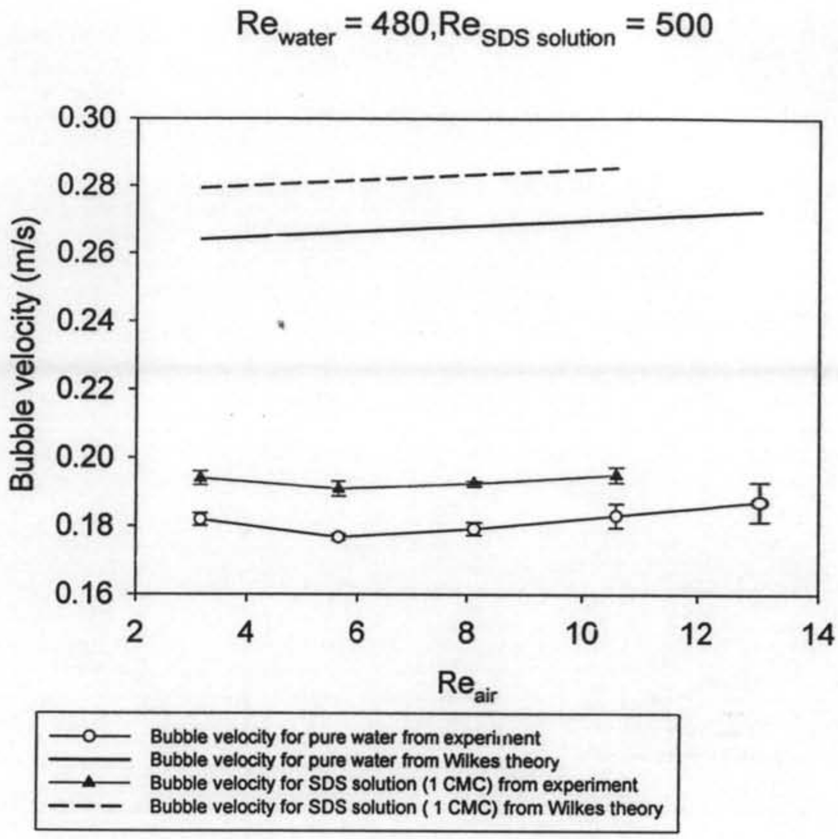

Figure F5 Comparison between Wilkes theory and experimental bubble velocity vs. air Reynolds number of pure water at $Re_{water} = 480$ and SDS solution (1 CMC) at $Re_{SDS\ solution} = 500$.

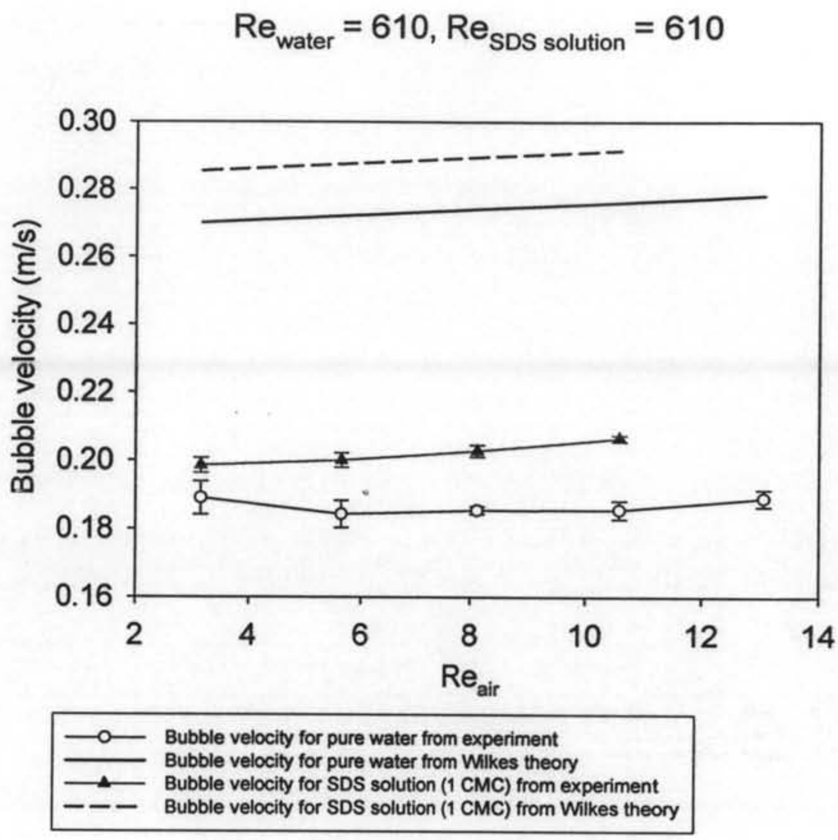

Figure F6 Comparison between Wilkes theory and experimental bubble velocity vs. air Reynolds number of pure water at $Re_{water} = 610$ and SDS solution (1 CMC) at $Re_{SDS\ solution} = 610$.

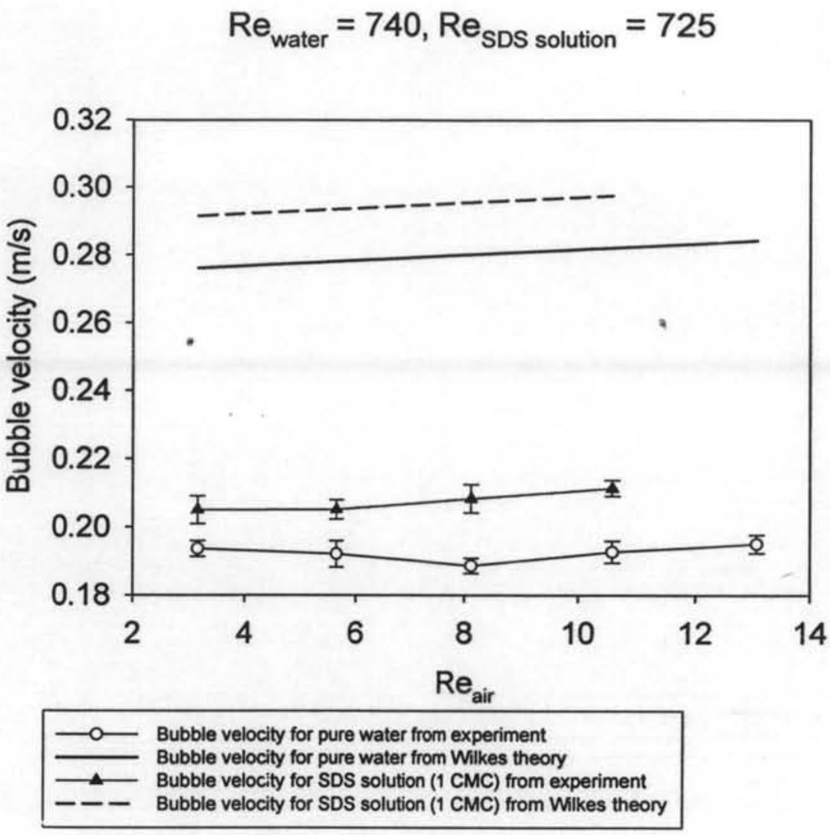

Figure F7 Comparison between Wilkes theory and experimental bubble velocity vs. air Reynolds number of pure water at Re_{water} = 740 and SDS solution (1 CMC) at $Re_{SDS\ solution}$ = 725.

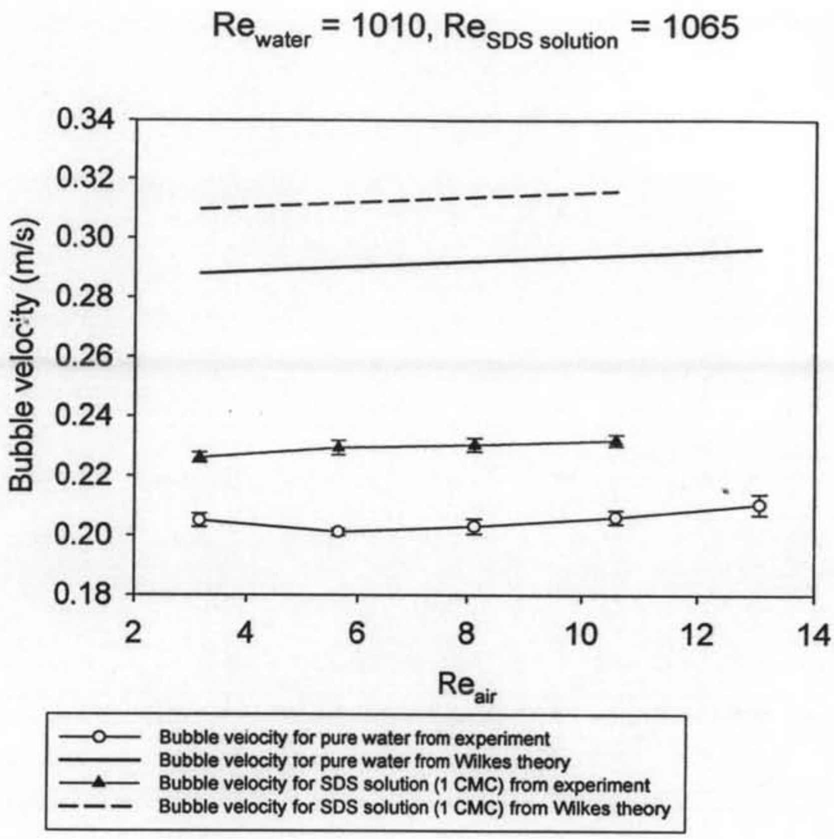

Figure F8 Comparison between Wilkes theory and experimental bubble velocity vs. air Reynolds number of pure water at $Re_{water} = 1010$ and SDS solution (1 CMC) at $Re_{SDS\ solution} = 1065$.

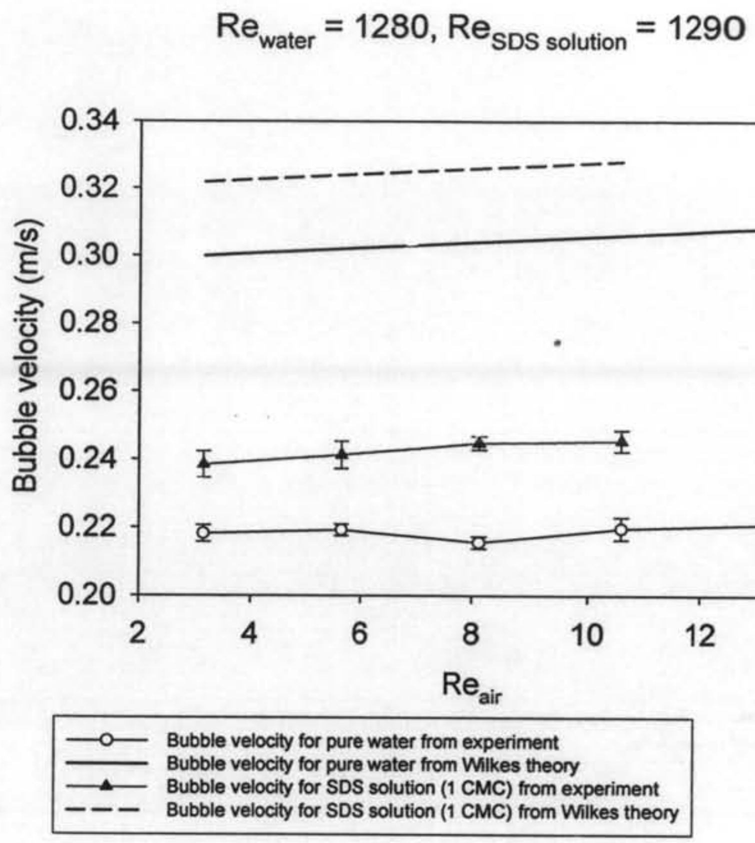

Figure F9 Comparison between Wilkes theory and experimental bubble velocity vs. air Reynolds number of pure water at Re_{water} = 1280 and SDS solution (1 CMC) at $Re_{SDS\ solution}$ = 1290.

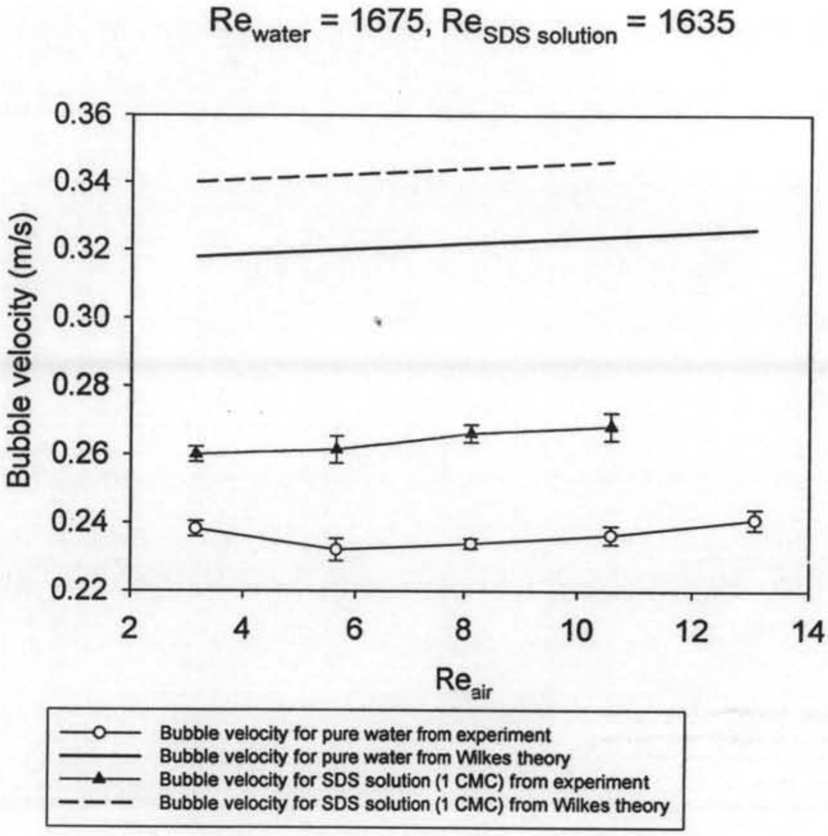

Figure F10 Comparison between Wilkes theory and experimental bubble velocity vs. air Reynolds number of pure water at $Re_{water} = 1675$ and SDS solution (1 CMC) at $Re_{SDS\ solution} = 1635$.

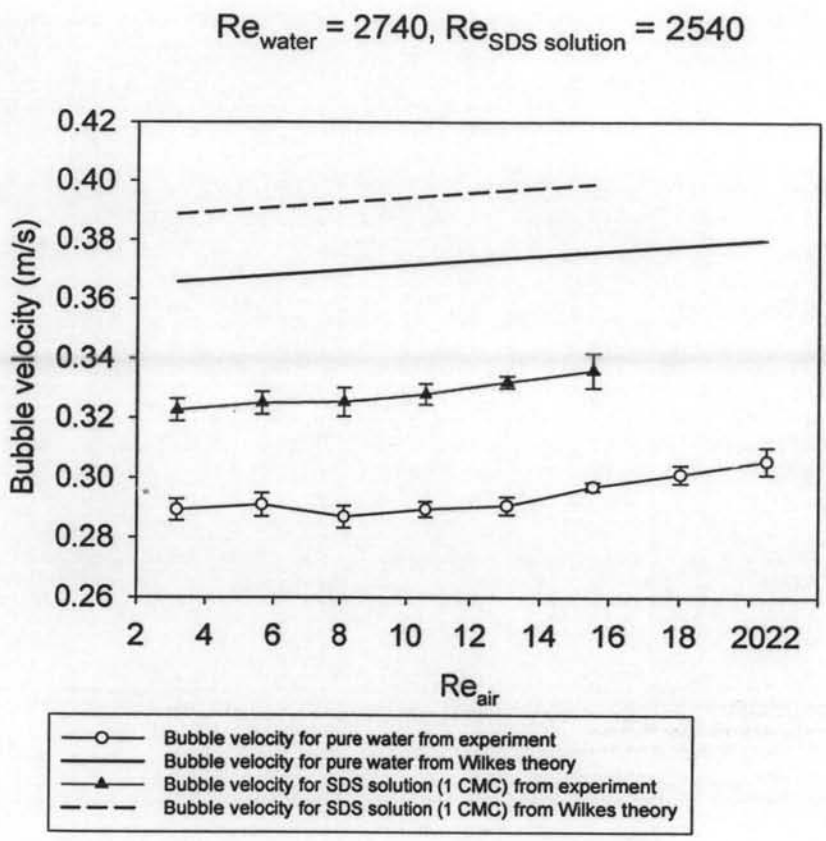

Figure F11 Comparison between Wilkes theory and experimental bubble velocity vs. air Reynolds number of pure water at $Re_{water} = 2740$ and SDS solution (1 CMC) at $Re_{SDS\ solution} = 2540$.

Appendix G Comparison The Pressure Gradient from The Experiment Between Pure Water and SDS Solution (1 CMC)

Table G1 Comparison the pressure gradient from the experiment between pure water and SDS solution (1 CMC) by opening the whole valve at pressure tab

Physical properties of air, water and SDS solution (1 CMC) used in experiment:

density of water, ρ_{water} = 994.7 kg/m^3; viscosity of water, μ_{water} = 8.51 × 10^{-4} Pa.s

density of water, $\rho_{SDS\ solution}$ = 994.97 kg/m^3; viscosity of SDS solution, $\mu_{SDS\ solution}$ = 1.01 × 10^{-3} Pa.s

density of air, ρ_{air} = 1.18 kg/m^3; viscosity of air, μ_{air} = 1.85 × 10^{-5} Pa.s

temperature, T = 31 °C (± 1 °C); inner pipe diameter, D = 0.019 m; cross-sectional area of pipe, A = 0.00028 m^2; pressure taps difference = 0.4 m

Re_{water}	Re_{air}	(dp/dz) from experiment		$Re_{SDS\ solution}$	Re_{air}	(dp/dz) from experiment	
		maximum (kPa/m)	minimum (kPa/m)			maximum (kPa/m)	minimum (kPa/m)
0	3.17	9.6877	9.6145	0	3.17	9.7444	9.7119
0	5.64	9.6389	9.5169	0	5.64	9.5736	9.5410
0	8.12	9.5657	9.3705	0	8.12	9.5085	9.4922
0	10.59	9.5657	9.1021	0	10.59	9.5085	9.4353
0	13.06	9.4779	8.7556	0	13.06	9.2580	9.1457
0	15.54	9.4047	8.6580	0	15.54	9.1213	9.0237
0	18.02	9.1655	8.1894	0	18.02	9.0335	8.8334
0	20.49	9.2485	7.7844	0	20.49	8.8578	8.6187
0	22.95	9.2485	7.3695	0	22.95	8.5113	8.3844
0	28.08	9.1265	7.2719	0	28.08	8.2380	8.0037
0	33.21	8.8581	6.8327	0	33.21	7.9305	7.6133
0	38.33	8.7605	6.5398	0	38.33	7.7402	7.4767
0	43.46	8.5408	6.5154	0	43.46	7.5059	7.1009
0	48.59	8.4920	6.3690	0	48.59	7.4181	6.7349
0	58.85	8.4188	5.5637	0	58.85	7.0358	6.1411
0	69.10	8.0772	5.2953	0	69.10	6.7105	5.2870
0	79.36	7.7112	5.1245	0	79.36	6.5478	4.6363
0	89.62	7.9796	3.9776	0	89.62	6.2631	3.4976
0	99.87	7.8332	4.4412	-	-	-	-
344	3.17	9.6877	9.5901	385	3.17	9.6875	9.6142
344	5.64	9.6389	9.5413	385	5.64	9.5898	9.5166
344	8.12	9.5413	9.4437	385	8.12	9.4272	9.3133
344	10.59	9.4925	9.3705	385	10.59	9.3946	9.2726
344	13.06	9.4925	9.0533	385	13.06	9.2889	9.0286
344	15.54	9.3705	8.7116	385	15.54	9.0969	8.7846
344	18.02	9.3266	8.4920	385	18.02	9.0872	8.7651

344	20.49	9.1362	8.1602	385	20.49	8.9310	8.7114
344	22.95	9.1021	7.9845	385	22.95	8.7846	8.3063
344	28.08	9.0240	7.4671	385	28.08	8.7602	8.4918
344	33.21	9.1021	7.0523	385	33.21	8.3454	7.9061
344	38.33	8.9801	6.7351	385	38.33	8.1648	7.7109
344	43.46	9.0045	6.3202	385	43.46	8.1257	7.4913
344	48.59	8.8337	6.1494	385	48.59	7.9549	7.2473
344	58.85	8.5896	5.8322	385	58.85	7.7109	6.9789
344	69.10	8.4920	5.6125	385	69.10	7.6377	6.5396
344	79.36	8.5408	4.7341	385	79.36	7.2229	6.0516
344	89.62	8.4920	4.7341	385	89.62	7.1253	5.7100
344	99.87	8.2480	4.4412	385	99.87	6.9545	5.8076
344	177	8.4920	2.1474	385	177	6.2468	2.5866
344	285	8.1016	-0.4880	385	285	4.2703	1.7569
344	356	7.4183	-1.6106	385	356	2.6354	1.3665
344	499	8.0528	-1.3177	385	499	2.5622	0.8541
344	713	6.6374	-1.3177	385	713	1.9521	0.5368
344	1425	5.1733	-1.0249	385	1425	0.8785	0.4148
344	2851	3.6604	0.0488	385	2851	1.3274	1.1176
344	4276	2.5134	0.2440	385	4276	1.3372	1.1225
344	4989	2.1962	0.3416	385	4989	1.4446	1.2786
344	5702	1.9278	0.6833	385	5702	1.3958	1.2835
344	7127	1.7570	0.8443	385	7127	1.4836	1.3665
344	14255	0.6101	0.5369	385	14255	1.0574	0.9517
344	21382	0.6833	0.6101	385	21382	0.9435	0.8459
344	28510	0.7809	0.6833	385	28510	0.9679	0.9761
344	35637	1.0737	1.0493	385	35637	1.3014	1.3421
344	42765	1.4641	1.2689	385	42765	1.8139	1.8301
344	49892	1.9034	1.5862	385	49892	2.2938	2.3182
344	57020	2.1230	2.0742	385	57020	2.6272	2.8713
344	64147	2.5622	2.5134	385	64147	2.9851	2.9851
344	71275	3.1235	3.1235	385	71275	3.4406	3.3837
477	3.17	9.7365	9.6389	500	3.17	9.7607	9.7363
477	5.64	9.7121	9.5657	500	5.64	9.7363	9.6630
477	8.12	9.6633	9.4925	500	8.12	9.4922	9.3214
477	10.59	9.5169	9.1997	500	10.59	9.5085	9.3214
477	13.06	9.4681	8.9801	500	13.06	9.3165	9.0286
477	15.54	9.4681	8.7605	500	15.54	9.4922	8.9798
477	18.02	9.4730	8.4969	500	18.02	9.1750	8.7602
477	20.49	9.2631	8.1162	500	20.49	9.0774	8.5650
477	22.95	9.2339	7.8673	500	22.95	8.9066	8.2722
477	28.08	9.2095	7.7160	500	28.08	8.9066	8.0769
477	33.21	9.0777	7.3695	500	33.21	8.5162	7.8085
477	38.33	9.0533	7.1743	500	38.33	8.4918	7.6865
477	43.46	8.6140	6.9059	500	43.46	8.1013	7.3937
477	48.59	9.0045	6.5398	500	48.59	8.0769	7.1985
477	58.85	9.1021	6.3934	500	58.85	7.9061	7.1009
477	69.10	8.9313	5.9786	500	69.10	7.3937	6.4908
477	79.36	8.4920	5.5637	500	79.36	7.5645	5.4416
477	89.62	8.2236	5.1489	500	89.62	6.7349	5.4172
477	99.87	8.8825	4.7585	500	99.87	7.4425	5.9296

477	177	7.9308	1.6106	500	177	6.4908	3.4650
477	285	8.5408	-0.3904	500	285	4.7095	0.9761
477	356	8.0040	-1.2689	500	356	3.2942	0.4392
477	499	7.1743	-1.2689	500	499	2.8794	0.4880
477	713	7.9552	-1.2201	500	713	2.3670	0.5612
477	1425	4.8317	-1.0249	500	1425	1.6593	0.4636
477	2851	3.3187	0.3904	500	2851	1.5666	1.1664
477	4276	2.2938	0.5369	500	4276	1.5324	1.2738
477	4989	2.4158	0.6101	500	4989	1.5861	1.3665
477	5702	2.0742	0.6491	500	5702	1.5812	1.3714
477	7127	1.5618	0.7077	500	7127	1.5763	1.4543
477	14255	0.9175	0.6003	500	14255	1.4478	1.3584
477	21382	0.8980	0.6784	500	21382	1.2770	1.1143
477	28510	1.1176	0.9419	500	28510	1.6105	1.3258
477	35637	1.4007	1.2396	500	35637	1.5617	1.5780
477	42765	2.0352	1.7814	500	42765	1.9359	2.0172
477	49892	2.4402	2.1913	500	49892	2.6842	2.6842
477	57020	2.9673	2.6696	500	57020	3.4162	3.4162
477	64147	3.5871	3.2065	500	64147	3.7823	3.7823
477	71275	4.3290	3.9825	500	71275	4.7095	4.7421
611	3.17	9.7610	9.7121	610	3.17	9.7607	9.7607
611	5.64	9.7121	9.6145	610	5.64	9.6630	9.6142
611	8.12	9.6877	9.4681	610	8.12	9.5898	9.4678
611	10.59	9.6145	9.2973	610	10.59	9.5329	9.3946
611	13.06	9.5657	9.1265	610	13.06	9.4922	9.2482
611	15.54	9.5169	8.8337	610	15.54	9.3409	9.1165
611	18.02	9.5462	8.5896	610	18.02	9.4678	8.9212
611	20.49	9.3949	8.0040	610	20.49	9.1506	8.7846
611	22.95	9.2827	8.0186	610	22.95	8.9066	8.5406
611	28.08	9.0582	7.6282	610	28.08	8.9066	8.3454
611	33.21	9.0874	7.4671	610	33.21	8.6870	8.2478
611	38.33	9.0045	7.2475	610	38.33	8.5650	8.0037
611	43.46	8.8581	6.9059	610	43.46	8.5894	7.7841
611	48.59	8.7361	6.8083	610	48.59	8.3210	7.5889
611	58.85	8.9069	6.3690	610	58.85	7.8329	7.1009
611	69.10	8.4432	5.8322	610	69.10	7.7597	6.8325
611	79.36	8.2724	5.5149	610	79.36	7.5645	6.6128
611	89.62	8.4188	5.2221	610	89.62	7.1009	6.0272
611	99.87	7.9308	5.2953	610	99.87	7.1741	5.9784
611	177	7.2231	2.8307	610	177	6.9301	3.1234
611	285	8.5896	-0.6833	610	285	5.3684	0.4880
611	356	8.4432	-1.1713	610	356	4.2947	0.2440
611	499	7.5647	-1.2201	610	499	3.5870	0.2196
611	713	7.4671	-1.7082	610	713	1.4885	0.4880
611	1425	4.6365	-0.4392	610	1425	0.9761	0.2440
611	2851	3.4651	0.0000	610	2851	1.3030	1.0688
611	4276	2.3426	0.7077	610	4276	1.3177	1.2250
611	4989	2.1474	0.8053	610	4989	1.4251	1.2445
611	5702	2.0742	0.9029	610	5702	1.4348	1.3470
611	7127	1.8058	0.9273	610	7127	1.4446	1.3665
611	14255	1.4885	0.8541	610	14255	1.3584	1.2445

611	21382	1.3421	1.0005	610	21382	1.3584	1.1631
611	28510	1.3909	1.2201	610	28510	1.5617	1.3177
611	35637	1.7326	1.6106	610	35637	1.7488	1.5780
611	42765	2.0742	2.0010	610	42765	2.0741	2.0741
611	49892	2.5867	2.3670	610	49892	2.7737	2.7086
611	57020	3.0015	2.9283	610	57020	3.5708	3.5220
611	64147	3.6116	3.4163	610	64147	3.9124	3.9043
611	71275	4.1728	3.9776	610	71275	4.7421	4.5631
744	3.17	9.9074	9.7854	725	3.17	9.7607	9.7607
744	5.64	9.8098	9.6633	725	5.64	9.7119	9.6142
744	8.12	9.7365	9.5657	725	8.12	9.6142	9.4109
744	10.59	9.7854	9.4681	725	10.59	9.5166	9.4109
744	13.06	9.5657	9.1753	725	13.06	9.5020	9.2287
744	15.54	9.6145	8.9801	725	15.54	9.3751	9.1311
744	18.02	9.5364	8.7409	725	18.02	9.2141	8.9212
744	20.49	9.4144	8.4774	725	20.49	9.0286	8.6479
744	22.95	9.2534	8.0528	725	22.95	8.9066	8.5162
744	28.08	8.9361	7.7990	725	28.08	8.8578	8.4186
744	33.21	9.0533	7.5891	725	33.21	8.7114	8.2722
744	38.33	8.5311	7.2719	725	38.33	8.4674	7.8817
744	43.46	8.8581	7.0523	725	43.46	8.3454	7.9061
744	48.59	8.7849	7.2963	725	48.59	8.1990	7.5645
744	58.85	8.3700	6.8327	725	58.85	8.1990	7.2961
744	69.10	8.2968	6.3690	725	69.10	7.4679	6.9789
744	79.36	7.8820	6.1494	725	79.36	7.1741	6.6128
744	89.62	8.0772	5.3197	725	89.62	6.8813	6.0516
744	99.87	8.5164	5.0513	725	99.87	6.3932	5.5880
744	177	8.7849	3.0747	725	177	4.7827	3.1478
744	285	8.3944	-0.7321	725	285	5.4660	0.6344
744	356	9.1265	-1.2689	725	356	3.8067	0.2196
744	499	7.3695	-1.8546	725	499	4.0507	0.0488
744	713	6.5886	-1.0737	725	713	2.6354	0.4148
744	1425	4.9293	-0.6833	725	1425	1.9033	0.3904
744	2851	3.4651	0.3172	725	2851	1.7325	1.2445
744	4276	2.3670	0.9029	725	4276	1.7179	1.4983
744	4989	2.3182	1.2689	725	4989	1.7081	1.5227
744	5702	2.1474	1.2445	725	5702	1.7618	1.5373
744	7127	2.2938	1.0493	725	7127	1.7081	1.6105
744	14255	1.1079	0.8687	725	14255	1.5861	1.4478
744	21382	1.1567	1.0054	725	21382	1.4641	1.3584
744	28510	1.4690	1.2787	725	28510	1.0167	1.4641
744	35637	1.8448	1.7179	725	35637	2.0741	1.6512
744	42765	2.4012	2.1572	725	42765	2.4402	2.4402
744	49892	3.0454	2.8258	725	49892	2.9851	3.0014
744	57020	3.6604	3.3870	725	57020	3.5626	3.5382
744	64147	4.5291	3.9727	725	64147	4.2947	4.2459
744	71275	5.2904	4.7829	725	71275	4.9698	5.0105
1010	3.17	9.8098	9.7121	1065	3.17	9.7932	9.7851
1010	5.64	9.7854	9.6633	1065	5.64	9.7119	9.6386
1010	8.12	9.7121	9.5657	1065	8.12	9.7119	9.5166
1010	10.59	9.6389	9.3949	1065	10.59	9.5166	9.2726

1010	13.06	9.5901	9.2485	1065	13.06	9.3653	9.1750
1010	15.54	9.3949	9.0777	1065	15.54	9.3019	8.9993
1010	18.02	9.3217	8.8093	1065	18.02	9.0579	8.9310
1010	20.49	9.1899	8.5799	1065	20.49	9.0481	8.7846
1010	22.95	9.0923	8.4530	1065	22.95	9.0042	8.5894
1010	28.08	8.9703	8.0723	1065	28.08	8.8090	8.4430
1010	33.21	8.8239	7.7844	1065	33.21	8.7602	8.1501
1010	38.33	8.8141	7.5452	1065	38.33	8.6626	8.1013
1010	43.46	8.9215	7.3354	1065	43.46	8.5406	7.8085
1010	48.59	8.7263	7.4183	1065	48.59	8.3210	7.6865
1010	58.85	8.5896	6.9791	1065	58.85	8.1745	7.3449
1010	69.10	8.1992	6.4910	1065	69.10	7.9793	6.9545
1010	79.36	8.1992	6.3202	1065	79.36	7.6621	6.8325
1010	89.62	7.9796	5.7004	1065	89.62	7.4913	6.4176
1010	99.87	7.8820	5.6858	1065	99.87	7.6133	6.0760
1010	177	7.2719	3.5383	1065	177	7.1253	4.4899
1010	285	8.3456	-0.3904	1065	285	5.1731	1.1713
1010	356	7.5159	-0.4880	1065	356	4.8315	0.9273
1010	499	7.0767	-0.6345	1065	499	2.8306	0.8541
1010	713	6.7839	-0.8785	1065	713	2.8550	0.3416
1010	1425	5.0269	-0.0488	1065	1425	2.4646	0.5612
1010	2851	2.8551	0.7321	1065	2851	2.0009	1.5129
1010	4276	2.4646	1.0249	1065	4276	2.0253	1.7081
1010	4989	2.2206	1.2201	1065	4989	1.9228	1.7764
1010	5702	2.2206	1.3421	1065	5702	1.8838	1.6788
1010	7127	1.9034	1.1225	1065	7127	1.8984	1.7667
1010	14255	1.2543	0.9615	1065	14255	1.6837	1.6186
1010	21382	1.3763	1.1567	1065	21382	1.5292	1.4316
1010	28510	1.7374	1.5666	1065	28510	2.2368	1.6918
1010	35637	2.2694	2.0742	1065	35637	2.1311	2.0741
1010	42765	2.8648	2.6403	1065	42765	2.6760	2.5459
1010	49892	3.2699	3.1967	1065	49892	3.2536	3.2780
1010	57020	4.1874	3.9044	1065	57020	4.0263	4.0263
1010	64147	4.5144	4.1972	1065	64147	4.3923	4.3923
1010	71275	4.7829	4.7097	1065	71275	5.3928	5.3684
1277	3.17	9.8830	9.8342	1290	3.17	9.7607	9.7607
1277	5.64	9.8342	9.7365	1290	5.64	9.6630	9.6793
1277	8.12	9.7610	9.5657	1290	8.12	9.4678	9.4678
1277	10.59	9.6145	9.4437	1290	10.59	9.3946	9.4109
1277	13.06	9.5413	9.2973	1290	13.06	9.2726	9.2482
1277	15.54	9.5413	9.0777	1290	15.54	9.2433	9.1897
1277	18.02	9.3852	8.8093	1290	18.02	9.1506	9.0969
1277	20.49	9.1314	8.6726	1290	20.49	8.9652	8.9164
1277	22.95	9.1167	8.5164	1290	22.95	8.8871	8.8383
1277	28.08	8.9703	8.2334	1290	28.08	8.6919	8.6431
1277	33.21	8.9020	8.0040	1290	33.21	8.5406	8.4283
1277	38.33	8.6726	7.9112	1290	38.33	8.3942	8.3014
1277	43.46	8.6384	7.6623	1290	43.46	8.3063	8.1697
1277	48.59	8.5652	7.5159	1290	48.59	8.2526	8.0233
1277	58.85	8.2236	7.2231	1290	58.85	7.8817	7.4767
1277	69.10	8.3700	6.9547	1290	69.10	7.8085	7.2229

1277	79.36	8.2724	6.4910	1290	79.36	7.6377	6.8569
1277	89.62	8.0284	6.3934	1290	89.62	7.2717	6.5640
1277	99.87	8.0284	5.8322	1290	99.87	6.8569	6.4420
1277	177	7.4183	4.1240	1290	177	5.9540	1.4153
1277	285	8.4920	0.2928	1290	285	3.8067	0.4392
1277	356	7.6135	0.2928	1290	356	3.3430	0.4880
1277	499	6.5886	-0.2928	1290	499	2.9038	0.4636
1277	713	5.0757	-0.0488	1290	713	3.0258	0.2684
1277	1425	4.9781	-0.5369	1290	1425	2.5622	0.3660
1277	2851	3.3431	0.3660	1290	2851	2.2938	1.6105
1277	4276	2.7575	1.2445	1290	4276	2.1961	1.9424
1277	4989	2.4402	1.3909	1290	4989	2.2401	1.9424
1277	5702	2.2694	1.2445	1290	5702	2.1669	1.9570
1277	7127	1.8546	1.1713	1290	7127	2.1571	2.0253
1277	14255	1.3958	1.0591	1290	14255	1.9928	1.8464
1277	21382	1.5373	1.3275	1290	21382	1.6268	1.5373
1277	28510	1.9717	1.7911	1290	28510	1.9196	1.8871
1277	35637	2.6599	2.4695	1290	35637	2.2531	2.2287
1277	42765	3.2358	3.0601	1290	42765	2.8143	2.7574
1277	49892	3.9239	3.6848	1290	49892	3.3024	3.3186
1277	57020	4.5327	4.0671	1290	57020	3.7823	3.7823
1277	64147	5.2026	5.1489	1290	64147	4.8722	4.8885
1277	71275	6.1006	5.8566	1290	71275	5.5717	5.5961
1676	3.17	9.7365	9.6877	1635	3.17	9.7607	9.7607
1676	5.64	9.7121	9.6389	1635	5.64	9.7444	9.7525
1676	8.12	9.6389	9.5657	1635	8.12	9.6630	9.6386
1676	10.59	9.6145	9.4925	1635	10.59	9.5654	9.5329
1676	13.06	9.5413	9.3949	1635	13.06	9.4678	9.4760
1676	15.54	9.5169	9.2729	1635	15.54	9.4516	9.3702
1676	18.02	9.3949	9.0289	1635	18.02	9.3458	9.2677
1676	20.49	9.3461	8.8629	1635	20.49	9.2726	9.1213
1676	22.95	9.3608	8.7605	1635	22.95	9.1555	9.0823
1676	28.08	9.1411	8.5408	1635	28.08	9.0091	8.8871
1676	33.21	9.0874	8.2236	1635	33.21	8.9700	8.7797
1676	38.33	8.9313	8.0528	1635	38.33	8.7992	8.5991
1676	43.46	8.7849	7.7795	1635	43.46	8.7211	8.4771
1676	48.59	8.6628	7.6379	1635	48.59	8.5308	8.3014
1676	58.85	8.4432	7.2719	1635	58.85	8.2526	7.9110
1676	69.10	8.4676	6.9059	1635	69.10	8.0721	7.7841
1676	79.36	8.9801	6.5154	1635	79.36	7.8573	7.4425
1676	89.62	8.6140	6.3934	1635	89.62	7.6280	7.1497
1676	99.87	8.3700	5.9542	1635	99.87	7.4425	6.8325
1676	177	7.8576	4.1972	1635	177	6.8325	4.6363
1676	285	6.9547	2.6843	1635	285	5.6124	2.8794
1676	356	6.1006	1.7082	1635	356	4.8315	2.3914
1676	499	6.3446	0.0000	1635	499	4.8071	1.3421
1676	713	5.6939	0.0000	1635	713	3.6114	0.9517
1676	1425	5.2709	-0.7321	1635	1425	2.3914	0.6344
1676	2851	3.0015	1.0737	1635	2851	2.4402	1.9765
1676	4276	2.7331	1.6594	1635	4276	2.3621	2.1181
1676	4989	2.4646	1.4885	1635	4989	2.4890	2.1571

1676	5702	2.2938	1.5373	1635	5702	2.4890	2.2450
1676	7127	2.0254	1.3421	1635	7127	2.5231	2.2401
1676	14255	1.7130	1.4007	1635	14255	2.3751	2.1717
1676	21382	1.9668	1.7716	1635	21382	2.3832	2.3263
1676	28510	2.6208	2.4207	1635	28510	2.4076	2.4564
1676	35637	3.2699	3.0405	1635	35637	2.8306	2.7655
1676	42765	4.0850	3.9141	1635	42765	3.3024	3.3430
1676	49892	4.5388	4.6218	1635	49892	3.8555	3.8717
1676	57020	5.7150	5.5735	1635	57020	4.8722	4.5143
1676	64147	6.5008	6.2714	1635	64147	5.1975	5.1243
1676	71275	6.9449	6.6960	1635	71275	5.8564	5.8564
2742	3.17	9.8342	9.7854	2540	3.17	9.7607	9.7607
2742	5.64	9.8098	9.7365	2540	5.64	9.6875	9.6630
2742	8.12	9.7610	9.6877	2540	8.12	9.5898	9.5898
2742	10.59	9.7121	9.6389	2540	10.59	9.5166	9.5085
2742	13.06	9.6389	9.5413	2540	13.06	9.4678	9.4597
2742	15.54	9.5901	9.3705	2540	15.54	9.3409	9.3214
2742	18.02	9.4925	9.2241	2540	18.02	9.3214	9.3507
2742	20.49	9.3852	9.1216	2540	20.49	9.2238	9.1994
2742	22.95	9.3022	8.8971	2540	22.95	8.9993	8.9798
2742	28.08	9.2387	8.7751	2540	28.08	9.0530	9.0384
2742	33.21	9.0142	8.7116	2540	33.21	8.7846	8.7846
2742	38.33	8.9508	8.3798	2540	38.33	8.8188	8.7895
2742	43.46	8.8825	8.2724	2540	43.46	8.6528	8.5747
2742	48.59	8.8629	7.9796	2540	48.59	8.5113	8.4478
2742	58.85	8.6775	7.9064	2540	58.85	8.3893	8.3014
2742	69.10	8.5652	7.5647	2540	69.10	8.2722	8.0428
2742	79.36	8.7849	7.3207	2540	79.36	8.0233	7.8378
2742	89.62	8.4432	6.8571	2540	89.62	7.7890	7.5889
2742	99.87	8.9069	6.5154	2540	99.87	7.5791	7.4913
2742	177	7.8576	6.5642	2540	177	6.5640	5.7344
2742	285	7.0767	3.6604	2540	285	5.3196	4.6851
2742	356	6.1006	2.6029	2540	356	4.9535	3.2210
2742	499	5.7102	2.0498	2540	499	4.3435	1.3421
2742	713	5.1733	1.1225	2540	713	3.8067	1.1713
2742	1425	4.1972	0.2684	2540	1425	3.0258	1.3665
2742	2851	3.7092	0.8053	2540	2851	2.8794	2.0985
2742	4276	3.4407	1.5373	2540	4276	2.7183	2.3426
2742	4989	3.2943	1.6838	2540	4989	2.7867	2.5963
2742	5702	2.9527	1.8790	2540	5702	2.7867	2.5427
2742	7127	2.4402	1.7082	2540	7127	2.6110	2.4808
2742	14255	2.3426	1.8448	2540	14255	3.0014	2.9770
2742	21382	2.8795	2.7087	2540	21382	3.2780	3.1885
2742	28510	3.6750	3.4993	2540	28510	3.3918	3.3674
2742	35637	4.4852	4.2899	2540	35637	3.8880	3.8555
2742	42765	5.1879	5.0855	2540	42765	4.2947	4.2703
2742	49892	5.8566	5.5833	2540	49892	5.3684	5.3684
2742	57020	6.5638	6.1494	2540	57020	5.7832	5.6856
2742	64147	8.0040	7.4330	2540	64147	6.3444	6.2956
2742	71275	8.0528	7.9064	2540	71275	7.1985	7.1009

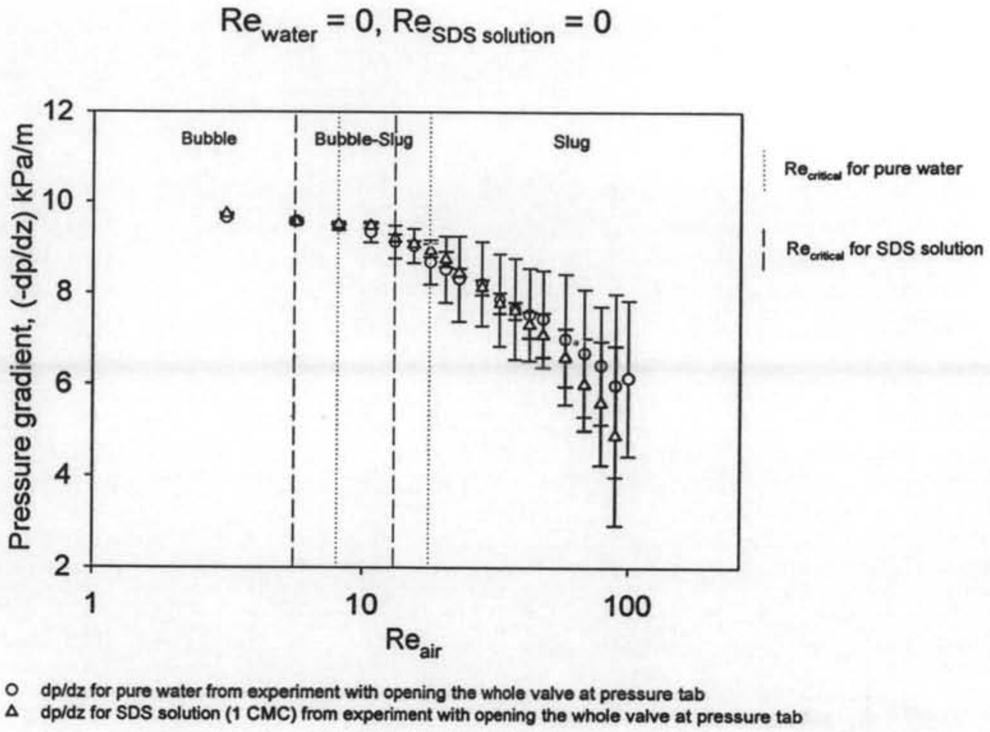

Figure G1 Comparison the pressure gradient from the experiment between pure water and SDS solution (1 CMC) by opening the whole valve at pressure tab vs. air Reynolds number of pure water at $Re_{water} = 0$ and $Re_{SDS\ solution} = 0$.

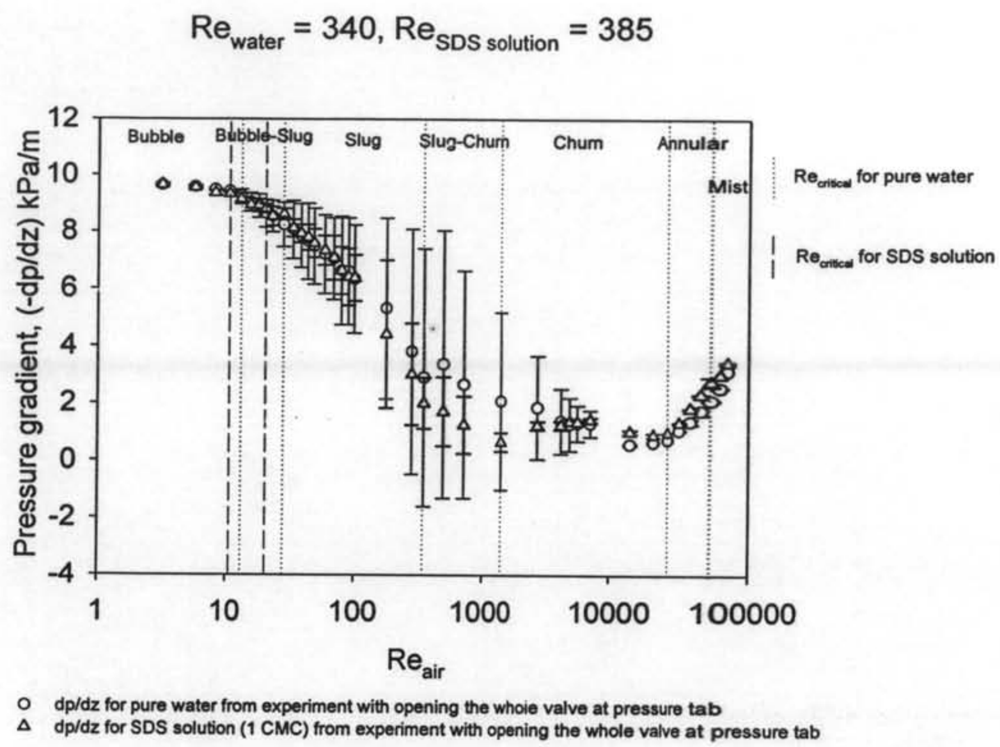

Figure G2 Comparison the pressure gradient from the experiment between pure water and SDS solution (1 CMC) by opening the whole valve at pressure tab vs. air Reynolds number of pure water at $Re_{water} = 340$ and $Re_{SDS\ solution} = 385$.

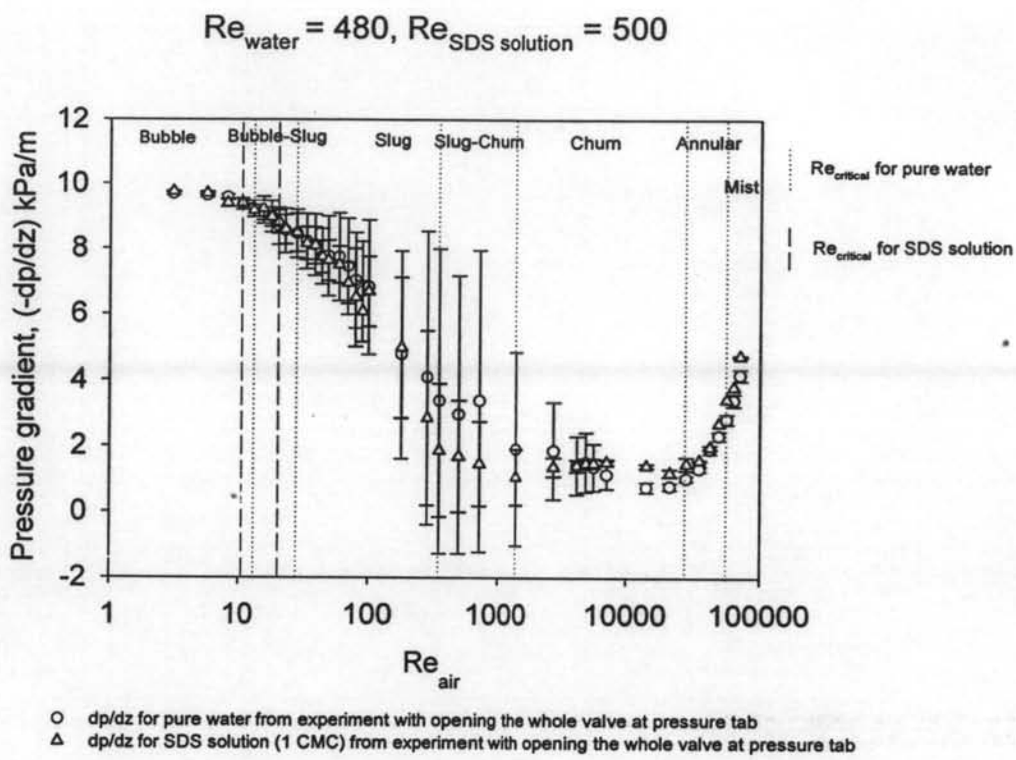

Figure G3 Comparison the pressure gradient from the experiment between pure water and SDS solution (1 CMC) by opening the whole valve at pressure tab vs. air Reynolds number of pure water at Re_{water} = 480 and $Re_{SDS\ solution}$ = 500.

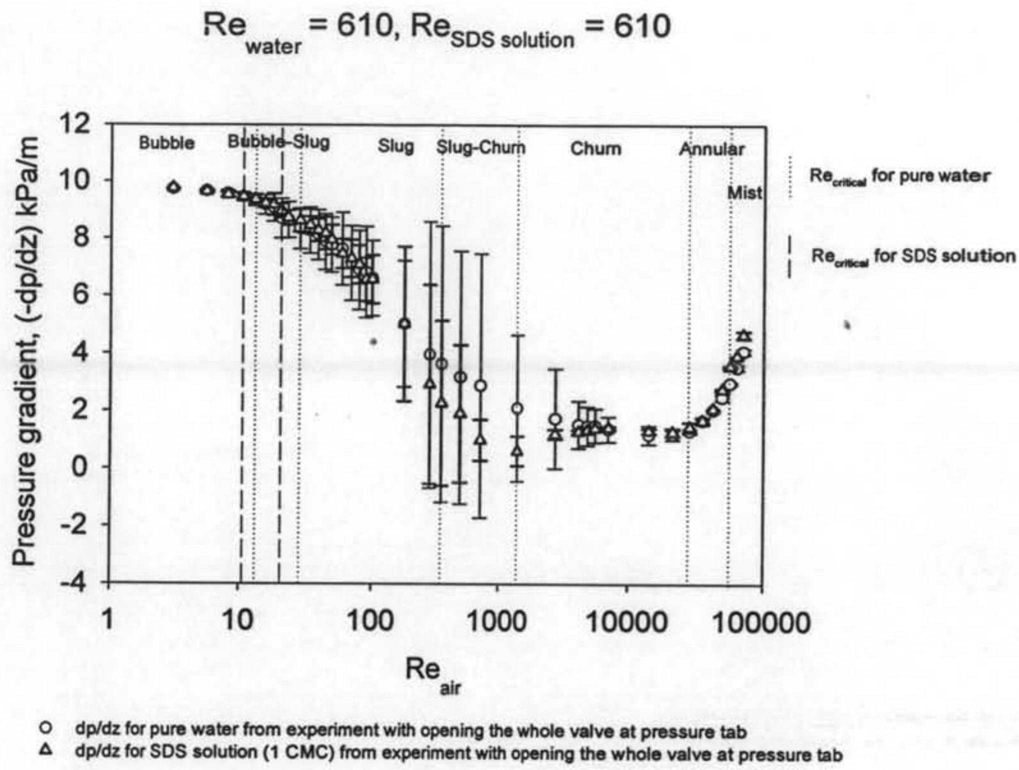

Figure G4 Comparison the pressure gradient from the experiment between pure water and SDS solution (1 CMC) by opening the whole valve at pressure tab vs. air Reynolds number of pure water at $Re_{water} = 610$ and $Re_{SDS\ solution} = 610$.

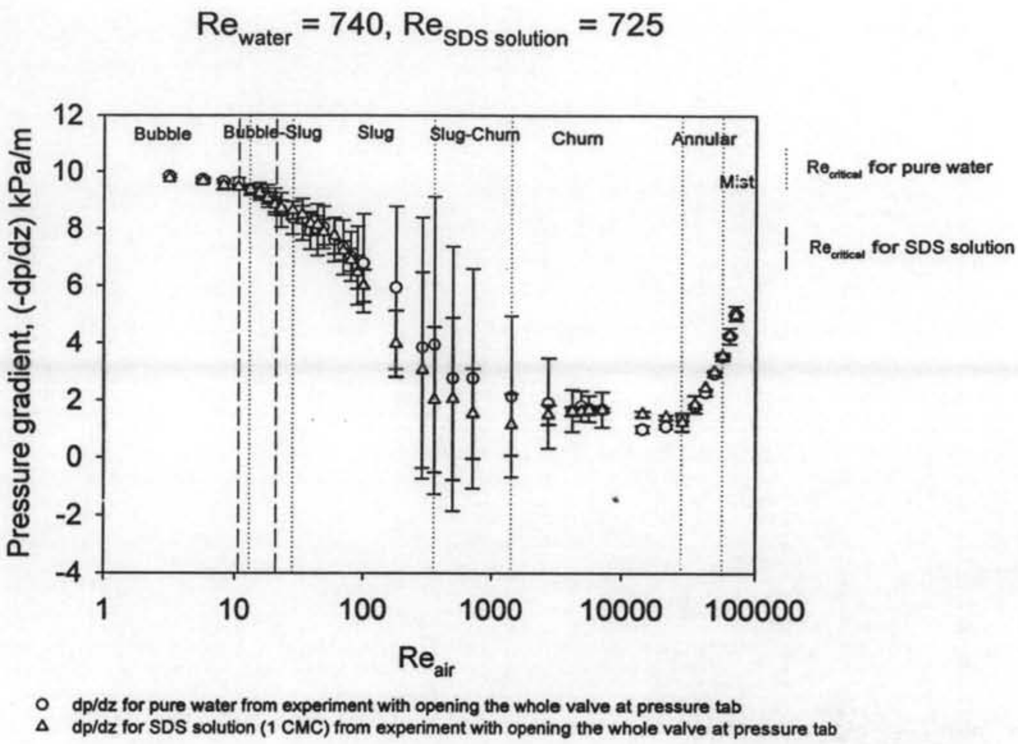

Figure G5 Comparison the pressure gradient from the experiment between pure water and SDS solution (1 CMC) by opening the whole valve at pressure tab vs. air Reynolds number of pure water at Re_{water} = 740 and $Re_{SDS\ solution}$ = 725.

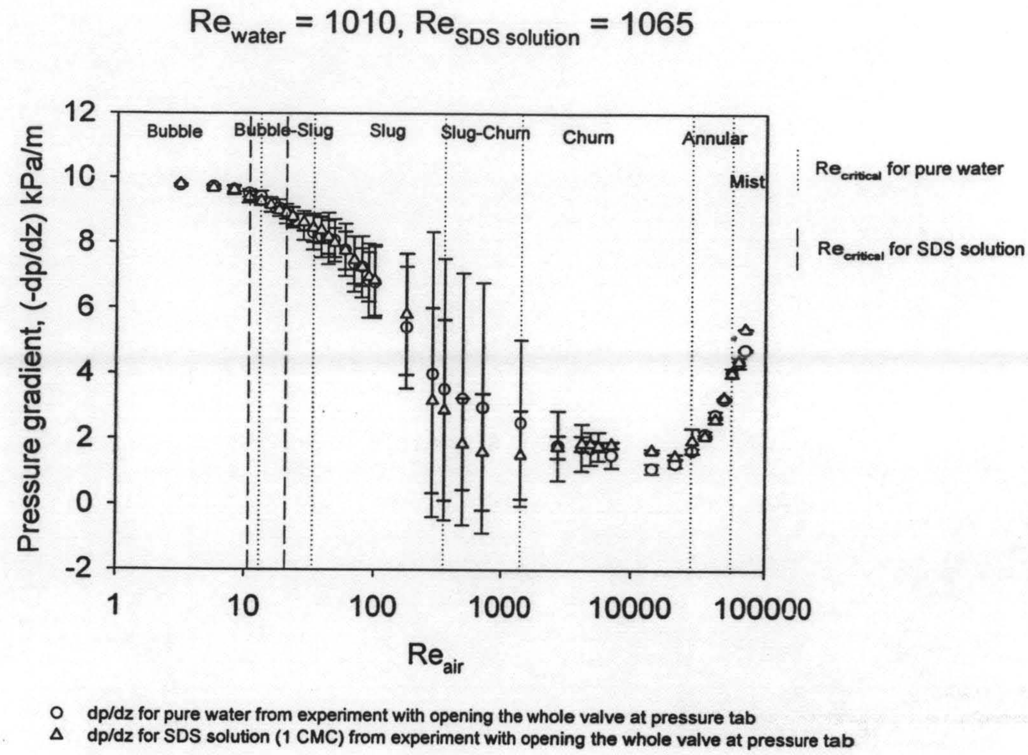

Figure G6 Comparison the pressure gradient from the experiment between pure water and SDS solution (1 CMC) by opening the whole valve at pressure tab vs. air Reynolds number of pure water at $Re_{water} = 1010$ and $Re_{SDS\ solution} = 1065$.

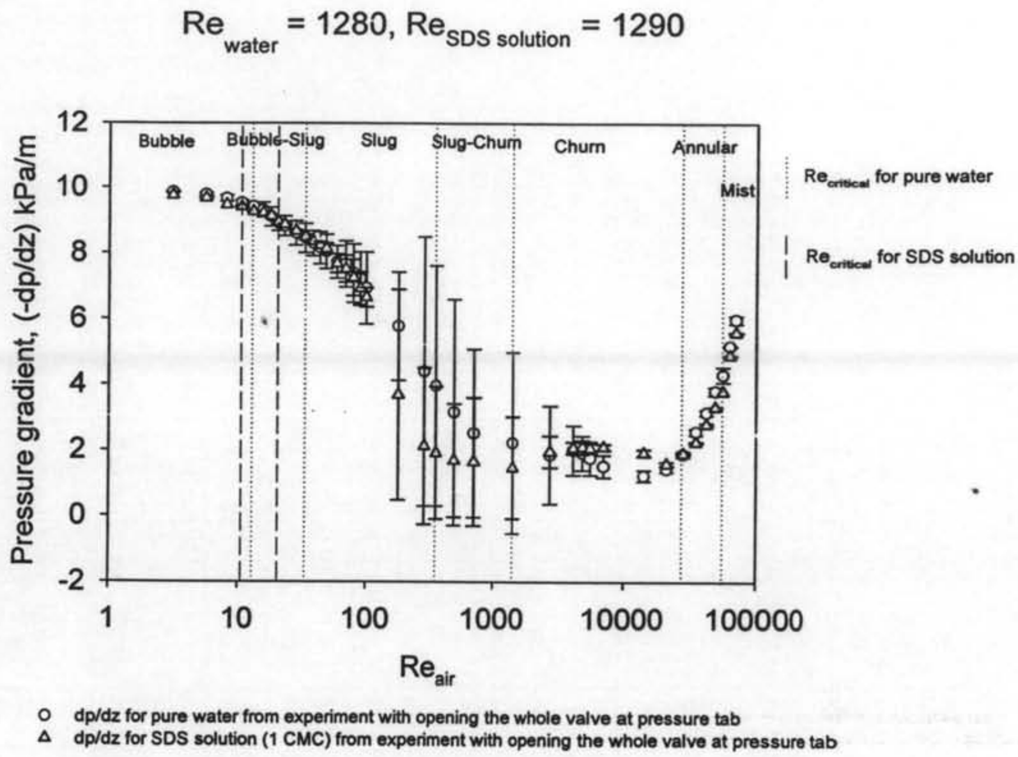

Figure G7 Comparison the pressure gradient from the experiment between pure water and SDS solution (1 CMC) by opening the whole valve at pressure tab vs. air Reynolds number of pure water at Re_{water} = 1280 and $Re_{SDS\ solution}$ = 1290.

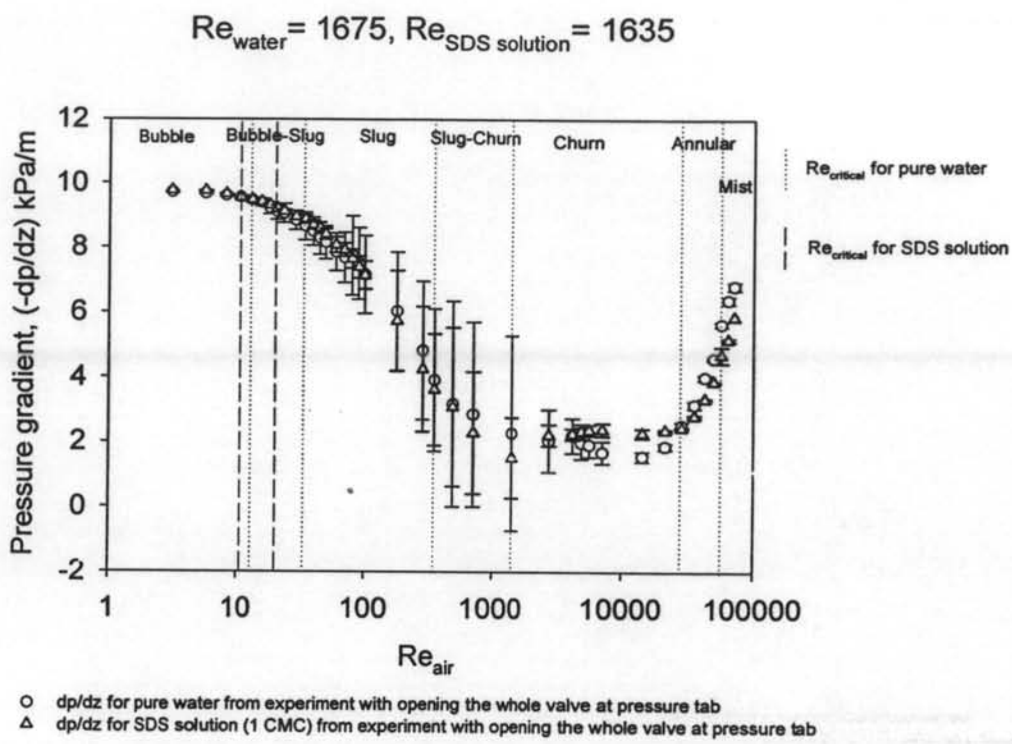

Figure G8 Comparison the pressure gradient from the experiment between pure water and SDS solution (1 CMC) by opening the whole valve at pressure tab vs. air Reynolds number of pure water at Re_{water} = 1675 and $Re_{SDS\ solution}$ = 1635.

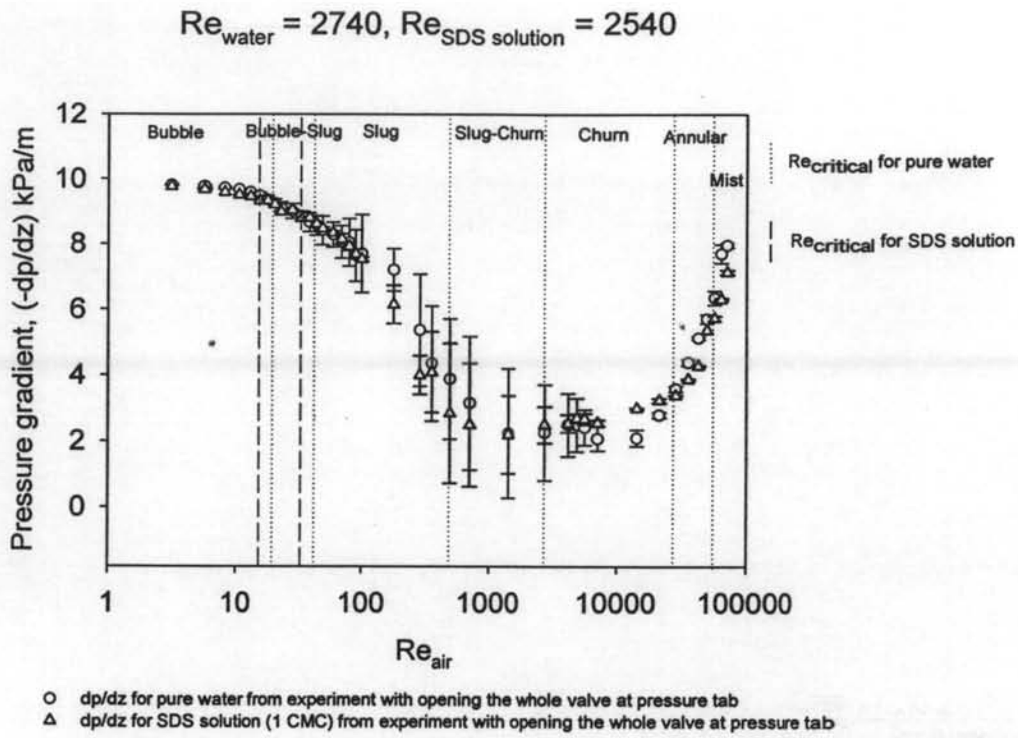

Figure G9 Comparison the pressure gradient from the experiment between pure water and SDS solution (1 CMC) by opening the whole valve at pressure tab vs. air Reynolds number of pure water at $Re_{water} = 2740$ and $Re_{SDS\ solution} = 2540$.

Table G2 Comparison the pressure gradient from the experiment between pure water and SDS solution (1 CMC) by nearly closing valve at pressure tab

Physical properties of air, water and SDS solution (1 CMC) used in experiment:

density of water, ρ_{water} = 994.7 kg/m^3; viscosity of water, $\mu_{water} = 8.51 \times 10^{-4}$ Pa.s

density of water, $\rho_{SDS\ solution}$ = 994.97 kg/m^3; viscosity of SDS solution, $\mu_{SDS\ solution}$ = 1.01×10^{-3} Pa.s

density of air, ρ_{air} = 1.18 kg/m^3; viscosity of air, $\mu_{air} = 1.85 \times 10^{-5}$ Pa.s

temperature, T = 31 °C (± 1 °C); inner pipe diameter, D = 0.019 m; cross-sectional area of pipe, A = 0.00028 m^2

pressure taps difference = 0.4 m

Re_{water}	Re_{air}	(dp/dz) from experiment		$Re_{SDS\ solution}$	Re_{air}	(dp/dz) from experiment	
		maximum (kPa/m)	minimum (kPa/m)			maximum (kPa/m)	minimum (kPa/m)
0	3.17	9.6848	9.6116	0	3.17	9.8339	9.8013
0	5.64	9.6360	9.5141	0	5.64	9.7119	9.7119
0	8.12	9.5628	9.3677	0	8.12	9.7037	9.5492
0	10.59	9.3482	9.2945	0	10.59	9.4678	9.3702
0	13.06	9.2896	9.1969	0	13.06	9.3946	9.2564
0	15.54	9.0408	8.9432	0	15.54	9.0237	8.9798
0	18.02	8.9871	8.8603	0	18.02	8.8773	8.7504
0	20.49	8.9432	8.5968	0	20.49	8.8090	8.7504
0	22.95	8.7139	8.4358	0	22.95	8.8090	8.5162
0	28.08	8.5383	8.3089	0	28.08	8.5211	8.3063
0	33.21	8.5041	8.0211	0	33.21	8.2722	7.9549
0	38.33	8.2260	7.7430	0	38.33	7.9110	7.5743
0	43.46	8.2553	7.4795	0	43.46	7.8085	7.1253
0	48.59	7.9918	7.2502	0	48.59	7.4425	7.1009
0	58.85	7.7479	6.8160	0	58.85	7.1985	6.8325
0	69.10	7.6454	6.4891	0	69.10	6.9545	6.4664
0	79.36	7.3429	6.1329	0	79.36	6.8081	6.0516
0	89.62	7.0404	5.8841	0	89.62	6.7495	5.4904
0	99.87	6.7086	5.7133	0	99.87	6.2468	5.0023
480	3.17	9.7336	9.6360	500	3.17	9.7607	9.7363
480	5.64	9.7092	9.5628	500	5.64	9.7363	9.6630
480	8.12	9.6604	9.4897	500	8.12	9.4922	9.3214
480	10.59	9.5628	9.5141	500	10.59	9.5085	9.3214
480	13.06	9.5628	9.4409	500	13.06	9.3605	9.3702
480	15.54	9.5141	9.2750	500	15.54	9.0823	9.0676
480	18.02	9.2701	8.9579	500	18.02	9.0530	8.8432
480	20.49	8.9774	8.7334	500	20.49	8.9700	8.7846
480	22.95	8.7920	8.5431	500	22.95	8.7895	8.7651
480	28.08	8.6456	8.3577	500	28.08	8.6382	8.5406

480	33.21	8.5627	8.2504	500	33.21	8.5162	8.4625
480	38.33	8.4456	8.1431	500	38.33	8.3063	8.2282
480	43	8.3236	7.9186	500	43.46	8.1404	8.0184
480	49	8.1723	7.6844	500	48.59	8.0233	7.8476
480	59	7.9479	7.3575	500	58.85	7.6719	7.5206
480	69	7.4649	6.7574	500	69.10	7.3205	7.1302
480	79	7.3380	6.7818	500	79.36	7.0374	6.6372
480	90	7.0990	6.4208	500	89.62	6.5836	6.2224
480	100	6.9526	6.2207	500	99.87	6.2468	5.8808
480	177	5.7328	4.8839	500	177	4.6607	4.3435
480	285	4.5131	3.3665	500	285	2.7574	2.0985
480	356	3.9764	2.6835	500	356	2.1864	1.3421
480	499	3.2689	1.8052	500	499	1.5959	1.2201
480	713	2.5371	1.3173	500	713	1.4885	0.8589
480	1425	2.1956	0.8538	500	1425	1.2201	0.5368
480	2851	2.4395	1.3173	500	2851	1.3079	1.1957
480	4276	2.3175	1.3661	500	4276	1.3177	1.2591
480	4989.23	1.9516	1.4247	500	4989	1.4007	1.2982
480	5701.98	1.9418	1.3612	500	5702	1.3909	1.3177
480	7127.48	1.4637	1.2246	500	7127	1.4104	1.3860
480	14254.95	0.9173	0.6001	500	14255	1.4478	1.3584
480	21382.43	0.8977	0.6782	500	21382	1.2770	1.1143
480	28509.90	1.1173	0.9416	500	28510	1.6105	1.3258
480	35637.38	1.4003	1.2393	500	35637	1.5617	1.5780
480	42764.86	2.0345	1.7808	500	42765	1.9359	2.0172
480	49892.33	2.4395	2.1907	500	49892	2.6842	2.6842
480	57019.81	2.9664	2.6688	500	57020	3.4162	3.4162
480	64147.29	3.5861	3.2055	500	64147	3.7823	3.7823
480	71274.76	4.3277	3.9813	500	71275	4.7095	4.7421
1010	3.17	9.8068	9.7092	1065	3.17	9.7932	9.7851
1010	5.64	9.7824	9.6604	1065	5.64	9.7119	9.6386
1010	8	9.7092	9.5628	1065	8.12	9.7119	9.5166
1010	11	9.6360	9.3921	1065	10.59	9.5166	9.2726
1010	13	9.5141	9.4653	1065	13.06	9.3653	9.1750
1010	16	9.4165	9.2457	1065	15.54	9.3019	8.9993
1010	18	9.3433	9.1481	1065	18.02	9.0579	8.9310
1010	20	9.2701	9.0262	1065	20.49	9.0481	8.7846
1010	23	9.2213	8.8554	1065	22.95	8.8920	8.6382
1010	28	9.0262	8.5870	1065	28.08	8.5015	8.3698
1010	33	8.9042	8.5627	1065	33.21	8.1697	8.1550
1010	38	8.7968	8.1821	1065	38.33	7.8866	7.8232
1010	43	8.5919	7.9772	1065	43.46	7.8524	7.8768
1010	49	8.4651	7.6405	1065	48.59	7.7012	7.6865
1010	59	8.3626	7.5137	1065	58.85	7.4669	7.4425
1010	69	8.1333	7.4063	1065	69.10	7.3351	7.1985
1010	79	8.0504	6.9575	1065	79.36	7.3693	7.0765
1010	89.62	7.5625	6.6110	1065	89.62	7.0667	6.7056
1010	99.87	7.3331	6.3915	1065	99.87	6.8227	6.7593
1010	176.83	6.2451	5.3181	1065	177	5.4660	5.0755
1010	285.10	4.8058	3.4885	1065	285	3.6017	2.9282
1010	356.37	4.5375	2.9274	1065	356	2.8794	2.4060

1010	498.92	3.6836	2.2443	1065	499	2.3426	1.7325
1010	712.75	3.2689	1.3905	1065	713	1.8301	1.1713
1010	1425.50	2.4395	1.3661	1065	1425	1.5861	0.7320
1010	2850.99	2.5615	1.6247	1065	2851	1.9131	1.5275
1010	4276.49	2.1956	1.4637	1065	4276	1.8887	1.6740
1010	4989.23	2.0736	1.4637	1065	4989	1.8301	1.7179
1010	5701.98	1.9516	1.3417	1065	5702	1.8594	1.7520
1010	7127.48	1.7808	1.2685	1065	7127	1.8789	1.7276
1010	14254.95	1.2539	0.9612	1065	14255	1.6837	1.6186
1010	21382	1.3759	1.1563	1065	21382	1.5292	1.4316
1010	28510	1.7369	1.5662	1065	28510	1.9928	1.9359
1010	35637	2.2687	2.0736	1065	35637	2.1311	2.0741
1010	42765	2.8640	2.6395	1065	42765	2.6760	2.5459
1010	49892	3.2689	3.1957	1065	49892	3.2536	3.2780
1010	57020	4.1862	3.9032	1065	57020	4.0263	4.0263
1010	64147	4.5131	4.1959	1065	64147	4.3923	4.3923
1010	71275	4.7814	4.7082	1065	71275	5.3928	5.3684
1680	3	9.7336	9.6848	1635	3.17	9.7607	9.7607
1680	6	9.7092	9.6360	1635	5.64	9.7444	9.7525
1680	8	9.6360	9.5628	1635	8.12	9.6630	9.6386
1680	11	9.6116	9.4897	1635	10.59	9.5654	9.5329
1680	13	9.5385	9.3921	1635	13.06	9.4678	9.4760
1680	16	9.5141	9.4165	1635	15.54	9.4516	9.3702
1680	18	9.5141	9.3677	1635	18.02	9.3458	9.2677
1680	20.49	9.4897	9.3189	1635	20.49	9.2726	9.1213
1680	22.95	9.3921	9.2213	1635	22.95	9.1555	9.0823
1680	28.08	9.2701	9.0262	1635	28.08	9.0091	8.8871
1680	33.21	9.0993	8.8798	1635	33.21	8.9700	8.7797
1680	38.33	8.9530	8.7334	1635	38.33	8.7992	8.5991
1680	43.46	8.6212	8.4553	1635	43.46	8.7211	8.4771
1680	48.59	8.5431	8.2845	1635	48.59	8.5308	8.3014
1680	58.85	8.4065	8.1528	1635	58.85	8.2624	8.0965
1680	69.10	8.2260	7.9381	1635	69.10	7.7744	7.7988
1680	79.36	8.0601	7.8064	1635	79.36	7.5938	7.5108
1680	89.62	7.9528	7.5722	1635	89.62	7.4230	7.3254
1680	99.87	7.7235	7.3819	1635	99.87	7.1985	7.0765
1680	176.83	6.8794	5.9036	1635	177	5.8515	5.5880
1680	285.10	5.3913	4.2935	1635	285	4.2703	3.6114
1680	356.37	4.6838	3.5861	1635	356	3.6602	3.0746
1680	499	3.7812	2.7078	1635	499	3.0404	2.2938
1680	713	3.6349	1.8052	1635	713	1.8789	1.1713
1680	1425	2.6591	1.8296	1635	1425	1.4397	0.8053
1680	2851	2.8542	1.9028	1635	2851	1.9912	1.8252
1680	4276	2.8786	1.9516	1635	4276	2.0741	2.0253
1680	4989	2.6835	2.0297	1635	4989	2.0937	2.0302
1680	5702	2.4395	1.8540	1635	5702	2.4450	2.2205
1680	7127	2.1565	1.7174	1635	7127	2.3962	2.1864
1680	14255	1.7125	1.4003	1635	14255	2.3751	2.1717
1680	21382	1.9662	1.7711	1635	21382	2.3832	2.3263
1680	28510	2.6200	2.4200	1635	28510	2.4076	2.4564
1680	35637	3.2689	3.0396	1635	35637	2.8306	2.7655

1680	42765	4.0837	3.9130	1635	42765	3.3024	3.3430
1680	49892	4.5375	4.6204	1635	49892	3.8555	3.8717
1680	57020	5.7133	5.5718	1635	57020	4.8722	4.5143
1680	64147	6.4988	6.2695	1635	64147	5.1975	5.1243
1680	71274.76	6.9428	6.6940	1635	71275	5.8564	5.8564
2740	3.167023	9.8312	9.7824	2540	3.17	9.7607	9.7607
2740	5.641754	9.8068	9.7336	2540	5.64	9.6875	9.6630
2740	8.116485	9.7580	9.6848	2540	8.12	9.5898	9.5898
2740	10.59122	9.7092	9.6360	2540	10.59	9.5166	9.5085
2740	13.06466	9.6360	9.5385	2540	13.06	9.4678	9.4597
2740	15.54068	9.5872	9.5385	2540	15.54	9.3409	9.3214
2740	18.01541	9.5628	9.5141	2540	18.02	9.3214	9.3507
2740	20.49014	9.5385	9.5141	2540	20.49	9.2238	9.1994
2740	22.94976	9.5385	9.4409	2540	22.95	8.9993	8.9798
2740	28.07798	9.3921	9.2945	2540	28.08	9.0530	9.0384
2740	33.2062	9.2701	9.1481	2540	33.21	8.7846	8.7846
2740	38.33442	9.0603	8.9774	2540	38.33	8.8188	8.7895
2740	43.46264	8.9822	8.7578	2540	43.46	8.6528	8.5747
2740	48.59086	8.8408	8.5383	2540	48.59	8.5113	8.4478
2740	58.84729	8.7090	8.3626	2540	58.85	8.3893	8.3014
2740	69.10373	8.5870	8.1284	2540	69.10	8.2722	8.0428
2740	79.36017	8.3333	7.9430	2540	79.36	8.0233	7.8378
2740	89.61661	8.2211	7.7332	2540	89.62	7.7890	7.5889
2740	99.87305	8.0894	7.5088	2540	99.87	7.5791	7.4913
2740	176.832	7.1477	6.2110	2540	177	6.7349	6.5982
2740	285.099	5.7328	4.8790	2540	285	5.2903	4.8754
2740	356.3738	5.1230	4.1472	2540	356	4.6363	4.2703
2740	498.9233	4.6351	3.2787	2540	499	3.6358	2.8696
2740	712.7476	3.9520	2.5127	2540	713	2.4255	1.9180
2740	1425.495	3.2445	2.1224	2540	1425	2.5866	1.5861
2740	2850.99	3.2933	2.1468	2540	2851	2.7818	2.0741
2740	4276.486	3.1714	2.1956	2540	4276	2.9282	2.5622
2740	4989.233	3.1957	2.2687	2540	4989	2.9136	2.6159
2740	5701.981	2.9274	1.9760	2540	5702	2.8794	2.4646
2740	7127.476	2.5908	2.0004	2540	7127	2.9136	2.5768
2740	14254.95	2.3419	1.8589	2540	14255	3.0014	2.9770
2740	21382.43	2.8786	2.7078	2540	21382	3.2780	3.1885
2740	28509.9	3.6739	3.4982	2540	28510	3.3918	3.3674
2740	35637.38	4.4838	4.2886	2540	35637	3.8880	3.8555
2740	42764.86	5.1864	5.0839	2540	42765	4.2947	4.2703
2740	49892.33	5.8548	5.5816	2540	49892	5.3684	5.3684
2740	57019.81	6.5818	6.1475	2540	57020	5.7832	5.6856
2740	64147.29	8.0016	7.4307	2540	64147	6.3444	6.2956
2740	71274.76	8.0650	7.9333	2540	71275	7.1985	7.1009

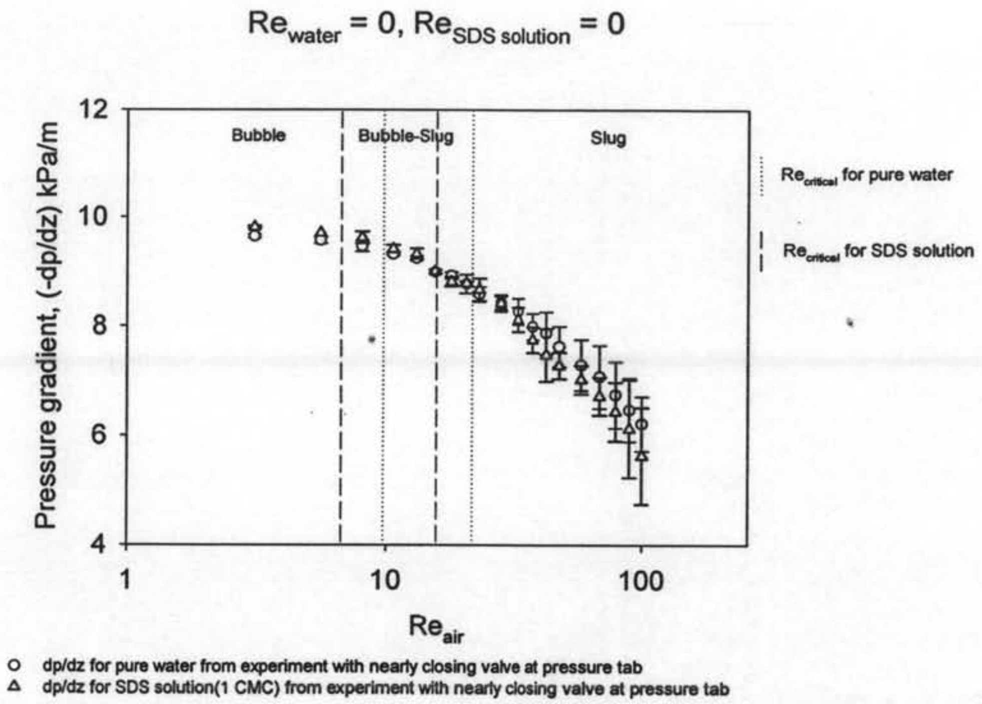

Figure G10 Comparison the pressure gradient from the experiment between pure water and SDS solution (1 CMC) by nearly closing valve at pressure tab vs. air Reynolds number of pure water at $Re_{water} = 0$ and $Re_{SDS\ solution} = 0$.

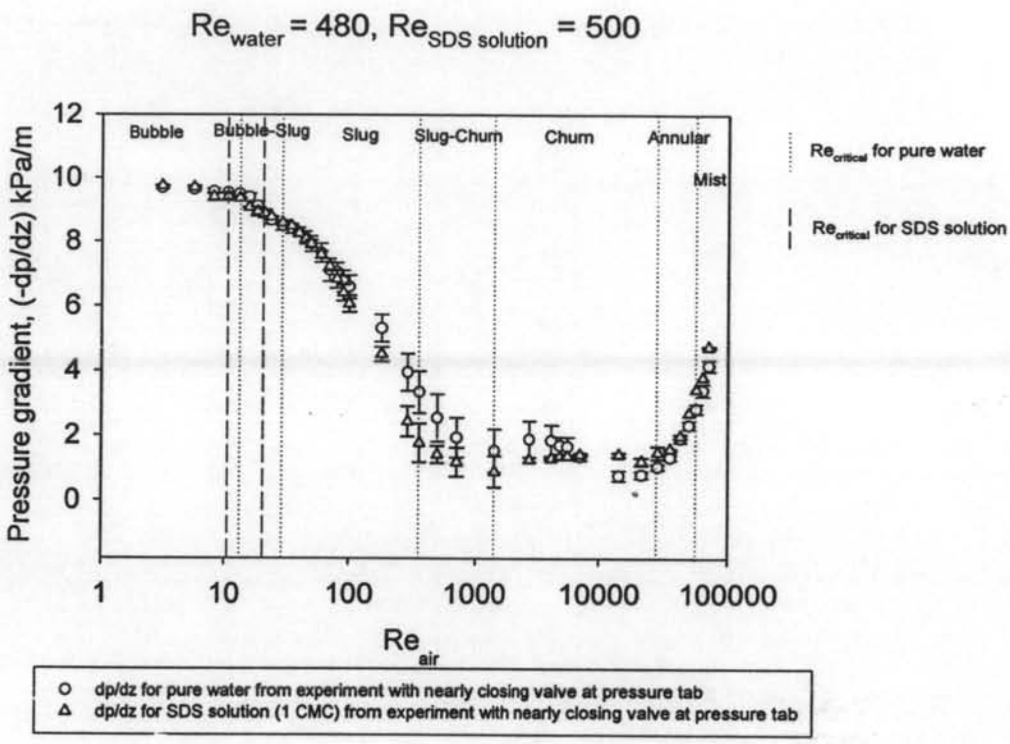

Figure G11 Comparison the pressure gradient from the experiment between pure water and SDS solution (1 CMC) by nearly closing valve at pressure tab vs. air Reynolds number of pure water at $Re_{water} = 480$ and $Re_{SDS\ solution} = 500$.

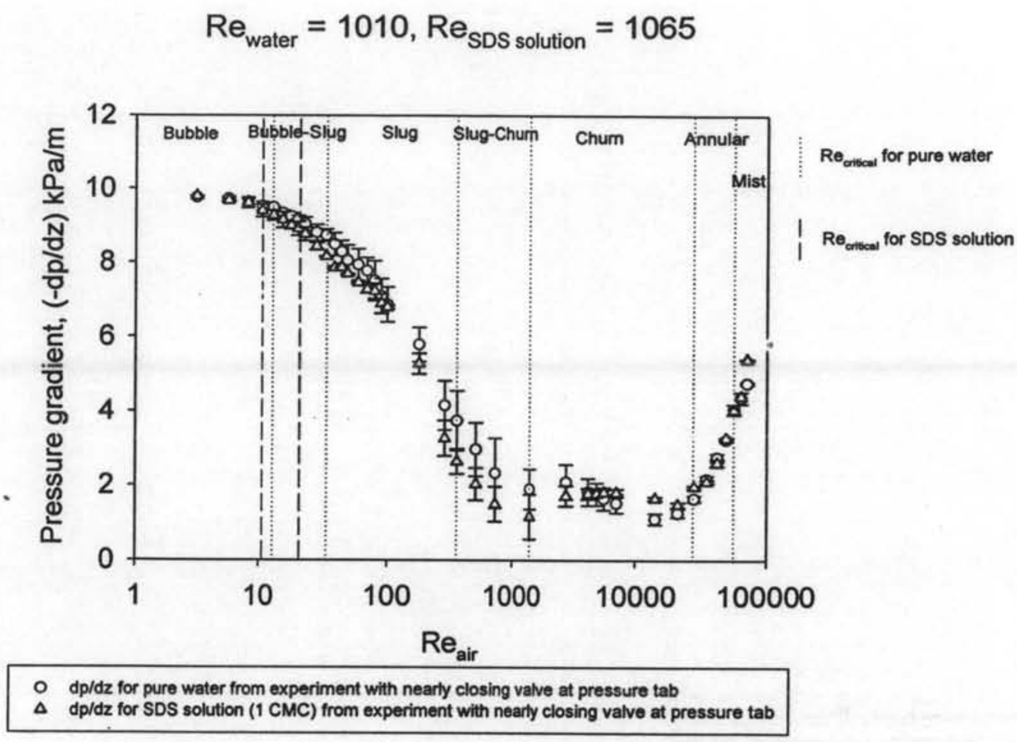

Figure G12 Comparison the pressure gradient from the experiment between pure water and SDS solution (1 CMC) by nearly closing valve at pressure tab vs. air Reynolds number of pure water at $Re_{water} = 1010$ and $Re_{SDS\ solution} = 1065$.

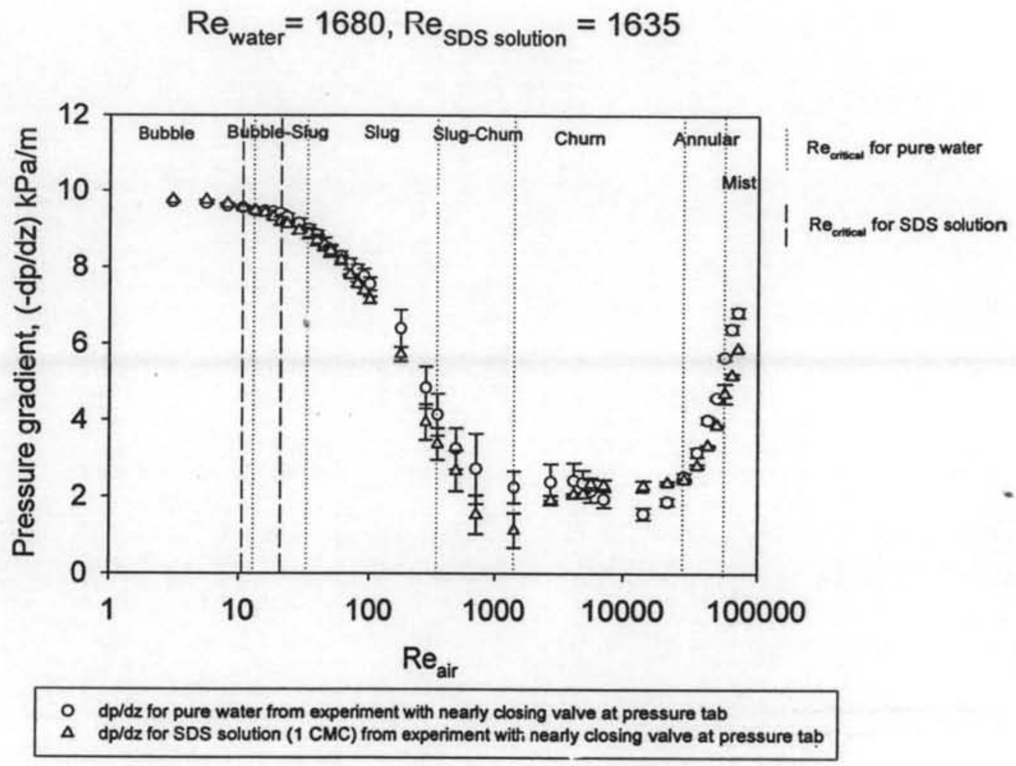

Figure G13 Comparison the pressure gradient from the experiment between pure water and SDS solution (1 CMC) by nearly closing valve at pressure tab vs. air Reynolds number of pure water at $Re_{water} = 1680$ and $Re_{SDS\ solution} = 1635$.

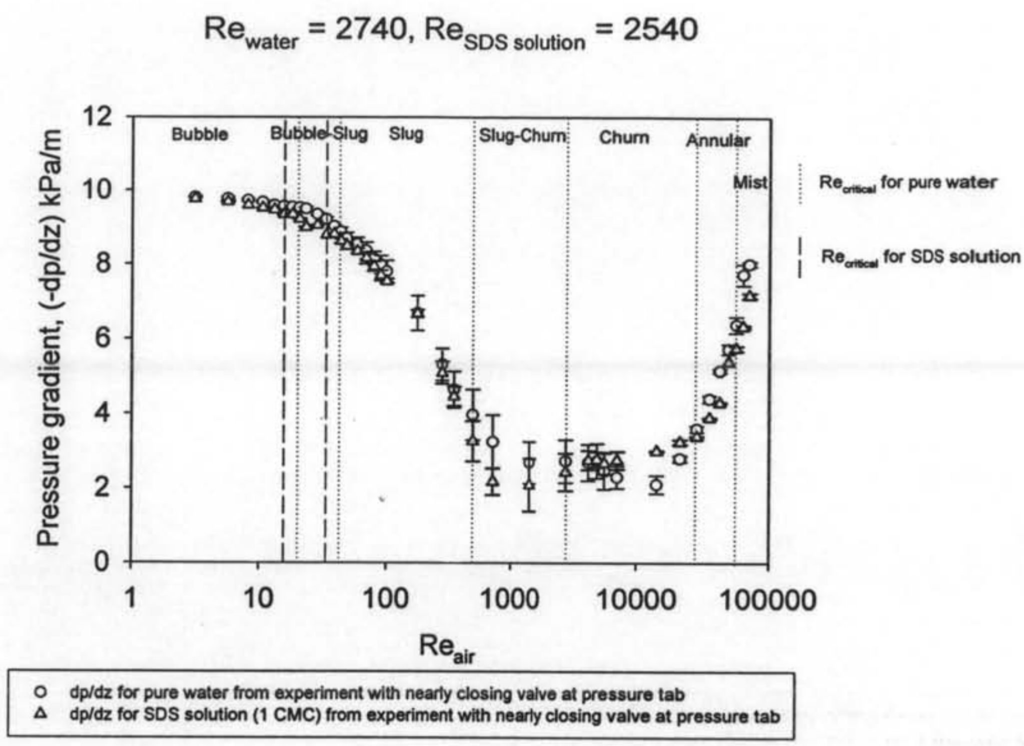

Figure G14 Comparison the pressure gradient from the experiment between pure water and SDS solution (1 CMC) by nearly closing valve at pressure tab vs. air Reynolds number of pure water at $Re_{water} = 2740$ and $Re_{SDS\ solution} = 2540$.

Appendix H Determination The Effect of Surfactant Concentration on Pressure Gradient

Table H1 Determination the pressure gradient from the experiment between pure water and SDS solution at 0.5, 1 and 2 CMC

Physical properties of air, water and SDS solution (1 CMC) used in experiment:

density of water, $\rho_{water} = 994.7$ kg/m^3; viscosity of water, $\mu_{water} = 8.51 \times 10^{-4}$ Pa.s

density of SDS solution (0.5 CMC), $\rho_{SDS\ solution} = 994.8$ kg/m^3; viscosity of SDS solution (0.5 CMC), $\mu_{SDS\ solution} = 9.3 \times 10^{-4}$ Pa.s

density of SDS solution (1 CMC), $\rho_{SDS\ solution} = 994.97$ kg/m^3; viscosity of SDS solution (1 CMC), $\mu_{SDS\ solution} = 1.01 \times 10^{-3}$ Pa.s

density of SDS solution (2 CMC), $\rho_{SDS\ solution} = 995.58$ kg/m^3; viscosity of SDS solution (2 CMC), $\mu_{SDS\ solution} = 1.09 \times 10^{-3}$ Pa.s

density of air, $\rho_{air} = 1.18$ kg/m^3; viscosity of air, $\mu_{air} = 1.85 \times 10^{-5}$ Pa.s

temperature, T = 31 °C (± 1 °C); inner pipe diameter, D = 0.019 m; cross-sectional area of pipe, A = 0.00028 m^2

pressure taps difference = 0.4 m

Re_{air}	Re_{water}	(dp/dz) from experiment		$Re_{SDS\ solution}$ at 0.5 CMC	(dp/dz) from experiment		$Re_{SDS\ solution}$ at 1 CMC	(dp/dz) from experiment		$Re_{SDS\ solution}$ at 2 CMC	(dp/dz) from experiment	
		maximum (kPa/m)	minimum (kPa/m)		maximum (kPa/m)	minimum (kPa/m)		maximum (kPa/m)	minimum (kPa/m)		maximum (kPa/m)	minimum (kPa/m)
3.17	1010	9.8068	9.7092	1020	-	-	1065	9.7932	9.7851	970	-	-
5.64	1010	9.7824	9.6604	1020	-	-	1065	9.7119	9.6386	970	-	-
8.12	1010	9.7092	9.5628	1020	-	-	1065	9.7119	9.5166	970	-	-
10.59	1010	9.6360	9.3921	1020	-	-	1065	9.5166	9.2726	970	-	-
13.06	1010	9.5141	9.4653	1020	-	-	1065	9.3653	9.1750	970	-	-
15.54	1010	9.4165	9.2457	1020	-	-	1065	9.3019	8.9993	970	-	-
18.02	1010	9.3433	9.1481	1020	-	-	1065	9.0579	8.9310	970	-	-

20.49	1010	9.2701	9.0262	1020	8.9734	8.6709	1065	9.0481	8.7846	970	9.2685	9.3809
22.95	1010	9.2213	8.8554	1020	8.8172	8.9148	1065	8.8920	8.6382	970	9.2539	9.3516
28.08	1010	9.0262	8.5870	1020	8.7733	8.7831	1065	8.5015	8.3698	970	9.0830	9.4004
33.21	1010	8.9042	8.5627	1020	8.7831	8.6367	1065	8.1697	8.1550	970	8.9023	8.9902
38.33	1010	8.7968	8.1821	1020	8.5196	8.3830	1065	7.8866	7.8232	970	8.7802	8.7558
43.46	1010	8.5919	7.9772	1020	8.2659	8.1732	1065	7.8524	7.8768	970	8.3993	8.4384
48.59	1010	8.4651	7.6405	1020	8.1292	7.8560	1065	7.7012	7.6865	970	8.4237	8.5214
58.85	1010	8.3626	7.5137	1020	7.9780	7.6120	1065	7.4669	7.4425	970	8.0575	8.1405
69.10	1010	8.1333	7.4063	1020	7.5632	7.3192	1065	7.3351	7.1985	970	7.7498	7.7303
79.36	1010	8.0504	6.9575	1020	7.2948	7.0753	1065	7.3693	7.0765	970	7.3494	7.5691
89.62	1010	7.5625	6.6110	1020	7.0997	6.8313	1065	7.0667	6.7056	970	6.9001	6.8171
99.87	1010	7.3331	6.3915	1020	6.7093	6.5629	1065	6.8227	6.7593	970	6.5192	6.6560
177	1010	6.2451	5.3181	1020	5.3430	4.9039	1065	5.4660	5.0755	970	4.8833	5.1031
285	1010	4.8058	3.4885	1020	3.5620	3.0741	1065	3.6017	2.9282	970	2.6858	3.8334
356	1010	4.5375	2.9274	1020	3.0985	2.5617	1065	2.8794	2.4060	970	2.1975	3.1742
499	1010	3.6836	2.2443	1020	2.5617	1.9030	1065	2.3426	1.7325	970	1.7824	2.4905
713	1010	3.2689	1.3905	1020	1.9518	1.2199	1065	1.8301	1.1713	970	1.1964	2.0510
1425	1010	2.4395	1.3661	1020	2.1958	0.3416	1065	1.5861	0.7320	970	0.6348	1.5871
2851	1010	2.5615	1.6247	1020	2.0738	1.0979	1065	1.9131	1.5275	970	1.8215	1.9680
4276	1010	2.1956	1.4637	1020	1.8298	1.5224	1065	1.8887	1.6740	970	1.9094	2.1731
4989	1010	2.0736	1.4637	1020	1.7078	1.5126	1065	1.8301	1.7179	970	2.0803	2.1535
5702	1010	1.9516	1.3417	1020	1.6346	1.4931	1065	1.8594	1.7520	970	2.0754	2.1487
7127	1010	1.7808	1.2685	1020	1.5858	1.4590	1065	1.8789	1.7276	970	2.1487	2.2512
14255	1010	1.2539	0.9612	1020	-	-	1065	1.6837	1.6186	970	-	-
21382	1010	1.3759	1.1563	1020	-	-	1065	1.5292	1.4316	970	-	-
28510	1010	1.7369	1.5662	1020	-	-	1065	1.9928	1.9359	970	-	-
35637	1010	2.2687	2.0736	1020	-	-	1065	2.1311	2.0741	970	-	-
42765	1010	2.8640	2.6395	1020	-	-	1065	2.6760	2.5459	970	-	-
49892	1010	3.2689	3.1957	1020	-	-	1065	3.2536	3.2780	970	-	-
57020	1010	4.1862	3.9032	1020	-	-	1065	4.0263	4.0263	970	-	-
64147	1010	4.5131	4.1959	1020	-	-	1065	4.3923	4.3923	970	-	-
71275	1010	4.7814	4.7082	1020	-	-	1065	5.3928	5.3684	970	-	-

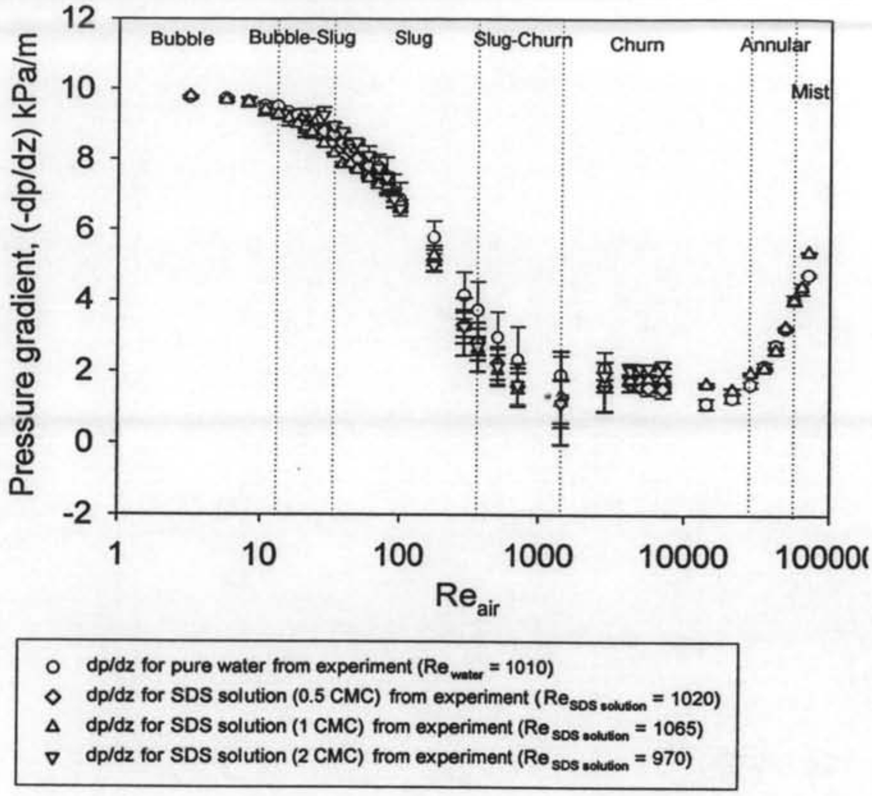

Figure H1 Determination the effect of surfactant concentration on pressure gradient (dp/dz).

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