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APPENDICES

Appendix A Two-Phase Flow

Table A1 Determination of flow regimes

Water velocity (cm/s)	Air flow rate (ml/min)			Air velocity (cm/s)			Predicted transition air flow rate (ml/min)	Predicted transition air velocity (cm/s)
	B	B-S	S	B	B-S	S		
0.00	50			0.29			285.89	1.68
0.00	100			0.59				
0.00		150			0.88			
0.00		200			1.17			
0.00		300			1.76			
0.00		400			2.35			
0.00			450			2.64		
1.17	50			0.29			308.11	1.81
1.17	100			0.59				
1.17		200			1.17			
1.17		300			1.76			
1.17		400			2.35			
1.17			450			2.64		
1.76	50			0.29			319.22	1.87
1.76	100			0.59				
1.76	150			0.88				
1.76		200			1.17			
1.76		300			1.76			
1.76		400			2.35			
1.76			500			2.93		
2.35	50			0.29			330.33	1.94
2.35	100			0.59				
2.35		200			1.17			
2.35		300			1.76			
2.35		400			2.35			
2.35		500			2.93			
2.35			550			3.23		
2.93	100			0.59			341.49	2.00
2.93		150			0.88			
2.93		200			1.17			
2.93		300			1.76			
2.93		400			2.35			
2.93								

Water velocity (cm/s)	Air flow rate (ml/min)			Air velocity (cm/s)			Predicted transition air flow rate (ml/min)	Predicted transition air velocity (cm/s)
	B	B-S	S	B	B-S	S		
2.93		500			2.93			
2.93			550		0.00	3.23		
3.52	100			0.59	0.00		352.56	2.07
3.52		200			1.17			
3.52		300			1.76			
3.52		400			2.35			
3.52		500			2.93			
3.52		550			3.23			
3.52			600			3.52		
4.11	100			0.59			363.67	2.13
4.11		200			1.17			
4.11		300			1.76			
4.11		400			2.35			
4.11		500			2.93			
4.11			550		0.00	3.23		
4.69	100			0.59	0.00		374.78	2.20
4.69		200			1.17			
4.69		300			1.76			
4.69		400			2.35			
4.69		500			2.93			
4.69			600			3.52		
5.28	100			0.59			385.89	2.26
5.28	200			1.17				
5.28		300			1.76			
5.28		400			2.35			
5.28		500			2.93			
5.28			600			3.52		
5.87	100			0.59			397.00	2.33
5.87	200			1.17				
5.87		300			1.76			
5.87		400			2.35			
5.87		500			2.93			
5.87		550			3.23			
5.87			600			3.52		
6.46	100			0.59			408.12	2.40
6.46	200			1.17				
6.46		300			1.76			
6.46		400			2.35			
6.46		500			2.93			
6.46		550			3.23			
6.46			600			3.52		

Water velocity (cm/s)	Air flow rate (ml/min)			Air velocity (cm/s)			Predicted transition air flow rate (ml/min)	Predicted transition air velocity (cm/s)
	B	B-S	S	B	B-S	S		
7.04 7.04 7.04 7.04 7.04 7.04	100 200	300 400 500	600	0.59 1.17	1.76 2.35 2.93	3.52	419.23	2.46
7.63 7.63 7.63 7.63 7.63 7.63	100 200	300 400 500	600	0.59 1.17	1.76 2.35 2.93	3.52	430.34	2.53
8.22 8.22 8.22 8.22 8.22 8.22	100 200 300	400 500	600	0.59 1.17 1.76	2.35 2.93	3.52	441.45	2.59
8.80 8.80 8.80 8.80 8.80 8.80 8.80	100 200 300	400 500 600	700	0.59 1.17 1.76	2.35 2.93 3.52	4.11	452.56	2.66
9.39 9.39 9.39 9.39 9.39 9.39 9.39	100 200 300	400 500 600	700	0.59 1.17 1.76	2.35 2.93 3.52	4.11	463.67	2.72
9.98 9.98 9.98 9.98 9.98 9.98	200 300	400 500 600	700	1.17 1.76	2.35 2.93 3.52	4.11	474.78	2.79
10.56 10.56	200 300			1.17 1.76				

Water velocity (cm/s)	Air flow rate (ml/min)			Air velocity (cm/s)			Predicted transition air flow rate (ml/min)	Predicted transition air velocity (cm/s)
	B	B-S	S	B	B-S	S		
10.56 10.56 10.56		500 600	700		2.93 3.52	4.11	485.89	2.85
11.15 11.15 11.15 11.15 11.15 11.15 11.15	200 300 400	500 600 700	750	1.17 1.76 2.35	2.93 3.52 4.11	4.40	497.00	2.92
11.74 11.74 11.74 11.74 11.74 11.74	200 300	400 500 600 700	800	1.17 1.76	2.35 2.93 3.52 4.11	4.69	508.12	2.98
12.32 12.32 12.32 12.32 12.32 12.32	200 300	400 500 600 700	800	1.17 1.76	2.35 2.93 3.52 4.11	4.69	519.22	3.05
12.91 12.91 12.91 12.91 12.91 12.91 12.91	200 300	400 500 600 700 800	900	1.17 1.76	2.35 2.93 3.52 4.11 4.69	5.28	530.33	3.11
13.50 13.50 13.50 13.50 13.50 13.50	200 300 400	500 600 700	800	1.17 1.76 2.35	2.93 3.52 4.11	4.69	541.44	3.18

Water velocity (cm/s)	Air flow rate (ml/min)			Air velocity (cm/s)			Predicted transition air flow rate (ml/min)	Predicted transition air velocity (cm/s)
	B	B-S	S	B	B-S	S		
14.08	200			1.17			552.56	3.24
14.08	300			1.76				
14.08		400			2.35			
14.08		500			2.93			
14.08		600			3.52			
14.08		700			4.11			
14.08			800			4.69		
14.67	300			1.76			563.67	3.31
14.67	400			2.35				
14.67		500			2.93			
14.67		600			3.52			
14.67		700			4.11			
14.67		800			4.69			
14.67			900			5.28		
15.26	300			1.76			574.78	
15.26	400			2.35				
15.26		500			2.93			
15.26		600			3.52			
15.26		700			4.11			
15.26		800			4.69			
15.26			900			5.28		
15.85	300			1.76			585.89	3.44
15.85	400			2.35				
15.85		500			2.93			
15.85		600			3.52			
15.85		700			4.11			
15.85		800			4.69			
15.85		900			5.28			
15.85			1000		0.00	5.87		

Note ; B is Bubble flow

B-S is Bubble to slug flow

S is Slug flow

Column diameter 1.9 cm, Cross-sectional area 2.84 cm²

Table A2 Determination of rise velocity of single slug (U_b) and slug length

Slug No.	slug length (cm)	Time (s)	Rising velocity U_b cm/s from experiment	Rising velocity U_b cm/s from theory	Value of c from experiment
1	15.00	7.7	14.16	15.10	0.33
2	10.00	7.7	14.16	15.10	0.33
3	21.50	7.77	14.03	15.10	0.33
4	7.00	7.77	14.03	15.10	0.33
5	2.50	7.79	13.99	15.10	0.32
6	5.50	7.78	14.01	15.10	0.32
7	8.30	7.79	13.99	15.10	0.32
8	13.50	7.48	14.57	15.10	0.34
9	13.00	7.83	13.92	15.10	0.32
10	20.00	7.59	14.36	15.10	0.33
11	7.50	7.53	14.48	15.10	0.34
12	16.00	7.68	14.19	15.10	0.33
13	41.00	7.45	14.63	15.10	0.34
14	48.00	7.24	15.06	15.10	0.35
15	10.50	7.66	14.23	15.10	0.33
16	5.50	7.77	14.03	15.10	0.33
17	11	7.27	14.99	15.10	0.35
18	9.5	7.76	14.05	15.10	0.33
19	4.5	7.79	13.99	15.10	0.32
20	14	7.57	14.40	15.10	0.33

Average c = 0.33

Table A3 Determination of void fraction and rise velocities of continuous generated slugs at a variety of air and water flow rate

Water flow rate (ml/min)	Air flow rate (L/min)	Air velocity (cm/s)	Rise velocity, U_s from theory (cm/s)	Rise velocity, U_s from equation (cm/s)	Void fraction from experiment	Void fraction from theory	Error of rise velocity (%)	Error of void fraction (%)	Average error of rise velocity (%)	Average error of void fraction (%)
0	0.5	2.93	18.63	17.63	0.11	0.17	5.36	36.21		
0	1.0	5.87	22.15	21.03	0.26	0.28	5.04	7.64		
0	1.5	8.80	25.67	26.04	0.35	0.34	1.44	3.05		
0	2.0	11.74	29.19	30.46	0.44	0.39	4.34	13.85		
0	2.5	14.67	32.72	33.77	0.48	0.43	3.21	9.74		
0	3.0	17.61	36.24	36.54	0.51	0.48	0.84	6.13		
0	4.0	23.47	43.28	44.29	0.59	0.53	2.34	10.88		
0	5.0	29.34	50.32	51.37	0.62	0.57	2.09	9.32		
0	6.0	35.21	57.36	55.38	0.65	0.64	3.45	2.36		
0	10.0	58.69	85.53	73.00	0.72	0.80	14.66	10.59	4.28	10.98
200	1.0	5.87	23.56	22.47	0.26	0.26	4.62	1.65		
200	2.0	11.74	30.60	29.92	0.42	0.39	2.25	7.01		
200	3.0	17.61	37.65	37.84	0.50	0.47	0.51	7.96		
200	4.0	23.47	44.69	46.79	0.57	0.50	4.70	13.98		
200	5.0	29.34	51.73	51.59	0.62	0.57	0.27	8.89		
200	6.0	35.21	58.77	58.46	0.74	0.60	0.53	23.25		

Water flow rate (ml/min)	Air flow rate (L/min)	Air velocity (cm/s)	Rise velocity, U_s from theory (cm/s)	Rise velocity, U_s from equation (cm/s)	Void fraction from experiment	Void fraction from theory	Error of rise velocity (%)	Error of void fraction (%)	Average error of rise velocity (%)	Average error of void fraction (%)
200	10.0	58.69	86.94	39.95	0.45	1.47	54.04	69.49		
200	12.0	70.42	101.03	46.56	0.55	1.51	53.91	63.44	27.19	41.27
500	1.0	5.87	25.67	25.14	0.22	0.23	2.08	7.55		
500	2.0	11.74	32.72	32.69	0.37	0.36	0.08	4.21		
500	3.0	17.61	39.76	39.95	0.45	0.44	0.49	1.70		
500	4.0	23.47	46.80	46.56	0.55	0.50	0.52	9.68		
500	5.0	29.34	53.84	53.57	0.62	0.55	0.50	13.66		
500	6.0	35.21	60.88	59.29	0.61	0.59	2.62	2.12		
500	10.0	58.69	89.05	73.59	0.67	0.80	17.37	15.74		
500	12.0	70.42	103.14	94.03	0.71	0.75	8.84	5.00	4.06	7.46
1000	1.0	5.87	29.19	28.45	0.19	0.21	2.56	7.09		
1000	2.0	11.74	36.24	35.54	0.34	0.33	1.92	3.97		
1000	3.0	17.61	43.28	40.81	0.43	0.43	5.70	0.53		
1000	4.0	23.47	50.32	49.61	0.50	0.47	1.41	5.32		
1000	5.0	29.34	57.36	57.13	0.54	0.51	0.40	4.63		
1000	6.0	35.21	64.41	63.59	0.60	0.55	1.26	8.09		
1000	10.0	58.69	92.57	82.45	0.67	0.71	10.94	5.69		
1000	12.0	70.42	106.66	89.70	0.71	0.79	15.90	9.25	5.01	5.57

Water flow rate (ml/min)	Air flow rate (L/min)	Air velocity (cm/s)	Rise velocity, U_s from theory (cm/s)	Rise velocity, U_s from equation (cm/s)	Void fraction from experiment	Void fraction from theory	Error of rise velocity (%)	Error of void fraction (%)	Average error of rise velocity (%)	Average error of void fraction (%)
1500	1.0	5.87	32.72	64.24	0.56	0.09	96.36	516.83		
1500	2.0	11.74	39.76	83.61	0.63	0.14	110.30	345.57		
1500	3.0	17.61	46.80	100.80	0.66	0.17	115.39	278.46		
1500	4.0	23.47	53.84	52.05	0.47	0.45	3.33	4.21		
1500	5.0	29.34	60.88	58.82	0.53	0.50	3.39	5.24		
1500	6.0	35.21	67.93	64.24	0.56	0.55	5.43	2.81		
1500	10.0	58.69	96.10	83.61	0.63	0.70	12.99	10.89		
1500	12.0	70.42	110.18	100.80	0.66	0.70	8.51	5.39	44.46	146.17
2000	1.0	5.87	36.24	35.05	0.16	0.17	3.28	6.64		
2000	2.0	11.74	43.28	42.32	0.31	0.28	2.21	11.24		
2000	3.0	17.61	50.32	48.21	0.37	0.37	4.19	2.53		
2000	4.0	23.47	57.36	56.67	0.43	0.41	1.21	3.36		
2000	5.0	29.34	64.41	61.60	0.49	0.48	4.36	2.97		
2000	6.0	35.21	71.45	67.40	0.54	0.52	5.66	2.41		
2000	10.0	58.69	99.62	84.29	0.62	0.70	15.39	10.90		
2000	12.0	70.42	113.70	100.18	0.64	0.70	11.90	9.20	6.02	6.16
2500	1.0	5.87	39.76	37.91	0.15	0.15	4.64	3.96		
2500	2.0	11.74	46.80	45.10	0.26	0.26	3.63	0.14		

Water flow rate (ml/min)	Air flow rate (L/min)	Air velocity (cm/s)	Rise velocity, U_s from theory (cm/s)	Rise velocity, U_s from equation (cm/s)	Void fraction from experiment	Void fraction from theory	Error of rise velocity (%)	Error of void fraction (%)	Average error of rise velocity (%)	Average error of void fraction (%)
2500	3.0	17.61	53.84	50.52	0.35	0.35	6.18	0.43		
2500	4.0	23.47	60.88	56.55	0.42	0.42	7.12	0.97		
2500	5.0	29.34	67.93	66.20	0.48	0.44	2.55	7.67		
2500	6.0	35.21	74.97	74.74	0.53	0.47	0.30	13.22		
2500	10.0	58.69	103.14	86.62	0.59	0.68	16.01	12.69		
2500	12.0	70.42	117.22	114.40	0.59	0.62	2.41	4.05	5.35	5.39

Table A4 Determination of air-lift pump operation

Initial		Ending		Void fraction	Required air flow rate from experiment (ml/min)	Required air velocity from experiment (cm/s)	Required air flow rate from theory (ml/min)	Required air velocity from theory (cm/s)	Error of air velocity (%)
H (cm)	h (cm)	H (cm)	h (cm)						
95.3	95.3	285.0	95.5	0.66	6200	36.38	8470.73	49.71	26.81
100.0	100.0	285.0	100.6	0.65	5900	34.62	7451.08	43.73	20.82
105.6	105.6	285.0	106.8	0.63	5900	34.62	6447.71	37.84	8.49
111.3	111.3	285.0	112.0	0.61	5300	31.10	5754.92	33.77	7.90
115.6	115.6	285.0	117.0	0.59	5000	29.34	5186.53	30.44	3.60
120.4	120.4	285.0	121.0	0.58	4600	27.00	4787.51	28.10	3.92
125.7	125.7	285.0	126.3	0.56	4100	24.06	4321.19	25.36	5.12
130.5	130.5	285.0	131.0	0.54	3750	22.01	3957.19	23.22	5.24
136.4	136.4	285.0	137.1	0.52	3700	21.71	3541.71	20.78	4.47
140.4	140.4	285.0	140.7	0.51	3300	19.37	3322.03	19.50	0.66
145.5	145.5	285.0	145.7	0.49	2900	17.02	3043.63	17.86	4.72
151.0	151.0	285.0	151.3	0.47	2700	15.85	2763.67	16.22	2.30
155.6	155.6	285.0	155.9	0.45	2450	14.38	2555.35	15.00	4.12
160.3	160.3	285.0	160.5	0.44	2300	13.50	2363.98	13.87	2.71
165.7	165.7	285.0	166.0	0.42	2000	11.74	2154.67	12.64	7.18
170.1	170.1	285.0	170.2	0.40	1950	11.44	2007.47	11.78	2.86
175.1	175.1	285.0	175.3	0.38	1800	10.56	1841.74	10.81	2.27
180.6	180.6	285.0	180.9	0.37	1700	9.98	1674.36	9.83	1.53
185.5	185.5	285.0	185.7	0.35	1500	8.80	1541.68	9.05	2.70

Initial		Ending		Void fraction	Required air flow rate from experiment (ml/min)	Required air velocity from experiment (cm/s)	Required air flow rate from theory (ml/min)	Required air velocity from theory (cm/s)	Error of air velocity (%)
H (cm)	h (cm)	H (cm)	h (cm)						
191.7	191.7	285.0	192.3	0.33	1450	8.51	1373.61	8.06	5.56
197.2	197.2	285.0	197.3	0.31	1300	7.63	1256.15	7.37	3.49
201.0	201.0	285.0	201.2	0.29	1200	7.04	1169.83	6.87	2.58
205.6	205.6	285.0	205.7	0.28	1100	6.46	1075.52	6.31	2.28
210.7	210.7	285.0	211.0	0.26	1000	5.87	971.11	5.70	2.98
215.2	215.2	285.0	215.2	0.24	950	5.58	893.05	5.24	6.38
222.6	222.6	285.0	222.6	0.22	800	4.69	764.63	4.49	4.63
227.0	227.0	285.0	227.1	0.20	750	4.40	691.71	4.06	8.43
230.7	230.7	285.0	230.7	0.19	700	4.11	635.96	3.73	10.07
235.6	235.6	285.0	235.6	0.17	650	3.81	563.50	3.31	15.35
240.6	240.6	285.0	240.6	0.16	600	3.52	493.35	2.90	21.62
245.7	245.7	285.0	245.7	0.14	500	2.93	425.44	2.50	17.52
250.4	250.4	285.0	250.4	0.12	500	2.93	365.89	2.15	36.65
255.1	255.1	285.0	255.1	0.10	450	2.64	309.03	1.81	45.62
265.5	265.5	285.0	265.6	0.07	300	1.76	190.85	1.12	57.19
268.5	268.5	285.0	268.5	0.06	250	1.47	160.19	0.94	56.06
275.6	275.6	285.0	275.6	0.03	150	0.88	88.42	0.52	69.64

Absolute average error of air velocities (%)

13.05

Note:

H = height of water in main column

h = height of water in reservoir column

Rising velocity of slug in stagnant water, $U_b = 15.11$ cm/s

Appendix B Flooding and pressure drop in packed column

Table B1 Data for generation of Eckert's type charts

Type of packing material	Height of bed (cm)	Liquid flowrate (ml/min)	Liquid mass velocity (g/cm ² .s), G _l	Gas mass rate (kg/m ² .s) at flood condition	Gas mass rate (g/cm ² .s) at flood condition, G _g	Parameter on coordinate Y	Parameter on coordinate X
Ceramic ball	80	500.00	0.15	70.00	7.00	44820.19	0.02
		800.00	0.24	58.33	5.83	31121.58	0.05
		1000.00	0.30	54.44	5.44	27109.02	0.06
		1200.00	0.36	38.89	3.89	13834.18	0.11
		1500.00	0.45	35.00	3.50	11205.05	0.15
		2000.00	0.60	19.44	1.94	3456.77	0.35
Ceramic ball	60	500.00	0.15	66.11	6.61	39977.16	0.03
		800.00	0.24	66.11	6.61	39977.16	0.04
		1000.00	0.30	58.33	5.83	31121.58	0.06
		1200.00	0.36	54.44	5.44	27109.02	0.08
		1500.00	0.45	42.78	4.28	16740.14	0.12
		2000.00	0.60	25.28	2.53	5845.64	0.27
Plastic raschig ring	80	500.00	0.15	62.22	6.22	12705.00	0.03
		800.00	0.24	58.33	5.83	11166.02	0.05
		1000.00	0.30	54.44	5.44	9726.37	0.06
		1200.00	0.36	50.55	5.06	8386.04	0.08
		1500.00	0.45	38.89	3.89	4963.53	0.13
		2000.00	0.60	21.39	2.14	1501.54	0.32
Plastic raschig ring	60	500.00	0.15	85.55	8.56	24018.99	0.02
		800.00	0.24	58.33	5.83	11166.02	0.05
		1000.00	0.30	46.66	4.67	7145.03	0.07
		1200.00	0.36	42.78	4.28	6006.15	0.10
		1500.00	0.45	25.28	2.53	2097.34	0.20
		2000.00	0.60	23.33	2.33	1786.26	0.29

Note ; Density of air 1.293 g/cm³
 Viscosity of water 0.82 cp

Table B2 Pressure drop at the variety of air and water mass velocities with plastic raschig ring

Height of bed (cm)	Water flow rate (ml/min)	Water mass velocity ($\text{g}/\text{cm}^2 \cdot \text{s}$)	Air flow rate (LPM)	Air mass velocity ($\text{g}/\text{cm}^2 \cdot \text{s}$)	Pressure drop (mmH_2O)	Pressure drop ($\text{mmH}_2\text{O}/\text{cm}$)
30	500	0.15	0.0	0.00	1.00	0.03
			0.5	0.19	2.00	0.07
			1.0	0.39	2.00	0.07
			1.5	0.58	2.00	0.07
			2.0	0.78	2.50	0.08
			2.5	0.97	2.50	0.08
			3.0	1.17	3.50	0.12
			3.5	1.36	4.00	0.13
			4.0	1.56	4.00	0.13
			4.5	1.75	4.00	0.13
			5.0	1.94	3.50	0.12
			5.5	2.14	3.50	0.12
			6.0	2.33	5.49	0.18
			6.5	2.53	5.49	0.18
			7.0	2.72	5.49	0.18
			8.0	3.11	7.49	0.25
			9.0	3.50	6.99	0.23
			10.0	3.89	8.49	0.28
			11.0	4.28	8.49	0.28
			12.0	4.67	15.48	0.52
			13.0	5.06	20.98	0.70
			14.0	5.44	16.98	0.57
			15.0	5.83	16.98	0.57
			16.0	6.22	19.98	0.67
			17.0	6.61	20.48	0.68
			18.0	7.00	19.98	0.67
			19.0	7.39	19.98	0.67
			20.0	7.78	19.98	0.67
22.0	8.56	19.98	0.67			
24.0	9.33	18.48	0.62			
26.0	10.11	14.98	0.50			
28.0	10.89	16.98	0.57			
30.0	11.67	15.48	0.52			

Height of bed (cm)	Water flow rate (ml/min)	Water mass velocity ($\text{g}/\text{cm}^2 \cdot \text{s}$)	Air flow rate (LPM)	Air mass velocity ($\text{g}/\text{cm}^2 \cdot \text{s}$)	Pressure drop (mmH_2O)	Pressure drop ($\text{mmH}_2\text{O}/\text{cm}$)
30	1000	0.30	0.0	0.00	2.50	0.08
			0.5	0.19	2.50	0.08
			1.0	0.39	2.50	0.08
			1.5	0.58	2.50	0.08
			2.0	0.78	2.50	0.08
			2.5	0.97	3.00	0.10
			3.0	1.17	4.50	0.15
			3.5	1.36	5.49	0.18
			4.0	1.56	6.49	0.22
			4.5	1.75	7.49	0.25
			5.0	1.94	11.49	0.38
			5.5	2.14	11.49	0.38
			6.0	2.33	13.49	0.45
			6.5	2.53	12.99	0.43
			7.0	2.72	12.99	0.43
			8.0	3.11	12.99	0.43
			9.0	3.50	13.98	0.47
			10.0	3.89	14.98	0.50
			11.0	4.28	15.48	0.52
			12.0	4.67	14.48	0.48
			13.0	5.06	11.99	0.40
14.0	5.44	15.98	0.53			
15.0	5.83	16.48	0.55			
16.0	6.22	16.98	0.57			
17.0	6.61	15.98	0.53			
18.0	7.00	15.98	0.53			
19.0	7.39	14.48	0.48			
20.0	7.78	16.48	0.55			
22.0	8.56	17.48	0.58			
24.0	9.33	17.48	0.58			
26.0	10.11	28.47	0.95			
28.0	10.89	34.96	1.17			
30.0	11.67	42.95	1.43			

Height of bed (cm)	Water flow rate (ml/min)	Water mass velocity ($\text{g}/\text{cm}^2 \cdot \text{s}$)	Air flow rate (LPM)	Air mass velocity ($\text{g}/\text{cm}^2 \cdot \text{s}$)	Pressure drop (mmH_2O)	Pressure drop ($\text{mmH}_2\text{O}/\text{cm}$)
30	1500	0.45	0.0	0.00	4.00	0.13
			0.5	0.19	4.00	0.13
			1.0	0.39	7.99	0.27
			1.5	0.58	8.49	0.28
			2.0	0.78	8.49	0.28
			2.5	0.97	8.99	0.30
			3.0	1.17	9.49	0.32
			3.5	1.36	10.49	0.35
			4.0	1.56	10.49	0.35
			4.5	1.75	11.49	0.38
			5.0	1.94	11.99	0.40
			5.5	2.14	16.48	0.55
			6.0	2.33	16.48	0.55
			6.5	2.53	16.98	0.57
			7.0	2.72	16.98	0.57
			8.0	3.11	15.98	0.53
			9.0	3.50	17.48	0.58
			10.0	3.89	16.98	0.57
			11.0	4.28	16.98	0.57
			12.0	4.67	17.98	0.60
			13.0	5.06	19.48	0.65
14.0	5.44	18.98	0.63			
15.0	5.83	17.98	0.60			
16.0	6.22	17.48	0.58			
17.0	6.61	17.98	0.60			
18.0	7.00	16.98	0.57			
19.0	7.39	15.98	0.53			
20.0	7.78	15.48	0.52			
22.0	8.56	15.98	0.53			
24.0	9.33	17.48	0.58			
26.0	10.11	25.47	0.85			
28.0	10.89	27.97	0.93			
30.0	11.67	19.48	0.65			

Height of bed (cm)	Water flow rate (ml/min)	Water mass velocity ($\text{g}/\text{cm}^2 \cdot \text{s}$)	Air flow rate (LPM)	Air mass velocity ($\text{g}/\text{cm}^2 \cdot \text{s}$)	Pressure drop (mmH_2O)	Pressure drop ($\text{mmH}_2\text{O}/\text{cm}$)
60	500	0.15	0.0	0.00	2.00	0.03
			0.5	0.19	2.50	0.04
			1.0	0.39	2.50	0.04
			1.5	0.58	2.50	0.04
			2.0	0.78	2.50	0.04
			2.5	0.97	2.50	0.04
			3.0	1.17	2.50	0.04
			3.5	1.36	3.00	0.05
			4.0	1.56	3.00	0.05
			4.5	1.75	3.50	0.06
			5.0	1.94	3.50	0.06
			5.5	2.14	4.00	0.07
			6.0	2.33	4.00	0.07
			6.5	2.53	4.00	0.07
			7.0	2.72	4.00	0.07
			8.0	3.11	4.00	0.07
			9.0	3.50	4.50	0.07
			10.0	3.89	6.00	0.10
			11.0	4.28	7.00	0.12
			12.0	4.67	7.00	0.12
			13.0	5.06	9.50	0.16
			14.0	5.44	12.00	0.20
			15.0	5.83	14.00	0.23
			16.0	6.22	14.00	0.23
			17.0	6.61	15.00	0.25
			18.0	7.00	15.50	0.26
			19.0	7.39	15.50	0.26
			20.0	7.78	17.50	0.29
			22.0	8.56	17.50	0.29
			24.0	9.33	17.00	0.28
26.0	10.11	19.00	0.32			
28.0	10.89	21.00	0.35			
30.0	11.67	21.00	0.35			

Height of bed (cm)	Water flow rate (ml/min)	Water mass velocity ($\text{g}/\text{cm}^2\cdot\text{s}$)	Air flow rate (LPM)	Air mass velocity ($\text{g}/\text{cm}^2\cdot\text{s}$)	Pressure drop (mmH_2O)	Pressure drop ($\text{mmH}_2\text{O}/\text{cm}$)
60	800	0.24	0.0	0.00	2.00	0.03
			0.5	0.19	2.50	0.04
			1.0	0.39	2.66	0.04
			1.5	0.58	2.66	0.04
			2.0	0.78	2.83	0.05
			2.5	0.97	2.83	0.05
			3.0	1.17	3.33	0.06
			3.5	1.36	3.50	0.06
			4.0	1.56	3.66	0.06
			4.5	1.75	4.00	0.07
			5.0	1.94	5.33	0.09
			5.5	2.14	5.99	0.10
			6.0	2.33	7.82	0.13
			6.5	2.53	8.82	0.15
			7.0	2.72	10.32	0.17
			8.0	3.11	11.65	0.19
			9.0	3.50	11.82	0.20
			10.0	3.89	15.65	0.26
			11.0	4.28	16.15	0.27
			12.0	4.67	18.48	0.31
			13.0	5.06	19.48	0.32
			14.0	5.44	20.64	0.34
			15.0	5.83	21.31	0.36
			16.0	6.22	21.64	0.36
17.0	6.61	20.98	0.35			
18.0	7.00	20.98	0.35			
19.0	7.39	21.48	0.36			
20.0	7.78	23.31	0.39			
22.0	8.56	22.14	0.37			
24.0	9.33	23.31	0.39			
26.0	10.11	33.13	0.55			
28.0	10.89	35.79	0.60			
30.0	11.67	37.29	0.62			

Height of bed (cm)	Water flow rate (ml/min)	Water mass velocity (g/cm ² .s)	Air flow rate (LPM)	Air mass velocity (g/cm ² .s)	Pressure drop (mmH ₂ O)	Pressure drop (mmH ₂ O/cm)
60	1000	0.3	0.0	0.00	2.50	0.04
			0.5	0.19	3.50	0.06
			1.0	0.39	3.50	0.06
			1.5	0.58	3.50	0.06
			2.0	0.78	4.00	0.07
			2.5	0.97	4.50	0.07
			3.0	1.17	4.50	0.07
			3.5	1.36	5.00	0.08
			4.0	1.56	5.50	0.09
			4.5	1.75	5.50	0.09
			5.0	1.94	7.00	0.12
			5.5	2.14	8.50	0.14
			6.0	2.33	10.50	0.17
			6.5	2.53	14.00	0.23
			7.0	2.72	15.00	0.25
			8.0	3.11	16.00	0.27
			9.0	3.50	19.00	0.32
			10.0	3.89	19.50	0.32
			11.0	4.28	19.50	0.32
			12.0	4.67	20.00	0.33
			13.0	5.06	19.00	0.32
14.0	5.44	19.00	0.32			
15.0	5.83	19.50	0.32			
16.0	6.22	19.50	0.32			
17.0	6.61	19.50	0.32			
18.0	7.00	21.50	0.36			
19.0	7.39	21.00	0.35			
20.0	7.78	20.00	0.33			
22.0	8.56	20.00	0.33			
24.0	9.33	17.00	0.28			
26.0	10.11	18.00	0.30			
28.0	10.89	18.00	0.30			
30.0	11.67	18.50	0.31			

Height of bed (cm)	Water flow rate (ml/min)	Water mass velocity ($\text{g}/\text{cm}^2\cdot\text{s}$)	Air flow rate (LPM)	Air mass velocity ($\text{g}/\text{cm}^2\cdot\text{s}$)	Pressure drop (mmH_2O)	Pressure drop ($\text{mmH}_2\text{O}/\text{cm}$)
60	1200	0.36	0.0	0.00	4.25	0.07
			0.5	0.19	4.74	0.08
			1.0	0.39	4.99	0.08
			1.5	0.58	5.49	0.09
			2.0	0.78	5.74	0.10
			2.5	0.97	5.99	0.10
			3.0	1.17	5.99	0.10
			3.5	1.36	5.99	0.10
			4.0	1.56	5.99	0.10
			4.5	1.75	6.24	0.10
			5.0	1.94	6.49	0.11
			5.5	2.14	6.99	0.12
			6.0	2.33	7.99	0.13
			6.5	2.53	8.74	0.15
			7.0	2.72	8.24	0.14
			8.0	3.11	8.99	0.15
			9.0	3.50	8.99	0.15
			10.0	3.89	11.99	0.20
			11.0	4.28	16.23	0.27
			12.0	4.67	16.98	0.28
			13.0	5.06	17.98	0.30
			14.0	5.44	22.23	0.37
			15.0	5.83	22.23	0.37
			16.0	6.22	22.48	0.37
			17.0	6.61	23.47	0.39
			18.0	7.00	22.73	0.38
			19.0	7.39	24.47	0.41
			20.0	7.78	23.97	0.40
			22.0	8.56	24.72	0.41
			24.0	9.33	27.22	0.45
26.0	10.11	31.22	0.52			
28.0	10.89	29.97	0.50			
30.0	11.67	29.22	0.49			

Height of bed (cm)	Water flow rate (ml/min)	Water mass velocity ($\text{g}/\text{cm}^2 \cdot \text{s}$)	Air flow rate (LPM)	Air mass velocity ($\text{g}/\text{cm}^2 \cdot \text{s}$)	Pressure drop (mmH_2O)	Pressure drop ($\text{mmH}_2\text{O}/\text{cm}$)
60	1500	0.45	0.0	0.00	1.50	0.02
			0.5	0.19	4.50	0.07
			1.0	0.39	4.99	0.08
			1.5	0.58	7.49	0.12
			2.0	0.78	7.49	0.12
			2.5	0.97	7.49	0.12
			3.0	1.17	7.49	0.12
			3.5	1.36	8.49	0.14
			4.0	1.56	9.49	0.16
			4.5	1.75	13.98	0.23
			5.0	1.94	13.98	0.23
			5.5	2.14	20.98	0.35
			6.0	2.33	20.98	0.35
			6.5	2.53	21.98	0.37
			7.0	2.72	20.48	0.34
			8.0	3.11	20.98	0.35
			9.0	3.50	21.98	0.37
			10.0	3.89	23.47	0.39
			11.0	4.28	23.97	0.40
			12.0	4.67	25.97	0.43
			13.0	5.06	26.97	0.45
14.0	5.44	27.47	0.46			
15.0	5.83	27.97	0.47			
16.0	6.22	28.47	0.47			
17.0	6.61	27.47	0.46			
18.0	7.00	26.97	0.45			
19.0	7.39	28.47	0.47			
20.0	7.78	30.47	0.51			
22.0	8.56	30.97	0.52			
24.0	9.33	37.46	0.62			
26.0	10.11	49.95	0.83			
28.0	10.89	28.47	0.47			
30.0	11.67	32.96	0.55			

Height of bed (cm)	Water flow rate (ml/min)	Water mass velocity ($\text{g}/\text{cm}^2.\text{s}$)	Air flow rate (LPM)	Air mass velocity ($\text{g}/\text{cm}^2.\text{s}$)	Pressure drop (mmH_2O)	Pressure drop ($\text{mmH}_2\text{O}/\text{cm}$)
60	2000	0.60	0.0	0.00	5.99	0.10
			0.5	0.19	5.99	0.10
			1.0	0.39	5.99	0.10
			1.5	0.58	6.49	0.11
			2.0	0.78	6.99	0.12
			2.5	0.97	10.99	0.18
			3.0	1.17	11.49	0.19
			3.5	1.36	13.49	0.22
			4.0	1.56	13.98	0.23
			4.5	1.75	14.98	0.25
			5.0	1.94	15.48	0.26
			5.5	2.14	15.98	0.27
			6.0	2.33	19.48	0.32
			6.5	2.53	19.48	0.32
			7.0	2.72	19.98	0.33
			8.0	3.11	20.98	0.35
			9.0	3.50	20.98	0.35
			10.0	3.89	21.48	0.36
			11.0	4.28	22.48	0.37
			12.0	4.67	23.97	0.40
			13.0	5.06	24.47	0.41
			14.0	5.44	29.97	0.50
			15.0	5.83	28.97	0.48
			16.0	6.22	25.47	0.42
			17.0	6.61	26.47	0.44
			18.0	7.00	25.97	0.43
			19.0	7.39	23.97	0.40
			20.0	7.78	27.97	0.47
22.0	8.56	29.97	0.50			
24.0	9.33	43.45	0.72			
26.0	10.11	45.95	0.77			
28.0	10.89	42.45	0.71			
30.0	11.67	42.45	0.71			

Height of bed (cm)	Water flow rate (ml/min)	Water mass velocity ($\text{g}/\text{cm}^2 \cdot \text{s}$)	Air flow rate (LPM)	Air mass velocity ($\text{g}/\text{cm}^2 \cdot \text{s}$)	Pressure drop (mmH_2O)	Pressure drop ($\text{mmH}_2\text{O}/\text{cm}$)
80	500	0.15	0.0	0.00	1.50	0.02
			0.5	0.19	1.50	0.02
			1.0	0.39	2.50	0.03
			1.5	0.58	2.00	0.02
			2.0	0.78	2.00	0.02
			2.5	0.97	3.00	0.04
			3.0	1.17	4.00	0.05
			3.5	1.36	3.50	0.04
			4.0	1.56	3.50	0.04
			4.5	1.75	3.50	0.04
			5.0	1.94	3.50	0.04
			5.5	2.14	4.00	0.05
			6.0	2.33	5.49	0.07
			6.5	2.53	6.49	0.08
			7.0	2.72	6.49	0.08
			8.0	3.11	5.99	0.07
			9.0	3.50	5.99	0.07
			10.0	3.89	5.99	0.07
			11.0	4.28	6.99	0.09
			12.0	4.67	6.99	0.09
			13.0	5.06	6.99	0.09
			14.0	5.44	7.49	0.09
			15.0	5.83	11.99	0.15
			16.0	6.22	13.98	0.17
			17.0	6.61	12.99	0.16
			18.0	7.00	12.49	0.16
			19.0	7.39	11.99	0.15
			20.0	7.78	11.99	0.15
			22.0	8.56	11.99	0.15
			24.0	9.33	12.49	0.16
26.0	10.11	13.98	0.17			
28.0	10.89	14.98	0.19			
30.0	11.67	14.48	0.18			

Height of bed (cm)	Water flow rate (ml/min)	Water mass velocity ($\text{g}/\text{cm}^2 \cdot \text{s}$)	Air flow rate (LPM)	Air mass velocity ($\text{g}/\text{cm}^2 \cdot \text{s}$)	Pressure drop (mmH_2O)	Pressure drop ($\text{mmH}_2\text{O}/\text{cm}$)
80	800	0.24	0.0	0.00	0.00	0.00
			0.5	0.19	2.00	0.02
			1.0	0.39	3.50	0.04
			1.5	0.58	4.50	0.06
			2.0	0.78	5.49	0.07
			2.5	0.97	5.99	0.07
			3.0	1.17	6.49	0.08
			3.5	1.36	6.99	0.09
			4.0	1.56	6.99	0.09
			4.5	1.75	7.99	0.10
			5.0	1.94	8.99	0.11
			5.5	2.14	9.49	0.12
			6.0	2.33	9.99	0.12
			6.5	2.53	9.99	0.12
			7.0	2.72	9.99	0.12
			8.0	3.11	16.48	0.21
			9.0	3.50	18.48	0.23
			10.0	3.89	19.98	0.25
			11.0	4.28	19.98	0.25
			12.0	4.67	21.48	0.27
			13.0	5.06	21.48	0.27
			14.0	5.44	22.48	0.28
			15.0	5.83	23.97	0.30
			16.0	6.22	24.47	0.31
			17.0	6.61	22.98	0.29
			18.0	7.00	22.48	0.28
			19.0	7.39	22.48	0.28
			20.0	7.78	25.47	0.32
			22.0	8.56	23.97	0.30
			24.0	9.33	24.97	0.31
26.0	10.11	23.47	0.29			
28.0	10.89	23.08	0.29			
30.0	11.67	22.98	0.29			

Height of bed (cm)	Water flow rate (ml/min)	Water mass velocity ($\text{g}/\text{cm}^2 \cdot \text{s}$)	Air flow rate (LPM)	Air mass velocity ($\text{g}/\text{cm}^2 \cdot \text{s}$)	Pressure drop (mmH_2O)	Pressure drop ($\text{mmH}_2\text{O}/\text{cm}$)
80	1000	0.30	0.0	0.00	2.00	0.02
			0.5	0.19	3.00	0.04
			1.0	0.39	4.50	0.06
			1.5	0.58	4.50	0.06
			2.0	0.78	4.99	0.06
			2.5	0.97	4.99	0.06
			3.0	1.17	5.99	0.07
			3.5	1.36	6.99	0.09
			4.0	1.56	6.99	0.09
			4.5	1.75	7.99	0.10
			5.0	1.94	8.49	0.11
			5.5	2.14	8.99	0.11
			6.0	2.33	9.49	0.12
			6.5	2.53	9.99	0.12
			7.0	2.72	9.99	0.12
			8.0	3.11	10.99	0.14
			9.0	3.50	13.98	0.17
			10.0	3.89	15.48	0.19
			11.0	4.28	16.48	0.21
			12.0	4.67	15.98	0.20
			13.0	5.06	15.98	0.20
			14.0	5.44	17.98	0.22
			15.0	5.83	17.48	0.22
			16.0	6.22	17.98	0.22
			17.0	6.61	17.98	0.22
			18.0	7.00	17.48	0.22
			19.0	7.39	16.48	0.21
			20.0	7.78	17.98	0.22
			22.0	8.56	16.48	0.21
			24.0	9.33	20.98	0.26
26.0	10.11	23.97	0.30			
28.0	10.89	22.48	0.28			
30.0	11.67	22.48	0.28			

Height of bed (cm)	Water flow rate (ml/min)	Water mass velocity (g/cm ² .s)	Air flow rate (LPM)	Air mass velocity (g/cm ² .s)	Pressure drop (mmH ₂ O)	Pressure drop (mmH ₂ O/cm)
80	1200	0.36	0.0	0.00	3.00	0.04
			0.5	0.19	3.50	0.04
			1.0	0.39	6.49	0.08
			1.5	0.58	6.49	0.08
			2.0	0.78	6.49	0.08
			2.5	0.97	7.49	0.09
			3.0	1.17	8.49	0.11
			3.5	1.36	8.49	0.11
			4.0	1.56	8.99	0.11
			4.5	1.75	9.49	0.12
			5.0	1.94	15.48	0.19
			5.5	2.14	15.98	0.20
			6.0	2.33	15.98	0.20
			6.5	2.53	15.98	0.20
			7.0	2.72	17.48	0.22
			8.0	3.11	18.98	0.24
			9.0	3.50	20.98	0.26
			10.0	3.89	22.48	0.28
			11.0	4.28	20.48	0.26
			12.0	4.67	21.48	0.27
			13.0	5.06	21.48	0.27
14.0	5.44	22.48	0.28			
15.0	5.83	22.48	0.28			
16.0	6.22	21.98	0.27			
17.0	6.61	21.48	0.27			
18.0	7.00	21.98	0.27			
19.0	7.39	21.98	0.27			
20.0	7.78	22.48	0.28			
22.0	8.56	22.98	0.29			
24.0	9.33	20.48	0.26			
26.0	10.11	25.97	0.32			
28.0	10.89	23.97	0.30			
30.0	11.67	25.97	0.32			

Height of bed (cm)	Water flow rate (ml/min)	Water mass velocity (g/cm ² .s)	Air flow rate (LPM)	Air mass velocity (g/cm ² .s)	Pressure drop (mmH ₂ O)	Pressure drop (mmH ₂ O/cm)
80	1500	0.45	0.0	0.00	6.99	0.09
			0.5	0.19	4.00	0.05
			1.0	0.39	5.49	0.07
			1.5	0.58	5.99	0.07
			2.0	0.78	10.49	0.13
			2.5	0.97	10.99	0.14
			3.0	1.17	10.99	0.14
			3.5	1.36	11.49	0.14
			4.0	1.56	11.99	0.15
			4.5	1.75	11.99	0.15
			5.0	1.94	12.49	0.16
			5.5	2.14	19.48	0.24
			6.0	2.33	19.98	0.25
			6.5	2.53	19.48	0.24
			7.0	2.72	18.98	0.24
			8.0	3.11	18.98	0.24
			9.0	3.50	19.98	0.25
			10.0	3.89	21.48	0.27
			11.0	4.28	21.48	0.27
			12.0	4.67	20.98	0.26
			13.0	5.06	22.48	0.28
14.0	5.44	21.98	0.27			
15.0	5.83	22.48	0.28			
16.0	6.22	20.48	0.26			
17.0	6.61	18.98	0.24			
18.0	7.00	19.48	0.24			
19.0	7.39	18.98	0.24			
20.0	7.78	18.48	0.23			
22.0	8.56	17.48	0.22			
24.0	9.33	18.48	0.23			
26.0	10.11	21.48	0.27			
28.0	10.89	19.98	0.25			
30.0	11.67	24.47	0.31			

Height of bed (cm)	Water flow rate (ml/min)	Water mass velocity ($\text{g}/\text{cm}^2 \cdot \text{s}$)	Air flow rate (LPM)	Air mass velocity ($\text{g}/\text{cm}^2 \cdot \text{s}$)	Pressure drop (mmH_2O)	Pressure drop ($\text{mmH}_2\text{O}/\text{cm}$)
80	2000	0.60	0.0	0.00	2.50	0.03
			0.5	0.19	4.50	0.06
			1.0	0.39	4.99	0.06
			1.5	0.58	5.99	0.07
			2.0	0.78	6.99	0.09
			2.5	0.97	7.49	0.09
			3.0	1.17	7.49	0.09
			3.5	1.36	8.49	0.11
			4.0	1.56	8.49	0.11
			4.5	1.75	12.99	0.16
			5.0	1.94	12.99	0.16
			5.5	2.14	22.98	0.29
			6.0	2.33	22.98	0.29
			6.5	2.53	22.98	0.29
			7.0	2.72	23.97	0.30
			8.0	3.11	23.47	0.29
			9.0	3.50	23.47	0.29
			10.0	3.89	25.47	0.32
			11.0	4.28	25.97	0.32
			12.0	4.67	25.47	0.32
			13.0	5.06	26.47	0.33
14.0	5.44	24.97	0.31			
15.0	5.83	25.97	0.32			
16.0	6.22	26.47	0.33			
17.0	6.61	26.47	0.33			
18.0	7.00	25.97	0.32			
19.0	7.39	25.47	0.32			
20.0	7.78	25.97	0.32			
22.0	8.56	28.47	0.36			
24.0	9.33	45.95	0.57			
26.0	10.11	60.44	0.76			
28.0	10.89	62.43	0.78			
30.0	11.67	63.43	0.79			

Table B3 Pressure drop at the variety of air and water mass velocities with ceramic balls

Height of bed (cm)	Water flow rate (ml/min)	Water mass velocity ($\text{g}/\text{cm}^2 \cdot \text{s}$)	Air flow rate (LPM)	Air mass velocity ($\text{g}/\text{cm}^2 \cdot \text{s}$)	Pressure drop (mmH_2O)	Pressure drop ($\text{mmH}_2\text{O}/\text{cm}$)
30	500	0.15	0.0	0.00	2.50	0.08
			0.5	0.19	2.50	0.08
			1.0	0.39	2.50	0.08
			1.5	0.58	2.50	0.08
			2.0	0.78	2.50	0.08
			2.5	0.97	2.66	0.09
			3.0	1.17	3.00	0.10
			3.5	1.36	3.50	0.12
			4.0	1.56	4.33	0.14
			4.5	1.75	4.66	0.16
			5.0	1.94	5.83	0.19
			5.5	2.14	6.66	0.22
			6.0	2.33	7.33	0.24
			6.5	2.53	8.32	0.28
			7.0	2.72	6.33	0.21
			8.0	3.11	6.33	0.21
			9.0	3.50	8.16	0.27
			10.0	3.89	8.16	0.27
			11.0	4.28	10.82	0.36
			12.0	4.67	12.32	0.41
13.0	5.06	14.15	0.47			
14.0	5.44	16.98	0.57			
15.0	5.83	17.98	0.60			
16.0	6.22	24.47	0.82			
17.0	6.61	24.31	0.81			
18.0	7.00	28.47	0.95			
19.0	7.39	29.63	0.99			
20.0	7.78	30.97	1.03			

Height of bed (cm)	Water flow rate (ml/min)	Water mass velocity ($\text{g}/\text{cm}^2 \cdot \text{s}$)	Air flow rate (LPM)	Air mass velocity ($\text{g}/\text{cm}^2 \cdot \text{s}$)	Pressure drop (mmH_2O)	Pressure drop ($\text{mmH}_2\text{O}/\text{cm}$)
30	1000	0.30	0.0	0.00	4.83	0.16
			0.5	0.19	4.83	0.16
			1.0	0.39	4.99	0.17
			1.5	0.58	4.99	0.17
			2.0	0.78	4.99	0.17
			2.5	0.97	4.99	0.17
			3.0	1.17	5.16	0.17
			3.5	1.36	5.33	0.18
			4.0	1.56	6.16	0.21
			4.5	1.75	5.33	0.18
			5.0	1.94	5.49	0.18
			5.5	2.14	6.49	0.22
			6.0	2.33	6.49	0.22
			6.5	2.53	6.49	0.22
			7.0	2.72	6.33	0.21
			8.0	3.11	6.49	0.22
			9.0	3.50	6.99	0.23
			10.0	3.89	8.82	0.29
			11.0	4.28	9.32	0.31
			12.0	4.67	15.82	0.53
13.0	5.06	17.65	0.59			
14.0	5.44	24.81	0.83			
15.0	5.83	24.81	0.83			
16.0	6.22	27.47	0.92			
17.0	6.61	28.14	0.94			
18.0	7.00	29.80	0.99			
19.0	7.39	28.47	0.95			
20.0	7.78	30.13	1.00			

Height of bed (cm)	Water flow rate (ml/min)	Water mass velocity (g/cm ² .s)	Air flow rate (LPM)	Air mass velocity (g/cm ² .s)	Pressure drop (mmH ₂ O)	Pressure drop (mmH ₂ O/cm)
30	1500	0.45	0.0	0.00	3.83	0.13
			0.5	0.19	4.50	0.15
			1.0	0.39	4.50	0.15
			1.5	0.58	4.66	0.16
			2.0	0.78	4.83	0.16
			2.5	0.97	5.16	0.17
			3.0	1.17	5.16	0.17
			3.5	1.36	5.49	0.18
			4.0	1.56	6.16	0.21
			4.5	1.75	7.99	0.27
			5.0	1.94	20.31	0.68
			5.5	2.14	19.15	0.64
			6.0	2.33	21.81	0.73
			6.5	2.53	26.97	0.90
			7.0	2.72	22.31	0.74
			8.0	3.11	28.64	0.95
			9.0	3.50	34.63	1.15
			10.0	3.89	26.97	0.90
			11.0	4.28	36.46	1.22
			12.0	4.67	37.29	1.24
13.0	5.06	36.29	1.21			
14.0	5.44	41.46	1.38			
15.0	5.83	40.96	1.37			
16.0	6.22	44.29	1.48			
17.0	6.61	46.28	1.54			
18.0	7.00	56.27	1.88			
19.0	7.39	48.78	1.63			
20.0	7.78	52.28	1.74			

Height of bed (cm)	Water flow rate (ml/min)	Water mass velocity ($\text{g}/\text{cm}^2 \cdot \text{s}$)	Air flow rate (LPM)	Air mass velocity ($\text{g}/\text{cm}^2 \cdot \text{s}$)	Pressure drop (mmH_2O)	Pressure drop ($\text{mmH}_2\text{O}/\text{cm}$)
60	500	0.15	0.0	0.00	2.50	0.04
			0.5	0.19	2.50	0.04
			1.0	0.39	2.50	0.04
			1.5	0.58	2.50	0.04
			2.0	0.78	2.50	0.04
			2.5	0.97	2.66	0.04
			3.0	1.17	3.16	0.05
			3.5	1.36	3.66	0.06
			4.0	1.56	4.00	0.07
			4.5	1.75	4.99	0.08
			5.0	1.94	5.49	0.09
			5.5	2.14	4.83	0.08
			6.0	2.33	5.66	0.09
			6.5	2.53	5.66	0.09
			7.0	2.72	5.49	0.09
			8.0	3.11	6.66	0.11
			9.0	3.50	6.33	0.11
			10.0	3.89	7.66	0.13
			11.0	4.28	10.16	0.17
			12.0	4.67	11.15	0.19
13.0	5.06	11.32	0.19			
14.0	5.44	12.15	0.20			
15.0	5.83	13.49	0.22			
16.0	6.22	22.48	0.37			
17.0	6.61	23.97	0.40			
18.0	7.00	24.31	0.41			
19.0	7.39	25.81	0.43			
20.0	7.78	27.14	0.45			

Height of bed (cm)	Water flow rate (ml/min)	Water mass velocity ($\text{g}/\text{cm}^2\cdot\text{s}$)	Air flow rate (LPM)	Air mass velocity ($\text{g}/\text{cm}^2\cdot\text{s}$)	Pressure drop (mmH_2O)	Pressure drop ($\text{mmH}_2\text{O}/\text{cm}$)
60	800	0.24	0.0	0.00	3.16	0.05
			0.5	0.19	3.16	0.05
			1.0	0.39	3.16	0.05
			1.5	0.58	3.16	0.05
			2.0	0.78	3.33	0.06
			2.5	0.97	3.66	0.06
			3.0	1.17	4.00	0.07
			3.5	1.36	3.50	0.06
			4.0	1.56	2.83	0.05
			4.5	1.75	4.16	0.07
			5.0	1.94	5.83	0.10
			5.5	2.14	4.50	0.07
			6.0	2.33	4.83	0.08
			6.5	2.53	7.33	0.12
			7.0	2.72	7.16	0.12
			8.0	3.11	8.99	0.15
			9.0	3.50	9.32	0.16
			10.0	3.89	10.16	0.17
			11.0	4.28	10.66	0.18
			12.0	4.67	11.82	0.20
13.0	5.06	15.32	0.26			
14.0	5.44	17.81	0.30			
15.0	5.83	19.15	0.32			
16.0	6.22	23.64	0.39			
17.0	6.61	29.97	0.50			
18.0	7.00	32.30	0.54			
19.0	7.39	32.96	0.55			
20.0	7.78	34.13	0.57			

Height of bed (cm)	Water flow rate (ml/min)	Water mass velocity ($\text{g}/\text{cm}^2 \cdot \text{s}$)	Air flow rate (LPM)	Air mass velocity ($\text{g}/\text{cm}^2 \cdot \text{s}$)	Pressure drop (mmH_2O)	Pressure drop ($\text{mmH}_2\text{O}/\text{cm}$)
60	1000	0.3	0.0	0.00	2.00	0.03
			0.5	0.19	2.00	0.03
			1.0	0.39	2.00	0.03
			1.5	0.58	2.00	0.03
			2.0	0.78	2.00	0.03
			2.5	0.97	2.00	0.03
			3.0	1.17	2.00	0.03
			3.5	1.36	2.16	0.04
			4.0	1.56	3.66	0.06
			4.5	1.75	4.00	0.07
			5.0	1.94	3.16	0.05
			5.5	2.14	3.33	0.06
			6.0	2.33	4.99	0.08
			6.5	2.53	5.49	0.09
			7.0	2.72	5.33	0.09
			8.0	3.11	5.99	0.10
			9.0	3.50	6.49	0.11
			10.0	3.89	7.82	0.13
			11.0	4.28	12.32	0.21
			12.0	4.67	15.32	0.26
13.0	5.06	18.65	0.31			
14.0	5.44	18.48	0.31			
15.0	5.83	26.47	0.44			
16.0	6.22	28.14	0.47			
17.0	6.61	29.14	0.49			
18.0	7.00	29.63	0.49			
19.0	7.39	29.47	0.49			
20.0	7.78	29.97	0.50			

Height of bed (cm)	Water flow rate (ml/min)	Water mass velocity ($\text{g}/\text{cm}^2 \cdot \text{s}$)	Air flow rate (LPM)	Air mass velocity ($\text{g}/\text{cm}^2 \cdot \text{s}$)	Pressure drop (mmH_2O)	Pressure drop ($\text{mmH}_2\text{O}/\text{cm}$)
60	1200	0.36	0.0	0.00	2.50	0.04
			0.5	0.19	2.16	0.04
			1.0	0.39	2.33	0.04
			1.5	0.58	2.50	0.04
			2.0	0.78	2.50	0.04
			2.5	0.97	4.16	0.07
			3.0	1.17	3.83	0.06
			3.5	1.36	5.49	0.09
			4.0	1.56	7.16	0.12
			4.5	1.75	6.83	0.11
			5.0	1.94	7.99	0.13
			5.5	2.14	7.66	0.13
			6.0	2.33	7.33	0.12
			6.5	2.53	8.49	0.14
			7.0	2.72	8.32	0.14
			8.0	3.11	8.99	0.15
			9.0	3.50	9.99	0.17
			10.0	3.89	9.32	0.16
			11.0	4.28	9.82	0.16
			12.0	4.67	20.81	0.35
13.0	5.06	21.48	0.36			
14.0	5.44	29.47	0.49			
15.0	5.83	30.80	0.51			
16.0	6.22	30.63	0.51			
17.0	6.61	31.97	0.53			
18.0	7.00	33.30	0.55			
19.0	7.39	34.13	0.57			
20.0	7.78	35.46	0.59			

Height of bed (cm)	Water flow rate (ml/min)	Water mass velocity ($\text{g}/\text{cm}^2\cdot\text{s}$)	Air flow rate (LPM)	Air mass velocity ($\text{g}/\text{cm}^2\cdot\text{s}$)	Pressure drop (mmH_2O)	Pressure drop ($\text{mmH}_2\text{O}/\text{cm}$)
60	1500	0.45	0.0	0.00	3.16	0.05
			0.5	0.19	3.16	0.05
			1.0	0.39	3.16	0.05
			1.5	0.58	3.50	0.06
			2.0	0.78	4.83	0.08
			2.5	0.97	4.99	0.08
			3.0	1.17	7.33	0.12
			3.5	1.36	7.33	0.12
			4.0	1.56	6.83	0.11
			4.5	1.75	9.66	0.16
			5.0	1.94	10.82	0.18
			5.5	2.14	9.82	0.16
			6.0	2.33	10.32	0.17
			6.5	2.53	11.15	0.19
			7.0	2.72	13.82	0.23
			8.0	3.11	14.82	0.25
			9.0	3.50	15.82	0.26
			10.0	3.89	23.64	0.39
			11.0	4.28	32.96	0.55
			12.0	4.67	34.80	0.58
13.0	5.06	35.30	0.59			
14.0	5.44	36.63	0.61			
15.0	5.83	36.63	0.61			
16.0	6.22	38.29	0.64			
17.0	6.61	39.29	0.65			
18.0	7.00	39.12	0.65			
19.0	7.39	41.62	0.69			
20.0	7.78	40.46	0.67			

Height of bed (cm)	Water flow rate (ml/min)	Water mass velocity ($\text{g}/\text{cm}^2 \cdot \text{s}$)	Air flow rate (LPM)	Air mass velocity ($\text{g}/\text{cm}^2 \cdot \text{s}$)	Pressure drop (mmH_2O)	Pressure drop ($\text{mmH}_2\text{O}/\text{cm}$)
60	2000	0.60	0.0	0.00	3.83	0.06
			0.5	0.19	4.16	0.07
			1.0	0.39	3.83	0.06
			1.5	0.58	5.33	0.09
			2.0	0.78	6.33	0.11
			2.5	0.97	6.66	0.11
			3.0	1.17	7.66	0.13
			3.5	1.36	7.16	0.12
			4.0	1.56	7.99	0.13
			4.5	1.75	8.49	0.14
			5.0	1.94	8.66	0.14
			5.5	2.14	16.32	0.27
			6.0	2.33	18.65	0.31
			6.5	2.53	27.80	0.46
			7.0	2.72	28.30	0.47
			8.0	3.11	27.80	0.46
			9.0	3.50	28.47	0.47
			10.0	3.89	30.30	0.51
			11.0	4.28	42.45	0.71
			12.0	4.67	48.61	0.81
			13.0	5.06	50.78	0.85
14.0	5.44	49.78	0.83			
15.0	5.83	53.11	0.89			
16.0	6.22	57.94	0.97			
17.0	6.61	58.27	0.97			
18.0	7.00	62.10	1.03			
19.0	7.39	76.25	1.27			
20.0	7.78	79.91	1.33			

Height of bed (cm)	Water flow rate (ml/min)	Water mass velocity ($\text{g}/\text{cm}^2 \cdot \text{s}$)	Air flow rate (LPM)	Air mass velocity ($\text{g}/\text{cm}^2 \cdot \text{s}$)	Pressure drop (mmH_2O)	Pressure drop ($\text{mmH}_2\text{O}/\text{cm}$)
80	500	0.15	0.0	0.00	1.17	0.01
			0.5	0.19	1.50	0.02
			1.0	0.39	1.50	0.02
			1.5	0.58	1.33	0.02
			2.0	0.78	1.33	0.02
			2.5	0.97	1.50	0.02
			3.0	1.17	1.17	0.01
			3.5	1.36	1.33	0.02
			4.0	1.56	1.33	0.02
			4.5	1.75	1.50	0.02
			5.0	1.94	2.00	0.02
			5.5	2.14	2.66	0.03
			6.0	2.33	4.00	0.05
			6.5	2.53	4.00	0.05
			7.0	2.72	3.50	0.04
			8.0	3.11	4.16	0.05
			9.0	3.50	5.49	0.07
			10.0	3.89	7.33	0.09
			11.0	4.28	6.66	0.08
			12.0	4.67	7.49	0.09
13.0	5.06	9.82	0.12			
14.0	5.44	10.82	0.14			
15.0	5.83	11.82	0.15			
16.0	6.22	15.65	0.20			
17.0	6.61	19.98	0.25			
18.0	7.00	19.98	0.25			
19.0	7.39	22.31	0.28			
20.0	7.78	24.97	0.31			

Height of bed (cm)	Water flow rate (ml/min)	Water mass velocity ($\text{g}/\text{cm}^2 \cdot \text{s}$)	Air flow rate (LPM)	Air mass velocity ($\text{g}/\text{cm}^2 \cdot \text{s}$)	Pressure drop (mmH_2O)	Pressure drop ($\text{mmH}_2\text{O}/\text{cm}$)
80	800	0.24	0.0	0.00	1.50	0.02
			0.5	0.19	1.50	0.02
			1.0	0.39	1.33	0.02
			1.5	0.58	1.66	0.02
			2.0	0.78	1.66	0.02
			2.5	0.97	1.66	0.02
			3.0	1.17	2.00	0.02
			3.5	1.36	2.50	0.03
			4.0	1.56	2.66	0.03
			4.5	1.75	3.50	0.04
			5.0	1.94	3.33	0.04
			5.5	2.14	4.66	0.06
			6.0	2.33	4.83	0.06
			6.5	2.53	4.99	0.06
			7.0	2.72	3.83	0.05
			8.0	3.11	4.00	0.05
			9.0	3.50	5.16	0.06
			10.0	3.89	6.99	0.09
			11.0	4.28	8.99	0.11
			12.0	4.67	11.49	0.14
13.0	5.06	15.15	0.19			
14.0	5.44	17.31	0.22			
15.0	5.83	23.97	0.30			
16.0	6.22	25.47	0.32			
17.0	6.61	25.97	0.32			
18.0	7.00	26.64	0.33			
19.0	7.39	26.97	0.34			
20.0	7.78	28.64	0.36			

Height of bed (cm)	Water flow rate (ml/min)	Water mass velocity ($\text{g}/\text{cm}^2 \cdot \text{s}$)	Air flow rate (LPM)	Air mass velocity ($\text{g}/\text{cm}^2 \cdot \text{s}$)	Pressure drop (mmH_2O)	Pressure drop ($\text{mmH}_2\text{O}/\text{cm}$)
80	1000	0.30	0.0	0.00	3.66	0.05
			0.5	0.19	3.66	0.05
			1.0	0.39	3.66	0.05
			1.5	0.58	3.83	0.05
			2.0	0.78	3.83	0.05
			2.5	0.97	4.00	0.05
			3.0	1.17	4.16	0.05
			3.5	1.36	5.66	0.07
			4.0	1.56	7.49	0.09
			4.5	1.75	7.33	0.09
			5.0	1.94	8.49	0.11
			5.5	2.14	8.99	0.11
			6.0	2.33	9.66	0.12
			6.5	2.53	9.82	0.12
			7.0	2.72	8.99	0.11
			8.0	3.11	9.99	0.12
			9.0	3.50	11.49	0.14
			10.0	3.89	12.99	0.16
			11.0	4.28	22.98	0.29
			12.0	4.67	26.31	0.33
13.0	5.06	28.14	0.35			
14.0	5.44	31.13	0.39			
15.0	5.83	32.13	0.40			
16.0	6.22	33.46	0.42			
17.0	6.61	33.80	0.42			
18.0	7.00	34.13	0.43			
19.0	7.39	34.13	0.43			
20.0	7.78	35.13	0.44			

Height of bed (cm)	Water flow rate (ml/min)	Water mass velocity (g/cm ² .s)	Air flow rate (LPM)	Air mass velocity (g/cm ² .s)	Pressure drop (mmH ₂ O)	Pressure drop (mmH ₂ O/cm)
80	1200	0.36	0.0	0.00	3.66	0.05
			0.5	0.19	4.16	0.05
			1.0	0.39	5.66	0.07
			1.5	0.58	6.33	0.08
			2.0	0.78	6.49	0.08
			2.5	0.97	7.16	0.09
			3.0	1.17	8.16	0.10
			3.5	1.36	8.32	0.10
			4.0	1.56	8.99	0.11
			4.5	1.75	8.49	0.11
			5.0	1.94	9.16	0.11
			5.5	2.14	8.82	0.11
			6.0	2.33	9.16	0.11
			6.5	2.53	9.16	0.11
			7.0	2.72	8.82	0.11
			8.0	3.11	9.32	0.12
			9.0	3.50	9.99	0.12
			10.0	3.89	22.14	0.28
			11.0	4.28	24.81	0.31
			12.0	4.67	27.97	0.35
13.0	5.06	29.14	0.36			
14.0	5.44	31.13	0.39			
15.0	5.83	31.30	0.39			
16.0	6.22	33.13	0.41			
17.0	6.61	33.30	0.42			
18.0	7.00	35.79	0.45			
19.0	7.39	34.46	0.43			
20.0	7.78	34.96	0.44			

Height of bed (cm)	Water flow rate (ml/min)	Water mass velocity ($\text{g}/\text{cm}^2 \cdot \text{s}$)	Air flow rate (LPM)	Air mass velocity ($\text{g}/\text{cm}^2 \cdot \text{s}$)	Pressure drop (mmH_2O)	Pressure drop ($\text{mmH}_2\text{O}/\text{cm}$)
80	1500	0.45	0.0	0.00	2.33	0.03
			0.5	0.19	4.00	0.05
			1.0	0.39	4.50	0.06
			1.5	0.58	5.33	0.07
			2.0	0.78	5.49	0.07
			2.5	0.97	6.49	0.08
			3.0	1.17	5.83	0.07
			3.5	1.36	6.66	0.08
			4.0	1.56	7.82	0.10
			4.5	1.75	8.16	0.10
			5.0	1.94	9.16	0.11
			5.5	2.14	9.49	0.12
			6.0	2.33	10.16	0.13
			6.5	2.53	14.65	0.18
			7.0	2.72	15.32	0.19
			8.0	3.11	19.15	0.24
			9.0	3.50	27.14	0.34
			10.0	3.89	27.97	0.35
			11.0	4.28	31.13	0.39
			12.0	4.67	32.47	0.41
13.0	5.06	34.13	0.43			
14.0	5.44	36.63	0.46			
15.0	5.83	27.80	0.35			
16.0	6.22	28.14	0.35			
17.0	6.61	37.96	0.47			
18.0	7.00	38.63	0.48			
19.0	7.39	39.46	0.49			
20.0	7.78	41.12	0.51			

Height of bed (cm)	Water flow rate (ml/min)	Water mass velocity (g/cm ² .s)	Air flow rate (LPM)	Air mass velocity (g/cm ² .s)	Pressure drop (mmH ₂ O)	Pressure drop (mmH ₂ O/cm)
80	2000	0.60	0.0	0.00	5.16	0.06
			0.5	0.19	6.66	0.08
			1.0	0.39	7.16	0.09
			1.5	0.58	7.16	0.09
			2.0	0.78	7.82	0.10
			2.5	0.97	8.49	0.11
			3.0	1.17	8.66	0.11
			3.5	1.36	9.16	0.11
			4.0	1.56	9.49	0.12
			4.5	1.75	27.47	0.34
			5.0	1.94	37.29	0.47
			5.5	2.14	36.29	0.45
			6.0	2.33	32.96	0.41
			6.5	2.53	37.13	0.46
			7.0	2.72	32.96	0.41
			8.0	3.11	33.30	0.42
			9.0	3.50	37.96	0.47
			10.0	3.89	40.46	0.51
			11.0	4.28	45.78	0.57
			12.0	4.67	48.11	0.60
13.0	5.06	49.28	0.62			
14.0	5.44	52.94	0.66			
15.0	5.83	52.78	0.66			
16.0	6.22	58.10	0.73			
17.0	6.61	60.27	0.75			
18.0	7.00	65.93	0.82			
19.0	7.39	73.25	0.92			
20.0	7.78	78.08	0.98			

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