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APPENDIX A

TABLES OF THE OUTPUTS

Table A-1 The results of case 1.1

Case1.1a	QCE	CryoSim		QCE	CryoSim		QCE	CryoSim	QCE	CryoSim		QCE	CryoSim	
Pipe length	Xo	Xo	%DIFF	Q/L	Q/L	%DIFF	Cum DeltaP	Cum DeltaP	Total Pressure drop	Total Pressure drop	%DIFF	P2	P2	%DIFF
				(kJ/s/m)	(kJ/s/m)		(mbar)	(mbar)	(mbar)	(mbar)		bar	bar	
1	0.0002530	0.0001087320	57.022924901	0.0258	0.01113460	56.842635659	111.19197	66.7980	111.19197	66.7980	39.9255	1.4030800	1.44820	-3.2158
2	0.0009300	0.0003986850	57.130645161	0.0258	0.01113460	56.842635659	484.68500	418.0410	373.49303	351.2430	5.9573	1.0303140	1.09695	-6.4675
3	0.0016060	0.0006886380	57.120921544	0.0258	0.01113460	56.842635659	550.57240	457.5480	65.88740	39.5070	40.0386	0.9644275	1.05745	-9.6454
4	0.0048530	0.0018351500	62.185246239	0.0258	0.00969485	62.423062016	601.68600	492.0270	51.11360	34.4790	32.5444	0.9133139	1.02297	-12.0064
5	0.0070180	0.0025994900	62.959675121	0.0258	0.00969485	62.423062016	322.89490	215.9850	-278.79110	-276.0420	0.9861	1.1921050	1.29901	-8.9678
6	0.0075590	0.0027905700	63.082815187	0.0258	0.00969485	62.423062016	331.50580	222.9280	8.61090	6.9430	19.3696	1.1834940	1.29207	-9.1742
							%DIFF	32.7529111						
Case1.1b	QCE	CryoSim		QCE	CryoSim		QCE	CryoSim	QCE	CryoSim		QCE	CryoSim	
Pipe length	Xo	Xo	%DIFF	Q/L	Q/L	%DIFF	Cum DeltaP	Cum DeltaP	Total Pressure drop	Total Pressure drop	%DIFF	P2	P2	%DIFF
				(kJ/s/m)	(kJ/s/m)		(mbar)	(mbar)	(mbar)	(mbar)		bar	bar	
1	0.000253	0.0001087320	57.022924901	0.0258	0.01113460	56.842635659	111.19197	66.7980	111.19197	66.7980	39.9255	1.4030800	1.44820	-3.2158
2	0.000930	0.0003986850	57.130645161	0.0258	0.01113460	56.842635659	484.68500	418.0410	373.49303	351.2430	5.9573	1.0303140	1.09695	-6.4675
3	0.001606	0.0006886380	57.120921544	0.0258	0.01113460	56.842635659	550.57240	457.5480	65.88740	39.5070	40.0386	0.9644275	1.05745	-9.6454
4	0.001852	0.0007883940	57.430129590	0.0258	0.01113460	56.842635659	567.25780	465.2430	16.68540	7.6950	53.8818	0.9477421	1.04975	-10.7633
5	0.002590	0.0010876600	58.005405405	0.0258	0.01113460	56.842635659	350.42590	250.3720	-216.83190	-214.8710	0.9043	1.1645740	1.26462	-8.5908
							%DIFF	28.5520848						

Table A-2 The results of case 1.2

Case1.1b	QCE	CryoSim		QCE	CryoSim		QCE	CryoSim	QCE	CryoSim		QCE	CryoSim	
Pipe length	Xo	Xo	%DIFF	Q/L	Q/L	%DIFF	Cum DeltaP	Cum DeltaP	Total Pressure drop	Total Pressure drop	%DIFF	P2	P2	%DIFF
				(kJ/s/m)	(kJ/s/m)		(mbar)	(mbar)	(mbar)	(mbar)		bar	bar	
1	0.000253	0.0001087320	57.022924901	0.0258	0.01113460	56.842635659	111.19197	66.7980	111.19197	66.7980	39.9255	1.4030800	1.44820	-3.2158
2	0.000930	0.0003986850	57.130645161	0.0258	0.01113460	56.842635659	484.68500	418.0410	373.49303	351.2430	5.9573	1.0303140	1.09695	-6.4675
3	0.001606	0.0006886380	57.120921544	0.0258	0.01113460	56.842635659	550.57240	457.5480	65.88740	39.5070	40.0386	0.9644275	1.05745	-9.6454
4	0.001852	0.0007883940	57.430129590	0.0258	0.01113460	56.842635659	567.25780	465.2430	16.68540	7.6950	53.8818	0.9477421	1.04975	-10.7633
5	0.002590	0.0010876600	58.005405405	0.0258	0.01113460	56.842635659	350.42590	250.3720	-216.83190	-214.8710	0.9043	1.1645740	1.26462	-8.5908
							%DIFF	28.5520848						

Table A-3 The results of case 1.3

Case1.3	QCE	CryoSim		QCE	CryoSim		QCE	CryoSim	QCE	CryoSim		QCE	CryoSim	
Pipe length	Xo	Xo	%DIFF	Q/L	Q/L	%DIFF	Cum DeltaP	Cum DeltaP	Total Pressure drop	Total Pressure drop	%DIFF	P2	P2	%DIFF
				(kJ/s/m)	(kJ/s/m)		(mbar)	(mbar)	(mbar)	(mbar)		bar	bar	
1	0.000811	0.000329195	59.408754624	0.0258	0.01113460	56.842635659	11.84841	8.207740	11.84841	8.20774	30.7271	1.503151	1.50679	-0.2421
2	0.002976	0.001207040	59.440860215	0.0258	0.01113460	56.842635659	337.36280	339.430000	325.51439	331.22226	-1.7535	1.177637	1.17556	0.1764
3	0.005141	0.002084900	59.445633145	0.0258	0.01113460	56.842635659	348.67160	348.649000	11.30880	9.21900	18.4794	1.166328	1.16635	-0.0019
4	0.008388	0.003231410	61.475798760	0.0258	0.00969485	62.423062016	415.56420	392.633000	66.89260	43.98400	34.2468	1.099435	1.12236	-2.0852
5	0.010552	0.003995750	62.132771039	0.0258	0.00969485	62.423062016	146.24050	114.294000	-269.32370	-278.33900	-3.3474	1.368759	1.40070	-2.3336
6	0.011093	0.004186840	62.256918778	0.0258	0.00969485	62.423062016	156.82210	122.768000	10.58160	8.47400	19.9176	1.358177	1.39223	-2.5073
							%DIFF	21.7151154						

Table A-4 The results of case 2

Case2.1	QCE	CryoSim		QCE	CryoSim		QCE	CryoSim	QCE	CryoSim		QCE	CryoSim	
Pipe length	Xo	Xo	%DIFF	Q/L	Q/L	%DIFF	Cum DeltaP	Cum DeltaP	Total Pressure drop	Total Pressure drop	%DIFF	P2	P2	%DIFF
				(kJ/s/m)	(kJ/s/m)		(mbar)	(mbar)	(mbar)	(mbar)		bar	bar	
1	0.000330	0.000308692	6.456969697	0.00105	0.00104067	0.888571429	0.37394	0.100379	0.37394	0.100379	73.1564	1.514626	1.51489	-0.0174
2	0.001211	0.001131870	6.534269199	0.00105	0.00104067	0.888571429	317.69870	313.335000	317.32476	313.234621	1.2889	1.197301	1.20166	-0.3641
3	0.002092	0.001955050	6.546367113	0.00105	0.00104067	0.888571429	318.06990	313.492000	0.37120	0.157000	57.7047	1.19693	1.2015	-0.3818
4	0.002202	0.002057950	6.541780200	0.00105	0.00104067	0.888571429	357.76140	353.232000	39.69150	39.740000	-0.1222	1.157238	1.16176	-0.3908
5	0.002422	0.002263740	6.534269199	0.00105	0.00104067	0.888571429	357.91100	353.289000	0.14960	0.057000	61.8984	1.157088	1.16171	-0.3995
6	0.003193	0.002984030	6.544628876	0.00105	0.00104067	0.888571429	80.91766	-3.455410	-276.99334	-356.744410	-28.7917	1.434082	1.51845	-5.8831
							%DIFF	104.270279						
Case2.2	QCE	CryoSim		QCE	CryoSim		QCE	CryoSim	QCE	CryoSim		QCE	CryoSim	
Pipe length	Xo	Xo	%DIFF	Q/L	Q/L	%DIFF	Cum DeltaP	Cum DeltaP	Total Pressure drop	Total Pressure drop	%DIFF	P2	P2	%DIFF
				(kJ/s/m)	(kJ/s/m)		(mbar)	(mbar)	(mbar)	(mbar)		bar	bar	
1	0.008117	0.003277730	59.618947887	0.0258	0.01105000	57.170542636	0.62912	0.201822	0.62912	0.201822	67.9200	1.514370	1.514790	-0.0277
2	0.029764	0.012018300	59.621354657	0.0258	0.01105000	57.170542636	319.22030	336.745	318.59118	336.54318	-5.6348	1.195779	1.178250	1.4659
3	0.05141	0.020758900	59.620890877	0.0258	0.01105000	57.170542636	321.75350	337.582	2.53320	0.83700	66.9588	1.193246	1.177410	1.3271
4	0.054116	0.021851500	59.620999335	0.0258	0.01105000	57.170542636	361.86600	384.33	40.11250	46.74800	-16.5422	1.153133	1.130660	1.9489
5	0.059528	0.024036700	59.621186668	0.0258	0.01105000	57.170542636	362.99730	384.634	1.13130	0.30400	73.1283	1.152002	1.130360	1.8786
6	0.078468	0.031684700	59.620864556	0.0258	0.01105000	57.170542636	88.84997	-266.152	-274.14733	-650.78600	-137.3855	1.426150	1.781150	-24.8922
							%DIFF	399.552155						
Case2.3	QCE	CryoSim		QCE	CryoSim		QCE	CryoSim	QCE	CryoSim		QCE	CryoSim	
Pipe length	Xo	Xo	%DIFF	Q/L	Q/L	%DIFF	Cum DeltaP	Cum DeltaP	Total Pressure drop	Total Pressure drop	%DIFF	P2	P2	%DIFF
				(kJ/s/m)	(kJ/s/m)		(mbar)	(mbar)	(mbar)	(mbar)		bar	bar	
1	0.000330	0.000308692	6.456969697	0.00105	0.00104670	0.314285714	0.373940	0.100379	0.37394	0.100379	73.1564	1.514626	1.51489	-0.0174
2	0.001211	0.001131870	6.534269199	0.00105	0.00104670	0.314285714	317.698700	313.335000	317.32476	313.234621	1.2889	1.197301	1.20166	-0.3641
3	0.002092	0.001955050	6.546367113	0.00105	0.00104670	0.314285714	318.069900	313.492000	0.37120	0.157000	57.7047	1.196930	1.2015	-0.3818
4	0.002202	0.002057950	6.541780200	0.00105	0.00104670	0.314285714	357.761400	353.232000	39.69150	39.740000	-0.1222	1.157238	1.16176	-0.3908
5	0.007614	0.004243110	44.272261623	0.02580	0.01105000	57.170542636	358.006800	353.319000	0.24540	0.087000	64.5477	1.156993	1.16168	-0.4051
6	0.026554	0.011891100	55.219176019	0.02580	0.01105000	57.170542636	81.900190	-35.879800	-276.10661	-389.198800	-40.9596	1.433099	1.55087	-8.2179
							%DIFF	143.809178						

Table A-5 The results of case 3

Case3	QCE	CryoSim		QCE	CryoSim		QCE	CryoSim	QCE	CryoSim		QCE	CryoSim	
Pipe length	Xo	Xo	%DIFF	Q/L	Q/L	%DIFF	Cum DeltaP	Cum DeltaP	Total Pressure drop	Total Pressure drop	%DIFF	P2	P2	%DIFF
				(kJ/s/m)	(kJ/s/m)		(mbar)	(mbar)	(mbar)	(mbar)		bar	bar	
1	0.000317	0.000308692	2.620820189	0.00105	0.00104067	0.888571429	0.40286	0.100379	0.40286	0.100379	75.0834	1.514597	1.51489	-0.0193
2	0.001164	0.001131870	2.760309278	0.00105	0.00104067	0.888571429	317.75020	313.335000	317.34734	313.234621	1.2960	1.197249	1.20166	-0.3684
3	0.002011	0.001955050	2.782197911	0.00105	0.00104067	0.888571429	318.14350	313.492000	0.39330	0.157000	60.0814	1.196856	1.20150	-0.3880
4	0.002223	0.002160850	2.795771480	0.00105	0.00104067	0.888571429	318.30000	313.548000	0.15650	0.056000	64.2173	1.196699	1.20145	-0.3970
5	0.002964	0.002778230	6.267543860	0.00105	0.00104067	0.888571429	41.32127	9.315862	-276.97873	-304.232138	-9.8395	1.473678	1.50568	-2.1716
							%DIFF	77.4550443						

Table A-6 The Results of Case 5

Fluid	Vol. Flow rate(Sm^3/hr)	100		200		500		1000		2000	
Oxygen		CryoSim	PDROP	CryoSim	PDROP	CryoSim	PDROP	CryoSim	PDROP	CryoSim	PDROP
Upstream Pressure(bara)		11.01325	11.01325	11.01325	11.01325	11.01325	11.01325	11.01325	11.01325	11.01325	11.01325
Temperature(K)		121.240224	121.240224	121.240224	121.240224	121.240224	121.240224	121.240224	121.240224	121.240224	121.240224
Xo		0.0126149	0.0126149	0.00630746	0.00630746	0.00252298	0.00252298	0.00126149	0.00126149	0.000630746	0.000630746
Liquid density(kg/m^3)		965.686	966	965.686	966	965.686	966	965.686	966	965.686	966
Gas Density(kg/m^3)		42.5307	34.96	42.5307	34.96	42.5307	34.96	42.5307	34.96	42.5307	34.96
Liquid viscosity(cP)		0.0949685	0.095	0.0949685	0.095	0.0949685	0.095	0.0949685	0.095	0.0949685	0.095
Gas viscosity(cP)		0.0110216	0.00973	0.0110216	0.00973	0.0110216	0.00973	0.0110216	0.00973	0.0110216	0.00973
Re(L)		1.88E+04	1.90E+04	3.79E+04	3.80E+04	9.50E+04	9.50E+04	1.90E+05	1.90E+05	3.81E+05	3.80E+05
Re(G)		2.07E+03	2.20E+03	2.07E+03	2.20E+03	2.07E+03	2.20E+03	2.07E+03	2.20E+03	2.07E+03	N/A
Friction factor(LO)		0.0298224	0.00741	0.0269218	0.00669	0.0246443	0.00612	0.0236967	0.00589	0.023152	0.00576
Friction factor(GO)		0.0238594	0.01225	0.0232442	0.01225	0.0228247	0.01225	0.0226682	0.01225	0.0225833	N/A
Lockhart-Martinelli parameter		14.6522	12.21	29.9429	23.32	77.5051	55.85	158.589	108.95	322.647	N/A
Total pressure drop(mbar)		4.915402	4.000	12.8956	12.200	56.1507	61.4	186.876	225.3	680.754	846.4
Upstream Pressure(bara)		7.01325	7.01325	7.01325	7.01325	7.01325	7.01325	7.01325	7.01325	7.01325	7.01325
Temperature(K)		113.819908	113.819908	113.819908	113.819908	113.819908	113.819908	113.819908	113.819908	113.819908	113.819908
Xo		0.0118112	0.0118112	0.00590561	0.00590561	0.00236224	0.00236224	0.00118112	0.00118112	0.000590561	0.000590561
Liquid density(kg/m^3)		1012.73	1013	1012.73	1013	1012.73	1013	1012.73	1013	1012.73	1013
Gas Density(kg/m^3)		27.2775	23.71	27.2775	23.71	27.2775	23.71	27.2775	23.71	27.2775	23.71
Liquid viscosity(cP)		0.109712	0.11	0.109712	0.11	0.109712	0.11	0.109712	0.11	0.109712	0.11
Gas viscosity(cP)		0.00974712	0.00918	0.00974712	0.00918	0.00974712	0.00918	0.00974712	0.00918	0.00974712	0.00918
Re(L)		1.63E+04	1.60E+04	3.28E+04	3.30E+04	8.23E+04	8.20E+04	1.65E+05	1.60E+05	3.30E+05	3.30E+05
Re(G)		2.19E+03	2.20E+03	2.19E+03	2.20E+03	2.19E+03	2.20E+03	2.19E+03	2.20E+03	2.19E+03	N/A
Friction factor(LO)		0.0305937	0.0076	0.0274272	0.00682	0.0249126	0.00619	0.0238541	0.00593	0.0232412	0.00578
Friction factor(GO)		0.0237237	0.01228	0.0231673	0.01228	0.0227896	0.01228	0.0226491	0.01228	0.022573	N/A
Lockhart-Martinelli parameter		12.3578	10.62	25.1398	20.2	64.8398	48.12	132.541	93.33	269.473	N/A
Total pressure drop(mbar)		6.238783	4.5	15.2295	12.9	60.449	61.4	188.365	220.1	660.451	810.1

Table A-6 The Results of Case 5 (Continued)

Fluid	Vol Flow rate(Sm^3/hr)	100		200		500		1000		2000	
Oxygen		CryoSim	PDROP	CryoSim	PDROP	CryoSim	PDROP	CryoSim	PDROP	CryoSim	PDROP
Upstream Pressure(bara)		5.01325	5.01325	5.01325	5.01325	5.01325	5.01325	5.01325	5.01325	5.01325	5.01325
Temperature(K)		108.689077	108.689077	108.689077	108.689077	108.689077	108.689077	108.689077	108.689077	108.689077	108.689077
Xo		0.0113854	0.0113854	0.0056927	0.0056927	0.00227708	0.00227708	0.00113854	0.00113854	0.00056927	0.00056927
Liquid density(kg/m^3)		1042.89	1043	1042.89	1043	1042.89	1043	1042.89	1043	1042.89	1043
Gas Density(kg/m^3)		19.7791	17.75	19.7791	17.75	19.7791	17.75	19.7791	17.75	19.7791	17.75
Liquid viscosity(cP)		0.122909	0.123	0.122909	0.123	0.122909	0.123	0.122909	0.123	0.122909	0.123
Gas viscosity(cP)		0.00900177	0.00879	0.00900177	0.00879	0.00900177	0.00879	0.00900177	0.00879	0.00900177	0.00879
Re(L)		1.46E+04	1.50E+04	2.93E+04	2.90E+04	7.35E+04	7.30E+04	1.47E+05	1.50E+05	2.94E+05	2.90E+05
Re(G)		2.29E+03	2.20E+03	2.29E+03	2.20E+03	2.29E+03	2.20E+03	2.29E+03	2.20E+03	2.29E+03	N/A
Friction factor(LO)		0.0312473	0.00776	0.0278592	0.00693	0.0251446	0.00625	0.0239913	0.00596	0.0233194	0.0058
Friction factor(GO)		0.0236428	0.01226	0.0231216	0.01226	0.0227688	0.01226	0.0226378	0.01226	0.0225669	N/A
Lockhart-Martinelli parameter		10.8344	9.5	21.9645	18.02	56.4959	42.74	115.361	82.4	234.522	N/A
Total pressure drop(mbar)		7.656119	4.9	17.8045	13.6	65.7733	62.1	193.246	218.4	652.615	789.1

Table A-6 The Results of Case 5 (Continued)

Fluid	Vol. Flow rate(Sm^3/hr	100		200		500		1000		2000	
Argon		CryoSim	PDROP	CryoSim	PDROP	CryoSim	PDROP	CryoSim	PDROP	CryoSim	PDROP
Upstream Pressure(bara)		5.01325	5.01325	5.01325	5.01325	5.01325	5.01325	5.01325	5.01325	5.01325	5.01325
Temperature(K)		105.7209	105.7209	105.7209	105.7209	105.7209	105.7209	105.7209	105.7209	105.7209	105.7209
Xo		0.0106521	0.0106521	0.00532607	0.00532607	0.00213043	0.00213043	0.00106521	0.00106521	0.000532607	0.000532607
Liquid density(kg/m^3)		1271.43	1271	1271.43	1271	1271.43	1271	1271.43	1271	1271.43	1271
Gas Density(kg/m^3)		25.5573	22.78	25.5573	22.78	25.5573	22.78	25.5573	22.78	25.5573	22.78
Liquid viscosity(cP)		0.151403	0.151	0.151403	0.151	0.151403	0.151	0.151403	0.151	0.151403	0.151
Gas viscosity(cP)		0.00909785	0.00913	0.00909785	0.00913	0.00909785	0.00913	0.00909785	0.00913	0.00909785	0.00913
Re(L)		1.46E+04	1.50E+04	2.94E+04	3.00E+04	7.39E+04	7.40E+04	1.48E+05	1.50E+05	2.96E+05	3.00E+05
Re(G)		2.62E+03	2.50E+03	2.62E+03	2.50E+03	2.62E+03	2.50E+03	2.62E+03	2.50E+03	2.62E+03	N/A
Friction factor(LO)		0.0312158	0.00774	0.027838	0.00691	0.0251333	0.00624	0.0239846	0.00596	0.0233156	0.0058
Friction factor(GO)		0.0234581	0.01184	0.0230179	0.01184	0.0227218	0.01184	0.0226123	0.01184	0.0225531	N/A
Lockhart-Martinelli parameter		12.0666	10.59	24.3995	20.09	62.5489	47.64	127.457	91.7	258.725	N/A
Total pressure drop(mbar)		7.616539	5.1	18.1256	14.5	69.0973	67.8	201.865	241.1	707.802	882.4
Fluid	Vol. Flow rate(Sm^3/hr	100		200		500		1000		2000	
Nitrogen		CryoSim	PDROP	CryoSim	PDROP	CryoSim	PDROP	CryoSim	PDROP	CryoSim	PDROP
Upstream Pressure(bara)		5.01325	5.01325	5.01325	5.01325	5.01325	5.01325	5.01325	5.01325	5.01325	5.01325
Temperature(K)		94.015049	94.015049	94.015049	94.015049	94.015049	94.015049	94.015049	94.015049	94.015049	94.015049
Xo		0.0128827	0.0128827	0.00644137	0.00644137	0.00257654	0.00257654	0.00128827	0.00128827	0.000644137	0.000644137
Liquid density(kg/m^3)		723.973	724	723.973	724	723.973	724	723.973	724	723.973	724
Gas Density(kg/m^3)		20.6826	17.97	20.6826	17.97	20.6826	17.97	20.6826	17.97	20.6826	17.97
Liquid viscosity(cP)		0.0818008	0.082	0.0818008	0.082	0.0818008	0.082	0.0818008	0.082	0.0818008	0.082
Gas viscosity(cP)		0.00677084	0.00673	0.00677084	0.00673	0.00677084	0.00673	0.00677084	0.00673	0.00677084	0.00673
Re(L)		1.88E+04	1.90E+04	3.79E+04	3.80E+04	9.50E+04	9.60E+04	1.90E+05	1.90E+05	3.81E+05	3.80E+05
Re(G)		2.97E+03	2.90E+03	2.97E+03	2.90E+03	2.97E+03	2.90E+03	2.97E+03	2.90E+03	2.97E+03	N/A
Friction factor(LO)		0.0298226	0.00739	0.0269219	0.00668	0.0246444	0.00612	0.0236967	0.00589	0.023152	0.00576
Friction factor(GO)		0.0235163	0.01138	0.0230505	0.01138	0.0227365	0.01138	0.0226203	0.01138	0.0225574	N/A
Lockhart-Martinelli parameter		11.8592	10.25	24.0822	19.59	61.8637	46.83	126.041	90.75	255.666	N/A
Total pressure drop(mbar)		5.586768	4.1	13.704	11.9	54.6354	57	174.155	205.4	601.62	756.8

APPENDIX B

TABLES OF PIPE AND FITTING PROPERTIES

Table B.1 Pipe Schedules and Nominal Pipe Diameters

Nominal OD, in	Schedule number: ASA B36.10 steel pipe	Schedule number: ASA B36.10 steel pipe, nominal wall thickness	Schedule number: ASA B36.10 stainless pipe	Wall thickness, in	*D*, in
$\frac{1}{8}$			10S	0.049	0.307
0.405	40	Std	40S	0.068	0.269
	80	XS	80S	0.095	0.215
$\frac{1}{4}$			10S	0.065	0.410
0.540	40	Std	40S	0.088	0.364
	80	XS	80S	0.119	0.302
$\frac{3}{8}$			10S	0.065	0.545
0.675	40	Std	40S	0.091	0.493
	80	XS	80S	0.126	0.423
			10S	0.083	0.674
$\frac{1}{2}$	40	Std	40S	0.109	0.622
0.840	80	XS	80S	0.147	0.546
	160			0.188	0.464
		XXS		0.294	0.252
			5S	0.065	0.920
			10S	0.083	0.884
$\frac{3}{4}$	40	Std	40S	0.113	0.824
1.050	80	XS	80S	0.154	0.742
	160			0.219	0.612
		XXS		0.308	0.434

Table B.1 Pipe Schedules and Nominal Pipe Diameters (*Continued*)

Nominal OD, in	Schedule number: ASA B36.10 steel pipe	Schedule number: ASAB36.10 steel pipe, nominal wall thickness	Schedule number: ASA B36.10 stainless pipe	Wall thickness, in	*D*, in
			5S	0.065	1.185
			10S	0.109	1.097
1	40	Std	40S	0.133	1.049
1.315	80	XS	80S	0.179	0.957
	160			0.250	0.815
		XXS		0.358	0.599
			5S	0.065	1.530
			10S	0.109	1.442
$1\frac{1}{4}$	40	Std	40S	0.140	1.380
1.660	80	XS	80S	0.191	1.278
	160			0.250	1.160
		XXS		0.382	0.896
			5S	0.065	1.770
			10S	0.109	1.682
$1\frac{1}{2}$	40	Std	40S	0.145	1.610
1.900	80	XS	80S	0.200	1.500
	160			0.281	1.338
		XXS		0.400	1.100
			5S	0.065	2.245
			10S	0.109	2.157
2	40	Std	40S	0.154	2.067
2.375	80	XS	80S	0.218	1.939
	160			0.344	1.687
		XXS		0.436	1.503
			5S	0.083	2.709
			10S	0.120	2,635
$2\frac{1}{2}$	40	Std	40S	0.203	2.469
2.875	80	XS	80S	0.276	2.323
	160			0.375	2.125
		XXS		0.552	1.771
			5S	0.083	3.334
			10S	0.120	3.260
3	40	Std	40S	0.216	3.068
3.500	80	XS	80S	0.300	2.900
	160			0.438	2.624
		XXS		0.600	2.300

Table B.1 Pipe Schedules and Nominal Pipe Diameters (*Continued*)

Nominal OD, in	Schedule number: ASA B36.10 steel pipe	Schedule number: ASA B36.10 steel pipe, nominal wall thickness	Schedule number: ASA B36.10 stainless pipe	Wall thickness, in	*D*, in
			5S	0.083	3.834
$3\frac{1}{2}$			10S	0.120	3.760
4.000	40	Std	40S	0.226	3.548
	80	XS	80S	0.318	3.364
			5S	0.083	4.334
			10S	0.120	4.260
	40	Std	40S	0.237	4.026
4	80	XS	80S	0.337	3.826
4.500	120			0.438	3.624
	160			0.531	3.438
		XXS		0.674	3.152
			5S	0.109	5.345
			10S	0.134	5.295
	40	Std	40S	0.258	5.047
5	80	XS	80S	0.375	4.813
5.563	120			0.500	4.563
	160			0.625	4.313
		XXS		0.750	4.063
			5S	0.109	6.407
			10S	0.134	6.357
	40	Std	40S	0.280	6.065
6	80	XS	80S	0.432	5.761
6.625	120			0.562	5.501
	160			0.719	5.187
		XXS		0.864	4.897
			5S	0.109	8.407
			10S	0.148	8.329
	20			0.250	8.125
	30			0.277	8.071
	40	Std	40S	0.322	7.981
8	60			0.406	7.813
8.625	80	XS	80S	0.500	7.625
	100			0.594	7.437
	120			0.719	7.187
	140			0.812	7.001
		XXS		0.875	6.875
	160			0.906	6.813

Table B.1 Pipe Schedules and Nominal Pipe Diameters (*Continued*)

Nominal OD, in	Schedule number: ASA B36.10 steel pipe	Schedule number: ASA B36.10 steel pipe, nominal wall thickness	Schedule number: ASA B36.10 stainless pipe	Wall thickness, in	*D*, in
			5S	0.134	10.482
			10S	0.165	10.420
	20			0.250	10.250
				0.279	10.192
	30			0.307	10.136
10	40	Std	40S	0.365	10.020
10.750	60	XS	80S	0.500	9.750
	80			0.594	9.562
	100			0.719	9.312
	120			0.844	9.062
	140			1.000	8.750
	160			1.125	8.500
			5S	0.165	12.420
			10S	0.180	12.390
	20			0.250	12.250
	30			0.330	12.090
		Std	40S	0.375	12.000
	40			0.406	11.938
12		XS	80S	0.500	11.750
12.750	60			0.562	11.626
	80			0.688	11.374
	100			0.844	11.062
	120			1.000	10.750
	140			1.125	10.500
	160			1.312	10.126
	10			0.250	13.500
	20			0.312	13.376
	30	Std		0.375	13.250
	40			0.438	13.124
		XS		0.500	13.000
				0.562	12.876
	60			0.594	12.812
14				0.625	12.750
14.000				0.688	12.624
	80			0.750	12.500
				0.875	12.250
	100			0.938	12.124
	120			1.094	11.812

Table B.1 Pipe Schedules and Nominal Pipe Diameters (*Continued*)

Nominal OD, in	Schedule number: ASA B36.10 steel pipe	Schedule number: ASA B36.10 steel pipe, nominal wall thickness	Schedule number: ASA B36.10 stainless pipe	Wall thickness, in	*D*, in
	140			1.250	11.500
	160			1.406	11.188
	10			0.250	15.500
	20			0.312	15.376
	30	Std		0.375	15.250
				0.438	15.124
	40	XS		0.500	15.000
				0.562	14.876
				0.625	14.750
16	60			0.656	14.688
16.000				0.688	14.624
				0.750	14.500
	80			0.844	14.312
				0.875	14.250
	100			1.031	13.938
	120			1.219	13.562
	140			1.438	13.124
	160			1.594	12.812
	10			0.250	17.500
	20			0.312	17.376
		Std		0.375	17.250
	30			0.438	17.124
		XS		0.500	17.000
	40			0.562	16.876
				0.625	16.750
18				0.688	16.624
18.000	60			0.750	16.500
				0.875	16.250
	80			0.938	16.124
	100			1.156	15.688
	120			1.375	15.250
	140			1.562	14.876
	160			1.781	14.438
	10			0.250	19.500
				0.312	19.376
	20	Std		0.375	19.250
				0.438	19.124

Table B.1 Pipe Schedules and Nominal Pipe Diameters (*Continued*)

Nominal OD, in	Schedule number: ASA B36.10 steel pipe	Schedule number: ASA B36.10 steel pipe, nominal wall thickness	Schedule number: ASA B36.10 stainless pipe	Wall thickness, in	*D*, in
	30	XS		0.500	19.000
				0.562	18.876
	40			0.594	18.812
				0.625	18.750
20				0.688	18.624
20.000				0.750	18.500
	60			0.812	18.376
				0.875	18.250
	80			1.031	17.938
	100			1.281	17.438
	120			1.500	17.000
	140			1.750	16.500
	160			1.969	16.062
	10			0.250	23.500
				0.312	23.376
	20	Std		0.375	23.250
				0.438	23.124
		XS		0.500	23.000
	30			0.562	22.876
				0.625	22.750
24	40			0.688	22.624
24.000				0.750	22.500
	60			0.969	22.062
	80			1.219	21.562
	100			1.531	20.938
	120			1.812	20.376
	140			2.062	19.876
	160			2.344	19.312
	10			0.312	29.376
30	20			0.500	29.000
30.000	30			0.625	28.750

SOURCE: Modified from Baumeister (1978), with data from ANSI B36.10 (1979).

Table B-2 Dimensions of Copper and Brass Pipe

(Based on ASTM B251 by permission: American Society for Testing and Materials, Philadelphia, Pa.)

Copper and Red Brass Pipe (ASTM B42 and B43)					
Nominal Pipe Size in.	Nominal Dimensions, in.				
	Regular Weight			Extra Strong	
	Outside Diameter	Inside Diameter	Wall Thickness	Inside Diameter	Wall Thickness
⅛	0.405	0.281	0.062	0.205	0.100
¼	0.540	0.376	0.082	0.294	0.123
⅜	0.675	0.495	0.090	0.421	0.127
½	0.840	0.626	0.107	0.542	0.149
¾	1.050	0.822	0.144	0.736	0.157
1	1.315	1.063	0.126	0.951	0.182
1¼	1.660	1.368	0.146	1.272	0.194
1½	1.900	1.600	0.150	1.494	0.203
2	2.375	2.063	0.156	1.933	0.221
2½	2.875	2.501	0.187	2.315	0.280
3	3.500	3.062	0.219	2.892	0.304
3½	4.000	3.500	0.250	3.358	0.321
4	4.500	4.000	0.250	3.818	0.341
5	5.562	5.062	0.250	4.812	0.375
6	6.625	6.125	0.250	5.751	0.437
8	8.625	8.001	0.312	7.625	0.500
10	10.750	10.020	0.365	9.750	0.500
12	12.750	12.000	0.375		

Type L: For interior use in general plumbing and heating
Type M: Non-pressure applications (drain, vents, etc.)

Table B-3 Constants for two-K method

Fitting type				K_1	K_∞
Elbows	90°	Standard (R/D = 1), screwed		800	0.40
		Standard (R/D = 1), flanged/welded		800	0.25
		Long-radius (R/D = 1.5), all types		800	0.20
		Mitered elbows (R/D=1.5)	1 Weld (90° angle)	1,000	1.15
			2 Weld (45° angles)	800	0.35
			3 Weld (30° angles)	800	0.30
			4 Weld (22½° angles)	800	0.27
			5 Weld (18° angles)	800	0.25
	45°	Standard (R/D = 1), all types		500	0.20
		Long-radius (R/D = 1.5), all types		500	0.15
		Mitered, 1 weld, 45° angle		500	0.25
		Mitered, 2 weld, 22½° angles		500	0.15
	180°	Standard (R/D = 1), screwed		1,000	0.60
		Standard (R/D = 1), flanged/welded		1,000	0.35
		Long radius (R/D = 1.5), all types		1,000	0.30
Tees	Used as elbow	Standard, screwed		500	0.70
		Long-radius, screwed		800	0.40
		Standard, flanged or welded		800	0.80
		Stub-in-type branch		1,000	1.00
	Run-through tee	Screwed		200	0.10
		Flanged or welded		150	0.50
		Stub-in-type branch		100	0.00
Valves	Gate, ball, plug	Full line size, β = 1.0		300	0.10
		Reduced trim, β = 0.9		500	0.15
		Reduced trim, β = 0.8		1,000	0.25
	Globe, standard			1,500	4.00
	Globe, angle or Y-type			1,000	2.00
	Diaphragm, dam type			1,000	2.00
	Butterfly			800	0.25
	Check	Lift		2,000	10.00
		Swing		1,500	1.50
		Tilting-disk		1,000	0.50

Note: Use R/D = 1.5 values for R/D = 5 pipe bends, 45° to 180°. Use appropriate tee values for flow through crosses.

APPENDIX C

LIQUID-GAS EQUILIBRIUM MONOGRAPH OF SELECTED CRYOGENS

Table C-1 Liquid-gas Equilibrium of Nitrogen

(the first figure relates to the liquid, the second to the gas)

T (K)	P (bar)	ρ	h	s	c_p	c_v	η	λ
63,148	0,1253	867,771	− 35,9204	0,5800	0,4663	0,2276	292,00	39,0267
		0,675123	15,4870	1,3949	0,2528	0,1791	4,5330	1,4597
64	0,1462	864,578	− 35,5195	0,5862	0,4712	0,2322	282,02	38,6540
		0,777932	15,6832	1,3871	0,2533	0,1793	4,5770	1,4788
66	0,2064	856,902	− 34,5644	0,6009	0,4794	0,2392	259,22	37,7701
		1,06815	16,1352	1,3699	0,2547	0,1798	4,6861	1,5242
68	0,2850	848,974	− 33,6007	0,6152	0,4845	0,2424	237,456	36,8766
		1,43709	16,5701	1,3538	0,2564	0,1804	4,8010	1,5720
70	0,3857	840,766	− 32,6285	0,6294	0,4877	0,2430	216,812	35,9736
		1,89763	16,9965	1,3390	0,2583	0,1810	4,9222	1,6197
72	0,5126	832,334	− 31,6478	0,6431	0,4897	0,2423	197,562	35,0705
		2,46406	17,4144	1,3252	0,2605	0,1817	5,0485	1,6675
74	0,6698	823,650	− 30,6670	0,6565	0,4910	0,2407	179,741	34,1579
		3,15151	17,8152	1,3122	0,2631	0,1826	5,1804	1,7153
76	0,8619	814,742	− 29,6778	0,6695	0,4922	0,2387	163,479	33,2501
		3,97230	18,1990	1,3001	0,2661	0,1834	5,3173	1,7655
77,347•	1,01325	808,607	− 29,0126	0,6782	0,4929	0,2372	153,409	32,6409
		4,61381	18,4463	1,2923	0,2682	0,1841	5,4124	1,8013
78	1,0936	805,609	− 28,6885	0,6823	0,4933	0,2366	148,810	32,3471
		4,94997	18,5657	1,2887	0,2693	0,1844	5,4590	1,8180
80	1,3699	796,253	− 27,6993	0,6948	0,4947	0,2344	135,735	31,4870
		6,09572	18,9153	1,2779	0,2731	0,1855	5,6060	1,8706
82	1,6961	786,672	− 26,7015	0,7070	0,4966	0,2325	124,221	30,6604
		7,42915	19,2394	1,2677	0,2773	0,1866	5,7575	1,9246
84	2,0775	776,868	− 25,6952	0,7189	0,4991	0,2307	114,201	29,7932
		8,97269	19,5464	1,2580	0,2821	0,1878	5,9137	1,9805
86	2,5194	766,811	− 24,6888	0,7306	0,5022	0,2292	105,552	28,9332
		10,7459	19,8364	1,2487	0,2875	0,1892	6,0746	2,0378
88	3,0278	756,530	− 23,6740	0,7420	0,5061	0,2278	98,173	28,0755
		12,7769	20,0922	1,2397	0,2935	0,1905	6,2405	2,0975
90	3,6079	745,997	− 22,6506	0,7534	0,5110	0,2266	91,887	27,2250
		15,0852	20,3225	1,2312	0,3004	0,1920	6,4113	2,1596
92	4,2657	735,184	− 21,6187	0,7645	0,5167	0,2257	86,5061	26,3793
		17,7017	20,5271	1,2228	0,3081	0,1936	6,5875	2,2265
94	5,0070	724,062	− 20,5698	0,7755	0,5236	0,2249	81,8309	25,5408
		20,6571	20,7062	1,2148	0,3169	0,1953	6,7694	2,2958
96	5,8376	712,326	− 19,5122	0,7864	0,5326	0,2245	77,8400	24,7046
		24,0480	20,8299	1,2071	0,3281	0,1972	6,9610	2,3699
98	6,7632	700,839	− 18,4377	0,7971	0,5410	0,2238	73,8184	23,8733
		27,7333	20,9535	1,1992	0,3386	0,1990	7,1526	2,4463
100	7,7904	688,653	− 17,3376	0,8079	0,5520	0,2233	70,1084	23,0467
		31,9353	21,0218	1,1915	0,3521	0,2011	7,3554	2,5323
102	8,9250	676,047	− 16,2204	0,8185	0,5649	0,2232	66,4270	22,2249
		36,6695	21,0474	1,1840	0,3680	0,2033	7,5676	2,6183
104	10,1740	662,937	− 15,0777	0,8292	0,5801	0,2230	62,7430	21,4054
		41,9921	21,0303	1,1764	0,3867	0,2058	7,7905	2,7163
106	11,5429	649,295	− 13,9093	0,8398	0,5982	0,2231	59,2061	20,5908
		47,9869	20,9535	1,1688	0,4093	0,2083	8,0264	2,8692
108	13,0405	635,036	− 12,7154	0,8505	0,6202	0,2232	55,864	19,7809
		54,7382	20,8171	1,1610	0,4371	0,2112	8,2778	3,1774
110	14,6729	620,021	− 11,4703	0,8613	0,6474	0,2235	52,593	18,9710
		62,4138	20,6124	1,1530	0,4718	0,2142	8,5492	3,4640
112	16,4481	604,137	− 10,1911	0,8723	0,6821	0,2239	49,3908	18,1660
		71,2101	20,3310	1,1447	0,5165	0,2176	8,8466	3,9418
114	18,3733	587,161	− 8,8522	0,8833	0,7278	0,2247	46,2358	17,3632
		81,3229	19,9558	1,1360	0,5760	0,2214	9,1773	4,5152
116	20,4575	568,728	− 7,4450	0,8949	0,7910	0,2257	43,0956	16,5653
		93,1726	19,4526	1,1267	0,6591	0,2256	9,5547	5,3991
118	22,7079	548,362	− 5,9441	0,9069	0,8845	0,2270	39,9379	15,7674
		107,2353	18,8045	1,1165	0,7833	0,2303	9,9974	6,3070
120	25,1347	525,111	− 4,3067	0,9198	1,0382	0,2291	36,6886	14,9742
		124,4915	17,9346	1,1050	0,9879	0,2359	10,5418	7,3820
122	27,7489	497,098	− 2,4390	0,9342	1,3394	0,2322	33,2127	14,1811
		146,7622	16,7407	1,0913	1,3881	0,2425	11,2605	8,6721
124	30,5738	459,084	− 0,1194	0,9519	2,2108	0,2376	29,1410	13,3927
		179,0617	14,9242	1,0732	2,5259	0,2507	12,3605	10,2249
126	33,6673	371,738	4,4858	0,9872		0,2535	21,9081	12,6044
		258,7598	10,3275	1,0336		0,2627	15,5453	12,2078
126,20	33,9996	314,0302	7,3597	1,0098			18,3226	

Table C-2 Liquid-gas Equilibrium of Oxygen

(the first figure relates to the liquid, the second to the gas)

T (K)	P (bar)	ρ	h	s	c_p	c_v	η	λ
54,351 Δ	0,00152	1306,61	-46,2109	0,5002	0,3977	0,2662	619,532	46,096
		0,010756	11,7349	1,5636	0,2175	0,1554	3,9210	1,1535
60	0,0073	1281,49	-43,9645	0,5396	0,3976	0,2572	508,3795	44,7955
		0,046845	12,9571	1,4877	0,2176	0,1554	4,3385	1,2800
64	0,0182	1263,77	-42,3735	0,5652	0,3977	0,2514	443,985	43,8085
		0,112742	13,8164	1,4431	0,2178	0,1554	4,6395	1,371
70	0,0623	1236,91	-39,9851	0,6008	0,3982	0,2433	364,2055	42,229
		0,343722	15,0878	1,3877	0,2187	0,1557	5,1025	1,511
74	0,1236	1218,54	-38,3897	0,6230	0,3989	0,2384	319,8280	41,1045
		0,647225	15,9158	1,3568	0,2197	0,1560	5,4210	1,607
80	0,3009	1190,43	-35,9894	0,6542	0,4005	0,2315	264,6990	39,3395
		1,466557	17,1156	1,3178	0,2220	0,1566	5,9195	1,758
84	0,5036	1171,26	-34,3820	0,6737	0,4020	0,2273	234,3420	38,119
		2,354931	17,8771	1,2956	0,2244	0,1574	6,2700	1,864
90	0,9940	1142,00	-31,9548	0,7015	0,4051	0,2215	196,9470	36,2515
		4,39822	18,9477	1,2668	0,2295	0,1587	6,831	2,034
90,18 •	1,01325	1141,00	-31,8951	0,7021	0,4052	0,2212	195,8305	36,1875
		4,47500	18,9739	1,2658	0,2297	0,1588	6,8485	2,0395
94	1,4854	1121,98	-30,2220	0,7191	0,4079	0,2179	176,398	34,9820
		6,36349	19,6025	1,2500	0,2342	0,1601	7,234	2,1565
100	2,5422	1090,62	-27,8455	0,7444	0,4138	0,2128	150,6155	33,0220
		10,46431	20,4819	1,2275	0,2434	0,1627	7,8925	2,357
104	3,5079	1069,12	-26,1702	0,7606	0,4188	0,2098	136,5530	31,7105
		14,13125	20,9904	1,2139	0,2514	0,1649	8,3750	2,5045
110	5,4341	1035,56	-23,6101	0,7841	0,4291	0,2055	119,0950	29,7295
		21,35816	21,6182	1,1953	0,2670	0,1690	9,1770	2,7495
114	7,0877	1011,66	-21,8639	0,7994	0,4382	0,2028	109,2705	28,3735
		27,55667	21,9363	1,1836	0,2803	0,1721	9,7740	2,9320
120	10,2156	974,088	-19,1642	0,8218	0,4568	0,1991	97,1055	26,3510
		39,42731	22,2394	1,1669	0,3064	0,1775	10,7840	3,2415
124	12,7882	946,990	-17,2970	0,8366	0,4740	0,1970	90,2135	24,9830
		49,43657	22,3081	1,1561	0,3295	0,1818	11,5505	3,4830
130	17,4775	902,646	-14,3502	0,8589	0,5166	0,1986	82,3295	22,9065
		68,51262	22,1685	1,1399	0,3778	0,1890	12,8800	4,0265
134	21,2195	869,769	-12,2553	0,8739	0,5548	0,1969	77,4415	21,4790
		84,74260	21,8751	1,1288	0,4248	0,1946	13,922	4,4990
140	27,8654	813,184	- 8,8560	0,8974	0,6447	0,1970	69,6565	19,2768
		116,6945	21,0247	1,1109	0,5422	0,2044	15,827	5,4690
144	33,0634	767,910	- 6,3221	0,9141	0,7726	0,1996	63,9630	17,7150
		145,7605	20,0504	1,0973	0,6946	0,2126	17,4545	6,4939
150	42,1897	675,508	- 1,6850	0,9436	1,3356	0,2111	53,6800	17,3630
		214,5698	17,3015	1,0702	1,4969	0,2315	21,1230	9,9010
154	49,3199	553,325	3,4492	0,9755	7,2344	0,2462	42,476	
		321,3053	12,6017	1,0350	6,2340	0,2738	26,8625	
154,576 •	50,4266	436,111	7,7959	1,0032		0,2893	33,8015	

ρ = *density* ($kg.m^{-3}$)

h = *enthalpy* ($kcal.kg^{-1}$)

s = *entropy* ($kcal.kg^{-1}.K^{-1}$)

Enthalpy and entropy are considered as nil for the perfect gas at zero absolute and 1 atm.

Latent heat of vaporisation = vapor enthalpy − liquid enthalpy.

c_p = *heat capacity at constant pressure* ($kcal.kg^{-1}.K^{-1}$)

c_v = *heat capacity at constant volume* ($kcal.kg^{-1}.K^{-1}$)

η = *viscosity; multiply this value by* 10^{-5} *to obtain poise.*

λ = *thermal conductivity; multiply this value by* 10^{-5} *to obtain* $cal.cm^{-1}s^{-1}K^{-1}$

Δ = *triple point*

• = *boiling point at 1 atm*

· = *critical point*

Table C-3 Liquid-gas Equilibrium of Argon

(the first figure relates to the liquid, the second to the gas)

T (K)	P (bar)	ρ	h	s	c_p	c_v	η	λ
83,78 Δ	0,687	1414,8	17,0121	0,3185		0,248		
		4,1090	55,9958	0,7836	0,129	0,075		
85	0,790	1407,1	17,3179	0,3220	0,253	0,228		
		4,6620	56,1128	0,7783	0,129	0,075		
87,29 •	1,01325	1392,8	17,9056	0,3283		0,197		
		5,8530	56,3142	0,7683	0,131	0,075		
90	1,338	1375,7	18,6055	0,3352	0,260	0,171	235,4	29,35
		7,5358	56,5476	0,7568	0,133	0,076	7,54	1,50
95	2,137	1344,1	19,9434	0,3493		0,139	202,6	27,72
		11,570	56,9155	0,7384	0,137	0,077	8,02	1,59
100	3,247	1310,9	21,3051	0,3631	0,276	0,122	176,1	26,10
		17,021	57,2237	0,7222	0,144	0,078	8,51	1,69
105	4,735	1276,7	22,7194	0,35	0,280	0,112	154,2	24,54
		24,211	57,4411	0,7071	0,152	0,079	9,02	1,80
110	6,665	1240,2	24,1671	0,3899	0,294	0,107	134,8	22,98
		33,490	57,5725	0,6935	0,162	0,081	9,56	1,92
115	9,107	1201,7	25,6674	0,4025	0,297	0,104	117,4	21,47
		45,331	57,6012	0,6804	0,176	0,084	10,15	2,06
120	12,131	1160,4	27,2226	0,4152	0,314	0,103	101,9	19,97
		60,365	57,4937	0,6675	0,194	0,086	10,78	2,22
125	15,812	1115,5	28,8663	0,4281	0,337	0,102	88,85	18,47
		79,466	57,2476	0,6553	0,220	0,089	11,51	2,41
130	20,233	1065,8	30,6079	0,4410	0,371	0,101	78,80	16,96
		103,95	56,7961	0,6426	0,258	0,093	12,36	2,64
135	25,485	1009,5	32,5119	0,4544	0,425	0,097	70,30	15,42
		136,05	56,0770	0,6290	0,320	0,102	13,43	2,94
140	31,675	942,15	34,6190	0,4685	0,529	0,103	61,47	13,9
		179,51	54,9637	0,6140	0,442	0,102	14,82	3,34
145	38,926	853,17	37,0438	0,4840	0,812	0,105		
		242,61	53,1361	0,5949	0,791	0,110		
150	47,388	680,87	41,5614	0,5096				
		392,16	48,6592	0,5569				
150,86 *	48,979	535,705	45,1927	0,5258				

ρ = *density* ($kg.m^{-3}$)
h = *enthalpy* ($kcal.kg^{-1}$)
s = *entropy* ($kcal.kg^{-1}.K^{-1}$)
Enthalpy and entropy are considered as nil for the perfect crystal at absolute zero and 1 atm.

Latent heat of vaporisation = vapor enthalpy – liquid enthalpy.

c_p = *heat capacity at constant pressure* ($kcal.kg^{-1}.K^{-1}$)
c_v = *heat capacity at constant volume* ($kcal.kg^{-1}.K^{-1}$)
η = *viscosity, multiply these values by* 10^{-5} *to obtain poises*
λ = *thermal conductivity; multiply these values by* 10^{-5} *to obtain* $cal.cm^{-1}.s^{-1}.K^{-1}$
Δ = *triple point*
• = *boiling point at 1 atm*
* = *critical point*

APPENDIX D

THE ERROR CALCULATION

The relative difference

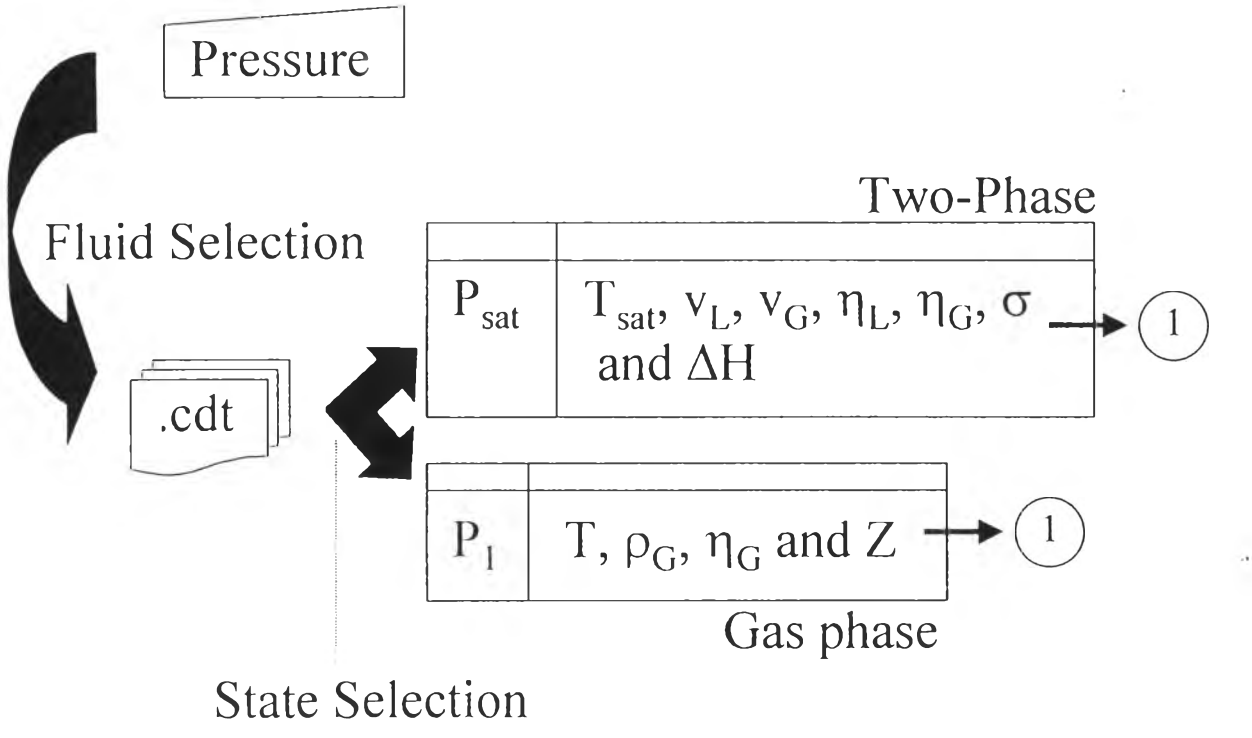
%DIFF = [(Reference data – Result of developed programme)/ Reference data]x100 (D-1)

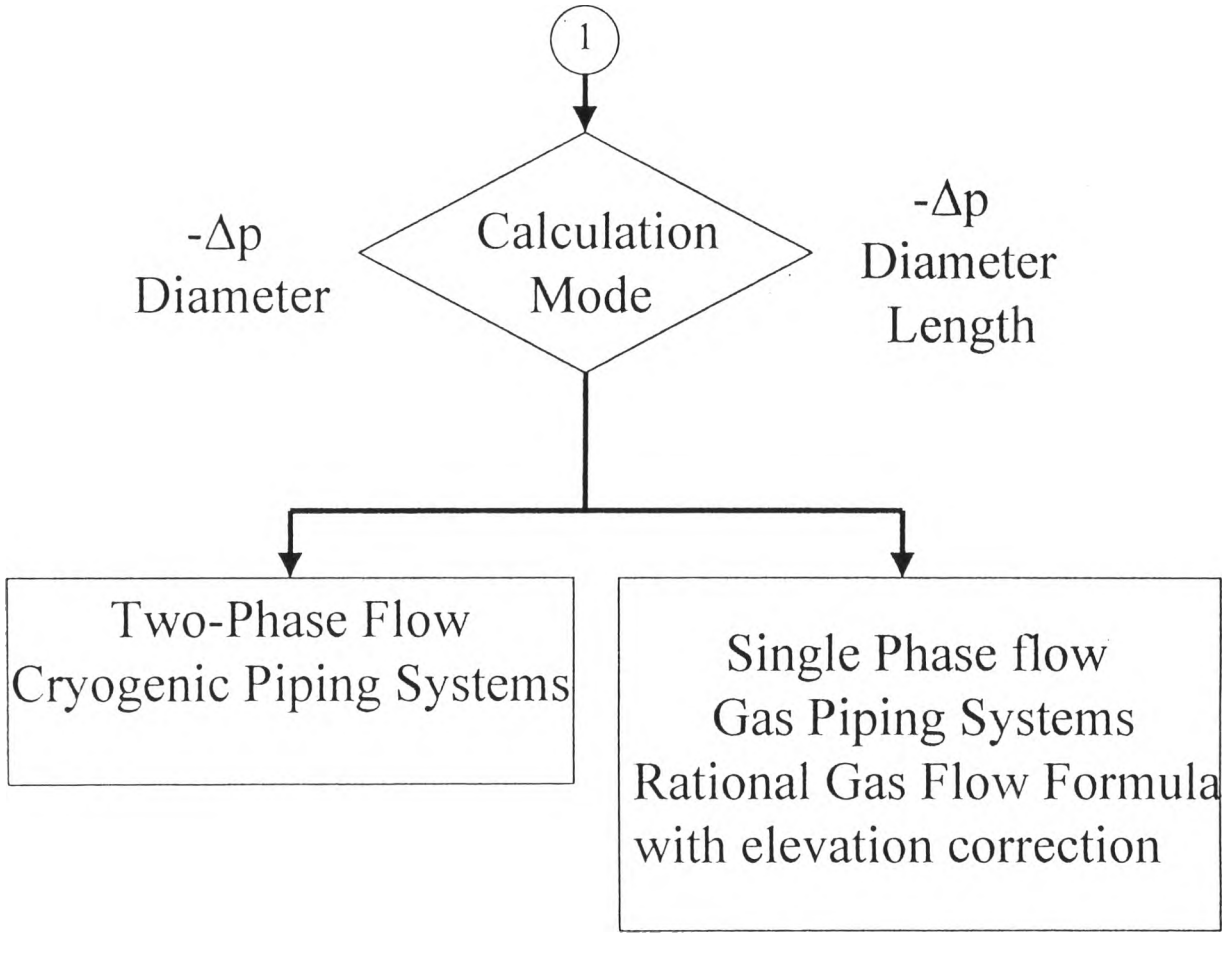
where

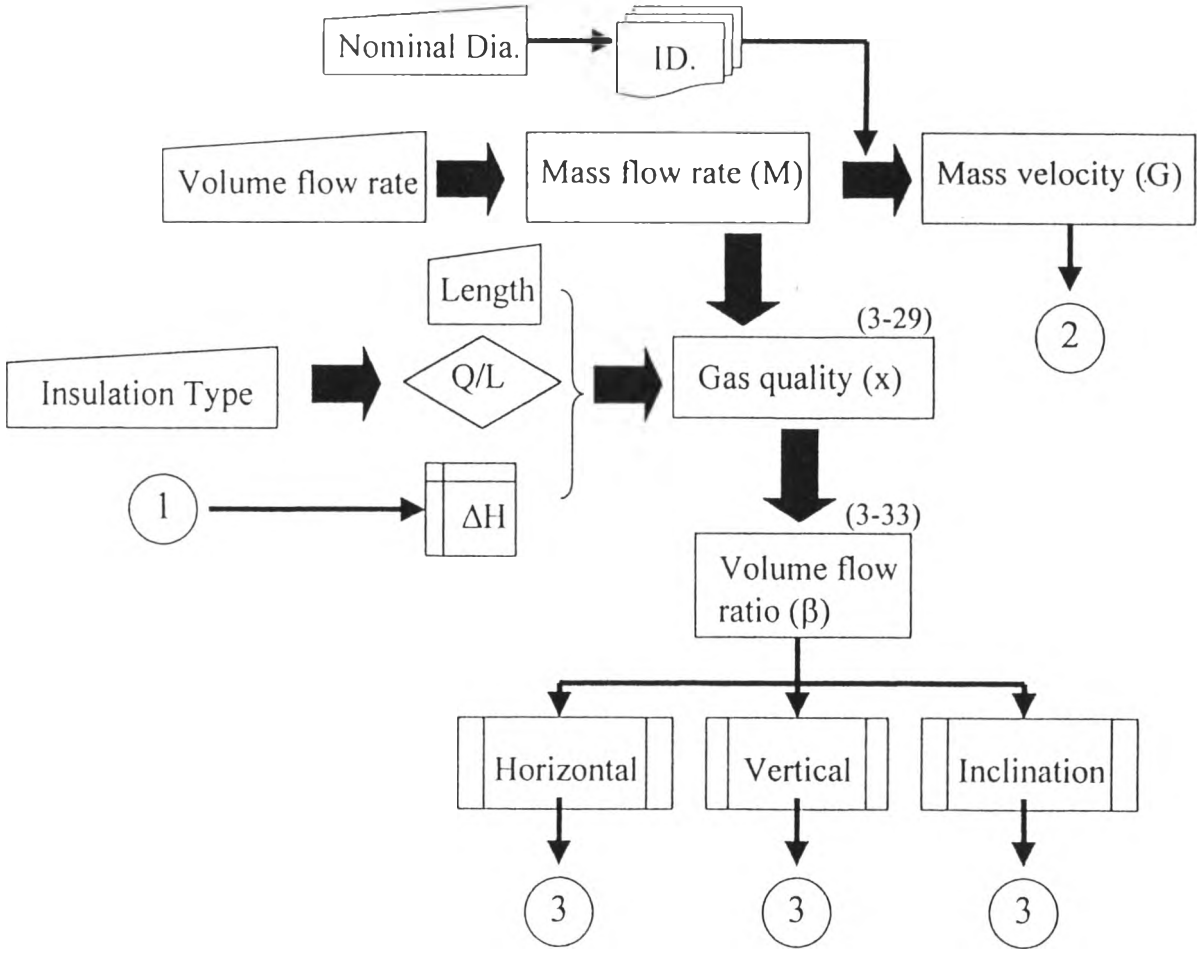
%DIFF is the relative error

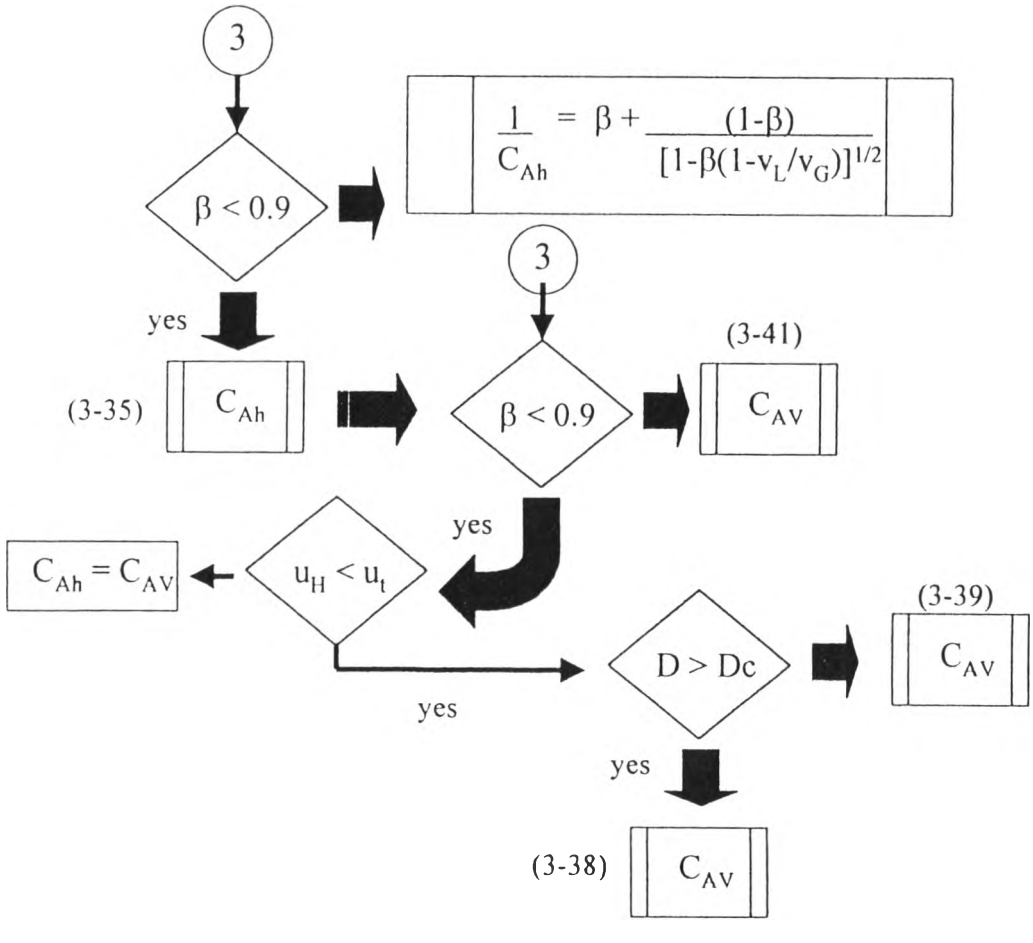
APPENDIX E

PROGRAMME FLOW CHART


Pressure
Fluid Selection
.cdt
Two-Phase
P_{sat}
T_{sat}, v_L, v_G, η_L, η_G, σ and ΔH
1
P_1
T, ρ_G, η_G and Z
1
Gas phase
State Selection


1
-Δp
Diameter
Calculation
Mode
-Δp
Diameter
Length
Two-Phase Flow
Cryogenic Piping Systems
Single Phase flow
Gas Piping Systems
Rational Gas Flow Formula
with elevation correction


Nominal Dia.
ID.
Volume flow rate
Mass flow rate (M)
Mass velocity (G)
2
Length
(3-29)
Insulation Type
Q/L
Gas quality (x)
1
ΔH
(3-33)
Volume flow ratio (β)
Horizontal
Vertical
Inclination
3
3
3


3
β < 0.9
1/C_Ah = β + (1-β) / [1-β(1-v_L/v_G)]^1/2
yes
3
(3-41)
(3-35)
C_Ah
β < 0.9
C_AV
yes
C_Ah = C_AV
u_H < u_t
(3-39)
D > Dc
C_AV
yes
yes
(3-38)
C_AV

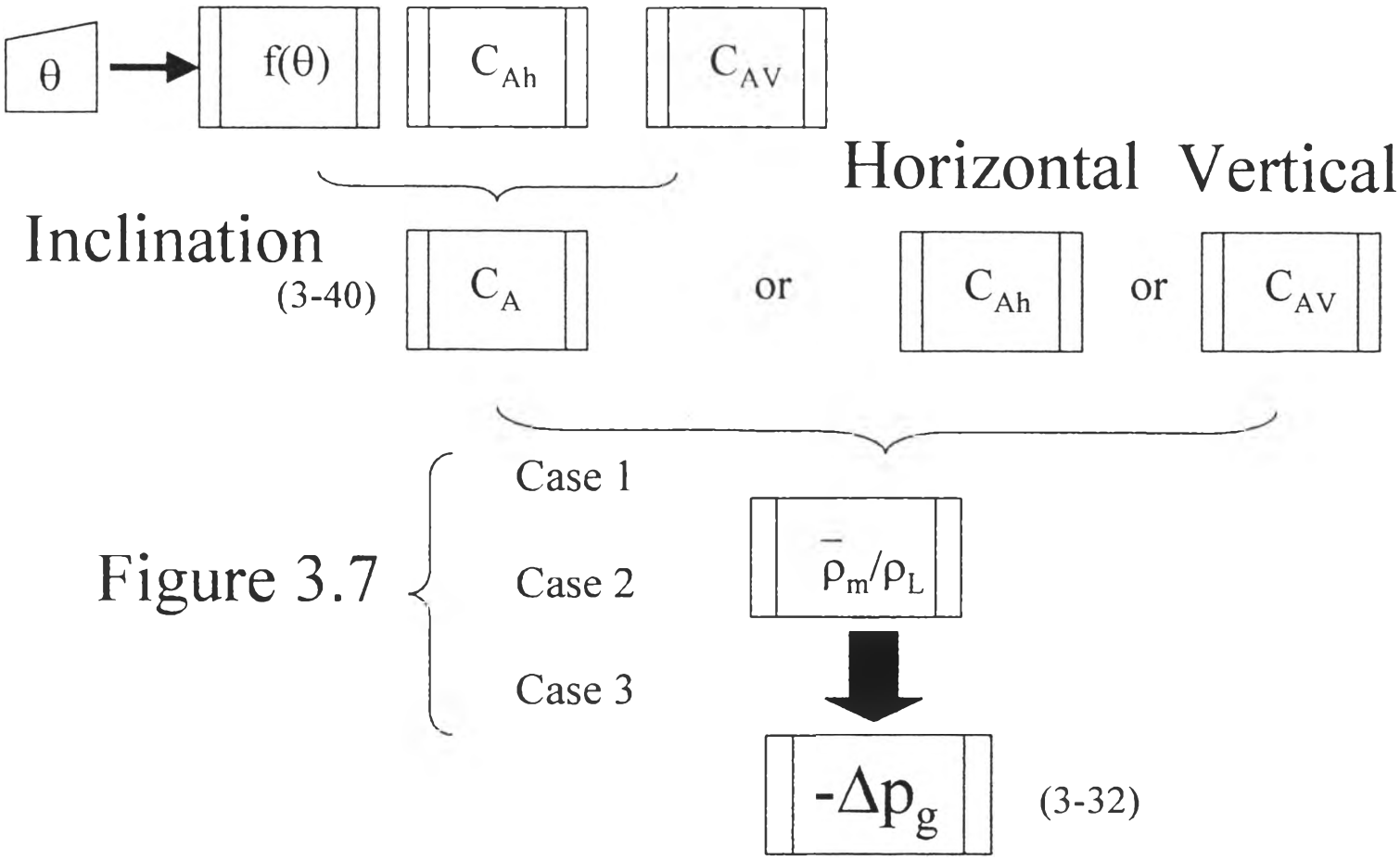
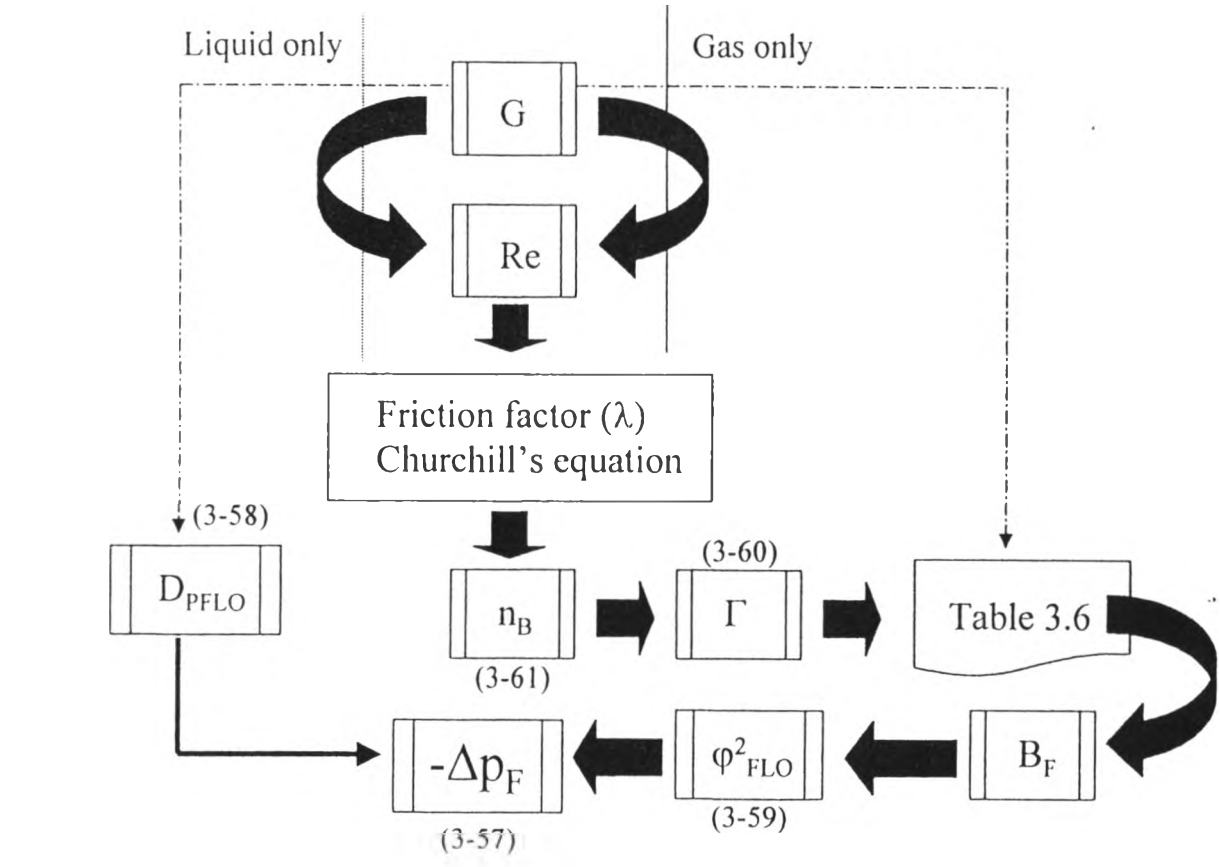
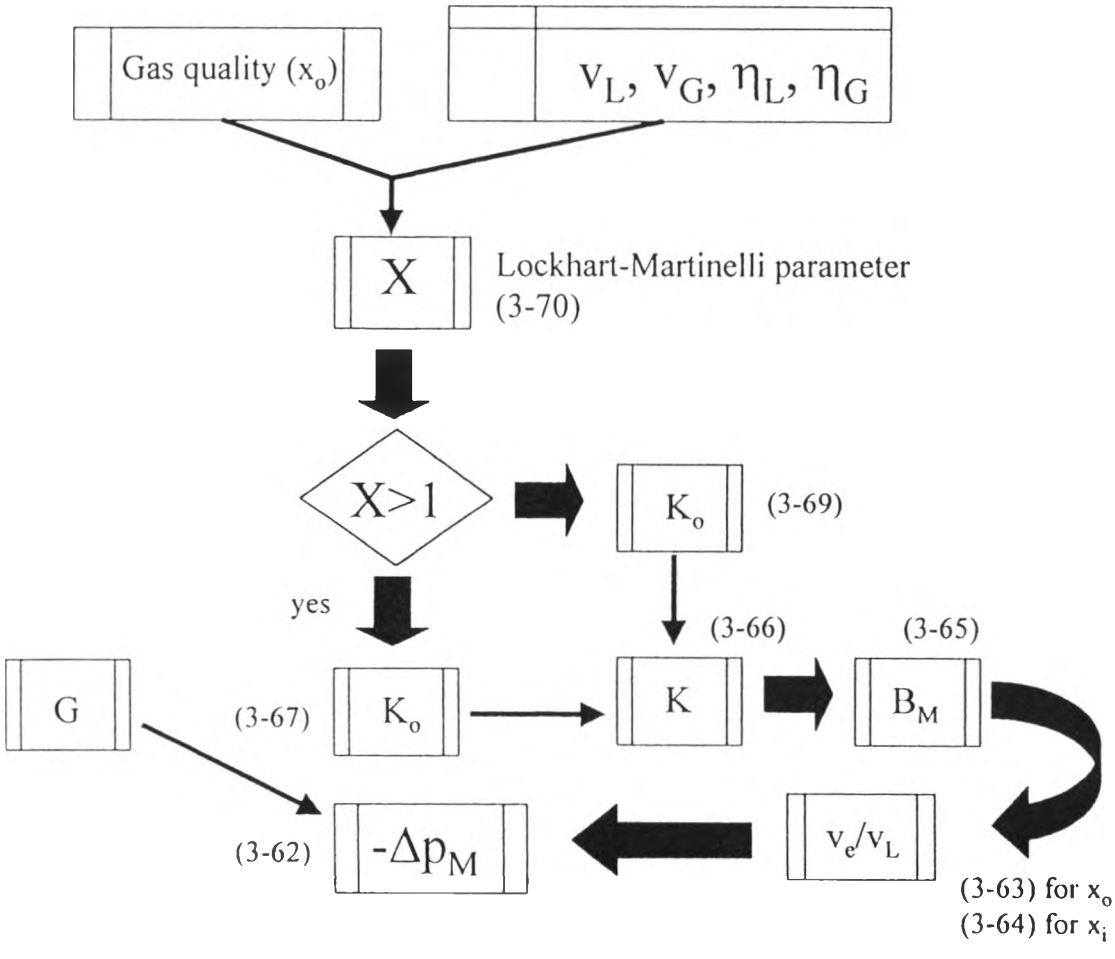
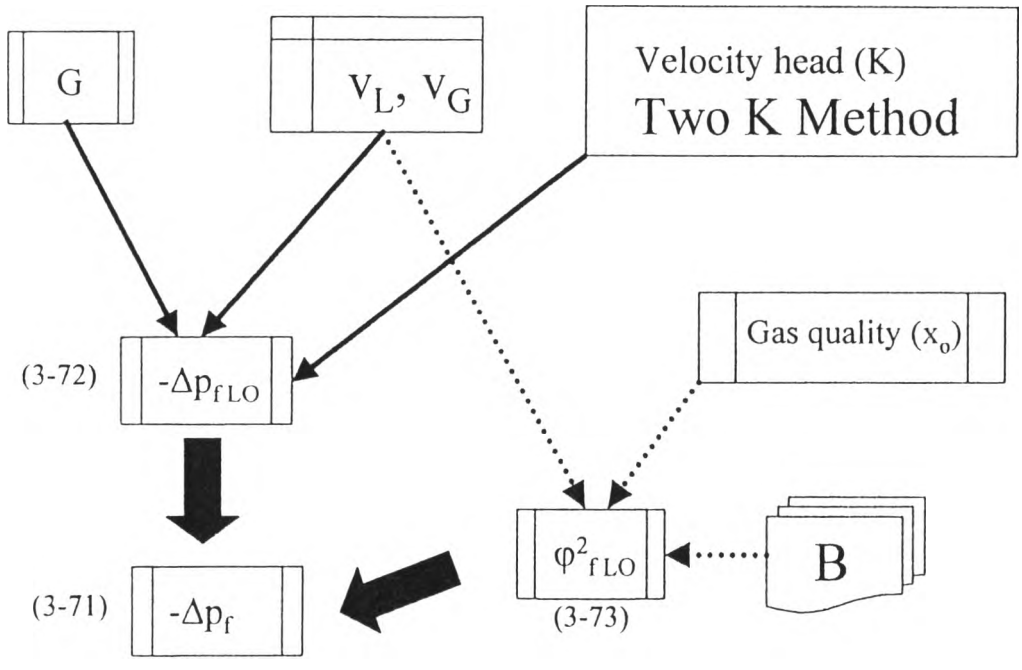

θ
f(θ)
C_{Ah}
C_{AV}
Horizontal Vertical
Inclination
(3-40)
C_A
or
C_{Ah}
or
C_{AV}
Case 1
Case 2
Case 3
$\bar{\rho}_m/\rho_L$
$-\Delta p_g$
(3-32)

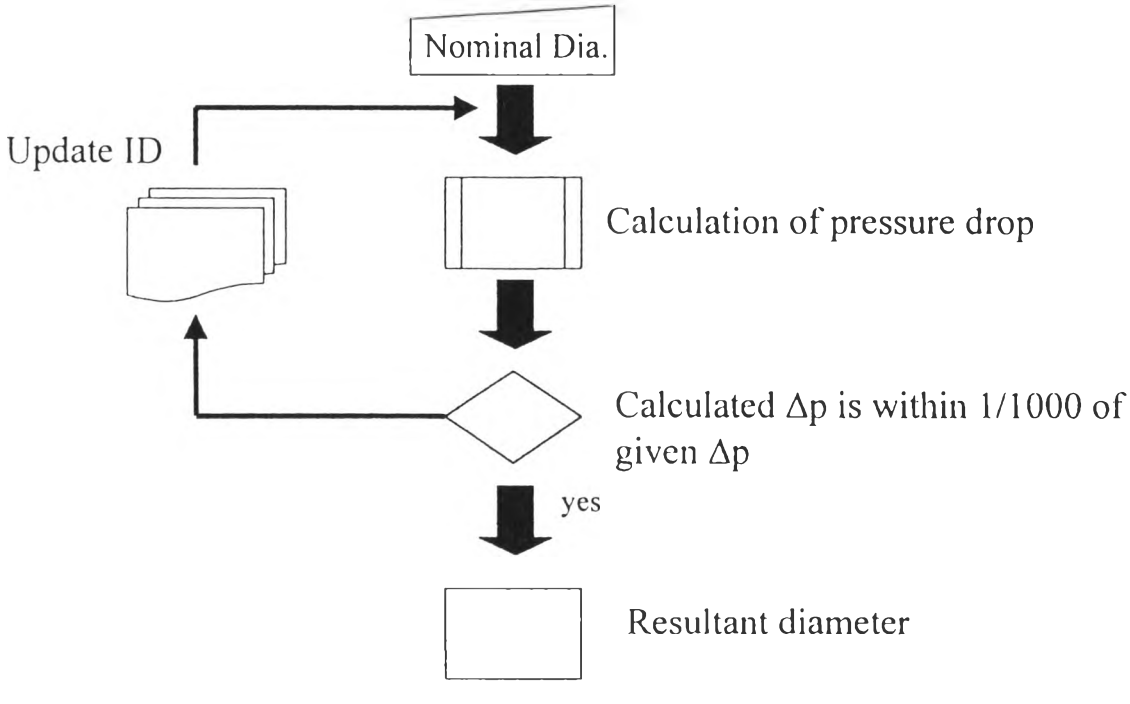
Figure 3.7


Liquid only
Gas only
G
Re
Friction factor (λ)
Churchill's equation
(3-58)
D_{PFLO}
n_B
(3-61)
(3-60)
Γ
Table 3.6
B_F
φ^2_{FLO}
(3-59)
$-\Delta p_F$
(3-57)


Gas quality (x_o)
v_L, v_G, η_L, η_G
X
Lockhart-Martinelli parameter
(3-70)
X>1
K_o
(3-69)
yes
(3-66)
(3-65)
G
(3-67)
K_o
K
B_M
v_e/v_L
(3-62)
$-\Delta p_M$
(3-63) for x_o
(3-64) for x_i



Calculation Mode : Diameter



VITA

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