



Appendix

Dataset collected from Literature:

Diameter	Liquid density	Gas density	Liquid viscosity	Gas viscosity	sigma	alpha	VSL	VSG	Status	Reference
0.0762	1000	1.2	1.10E-03	0.000018	0.06	90	0.01	20	Loaded	Saadi
0.0762	1000	1.2	1.10E-03	0.000018	0.06	90	0.05	21.8	Loaded	Saadi
0.0762	1000	1.2	1.10E-03	0.000018	0.06	90	0.1	21.2	Loaded	Saadi
0.0762	1000	1.2	1.10E-03	0.000018	0.06	75	0.01	24.7	Loaded	Saadi
0.0762	1000	1.2	1.10E-03	0.000018	0.06	75	0.05	23.8	Loaded	Saadi
0.0762	1000	1.2	1.10E-03	0.000018	0.06	75	0.1	26.9	Loaded	Saadi
0.0762	1000	1.2	1.10E-03	0.000018	0.06	60	0.01	24.3	Loaded	Saadi
0.0762	1000	1.2	1.10E-03	0.000018	0.06	60	0.05	31.9	Loaded	Saadi
0.0762	1000	1.2	1.10E-03	0.000018	0.06	60	0.1	30.7	Loaded	Saadi
0.0762	1000	1.2	1.10E-03	0.000018	0.06	45	0.01	28.4	Loaded	Saadi
0.0762	1000	1.2	1.10E-03	0.000018	0.06	45	0.05	32.5	Loaded	Saadi
0.0762	1000	1.2	1.10E-03	0.000018	0.06	45	0.1	30	Loaded	Saadi
0.06	997.9	1.2	1.10E-03	0.000018	0.06	20	0.02	13.94	Loaded	Vierra water
0.06	997.9	1.2	1.10E-03	0.000018	0.06	20	0.06	14.54	Loaded	Vierra water
0.06	997.9	1.2	1.10E-03	0.000018	0.06	20	0.1	19.09	Loaded	Vierra water
0.06	997.9	1.2	1.10E-03	0.000018	0.06	30	0.01	19.47	Loaded	Vierra water
0.06	997.9	1.2	1.10E-03	0.000018	0.06	30	0.02	22.4	Loaded	Vierra water
0.06	997.9	1.2	1.10E-03	0.000018	0.06	30	0.05	23.32	Loaded	Vierra water
0.06	997.9	1.2	1.10E-03	0.000018	0.06	30	0.1	25.32	Loaded	Vierra water
0.06	997.9	1.2	1.10E-03	0.000018	0.06	30	0.2	25.63	Loaded	Vierra water
0.06	997.9	1.2	1.10E-03	0.000018	0.06	45	0.01	19.8	Loaded	Vierra water
0.06	997.9	1.2	1.10E-03	0.000018	0.06	45	0.02	21.46	Loaded	Vierra water
0.06	997.9	1.2	1.10E-03	0.000018	0.06	45	0.05	25.19	Loaded	Vierra water
0.06	997.9	1.2	1.10E-03	0.000018	0.06	45	0.1	24.76	Loaded	Vierra water
0.06	997.9	1.2	1.10E-03	0.000018	0.06	45	0.2	24.69	Loaded	Vierra water
0.06	997.9	1.2	1.10E-03	0.000018	0.06	60	0.01	19.48	Loaded	Vierra water
0.06	997.9	1.2	1.10E-03	0.000018	0.06	60	0.02	21.72	Loaded	Vierra water
0.06	997.9	1.2	1.10E-03	0.000018	0.06	60	0.05	23.7	Loaded	Vierra water
0.06	997.9	1.2	1.10E-03	0.000018	0.06	60	0.1	25.57	Loaded	Vierra water
0.06	997.9	1.2	1.10E-03	0.000018	0.06	60	0.2	24.86	Loaded	Vierra water
0.06	997.9	1.2	1.10E-03	0.000018	0.06	70	0.01	18.11	Loaded	Vierra water
0.06	997.9	1.2	1.10E-03	0.000018	0.06	70	0.02	20.03	Loaded	Vierra water
0.06	997.9	1.2	1.10E-03	0.000018	0.06	70	0.05	24.18	Loaded	Vierra water
0.06	997.9	1.2	1.10E-03	0.000018	0.06	70	0.1	23.47	Loaded	Vierra water
0.06	997.9	1.2	1.10E-03	0.000018	0.06	70	0.2	23.72	Loaded	Vierra water
0.06	997.9	1.2	1.10E-03	0.000018	0.06	78	0.01	16.45	Loaded	Vierra water

0.06	997.9	1.2	1.10E-03	0.000018	0.06	78	0.02	18.97	Loaded	Vierra water
0.06	997.9	1.2	1.10E-03	0.000018	0.06	78	0.05	21.94	Loaded	Vierra water
0.06	997.9	1.2	1.10E-03	0.000018	0.06	78	0.1	24.4	Loaded	Vierra water
0.06	997.9	1.2	1.10E-03	0.000018	0.06	78	0.2	24.49	Loaded	Vierra water
0.06	800	1.2	2.50E-03	0.000018	0.0249	20	0.02	13.94	Loaded	Vierra oil
0.06	800	1.2	2.50E-03	0.000018	0.0249	20	0.06	14.54	Loaded	Vierra oil
0.06	800	1.2	2.50E-03	0.000018	0.0249	20	0.1	19.09	Loaded	Vierra oil
0.06	800	1.2	2.50E-03	0.000018	0.0249	30	0.01	19.47	Loaded	Vierra oil
0.06	800	1.2	2.50E-03	0.000018	0.0249	30	0.02	22.4	Loaded	Vierra oil
0.06	800	1.2	2.50E-03	0.000018	0.0249	30	0.05	23.32	Loaded	Vierra oil
0.06	800	1.2	2.50E-03	0.000018	0.0249	30	0.1	25.32	Loaded	Vierra oil
0.06	800	1.2	2.50E-03	0.000018	0.0249	30	0.2	25.63	Loaded	Vierra oil
0.06	800	1.2	2.50E-03	0.000018	0.0249	45	0.01	19.8	Loaded	Vierra oil
0.06	800	1.2	2.50E-03	0.000018	0.0249	45	0.02	21.46	Loaded	Vierra oil
0.112014	1073.24	2.992301836	0.001193673	1.10E-05	0.06	70	0.009391	10.14588	Loaded	Veeken
0.12573	1073.24	2.992301836	0.001193673	1.10E-05	0.06	70	0.007454	9.794161	Loaded	Veeken
0.071374	1073.24	4.127312877	0.001193673	1.10E-05	0.06	66	0.023131	10.28265	Loaded	Veeken
0.072898	1073.24	4.488452754	0.001193673	1.10E-05	0.06	69	0.022174	11.22257	Loaded	Veeken
0.075946	1073.24	4.488452754	0.001193673	1.10E-05	0.06	90	0.02043	10.33963	Loaded	Veeken
0.075946	1073.24	4.488452754	0.001193673	1.10E-05	0.06	67	0.02043	10.33963	Loaded	Veeken
0.072898	1073.24	4.127312877	0.001193673	1.10E-05	0.06	76	0.022174	11.2655	Loaded	Veeken
0.100584	1073.24	4.488452754	0.001193673	1.10E-05	0.06	63	0.011647	11.33583	Loaded	Veeken
0.124206	1073.24	4.488452754	0.001193673	1.10E-05	0.06	68	0.007638	9.069555	Loaded	Veeken
0.124206	1073.24	4.488452754	0.001193673	1.10E-05	0.06	74	0.007638	10.11032	Loaded	Veeken
0.124206	1073.24	4.488452754	0.001193673	1.10E-05	0.06	70	0.007638	10.55637	Loaded	Veeken
0.124206	1073.24	4.488452754	0.001193673	1.10E-05	0.06	61	0.007638	12.93527	Loaded	Veeken
0.075946	1073.24	4.488452754	0.001193673	1.10E-05	0.06	63	0.02043	10.33963	Loaded	Veeken
0.04445	1073.24	4.488452754	0.001193673	1.10E-05	0.06	74	0.059639	12.76999	Loaded	Veeken
0.124206	1073.24	4.488452754	0.001193673	1.10E-05	0.06	66	0.007638	8.177468	Loaded	Veeken
0.124206	1073.24	4.488452754	0.001193673	1.10E-05	0.06	73	0.007638	9.366917	Loaded	Veeken
0.124206	1073.24	4.488452754	0.001193673	1.10E-05	0.06	60	0.007638	10.55637	Loaded	Veeken
0.124206	1073.24	4.488452754	0.001193673	1.10E-05	0.06	43	0.007638	11.00241	Loaded	Veeken
0.124206	1073.24	4.488452754	0.001193673	1.10E-05	0.06	71	0.007638	9.366917	Loaded	Veeken
0.100584	1073.24	5.262323919	0.001193673	1.10E-05	0.06	48	0.011647	10.24893	Loaded	Veeken
0.112014	1073.24	10.36111299	0.000490595	1.26E-05	0.06	77	0.009391	8.456204	Loaded	Veeken
0.108712	1073.24	17.42354239	0.000660216	1.22E-05	0.06	63	0.009971	6.406433	Loaded	Veeken
0.154686	1073.24	10.03185619	0.00041292	1.30E-05	0.06	72	0.004925	10.07548	Loaded	Veeken
0.112014	1073.24	32.98046983	0.000613609	1.27E-05	0.06	70	0.009391	3.453571	Loaded	Veeken
0.112014	1073.24	59.36027916	0.000648117	1.35E-05	0.06	70	0.009391	2.951997	Loaded	Veeken
0.108712	1073.24	10.59305593	0.000561569	1.23E-05	0.06	68	0.009971	9.659205	Loaded	Veeken
0.154686	1073.24	56.34984812	0.000515596	1.39E-05	0.06	59	0.004925	2.527513	Loaded	Veeken

0.108712	1073.24	65.59798812	0.000602674	1.42E-05	0.06	90	0.009971	2.655966	Loaded	Veeken
0.108712	1073.24	56.91929581	0.000602674	1.38E-05	0.06	90	0.009971	3.06093	Loaded	Veeken
0.108712	1073.24	31.2445499	0.00041292	1.38E-05	0.06	90	0.009971	4.739774	Loaded	Veeken
0.108712	1073.24	56.91929581	0.000602674	1.38E-05	0.06	90	0.009971	2.754819	Loaded	Veeken
0.154686	1073.24	29.5486647	0.000400849	1.37E-05	0.06	75	0.004925	7.979061	Loaded	Veeken
0.154686	1073.24	22.22331287	0.00043884	1.33E-05	0.06	75	0.004925	7.806737	Loaded	Veeken
0.154686	1073.24	33.45528775	0.000445713	1.35E-05	0.06	51	0.004925	5.451711	Loaded	Veeken
0.154686	1073.24	25.3657135	0.000425573	1.34E-05	0.06	51	0.004925	6.48886	Loaded	Veeken
0.154686	1073.24	17.51687435	0.000419172	1.32E-05	0.06	51	0.004925	7.872612	Loaded	Veeken
0.154686	1073.24	15.61175752	0.000698421	1.21E-05	0.06	51	0.004925	9.973096	Loaded	Veeken
0.108712	1073.24	32.53951483	0.000685359	1.26E-05	0.06	27	0.009971	4.151844	Loaded	Veeken
0.108712	1073.24	23.14829936	0.000648117	1.25E-05	0.06	27	0.009971	5.058073	Loaded	Veeken
0.108712	1073.24	16.07070188	0.000832576	1.18E-05	0.06	27	0.009971	7.846103	Loaded	Veeken
0.112014	1073.24	9.047691795	0.000685359	1.18E-05	0.06	47	0.009391	16.98501	Loaded	Veeken
0.112014	1073.24	14.43744182	0.000613609	1.21E-05	0.06	55	0.009391	8.452754	Loaded	Veeken
0.112014	1073.24	27.22920286	0.000698421	1.22E-05	0.06	60	0.009391	4.647804	Loaded	Veeken
0.112014	1073.24	18.38109526	0.000754178	1.18E-05	0.06	60	0.009391	5.655632	Loaded	Veeken
0.112014	1073.24	16.00697883	0.000725578	1.19E-05	0.06	60	0.009391	6.212094	Loaded	Veeken
0.112014	1073.24	13.87500677	0.000784308	1.17E-05	0.06	60	0.009391	6.189351	Loaded	Veeken
0.112014	1073.24	14.3491339	0.000515596	1.25E-05	0.06	60	0.009391	6.299832	Loaded	Veeken
0.154686	1073.24	17.73390852	0.000546238	1.26E-05	0.06	50	0.004925	6.088185	Loaded	Veeken
0.156972	1073.24	8.446289825	0.000551916	1.23E-05	0.06	72	0.004782	10.56438	Loaded	Veeken
0.154686	1073.24	8.148316936	0.000452752	1.28E-05	0.06	64	0.004925	12.40445	Loaded	Veeken
0.112014	1073.24	32.96832078	0.000725578	1.24E-05	0.06	60	0.009391	4.319572	Loaded	Veeken
0.112014	1073.24	32.10316762	0.000542499	1.29E-05	0.06	69	0.009391	4.02012	Loaded	Veeken
0.112014	1073.24	16.49525418	0.000432128	1.30E-05	0.06	71	0.009391	6.373945	Loaded	Veeken
0.108712	1073.24	18.03893406	0.00041292	1.32E-05	0.06	65	0.009971	9.797496	Loaded	Veeken
0.108712	1073.24	24.37329626	0.000445713	1.32E-05	0.06	65	0.009971	5.724644	Loaded	Veeken
0.108712	1073.24	17.04919757	0.000459961	1.29E-05	0.06	65	0.009971	7.092678	Loaded	Veeken
0.108712	1073.24	62.25603885	0.000507059	1.40E-05	0.06	58	0.009971	3.083122	Loaded	Veeken
0.112014	1073.24	12.68238275	0.000486602	1.28E-05	0.06	61	0.009391	11.37155	Loaded	Veeken
0.112014	1073.24	15.44780556	0.00098185	1.12E-05	0.06	59	0.009391	4.753491	Loaded	Veeken
0.108712	1073.24	17.40353303	0.000754178	1.21E-05	0.06	42	0.009971	8.008696	Loaded	Veeken
0.118618	1073.24	19.4769013	0.001046702	1.16E-05	0.06	28	0.008375	3.102182	Loaded	Veeken
0.073152	1073.24	20.90511046	0.000849535	1.20E-05	0.06	41	0.02202	5.247444	Loaded	Veeken
0.108712	1073.24	23.28747792	0.001093002	1.16E-05	0.06	26	0.009971	4.793199	Loaded	Veeken
0.099568	1073.24	17.04090537	0.001193673	1.14E-05	0.06	34	0.011886	4.852534	Loaded	Veeken
0.112014	1073.24	22.15389957	0.000799975	1.21E-05	0.06	44	0.009391	4.256235	Loaded	Veeken
0.156972	1073.24	82.3760606	0.000571465	1.46E-05	0.06	60	0.004782	3.205776	Loaded	Veeken
0.154686	1073.24	66.51483154	0.000571465	1.40E-05	0.06	75	0.004925	5.252258	Loaded	Veeken
0.050673	1073	8.072686025	0.00094442	1.15E-05	0.06	90	0	8.831558	unloaded	Luo

0.050673	1073	7.181223765	0.00094442	1.14E-05	0.06	90	0.005507	11.58254	unloaded	Luo
0.050673	1073	12.38142028	0.00094442	1.15E-05	0.06	90	0.002295	6.813841	unloaded	Luo
0.050673	1073	10.40039304	0.00094442	1.15E-05	0.06	90	0.009178	10.8537	unloaded	Luo
0.050673	1073	4.457311302	0.00094442	1.14E-05	0.06	90	0.001836	17.32784	unloaded	Luo
0.050673	1073	4.704939708	0.00094442	1.14E-05	0.06	90	0.003671	17.67861	unloaded	Luo
0.050673	1073	5.447824925	0.00094442	1.14E-05	0.06	90	0.000918	15.70412	unloaded	Luo
0.050673	1073	7.924108982	0.00094442	1.15E-05	0.06	90	9.18E-05	12.74596	unloaded	Luo
0.050673	1073	9.657507822	0.00094442	1.15E-05	0.06	90	0.001836	6.151897	unloaded	Luo
0.050673	1073	6.339287186	0.00094442	1.14E-05	0.06	90	0.000551	13.49572	unloaded	Luo
0.050673	1073	7.428852171	0.00094442	1.14E-05	0.06	90	9.18E-05	11.19645	unloaded	Luo
0.050673	1073	8.419365793	0.00094442	1.15E-05	0.06	90	0.001836	5.64527	unloaded	Luo
0.050673	1073	10.40039304	0.00094442	1.15E-05	0.06	90	0.002753	10.8537	unloaded	Luo
0.062001	1073	2.476284057	0.00094442	1.14E-05	0.06	90	0.003065	14.42336	Loaded	Luo
0.044475	1073	3.962054491	0.00094442	1.14E-05	0.06	90	0.005957	9.732787	Loaded	Luo
0.044475	1073	4.457311302	0.00094442	1.14E-05	0.06	90	0.005957	8.651366	Loaded	Luo
0.050673	1073	2.723912463	0.00094442	1.14E-05	0.06	90	0.004589	9.59696	Loaded	Luo
0.050673	1073	2.971540868	0.00094442	1.14E-05	0.06	90	0.004589	7.597593	Loaded	Luo
0.050673	1073	4.061105853	0.00094442	1.14E-05	0.06	90	0.004589	11.70361	Loaded	Luo
0.050673	1073	2.575335419	0.00094442	1.14E-05	0.06	90	0.004589	13.84177	Loaded	Luo
0.050673	1073	8.419365793	0.00094442	1.15E-05	0.06	90	0.004589	8.185642	Loaded	Luo
0.050673	1073	9.409879416	0.00094442	1.15E-05	0.06	90	0.002753	6.313789	Loaded	Luo
0.050673	1073	7.924108982	0.00094442	1.15E-05	0.06	90	0.001836	8.547292	Loaded	Luo
0.050673	1073	10.64802144	0.00094442	1.15E-05	0.06	90	9.18E-05	6.13759	Loaded	Luo
0.050673	1073	6.438338548	0.00094442	1.14E-05	0.06	90	0.001377	7.382277	Loaded	Luo
0.050673	1073	6.438338548	0.00094442	1.14E-05	0.06	90	0.000459	7.013163	Loaded	Luo
0.050673	1073	5.051619476	0.00094442	1.14E-05	0.06	90	9.18E-05	9.408784	Loaded	Luo
0.050673	1073	4.952568114	0.00094442	1.14E-05	0.06	90	0.002753	7.19772	Loaded	Luo
0.048412	1073	10.15276463	0.00094442	1.15E-05	0.06	90	0.000151	6.41106	Loaded	Luo
0.060325	1073	11.63853507	0.00094442	1.15E-05	0.06	90	0.000648	2.737461	Loaded	Luo
0.050673	1073	8.419365793	0.00094442	1.15E-05	0.06	90	9.18E-05	10.16149	Loaded	Luo
0.050673	1073	8.419365793	0.00094442	1.15E-05	0.06	90	0.000459	6.209797	Loaded	Luo
0.050673	1073	3.565849042	0.00094442	1.14E-05	0.06	90	9.18E-05	9.996833	Loaded	Luo
0.050673	1073	7.924108982	0.00094442	1.15E-05	0.06	90	0.005507	7.79753	Loaded	Luo
0.050673	1073	6.438338548	0.00094442	1.14E-05	0.06	90	0.002753	9.227846	Loaded	Luo
0.050673	1073	6.933595359	0.00094442	1.14E-05	0.06	90	7.34E-05	8.225965	Loaded	Luo
0.050673	1073	8.914622605	0.00094442	1.15E-05	0.06	90	9.18E-05	6.664555	Loaded	Luo
0.050673	1073	8.666994199	0.00094442	1.15E-05	0.06	90	0.001836	8.225965	Loaded	Luo
0.050673	1073	9.657507822	0.00094442	1.15E-05	0.06	90	0.001836	7.382277	Loaded	Luo
0.050673	1073	6.438338548	0.00094442	1.14E-05	0.06	90	9.18E-05	7.19772	Loaded	Luo
0.050673	1073	6.438338548	0.00094442	1.14E-05	0.06	90	9.18E-05	8.305061	Loaded	Luo
0.050673	1073	8.419365793	0.00094442	1.15E-05	0.06	90	0.000184	6.350929	Loaded	Luo

0.050673	1073	7.428852171	0.00094442	1.14E-05	0.06	90	0.001836	6.397973	Loaded	Luo
0.050673	1073	7.181223765	0.00094442	1.14E-05	0.06	90	0.002295	9.100565	Loaded	Luo
0.050673	1073	7.924108982	0.00094442	1.15E-05	0.06	90	0.000918	7.497625	Loaded	Luo
0.050673	1073	8.419365793	0.00094442	1.15E-05	0.06	90	0.001377	5.64527	Loaded	Luo
0.050673	1073	7.676480576	0.00094442	1.14E-05	0.06	90	0.00101	7.894273	Loaded	Luo
0.050673	1073	4.457311302	0.00094442	1.14E-05	0.06	90	0.000459	7.464302	Loaded	Luo
0.050673	1073	6.438338548	0.00094442	1.14E-05	0.06	90	0.000459	8.305061	Loaded	Luo
0.050673	1073	6.933595359	0.00094442	1.14E-05	0.06	90	9.18E-05	8.911462	Loaded	Luo
0.050673	1073	7.329800808	0.00094442	1.14E-05	0.06	90	9.18E-05	8.429762	Loaded	Luo
0.050673	1073	8.171737388	0.00094442	1.15E-05	0.06	90	0.001285	9.160734	Loaded	Luo
0.050673	1073	7.676480576	0.00094442	1.14E-05	0.06	90	0.000459	7.739484	Loaded	Luo
0.050673	1073	6.190710142	0.00094442	1.14E-05	0.06	90	0.000229	8.445324	Loaded	Luo
0.047422	1073	5.943081736	0.00094442	1.14E-05	0.06	90	9.43E-05	10.27311	Loaded	Luo
0.050673	1073	5.943081736	0.00094442	1.14E-05	0.06	90	0.000688	7.997466	Loaded	Luo
0.050673	1073	9.063199648	0.00094442	1.15E-05	0.06	90	9.18E-05	9.83295	Loaded	Luo
0.050673	1073	6.933595359	0.00094442	1.14E-05	0.06	90	0.001377	8.225965	Loaded	Luo
0.050673	1073	8.171737388	0.00094442	1.15E-05	0.06	90	0.002753	8.5791	Loaded	Luo
0.050673	1073	7.924108982	0.00094442	1.15E-05	0.06	90	0.002295	8.99715	Loaded	Luo
0.047422	1073	5.447824925	0.00094442	1.14E-05	0.06	90	0.000105	12.20321	Loaded	Luo
0.050673	1073	5.695453331	0.00094442	1.14E-05	0.06	90	9.18E-05	10.01422	Loaded	Luo
0.062001	724.5263697	34.84810172	0.000507059	1.33E-05	0.02	90	0.002851	1.765131	Loaded	Turner
0.050673	1073.24	19.22653888	0.000507059	1.29E-05	0.06	90	0.006889	2.577146	Loaded	Turner
0.051841	1073.24	5.191165497	0.000507059	1.26E-05	0.06	90	0.006176	12.42188	Loaded	Turner
0.050673	1073.24	25.95582748	0.000507059	1.31E-05	0.06	90	0.006861	3.259487	Loaded	Turner
0.050673	735.0649351	21.62985624	0.000507059	1.30E-05	0.02	90	0.004584	2.428135	Loaded	Turner
0.050673	735.0649351	173.3753143	0.000507059	2.10E-05	0.02	90	0.052347	1.045169	Loaded	Turner
0.050673	735.0649351	165.0598363	0.000507059	2.03E-05	0.02	90	0.100437	2.106382	unloaded	Turner
0.050673	746.701847	175.9228307	0.000507059	2.12E-05	0.02	90	0.125846	2.516661	unloaded	Turner
0.075997	753.0601384	160.5415996	0.000507059	1.99E-05	0.02	90	0.139356	0.859184	Loaded	Turner
0.062001	753.0601384	170.1548691	0.000507059	2.07E-05	0.02	90	0.126221	0.84615	Loaded	Turner
0.050673	758.7131367	169.4338739	0.000507059	2.06E-05	0.02	90	0.175818	1.25673	Loaded	Turner
0.050673	758.7131367	166.8863575	0.000507059	2.04E-05	0.02	90	0.252347	1.831278	unloaded	Turner
0.062001	758.7131367	160.4454669	0.000507059	1.99E-05	0.02	90	0.163007	1.118478	Loaded	Turner
0.062001	758.7131367	148.6211455	0.000507059	1.91E-05	0.02	90	0.241591	1.789568	unloaded	Turner
0.050673	758.7131367	166.0692296	0.000507059	2.04E-05	0.02	90	0.265067	1.981244	unloaded	Turner
0.062001	738.9033943	176.1631625	0.000507059	2.12E-05	0.02	90	0.106438	1.145288	Loaded	Turner
0.062001	738.9033943	173.7598451	0.000507059	2.10E-05	0.02	90	0.162881	1.776865	unloaded	Turner
0.062001	738.9033943	154.3891072	0.000507059	1.95E-05	0.02	90	0.085567	1.309383	Loaded	Turner
0.062001	738.9033943	145.4007003	0.000507059	1.88E-05	0.02	90	0.118155	1.919819	unloaded	Turner
0.062001	711.0552764	394.8650422	0.000507059	5.84E-05	0.02	90	0.022988	0.697887	Loaded	Turner
0.062001	711.0552764	355.931301	0.000507059	4.79E-05	0.02	90	0.045989	1.548899	unloaded	Turner

0.050673	720.1017812	106.9956889	0.000507059	1.64E-05	0.02	90	0.032184	2.175566	unloaded	Turner
0.100533	720.1017812	76.42549204	0.000507059	1.49E-05	0.02	90	0.009191	1.188563	Loaded	Turner
0.100533	720.1017812	73.06084774	0.000507059	1.48E-05	0.02	90	0.012677	1.714754	unloaded	Turner
0.050673	1073.24	88.2017471	0.000507059	1.55E-05	0.06	90	0.003184	11.68278	unloaded	Turner
0.050673	1073.24	116.3686266	0.000507059	1.70E-05	0.06	90	0.002443	6.794399	unloaded	Turner
0.050673	1073.24	130.0194692	0.000507059	1.78E-05	0.06	90	0.001886	4.693759	unloaded	Turner
0.050673	1073.24	139.1040088	0.000507059	1.84E-05	0.06	90	0.001438	3.345939	unloaded	Turner
0.050673	1073.24	243.0234514	0.000507059	2.81E-05	0.06	90	0.004338	1.650663	unloaded	Turner
0.050673	1073.24	237.015158	0.000507059	2.73E-05	0.06	90	0.006206	2.421448	unloaded	Turner
0.050673	1073.24	230.0455377	0.000507059	2.65E-05	0.06	90	0.007994	3.213294	unloaded	Turner
0.050673	1073.24	219.9035384	0.000507059	2.54E-05	0.06	90	0.010012	4.210376	unloaded	Turner
0.050673	698.7654321	91.42219236	0.000507059	1.56E-05	0.02	90	0.032274	1.479091	unloaded	Turner
0.050673	698.7654321	83.49124508	0.000507059	1.52E-05	0.02	90	0.048552	2.436503	unloaded	Turner
0.050673	698.7654321	71.13819385	0.000507059	1.47E-05	0.02	90	0.070134	4.130717	unloaded	Turner
0.050673	698.7654321	59.8906686	0.000507059	1.42E-05	0.02	90	0.084088	5.882605	unloaded	Turner
0.050673	696.3582677	91.08572793	0.000507059	1.56E-05	0.02	90	0.089227	2.344239	unloaded	Turner
0.050673	696.3582677	89.45147213	0.000507059	1.55E-05	0.02	90	0.124232	3.323563	unloaded	Turner
0.050673	696.3582677	85.75036339	0.000507059	1.53E-05	0.02	90	0.1718	4.79451	unloaded	Turner
0.050673	696.3582677	80.75146329	0.000507059	1.51E-05	0.02	90	0.22041	6.53189	unloaded	Turner
0.04445	1073.24	135.258701	0.000507059	1.81E-05	0.06	90	0.001904	1.822139	unloaded	Turner
0.04445	1073.24	124.1073085	0.000507059	1.74E-05	0.06	90	0.00289	3.014879	unloaded	Turner
0.04445	1073.24	101.1315945	0.000507059	1.61E-05	0.06	90	0.004292	5.493993	unloaded	Turner
0.04445	1073.24	75.70449683	0.000507059	1.49E-05	0.06	90	0.00526	8.995613	unloaded	Turner
0.04445	769.439913	133.7686442	0.000507059	1.80E-05	0.02	90	0.011919	3.392807	unloaded	Turner
0.04445	769.439913	127.6161518	0.000507059	1.76E-05	0.02	90	0.01679	5.009663	unloaded	Turner
0.04445	769.439913	115.6476313	0.000507059	1.69E-05	0.02	90	0.023603	7.771415	unloaded	Turner
0.04445	769.439913	105.9862956	0.000507059	1.64E-05	0.02	90	0.027865	10.01115	unloaded	Turner
0.04445	1073.24	123.7227777	0.000507059	1.74E-05	0.06	90	0.001391	2.425141	unloaded	Turner
0.04445	1073.24	106.8995562	0.000507059	1.64E-05	0.06	90	0.002083	4.203692	unloaded	Turner
0.04445	1073.24	88.39401249	0.000507059	1.55E-05	0.06	90	0.002678	6.537245	unloaded	Turner
0.04445	1073.24	72.53211792	0.000507059	1.47E-05	0.06	90	0.00321	9.548737	unloaded	Turner
0.050673	768.6040196	125.5012325	0.000507059	1.75E-05	0.02	90	0.017345	3.253189	unloaded	Turner
0.050673	768.6040196	121.4636594	0.000507059	1.73E-05	0.02	90	0.022569	4.373835	unloaded	Turner
0.050673	751.8597237	122.8575834	0.000507059	1.74E-05	0.02	90	0.010954	1.499111	unloaded	Turner
0.050673	751.8597237	116.0802285	0.000507059	1.70E-05	0.02	90	0.012749	1.846641	unloaded	Turner
0.050673	751.8597237	103.2945801	0.000507059	1.62E-05	0.02	90	0.016855	2.743563	unloaded	Turner
0.050673	751.8597237	84.8371028	0.000507059	1.53E-05	0.02	90	0.020841	4.130409	unloaded	Turner
0.062001	1073.24	36.53042387	0.000507059	1.34E-05	0.06	90	0.034478	2.709356	Loaded	Turner
0.062001	1073.24	33.83870842	0.000507059	1.33E-05	0.06	90	0.032842	3.079678	Loaded	Turner
0.062001	1073.24	39.51053739	0.000507059	1.35E-05	0.06	90	0.021863	2.723963	Loaded	Turner
0.062001	1073.24	52.96911461	0.000507059	1.40E-05	0.06	90	0.019916	2.045334	Loaded	Turner

0.062001	1073.24	26.53262365	0.000507059	1.31E-05	0.06	90	0.021969	4.807176	Loaded	Turner
0.187604	779.6143251	15.14089937	0.000507059	1.28E-05	0.02	90	0.003844	3.286484	Loaded	Turner
0.187604	779.6143251	20.28399852	0.000507059	1.29E-05	0.02	90	0.002605	1.662522	Loaded	Turner
0.187604	779.6143251	22.06245336	0.000507059	1.30E-05	0.02	90	0.001861	1.092351	Loaded	Turner
0.187604	779.6143251	23.26411204	0.000507059	1.30E-05	0.02	90	0.001097	0.610378	Loaded	Turner

Barnea's Model

Considering the momentum balance equations of the gas and liquid film:

Liquid film:

$$-A_l \left(\frac{dp}{dL} \right)_F + \tau_i S_i - \tau_{wl} S_{wl} - \rho_l A_l g \sin \theta = 0$$

Gas core:

$$-A_g \left(\frac{dp}{dL} \right)_g - \tau_i S_i - \rho_c A_c g \sin \theta = 0$$

Here A_l and A_g represent the cross section of the pipe where the liquid and gas-core flow. τ_i is the interfacial shear stress. S_i is interfacial surface. τ_{wl} is the wall shear stress, and S_{wl} is the area that it acts on. ρ_l is the liquid density, and ρ_g is the gas density. θ is the inclination angle from the horizontal, g is the gravitational acceleration, p is the static pressure, and L is the unit length.

Simplifying for pressure, the combined momentum balance equation:

$$\tau_i S_i \left(\frac{1}{A_l} + \frac{1}{A_c} \right) - \tau_{wl} \frac{S_{wl}}{A_l} - g(\rho_l - \rho_c) \sin \theta = 0$$

The wall shear stress:

$$\tau_{wl} = f_l \frac{\rho_l v_l^2}{2}$$

Where f_l is the wall friction factor obtained from :

$$f_l = C_L \left(\frac{D_{hl} v_l \rho_l}{\mu_l} \right)^{-n}$$

$C_L = 16$, $n = 1$ and for turbulent flow in the film $C_L = 0.046$, $n = 0.2$. D_{hl} is the hydraulic diameter: $D_{hl} = 4 \frac{A_l}{S_{wl}}$, μ_l is the liquid

dynamic viscosity.

v_l is the liquid velocity defined as follows:

$$v_l = \frac{v_{sl} A}{A_l}$$

v_l is the total liquid velocity v_{sl} is the superficial liquid velocity.

Considering the geometric relationships, the equation for the interfacial shear stress could be obtained as follows:

Here we have $\bar{\delta}$ as the dimensionless film thickness defined

$$\text{by } \bar{\delta} = \frac{\delta}{D}.$$

$$\tau_i = g(\rho_l - \rho_c) \left[1 - \frac{v_{sl} f_e}{v_{sg} + v_{sl} f_e} \right] D \sin \theta (\bar{\delta} - \bar{\delta}^2) (1 - 2\bar{\delta}) + \frac{1}{32} C_l \rho_l \left[\frac{D \rho_l}{\mu_l} \right]^{-n} [v_{sl} (1 - f_e)]^{2-n} \left[\frac{1 - 2\bar{\delta}}{(\bar{\delta} - \bar{\delta}^2)^2} \right]$$

The interfacial shear stress applied by the gas phase on the liquid film for vertical upward flow is as follows:

$$\tau_i = f_i \frac{\rho_g v_g^2}{(1 - 2\bar{\delta})^4}$$

f_i is defined as the interfacial friction factor between the gas core and the liquid film. The correlation of interfacial friction factor from Wallis [41] is:

$$f_i = f_{sg} (1 + 300\bar{\delta})$$

Barnea [42] suggested two mechanisms for the transition from annular to intermittent:

The stability Criterion

which represent the instability of annular flow. Deriving the combined momentum balance equation with respect to $\bar{\delta}$ and equating it to zero yields:

$$g(\rho_l - \rho_g) D \sin \theta \left[(1 - 2\bar{\delta})^2 - 2(\bar{\delta} - \bar{\delta}^2) \right] - \frac{1}{16} C_l \rho_l \left[\frac{D \rho_l}{\mu_l} \right]^{-n} [v_{sl}]^{2-n} \left[\frac{(\bar{\delta} - \bar{\delta}^2) + (1 - 2\bar{\delta})^2}{(\bar{\delta} - \bar{\delta}^2)^3} \right] = 0$$

Solving the shear stress equations simultaneously, with the solution satisfying the derivative, gives the critical gas velocity v_{sg_Crit} .

The Spontaneous Blockage Criterion

When the film thickness gets large enough, it creates “a bridge” and initiates slugs. At this point, the transition from annular to slug is reached following the criterion of the minimum holdup in a slug as indicated by Taitel, et al. [43] for pipelines blockage as reported by Cleide Vieira (2020):

$$\frac{H_L}{H_{LLS,min}} \geq 0.5$$

Turner's Model

$$v_{sg_crit} = 5.46 \left[\frac{\sigma (\rho_l - \rho_g)}{\rho_g^2} \right]^{0.25}$$

v_{sg_crit} (m/s) is the critical gas velocity, ρ_l (kg/m³) is the liquid density, ρ_g (kg/m³) is the gas density and σ (N/m) is the interfacial tension.

An adjustment factor of 20% was considered by Turner, thus, the value of 5.463 becomes 6.556.

