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APPENDICES

APPENDIX A

Two-Phase Flow

Table A1 Determination of flow regimes and the pressure gradient as measured by a manometer in each flow regime
Physical properties of air and water used in the experiments:
viscosity of water, μ_{water} = 8.48 x 10^{-4} kg/m.s; density of water, ρ_{water} = 995 kg/m^3
viscosity of air, μ_{air} = 1.85 x 10^{-5} kg/m.s; density of air, ρ_{air} = 1.18 kg/m^3
temperature, T = 31°C (± 1°C); diameter of the pipe, D = 0.019 m; pressure taps difference = 0.4 m

Water flow rate Q_{water} (ml/min)	Sup. water velocity j_{water} (m/s)	Air flow rate Q_{air} (l/min)	Sup. air velocity j_{air} (m/s)	Reynolds number of air Re_{air}	Flow regime	Water levels difference in manometer, (m)		$(-dp/dz)_{exp}$ from experiment	
						Minimum	Maximum	Minimum (kPa/m)	Maximum (kPa/m)
0.00	0.00	0.000	0.0000	0.00	-	0.400	0.400	9.76	9.76
0.00	0.00	0.036	0.0021	2.56	bubble	0.400	0.400	9.76	9.76
0.00	0.00	0.071	0.0042	5.05	bubble	0.395	0.395	9.64	9.64
0.00	0.00	0.103	0.0060	7.32	bubble-slug	0.393	0.393	9.59	9.59
0.00	0.00	0.132	0.0077	9.38	bubble-slug	0.389	0.389	9.49	9.49
0.00	0.00	0.162	0.0095	11.51	bubble-slug	0.385	0.385	9.39	9.39
0.00	0.00	0.196	0.0115	13.93	bubble-slug	0.380	0.380	9.27	9.27
0.00	0.00	0.235	0.0138	16.70	bubble-slug	0.368	0.382	8.98	9.32
0.00	0.00	0.273	0.0160	19.40	bubble-slug	0.360	0.378	8.78	9.22
0.00	0.00	0.307	0.0180	21.82	slug	0.353	0.375	8.61	9.15
0.00	0.00	0.356	0.0209	25.30	slug	0.340	0.370	8.30	9.03

Table A1 continued

Water flow rate Q_{water} (ml/min)	Sup. water velocity j_{water} (m/s)	Air flow rate Q_{air} (l/min)	Sup. air velocity j_{air} (m/s)	Reynolds number of air Re_{air}	Flow regime	Water levels difference in manometer, (m)		$(-dp/dz)_{exp}$ from experiment	
						Minimum	Maximum	Minimum (kPa/m)	Maximum (kPa/m)
0.00	0.00	0.395	0.0232	28.07	slug	0.325	0.370	7.93	9.03
0.00	0.00	0.450	0.0264	31.98	slug	0.290	0.365	7.08	8.91
0.00	0.00	0.510	0.0299	36.24	slug	0.285	0.358	6.95	8.74
0.00	0.00	0.568	0.0333	40.37	slug	0.275	0.360	6.71	8.78
0.00	0.00	0.660	0.0387	46.90	slug	0.255	0.365	6.22	8.91
0.00	0.00	0.722	0.0424	51.31	slug	0.235	0.400	5.73	9.76
0.00	0.00	0.789	0.0463	56.07	slug	0.215	0.375	5.25	9.15
0.00	0.00	0.867	0.0509	61.61	slug	0.195	0.370	4.76	9.03
224	0.0131	0.000	0.0000	0.00	-	0.400	0.400	9.76	9.76
224	0.0131	0.036	0.0021	2.56	bubble	0.395	0.395	9.64	9.64
224	0.0131	0.071	0.0042	5.05	bubble	0.390	0.390	9.52	9.52
224	0.0131	0.103	0.0060	7.32	bubble	0.387	0.387	9.44	9.44
224	0.0131	0.132	0.0077	9.38	bubble-slug	0.384	0.384	9.37	9.37
224	0.0131	0.162	0.0095	11.51	bubble-slug	0.376	0.380	9.18	9.27
224	0.0131	0.196	0.0115	13.93	bubble-slug	0.370	0.374	9.03	9.13
224	0.0131	0.235	0.0138	16.70	bubble-slug	0.361	0.367	8.81	8.96
224	0.0131	0.273	0.0160	19.40	bubble-slug	0.355	0.362	8.66	8.83
224	0.0131	0.307	0.0180	21.82	bubble-slug	0.348	0.358	8.49	8.74
224	0.0131	0.356	0.0209	25.30	slug	0.340	0.350	8.30	8.54
224	0.0131	0.395	0.0232	28.07	slug	0.329	0.343	8.03	8.37

Table A1 continued

Water flow rate Q_{water} (ml/min)	Sup. water velocity j_{water} (m/s)	Air flow rate Q_{air} (l/min)	Sup. air velocity j_{air} (m/s)	Reynolds number of air Re_{air}	Flow regime	Water levels difference in manometer, (m)		$(-dp/dz)_{exp}$ from experiment	
						Minimum	Maximum	Minimum (kPa/m)	Maximum (kPa/m)
224	0.0131	0.450	0.0264	31.98	slug	0.321	0.334	7.83	8.15
224	0.0131	0.510	0.0299	36.24	slug	0.312	0.330	7.61	8.05
224	0.0131	0.568	0.0333	40.37	slug	0.297	0.340	7.25	8.30
224	0.0131	0.660	0.0387	46.90	slug	0.290	0.335	7.08	8.17
224	0.0131	0.722	0.0424	51.31	slug	0.277	0.347	6.76	8.47
224	0.0131	0.789	0.0463	56.07	slug	0.262	0.348	6.39	8.49
224	0.0131	0.867	0.0509	61.61	slug	0.255	0.345	6.22	8.42
224	0.0131	1.022	0.0600	72.63	slug	0.250	0.310	6.10	7.56
224	0.0131	2.394	0.1405	170.13	slug	0.020	0.300	0.49	7.32
224	0.0131	4.000	0.2347	284.26	slug	0.000	0.320	0.00	7.81
224	0.0131	5.326	0.3126	378.50	slug-churn	-0.080	0.260	-1.95	6.34
224	0.0131	7.058	0.4142	501.58	slug-churn	-0.040	0.240	-0.98	5.86
224	0.0131	10	0.5869	710.66	slug-churn	-0.050	0.240	-1.22	5.86
224	0.0131	20	1.1737	1421.32	churn	-0.020	0.130	-0.49	3.17
224	0.0131	30	1.7606	2131.98	churn	0.025	0.120	0.61	2.93
224	0.0131	40	2.3474	2842.63	churn	0.030	0.125	0.73	3.05
224	0.0131	50	2.9343	3553.29	churn	0.050	0.115	1.22	2.81
224	0.0131	60	3.5211	4263.95	churn	0.040	0.100	0.98	2.44
224	0.0131	70	4.1080	4974.61	churn	0.055	0.095	1.34	2.32
224	0.0131	100	5.8685	7106.59	churn	0.040	0.080	0.98	1.95

Table A1 continued

Water flow rate Q_{water} (ml/min)	Sup. water velocity j_{water} (m/s)	Air flow rate Q_{air} (l/min)	Sup. air velocity j_{air} (m/s)	Reynolds number of air Re_{air}	Flow regime	Water levels difference in manometer, (m)		$(-dp/dz)_{exp}$ from experiment	
						Minimum	Maximum	Minimum (kPa/m)	Maximum (kPa/m)
224	0.0131	200	11.7371	14213.17	annular	0.030	0.038	0.73	0.93
224	0.0131	300	17.6056	21319.76	annular	0.028	0.036	0.68	0.88
224	0.0131	400	23.4742	28426.35	annular	0.030	0.040	0.73	0.98
224	0.0131	500	29.3427	35532.93	annular	0.040	0.046	0.98	1.12
224	0.0131	600	35.2113	42639.52	annular	0.051	0.057	1.24	1.39
224	0.0131	700	41.0798	49746.11	annular	0.070	0.070	1.71	1.71
224	0.0131	800	46.9484	56852.69	mist	0.091	0.091	2.22	2.22
224	0.0131	900	52.8169	63959.28	mist	0.109	0.109	2.66	2.66
224	0.0131	1000	58.6854	71065.87	mist	0.134	0.134	3.27	3.27
325	0.0191	0.000	0.0000	0.00	-	0.400	0.400	9.76	9.76
325	0.0191	0.036	0.0021	2.56	bubble	0.395	0.395	9.64	9.64
325	0.0191	0.071	0.0042	5.05	bubble	0.390	0.390	9.52	9.52
325	0.0191	0.103	0.0060	7.32	bubble	0.388	0.388	9.47	9.47
325	0.0191	0.132	0.0077	9.38	bubble-slug	0.385	0.388	9.39	9.47
325	0.0191	0.162	0.0095	11.51	bubble-slug	0.376	0.386	9.18	9.42
325	0.0191	0.196	0.0115	13.93	bubble-slug	0.371	0.384	9.05	9.37
325	0.0191	0.235	0.0138	16.70	bubble-slug	0.366	0.379	8.93	9.25
325	0.0191	0.273	0.0160	19.40	bubble-slug	0.359	0.374	8.76	9.13
325	0.0191	0.307	0.0180	21.82	bubble-slug	0.351	0.366	8.57	8.93
325	0.0191	0.356	0.0209	25.30	bubble-slug	0.343	0.370	8.37	9.03

Table A1 continued

Water flow rate Q_{water} (ml/min)	Sup. water velocity j_{water} (m/s)	Air flow rate Q_{air} (l/min)	Sup. air velocity j_{air} (m/s)	Reynolds number of air Re_{air}	Flow regime	Water levels difference in manometer, (m)		(-dp/dz)$_{exp}$ from experiment	
						Minimum	Maximum	Minimum (kPa/m)	Maximum (kPa/m)
325	0.0191	0.395	0.0232	28.07	slug	0.324	0.365	7.91	8.91
325	0.0191	0.450	0.0264	31.98	slug	0.314	0.367	7.66	8.96
325	0.0191	0.510	0.0299	36.24	slug	0.302	0.361	7.37	8.81
325	0.0191	0.568	0.0333	40.37	slug	0.292	0.358	7.13	8.74
325	0.0191	0.660	0.0387	46.90	slug	0.283	0.350	6.91	8.54
325	0.0191	0.722	0.0424	51.31	slug	0.270	0.346	6.59	8.44
325	0.0191	0.789	0.0463	56.07	slug	0.260	0.344	6.34	8.39
325	0.0191	0.867	0.0509	61.61	slug	0.251	0.340	6.12	8.30
325	0.0191	1.022	0.0600	72.63	slug	0.150	0.340	3.66	8.30
325	0.0191	2.394	0.1405	170.13	slug	0.080	0.330	1.95	8.05
325	0.0191	4.000	0.2347	284.26	slug	0.020	0.320	0.49	7.81
325	0.0191	5.326	0.3126	378.50	slug	-0.020	0.310	-0.49	7.56
325	0.0191	7.058	0.4142	501.58	slug-churn	-0.040	0.250	-0.98	6.10
325	0.0191	10.000	0.5869	710.66	slug-churn	-0.040	0.180	-0.98	4.39
325	0.0191	20.000	1.1737	1421.32	churn	-0.050	0.170	-1.22	4.15
325	0.0191	30.000	1.7606	2131.98	churn	-0.020	0.140	-0.49	3.42
325	0.0191	40.000	2.3474	2842.63	churn	0.000	0.120	0.00	2.93
325	0.0191	50.000	2.9343	3553.29	churn	0.040	0.100	0.98	2.44
325	0.0191	60.000	3.5211	4263.95	churn	0.030	0.100	0.73	2.44
325	0.0191	70.000	4.1080	4974.61	churn	0.040	0.090	0.98	2.20

Table A1 continued

Water flow rate Q_{water} (ml/min)	Sup. water velocity j_{water} (m/s)	Air flow rate Q_{air} (l/min)	Sup. air velocity j_{air} (m/s)	Reynolds number of air Re_{air}	Flow regime	Water levels difference in manometer, (m)		$(-dp/dz)_{exp}$ from experiment	
						Minimum	Maximum	Minimum (kPa/m)	Maximum (kPa/m)
325	0.0191	100.000	5.8685	7106.59	churn	0.040	0.090	0.98	2.20
325	0.0191	200.000	11.7371	14213.17	annular	0.031	0.039	0.76	0.95
325	0.0191	300.000	17.6056	21319.76	annular	0.031	0.037	0.76	0.90
325	0.0191	400.000	23.4742	28426.35	annular	0.039	0.047	0.95	1.15
325	0.0191	500.000	29.3427	35532.93	annular	0.047	0.055	1.15	1.34
325	0.0191	600.000	35.2113	42639.52	annular	0.055	0.065	1.34	1.59
325	0.0191	700.000	41.0798	49746.11	annular	0.071	0.075	1.73	1.83
325	0.0191	800.000	46.9484	56852.69	mist	0.087	0.097	2.12	2.37
325	0.0191	900.000	52.8169	63959.28	mist	0.105	0.113	2.56	2.76
325	0.0191	1000.000	58.6854	71065.87	mist	0.121	0.125	2.95	3.05
427	0.0251	0.000	0.0000	0.00	-	0.400	0.400	9.76	9.76
427	0.0251	0.036	0.0021	2.56	bubble	0.396	0.396	9.66	9.66
427	0.0251	0.071	0.0042	5.05	bubble	0.392	0.392	9.57	9.57
427	0.0251	0.103	0.0060	7.32	bubble	0.390	0.390	9.52	9.52
427	0.0251	0.132	0.0077	9.38	bubble	0.384	0.390	9.37	9.52
427	0.0251	0.162	0.0095	11.51	bubble-slug	0.378	0.388	9.22	9.47
427	0.0251	0.196	0.0115	13.93	bubble-slug	0.373	0.387	9.10	9.44
427	0.0251	0.235	0.0138	16.70	bubble-slug	0.365	0.384	8.91	9.37
427	0.0251	0.273	0.0160	19.40	bubble-slug	0.359	0.380	8.76	9.27
427	0.0251	0.307	0.0180	21.82	bubble-slug	0.350	0.377	8.54	9.20

Table A1 continued

Water flow rate Q_{water} (ml/min)	Sup. water velocity j_{water} (m/s)	Air flow rate Q_{air} (l/min)	Sup. air velocity j_{air} (m/s)	Reynolds number of air Re_{air}	Flow regime	Water levels difference in manometer, (m)		$(-dp/dz)_{exp}$ from experiment	
						Minimum	Maximum	Minimum (kPa/m)	Maximum (kPa/m)
427	0.0251	0.356	0.0209	25.30	bubble-slug	0.340	0.374	8.30	9.13
427	0.0251	0.395	0.0232	28.07	bubble-slug	0.329	0.368	8.03	8.98
427	0.0251	0.450	0.0264	31.98	slug	0.317	0.366	7.74	8.93
427	0.0251	0.510	0.0299	36.24	slug	0.310	0.361	7.56	8.81
427	0.0251	0.568	0.0333	40.37	slug	0.302	0.359	7.37	8.76
427	0.0251	0.660	0.0387	46.90	slug	0.288	0.352	7.03	8.59
427	0.0251	0.722	0.0424	51.31	slug	0.272	0.348	6.64	8.49
427	0.0251	0.789	0.0463	56.07	slug	0.267	0.358	6.52	8.74
427	0.0251	0.867	0.0509	61.61	slug	0.255	0.342	6.22	8.35
427	0.0251	1.022	0.0600	72.63	slug	0.250	0.320	6.10	7.81
427	0.0251	2.394	0.1405	170.13	slug	0.090	0.290	2.20	7.08
427	0.0251	4.000	0.2347	284.26	slug	0.000	0.310	0.00	7.56
427	0.0251	5.326	0.3126	378.50	slug	-0.020	0.300	-0.49	7.32
427	0.0251	7.058	0.4142	501.58	slug	-0.040	0.280	-0.98	6.83
427	0.0251	10.000	0.5869	710.66	slug-churn	-0.090	0.260	-2.20	6.34
427	0.0251	20.000	1.1737	1421.32	slug-churn	-0.040	0.180	-0.98	4.39
427	0.0251	30.000	1.7606	2131.98	slug-churn	0.000	0.150	0.00	3.66
427	0.0251	40.000	2.3474	2842.63	churn	0.020	0.120	0.49	2.93
427	0.0251	50.000	2.9343	3553.29	churn	0.050	0.110	1.22	2.68
427	0.0251	60.000	3.5211	4263.95	churn	0.050	0.105	1.22	2.56

Table A1 continued

Water flow rate Q_{water} (ml/min)	Sup. water velocity j_{water} (m/s)	Air flow rate Q_{air} (l/min)	Sup. air velocity j_{air} (m/s)	Reynolds number of air Re_{air}	Flow regime	Water levels difference in manometer, (m)		$(-dp/dz)_{exp}$ from experiment	
						Minimum	Maximum	Minimum (kPa/m)	Maximum (kPa/m)
427	0.0251	70.000	4.1080	4974.61	churn	0.060	0.095	1.46	2.32
427	0.0251	100.000	5.8685	7106.59	churn	0.040	0.090	0.98	2.20
427	0.0251	200.000	11.7371	14213.17	annular	0.035	0.050	0.85	1.22
427	0.0251	300.000	17.6056	21319.76	annular	0.040	0.048	0.98	1.17
427	0.0251	400.000	23.4742	28426.35	annular	0.053	0.057	1.29	1.39
427	0.0251	500.000	29.3427	35532.93	annular	0.066	0.070	1.61	1.71
427	0.0251	600.000	35.2113	42639.52	annular	0.085	0.089	2.07	2.17
427	0.0251	700.000	41.0798	49746.11	annular	0.101	0.109	2.46	2.66
427	0.0251	800.000	46.9484	56852.69	mist	0.120	0.128	2.93	3.12
427	0.0251	900.000	52.8169	63959.28	mist	0.140	0.151	3.42	3.68
427	0.0251	1000.000	58.6854	71065.87	mist	0.170	0.180	4.15	4.39
529	0.0311	0.000	0.0000	0.00	-	0.400	0.400	9.76	9.76
529	0.0311	0.036	0.0021	2.56	bubble	0.395	0.395	9.64	9.64
529	0.0311	0.071	0.0042	5.05	bubble	0.392	0.392	9.57	9.57
529	0.0311	0.103	0.0060	7.32	bubble	0.390	0.390	9.52	9.52
529	0.0311	0.132	0.0077	9.38	bubble	0.386	0.390	9.42	9.52
529	0.0311	0.162	0.0095	11.51	bubble	0.381	0.388	9.30	9.47
529	0.0311	0.196	0.0115	13.93	bubble-slug	0.373	0.387	9.10	9.44
529	0.0311	0.235	0.0138	16.70	bubble-slug	0.366	0.386	8.93	9.42
529	0.0311	0.273	0.0160	19.40	bubble-slug	0.360	0.381	8.78	9.30

Table A1 continued

Water flow rate Q_{water} (ml/min)	Sup. water velocity j_{water} (m/s)	Air flow rate Q_{air} (l/min)	Sup. air velocity j_{air} (m/s)	Reynolds number of air Re_{air}	Flow regime	Water levels difference in manometer, (m)		$(-dp/dz)_{exp}$ from experiment	
						Minimum	Maximum	Minimum (kPa/m)	Maximum (kPa/m)
529	0.0311	0.307	0.0180	21.82	bubble-slug	0.352	0.379	8.59	9.25
529	0.0311	0.356	0.0209	25.30	bubble-slug	0.344	0.372	8.39	9.08
529	0.0311	0.395	0.0232	28.07	bubble-slug	0.333	0.368	8.13	8.98
529	0.0311	0.450	0.0264	31.98	bubble-slug	0.324	0.363	7.91	8.86
529	0.0311	0.510	0.0299	36.24	slug	0.311	0.357	7.59	8.71
529	0.0311	0.568	0.0333	40.37	slug	0.306	0.352	7.47	8.59
529	0.0311	0.660	0.0387	46.90	slug	0.293	0.346	7.15	8.44
529	0.0311	0.722	0.0424	51.31	slug	0.285	0.344	6.95	8.39
529	0.0311	0.789	0.0463	56.07	slug	0.272	0.360	6.64	8.78
529	0.0311	0.867	0.0509	61.61	slug	0.265	0.339	6.47	8.27
529	0.0311	1.022	0.0600	72.63	slug	0.250	0.320	6.10	7.81
529	0.0311	2.394	0.1405	170.13	slug	0.100	0.360	2.44	8.78
529	0.0311	4.000	0.2347	284.26	slug	-0.010	0.400	-0.24	9.76
529	0.0311	5.326	0.3126	378.50	slug	-0.050	0.380	-1.22	9.27
529	0.0311	7.058	0.4142	501.58	slug	-0.060	0.320	-1.46	7.81
529	0.0311	10.000	0.5869	710.66	slug-churn	-0.080	0.260	-1.95	6.34
529	0.0311	20.000	1.1737	1421.32	slug-churn	-0.040	0.160	-0.98	3.90
529	0.0311	30.000	1.7606	2131.98	churn	-0.020	0.140	-0.49	3.42
529	0.0311	40.000	2.3474	2842.63	churn	0.000	0.140	0.00	3.42
529	0.0311	50.000	2.9343	3553.29	churn	0.040	0.130	0.98	3.17

Table A1 continued

Water flow rate Q_{water} (ml/min)	Sup. water velocity j_{water} (m/s)	Air flow rate Q_{air} (l/min)	Sup. air velocity j_{air} (m/s)	Reynolds number of air Re_{air}	Flow regime	Water levels difference in manometer, (m)		$(-dp/dz)_{exp}$ from experiment	
						Minimum	Maximum	Minimum (kPa/m)	Maximum (kPa/m)
529	0.0311	60.000	3.5211	4263.95	churn	0.020	0.100	0.49	2.44
529	0.0311	70.000	4.1080	4974.61	churn	0.050	0.100	1.22	2.44
529	0.0311	100.000	5.8685	7106.59	churn	0.040	0.100	0.98	2.44
529	0.0311	200.000	11.7371	14213.17	annular	0.036	0.050	0.88	1.22
529	0.0311	300.000	17.6056	21319.76	annular	0.038	0.046	0.93	1.12
529	0.0311	400.000	23.4742	28426.35	annular	0.050	0.056	1.22	1.37
529	0.0311	500.000	29.3427	35532.93	annular	0.061	0.069	1.49	1.68
529	0.0311	600.000	35.2113	42639.52	annular	0.073	0.085	1.78	2.07
529	0.0311	700.000	41.0798	49746.11	annular	0.093	0.099	2.27	2.42
529	0.0311	800.000	46.9484	56852.69	mist	0.111	0.117	2.71	2.86
529	0.0311	900.000	52.8169	63959.28	mist	0.125	0.135	3.05	3.29
529	0.0311	1000.000	58.6854	71065.87	mist	0.150	0.167	3.66	4.08
732	0.043	0.000	0.0000	0.00	-	0.398	0.398	9.71	9.71
732	0.043	0.036	0.0021	2.56	bubble	0.392	0.392	9.57	9.57
732	0.043	0.071	0.0042	5.05	bubble	0.388	0.391	9.47	9.54
732	0.043	0.103	0.0060	7.32	bubble	0.382	0.392	9.32	9.57
732	0.043	0.132	0.0077	9.38	bubble	0.379	0.391	9.25	9.54
732	0.043	0.162	0.0095	11.51	bubble	0.369	0.390	9.00	9.52
732	0.043	0.196	0.0115	13.93	bubble	0.362	0.391	8.83	9.54
732	0.043	0.235	0.0138	16.70	bubble-slug	0.357	0.386	8.71	9.42

Table A1 continued

Water flow rate Q_{water} (ml/min)	Sup. water velocity j_{water} (m/s)	Air flow rate Q_{air} (l/min)	Sup. air velocity j_{air} (m/s)	Reynolds number of air Re_{air}	Flow regime	Water levels difference in manometer, (m)		$(-dp/dz)_{exp}$ from experiment	
						Minimum	Maximum	Minimum (kPa/m)	Maximum (kPa/m)
732	0.043	0.273	0.0160	19.40	bubble-slug	0.347	0.383	8.47	9.35
732	0.043	0.307	0.0180	21.82	bubble-slug	0.338	0.380	8.25	9.27
732	0.043	0.356	0.0209	25.30	bubble-slug	0.326	0.375	7.96	9.15
732	0.043	0.395	0.0232	28.07	bubble-slug	0.320	0.360	7.81	8.78
732	0.043	0.450	0.0264	31.98	bubble-slug	0.305	0.365	7.44	8.91
732	0.043	0.510	0.0299	36.24	bubble-slug	0.297	0.357	7.25	8.71
732	0.043	0.568	0.0333	40.37	bubble-slug	0.285	0.353	6.95	8.61
732	0.043	0.660	0.0387	46.90	slug	0.275	0.366	6.71	8.93
732	0.043	0.722	0.0424	51.31	slug	0.271	0.354	6.61	8.64
732	0.043	0.789	0.0463	56.07	slug	0.250	0.360	6.10	8.78
732	0.043	0.867	0.0509	61.61	slug	0.255	0.360	6.22	8.78
732	0.043	1.022	0.0600	72.63	slug	0.260	0.350	6.34	8.54
732	0.043	2.394	0.1405	170.13	slug	0.100	0.360	2.44	8.78
732	0.043	4.000	0.2347	284.26	slug	-0.020	0.360	-0.49	8.78
732	0.043	5.326	0.3126	378.50	slug	-0.040	0.360	-0.98	8.78
732	0.043	7.058	0.4142	501.58	slug	-0.060	0.340	-1.46	8.30
732	0.043	10.000	0.5869	710.66	slug	-0.100	0.300	-2.44	7.32
732	0.043	20.000	1.1737	1421.32	slug-churn	-0.080	0.160	-1.95	3.90
732	0.043	30.000	1.7606	2131.98	churn	-0.040	0.140	-0.98	3.42
732	0.043	40.000	2.3474	2842.63	churn	0.020	0.140	0.49	3.42

Table A1 continued

Water flow rate Q_{water} (ml/min)	Sup. water velocity j_{water} (m/s)	Air flow rate Q_{air} (l/min)	Sup. air velocity j_{air} (m/s)	Reynolds number of air Re_{air}	Flow regime	Water levels difference in manometer, (m)		$(-dp/dz)_{exp}$ from experiment	
						Minimum	Maximum	Minimum (kPa/m)	Maximum (kPa/m)
732	0.043	50.000	2.9343	3553.29	churn	0.040	0.120	0.98	2.93
732	0.043	60.000	3.5211	4263.95	churn	0.030	0.090	0.73	2.20
732	0.043	70.000	4.1080	4974.61	churn	0.015	0.110	0.37	2.68
732	0.043	100.000	5.8685	7106.59	churn	0.030	0.100	0.73	2.44
732	0.043	200.000	11.7371	14213.17	annular	0.040	0.050	0.98	1.22
732	0.043	300.000	17.6056	21319.76	annular	0.045	0.050	1.10	1.22
732	0.043	400.000	23.4742	28426.35	annular	0.055	0.065	1.34	1.59
732	0.043	500.000	29.3427	35532.93	annular	0.072	0.080	1.76	1.95
732	0.043	600.000	35.2113	42639.52	annular	0.090	0.098	2.20	2.39
732	0.043	700.000	41.0798	49746.11	annular	0.110	0.116	2.68	2.83
732	0.043	800.000	46.9484	56852.69	mist	0.134	0.144	3.27	3.51
732	0.043	900.000	52.8169	63959.28	mist	0.154	0.162	3.76	3.95
732	0.043	1000.000	58.6854	71065.87	mist	0.188	0.197	4.59	4.81
936	0.055	0.000	0.0000	0.00	-	0.396	0.396	9.66	9.66
936	0.055	0.036	0.0021	2.56	bubble	0.392	0.392	9.57	9.57
936	0.055	0.071	0.0042	5.05	bubble	0.388	0.394	9.47	9.61
936	0.055	0.103	0.0060	7.32	bubble	0.386	0.392	9.42	9.57
936	0.055	0.132	0.0077	9.38	bubble	0.378	0.390	9.22	9.52
936	0.055	0.162	0.0095	11.51	bubble	0.374	0.388	9.13	9.47
936	0.055	0.196	0.0115	13.93	bubble	0.368	0.388	8.98	9.47

Table A1 continued

Water flow rate Q_{water} (ml/min)	Sup. water velocity j_{water} (m/s)	Air flow rate Q_{air} (l/min)	Sup. air velocity j_{air} (m/s)	Reynolds number of air Re_{air}	Flow regime	Water levels difference in manometer, (m)		$(-dp/dz)_{exp}$ from experiment	
						Minimum	Maximum	Minimum (kPa/m)	Maximum (kPa/m)
936	0.055	0.235	0.0138	16.70	bubble	0.362	0.384	8.83	9.37
936	0.055	0.273	0.0160	19.40	bubble-slug	0.352	0.381	8.59	9.30
936	0.055	0.307	0.0180	21.82	bubble-slug	0.344	0.379	8.39	9.25
936	0.055	0.356	0.0209	25.30	bubble-slug	0.334	0.375	8.15	9.15
936	0.055	0.395	0.0232	28.07	bubble-slug	0.326	0.367	7.96	8.96
936	0.055	0.450	0.0264	31.98	bubble-slug	0.318	0.361	7.76	8.81
936	0.055	0.510	0.0299	36.24	bubble-slug	0.312	0.353	7.61	8.61
936	0.055	0.568	0.0333	40.37	bubble-slug	0.306	0.349	7.47	8.52
936	0.055	0.660	0.0387	46.90	slug	0.296	0.343	7.22	8.37
936	0.055	0.722	0.0424	51.31	slug	0.286	0.349	6.98	8.52
936	0.055	0.789	0.0463	56.07	slug	0.274	0.339	6.69	8.27
936	0.055	0.867	0.0509	61.61	slug	0.267	0.333	6.52	8.13
936	0.055	1.022	0.0600	72.63	slug	0.254	0.340	6.20	8.30
936	0.055	2.394	0.1405	170.13	slug	0.140	0.380	3.42	9.27
936	0.055	4.000	0.2347	284.26	slug	0.030	0.350	0.73	8.54
936	0.055	5.326	0.3126	378.50	slug	0.000	0.370	0.00	9.03
936	0.055	7.058	0.4142	501.58	slug	-0.020	0.330	-0.49	8.05
936	0.055	10.000	0.5869	710.66	slug	-0.08	0.28	-1.95	6.83
936	0.055	20.000	1.1737	1421.32	slug-churn	-0.04	0.22	-0.98	5.37
936	0.055	30.000	1.7606	2131.98	churn	0	0.12	0.00	2.93

Table A1 continued

Water flow rate Q_{water} (ml/min)	Sup. water velocity j_{water} (m/s)	Air flow rate Q_{air} (l/min)	Sup. air velocity j_{air} (m/s)	Reynolds number of air Re_{air}	Flow regime	Water levels difference in manometer, (m)		$(-dp/dz)_{exp}$ from experiment	
						Minimum	Maximum	Minimum (kPa/m)	Maximum (kPa/m)
936	0.055	40.000	2.3474	2842.63	churn	0.02	0.15	0.49	3.66
936	0.055	50.000	2.9343	3553.29	churn	0.04	0.13	0.98	3.17
936	0.055	60.000	3.5211	4263.95	churn	0.05	0.11	1.22	2.68
936	0.055	70.000	4.1080	4974.61	churn	0.04	0.11	0.98	2.68
936	0.055	100.000	5.8685	7106.59	churn	0.045	0.105	1.10	2.56
936	0.055	200.000	11.7371	14213.17	annular	0.045	0.061	1.10	1.49
936	0.055	300.000	17.6056	21319.76	annular	0.053	0.061	1.29	1.49
936	0.055	400.000	23.4742	28426.35	annular	0.065	0.071	1.59	1.73
936	0.055	500.000	29.3427	35532.93	annular	0.085	0.091	2.07	2.22
936	0.055	600.000	35.2113	42639.52	annular	0.107	0.113	2.61	2.76
936	0.055	700.000	41.0798	49746.11	annular	0.124	0.135	3.03	3.29
936	0.055	800.000	46.9484	56852.69	mist	0.15	0.159	3.66	3.88
936	0.055	900.000	52.8169	63959.28	mist	0.175	0.185	4.27	4.51
936	0.055	1000.000	58.6854	71065.87	mist	0.21	0.216	5.12	5.27
1241	0.073	0.000	0.0000	0.00	-	0.394	0.394	9.61	9.61
1241	0.073	0.036	0.0021	2.56	bubble	0.391	0.391	9.54	9.54
1241	0.073	0.071	0.0042	5.05	bubble	0.389	0.393	9.49	9.59
1241	0.073	0.103	0.0060	7.32	bubble	0.387	0.393	9.44	9.59
1241	0.073	0.132	0.0077	9.38	bubble	0.379	0.391	9.25	9.54
1241	0.073	0.162	0.0095	11.51	bubble	0.377	0.387	9.20	9.44

Table A1 continued

Water flow rate Q_{water} (ml/min)	Sup. water velocity j_{water} (m/s)	Air flow rate Q_{air} (l/min)	Sup. air velocity j_{air} (m/s)	Reynolds number of air Re_{air}	Flow regime	Water levels difference in manometer, (m)		$(-dp/dz)_{exp}$ from experiment	
						Minimum	Maximum	Minimum (kPa/m)	Maximum (kPa/m)
1241	0.073	0.196	0.0115	13.93	bubble	0.369	0.385	9.00	9.39
1241	0.073	0.235	0.0138	16.70	bubble	0.365	0.381	8.91	9.30
1241	0.073	0.273	0.0160	19.40	bubble	0.357	0.379	8.71	9.25
1241	0.073	0.307	0.0180	21.82	bubble	0.345	0.375	8.42	9.15
1241	0.073	0.356	0.0209	25.30	bubble	0.337	0.369	8.22	9.00
1241	0.073	0.395	0.0232	28.07	bubble-slug	0.329	0.371	8.03	9.05
1241	0.073	0.450	0.0264	31.98	bubble-slug	0.321	0.365	7.83	8.91
1241	0.073	0.510	0.0299	36.24	bubble-slug	0.313	0.375	7.64	9.15
1241	0.073	0.568	0.0333	40.37	bubble-slug	0.305	0.365	7.44	8.91
1241	0.073	0.660	0.0387	46.90	bubble-slug	0.299	0.355	7.30	8.66
1241	0.073	0.722	0.0424	51.31	bubble-slug	0.291	0.359	7.10	8.76
1241	0.073	0.789	0.0463	56.07	slug	0.283	0.351	6.91	8.57
1241	0.073	0.867	0.0509	61.61	slug	0.275	0.339	6.71	8.27
1241	0.073	1.022	0.0600	72.63	slug	0.280	0.340	6.83	8.30
1241	0.073	2.394	0.1405	170.13	slug	0.150	0.330	3.66	8.05
1241	0.073	4.000	0.2347	284.26	slug	0.100	0.320	2.44	7.81
1241	0.073	5.326	0.3126	378.50	slug	0.020	0.360	0.49	8.78
1241	0.073	7.058	0.4142	501.58	slug	0.010	0.300	0.24	7.32
1241	0.073	10.000	0.5869	710.66	slug	-0.050	0.290	-1.22	7.08
1241	0.073	20.000	1.1737	1421.32	slug-churn	-0.030	0.200	-0.73	4.88

Table A1 continued

Water flow rate Q_{water} (ml/min)	Sup. water velocity j_{water} (m/s)	Air flow rate Q_{air} (l/min)	Sup. air velocity j_{air} (m/s)	Reynolds number of air Re_{air}	Flow regime	Water levels difference in manometer, (m)		$(-dp/dz)_{exp}$ from experiment	
						Minimum	Maximum	Minimum (kPa/m)	Maximum (kPa/m)
1241	0.073	30.000	1.7606	2131.98	churn	-0.010	0.130	-0.24	3.17
1241	0.073	40.000	2.3474	2842.63	churn	0.030	0.140	0.73	3.42
1241	0.073	50.000	2.9343	3553.29	churn	0.045	0.135	1.10	3.29
1241	0.073	60.000	3.5211	4263.95	churn	0.050	0.140	1.22	3.42
1241	0.073	70.000	4.1080	4974.61	churn	0.040	0.120	0.98	2.93
1241	0.073	100.000	5.8685	7106.59	churn	0.050	0.110	1.22	2.68
1241	0.073	200.000	11.7371	14213.17	annular	0.059	0.070	1.44	1.71
1241	0.073	300.000	17.6056	21319.76	annualr	0.068	0.074	1.66	1.81
1241	0.073	400.000	23.4742	28426.35	annualr	0.087	0.093	2.12	2.27
1241	0.073	500.000	29.3427	35532.93	annualr	0.108	0.116	2.64	2.83
1241	0.073	600.000	35.2113	42639.52	annualr	0.131	0.137	3.20	3.34
1241	0.073	700.000	41.0798	49746.11	annualr	0.157	0.162	3.83	3.95
1241	0.073	800.000	46.9484	56852.69	mist	0.190	0.197	4.64	4.81
1241	0.073	900.000	52.8169	63959.28	mist	0.220	0.227	5.37	5.54
1241	0.073	1000.000	58.6854	71065.87	mist	0.275	0.280	6.71	6.83
2055	0.121	0.000	0.0000	0.00	-	0.397	0.397	9.69	9.69
2055	0.121	0.036	0.0021	2.56	bubble	0.393	0.393	9.59	9.59
2055	0.121	0.071	0.0042	5.05	bubble	0.390	0.390	9.52	9.52
2055	0.121	0.103	0.0060	7.32	bubble	0.389	0.389	9.49	9.49
2055	0.121	0.132	0.0077	9.38	bubble	0.386	0.386	9.42	9.42

Table A1 continued

Water flow rate Q_{water} (ml/min)	Sup. water velocity j_{water} (m/s)	Air flow rate Q_{air} (l/min)	Sup. air velocity j_{air} (m/s)	Reynolds number of air Re_{air}	Flow regime	Water levels difference in manometer, (m)		$(-dp/dz)_{exp}$ from experiment	
						Minimum	Maximum	Minimum (kPa/m)	Maximum (kPa/m)
2055	0.121	0.162	0.0095	11.51	bubble	0.382	0.382	9.32	9.32
2055	0.121	0.196	0.0115	13.93	bubble	0.380	0.380	9.27	9.27
2055	0.121	0.235	0.0138	16.70	bubble	0.376	0.376	9.18	9.18
2055	0.121	0.273	0.0160	19.40	bubble	0.369	0.373	9.00	9.10
2055	0.121	0.307	0.0180	21.82	bubble	0.365	0.369	8.91	9.00
2055	0.121	0.356	0.0209	25.30	bubble	0.359	0.365	8.76	8.91
2055	0.121	0.395	0.0232	28.07	bubble	0.352	0.360	8.59	8.78
2055	0.121	0.450	0.0264	31.98	bubble	0.340	0.359	8.30	8.76
2055	0.121	0.510	0.0299	36.24	bubble-slug	0.340	0.360	8.30	8.78
2055	0.121	0.568	0.0333	40.37	bubble-slug	0.331	0.349	8.08	8.52
2055	0.121	0.660	0.0387	46.90	bubble-slug	0.325	0.365	7.93	8.91
2055	0.121	0.722	0.0424	51.31	bubble-slug	0.317	0.353	7.74	8.61
2055	0.121	0.789	0.0463	56.07	bubble-slug	0.309	0.343	7.54	8.37
2055	0.121	0.867	0.0509	61.61	bubble-slug	0.301	0.353	7.35	8.61
2055	0.121	1.022	0.0600	72.63	slug	0.296	0.340	7.22	8.30
2055	0.121	2.394	0.1405	170.13	slug	0.190	0.330	4.64	8.05
2055	0.121	4.000	0.2347	284.26	slug	0.120	0.340	2.93	8.30
2055	0.121	5.326	0.3126	378.50	slug	0.040	0.310	0.98	7.56
2055	0.121	7.058	0.4142	501.58	slug	0.010	0.340	0.24	8.30
2055	0.121	10.000	0.5869	710.66	slug	-0.030	0.260	-0.73	6.34

Table A1 continued

Water flow rate Q_{water} (ml/min)	Sup. water velocity j_{water} (m/s)	Air flow rate Q_{air} (l/min)	Sup. air velocity j_{air} (m/s)	Reynolds number of air Re_{air}	Flow regime	Water levels difference in manometer, (m)		$(-dp/dz)_{exp}$ from experiment	
						Minimum	Maximum	Minimum (kPa/m)	Maximum (kPa/m)
2055	0.121	20.000	1.1737	1421.32	slug-churn	-0.020	0.220	-0.49	5.37
2055	0.121	30.000	1.7606	2131.98	churn	0.000	0.200	0.00	4.88
2055	0.121	40.000	2.3474	2842.63	churn	0.020	0.160	0.49	3.90
2055	0.121	50.000	2.9343	3553.29	churn	0.030	0.150	0.73	3.66
2055	0.121	60.000	3.5211	4263.95	churn	0.050	0.140	1.22	3.42
2055	0.121	70.000	4.1080	4974.61	churn	0.060	0.140	1.46	3.42
2055	0.121	100.000	5.8685	7106.59	churn	0.050	0.110	1.22	2.68
2055	0.121	200.000	11.7371	14213.17	annular	0.070	0.090	1.71	2.20
2055	0.121	300.000	17.6056	21319.76	annualr	0.096	0.108	2.34	2.64
2055	0.121	400.000	23.4742	28426.35	annualr	0.122	0.132	2.98	3.22
2055	0.121	500.000	29.3427	35532.93	annualr	0.150	0.166	3.66	4.05
2055	0.121	600.000	35.2113	42639.52	annualr	0.182	0.196	4.44	4.78
2055	0.121	700.000	41.0798	49746.11	annualr	0.213	0.221	5.20	5.39
2055	0.121	800.000	46.9484	56852.69	mist	0.251	0.257	6.12	6.27
2055	0.121	900.000	52.8169	63959.28	mist	0.298	0.302	7.27	7.37
2055	0.121	1000.000	58.6854	71065.87	mist	0.322	0.328	7.86	8.00

Table A2 Determination of flow regimes and the pressure gradients as measured by a manometer in each flow regime

Physical properties of air and (50 vol% glycerol + 50 vol% water) solution used in the experiments:

viscosity of glycerol solution, $\mu_{solution}$ = 4.48 x 10^{-3} kg/m.s; density of glycerol solution, $\rho_{solution}$ = 1121 kg/m^3

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

temperature, T = 31°C (± 1°C); diameter of the pipe, D = 0.019 m; pressure taps difference = 0.4 m

Solution flow rate $Q_{solution}$ (ml/min)	Sup. solution velocity $j_{solution}$ (m/s)	Air flow rate Q_{air} (l/min)	Sup. air velocity j_{air} (m/s)	Reynolds number of air Re_{air}	Flow regime	Solution levels difference in manometer, (m)		$(-dp/dz)_{exp}$ from experiment	
						Minimum	Maximum	Minimum (kPa/m)	Maximum (kPa/m)
0	0.0000	0.000	0.0000	0.00	-	0.400	0.400	11.00	11.00
0	0.0000	0.036	0.0021	2.56	bubble	0.397	0.397	10.91	10.91
0	0.0000	0.071	0.0042	5.05	bubble	0.395	0.395	10.86	10.86
0	0.0000	0.103	0.0060	7.32	bubble	0.389	0.389	10.69	10.69
0	0.0000	0.132	0.0077	9.38	bubble	0.381	0.381	10.47	10.47
0	0.0000	0.162	0.0095	11.51	bubble	0.373	0.377	10.25	10.36
0	0.0000	0.196	0.0115	13.93	bubble-slug	0.365	0.373	10.03	10.25
0	0.0000	0.235	0.0138	16.70	bubble-slug	0.355	0.365	9.76	10.03
0	0.0000	0.273	0.0160	19.40	bubble-slug	0.347	0.367	9.54	10.09
0	0.0000	0.307	0.0180	21.82	bubble-slug	0.331	0.355	9.10	9.76
0	0.0000	0.356	0.0209	25.30	bubble-slug	0.319	0.349	8.77	9.59
0	0.0000	0.395	0.0232	28.07	bubble-slug	0.309	0.355	8.50	9.76
0	0.0000	0.450	0.0264	31.98	slug	0.299	0.327	8.22	8.99
0	0.0000	0.510	0.0299	36.24	slug	0.287	0.325	7.89	8.94

Table A2 continued

Solution flow rate $Q_{solution}$ (ml/min)	Sup. solution velocity $j_{solution}$ (m/s)	Air flow rate Q_{air} (l/min)	Sup. air velocity j_{air} (m/s)	Reynolds number of air Re_{air}	Flow regime	Solution levels difference in manometer, (m)		$(-dp/dz)_{exp}$ from experiment	
						Minimum	Maximum	Minimum (kPa/m)	Maximum (kPa/m)
0	0.0000	0.568	0.0333	40.37	slug	0.277	0.325	7.62	8.94
0	0.0000	0.660	0.0387	46.90	slug	0.267	0.319	7.34	8.77
0	0.0000	0.722	0.0424	51.31	slug	0.255	0.305	7.01	8.39
0	0.0000	0.789	0.0463	56.07	slug	0.245	0.305	6.74	8.39
0	0.0000	0.867	0.0509	61.61	slug	0.233	0.315	6.41	8.66
358	0.0210	0.000	0.0000	0.00	-	0.398	0.398	10.94	10.94
358	0.0210	0.036	0.0021	2.56	bubble	0.395	0.395	10.86	10.86
358	0.0210	0.071	0.0042	5.05	bubble	0.390	0.390	10.72	10.72
358	0.0210	0.103	0.0060	7.32	bubble	0.385	0.385	10.58	10.58
358	0.0210	0.132	0.0077	9.38	bubble	0.381	0.381	10.47	10.47
358	0.0210	0.162	0.0095	11.51	bubble	0.373	0.377	10.25	10.36
358	0.0210	0.196	0.0115	13.93	bubble	0.367	0.373	10.09	10.25
358	0.0210	0.235	0.0138	16.70	bubble-slug	0.360	0.370	9.90	10.17
358	0.0210	0.273	0.0160	19.40	bubble-slug	0.352	0.360	9.68	9.90
358	0.0210	0.307	0.0180	21.82	bubble-slug	0.342	0.354	9.40	9.73
358	0.0210	0.356	0.0209	25.30	bubble-slug	0.340	0.350	9.35	9.62
358	0.0210	0.395	0.0232	28.07	bubble-slug	0.320	0.344	8.80	9.46
358	0.0210	0.450	0.0264	31.98	bubble-slug	0.314	0.340	8.63	9.35
358	0.0210	0.510	0.0299	36.24	bubble-slug	0.304	0.334	8.36	9.18
358	0.0210	0.568	0.0333	40.37	slug	0.294	0.330	8.08	9.07

Table A2 continued

Solution flow rate $Q_{solution}$ (ml/min)	Sup. solution velocity $j_{solution}$ (m/s)	Air flow rate Q_{air} (l/min)	Sup. air velocity j_{air} (m/s)	Reynolds number of air Re_{air}	Flow regime	Solution levels difference in manometer, (m)		$(-dp/dz)_{exp}$ from experiment	
						Minimum	Maximum	Minimum (kPa/m)	Maximum (kPa/m)
358	0.0210	0.660	0.0387	46.90	slug	0.286	0.324	7.86	8.91
358	0.0210	0.722	0.0424	51.31	slug	0.278	0.310	7.64	8.52
358	0.0210	0.789	0.0463	56.07	slug	0.272	0.310	7.48	8.52
358	0.0210	0.867	0.0509	61.61	slug	0.264	0.310	7.26	8.52
358	0.0210	1.022	0.0600	72.63	slug	0.254	0.300	6.98	8.25
358	0.0210	2.394	0.1405	170.13	slug	0.150	0.250	4.12	6.87
358	0.0210	4.000	0.2347	284.26	slug	0.050	0.210	1.37	5.77
358	0.0210	5.326	0.3126	378.50	slug	0.030	0.230	0.82	6.32
358	0.0210	7.058	0.4142	501.58	slug-churn	0.020	0.210	0.55	5.77
358	0.0210	10.000	0.5869	710.66	slug-churn	0.030	0.150	0.82	4.12
358	0.0210	20.000	1.1737	1421.32	churn	0.020	0.120	0.55	3.30
358	0.0210	30.000	1.7606	2131.98	churn	0.035	0.095	0.96	2.61
358	0.0210	40.000	2.3474	2842.63	churn	0.047	0.085	1.29	2.34
358	0.0210	50.000	2.9343	3553.29	churn	0.035	0.090	0.96	2.47
358	0.0210	60.000	3.5211	4263.95	churn	0.050	0.085	1.37	2.34
358	0.0210	70.000	4.1080	4974.61	churn	0.058	0.082	1.59	2.25
358	0.0210	100.000	5.8685	7106.59	churn	0.055	0.085	1.51	2.34
358	0.0210	200.000	11.7371	14213.17	annular	0.048	0.053	1.32	1.46
358	0.0210	300.000	17.6056	21319.76	annular	0.056	0.056	1.54	1.54
358	0.0210	400.000	23.4742	28426.35	annular	0.069	0.069	1.90	1.90

Table A2 continued

Solution flow rate $Q_{solution}$ (ml/min)	Sup. solution velocity $j_{solution}$ (m/s)	Air flow rate Q_{air} (l/min)	Sup. air velocity j_{air} (m/s)	Reynolds number of air Re_{air}	Flow regime	Solution levels difference in manometer, (m)		$(-dp/dz)_{exp}$ from experiment	
						Minimum	Maximum	Minimum (kPa/m)	Maximum (kPa/m)
358	0.0210	500.000	29.3427	35532.93	annular	0.090	0.090	2.47	2.47
358	0.0210	600.000	35.2113	42639.52	annular	0.108	0.108	2.97	2.97
358	0.0210	700.000	41.0798	49746.11	annular	0.133	0.133	3.66	3.66
358	0.0210	800.000	46.9484	56852.69	mist	0.169	0.169	4.65	4.65
545	0.0320	0.000	0.0000	0.00	-	0.397	0.397	10.91	10.91
545	0.0320	0.036	0.0021	2.56	bubble	0.393	0.393	10.80	10.80
545	0.0320	0.071	0.0042	5.05	bubble	0.388	0.388	10.67	10.67
545	0.0320	0.103	0.0060	7.32	bubble	0.384	0.384	10.56	10.56
545	0.0320	0.132	0.0077	9.38	bubble	0.379	0.379	10.42	10.42
545	0.0320	0.162	0.0095	11.51	bubble	0.374	0.374	10.28	10.28
545	0.0320	0.196	0.0115	13.93	bubble	0.368	0.370	10.12	10.17
545	0.0320	0.235	0.0138	16.70	bubble	0.364	0.368	10.01	10.12
545	0.0320	0.273	0.0160	19.40	bubble	0.354	0.362	9.73	9.95
545	0.0320	0.307	0.0180	21.82	bubble-slug	0.346	0.356	9.51	9.79
545	0.0320	0.356	0.0209	25.30	bubble-slug	0.340	0.350	9.35	9.62
545	0.0320	0.395	0.0232	28.07	bubble-slug	0.335	0.351	9.21	9.65
545	0.0320	0.450	0.0264	31.98	bubble-slug	0.322	0.342	8.85	9.40
545	0.0320	0.510	0.0299	36.24	bubble-slug	0.314	0.338	8.63	9.29
545	0.0320	0.568	0.0333	40.37	bubble-slug	0.306	0.326	8.41	8.96
545	0.0320	0.660	0.0387	46.90	bubble-slug	0.294	0.322	8.08	8.85

Table A2 continued

Solution flow rate $Q_{solution}$ (ml/min)	Sup. solution velocity $j_{solution}$ (m/s)	Air flow rate Q_{air} (l/min)	Sup. air velocity j_{air} (m/s)	Reynolds number of air Re_{air}	Flow regime	Solution levels difference in manometer, (m)		$(-dp/dz)_{exp}$ from experiment	
						Minimum	Maximum	Minimum (kPa/m)	Maximum (kPa/m)
545	0.0320	0.722	0.0424	51.31	slug	0.290	0.318	7.97	8.74
545	0.0320	0.789	0.0463	56.07	slug	0.278	0.318	7.64	8.74
545	0.0320	0.867	0.0509	61.61	slug	0.270	0.310	7.42	8.52
545	0.0320	1.022	0.0600	72.63	slug	0.262	0.310	7.20	8.52
545	0.0320	2.394	0.1405	170.13	slug	0.168	0.240	4.62	6.60
545	0.0320	4.000	0.2347	284.26	slug	0.120	0.200	3.30	5.50
545	0.0320	5.326	0.3126	378.50	slug	0.080	0.180	2.20	4.95
545	0.0320	7.058	0.4142	501.58	slug-churn	0.060	0.150	1.65	4.12
545	0.0320	10.000	0.5869	710.66	slug-churn	0.050	0.132	1.37	3.63
545	0.0320	20.000	1.1737	1421.32	slug-churn	0.030	0.100	0.82	2.75
545	0.0320	30.000	1.7606	2131.98	churn	0.030	0.095	0.82	2.61
545	0.0320	40.000	2.3474	2842.63	churn	0.040	0.095	1.10	2.61
545	0.0320	50.000	2.9343	3553.29	churn	0.050	0.095	1.37	2.61
545	0.0320	60.000	3.5211	4263.95	churn	0.055	0.083	1.51	2.28
545	0.0320	70.000	4.1080	4974.61	churn	0.061	0.085	1.68	2.34
545	0.0320	100.000	5.8685	7106.59	churn	0.060	0.080	1.65	2.20
545	0.0320	200.000	11.7371	14213.17	annular	0.055	0.064	1.51	1.76
545	0.0320	300.000	17.6056	21319.76	annular	0.065	0.069	1.79	1.90
545	0.0320	400.000	23.4742	28426.35	annular	0.082	0.082	2.25	2.25
545	0.0320	500.000	29.3427	35532.93	annular	0.109	0.109	3.00	3.00

Table A2 continued

Solution flow rate $Q_{solution}$ (ml/min)	Sup. solution velocity $j_{solution}$ (m/s)	Air flow rate Q_{air} (l/min)	Sup. air velocity j_{air} (m/s)	Reynolds number of air Re_{air}	Flow regime	Solution levels difference in manometer, (m)		$(-dp/dz)_{exp}$ from experiment	
						Minimum	Maximum	Minimum (kPa/m)	Maximum (kPa/m)
545	0.0320	600.000	35.2113	42639.52	annular	0.129	0.129	3.55	3.55
545	0.0320	700.000	41.0798	49746.11	annular	0.153	0.153	4.21	4.21
545	0.0320	800.000	46.9484	56852.69	mist	0.193	0.193	5.31	5.31
705	0.0414	0.000	0.0000	0.00	-	0.395	0.395	10.86	10.86
705	0.0414	0.036	0.0021	2.56	bubble	0.391	0.391	10.75	10.75
705	0.0414	0.071	0.0042	5.05	bubble	0.387	0.387	10.64	10.64
705	0.0414	0.103	0.0060	7.32	bubble	0.384	0.384	10.56	10.56
705	0.0414	0.132	0.0077	9.38	bubble	0.38	0.38	10.45	10.45
705	0.0414	0.162	0.0095	11.51	bubble	0.376	0.376	10.34	10.34
705	0.0414	0.196	0.0115	13.93	bubble	0.37	0.374	10.17	10.28
705	0.0414	0.235	0.0138	16.70	bubble	0.364	0.371	10.01	10.20
705	0.0414	0.273	0.0160	19.40	bubble	0.358	0.364	9.84	10.01
705	0.0414	0.307	0.0180	21.82	bubble-slug	0.348	0.356	9.57	9.79
705	0.0414	0.356	0.0209	25.30	bubble-slug	0.34	0.352	9.35	9.68
705	0.0414	0.395	0.0232	28.07	bubble-slug	0.335	0.349	9.21	9.59
705	0.0414	0.450	0.0264	31.98	bubble-slug	0.329	0.343	9.05	9.43
705	0.0414	0.510	0.0299	36.24	bubble-slug	0.321	0.337	8.83	9.26
705	0.0414	0.568	0.0333	40.37	bubble-slug	0.315	0.335	8.66	9.21
705	0.0414	0.660	0.0387	46.90	bubble-slug	0.305	0.325	8.39	8.94
705	0.0414	0.722	0.0424	51.31	bubble-slug	0.301	0.321	8.28	8.83

Table A2 continued

Solution flow rate $Q_{solution}$ (ml/min)	Sup. solution velocity $j_{solution}$ (m/s)	Air flow rate Q_{air} (l/min)	Sup. air velocity j_{air} (m/s)	Reynolds number of air Re_{air}	Flow regime	Solution levels difference in manometer, (m)		$(-dp/dz)_{exp}$ from experiment	
						Minimum	Maximum	Minimum (kPa/m)	Maximum (kPa/m)
705	0.0414	0.789	0.0463	56.07	slug	0.293	0.321	8.06	8.83
705	0.0414	0.867	0.0509	61.61	slug	0.285	0.311	7.84	8.55
705	0.0414	1.022	0.0600	72.63	slug	0.265	0.305	7.29	8.39
705	0.0414	2.394	0.1405	170.13	slug	0.19	0.23	5.22	6.32
705	0.0414	4.000	0.2347	284.26	slug	0.13	0.2	3.57	5.50
705	0.0414	5.326	0.3126	378.50	slug	0.08	0.18	2.20	4.95
705	0.0414	7.058	0.4142	501.58	slug	0.06	0.16	1.65	4.40
705	0.0414	10.000	0.5869	710.66	slug-churn	0.05	0.13	1.37	3.57
705	0.0414	20.000	1.1737	1421.32	slug-churn	0.03	0.14	0.82	3.85
705	0.0414	30.000	1.7606	2131.98	churn	0.03	0.1	0.82	2.75
705	0.0414	40.000	2.3474	2842.63	churn	0.045	0.105	1.24	2.89
705	0.0414	50.000	2.9343	3553.29	churn	0.05	0.1	1.37	2.75
705	0.0414	60.000	3.5211	4263.95	churn	0.06	0.1	1.65	2.75
705	0.0414	70.000	4.1080	4974.61	churn	0.07	0.094	1.92	2.58
705	0.0414	100.000	5.8685	7106.59	churn	0.065	0.095	1.79	2.61
705	0.0414	200.000	11.7371	14213.17	annular	0.059	0.075	1.62	2.06
705	0.0414	300.000	17.6056	21319.76	annular	0.068	0.076	1.87	2.09
705	0.0414	400.000	23.4742	28426.35	annular	0.087	0.097	2.39	2.67
705	0.0414	500.000	29.3427	35532.93	annular	0.111	0.115	3.05	3.16
705	0.0414	600.000	35.2113	42639.52	annular	0.133	0.133	3.66	3.66

Table A2 continued

Solution flow rate $Q_{solution}$ (ml/min)	Sup. solution velocity $j_{solution}$ (m/s)	Air flow rate Q_{air} (l/min)	Sup. air velocity j_{air} (m/s)	Reynolds number of air Re_{air}	Flow regime	Solution levels difference in manometer, (m)		$(-dp/dz)_{exp}$ from experiment	
						Minimum	Maximum	Minimum (kPa/m)	Maximum (kPa/m)
705	0.0414	700.000	41.0798	49746.11	annular	0.16	0.16	4.40	4.40
705	0.0414	800.000	46.9484	56852.69	mist	0.195	0.195	5.36	5.36
1102	0.0647	0.000	0.0000	0.00	-	0.398	0.398	10.94	10.94
1102	0.0647	0.036	0.0021	2.56	bubble	0.396	0.396	10.89	10.89
1102	0.0647	0.071	0.0042	5.05	bubble	0.394	0.394	10.83	10.83
1102	0.0647	0.103	0.0060	7.32	bubble	0.393	0.393	10.80	10.80
1102	0.0647	0.132	0.0077	9.38	bubble	0.391	0.391	10.75	10.75
1102	0.0647	0.162	0.0095	11.51	bubble	0.388	0.388	10.67	10.67
1102	0.0647	0.196	0.0115	13.93	bubble	0.384	0.384	10.56	10.56
1102	0.0647	0.235	0.0138	16.70	bubble	0.38	0.38	10.45	10.45
1102	0.0647	0.273	0.0160	19.40	bubble	0.374	0.376	10.28	10.34
1102	0.0647	0.307	0.0180	21.82	bubble	0.366	0.368	10.06	10.12
1102	0.0647	0.356	0.0209	25.30	bubble-slug	0.36	0.364	9.90	10.01
1102	0.0647	0.395	0.0232	28.07	bubble-slug	0.35	0.356	9.62	9.79
1102	0.0647	0.450	0.0264	31.98	bubble-slug	0.338	0.346	9.29	9.51
1102	0.0647	0.510	0.0299	36.24	bubble-slug	0.333	0.341	9.16	9.37
1102	0.0647	0.568	0.0333	40.37	bubble-slug	0.328	0.342	9.02	9.40
1102	0.0647	0.660	0.0387	46.90	bubble-slug	0.318	0.334	8.74	9.18
1102	0.0647	0.722	0.0424	51.31	bubble-slug	0.308	0.332	8.47	9.13
1102	0.0647	0.789	0.0463	56.07	bubble-slug	0.302	0.322	8.30	8.85

Table A2 continued

Solution flow rate $Q_{solution}$ (ml/min)	Sup. solution velocity $j_{solution}$ (m/s)	Air flow rate Q_{air} (l/min)	Sup. air velocity j_{air} (m/s)	Reynolds number of air Re_{air}	Flow regime	Solution levels difference in manometer, (m)		$(-dp/dz)_{exp}$ from experiment	
						Minimum	Maximum	Minimum (kPa/m)	Maximum (kPa/m)
1102	0.0647	0.867	0.0509	61.61	slug	0.298	0.318	8.19	8.74
1102	0.0647	1.022	0.0600	72.63	slug	0.286	0.314	7.86	8.63
1102	0.0647	2.394	0.1405	170.13	slug	0.2	0.25	5.50	6.87
1102	0.0647	4.000	0.2347	284.26	slug	0.14	0.22	3.85	6.05
1102	0.0647	5.326	0.3126	378.50	slug	0.075	0.19	2.06	5.22
1102	0.0647	7.058	0.4142	501.58	slug	0.06	0.19	1.65	5.22
1102	0.0647	10.000	0.5869	710.66	slug-churn	0.055	0.155	1.51	4.26
1102	0.0647	20.000	1.1737	1421.32	slug-churn	0.04	0.12	1.10	3.30
1102	0.0647	30.000	1.7606	2131.98	churn	0.035	0.115	0.96	3.16
1102	0.0647	40.000	2.3474	2842.63	churn	0.05	0.11	1.37	3.02
1102	0.0647	50.000	2.9343	3553.29	churn	0.06	0.105	1.65	2.89
1102	0.0647	60.000	3.5211	4263.95	churn	0.07	0.105	1.92	2.89
1102	0.0647	70.000	4.1080	4974.61	churn	0.07	0.105	1.92	2.89
1102	0.0647	100.000	5.8685	7106.59	churn	0.065	0.1	1.79	2.75
1102	0.0647	200.000	11.7371	14213.17	annular	0.07	0.09	1.92	2.47
1102	0.0647	300.000	17.6056	21319.76	annular	0.088	0.098	2.42	2.69
1102	0.0647	400.000	23.4742	28426.35	annular	0.11	0.118	3.02	3.24
1102	0.0647	500.000	29.3427	35532.93	annular	0.13	0.138	3.57	3.79
1102	0.0647	600.000	35.2113	42639.52	annular	0.16	0.162	4.40	4.45
1102	0.0647	700.000	41.0798	49746.11	annular	0.19	0.19	5.22	5.22

Table A2 continued

Solution flow rate $Q_{solution}$ (ml/min)	Sup. solution velocity $j_{solution}$ (m/s)	Air flow rate Q_{air} (l/min)	Sup. air velocity j_{air} (m/s)	Reynolds number of air Re_{air}	Flow regime	Solution levels difference in manometer, (m)		(-dp/dz)$_{exp}$ from experiment	
						Minimum	Maximum	Minimum (kPa/m)	Maximum (kPa/m)
1102	0.0647	800.000	46.9484	56852.69	mist	0.233	0.233	6.41	6.41
1560	0.0915	0.000	0.0000	0.00	-	0.4	0.4	11.00	11.00
1560	0.0915	0.036	0.0021	2.56	bubble	0.397	0.397	10.91	10.91
1560	0.0915	0.071	0.0042	5.05	bubble	0.395	0.395	10.86	10.86
1560	0.0915	0.103	0.0060	7.32	bubble	0.394	0.394	10.83	10.83
1560	0.0915	0.132	0.0077	9.38	bubble	0.392	0.392	10.78	10.78
1560	0.0915	0.162	0.0095	11.51	bubble	0.388	0.388	10.67	10.67
1560	0.0915	0.196	0.0115	13.93	bubble	0.382	0.386	10.50	10.61
1560	0.0915	0.235	0.0138	16.70	bubble	0.378	0.382	10.39	10.50
1560	0.0915	0.273	0.0160	19.40	bubble	0.374	0.378	10.28	10.39
1560	0.0915	0.307	0.0180	21.82	bubble	0.37	0.376	10.17	10.34
1560	0.0915	0.356	0.0209	25.30	bubble	0.366	0.372	10.06	10.23
1560	0.0915	0.395	0.0232	28.07	bubble-slug	0.36	0.368	9.90	10.12
1560	0.0915	0.450	0.0264	31.98	bubble-slug	0.354	0.364	9.73	10.01
1560	0.0915	0.510	0.0299	36.24	bubble-slug	0.346	0.358	9.51	9.84
1560	0.0915	0.568	0.0333	40.37	bubble-slug	0.34	0.354	9.35	9.73
1560	0.0915	0.660	0.0387	46.90	bubble-slug	0.334	0.355	9.18	9.76
1560	0.0915	0.722	0.0424	51.31	bubble-slug	0.325	0.349	8.94	9.59
1560	0.0915	0.789	0.0463	56.07	bubble-slug	0.319	0.339	8.77	9.32
1560	0.0915	0.867	0.0509	61.61	bubble-slug	0.313	0.335	8.61	9.21

Table A2 continued

Solution flow rate $Q_{solution}$ (ml/min)	Sup. solution velocity $j_{solution}$ (m/s)	Air flow rate Q_{air} (l/min)	Sup. air velocity j_{air} (m/s)	Reynolds number of air Re_{air}	Flow regime	Solution levels difference in manometer, (m)		$(-dp/dz)_{exp}$ from experiment	
						Minimum	Maximum	Minimum (kPa/m)	Maximum (kPa/m)
1560	0.0915	1.022	0.0600	72.63	slug	0.305	0.325	8.39	8.94
1560	0.0915	2.394	0.1405	170.13	slug	0.22	0.26	6.05	7.15
1560	0.0915	4.000	0.2347	284.26	slug	0.16	0.2	4.40	5.50
1560	0.0915	5.326	0.3126	378.50	slug	0.11	0.18	3.02	4.95
1560	0.0915	7.058	0.4142	501.58	slug	0.09	0.16	2.47	4.40
1560	0.0915	10.000	0.5869	710.66	slug-churn	0.008	0.15	0.22	4.12
1560	0.0915	20.000	1.1737	1421.32	slug-churn	0.06	0.125	1.65	3.44
1560	0.0915	30.000	1.7606	2131.98	churn	0.04	0.11	1.10	3.02
1560	0.0915	40.000	2.3474	2842.63	churn	0.065	0.12	1.79	3.30
1560	0.0915	50.000	2.9343	3553.29	churn	0.08	0.13	2.20	3.57
1560	0.0915	60.000	3.5211	4263.95	churn	0.085	0.12	2.34	3.30
1560	0.0915	70.000	4.1080	4974.61	churn	0.085	0.12	2.34	3.30
1560	0.0915	100.000	5.8685	7106.59	churn	0.07	0.115	1.92	3.16
1560	0.0915	200.000	11.7371	14213.17	annular	0.09	0.11	2.47	3.02
1560	0.0915	300.000	17.6056	21319.76	annular	0.11	0.125	3.02	3.44
1560	0.0915	400.000	23.4742	28426.35	annular	0.14	0.154	3.85	4.23
1560	0.0915	500.000	29.3427	35532.93	annular	0.161	0.171	4.43	4.70
1560	0.0915	600.000	35.2113	42639.52	annular	0.183	0.192	5.03	5.28
1560	0.0915	700.000	41.0798	49746.11	annular	0.212	0.217	5.83	5.97
1560	0.0915	800.000	46.9484	56852.69	mist	0.252	0.252	6.93	6.93

Table A2 continued

Solution flow rate $Q_{solution}$ (ml/min)	Sup. solution velocity $j_{solution}$ (m/s)	Air flow rate Q_{air} (l/min)	Sup. air velocity j_{air} (m/s)	Reynolds number of air Re_{air}	Flow regime	Solution levels difference in manometer, (m)		$(-dp/dz)_{exp}$ from experiment	
						Minimum	Maximum	Minimum (kPa/m)	Maximum (kPa/m)
1794	0.1053	0.000	0.0000	0.00	-	0.397	0.397	10.91	10.91
1794	0.1053	0.036	0.0021	2.56	bubble	0.395	0.395	10.86	10.86
1794	0.1053	0.071	0.0042	5.05	bubble	0.394	0.394	10.83	10.83
1794	0.1053	0.103	0.0060	7.32	bubble	0.392	0.392	10.78	10.78
1794	0.1053	0.132	0.0077	9.38	bubble	0.389	0.389	10.69	10.69
1794	0.1053	0.162	0.0095	11.51	bubble	0.385	0.385	10.58	10.58
1794	0.1053	0.196	0.0115	13.93	bubble	0.383	0.383	10.53	10.53
1794	0.1053	0.235	0.0138	16.70	bubble	0.378	0.382	10.39	10.50
1794	0.1053	0.273	0.0160	19.40	bubble	0.374	0.376	10.28	10.34
1794	0.1053	0.307	0.0180	21.82	bubble	0.371	0.375	10.20	10.31
1794	0.1053	0.356	0.0209	25.30	bubble	0.365	0.371	10.03	10.20
1794	0.1053	0.395	0.0232	28.07	bubble	0.36	0.366	9.90	10.06
1794	0.1053	0.450	0.0264	31.98	bubble-slug	0.356	0.362	9.79	9.95
1794	0.1053	0.510	0.0299	36.24	bubble-slug	0.35	0.36	9.62	9.90
1794	0.1053	0.568	0.0333	40.37	bubble-slug	0.346	0.356	9.51	9.79
1794	0.1053	0.660	0.0387	46.90	bubble-slug	0.34	0.352	9.35	9.68
1794	0.1053	0.722	0.0424	51.31	bubble-slug	0.332	0.346	9.13	9.51
1794	0.1053	0.789	0.0463	56.07	bubble-slug	0.326	0.342	8.96	9.40
1794	0.1053	0.867	0.0509	61.61	bubble-slug	0.32	0.34	8.80	9.35
1794	0.1053	1.022	0.0600	72.63	bubble-slug	0.306	0.326	8.41	8.96

Table A2 continued

Solution flow rate $Q_{solution}$ (ml/min)	Sup. solution velocity $j_{solution}$ (m/s)	Air flow rate Q_{air} (l/min)	Sup. air velocity j_{air} (m/s)	Reynolds number of air Re_{air}	Flow regime	Solution levels difference in manometer, (m)		$(-dp/dz)_{exp}$ from experiment	
						Minimum	Maximum	Minimum (kPa/m)	Maximum (kPa/m)
1794	0.1053	2.394	0.1405	170.13	slug	0.23	0.27	6.32	7.42
1794	0.1053	4.000	0.2347	284.26	slug	0.17	0.24	4.67	6.60
1794	0.1053	5.326	0.3126	378.50	slug	0.14	0.21	3.85	5.77
1794	0.1053	7.058	0.4142	501.58	slug	0.09	0.19	2.47	5.22
1794	0.1053	10.000	0.5869	710.66	slug-churn	0.08	0.17	2.20	4.67
1794	0.1053	20.000	1.1737	1421.32	slug-churn	0.05	0.15	1.37	4.12
1794	0.1053	30.000	1.7606	2131.98	slug-churn	0.045	0.14	1.24	3.85
1794	0.1053	40.000	2.3474	2842.63	churn	0.06	0.13	1.65	3.57
1794	0.1053	50.000	2.9343	3553.29	churn	0.08	0.13	2.20	3.57
1794	0.1053	60.000	3.5211	4263.95	churn	0.09	0.13	2.47	3.57
1794	0.1053	70.000	4.1080	4974.61	churn	0.1	0.13	2.75	3.57
1794	0.1053	100.000	5.8685	7106.59	churn	0.08	0.12	2.20	3.30
1794	0.1053	200.000	11.7371	14213.17	annular	0.1	0.11	2.75	3.02
1794	0.1053	300.000	17.6056	21319.76	annular	0.125	0.133	3.44	3.66
1794	0.1053	400.000	23.4742	28426.35	annular	0.157	0.163	4.32	4.48
1794	0.1053	500.000	29.3427	35532.93	annular	0.184	0.189	5.06	5.20
1794	0.1053	600.000	35.2113	42639.52	annular	0.198	0.204	5.44	5.61
1794	0.1053	700.000	41.0798	49746.11	annular	0.214	0.222	5.88	6.10
1794	0.1053	800.000	46.9484	56852.69	mist	0.252	0.252	6.93	6.93

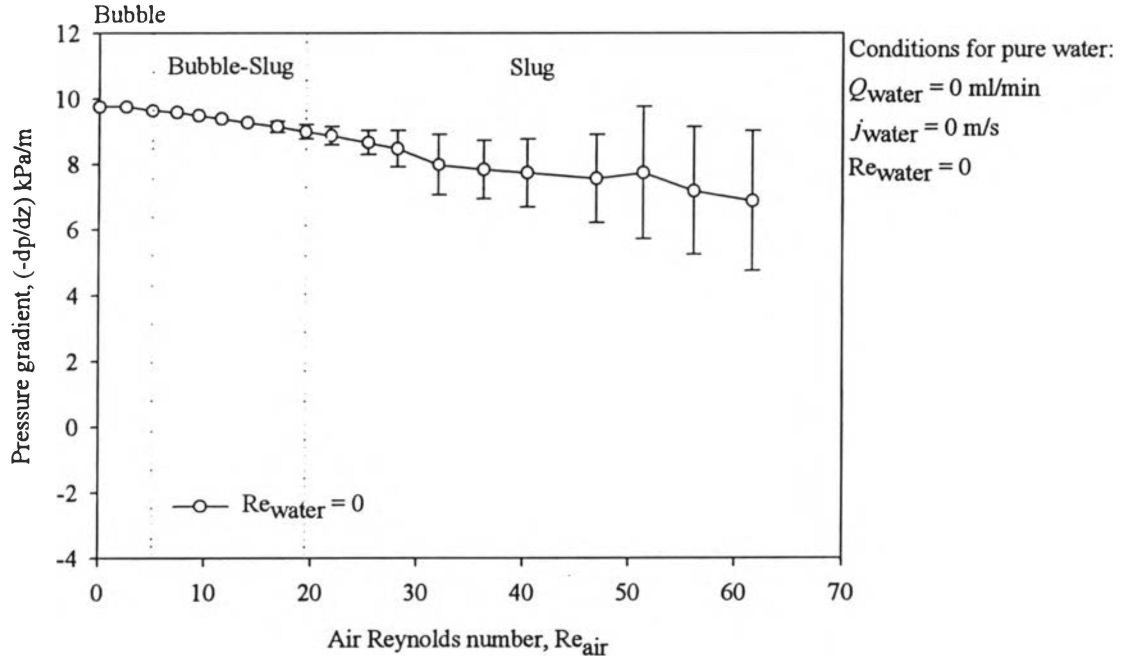


Figure A1 Pressure gradient data for air-pure water mixture.

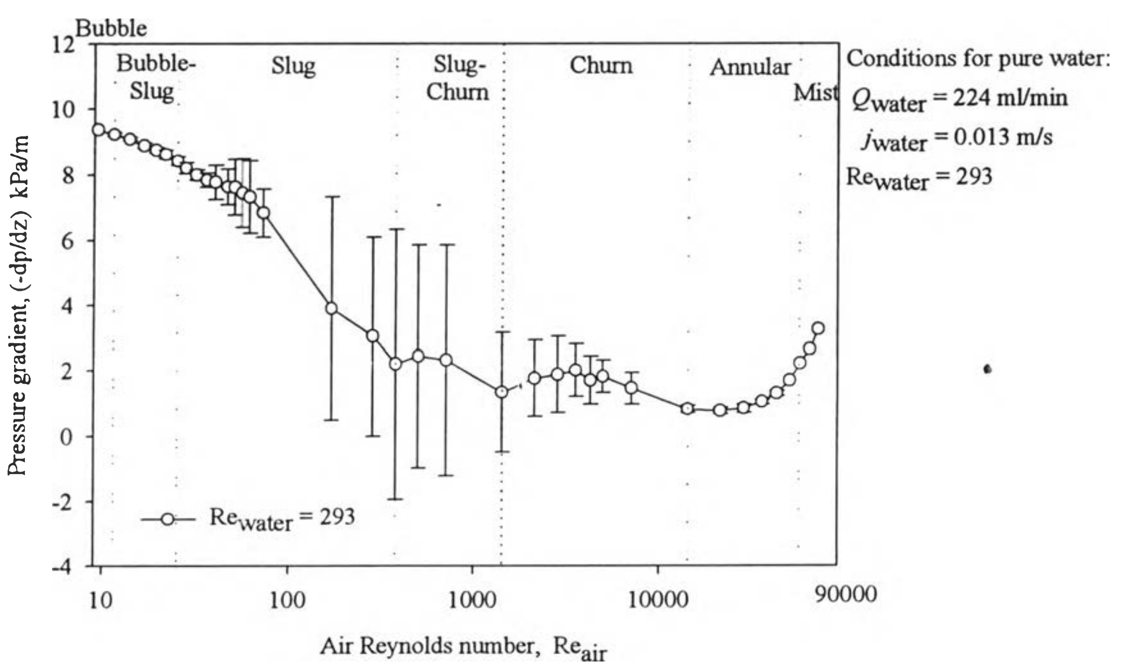


Figure A2 Pressure gradient data for air-pure water mixture.

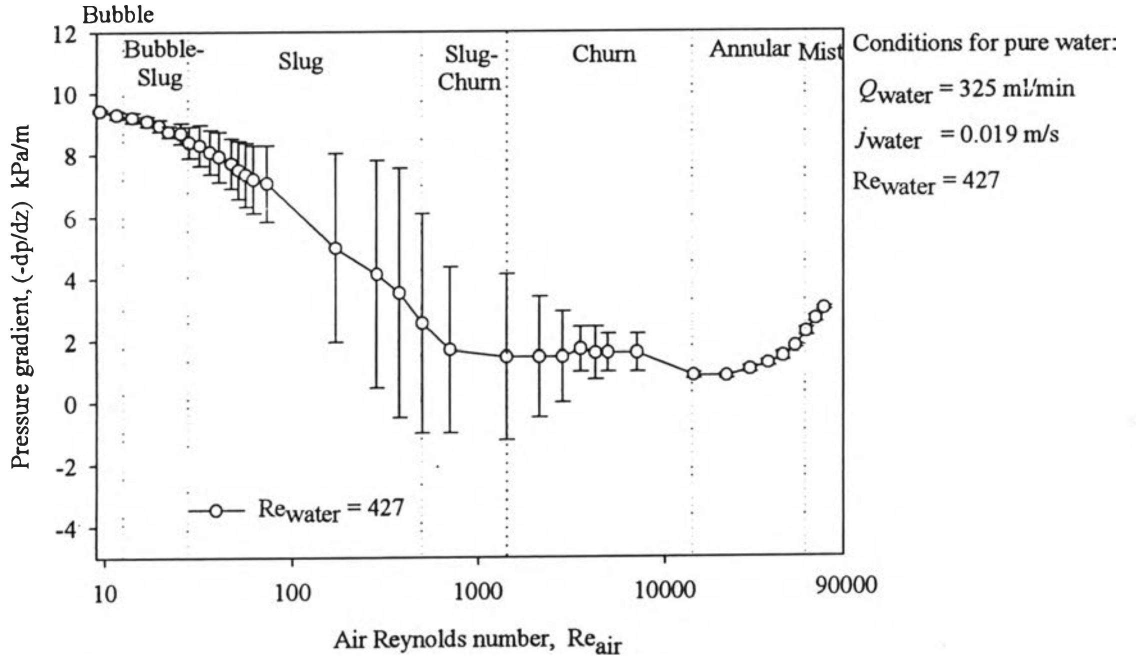


Figure A3 Pressure gradient data for air-pure water mixture.

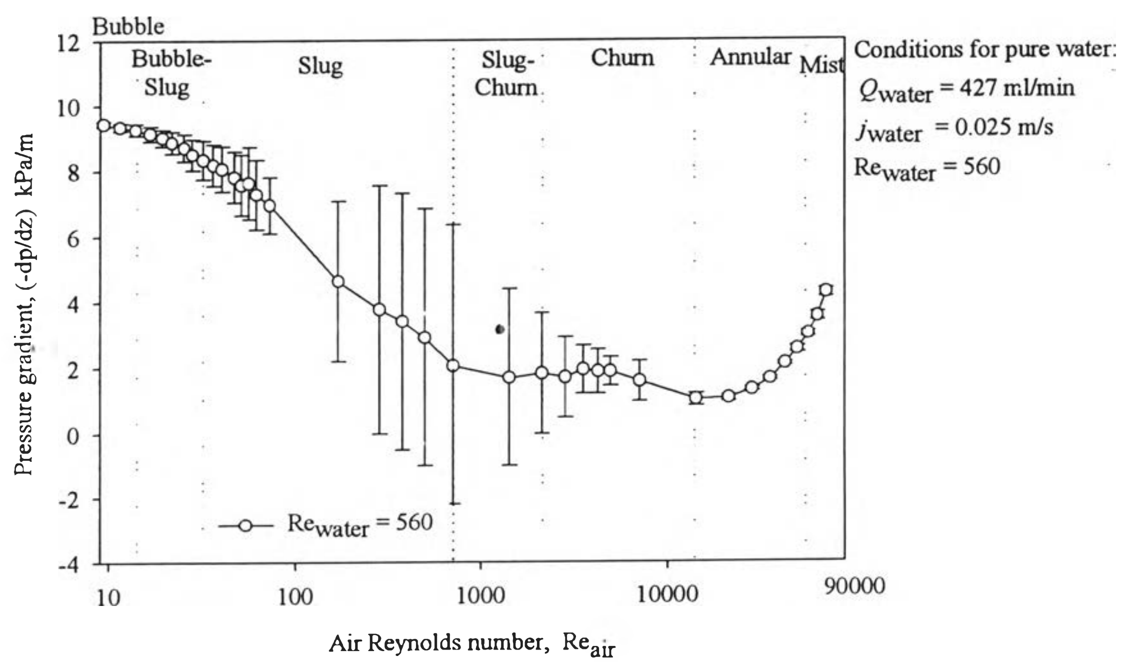


Figure A4 Pressure gradient data for air-pure water mixture.

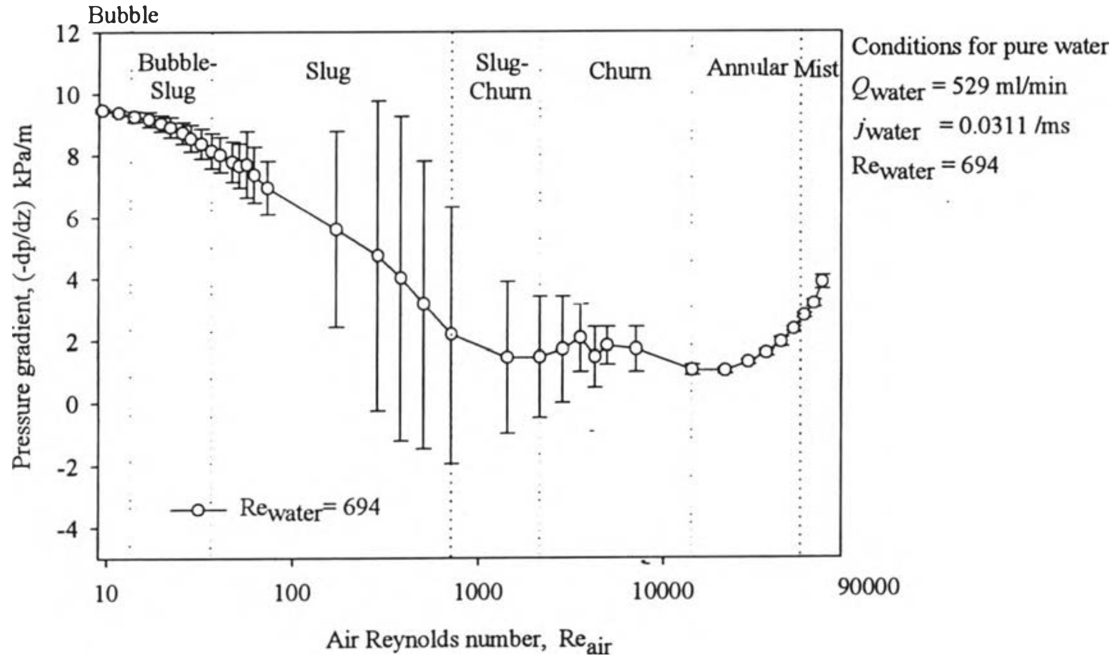


Figure A5 Pressure gradient data for air-pure water mixture.

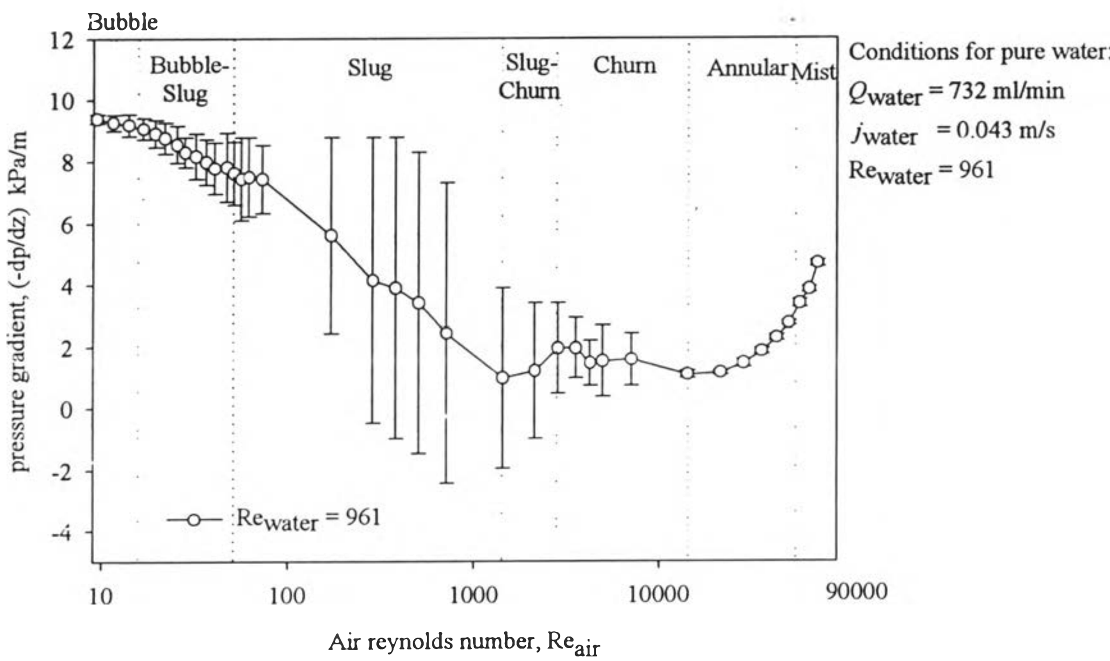


Figure A6 Pressure gradient data for air-pure water mixture.

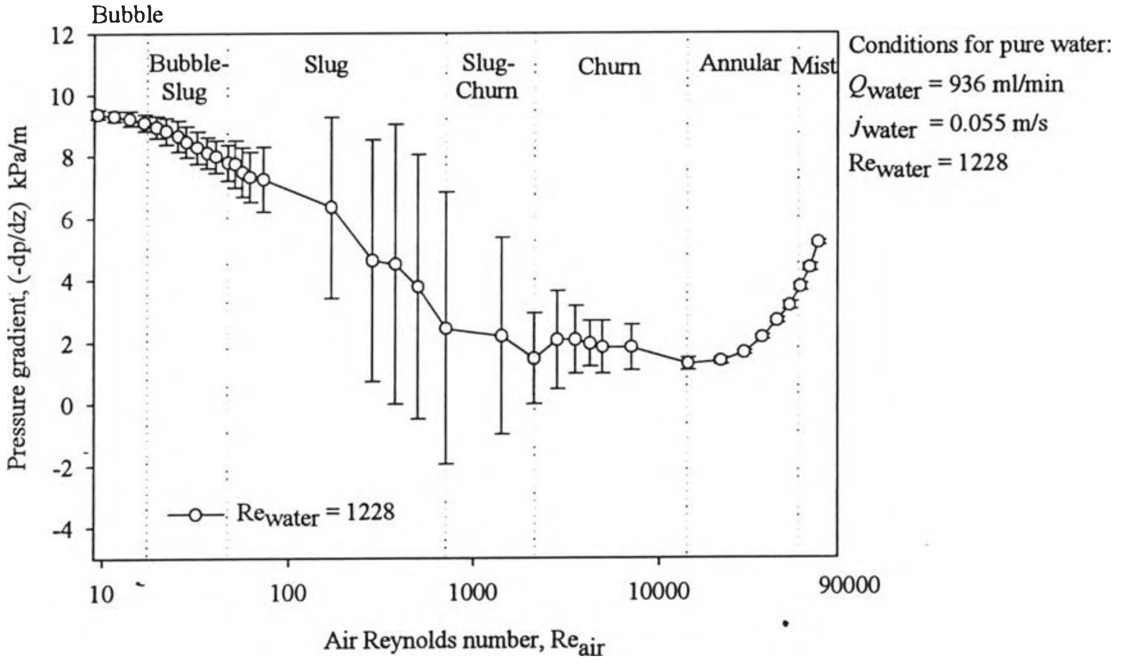


Figure A7 Pressure gradient data for air-pure water mixture.

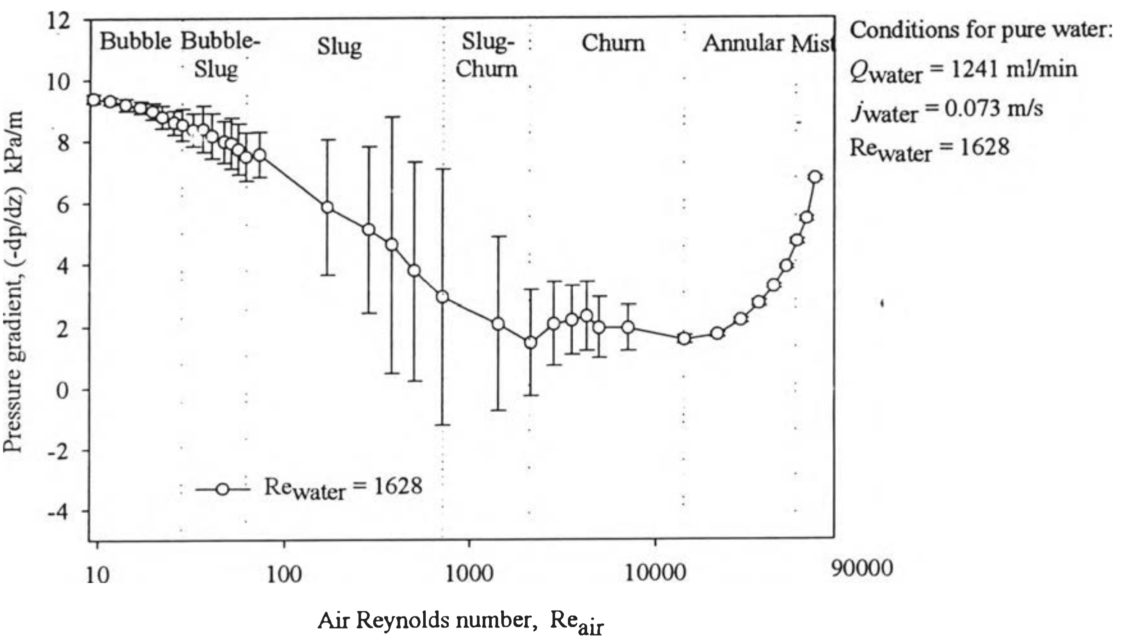


Figure A8 Pressure gradient data for air-pure water mixture.

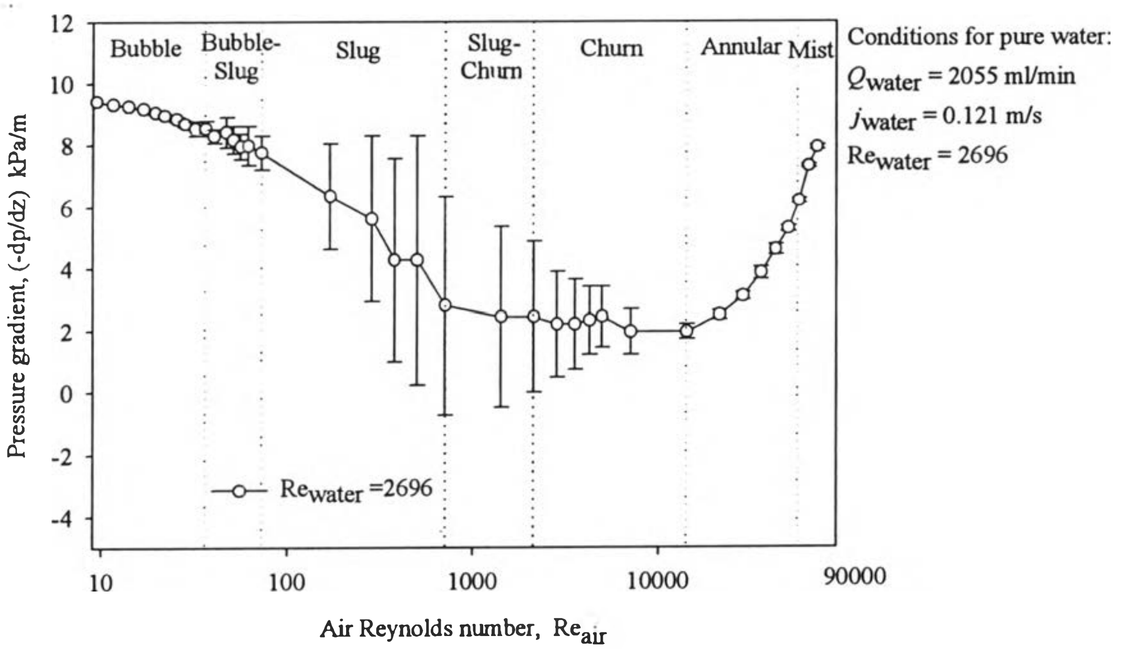


Figure A9 Pressure gradient data for air-pure water mixture.

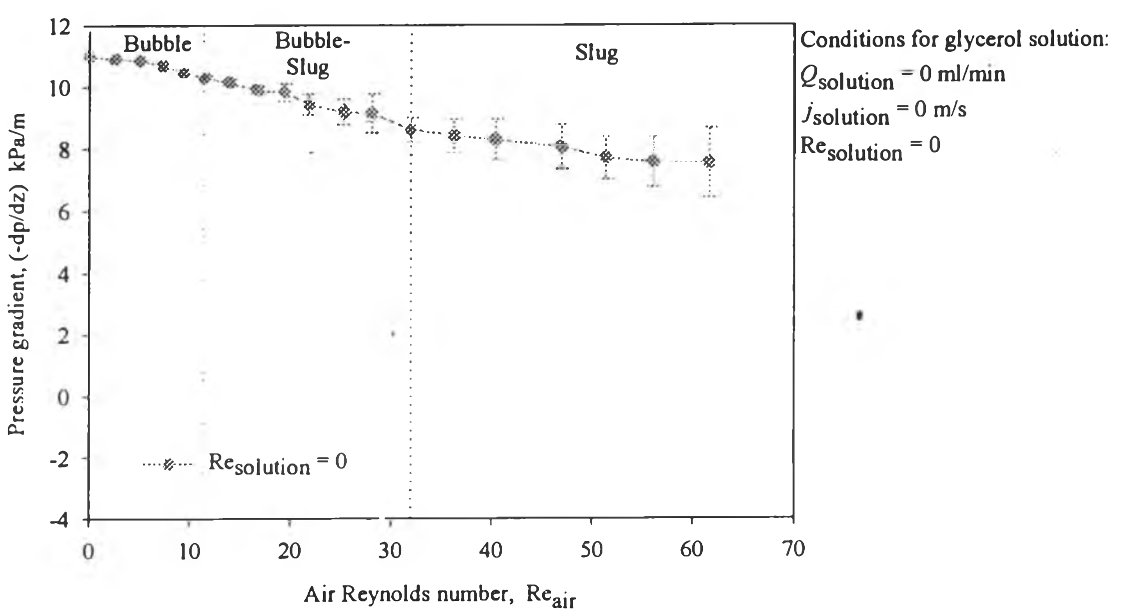


Figure A10 Pressure gradient data for air-50 vol% glycerol solution mixture.

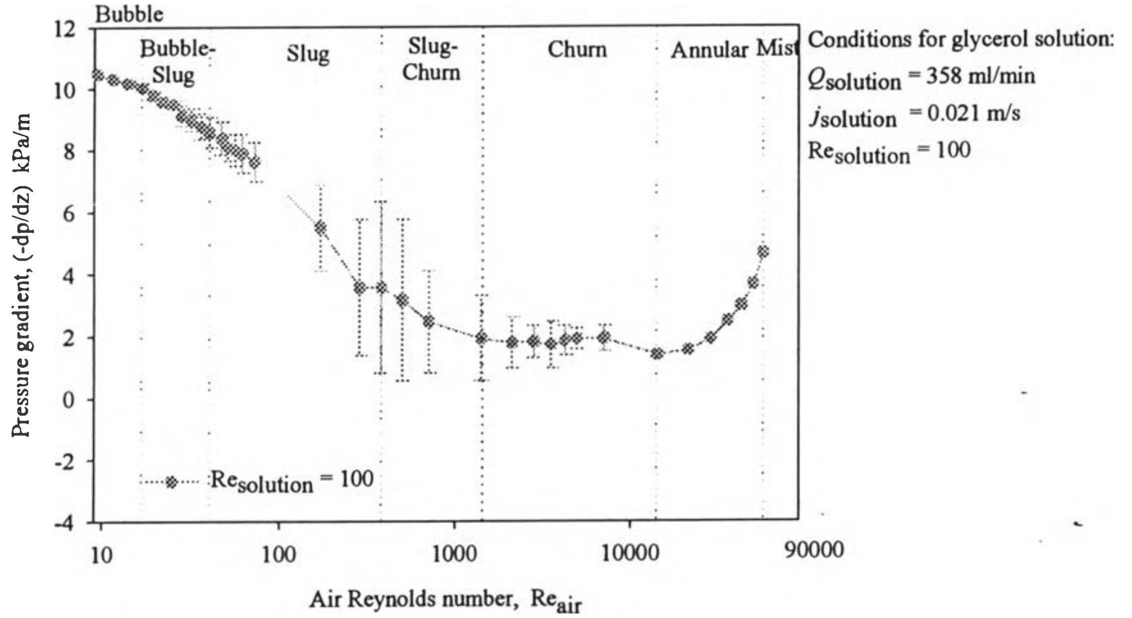


Figure A11 Pressure gradient data for air-50 vol% glycerol solution mixture.

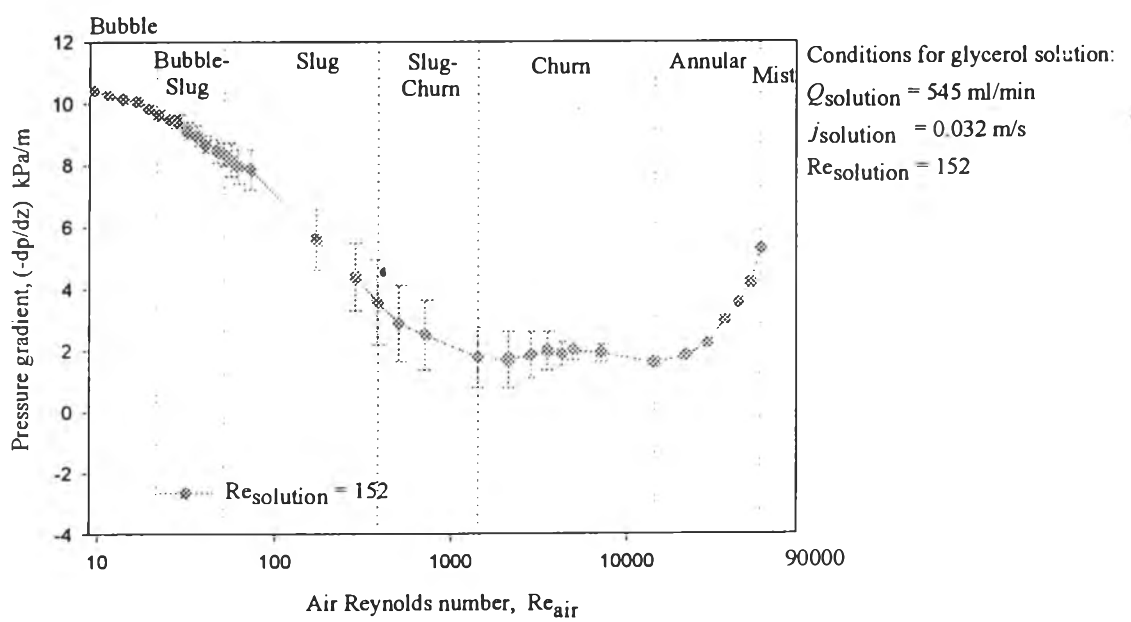


Figure A12 Pressure gradient data for air-50 vol% glycerol solution mixture.

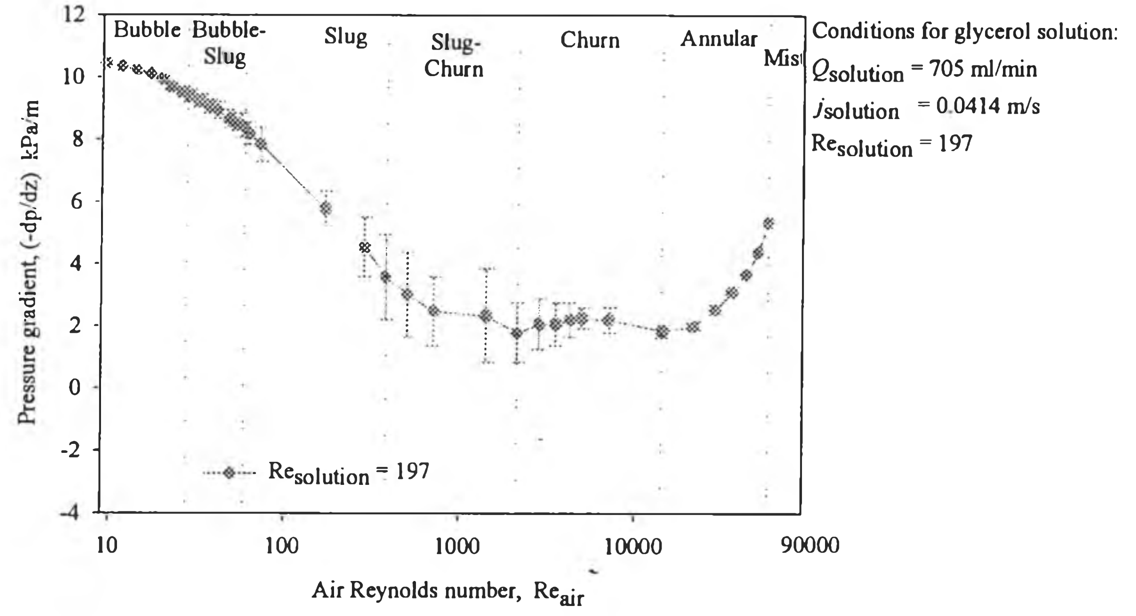


Figure A13 Pressure gradient data for air-50 vol% glycerol solution mixture.

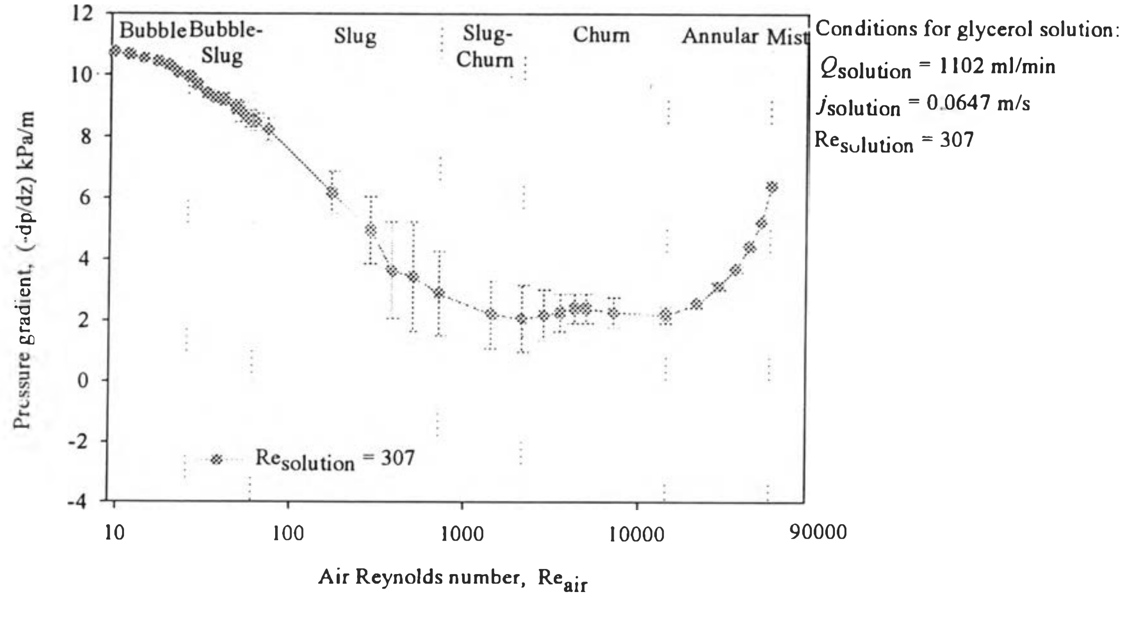


Figure A14 Pressure gradient data for air-50 vol% glycerol solution mixture.

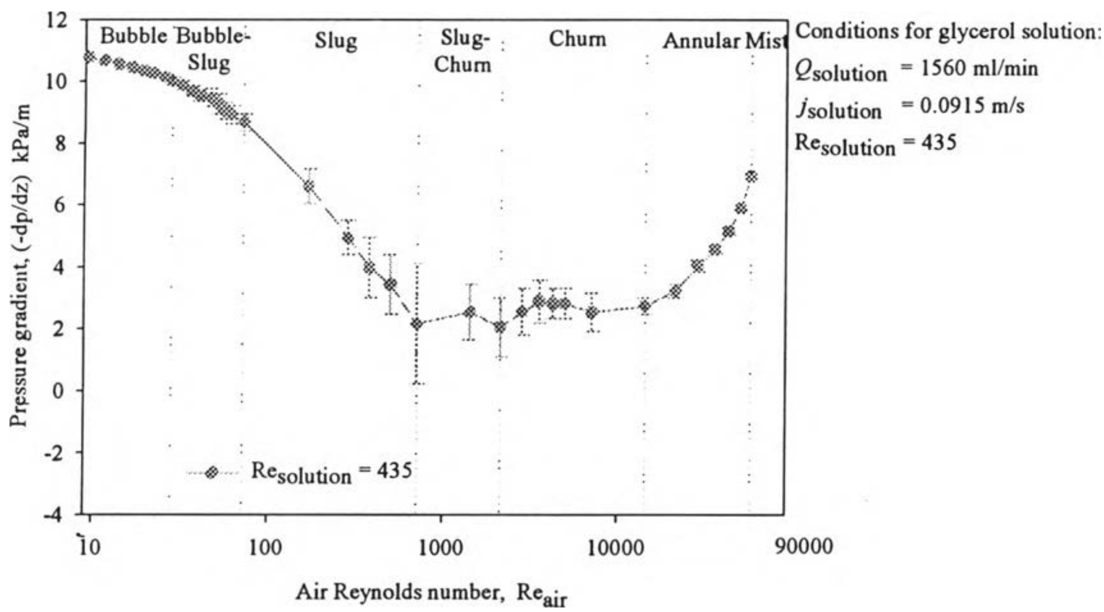


Figure A15 Pressure gradient data for air-50 vol% glycerol solution mixture.

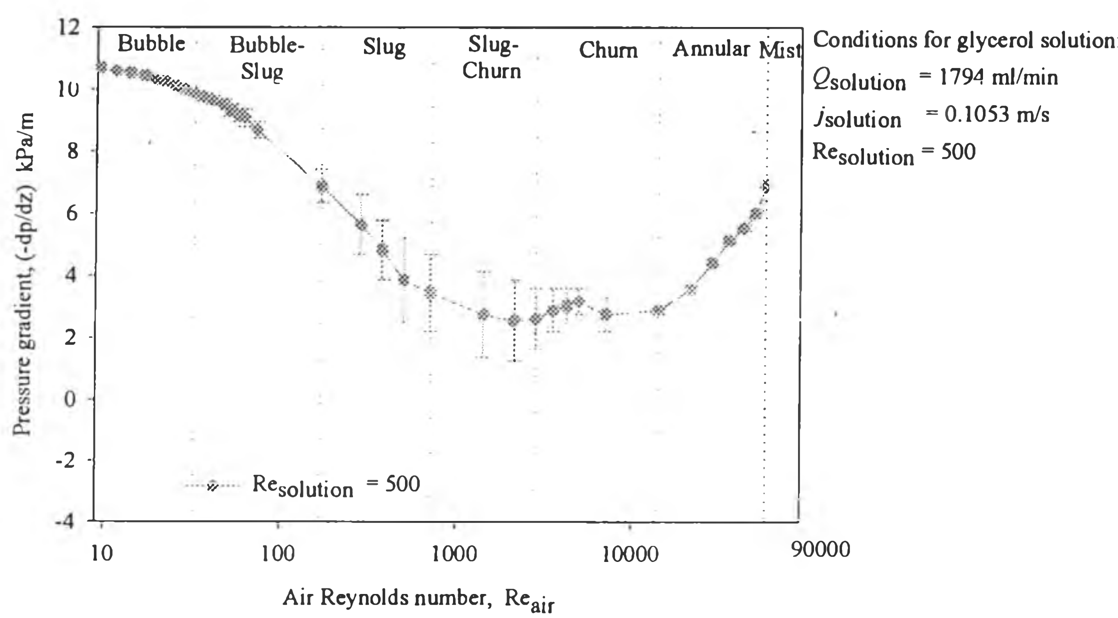


Figure A16 Pressure gradient data for air-50 vol% glycerol solution mixture.

APPENDIX B

Critical Reynolds Numbers of Air in Two-Phase Flow

Table B1 Determination of critical Reynolds number of air in air-pure water mixture
Physical properties of air and water used in the experiments :
viscosity of water, μ_{water} = 8.48 x 10^{-4} kg/m.s; density of water, ρ_{water} = 995 kg/m^3
viscosity of air, μ_{air} = 1.85 x 10^{-5} kg/m.s; density of air, ρ_{air} = 1.18 kg/m^3
temperature, T = 31°C (± 1°C); diameter of the pipe, D = 0.019 m

Water flow rate Q_{water} (ml/min)	Sup. water velocity j_{water} (m/s)	Reynolds number of water Re_{water}	Air flow rate Q_{air} (l/min)	Sup. air velocity j_{air} (m/s)	Critical Reynolds number of air $(Re_{air})_{critical}$	Flow regime
224	0.0131	293	0.132	0.0770	9	bubble-slug
224	0.0131	293	0.356	0.3126	25	slug
224	0.0131	293	5.326	0.3126	378	slug-churn
224	0.0131	293	20	1.1737	1421	churn
224	0.0131	293	200	11.7370	14213	annular
224	0.0131	293	800	46.9484	56853	mist
325	0.0191	427	0.132	0.0077	9	bubble-slug
325	0.0191	427	0.395	0.0232	28	slug
325	0.0191	427	7.058	0.4142	502	slug-churn
325	0.0191	427	20	1.1737	1421	churn
325	0.0191	427	200	11.7371	14213	annular
325	0.0191	427	800	46.9484	56853	mist
427	0.0251	560	0.162	0.0095	12	bubble-slug
427	0.0251	560	0.450	0.0264	32	slug
427	0.0251	560	10	0.5869	711	slug-churn
427	0.0251	560	30	1.7606	2132	churn
427	0.0251	560	200	11.7370	14213	annular
427	0.0251	560	800	46.9484	56853	mist
529	0.0311	694	0.196	0.0115	14	bubble-slug
529	0.0311	694	0.510	0.0299	36	slug
529	0.0311	694	10	0.5869	711	slug-churn
529	0.0311	694	30	1.7606	2132	churn
529	0.0311	694	200	11.7371	14213	annular
529	0.0311	694	800	46.9484	56853	mist
732	0.043	961	0.235	0.0138	17	bubble-slug
732	0.043	961	0.660	0.0387	47	slug
732	0.043	961	20	1.1737	1421	slug-churn

Table B1 continued

Water flow rate Q_{water} (ml/min)	Sup. water velocity j_{water} (m/s)	Reynolds number of water Re_{water}	Air flow rate Q_{air} (l/min)	Sup. air velocity j_{air} (m/s)	Critical Reynolds number of air $(Re_{air})_{critical}$	Flow regime
732	0.043	961	40	2.3474	2843	churn
732	0.043	961	200	11.7371	14213	annular
732	0.043	961	800	46.9484	56853	mist
936	0.055	1228	0.235	0.0138	17	bubble-slug
936	0.055	1228	0.660	0.0387	47	slug
936	0.055	1228	20	1.1737	1421	slug-churn
936	0.055	1228	30	1.7606	2132	churn
0.936	0.055	1228	200	11.7371	14213	annular
0.936	0.055	1228	800	46.9484	56853	mist
1241	0.073	1628	0.395	0.0232	28	bubble-slug
1241	0.073	1628	0.789	0.0463	56	slug
1241	0.073	1628	20	1.1737	1421	slug-churn
1241	0.073	1628	30	1.7606	2132	churn
1241	0.073	1628	200	11.7371	14213	annular
1241	0.073	1628	800	46.9484	56853	mist
2055	0.121	2696	0.510	0.0299	36	bubble-slug
2055	0.121	2696	1.022	0.0600	73	slug
2055	0.121	2696	20	1.1737	1421	slug-churn
2055	0.121	2696	30	1.7606	2132	churn
2055	0.121	2696	200	11.7371	14213	annular
2055	0.121	2696	800	46.9484	56853	mist

Table B2 Determination of critical Reynolds number of air in air-50 vol% glycerol solution mixture

Physical properties of air and 50 vol% glycerol solution used in the experiments:
viscosity of glycerol solution, $\mu_{solution} = 4.48 \times 10^{-3}$ kg/m.s
density of glycerol solution, ρsolution = 1121 kg/m^3
viscosity of air, $\mu_{air} = 1.85 \times 10^{-5}$ kg/m.s; density of air, $\rho_{air} = 1.18$ kg/m^3
temperature, T = 31°C (± 1°C); diameter of the pipe, D = 0.019 m

Solution flow rate $Q_{solution}$ (ml/min)	Sup. Sol$^{n.}$ velocity $j_{solution}$ (m/s)	Reynolds number of solution $Re_{solution}$	Air flow rate Q_{air} (l/min)	Sup. air velocity j_{air} (m/s)	Critical Reynolds number of air $(Re_{air})_{critical}$	Flow regime
358	0.021	100	0.235	0.0138	17	bubble-slug
358	0.021	100	0.568	0.0333	40	slug
358	0.021	100	7.058	0.4142	502	slug-churn
358	0.021	100	20.000	1.1737	1421	churn
358	0.021	100	200.000	11.7371	14213	annular
358	0.021	100	800.000	46.9484	56853	mist
545	0.032	152	0.307	0.0180	22	bubble-slug
545	0.032	152	0.722	0.0424	51	slug
545	0.032	152	7.058	0.4142	502	slug-churn
545	0.032	152	30.000	1.7606	2132	churn
545	0.032	152	200.000	11.7371	14213	annular
545	0.032	152	800.000	46.9484	56853	mist
705	0.0414	197	0.307	0.0180	22	bubble-slug
705	0.0414	197	0.789	0.0463	56	slug
705	0.0414	197	10.000	0.5869	711	slug-churn
705	0.0414	197	30.000	1.7606	2132	churn
705	0.0414	197	200.000	11.7371	14213	annular
705	0.0414	197	800.000	46.9484	56853	mist
1102	0.0647	307	0.356	0.0209	25	bubble-slug
1102	0.0647	307	0.867	0.0509	62	slug
1102	0.0647	307	10.000	0.5869	711	slug-churn
1102	0.0647	307	30.000	1.7606	2132	churn
1102	0.0647	307	200.000	11.7371	14213	annular
1102	0.0647	307	800.000	46.9484	56853	mist
1560	0.0915	435	0.395	0.0232	28	bubble-slug
1560	0.0915	435	1.022	0.0600	73	slug
1560	0.0915	435	10.000	0.5869	711	slug-churn

Table B2 continued

Solution flow rate $Q_{solution}$ (ml/min)	Sup. Sol$^{n.}$ velocity $j_{solution}$ (m/s)	Reynolds number of solution $Re_{solution}$	Air flow rate Q_{air} (l/min)	Sup. air velocity j_{air} (m/s)	Critical Reynolds number of air $(Re_{air})_{critical}$	Flow regime
1560	0.0915	435	30.000	1.7606	2132	churn
1560	0.0915	435	200.000	11.7371	14213	annular
1560	0.0915	435	800.000	46.9484	56853	mist
1794	0.1053	500	0.450	0.0264	32	bubble-slug
1794	0.1053	500	2.394	0.1405	170	slug
1794	0.1053	500	10.000	0.5869	711	slug-churn
1794	0.1053	500	40.000	2.3474	2843	churn
1794	0.1053	500	200.000	11.7371	14213	annular
1794	0.1053	500	800.000	46.9484	56853	mist

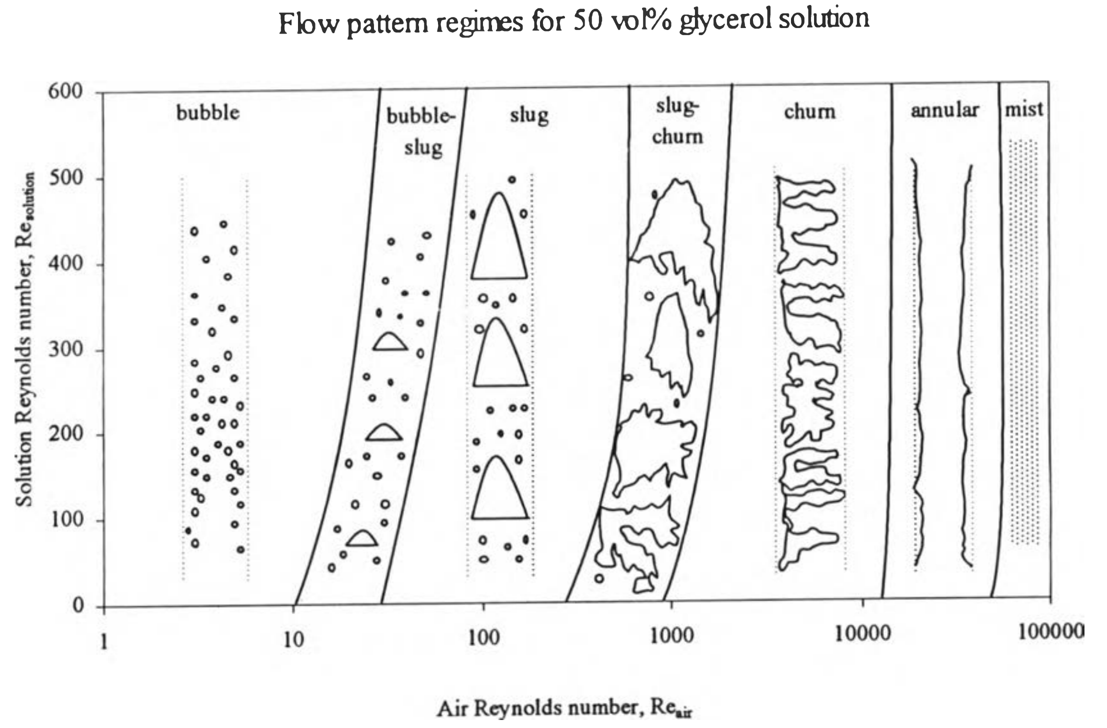


Figure B1 Flow pattern regimes for air-pure water mixture.

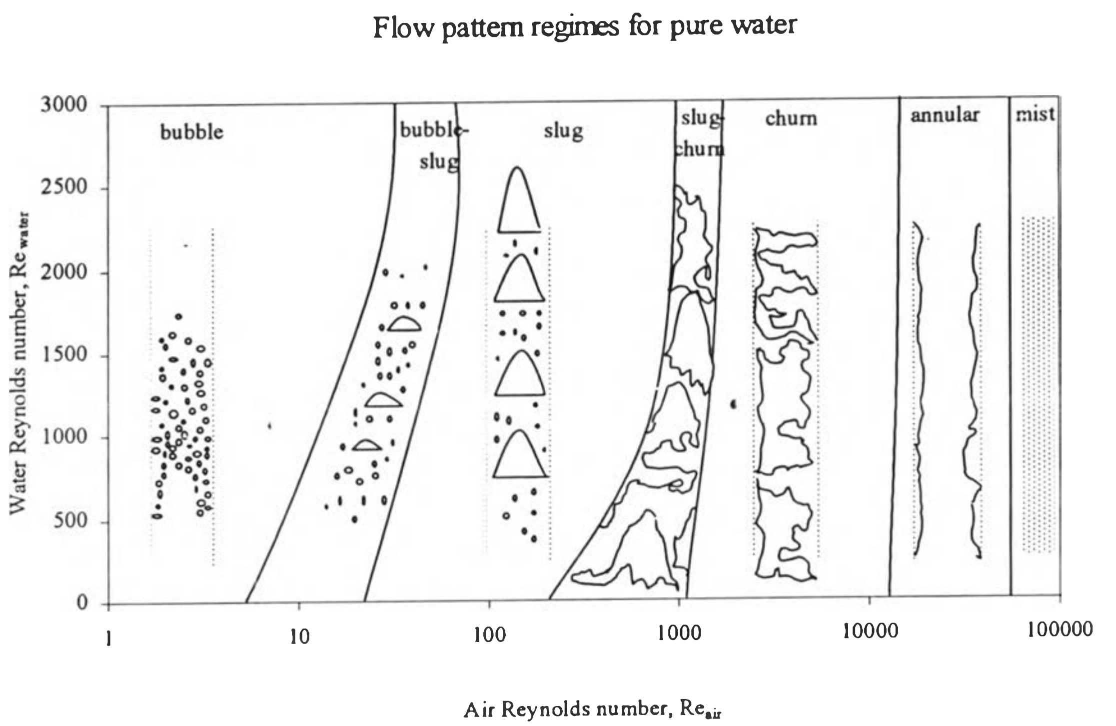


Figure B2 Flow pattern regimes for air-50 vol% glycerol solution mixture.

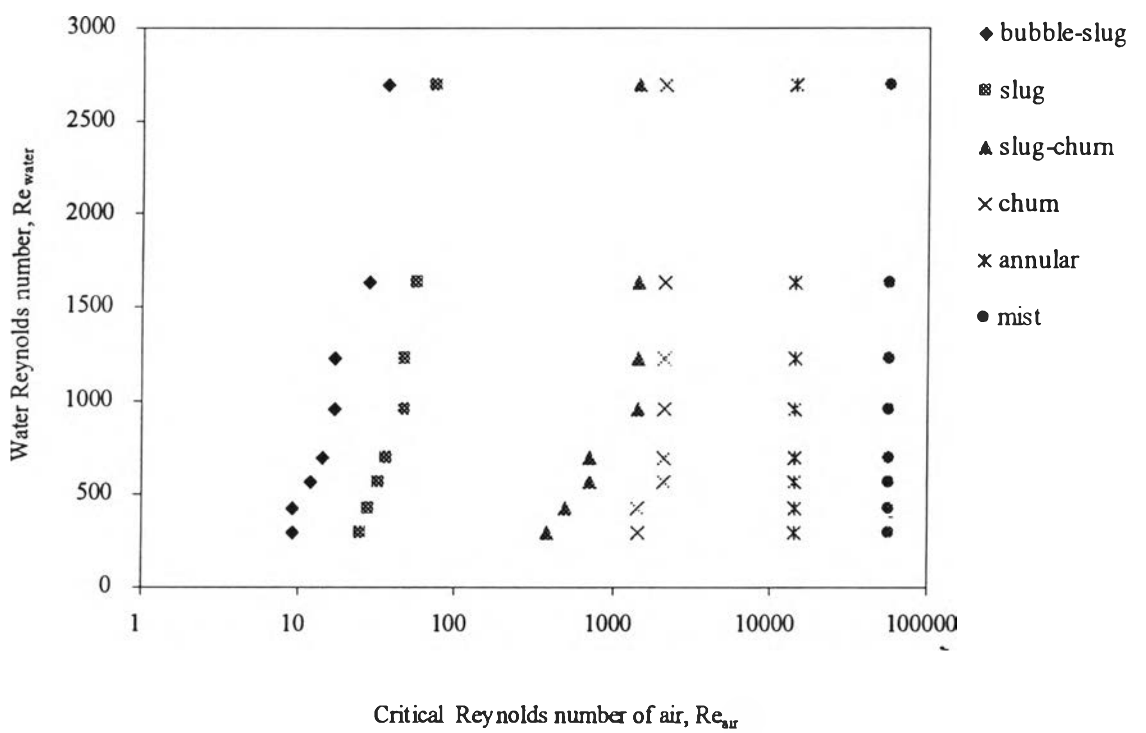


Figure B3 Critical Reynolds numbers of air at different flow regimes in air-pure water system.

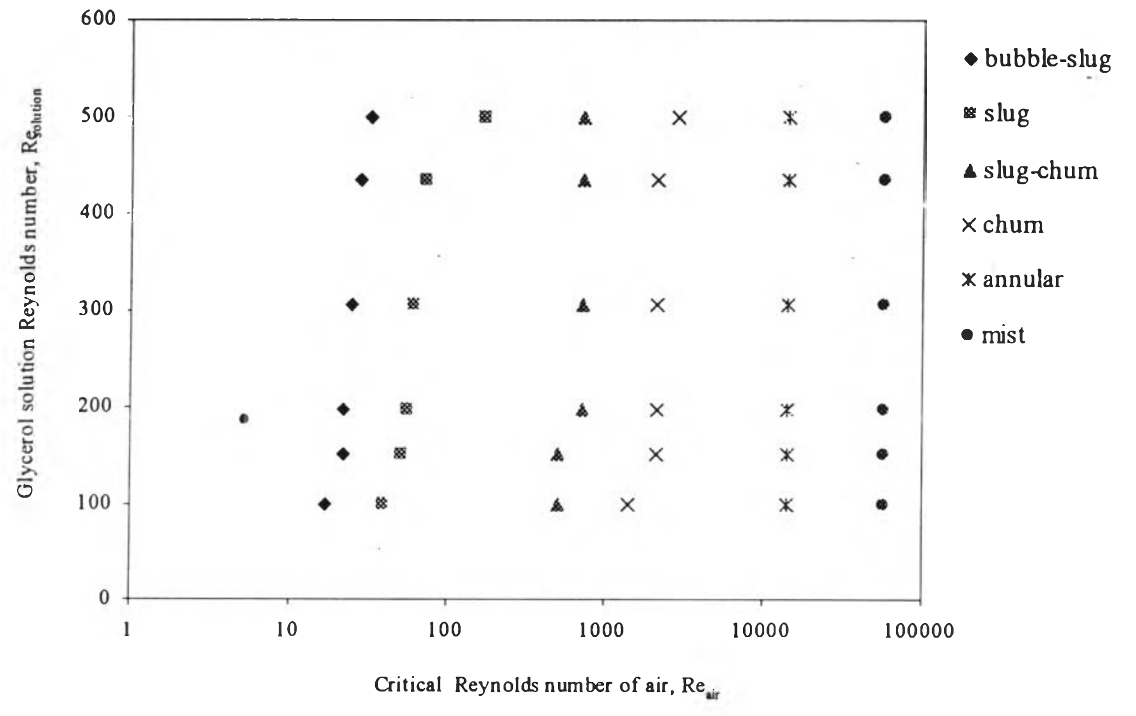


Figure B4 Critical Reynolds numbers of air at different flow regimes in air-50 vol% glycerol solution system.

APPENDIX C

Comparison between Theory and Experimental Data for Pressure Gradient

Table C1 Determination of pressure gradients from theory and experiment in bubble flow regime
Physical properties of air and water used in the experiments:
viscosity of water, μ_{water} = 8.48 x 10^{-4} kg/m.s; density of water, ρ_{water} = 995 kg/m^3
viscosity of air, μ_{air} = 1.85 x 10^{-5} kg/m.s; density of air, ρ_{air} = 1.18 kg/m^3
temperature, T = 31°C (± 1°C); diameter of the pipe, D = 0.019 m; pressure taps difference = 0.4 m

Water flow rate Q_{water} (ml/min)	Sup. water velocity j_{water} (m/s)	Air flow rate Q_{air} (l/min)	Sup. air velocity j_{air} (m/s)	Flow regime	Void fraction from theory ε	$(-dp/dz)_{cal}$ from theory (kPa/m)	Reynolds number of air Re_{air}	$(-dp/dz)_{exp}$ from experiment Minimum (kPa/m)	$(-dp/dz)_{exp}$ from experiment Maximum (kPa/m)
0	0.0000	0.036	0.0021	bubble	0.0138	9.63	2.56	9.76	9.76
0	0.0000	0.071	0.0042	bubble	0.0268	9.50	5.05	9.64	9.64
224	0.0131	0.036	0.0021	bubble	0.0127	9.64	2.56	9.64	9.64
224	0.0131	0.071	0.0042	bubble	0.0247	9.52	5.05	9.52	9.52
224	0.0131	0.103	0.0060	bubble	0.0355	9.41	7.32	9.44	9.44
325	0.0191	0.036	0.0021	bubble	0.0123	9.64	2.56	9.64	9.64
325	0.0191	0.071	0.0042	bubble	0.0239	9.53	5.05	9.52	9.52
325	0.0191	0.103	0.0060	bubble	0.0343	9.43	7.32	9.47	9.47
427	0.0251	0.036	0.0021	bubble	0.0119	9.64	2.56	9.66	9.66
427	0.0251	0.071	0.0042	bubble	0.0231	9.54	5.05	9.57	9.57
427	0.0251	0.103	0.0060	bubble	0.0332	9.44	7.32	9.52	9.52
427	0.0251	0.132	0.0077	bubble	0.0421	9.35	9.38	9.37	9.52

Table C1 continued

Water flow rate Q_{water} (ml/min)	Sup. water velocity j_{water} (m/s)	Air flow rate Q_{air} (l/min)	Sup. air velocity j_{air} (m/s)	Flow regime	Void fraction from theory ε	$(-dp/dz)_{cal}$ from theory (kPa/m)	Reynolds number of air Re_{air}	$(-dp/dz)_{exp}$ from experiment Minimum (kPa/m)	Maximum (kPa/m)
529	0.0311	0.036	0.0021	bubble	0.0115	9.65	2.56	9.64	9.64
529	0.0311	0.071	0.0042	bubble	0.0224	9.54	5.05	9.57	9.57
529	0.0311	0.103	0.0060	bubble	0.0321	9.45	7.32	9.52	9.52
529	0.0311	0.132	0.0077	bubble	0.0408	9.36	9.38	9.42	9.52
529	0.0311	0.162	0.0095	bubble	0.0496	9.28	11.51	9.3	9.47
732	0.0430	0.036	0.0021	bubble	0.0108	9.66	2.56	9.57	9.57
732	0.0430	0.071	0.0042	bubble	0.021	9.56	5.05	9.47	9.54
732	0.0430	0.103	0.0060	bubble	0.0302	9.47	7.32	9.32	9.57
732	0.0430	0.132	0.0077	bubble	0.0384	9.39	9.38	9.25	9.54
732	0.0430	0.162	0.0095	bubble	0.0467	9.31	11.51	9	9.52
732	0.0430	0.196	0.0115	bubble	0.056	9.21	13.93	8.83	9.54
936	0.0550	0.036	0.0021	bubble	0.0101	9.66	2.56	9.57	9.57
936	0.0550	0.071	0.0042	bubble	0.0198	9.57	5.05	9.47	9.61
936	0.0550	0.103	0.0050	bubble	0.0285	9.48	7.32	9.42	9.57
936	0.0550	0.132	0.0077	bubble	0.0362	9.41	9.38	9.22	9.52
936	0.0550	0.162	0.0095	bubble	0.0441	9.33	11.51	9.13	9.47
936	0.0550	0.196	0.0115	bubble	0.0529	9.24	13.93	8.98	9.47
936	0.0550	0.235	0.0138	bubble	0.0627	9.15	16.70	8.83	9.37

Table C1 continued

Water flow rate Q_{water} (ml/min)	Sup. water velocity j_{water} (m/s)	Air flow rate Q_{air} (l/min)	Sup. air velocity j_{air} (m/s)	Flow regime	Void fraction from theory ε	$(-dp/dz)_{cal}$ from theory (kPa/m)	Reynolds number of air Re_{air}	$(-dp/dz)_{exp}$ from experiment	
								Minimum (kPa/m)	Maximum (kPa/m)
1241	0.0729	0.036	0.0021	bubble	0.0093	9.67	2.56	9.54	9.54
1241	0.0729	0.071	0.0042	bubble	0.0183	9.58	5.05	9.49	9.59
1241	0.0729	0.103	0.0060	bubble	0.0263	9.50	7.32	9.44	9.59
1241	0.0729	0.132	0.0077	bubble	0.0334	9.43	9.38	9.25	9.54
1241	0.0729	0.162	0.0095	bubble	0.0407	9.36	11.51	9.2	9.44
1241	0.0729	0.196	0.0115	bubble	0.0489	9.28	13.93	9	9.39
1241	0.0729	0.235	0.0138	bubble	0.058	9.19	16.70	8.91	9.3
1241	0.0729	0.273	0.0160	bubble	0.0668	9.11	19.40	8.71	9.25
1241	0.0729	0.307	0.0180	bubble	0.0745	9.03	21.82	8.42	9.15
1241	0.0729	0.356	0.0208	bubble	0.0853	8.93	25.30	8.22	9
2055	0.121	0.036	0.0021	bubble	0.0077	9.69	2.56	9.59	9.59
2055	0.121	0.071	0.0042	bubble	0.0151	9.61	5.05	9.52	9.52
2055	0.121	0.103	0.0060	bubble	0.0218	9.55	7.32	9.49	9.49
2055	0.121	0.132	0.0077	bubble	0.0277	9.49	9.38	9.42	9.42
2055	0.121	0.162	0.0095	bubble	0.0338	9.43	11.51	9.32	9.32
2055	0.121	0.196	0.0115	bubble	0.0406	9.36	13.93	9.27	9.27
2055	0.121	0.235	0.0138	bubble	0.0483	9.29	16.70	9.18	9.18
2055	0.121	0.273	0.0160	bubble	0.0557	9.22	19.40	9	9.1
2055	0.121	0.307	0.0180	bubble	0.0622	9.15	21.82	8.91	9

Table C1 continued

Water flow rate Q_{water} (ml/min)	Sup. water velocity j_{water} (m/s)	Air flow rate Q_{air} (l/min)	Sup. air velocity j_{air} (m/s)	Flow regime	Void fraction from theory ε	$(-dp/dz)_{cal}$ from theory (kPa/m)	Reynolds number of air Re_{air}	$(-dp/dz)_{exp}$ from experiment Minimum (kPa/m)	$(-dp/dz)_{exp}$ from experiment Maximum (kPa/m)
2055	0.121	0.356	0.0208	bubble	0.0714	9.06	25.30	8.76	8.91
2055	0.121	0.395	0.0232	bubble	0.0786	8.99	28.07	8.59	8.78
2055	0.121	0.45	0.0264	bubble	0.0886	8.90	31.98	8.3	8.76

Note; Superficial water velocity, $j_{water} = \dfrac{Q_{water}}{A}$

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

Q_{air} = volumetric flow rate of air; Q_{water} = volumetric flow rate of water; A = cross-sectional area of the pipe

Table C2 Determination of pressure gradients from theory and experiment in slug flow regime

Physical properties of air and water used in the experiments:

viscosity of water, $\mu_{water} = 8.48 \times 10^{-4}$ kg/m.s; density of water, $\rho_{water} = 995$ kg/m^3

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

temperature, T = 31°C (± 1°C); diameter of the pipe, D = 0.019 m; pressure taps difference = 0.4 m

Water flow rate Q_{water} (ml/min)	Sup. water velocity j_{water} (m/s)	Air flow rate Q_{air} (l/min)	Sup. air velocity j_{air} (m/s)	Reynolds number of air Re_{air}	Flow regime	Void fraction from theory, ε	Mean liq. velocity $\bar{u}_l$ m/s	Reynolds number of liquid slug Re_{slug}	Fanning friction factor f_F	$(-dp/dz)_{cal}$ from theory (kPa/m)	$(-dp/dz)_{exp}$ from experiment Minimum (kPa/m)	$(-dp/dz)_{exp}$ from experiment Maximum (kPa/m)
0	0.000	0.307	0.0180	21.82	slug	0.1043	0.0180	401	0.0399	8.74	8.61	9.15
0	0.000	0.356	0.0208	25.30	slug	0.1186	0.0208	464	0.0345	8.60	8.30	9.03
0	0.000	0.395	0.0232	28.07	slug	0.1296	0.0232	517	0.0309	8.50	7.93	9.03
0	0.000	0.450	0.0264	31.98	slug	0.1445	0.0264	589	0.0272	8.35	7.08	8.91
0	0.000	0.510	0.0299	36.24	slug	0.1600	0.0299	667	0.0240	8.20	6.95	8.74
0	0.000	0.568	0.0334	40.37	slug	0.1744	0.0334	745	0.0215	8.06	6.71	8.78
0	0.000	0.660	0.0388	46.90	slug	0.1960	0.0388	865	0.0185	7.85	6.22	8.91
0	0.000	0.722	0.0424	51.31	slug	0.2098	0.0424	945	0.0169	7.72	5.73	9.76
0	0.000	0.789	0.0463	56.07	slug	0.2240	0.0463	1032	0.0155	7.58	5.25	9.15
0	0.000	0.867	0.0508	61.61	slug	0.2398	0.0508	1133	0.0141	7.42	4.76	9.03
224	0.0131	0.356	0.0208	25.30	slug	0.1088	0.0339	756	0.0212	8.70	8.30	8.54
224	0.0131	0.395	0.0232	28.07	slug	0.1191	0.0363	809	0.0198	8.60	8.03	8.37
224	0.0131	0.450	0.0264	31.98	slug	0.1330	0.0395	881	0.0182	8.47	7.83	8.15

Table C2 continued

Water flow rate Q_{water} (ml/min)	Sup. water velocity j_{water} (m/s)	Air flow rate Q_{air} (l/min)	Sup. air velocity j_{air} (m/s)	Reynolds number of air Re_{air}	Flow regime	Void fraction from theory, ε	Mean liq. velocity $\overline{u_l}$ m/s	Reynolds number of liquid slug Re_{slug}	Fanning friction factor f_F	$(-dp/dz)_{cal}$ from theory (kPa/m)	$(-dp/dz)_{exp}$ from experiment	
											Minimum (kPa/m)	Maximum (kPa/m)
224	0.0131	0.510	0.0299	36.24	slug	0.1476	0.0430	959	0.0167	8.32	7.61	8.05
224	0.0131	0.568	0.0334	40.37	slug	0.1611	0.0465	1037	0.0154	8.19	7.21	8.30
224	0.0131	0.660	0.0388	46.90	slug	0.1815	0.0519	1157	0.0138	7.99	7.08	8.17
224	0.0131	0.722	0.0424	51.31	slug	0.1946	0.0555	1237	0.0129	7.86	6.76	8.47
224	0.0131	0.789	0.0463	56.07	slug	0.2082	0.0594	1324	0.0121	7.73	6.39	8.49
224	0.0131	0.867	0.0508	61.61	slug	0.2232	0.0639	1425	0.0112	7.59	6.22	8.42
224	0.0131	1.022	0.0600	72.63	slug	0.2511	0.0731	1630	0.0098	7.31	6.10	7.56
224	0.0131	2.394	0.1405	170.13	slug	0.4188	0.1536	3424	-	-	0.49	7.32
224	0.0131	4.000	0.2347	284.26	slug	0.5233	0.2478	5525	0.0092	4.68	0.00	7.81
325	0.0191	0.395	0.0232	28.07	slug	0.1149	0.0423	943	0.0170	8.64	7.91	8.91
325	0.0191	0.450	0.0264	31.98	slug	0.1284	0.0455	1014	0.0158	8.51	7.66	8.96
325	0.0191	0.510	0.0299	36.24	slug	0.1456	0.0490	1092	0.0146	8.34	7.37	8.81
325	0.0191	0.568	0.0334	40.37	slug	0.1558	0.0525	1170	0.0137	8.24	7.13	8.74
325	0.0191	0.660	0.0388	46.90	slug	0.1757	0.0579	1291	0.0124	8.05	6.91	8.54
325	0.0191	0.722	0.0424	51.31	slug	0.1885	0.0615	1371	0.0117	7.92	6.59	8.44
325	0.0191	0.789	0.0463	56.07	slug	0.2017	0.0654	1458	0.0110	7.80	6.34	8.39
325	0.0191	0.867	0.0508	61.61	slug	0.2165	0.0699	1558	0.0103	7.65	6.12	8.3
325	0.0191	1.022	0.0600	72.63	slug	0.2438	0.0791	1763	0.0091	7.39	5.86	8.3
325	0.0191	2.394	0.1405	170.13	slug	0.4101	0.1596	3558	-	-	1.95	9.03

Table C2 continued

Water flow rate Q_{water} (ml/min)	Sup. water velocity j_{water} (m/s)	Air flow rate Q_{air} (l/min)	Sup. air velocity j_{air} (m/s)	Reynolds number of air Re_{air}	Flow regime	Void fraction from theory, ε	Mean liq. velocity $\overline{u_l}$ m/s	Reynolds number of liquid slug Re_{slug}	Fanning friction factor f_F	$(-dp/dz)_{cal}$ from theory (kPa/m)	$(-dp/dz)_{exp}$ from experiment	
											Minimum (kPa/m)	Maximum (kPa/m)
325	0.0191	4.000	0.2347	284.26	slug	0.5151	0.2538	5658	0.0091	4.76	0.49	8.78
325	0.0191	5.326	0.3126	378.50	slug	0.5693	0.3317	7395	0.0085	4.25	0	8.54
427	0.0251	0.450	0.0264	31.98	slug	0.1241	0.0515	1148	0.0139	8.55	7.74	8.93
427	0.0251	0.510	0.0299	36.24	slug	0.1379	0.0550	1226	0.0130	8.42	7.56	8.81
427	0.0251	0.568	0.0334	40.37	slug	0.1507	0.0585	1304	0.0123	8.29	7.37	8.76
427	0.0251	0.660	0.0388	46.90	slug	0.1701	0.0639	1425	0.0112	8.10	7.03	8.59
427	0.0251	0.722	0.0424	51.31	slug	0.1826	0.0675	1505	0.0106	7.98	6.64	8.49
427	0.0251	0.789	0.0463	56.07	slug	0.1956	0.0714	1592	0.0101	7.86	6.52	8.74
427	0.0251	0.867	0.0508	61.61	slug	0.2100	0.0759	1692	0.0095	7.72	6.22	8.35
427	0.0251	1.022	0.0600	72.63	slug	0.2369	0.0851	1897	0.0084	7.45	6.1	7.81
427	0.0251	2.394	0.1405	170.13	slug	0.4017	0.1656	3692	-	-	2.2	7.08
427	0.0251	4.000	0.2347	284.26	slug	0.5071	0.2598	5792	0.0091	4.84	0	7.56
427	0.0251	5.326	0.3126	378.50	slug	0.5619	0.3377	7529	0.0085	4.32	-0.49	8.54
427	0.0251	7.058	0.4142	501.58	slug	0.6107	0.4393	9794	0.0079	3.86	-0.98	6.83
529	0.0311	0.510	0.0299	36.24	slug	0.1335	0.0610	1360	0.0118	8.46	7.59	8.71
529	0.0311	0.568	0.0334	40.37	slug	0.1460	0.0645	1438	0.0111	8.34	7.47	8.59
529	0.0311	0.660	0.0388	46.90	slug	0.1649	0.0699	1558	0.0103	8.16	7.15	8.44
529	0.0311	0.722	0.0424	51.31	slug	0.1771	0.0735	1639	0.0098	8.04	6.95	8.39
529	0.0311	0.789	0.0463	56.07	slug	0.1898	0.0774	1726	0.0093	7.91	6.64	8.78

Table C2 continued

Water flow rate Q_{water} (ml/min)	Sup. water velocity j_{water} (m/s)	Air flow rate Q_{air} (l/min)	Sup. air velocity j_{air} (m/s)	Reynolds number of air Re_{air}	Flow regime	Void fraction from theory, ε	Mean liq. velocity $\overline{u_l}$ m/s	Reynolds number of liquid slug Re_{slug}	Fanning friction factor f_F	$(-dp/dz)_{cal}$ from theory (kPa/m)	$(-dp/dz)_{exp}$ from experiment	
											Minimum (kPa/m)	Maximum (kPa/m)
529	0.0311	0.867	0.0508	61.61	slug	0.2040	0.0819	1826	0.0088	7.77	6.47	8.27
529	0.0311	1.022	0.0600	72.63	slug	0.2304	0.0911	2031	0.0079	7.52	6.1	7.81
529	0.0311	2.394	0.1405	170.13	slug	0.3936	0.1716	3826	-	-	2.44	8.78
529	0.0311	4.000	0.2347	284.26	slug	0.4994	0.2658	5926	0.0636	5.12	-0.24	9.76
529	0.0311	5.326	0.3126	378.50	slug	0.5547	0.3437	7663	0.0632	4.69	-1.22	9.27
529	0.0311	7.058	0.4142	501.58	slug	0.6043	0.4453	9928	0.0628	4.38	-1.46	7.81
732	0.043	0.660	0.0388	46.90	slug	0.1555	0.0818	1824	0.0088	8.25	6.71	8.93
732	0.043	0.722	0.0424	51.31	slug	0.1671	0.0854	1904	0.0084	8.14	6.61	8.64
732	0.043	0.789	0.0463	56.07	slug	0.1793	0.0893	1991	0.0080	8.02	6.1	8.78
732	0.043	0.867	0.0509	61.63	slug	0.1929	0.0939	2093	-	-	6.22	8.78
732	0.043	1.022	0.0600	72.63	slug	0.2184	0.1030	2296	-	-	6.34	8.54
732	0.043	2.394	0.1405	170.13	slug	0.3784	0.1835	4091	0.0099	6.09	2.44	8.78
732	0.043	4.000	0.2347	284.26	slug	0.4847	0.2777	6191	0.0089	5.07	-0.49	8.78
732	0.043	5.326	0.3126	378.50	slug	0.5410	0.3556	7928	0.0084	4.53	-0.98	8.78
732	0.043	7.058	0.4142	501.58	slug	0.5920	0.4572	10193	0.0079	4.05	-1.46	8.3
732	0.043	10.000	0.5869	710.66	slug	0.6471	0.6299	14043	0.0073	3.55	-2.44	7.32
936	0.055	0.660	0.0387	46.90	slug	0.1470	0.0937	2089	-	-	7.22	8.37
936	0.055	0.722	0.0424	51.31	slug	0.1582	0.0974	2171	-	-	6.98	8.52
936	0.055	0.789	0.0463	56.07	slug	0.1699	0.1013	2258	-	-	6.69	8.27

Table C2 continued

Water flow rate Q_{water} (ml/min)	Sup. water velocity j_{water} (m/s)	Air flow rate Q_{air} (l/min)	Sup. air velocity j_{air} (m/s)	Reynolds number of air Re_{air}	Flow regime	Void fraction from theory, ε	Mean liq. velocity $\bar{u}_l$ m/s	Reynolds number of liquid slug Re_{slug}	Fanning friction factor f_F	$(-dp/dz)_{cal}$ from theory (kPa/m)	$(-dp/dz)_{exp}$ from experiment Minimum (kPa/m)	$(-dp/dz)_{exp}$ from experiment Maximum (kPa/m)
936	0.055	0.867	0.0509	61.63	slug	0.1830	0.1059	2361	-	-	6.52	8.13
936	0.055	1.022	0.0600	72.63	slug	0.2075	0.1150	2564	-	-	6.2	8.3
936	0.055	2.394	0.1405	170.13	slug	0.3643	0.1955	4359	0.0097	6.23	3.42	9.27
936	0.055	4.000	0.2347	284.26	slug	0.4707	0.2897	6459	0.0088	5.21	0.73	8.54
936	0.055	5.326	0.3126	378.50	slug	0.5279	0.3676	8195	0.0083	4.66	0	9.03
936	0.055	7.058	0.4142	501.58	slug	0.5801	0.4692	10460	0.0078	4.17	-0.49	8.05
936	0.055	10.000	0.5869	710.66	slug	0.6370	0.6419	14311	0.0072	3.66	-1.95	6.83
1241	0.073	0.789	0.0463	56.07	slug	0.1575	0.1192	2657	-	-	6.91	8.57
1241	0.073	0.867	0.0509	61.63	slug	0.1699	0.1238	2760	-	-	6.71	8.27
1241	0.073	1.022	0.0600	72.6300	slug	0.1932	0.1329	2963	-	-	6.83	8.3
1241	0.073	2.394	0.1405	170.13	slug	0.3451	0.2134	4758	0.0095	6.42	3.66	8.05
1241	0.073	4.000	0.2347	284.26	slug	0.4513	0.3076	6858	0.0087	5.40	2.44	7.81
1241	0.073	5.326	0.3126	378.50	slug	0.5094	0.3855	8594	0.0082	4.85	0.49	8.78
1241	0.073	7.058	0.4142	501.58	slug	0.5631	0.4871	10859	0.0077	4.35	0.24	7.32
1241	0.073	10.000	0.5869	710.66	slug	0.6225	0.6598	14710	0.0072	3.81	-1.22	7.08
2055	0.121	1.022	0.0600	72.63	slug	0.1631	0.1810	4035	0.0099	8.20	7.22	8.3
2055	0.121	2.394	0.1405	170.13	slug	0.3025	0.2615	5830	0.0090	6.85	4.64	8.05
2055	0.121	4.000	0.2347	284.26	slug	0.4065	0.3557	7930	0.0084	5.86	2.93	8.3
2055	0.121	5.326	0.3126	378.50	slug	0.4659	0.4336	9667	0.0080	5.30	0.98	8.3

Table C2 continued

Water flow rate Q_{water} (ml/min)	Sup. water velocity j_{water} (m/s)	Air flow rate Q_{air} (l/min)	Sup. air velocity j_{air} (m/s)	Reynolds number of air Re_{air}	Flow regime	Void fraction from theory, ε	Mean liq. velocity $\overline{u_l}$ m/s	Reynolds number of liquid slug Re_{slug}	Fanning friction factor f_F	$(-dp/dz)_{cal}$ from theory (kPa/m)	$(-dp/dz)_{exp}$ from experiment	
											Minimum (kPa/m)	Maximum (kPa/m)
2055	0.121	7.058	0.4142	501.58	slug	0.5224	0.5352	11932	0.0076	4.77	0.24	8.3
2055	0.121	10.000	0.5869	710.66	slug	0.5868	0.7079	15782	0.0070	4.19	-0.73	6.34

Note; Superficial water velocity, $j_{water} = \dfrac{Q_{water}}{A}$; Superficial air velocity, $j_{air} = \dfrac{Q_{air}}{A}$

Mean liquid velocity, $\overline{u_l} = \dfrac{Q_{air} + Q_{water}}{A}$

Reynolds number of the liquid slug, $Re_{slug} = \dfrac{\rho_{water}\overline{u_l}D}{\mu_{water}}$

Q_{water} = volumetric flow rate of water; Q_{air} = volumetric flow rate of air; A = cross-sectional area of the pipe;

D = diameter of the pipe

Table C3 Determination of pressure gradients from theory and experiment in annualr and mist flow regimes

Physical properties of air and water used in the experiments:

viscosity of water, μ_{water} = 8.48 x 10^{-4} kg/m.s; density of water, ρ_{water} = 995 kg/m^3

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

temperature, T = 31°C (± 1°C); diameter of the pipe, D = 0.019 m; pressure taps difference = 0.4 m

Water flow rate Q_{water} (ml/min)	Sup. water velocity j_{water} (m/s)	Air flow rate Q_{air} (l/min)	Sup. air velocity j_{air} (m/s)	Flow regime	Reynolds number of water Re_{water}	Fanning friction factor of water f_F	Reynolds number of air Re_{air}	Fanning friction factor of air f_F	$(-dp/dz)_{cal}$ from theory			$(-dp/dz)_{exp}$ from experiment	
									water only (kPa/m)	air only (kPa/m)	two-phase (kPa/m)	Minimum (kPa/m)	Maximum (kPa/m)
224	0.0131	200	11.74	annualr	292	0.0548	14213	0.0072	0.9847	123.80	2.7	0.73	0.93
224	0.0131	300	17.61	annualr	292	0.0548	21320	0.0065	0.9847	251.71	1.43	0.68	0.88
224	0.0131	400	23.47	annualr	292	0.0548	28426	0.0061	0.9847	416.42	0.95	0.73	0.98
224	0.0131	500	29.34	annualr	292	0.0548	35533	0.0058	0.9847	615.36	1.18	0.98	1.12
224	0.0131	600	35.21	annualr	292	0.0548	42640	0.0055	0.9847	846.63	1.5	1.24	1.39
224	0.0131	700	41.08	annualr	292	0.0548	49746	0.0053	0.9847	1108.80	1.87	1.71	1.71
224	0.0131	800	46.95	mist	292	0.0548	56853	0.0051	0.9847	1400.68	2.27	2.22	2.22
224	0.0131	900	52.82	mist	292	0.0548	63959	0.0050	0.9847	1721.30	2.7	2.66	2.66
224	0.0131	1000	58.69	mist	292	0.0548	71066	0.0048	0.9847	2069.81	3.16	3.27	3.27
325	0.0191	200	11.74	annular	426	0.0376	14213	0.0072	1.4357	123.80	2.72	0.76	0.95
325	0.0191	300	17.61	annular	426	0.0376	21320	0.0065	1.4357	251.71	1.46	0.76	0.9
325	0.0191	400	23.47	annular	426	0.0376	28426	0.0061	1.4357	416.42	1.03	0.95	1.15

Table C3 continued

Water flow rate Q_{water} (ml/min)	Sup. water velocity j_{water} (m/s)	Air flow rate Q_{air} (l/min)	Sup. air velocity j_{air} (m/s)	Flow regime	Reynolds number of water Re_{water}	Fanning friction factor of water f_F	Reynolds number of air Re_{air}	Fanning friction factor of air f_F	$(-dp/dz)_{cal}$ from theory			$(-dp/dz)_{exp}$ from experiment	
									water only (kPa/m)	air only (kPa/m)	two-phase (kPa/m)	Minimum (kPa/m)	Maximum (kPa/m)
325	0.0191	500	29.34	annular	426	0.0376	35533	0.0058	1.4357	615.36	1.26	1.15	1.34
325	0.0191	600	35.21	annular	426	0.0376	42640	0.0055	1.4357	846.63	1.59	1.34	1.59
325	0.0191	700	41.08	annular	426	0.0376	49746	0.0053	1.4357	1108.80	1.96	1.73	1.83
325	0.0191	800	46.95	mist	426	0.0376	56853	0.0051	1.4357	1400.68	2.38	2.12	2.37
325	0.0191	900	52.82	mist	426	0.0376	63959	0.0050	1.4357	1721.30	2.83	2.56	2.76
325	0.0191	1000	58.69	mist	426	0.0376	71066	0.0048	1.4357	2069.81	3.3	2.95	3.05
427	0.0251	200	11.74	annular	560	0.0286	14213	0.0072	1.8867	123.80	2.73	0.85	1.22
427	0.0251	300	17.61	annular	560	0.0286	21320	0.0065	1.8867	251.71	1.49	0.98	1.17
427	0.0251	400	23.47	annular	560	0.0286	28426	0.0061	1.8867	416.42	1.1	1.29	1.39
427	0.0251	500	29.34	annular	560	0.0286	35533	0.0058	1.8867	615.36	1.34	1.61	1.71
427	0.0251	600	35.21	annular	560	0.0286	42640	0.0055	1.8867	846.63	1.66	2.07	2.17
427	0.0251	700	41.08	annular	560	0.0286	49746	0.0053	1.8867	1108.80	2.05	2.46	2.66
427	0.0251	800	46.95	mist	560	0.0286	56853	0.0051	1.8867	1400.68	2.46	2.93	3.12
427	0.0251	900	52.82	mist	560	0.0286	63959	0.0050	1.8867	1721.30	2.94	3.42	3.68
427	0.0251	1000	58.69	mist	560	0.0286	71066	0.0048	1.8867	2069.81	3.43	4.15	4.39
529	0.0311	200	11.74	annular	693	0.0231	14213	0.0072	2.3377	123.80	2.73	0.88	1.22
529	0.0311	300	17.61	annular	693	0.0231	21320	0.0065	2.3377	251.71	1.52	0.93	1.12
529	0.0311	400	23.47	annular	693	0.0231	28426	0.0061	2.3377	416.42	1.16	1.22	1.37

Table C3 continued

Water flow rate Q_{water} (ml/min)	Sup. water velocity j_{water} (m/s)	Air flow rate Q_{air} (l/min)	Sup. air velocity j_{air} (m/s)	Flow regime	Reynolds number of water Re_{water}	Fanning friction factor of water f_F	Reynolds number of air Re_{air}	Fanning friction factor of air f_F	$(-dp/dz)_{cal}$ from theory			$(-dp/dz)_{exp}$ from experiment	
									water only (kPa/m)	air only (kPa/m)	two-phase (kPa/m)	Minimum (kPa/m)	Maximum (kPa/m)
529	0.0311	500	29.34	annular	693	0.0231	35533	0.0058	2.3377	615.36	1.39	1.49	1.68
529	0.0311	600	35.21	annular	693	0.0231	42640	0.0055	2.3377	846.63	1.73	1.78	2.07
529	0.0311	700	41.08	annular	693	0.0231	49746	0.0053	2.3377	1108.80	2.12	2.27	2.42
529	0.0311	800	46.95	mist	693	0.0231	56853	0.0051	2.3377	1400.68	2.55	2.71	2.86
529	0.0311	900	52.82	mist	693	0.0231	63959	0.0050	2.3377	1721.30	3.02	3.05	3.29
529	0.0311	1000	58.69	mist	693	0.0231	71066	0.0048	2.3377	2069.81	3.53	3.66	4.08
732	0.043	200	11.74	annular	959	0.0167	14213	0.0072	3.2322	123.80	2.74	0.98	1.22
732	0.043	300	17.61	annular	959	0.0167	21320	0.0065	3.2322	251.71	1.58	1.1	1.22
732	0.043	400	23.47	annular	959	0.0167	28426	0.0061	3.2322	416.42	1.26	1.34	1.59
732	0.043	500	29.34	annular	959	0.0167	35533	0.0058	3.2322	615.36	1.5	1.76	1.95
732	0.043	600	35.21	annular	959	0.0167	42640	0.0055	3.2322	846.63	1.84	2.2	2.39
732	0.043	700	41.08	annular	959	0.0167	49746	0.0053	3.2322	1108.80	2.24	2.68	2.83
732	0.043	800	46.95	mist	959	0.0167	56853	0.0051	3.2322	1400.68	2.69	3.27	3.51
732	0.043	900	52.82	mist	959	0.0167	63959	0.0050	3.2322	1721.30	3.17	3.76	3.95
732	0.043	1000	58.69	mist	959	0.0167	71066	0.0048	3.2322	2069.81	3.7	4.59	4.81
936	0.055	200	11.74	annular	1226	0.0130	14213	0.0072	4.1342	123.80	2.75	1.1	1.49
936	0.055	300	17.61	annular	1226	0.0130	21320	0.0065	4.1342	251.71	1.62	1.29	1.49
936	0.055	400	23.47	annular	1226	0.0130	28426	0.0061	4.1342	416.42	1.34	1.59	1.73

Table C3 continued

Water flow rate Q_{water} (ml/min)	Sup. water velocity j_{water} (m/s)	Air flow rate Q_{air} (l/min)	Sup. air velocity j_{air} (m/s)	Flow regime	Reynolds number of water Re_{water}	Fanning friction factor of water f_F	Reynolds number of air Re_{air}	Fanning friction factor of air f_F	$(-dp/dz)_{cal}$ from theory			$(-dp/dz)_{exp}$ from experiment	
									water only (kPa/m)	air only (kPa/m)	two-phase (kPa/m)	Minimum (kPa/m)	Maximum (kPa/m)
936	0.055	500	29.34	annular	1226	0.0130	35533	0.0058	4.1342	615.36	1.58	2.07	2.22
936	0.055	600	35.21	annular	1226	0.0130	42640	0.0055	4.1342	846.63	1.93	2.61	2.76
936	0.055	700	41.08	annular	1226	0.0130	49746	0.0053	4.1342	1108.80	2.35	3.03	3.29
936	0.055	800	46.95	mist	1226	0.0130	56853	0.0051	4.1342	1400.68	2.8	3.66	3.88
936	0.055	900	52.82	mist	1226	0.0130	63959	0.0050	4.1342	1721.30	3.3	4.27	4.51
936	0.055	1000	58.69	mist	1226	0.0130	71066	0.0048	4.1342	2069.81	3.83	5.12	5.27
1241	0.073	200	11.74	annular	1625	0.0098	14213	0.0072	5.4797	123.80	2.77	1.44	1.71
1241	0.073	300	17.61	annular	1625	0.0098	21320	0.0065	5.4797	251.71	1.69	1.66	1.81
1241	0.073	400	23.47	annular	1625	0.0098	28426	0.0061	5.4797	416.42	1.45	2.12	2.27
1241	0.073	500	29.34	annular	1625	0.0098	35533	0.0058	5.4797	615.36	1.69	2.64	2.83
1241	0.073	600	35.21	annular	1625	0.0098	42640	0.0055	5.4797	846.63	2.05	3.2	3.34
1241	0.073	700	41.08	annular	1625	0.0098	49746	0.0053	5.4797	1108.80	2.48	3.83	3.95
1241	0.073	800	46.95	mist	1625	0.0098	56853	0.0051	5.4797	1400.68	2.95	4.64	4.81
1241	0.073	900	52.82	mist	1625	0.0098	63959	0.0050	5.4797	1721.30	3.47	5.37	5.54
1241	0.073	1000	58.69	mist	1625	0.0098	71066	0.0048	5.4797	2069.81	4.01	6.71	6.83
2055	0.121	200	11.74	annular	2698	0.0059	14213	0.0072	9.0952	123.80	2.81	1.71	2.2
2055	0.121	300	17.61	annular	2698	0.0059	21320	0.0065	9.0952	251.71	1.83	2.34	2.64
2055	0.121	400	23.47	annular	2698	0.0059	28426	0.0061	9.0952	416.42	1.66	2.98	3.22

Table C3 continued

Water flow rate Q_{water} (ml/min)	Sup. water velocity j_{water} (m/s)	Air flow rate Q_{air} (l/min)	Sup. air velocity j_{air} (m/s)	Flow regime	Reynolds number of water Re_{water}	Fanning friction factor of water f_F	Reynolds number of air Re_{air}	Fanning friction factor of air f_F	$(-dp/dz)_{cal}$ from theory			$(-dp/dz)_{exp}$ from experiment	
									water only (kPa/m)	air only (kPa/m)	two-phase (kPa/m)	Minimum (kPa/m)	Maximum (kPa/m)
2055	0.121	500	29.34	annular	2698	0.0059	35533	0.0058	9.0952	615.36	1.92	3.66	4.05
2055	0.121	600	35.21	annular	2698	0.0059	42640	0.0055	9.0952	846.63	2.31	4.44	4.78
2055	0.121	700	41.08	annular	2698	0.0059	49746	0.0053	9.0952	1108.80	2.76	5.2	5.39
2055	0.121	800	46.95	mist	2698	0.0059	56853	0.0051	9.0952	1400.68	3.27	6.12	6.27
2055	0.121	900	52.82	mist	2698	0.0059	63959	0.0050	9.0952	1721.30	3.81	7.27	7.37
2055	0.121	1000	58.69	mist	2698	0.0059	71066	0.0048	9.0952	2069.81	4.39	7.86	8

Note; Superficial water velocity, $j_{water} = \frac{Q_{water}}{A}$; Superficial air velocity, $j_{air} = \frac{Q_{air}}{A}$

Pressure gradient for water, $\left(-\frac{dp}{dz}\right)_{water\ only} = \frac{2 f_F \rho_{water} j_{water}^2}{D}$; Pressure gradient for air, $\left(-\frac{dp}{dz}\right)_{air\ only} = \frac{2 f_F \rho_{air} j_{air}^2}{D}$

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

Martinelli parameter, X, void fraction of air, ε, and gas two-phase flow multiplier, ϕ_g^2, can be calculated by using the following equations:

$$\left(1+X^{2/3.61}\right)^{3.61}\left((dp/dz)_{go}-\frac{(dp/dz)_{lo}}{X^2}\right)=9749\left(1-\frac{1}{\left(\left(1+0.0904X^{0.548}\right)^{2.82}\right)}\right)$$

$$\varepsilon=\frac{1}{\left(1+0.0904\,X^{0.548}\right)^{2.82}}$$

$$\phi_g=\left(1+X^{2/n}\right)^{n/2}$$

Table C3 (continued) Calculation of two-phase pressure gradient by using X, Φ_g^2, and pressure gradient of air in annular and mist flow regimes

Water flow rate Q_{water} (ml/min)	Air flow rate Q_{air} (l/min)	Martinelli parameter X	Void fraction ε	Gas two-phase flow multiplier Φ_g	Φ_g^2	Pressure gradient for two-phase flow $(-dp/dz)_{tp}$ (kPa/m)
224	200	1.7100	0.7241	4.66	21.73	2.70
224	300	0.4200	0.8571	2.38	5.69	1.43
224	400	0.0830	0.9376	1.50	2.25	0.95
224	500	0.0520	0.9512	1.38	1.90	1.18
224	600	0.0405	0.9573	1.33	1.76	1.50
224	700	0.0340	0.9611	1.29	1.68	1.87
224	800	0.0290	0.9643	1.27	1.61	2.27
224	900	0.0257	0.9665	1.25	1.56	2.70
224	1000	0.0231	0.9684	1.23	1.52	3.16
325	200	1.72	0.7234	4.68	21.87	2.72
325	300	0.4273	0.8559	2.40	5.76	1.46
325	400	0.1013	0.9307	1.56	2.45	1.03
325	500	0.0636	0.9458	1.43	2.03	1.26
325	600	0.049	0.9527	1.36	1.86	1.59
325	700	0.0406	0.9572	1.33	1.76	1.96
325	800	0.035	0.9605	1.30	1.69	2.38
325	900	0.031	0.9630	1.28	1.64	2.83
325	1000	0.0279	0.9650	1.26	1.59	3.30
427	200	1.723	0.7232	4.68	21.92	2.73
427	300	0.439	0.8540	2.43	5.88	1.49
427	400	0.117	0.9253	1.62	2.61	1.10
427	500	0.074	0.9413	1.47	2.15	1.34
427	600	0.056	0.9493	1.39	1.95	1.66
427	700	0.047	0.9538	1.36	1.84	2.05
427	800	0.04	0.9576	1.32	1.75	2.46
427	900	0.036	0.9599	1.30	1.70	2.94
427	1000	0.032	0.9623	1.28	1.65	3.43
529	200	1.726	0.7230	4.69	21.96	2.73
529	300	0.451	0.8520	2.45	6.01	1.52
529	400	0.131	0.9208	1.66	2.76	1.16
529	500	0.0823	0.9379	1.50	2.24	1.39
529	600	0.0631	0.9460	1.42	2.03	1.73
529	700	0.0522	0.9511	1.38	1.90	2.12
529	800	0.0449	0.9549	1.35	1.81	2.55
529	900	0.0397	0.9578	1.32	1.75	3.02

Table C3 continued

Water flow rate Q_{water} (ml/min)	Air flow rate Q_{air} (l/min)	Martinelli parameter X	Void fraction ε	Gas two-phase flow multiplier Φ_g	Φ_g^2	Pressure gradient for two-phase flow $(-dp/dz)_{tp}$ (kPa/m)
529	1000	0.0357	0.9601	1.30	1.70	3.53
732	200	1.7315	0.7226	4.69	22.04	2.74
732	300	0.4705	0.8489	2.49	6.21	1.58
732	400	0.1541	0.9139	1.73	2.99	1.26
732	500	0.0974	0.9321	1.55	2.41	1.50
732	600	0.0746	0.9410	1.47	2.16	1.84
732	700	0.0616	0.9466	1.42	2.01	2.24
732	800	0.0530	0.9507	1.38	1.91	2.69
732	900	0.0468	0.9539	1.35	1.84	3.17
732	1000	0.0420	0.9565	1.33	1.78	3.70
936	200	1.7372	0.7222	4.70	22.12	2.75
936	300	0.4884	0.8461	2.53	6.40	1.62
936	400	0.1738	0.9084	1.79	3.19	1.34
936	500	0.1106	0.9275	1.60	2.54	1.58
936	600	0.0847	0.9369	1.51	2.27	1.93
936	700	0.0699	0.9430	1.45	2.11	2.35
936	800	0.0601	0.9474	1.41	1.99	2.80
936	900	0.0530	0.9507	1.38	1.91	3.30
936	1000	0.0476	0.9535	1.36	1.85	3.83
1241	200	1.7458	0.7216	4.72	22.25	2.77
1241	300	0.5122	0.8425	2.58	6.65	1.69
1241	400	0.1988	0.9019	1.86	3.44	1.45
1241	500	0.1278	0.9218	1.65	2.72	1.69
1241	600	0.0979	0.9320	1.55	2.41	2.05
1241	700	0.0808	0.9385	1.49	2.23	2.48
1241	800	0.0694	0.9432	1.45	2.10	2.95
1241	900	0.0612	0.9468	1.42	2.01	3.47
1241	1000	0.0549	0.9498	1.39	1.93	4.01
2055	200	1.7682	0.7200	4.75	22.58	2.81
2055	300	0.5647	0.8349	2.69	7.21	1.83
2055	400	0.2504	0.8897	1.99	3.96	1.66
2055	500	0.1647	0.9109	1.76	3.10	1.92
2055	600	0.1266	0.9222	1.65	2.71	2.31
2055	700	0.1045	0.9296	1.57	2.48	2.76
2055	800	0.0898	0.9350	1.52	2.32	3.27
2055	900	0.0791	0.9392	1.49	2.21	3.81
2055	1000	0.0710	0.9425	1.45	2.12	4.39

Table C4 Determination of pressure gradients from the thoery and experiment in bubble flow regime
Physical properties of air and (50 vol% glycerol + 50 vol% water) solution used in the experiments:
viscosity of glycerol solution, $\mu_{solution}$ = 4.48 x 10^{-3} kg/m.s; density of glycerol solution, $\rho_{solution}$ = 1121 kg/m^3
viscosity of air, μ_{air} = 1.85 x 10^{-5} kg/m.s; density of air, ρ_{air} = 1.18 kg/m^3
temperature, T = 31°C (± 1°C); diameter of the pipe, D = 0.019 m; pressure taps difference = 0.4 m

Solution flow rate $Q_{solution}$ (ml/min)	Sup. Sol^n velocity $j_{solution}$ (m/s)	Air flow rate Q_{air} (l/min)	Sup. air velocity j_{air} (m/s)	Flow regime	Void fraction from theory ε	$(-dp/dz)_{cal}$ from theory (kPa/m)	Reynolds number of air Re_{air}	$(-dp/dz)_{exp}$ from experiment Minimum (kPa/m)	Maximum (kPa/m)
0	0.0000	0.036	0.0021	bubble	0.0138	10.85	2.56	10.91	10.91
0	0.0000	0.071	0.0042	bubble	0.0268	10.70	5.05	10.86	10.86
0	0.0000	0.103	0.0060	bubble	0.0385	10.57	7.32	10.69	10.69
0	0.0000	0.132	0.0077	bubble	0.0488	10.46	9.38	10.47	10.47
0	0.0000	0.162	0.0095	bubble	0.0592	10.35	11.51	10.25	10.36
358	0.0210	0.036	0.0021	bubble	0.0121	10.86	2.56	10.86	10.86
358	0.0210	0.071	0.0042	bubble	0.0236	10.74	5.05	10.72	10.72
358	0.0210	0.103	0.0060	bubble	0.0339	10.62	7.32	10.58	10.58
358	0.0210	0.132	0.0077	bubble	0.0431	10.52	9.38	10.47	10.47
358	0.0210	0.162	0.0095	bubble	0.0523	10.42	11.51	10.25	10.36
358	0.0210	0.196	0.0115	bubble	0.0626	10.31	13.93	10.09	10.25
545	0.0320	0.036	0.0021	bubble	0.0114	10.87	2.56	10.8	10.8
545	0.0320	0.071	0.0042	bubble	0.0223	10.75	5.05	10.67	10.67

Table C4 continued

Solution flow rate $Q_{solution}$ (ml/min)	Sup. Sol$^{n.}$ velocity $j_{solution}$ (m/s)	Air flow rate Q_{air} (l/min)	Sup. air velocity j_{air} (m/s)	Flow regime	Void fraction from theory ε	$(-dp/dz)_{cal}$ from theory (kPa/m)	Reynolds number of air Re_{air}	$(-dp/dz)_{exp}$ from experiment	
								Minimum (kPa/m)	Maximum (kPa/m)
545	0.0320	0.103	0.0060	bubble	0.0320	10.65	7.32	10.56	10.56
545	0.0320	0.132	0.0077	bubble	0.0406	10.55	9.38	10.42	10.42
545	0.0320	0.162	0.0095	bubble	0.0494	10.45	11.51	10.28	10.28
545	0.0320	0.196	0.0115	bubble	0.0591	10.35	13.93	10.12	10.17
545	0.0320	0.235	0.0138	bubble	0.0700	10.23	16.70	10.01	10.12
545	0.0320	0.273	0.0160	bubble	0.0805	10.11	19.40	9.73	9.95
705	0.0414	0.036	0.0021	bubble	0.0109	10.88	2.56	10.75	10.75
705	0.0414	0.071	0.0042	bubble	0.0212	10.76	5.05	10.64	10.64
705	0.0414	0.103	0.0060	bubble	0.0304	10.66	7.32	10.56	10.56
705	0.0414	0.132	0.0077	bubble	0.0387	10.57	9.38	10.45	10.45
705	0.0414	0.162	0.0095	bubble	0.0471	10.48	11.51	10.34	10.34
705	0.0414	0.196	0.0115	bubble	0.0564	10.38	13.93	10.17	10.28
705	0.0414	0.235	0.0138	bubble	0.0669	10.26	16.70	10.01	10.20
705	0.0414	0.273	0.0160	bubble	0.0768	10.15	19.40	9.84	10.01
1102	0.0647	0.036	0.0021	bubble	0.0097	10.89	2.56	10.89	10.89
1102	0.0647	0.071	0.0042	bubble	0.0189	10.79	5.05	10.83	10.83
1102	0.0647	0.103	0.0060	bubble	0.0272	10.70	7.32	10.8	10.8
1102	0.0647	0.132	0.0077	bubble	0.0347	10.62	9.38	10.75	10.75
1102	0.0647	0.162	0.0095	bubble	0.0422	10.53	11.51	10.67	10.67

Table C4 continued

Solution flow rate $Q_{solution}$ (ml/min)	Sup. Sol^n velocity $j_{solution}$ (m/s)	Air flow rate Q_{air} (l/min)	Sup. air velocity j_{air} (m/s)	Flow regime	Void fraction from theory ε	$(-dp/dz)_{cal}$ from theory (kPa/m)	Reynolds number of air Re_{air}	$(-dp/dz)_{exp}$ from experiment	
								Minimum (kPa/m)	Maximum (kPa/m)
1102	0.0647	0.196	0.0115	bubble	0.0506	10.44	13.93	10.56	10.56
1102	0.0647	0.235	0.0138	bubble	0.0601	10.34	16.70	10.45	10.45
1102	0.0647	0.273	0.0160	bubble	0.0691	10.24	19.40	10.28	10.34
1102	0.0647	0.307	0.0180	bubble	0.0771	10.15	21.82	10.06	10.12
1560	0.0915	0.036	0.0021	bubble	0.0086	10.90	2.56	10.91	10.91
1560	0.0915	0.071	0.0042	bubble	0.0169	10.81	5.05	10.86	10.86
1560	0.0915	0.103	0.0060	bubble	0,0243	10.73	7.32	10.83	10.83
1560	0.0915	0.132	0.0077	bubble	0.0309	10.66	9.38	10.78	10.78
1560	0.0915	0.162	0.0095	bubble	0.0377	10.58	11.51	10.67	10.67
1560	0.0915	0.196	0.0115	bubble	0.0453	10.50	13.93	10.5	10.61
1560	0.0915	0.235	0.0138	bubble	0.0538	10.41	16.70	10.39	10.50
1560	0.0915	0.273	0.0160	bubble	0.0619	10.32	19.40	10.28	10.39
1560	0.0915	0.307	0.0180	bubble	0.0691	10.24	21.82	10.17	10.34
1560	0.0915	0.356	0.0209	bubble	0.0793	10.13	25.30	10.06	10.23
1794	0.1053	0.036	0.0021	bubble	0.0082	10.91	2.56	10.86	10.86
1794	0.1053	0.071	0.0042	bubble	0.0160	10.82	5.05	10.83	10.83
1794	0.1053	0.103	0.0060	bubble	0.0230	10.74	7.32	10.78	10.78
1794	0.1053	0.132	0.0077	bubble	0.0293	10.67	9.38	10.69	10.69
1794	0.1053	0.162	0.0095	bubble	0.0358	10.60	11.51	10.58	10.58

Table C4 continued

Solution flow rate $Q_{solution}$ (ml/min)	Sup. Sol^{n} velocity $j_{solution}$ (m/s)	Air flow rate Q_{air} (l/min)	Sup. air velocity j_{air} (m/s)	Flow regime	Void fraction from theory ε	$(-dp/dz)_{cal}$ from theory (kPa/m)	Reynolds number of air Re_{air}	$(-dp/dz)_{exp}$ from experiment	
								Minimum (kPa/m)	Maximum (kPa/m)
1794	0.1053	0.196	0.0115	bubble	0.0429	10.52	13.93	10.53	10.53
1794	0.1053	0.235	0.0138	bubble	0.0510	10.44	16.70	10.39	10.50
1794	0.1053	0.273	0.0160	bubble	0.0588	10.35	19.40	10.28	10.34
1794	0.1053	0.307	0.0180	bubble	0.0657	10.27	21.82	10.2	10.31
1794	0.1053	0.356	0.0209	bubble	0.0753	10.17	25.30	10.03	10.20
1794	0.1053	0.395	0.0232	bubble	0.0829	10.09	28.07	9.9	10.06

Note; Superficial solution velocity, $j_{solution} = \frac{Q_{solution}}{A}$

Superficial air velocity, $j_{air} = \frac{Q_{air}}{A}$

Q_{air} = volumetric flow rate of air; $Q_{solution}$ = volumetric flow rate of glycerol solution; A = cross-sectional area of the pipe

Table C5 Determination of pressure gradients from the theory and experiment in slug flow regime

Physical properties of air and (50 vol% glycerol + 50 vol% water) solution used in the experiments:

viscosity of glycerol solution, $\mu_{solution} = 4.48 \times 10^{-3}$ kg/m.s; density of glycerol solution, $\rho_{solution} = 1121$ kg/m^3

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

temperature, T = 31°C (± 1°C); diameter of the pipe, D = 0.019 m; pressure taps difference = 0.4 m

Solution flow rate $Q_{solution}$ (ml/min)	Sup. Sol^n velocity $j_{solution}$ (m/s)	Air flow rate Q_{air} (l/min)	Sup. air velocity j_{air} (m/s)	Reynolds number of air Re_{air}	Flow regime	Void faraction from theory, ε	Mean liq. velocity $\overline{u_l}$ m/s	Reynolds number of liquid slug Re_{slug}	Fanning friction factor f_F	$(-dp/dz)_{cal}$ from theory (kPa/m)	$(-dp/dz)_{exp}$ from experiment	
											Minimum (kPa/m)	Maximum (kPa/m)
0	0.0000	0.450	0.0264	31.98	slug	0.1445	0.0264	125	0.1276	9.42	8.22	8.99
0	0.0000	0.510	0.0299	36.24	slug	0.1600	0.0299	142	0.1125	9.25	7.89	8.94
0	0.0000	0.568	0.0333	40.37	slug	0.1744	0.0333	158	0.1011	9.09	7.62	8.94
0	0.0000	0.660	0.0387	46.90	slug	0.1960	0.0387	184	0.0870	8.85	7.34	8.77
0	0.0000	0.722	0.0424	51.31	slug	0.2098	0.0424	201	0.0795	8.70	7.01	8.39
0	0.0000	0.789	0.0463	56.07	slug	0.2240	0.0463	220	0.0727	8.55	6.74	8.39
0	0.0000	0.867	0.0509	61.61	slug	0.2398	0.0509	242	0.0662	8.38	6.41	8.66
358	0.0210	0.568	0.0333	40.37	slug	0.1541	0.0543	258	0.0620	9.32	8.08	9.07
358	0.0210	0.660	0.0387	46.90	slug	0.1738	0.0597	284	0.0564	9.11	7.86	8.91
358	0.0210	0.722	0.0424	51.31	slug	0.1865	0.0634	301	0.0532	8.97	7.64	8.52
358	0.0210	0.789	0.0463	56.07	slug	0.1997	0.0673	320	0.0500	8.82	7.48	8.52
358	0.0210	0.867	0.0509	61.61	slug	0.2143	0.0719	341	0.0469	8.66	7.26	8.52
358	0.0210	1.022	0.0600	72.63	slug	0.2416	0.0810	385	0.0416	8.36	6.98	8.25
358	0.0210	2.394	0.1405	170.13	slug	0.4073	0.1615	767	0.0209	6.56	4.12	6.87

Table C5 continued

Solution flow rate $Q_{solution}$ (ml/min)	Sup. Sol[n] velocity $j_{solution}$ (m/s)	Air flow rate Q_{air} (l/min)	Sup. air velocity j_{air} (m/s)	Reynolds number of air Re_{air}	Flow regime	Void faraction from theory, ε	Mean liq. velocity $\overline{u_l}$ m/s	Reynolds number of liquid slug Re_{slug}	Fanning friction factor f_F	$(-dp/dz)_{cal}$ from theory (kPa/m)	$(-dp/dz)_{exp}$ from experiment Minimum (kPa/m)	$(-dp/dz)_{exp}$ from experiment Maximum (kPa/m)
358	0.0210	4.000	0.2347	284.26	slug	0.5125	0.2557	1215	0.0132	5.41	1.37	5.77
358	0.0210	5.326	0.3126	378.50	slug	0.5669	0.3336	1584	0.0101	4.82	0.82	6.32
545	0.0320	0.722	0.0424	51.31	slug	0.1763	0.0744	353	0.0453	9.08	7.97	8.74
545	0.0320	0.789	0.0463	56.07	slug	0.189	0.0783	372	0.0430	8.94	7.64	8.74
545	0.0320	0.867	0.0509	61.61	slug	0.2031	0.0829	394	0.0406	8.79	7.42	8.52
545	0.0320	1.022	0.0600	72.63	slug	0.2294	0.0920	437	0.0366	8.50	7.2	8.52
545	0.0320	2.394	0.1405	170.13	slug	0.3924	0.1725	819	0.0195	6.72	4.62	6.6
545	0.0320	4.000	0.2347	284.26	slug	0.4982	0.2667	1267	0.0126	5.57	3.3	5.5
545	0.0320	5.326	0.3126	378.50	slug	0.5536	0.3446	1637	0.0098	4.97	2.2	4.95
705	0.0414	0.789	0.0463	56.07	slug	0.1806	0.0877	417	0.0384	9.04	8.06	8.83
705	0.0414	0.867	0.0509	61.61	slug	0.1943	0.0923	438	0.0365	8.89	7.84	8.55
705	0.0414	1.022	0.0600	72.63	slug	0.2199	0.1014	482	0.0332	8.61	7.29	8.39
705	0.0414	2.394	0.1405	170.13	slug	0.3804	0.1819	864	0.0185	6.86	5.22	6.32
705	0.0414	4.000	0.2347	284.26	slug	0.4866	0.2761	1312	0.0122	5.70	3.57	5.5
705	0.0414	5.326	0.3126	378.50	slug	0.5428	0.3540	1681	0.0095	5.09	2.2	4.95
1102	0.0647	0.867	0.0509	61.61	slug	0.1756	0.1156	549	0.0291	9.10	8.19	8.74
1102	0.0647	1.022	0.0600	72.63	slug	0.1995	0.1247	592	0.0270	8.84	7.86	8.63
1102	0.0647	2.394	0.1405	170.13	slug	0.3536	0.2052	975	0.0164	7.16	5.5	6.87
1102	0.0647	4.000	0.2347	284.26	slug	0.4599	0.2994	1422	0.0112	6.00	3.85	6.05
1102	0.0647	5.326	0.3126	378.50	slug	0.5177	0.3773	1792	0.0089	5.38	2.06	5.22

Table C5 continued

Solution flow rate $Q_{solution}$ (ml/min)	Sup. Sol^n velocity $j_{solution}$ (m/s)	Air flow rate Q_{air} (l/min)	Sup. air velocity j_{air} (m/s)	Reynolds number of air Re_{air}	Flow regime	Void faraction from theory, ε	Mean liq. velocity $\overline{u_l}$ m/s	Reynolds number of liquid slug Re_{slug}	Fanning friction factor f_F	$(-dp/dz)_{cal}$ from theory (kPa/m)	$(-dp/dz)_{exp}$ from experiment	
											Minimum (kPa/m)	Maximum (kPa/m)
1560	0.0915	1.022	0.0600	72.63	slug	0.1801	0.1515	720	0.0222	9.07	8.39	8.94
1560	0.0915	2.394	0.1405	170.13	slug	0.3271	0.2320	1102	0.0145	7.46	6.05	7.15
1560	0.0915	4.000	0.2347	284.26	slug	0.4326	0.3262	1550	0.0103	6.31	4.4	5.5
1560	0.0915	5.326	0.3126	378.50	slug	0.4914	0.4041	1919	0.0083	5.67	3.02	4.95
1794	0.1053	2.394	0.1405	170.13	slug	0.315	0.2458	1168	0.0137	7.60	6.32	7.42
1794	0.1053	4.000	0.2347	284.26	slug	0.4198	0.3400	1615	0.0099	6.46	4.67	6.6
1794	0.1053	5.326	0.3126	378.50	slug	0.479	0.4179	1985	0.0081	5.82	3.85	5.77
1794	0.1053	7.058	0.4142	501.58	slug	0.5348	0.5195	2468	0.0065	5.21	2.47	5.22

Note; Superficial solution velocity, $j_{solution} = \dfrac{Q_{solution}}{A}$; Superficial air velocity, $j_{air} = \dfrac{Q_{air}}{A}$

Mean liquid velocity, $\overline{u_l} = \dfrac{Q_{air} + Q_{solution}}{A}$

Reynolds number of the liquid slug, $Re_{slug} = \dfrac{\rho_{solution}\overline{u_l}D}{\mu_{solution}}$

Q_{air} = volumetric flow rate of air; $Q_{solution}$ = volumetric flow rate of glycerol solution; A = cross-sectional area of the pipe; D = diameter of the pipe

Table C6 Determination of pressure gradients from theory and experiment in annualr and mist flow regimes
Physical properties of air and (50 vol% glycerol + 50 vol% water) solution used in the experiments:
viscosity of glycerol solution, $\mu_{solution}$ = 4.48 x 10^{-3} kg/m.s; density of glycerol solution, $\rho_{solution}$ = 1121 kg/m^3
viscosity of air, μ_{air} = 1.85 x 10^{-5} kg/m.s; density of air, ρ_{air} = 1.18 kg/m^3
temperature, T = 31°C (± 1°C); diameter of the pipe, D = 0.019 m; pressure taps difference = 0.4 m

Solution flow rate $Q_{solution}$ (ml/min)	Sup. Solution velocity $j_{solution}$ (m/s)	Air flow rate Q_{air} (l/min)	Sup. air velocity j_{air} (m/s)	Flow regime	Reynolds number of solution $Re_{solution}$	Fanning friction factor of solution f_F	Reynolds number of air Re_{air}	Fanning friction factor of air f_F	$(-dp/dz)_{cal}$ from theory			$(-dp/dz)_{exp}$ from experiment	
									solution only (kPa/m)	air only (kPa/m)	two phase (kPa/m)	Minimum (kPa/m)	Maximum (kPa/m)
358	0.0210	200	11.74	annualr	100	0.1604	14213	0.0072	8.3469	123.80	3.35	1.32	1.46
358	0.0210	300	17.61	annular	100	0.1604	21320	0.0065	8.3469	251.71	2.15	1.54	1.54
358	0.0210	400	23.47	annular	100	0.1604	28426	0.0061	8.3469	416.42	1.75	1.9	1.9
358	0.0210	500	29.34	annular	100	0.1604	35533	0.0058	8.3469	615.36	1.93	2.47	2.47
358	0.0210	600	35.21	annular	100	0.1604	42640	0.0055	8.3469	846.63	2.3	2.97	2.97
358	0.0210	700	41.08	annular	100	0.1604	49746	0.0053	8.3469	1108.80	2.74	3.66	3.66
358	0.0210	800	46.95	mist	100	0.1604	56853	0.0051	8.3469	1400.68	3.23	4.65	4.65
545	0.0320	200	11.74	annualr	152	0.1053	14213	0.0072	12.7192	123.80	3.39	1.51	1.76
545	0.0320	300	17.61	annular	152	0.1053	21320	0.0065	12.7192	251.71	2.28	1.79	1.9
545	0.0320	400	23.47	annular	152	0.1053	28426	0.0061	12.7192	416.42	1.96	2.25	2.25
545	0.0320	500	29.34	annular	152	0.1053	35533	0.0058	12.7192	615.36	2.17	3	3
545	0.0320	600	35.21	annular	152	0.1053	42640	0.0055	12.7192	846.63	2.55	3.55	3.55

Table C6 continued

Solution flow rate $Q_{solution}$ (ml/min)	Sup. Solution velocity $j_{solution}$ (m/s)	Air flow rate Q_{air} (l/min)	Sup. air velocity j_{air} (m/s)	·Flow regime	Reynolds number of solution $Re_{solution}$	Fanning friction factor of solution f_F	Reynolds number of air Re_{air}	Fanning friction factor of air f_F	$(-dp/dz)_{cal}$ from theory			$(-dp/dz)_{exp}$ from experiment	
									solution only (kPa/m)	air only (kPa/m)	two phase (kPa/m)	Minimum (kPa/m)	Maximum (kPa/m)
545	0.0320	700	41.08	annular	152	0.1053	49746	0.0053	12.7192	1108.80	3.02	4.21	4.21
545	0.0320	800	46.95	mist	152	0.1053	56853	0.0051	12.7192	1400.68	3.54	5.31	5.31
705	0.0414	200	11.74	annualr	197	0.0814	14213	0.0072	16.4554	123.80	3.42	1.62	2.06
705	0.0414	300	17.61	annular	197	0.0814	21320	0.0065	16.4554	251.71	2.37	1.87	2.09
705	0.0414	400	23.47	annular	197	0.0814	28426	0.0061	16.4554	416.42	2.11	2.39	2.67
705	0.0414	500	29.34	annular	197	0.0814	35533	0.0058	16.4554	615.36	2.33	3.05	3.16
705	0.0414	600	35.21	annular	197	0.0814	42640	0.0055	16.4554	846.63	2.73	3.66	3.66
705	0.0414	700	41.08	annular	197	0.0814	49746	0.0053	16.4554	1108.80	3.22	4.4	4.4
705	0.0414	800	46.95	mist	197	0.0814	56853	0.0051	16.4554	1400.68	3.76	5.36	5.36
1102	0.0647	200	11.74	annualr	307	0.0521	14213	0.0072	25.7165	123.80	3.51	1.92	2.47
1102	0.0647	300	17.61	annular	307	0.0521	21320	0.0065	25.7165	251.71	2.57	2.42	2.69
1102	0.0647	400	23.47	annular	307	0.0521	28426	0.0061	25.7165	416.42	2.41	3.02	3.24
1102	0.0647	500	29.34	annular	307	0.0521	35533	0.0058	25.7165	615.36	2.67	3.57	3.79
1102	0.0647	600	35.21	annular	307	0.0521	42640	0.0055	25.7165	846.63	3.1	4.4	4.45
1102	0.0647	700	41.08	annular	307	0.0521	49746	0.0053	25.7165	1108.80	3.62	5.22	5.22
1102	0.0647	800	46.95	mist	307	0.0521	56853	0.0051	25.7165	1400.68	4.2	6.41	6.41
1560	0.0915	200	11.74	annualr	435	0.0368	14213	0.0072	36.3688	123.80	3.6	2.47	3.02
1560	0.0915	300	17.61	annular	435	0.0368	21320	0.0065	36.3688	251.71	2.77	3.02	3.44

Table C6 continued

Solution flow rate $Q_{solution}$ (ml/min)	Sup. Solution velocity $j_{solution}$ (m/s)	Air flow rate Q_{air} (l/min)	Sup. air velocity j_{air} (m/s)	Flow regime	Reynolds number of solution $Re_{solution}$	Fanning friction factor of solution f_F	Reynolds number of air Re_{air}	Fanning friction factor of air f_F	$(-dp/dz)_{cal}$ from theory			$(-dp/dz)_{exp}$ from experiment	
									solution only (kPa/m)	air only (kPa/m)	two phase (kPa/m)	Minimum (kPa/m)	Maximum (kPa/m)
1560	0.0915	400	23.47	annular	435	0.0368	28426	0.0061	36.3688	416.42	2.68	3.85	4.23
1560	0.0915	500	29.34	annular	435	0.0368	35533	0.0058	36.3688	615.36	2.98	4.43	4.7
1560	0.0915	600	35.21	annular	435	0.0368	42640	0.0055	36.3688	846.63	3.44	5.03	5.28
1560	0.0915	700	41.08	annular	435	0.0368	49746	0.0053	36.3688	1108.80	4	5.83	5.97
1560	0.0915	800	46.95	mist	435	0.0368	56853	0.0051	36.3688	1400.68	4.61	6.93	6.93
1794	0.1053	200	11.74	annualr	500	0.0320	14213	0.0072	41.8540	123.80	3.65	2.75	3.02
1794	0.1053	300	17.61	annular	500	0.0320	21320	0.0065	41.8540	251.71	2.86	3.44	3.66
1794	0.1053	400	23.47	annular	500	0.0320	28426	0.0061	41.8540	416.42	2.8	4.32	4.48
1794	0.1053	500	29.34	annular	500	0.0320	35533	0.0058	41.8540	615.36	3.11	5.06	5.2
1794	0.1053	600	35.21	annular	500	0.0320	42640	0.0055	41.8540,	846.63	3.6	5.44	5.61
1794	0.1053	700	41.08	annular	500	0.0320	49746	0.0053	41.8540	1108.80	4.17	5.88	6.1
1794	0.1053	800	46.95	mist	500	0.0320	56853	0.0051	41.8540	1400.68	4.8	6.93	6.93

Note; Superficial solution velocity, $j_{solution} = \frac{Q_{solution}}{A}$; Superficial air velocity, $j_{air} = \frac{Q_{air}}{A}$

Pressure gradient for solution, $\left(-\frac{dp}{dz}\right)_{solution\ only} = \frac{2 f_F \rho_{solution} j^2_{solution}}{D}$; Pressure gradient for air, $\left(-\frac{dp}{dz}\right)_{air\ only} = \frac{2 f_F \rho_{air} j^2_{air}}{D}$

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

Martinelli parameter, X, void fraction of air, ε, and gas two-phase flow multiplier, ϕ_g^2, can be calculated by using the following equations:

$$\left(1+X^{2/3.61}\right)^{3.61}\left((dp/dz)_{go} - \frac{(dp/dz)_{lo}}{X^2}\right) = 10985.4\left(1-\frac{1}{\left(\left(1+0.0904X^{0.548}\right)^{2.82}\right)}\right)$$

$$\varepsilon = \frac{1}{\left(1+0.0904\,X^{0.548}\right)^{2.82}}$$

$$\phi_g = \left(1+X^{2/n}\right)^{n/2}$$

Table C6 (continued) Calculation of two-phase pressure gradient by using X, Φ_g^2, and pressure gradient of air in annular and mist flow regimes

Solution flow rate $Q_{solution}$ (ml/min)	Air flow rate Q_{air} (l/min)	Martinelli parameter X	Void fraction ε	Gas two-phase flow multiplier Φ_g	Φ_g^2	Pressure gradient for two-phase flow $(-dp/dz)_{tp}$ (kPa/m)
358	200	2.05	0.7012	5.19	26.94	3.35
358	300	0.6821	0.8192	2.92	8.50	2.15
358	400	0.2708	0.8852	2.04	4.17	1.75
358	500	0.1669	0.9103	1.77	3.12	1.93
358	600	0.1253	0.9226	1.64	2.70	2.30
358	700	0.1023	0.9304	1.57	2.46	2.74
358	800	0.0873	0.9359	1.52	2.30	3.23
545	200	2.0762	0.6999	5.22	27.28	3.39
545	300	0.7262	0.8137	3.00	8.99	2.28
545	400	0.3219	0.8748	2.16	4.68	1.96
545	500	0.2048	0.9004	1.87	3.51	2.17
545	600	0.1548	0.9137	1.73	3.00	2.55
545	700	0.1266	0.9222	1.65	2.71	3.02
545	800	0.1081	0.9284	1.59	2.52	3.54
705	200	2.0942	0.6988	5.25	27.57	3.42
705	300	0.7593	0.8097	3.06	9.37	2.37
705	400	0.3571	0.8682	2.25	5.04	2.11
705	500	0.2317	0.8939	1.94	3.77	2.33
705	600	0.176	0.9078	1.79	3.21	2.73
705	700	0.1441	0.9168	1.70	2.89	3.22
705	800	0.1231	0.9233	1.64	2.67	3.76
1102	200	2.1371	0.6961	5.31	28.25	3.51
1102	300	0.8288	0.8016	3.19	10.17	2.57
1102	400	0.4263	0.8561	2.40	5.75	2.41
1102	500	0.2856	0.3821	2.08	4.32	2.67
1102	600	0.2191	0.8969	1.91	3.65	3.10
1102	700	0.18	0.9067	1.80	3.26	3.62
1102	800	0.154	0.9139	1.73	2.99	4.20
1560	200	2.184	0.6933	5.39	29.00	3.60
1560	300	0.8953	0.7943	3.31	10.95	2.77
1560	400	0.4886	0.8461	2.53	6.40	2.68
1560	500	0.335	0.8723	2.19	4.82	2.98
1560	600	0.259	0.8878	2.01	4.05	3.44
1560	700	0.2135	0.8982	1.90	3.59	4.00
1560	800	0.183	0.9060	1.81	3.29	4.61

Table C6 continued

Solution flow rate $Q_{solution}$ (ml/min)	Air flow rate Q_{air} (l/min)	Martinelli parameter X	Void fraction ε	Gas two-phase flow multiplier		Pressure gradient for two-phase flow $(-dp/dz)_{tp}$ (kPa/m)
				Φ_g	Φ_g^2	
1794	200	2.2072	0.6919	5.42	29.37	3.65
1794	300	0.9257	0.7911	3.36	11.31	2.86
1794	400	0.5163	0.8419	2.59	6.70	2.80
1794	500	0.3572	0.8681	2.25	5.04	3.11
1794	600	0.2771	0.8839	2.06	4.23	3.60
1794	700	0.2288	0.8946	1.94	3.75	4.17
1794	800	0.1962	0.9025	1.85	3.42	4.80

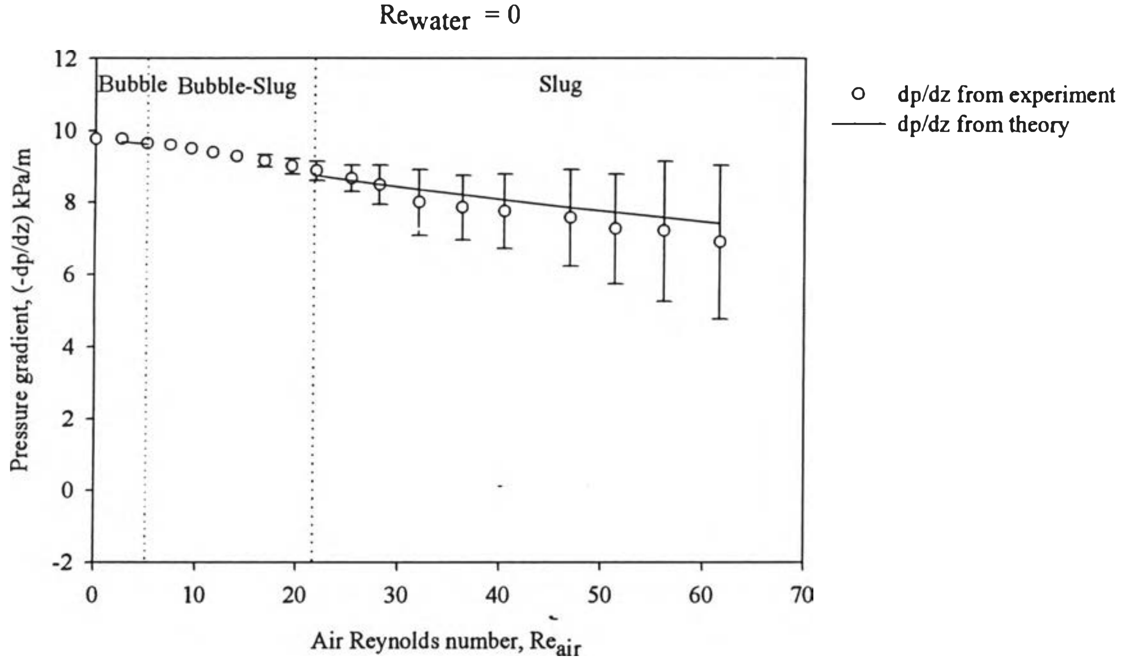


Figure C1 Comparison between theory and experimental pressure gradient vs. air Reynolds number of air-pure water mixture.

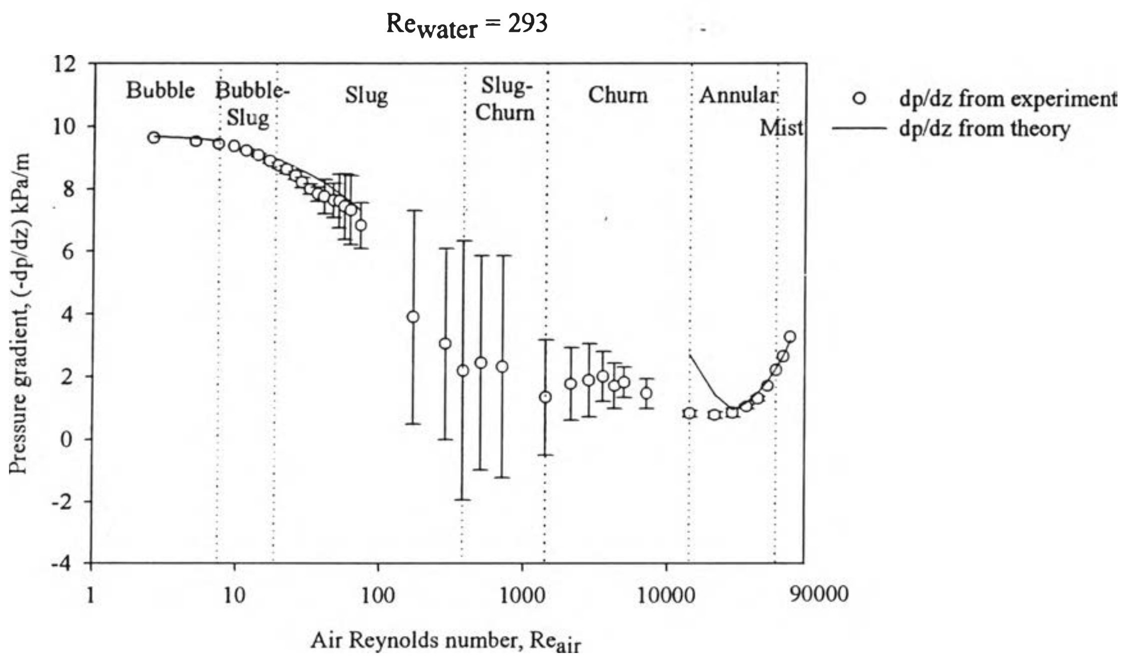


Figure C2 Comparison between theory and experimental pressure gradient vs. air Reynolds number of air-pure water mixture.

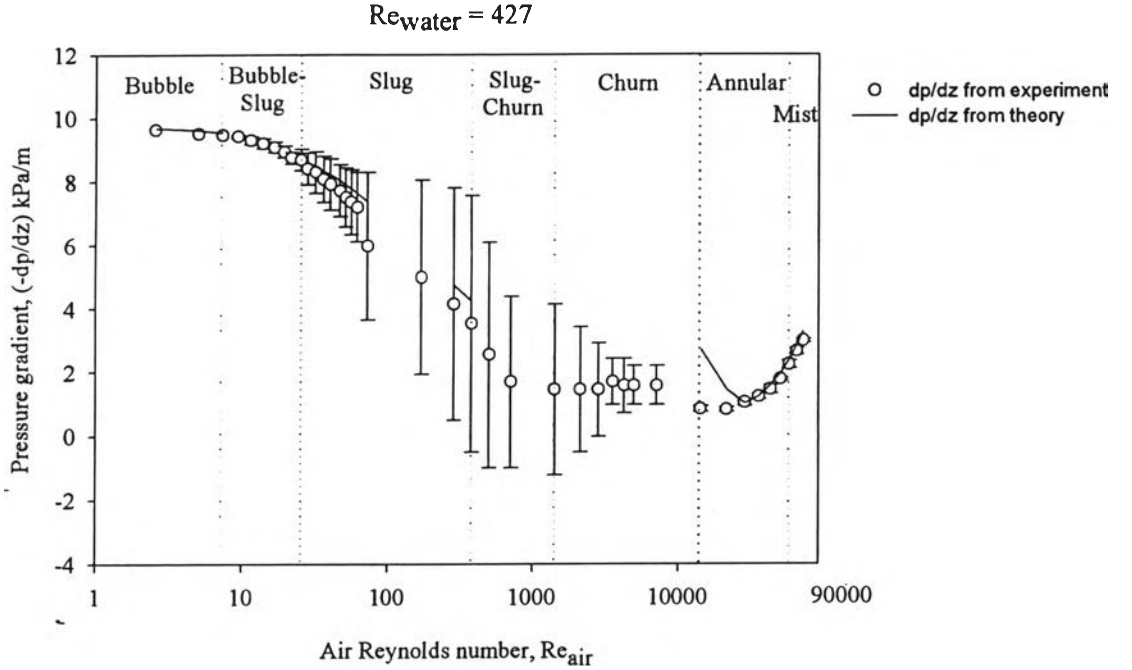


Figure C3 Comparison between theory and experimental pressure gradient vs. air Reynolds number of air-pure water mixture.

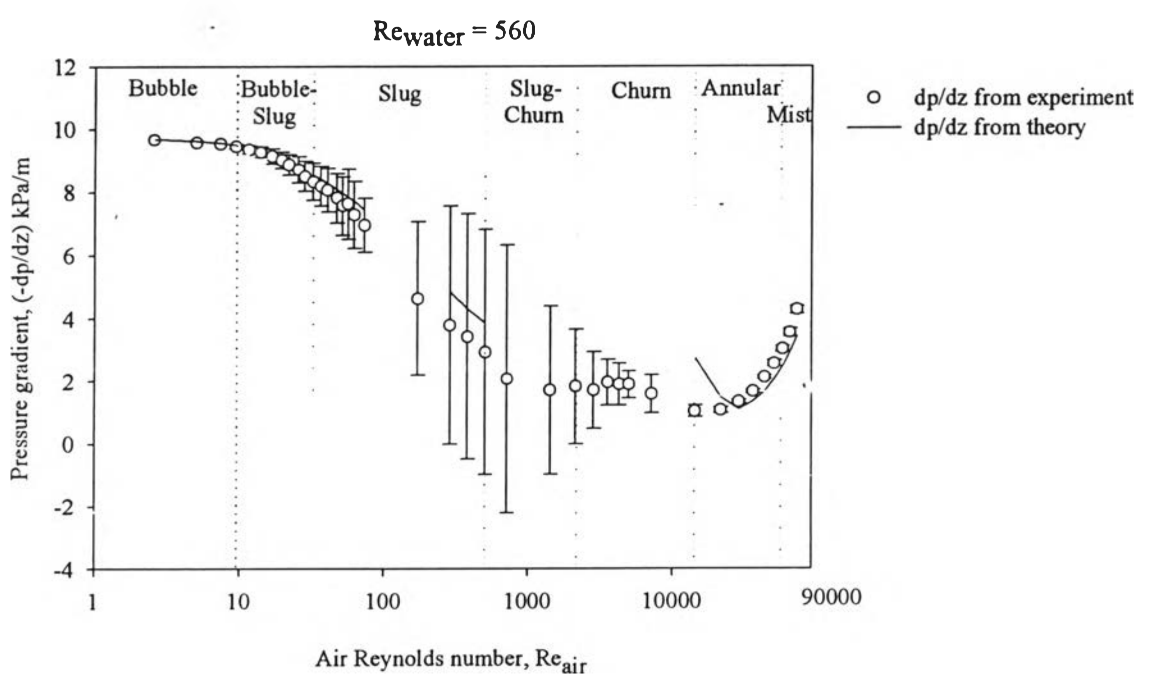


Figure C4 Comparison between theory and experimental pressure gradient vs. air Reynolds number of air-pure water mixture.

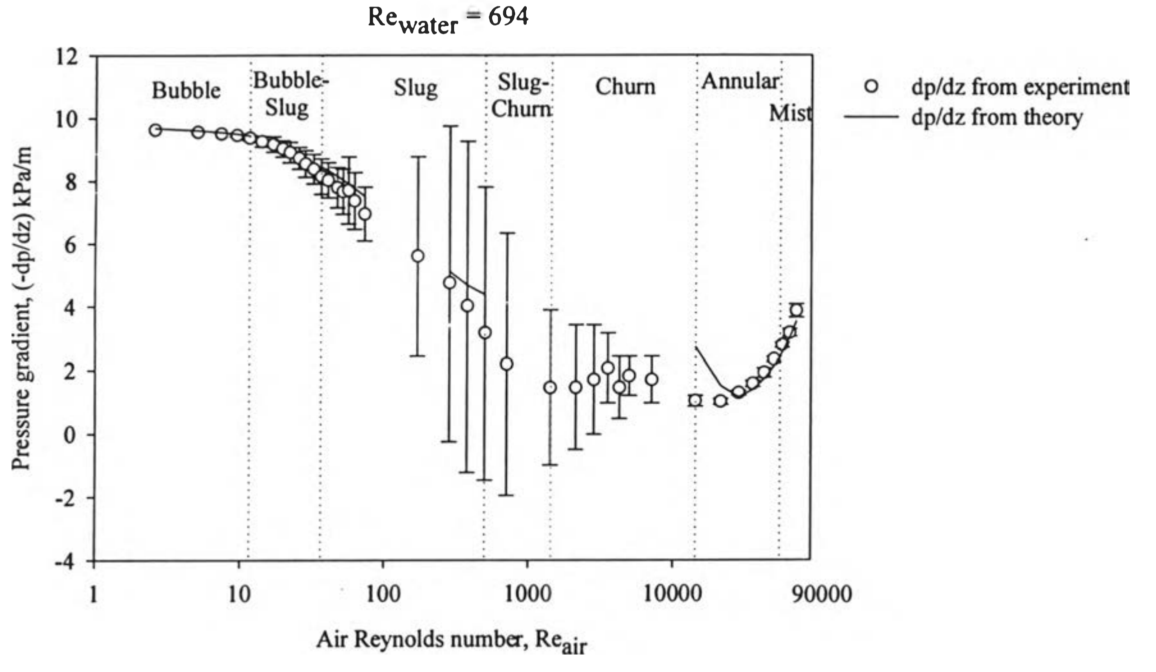


Figure C5 Comparison between theory and experimental pressure gradient vs. air Reynolds number of air-pure water mixture.

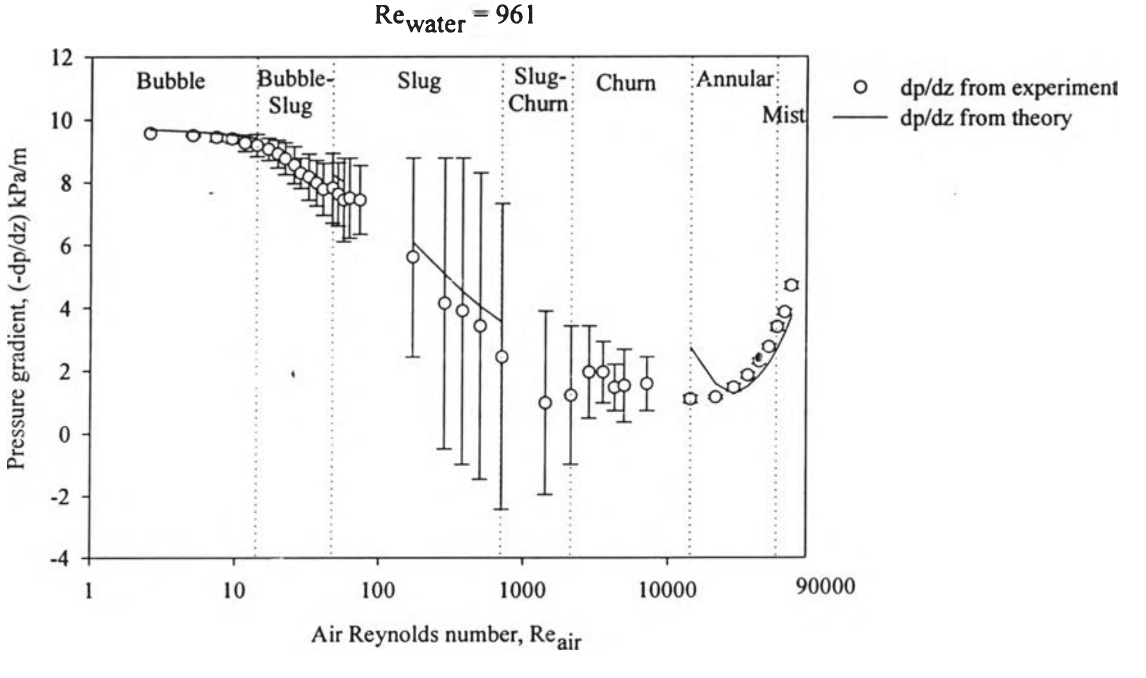


Figure C6 Comparison between theory and experimental pressure gradient vs. air Reynolds number of air-pure water mixture.

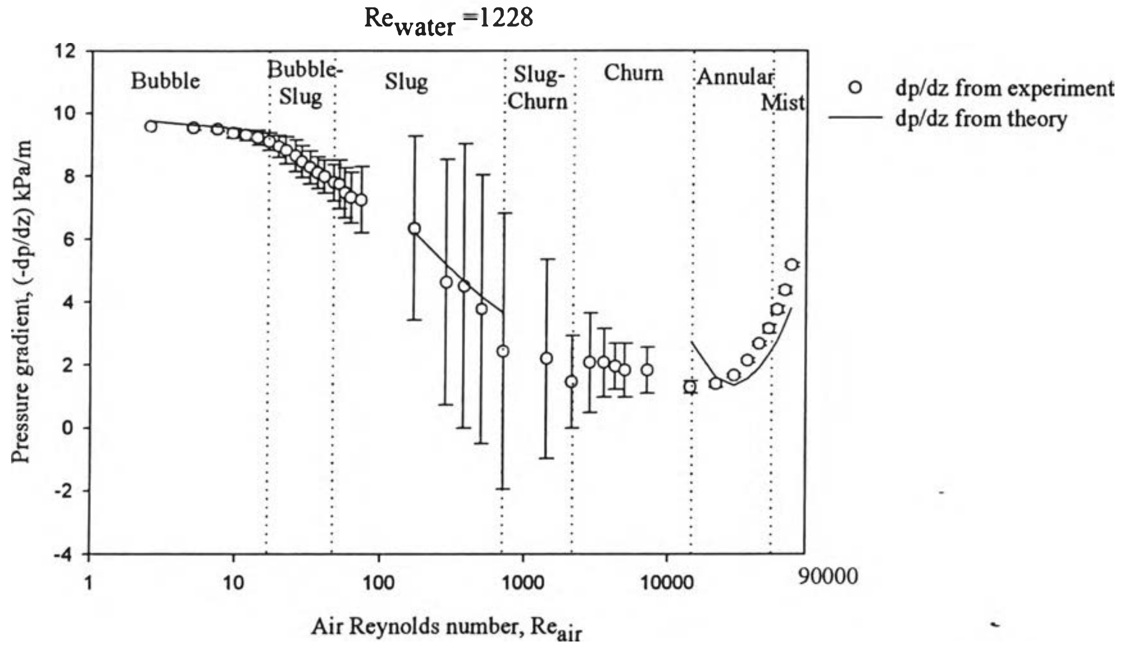


Figure C7 Comparison between theory and experimental pressure gradient vs. air Reynolds number of air-pure water mixture.

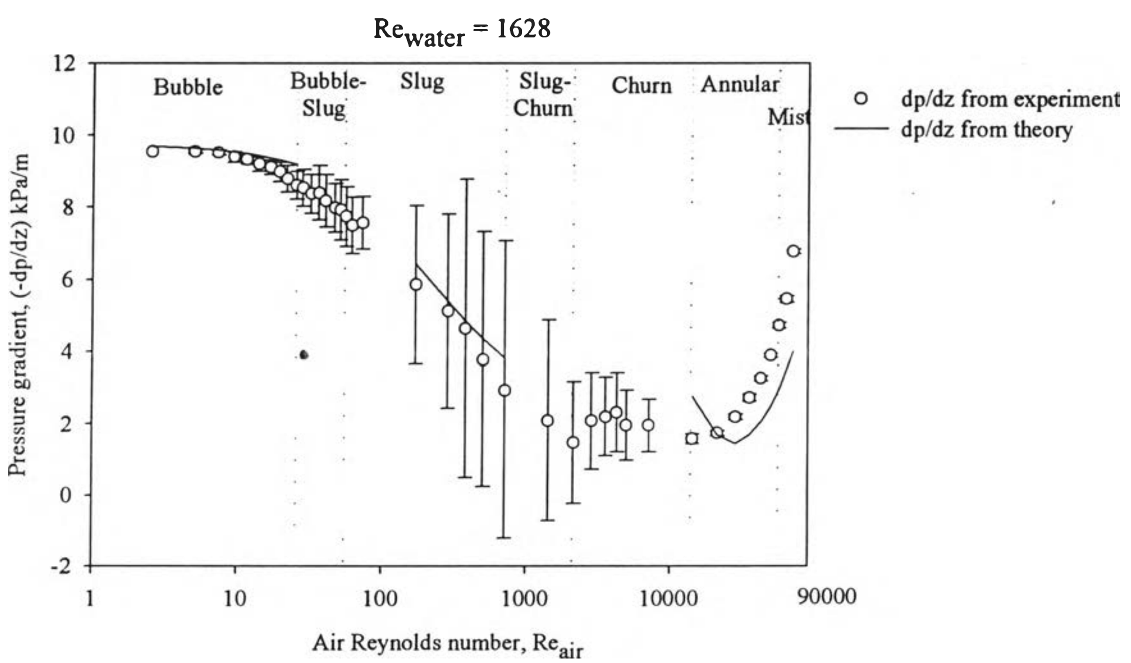


Figure C8 Comparison between theory and experimental pressure gradient vs. air Reynolds number of air-pure water mixture.

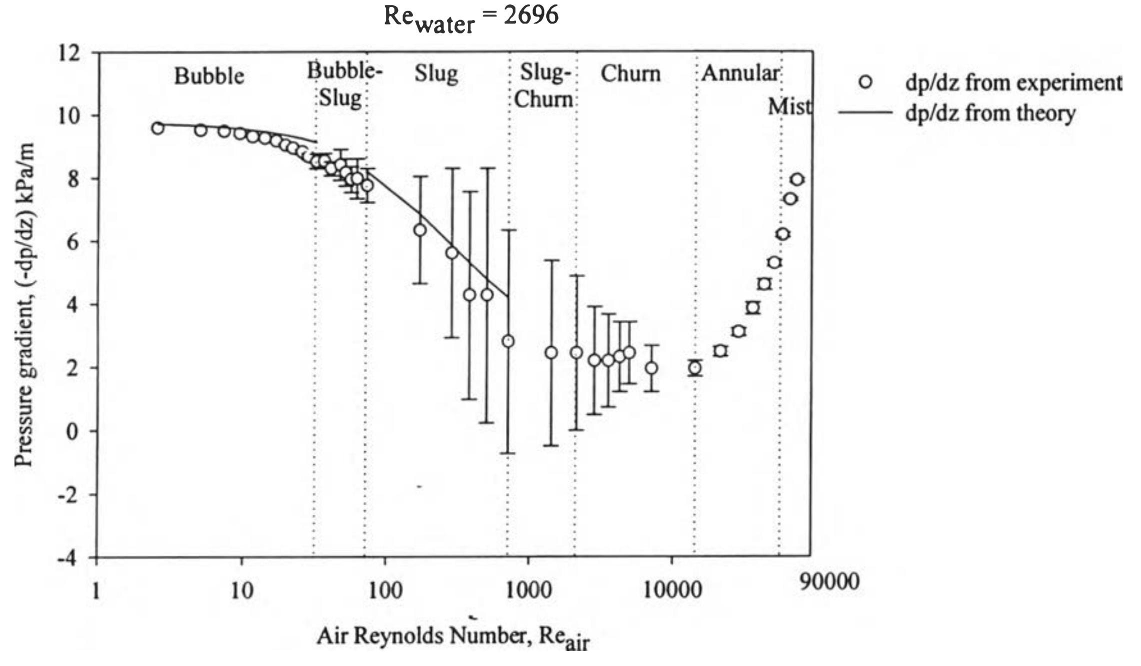


Figure C9 Comparison between theory and experimental pressure gradient vs. air Reynolds number of air-pure water mixture.

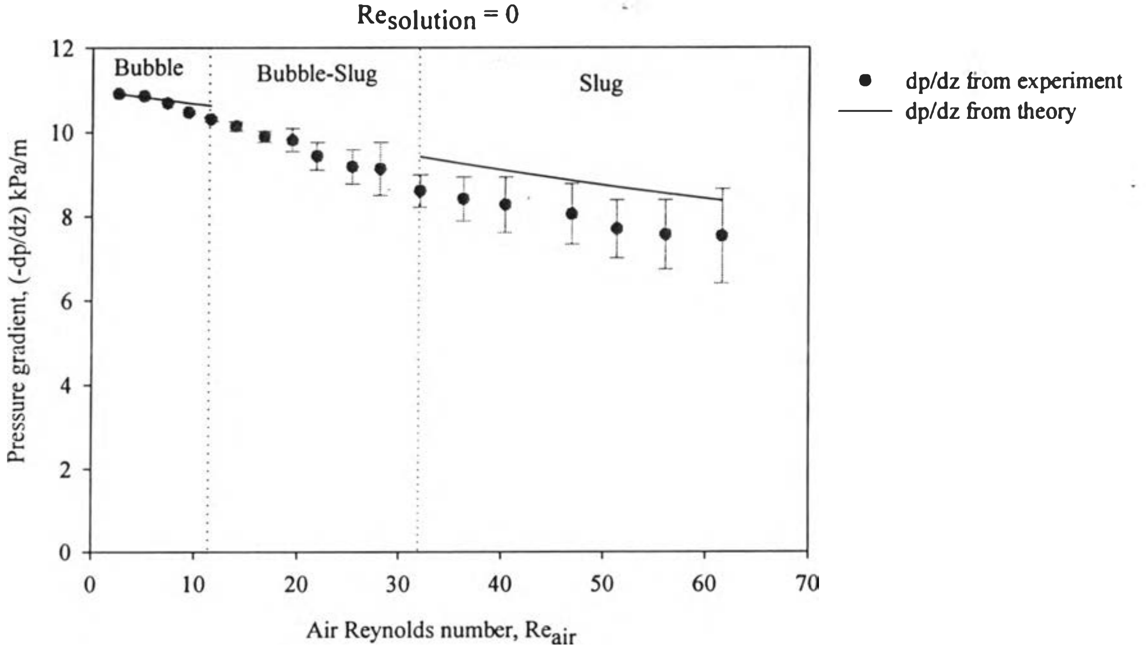


Figure C10 Comparison between theory and experimental pressure gradient vs. air Reynolds number of air-50 vol% glycerol solution mixture.

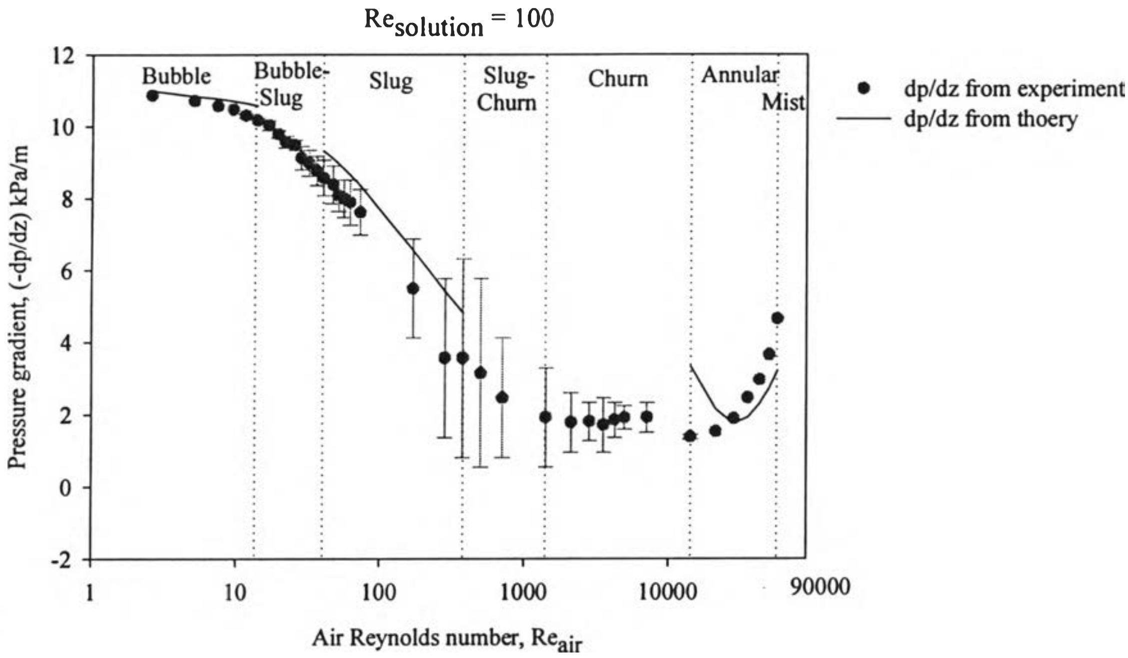


Figure C11 Comparison between theory and experimental pressure gradient vs. air Reynolds number of air-50 vol% glycerol solution mixture.

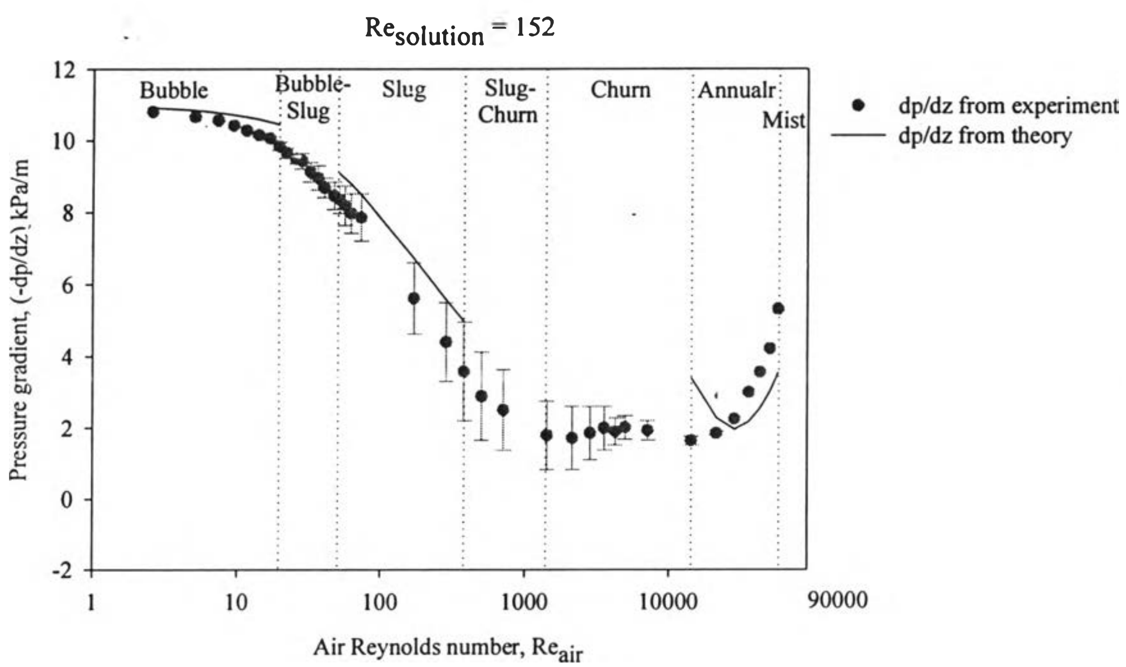


Figure C12 Comparison between theory and experimental pressure gradient vs. air Reynolds number of air-50 vol% glycerol solution mixture.

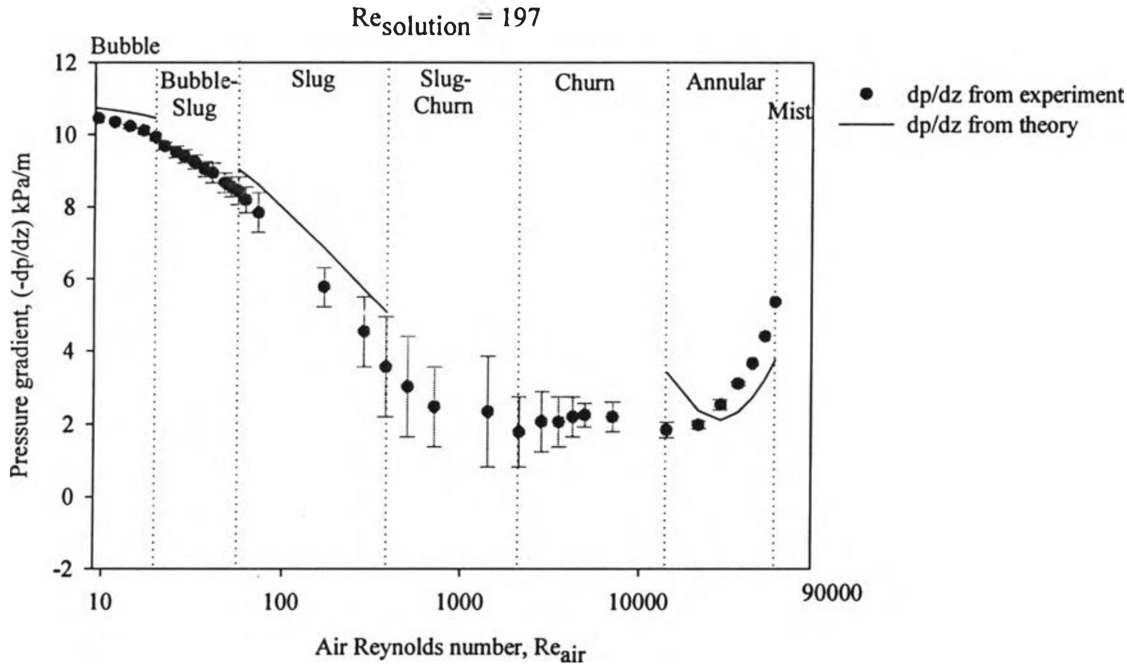


Figure C13 Comparison between theory and experimental pressure gradient vs. air Reynolds number of air-50 vol% glycerol solution mixture.

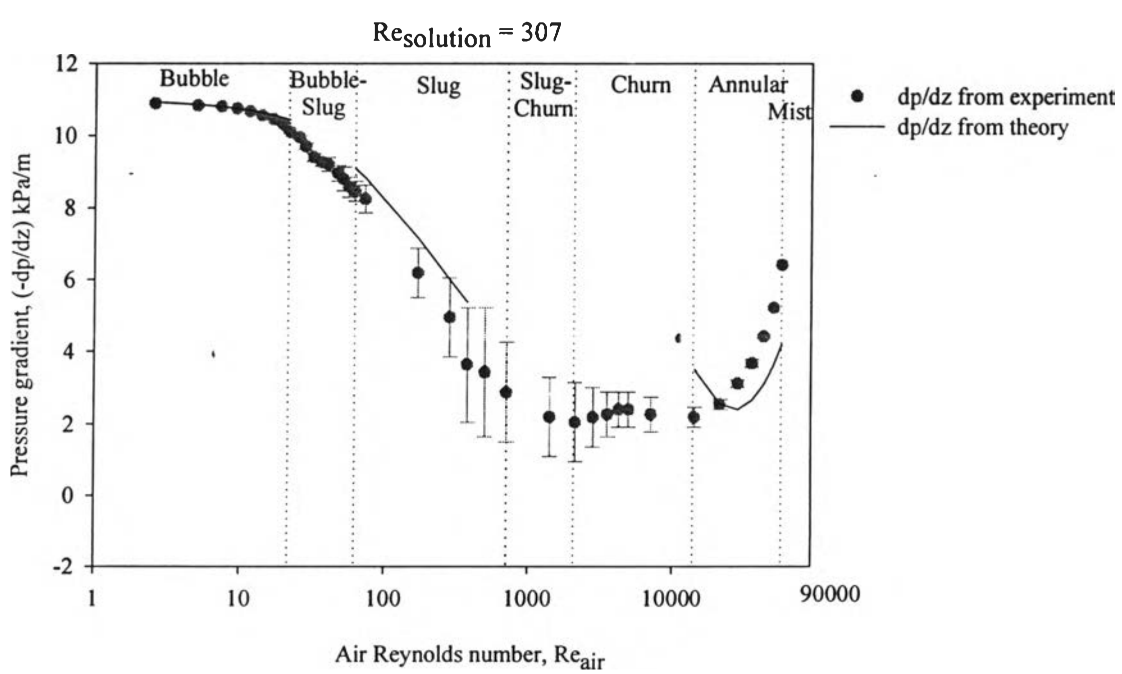


Figure C14 Comparison between theory and experimental pressure gradient vs. air Reynolds number of air-50 vol% glycerol solution mixture.

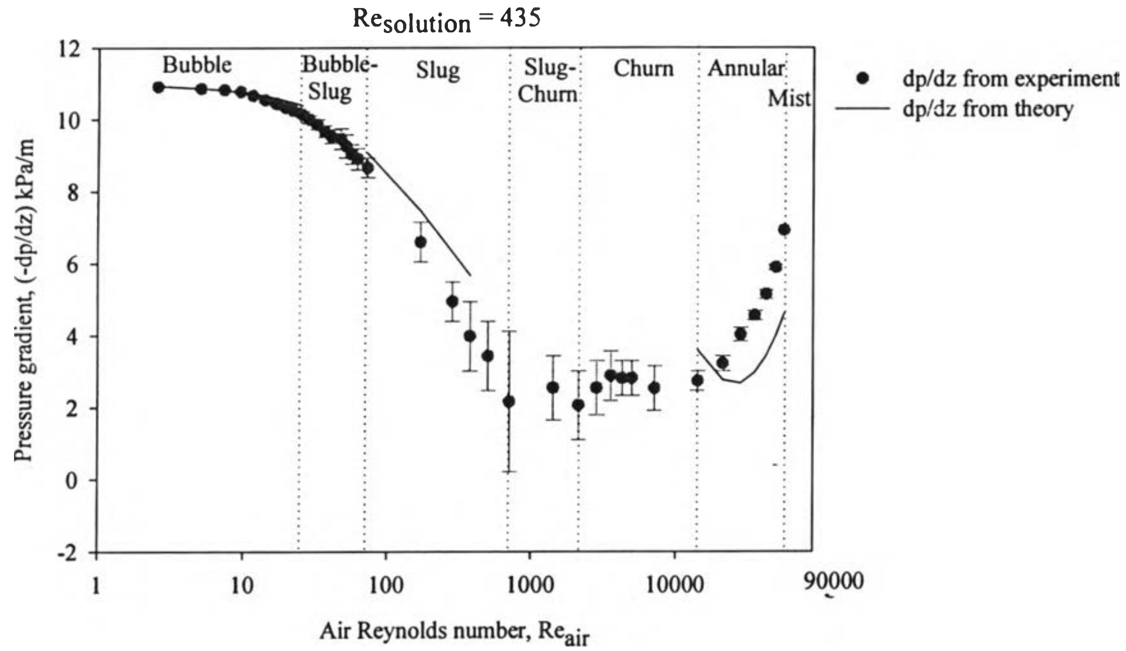


Figure C15 Comparison between theory and experimental pressure gradient vs. air Reynolds number of air-50 vol% glycerol solution mixture.

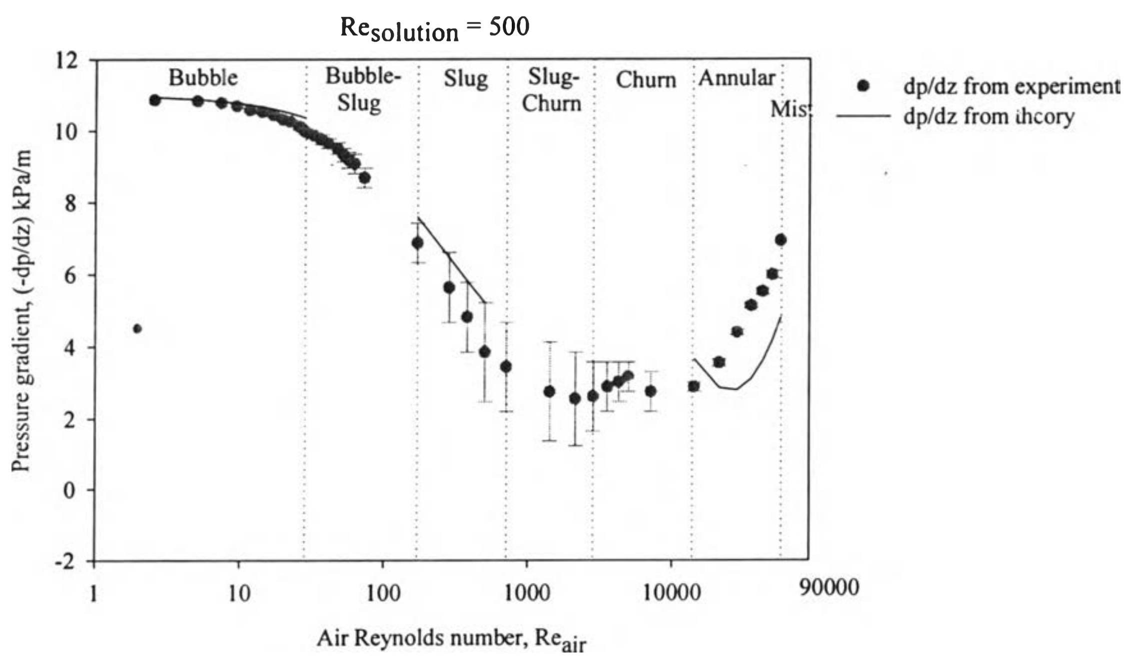
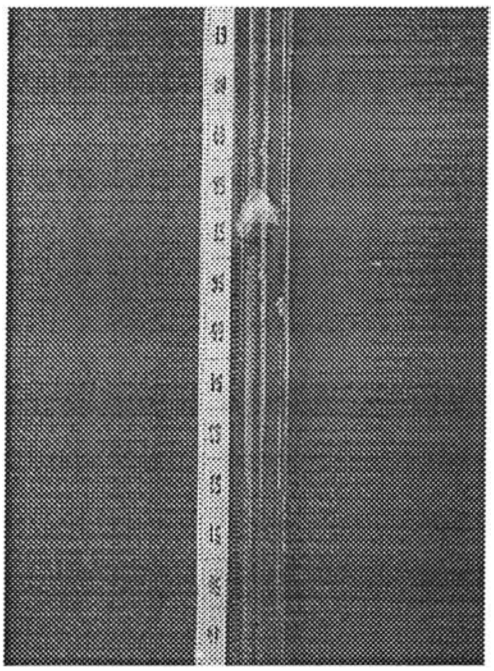


Figure C16 Comparison between theory and experimental pressure gradient vs. air Reynolds number of air-50 vol% glycerol solution mixture.

Appendix D

Photos of Different Flow Regimes



Water flow rate, Q_{water} = 224 ml/min

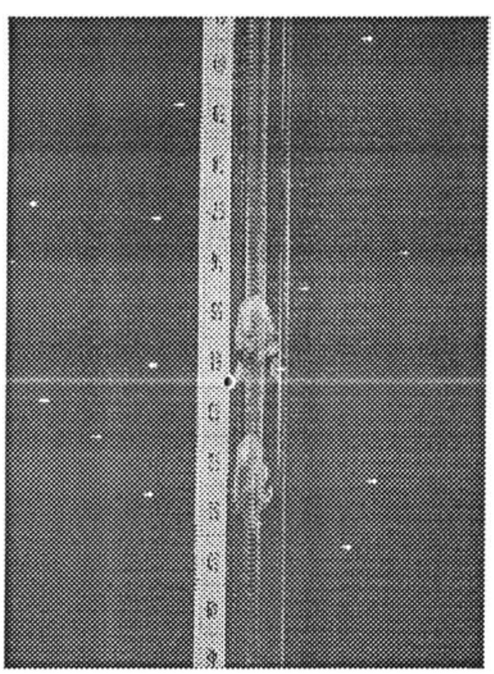
Superficial water velocity, j_{water} = 0.0131 m/s

Air flow rate, Q_{air} = 0.071 l/min

Superficial air velocity, j_{air} = 0.0042 m/s

Flow regime: Bubble

Figure D1 Bubble flow regime for air-water mixture.



Water flow rate, Q_{water} = 224 ml/min

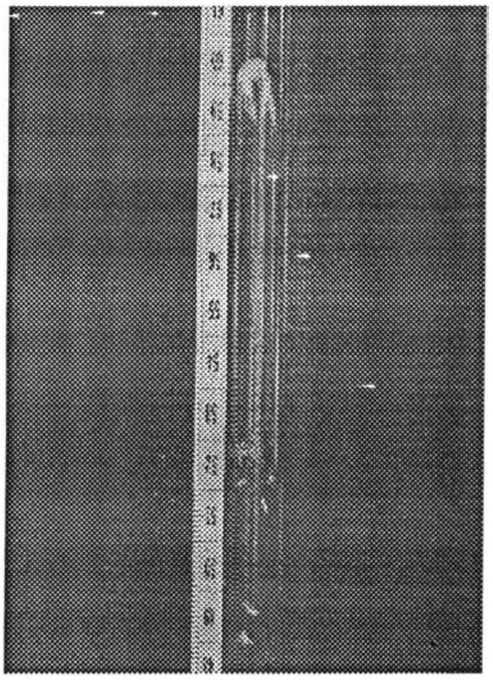
Superficial water velocity, j_{water} = 0.0131 m/s

Air flow rate, Q_{air} = 0.196 l/min

Superficial air velocity, j_{air} = 0.0115 m/s

Flow regime: Bubble-Slug

Figure D2 Bubble-Slug flow regime for air-water mixture.



Water flow rate, Q_{water} = 224 ml/min

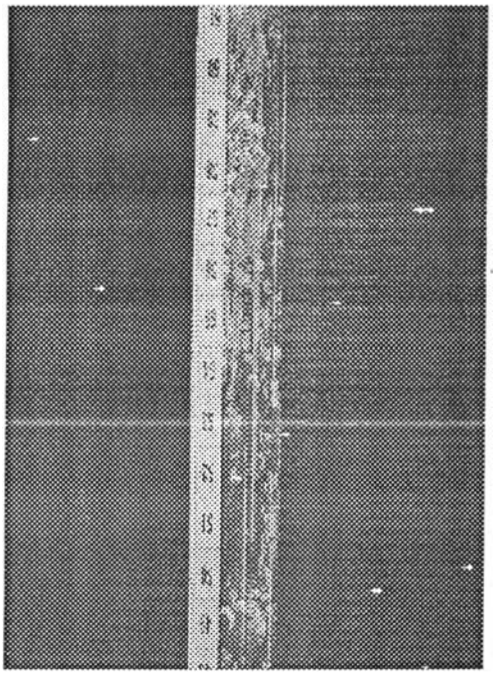
Superficial water velocity, j_{water} = 0.0131 m/s

Air flow rate, Q_{air} = 0.395 l/min

Superficial air velocity, j_{air} = 0.0232 m/s

Flow regime: Slug

Figure D3 Slug flow regime for air-water mixture.



Water flow rate, Q_{water} = 224 ml/min

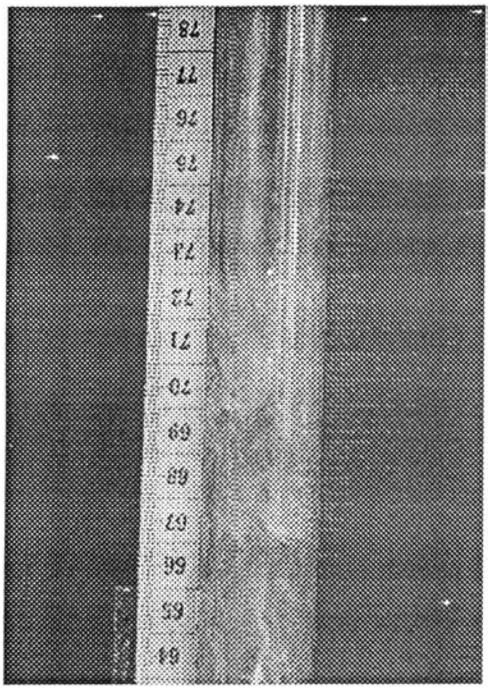
Superficial water velocity, j_{water} = 0.0131 m/s

Air flow rate, Q_{air} = 5.326 l/min

Superficial air velocity, j_{air} = 0.3126 m/s

Flow regime: Slug-Churn

Figure D4 Slug-Churn flow regime for air-water mixture.



Water flow rate, Q_{water} = 224 ml/min

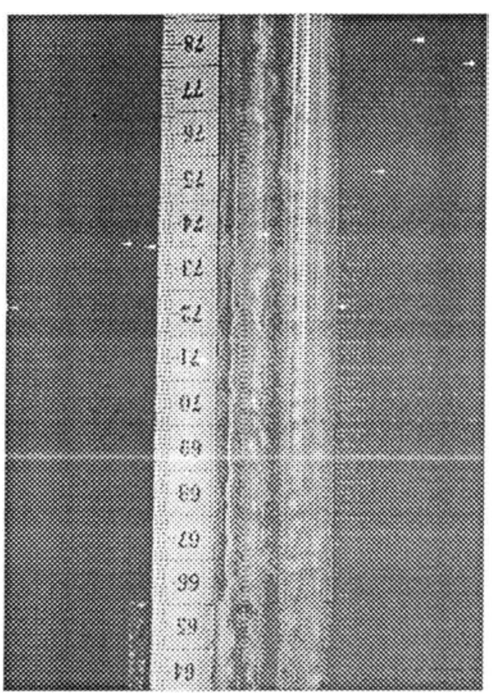
Superficial water velocity, j_{water} = 0.0131 m/s

Air flow rate, Q_{air} = 50 l/min

Superficial air velocity, j_{air} = 2.93 m/s

Flow regime: Churn

Figure D5 Churn flow regime for air-water mixture.



Water flow rate, Q_{water} = 224 ml/min

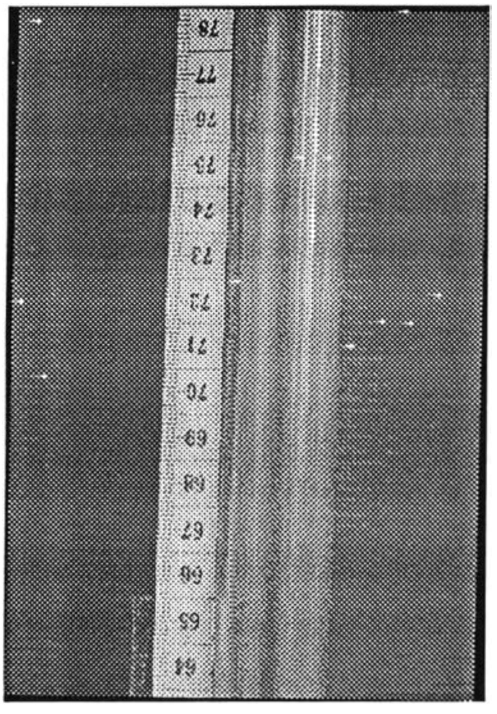
Superficial water velocity, j_{water} = 0.0131 m/s

Air flow rate, Q_{air} = 300 l/min

Superficial air velocity, j_{air} = 17.61 m/s

Flow regime: Annular

Figure D6 Annular flow regime for air-water mixture.



Water flow rate, Q_{water} = 224 ml/min

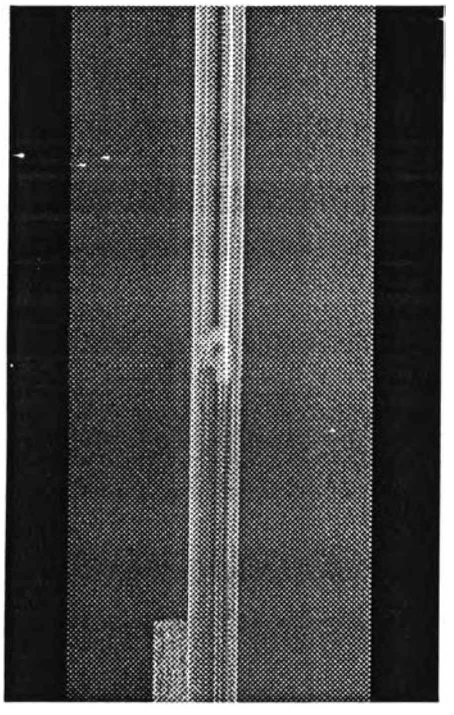
Superficial water velocity, j_{water} = 0.0131 m/s

Air flow rate, Q_{air} = 800 l/min

Superficial air velocity, j_{air} = 46.95 m/s

Flow regime: Mist

Figure D7 Mist flow regime for air-water mixture.



Solution flow rate, $Q_{solution}$ = 1794 ml/min

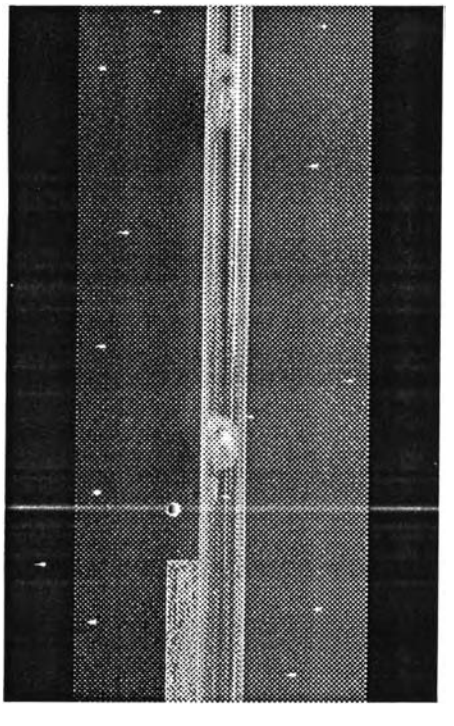
Superficial solution velocity, $j_{solution}$ = 0.1053 m/s

Air flow rate, Q_{air} = 0.196 l/min

Sueprficial air velocity, j_{air} = 0.0115 m/s

Flow regime: Bubble

Figure D8 Bubble flow regime for air-50 vol% glycerol solution mixture.



Solution flow rate, $Q_{solution}$ = 1794 ml/min

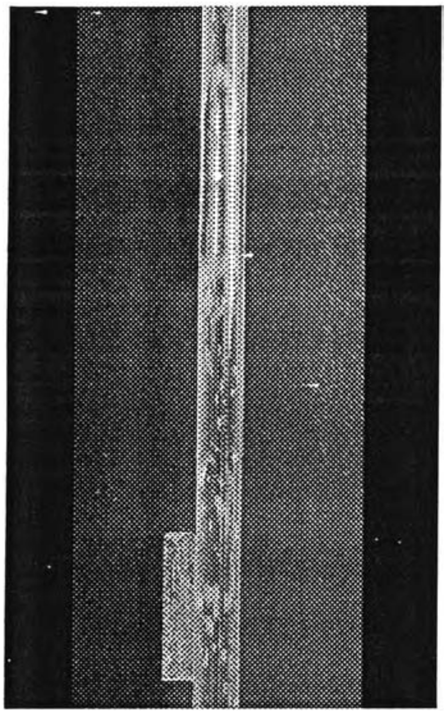
Superficial solution velocity, $j_{solution}$ = 0.1053 m/s

Air flow rate, Q_{air} = 0.450 l/min

Sueprficial air velocity, j_{air} = 0.0264 m/s

Flow regime: Bubble-Slug

Figure D9 Bubble-Slug flow regime for air-50 vol% glycerol solution mixture.



Solution flow rate, $Q_{solution}$ = 1794 ml/min

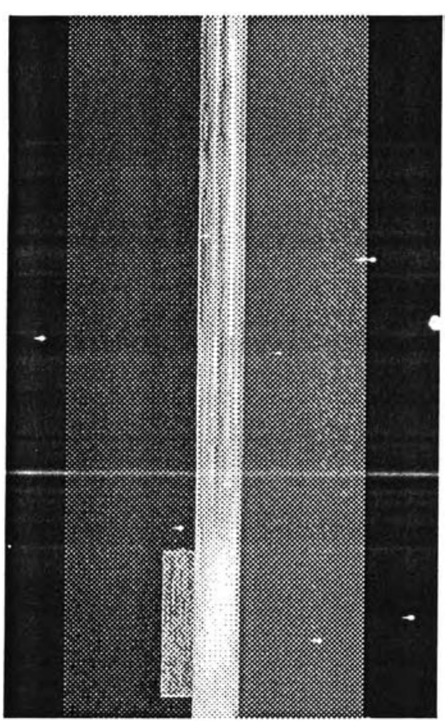
Superficial solution velocity, $j_{solution}$ = 0.1053 m/s

Air flow rate, Q_{air} = 2.394 l/min

Sueprficial air velocity, j_{air} = 0.141 m/s

Flow regime: Slug

Figure D10 Slug flow regime for air-50 vol% glycerol solution mixture.



Solution flow rate, $Q_{solution}$ = 1794 ml/min

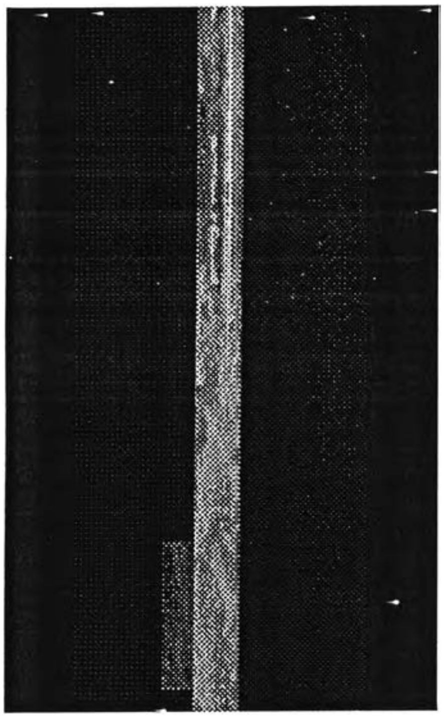
Superficial solution velocity, $j_{solution}$ = 0.1053 m/s

Air flow rate, Q_{air}= 10 l/min

Superficial air velocity, j_{air}= 0.587 m/s

Flow regime: Slug-Churn

Figure D11 Slug-Churn flow regime for air-50 vol% glycerol solution mixture.



Solution flow rate, $Q_{solution}$ = 1794 ml/min

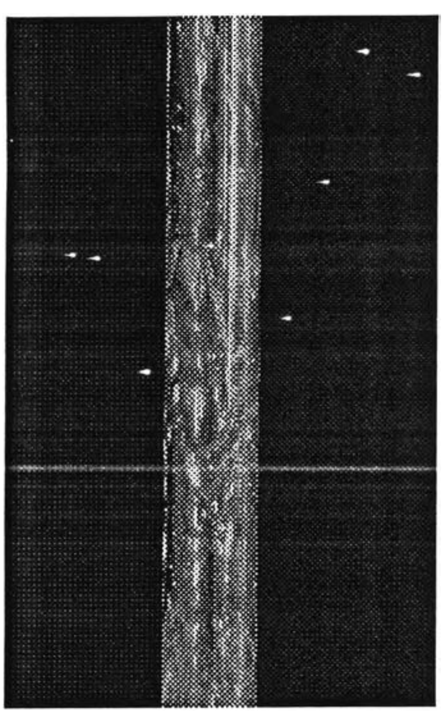
Superficial solution velocity, $j_{solution}$ = 0.1053 m/s

Air flow rate, Q_{air} = 40 l/min

Sueprficial air velocity, j_{air} = 2.35 m/s

Flow regime: Churn

Figure D12 Churn flow regime for air-50 vol% glycerol solution mixture.



Solution flow rate, $Q_{solution}$ = 1794 ml/min

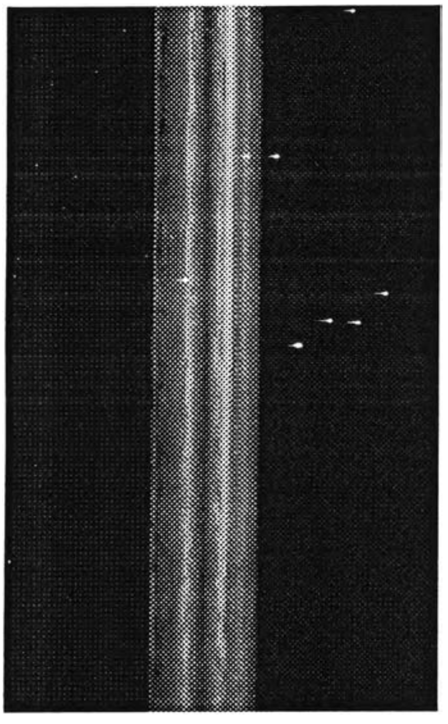
Superficial solution velocity, $j_{solution}$ = 0.1053 m/s

Air flow rate, Q_{air} = 400 l/min

Sueprficial air velocity, j_{air} = 23.47 m/s

Flow regime: Annular

Figure D13 Annular flow regime for air-5o vol% glycerol solution mixture.



Solution flow rate, $Q_{solution}$ = 1794 ml/min

Superficial solution velocity, $j_{solution}$ = 0.1053 m/s

Air flow rate, Q_{air} = 800 l/min

Sueprficial air velocity, j_{air} = 46.95 m/s

Flow regime: Mist

Figure D14 Mist flow regime for air-50 vol% glycerol solution mixture.

Appendix E

Experimental setup

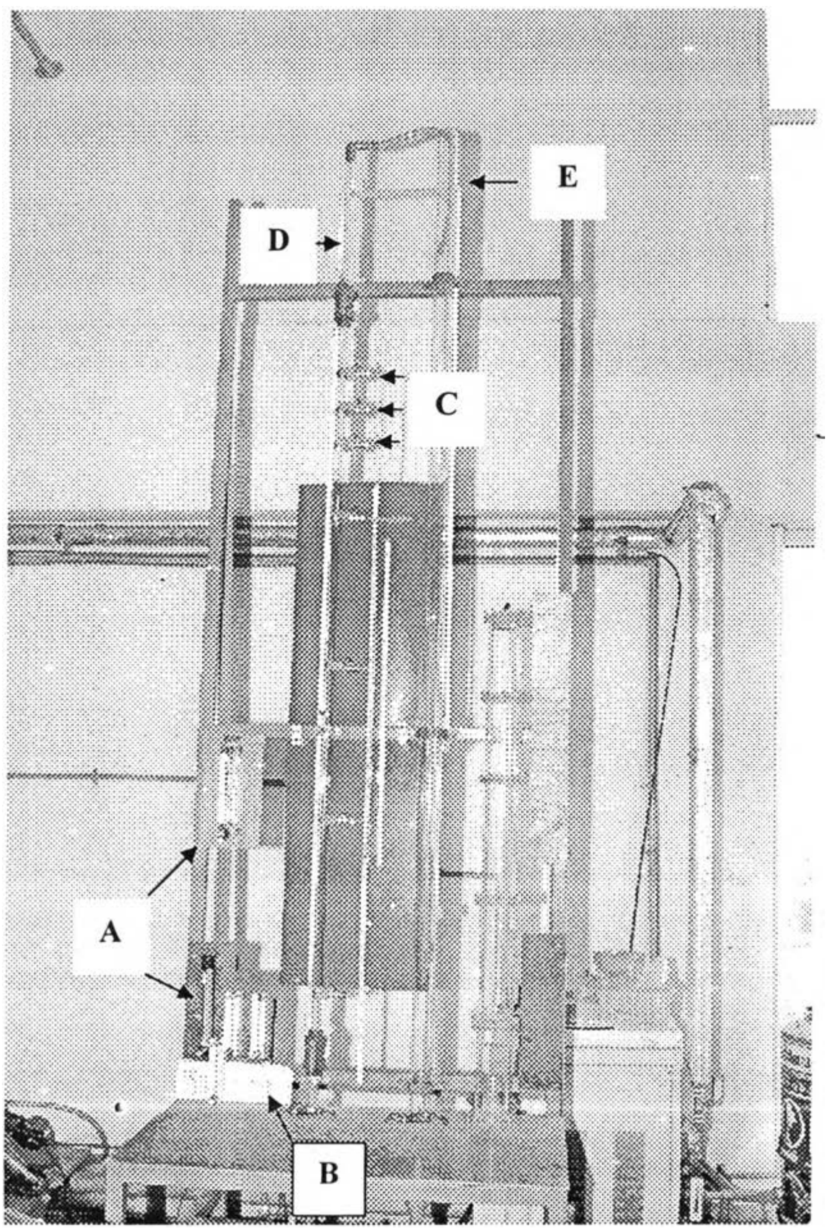


Figure E1 Experimental setup: A = air rotameter, B = water rotameter, C = pressure taps to measure the pressure gradient, D = two-phase flow testing pipe with diameter of 0.019-m, E = over flow pipe with the diameter of 0.054-m.

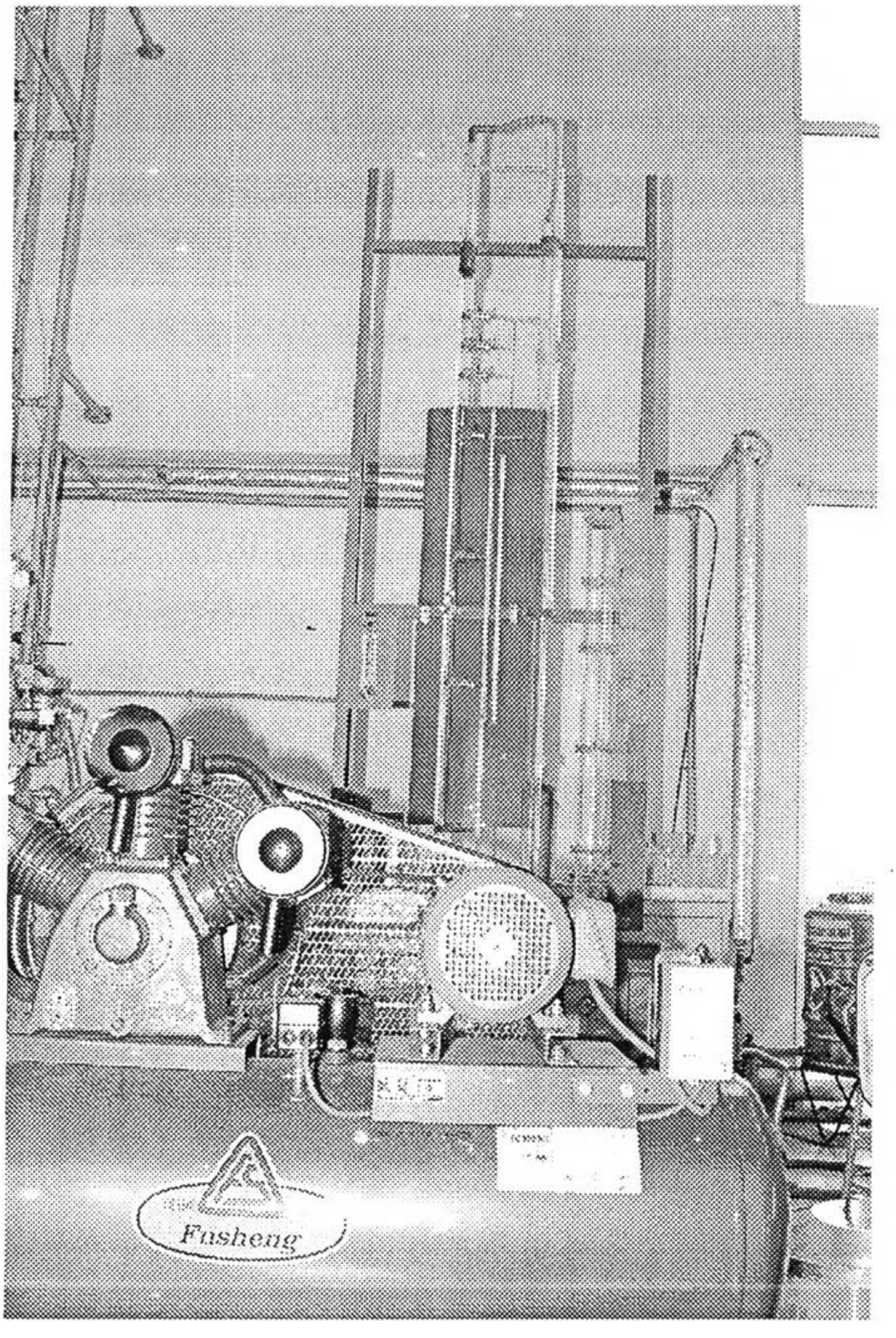


Figure E2 Air compressor used in annular and annular-mist flow regimes.

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