Appendix B

Ammonia Refrigeration Application Data

General

Refrigeration engineers frequently need to consult ammonia thermodynamic property tables as they analyze a particular mechanical vapor compression refrigeration cycle. Many repetitive and similar computations are performed by these engineers for typically encountered conditions.

IIAR has attempted to develop some special application tables which can eliminate many of the tedious, repetitive calculations, particularly when close approximations are sufficient for the task such as when a variety of options are being compared or trend graphs are being developed.

Application tables and graphs have been developed to allow rapid approximation of compressor power per ton, compressor displacement per ton, mass flow rate per ton, and liquid flow rate per ton for liquid overfeed systems. Coupled with knowledge of evaporator tonnage, suction temperature (pressure) and condensing temperature (pressure), a conceptual cycle analysis and preliminary design of a refrigeration system can be completed with minimal calculation effort on the part of the engineer.

As a design is more fully developed it is recommended that the detailed calculations based on the property tables be performed for the final set of design conditions. These application tables and graphs are to help the engineer get "in the ballpark" quickly to avoid tedious calculations for a variety of possible design conditions.

Compressor Displacement

A refrigeration compressor is a volumetric device whereby the capacity is a function of swept volume and a volumetric efficiency. The swept volume is calculable for a given compressor based on speed and geometry. Volumetric efficiency accounts for losses due to leakage, re-expansion of gas associated with clearance volumes (reciprocating compressors), pressure losses through valve openings, over-compression or under-compression (rotary screw compressors), etc.

For a given refrigeration evaporator tonnage, liquid temperature and suction pressure, the volumetric flow of ammonia vapor at the compressor suction inlet can be computed by performing a series of calculations using thermodynamic property data.

Alternatively, Figure B-1 has been generated which allows one to quickly look up a cfm/ton for a series of more commonly encountered refrigeration cycle conditions. Figure B-2 does the same for booster applications.

Figure B-3 provides reasonable estimates of typical volumetric efficiencies for different compressor types. The required compressor displacement (C. D.) is then computed as follows:

Evaporator Tons x cfm/ton x $^{1}/_{Eff_{vol}}$ = C. D.

The following example shows how the table and graph can be used to quickly estimate required compressor displacement.

Example A 1000 ton load must be handled at a suction temperature of +20°F and condensing temperature of 95°F. What compressor swept volume will be required if reciprocating compressors are used?

Figure B-1 indicates that the actual flowrate at the above conditions will be 2.53 cfm/ton. Figure B-4 provides the compression ratio (C.R.) of 4.06. Looking at the graph of volumetric efficiency of a reciprocating compressor (Figure B-3) at a C.R. of about 4.1 we find a predicted volumetric efficiency of about 0.78. The compressor swept volume cfm required is calculated:

1000 x 2.53 x $^{1}/_{0.78}$ = 3244 cfm

Compressor Power

A refrigeration compressor's power requirement expressed in terms of brake horsepower per ton (BHP/Ton) is a function of suction conditions, discharge conditions, and to a lesser extent the type of compressor. Normally the BHP/Ton is determined by using manufacturer's catalog data along with certain adjustments for liquid subcooling, type of oil cooling, etc.

Approximate compressor BHP/Ton can also be established by calculating the isentropic work of compression, refrigerant mass flow and then applying an appropriate adiabatic compression efficiency. Figures B-6 and B-7 show the isentropic work of compression for some typically encountered high stage and booster applications. These figures eliminate the calculations and interpolations normally required for determination of isentropic work of compression.

Figures B-8 and B-9 depict the isentropic power per ton for commonly encountered refrigeration cycle conditions. These figures are based on liquid being supplied to the evaporator at the saturated discharge temperature, saturated compressor suction and isentropic (perfect) compression. Results are given in terms of HP/Ton.

The actual work of compression and compressor BHP/Ton are related to the isentropic work of compression and HP/Ton by a factor known as the adiabatic compression efficiency. Adiabatic compression efficiency is defined as:

$$\mathrm{Eff}_{a.c.} = \frac{isentropic\_work\_of\_compression}{actual\_work\_of\_compression}$$

The range of typical adiabatic compression efficiencies for ammonia compressors is shown in Figure B-10.

The estimated actual compressor brake horsepower requirements can then be computed as follows:

$$BHP = Tons \times \frac{HP / Ton}{Eff_{a.c.}}$$

The following example shows how the tables and graphs can be used to quickly estimate the compressor brake horsepower requirement for a given set of conditions.

Example A 1000 ton evaporator load must be handled at a suction temperature of +20°F and condensing temperature of 95°F. Screw compressors with thermosyphon oil cooling will be used. What brake horsepower requirement is expected?

C.R. = 4.06 (Figure B-4)

$^{HP}/_{TON}$ = 0.874 (Figure B-8)

Looking at Figure B-10 for a suction temperature of +20°F and maximum adiabatic efficiency (due to compressor type and oil cooling method) we would get an efficiency of about 0.80. The resultant brake horsepower requirement would be:

$$1000\ Tons \times \frac{0.874 HP / Ton}{0.80} = 1093 \text{ BHP}$$

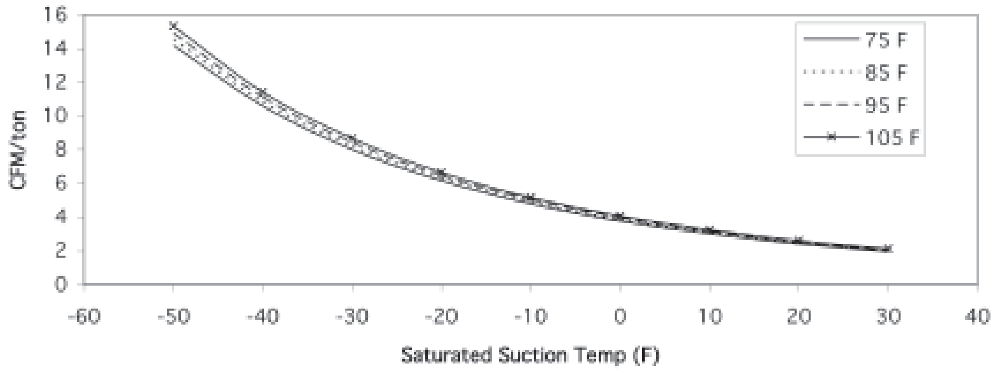
Refrigerant Mass Flow

Tables and graphs (Figures B-11 and B-12) of refrigerant mass flow per ton of refrigeration have been prepared for both high stage and booster conditions. The temperature of the liquid supplied to the evaporator is assumed to be the saturation temperature corresponding with condensing or intermediate pressure. These tables are relatively straight forward and do not require further explanation.

Liquid Overfeed System Pump Rates

A table and graph (Figure B-13) has been prepared which allows one to look up a flow rate if the saturated evaporator temperature and the circulating number (ratio of liquid weight pumped to the weight vaporized) are known. The table is based on the assumption that the liquid temperature supplied to the evaporator is equal to the suction saturation temperature.

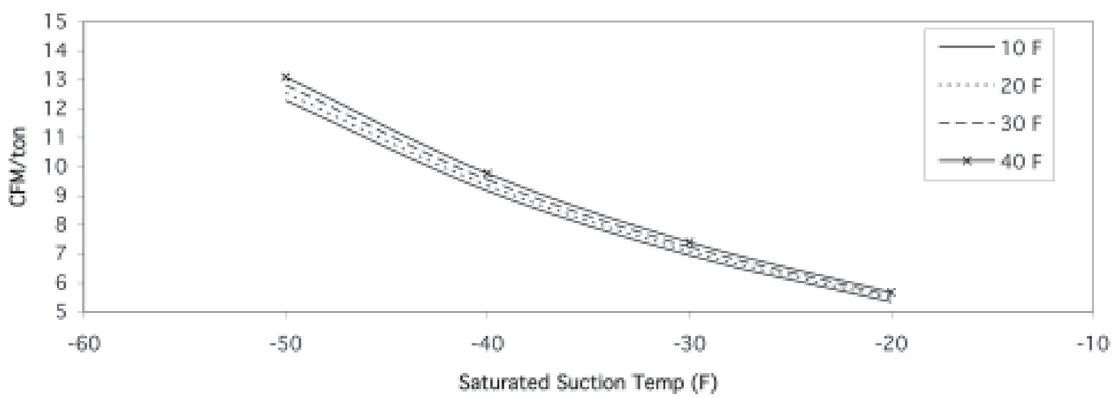
Figure B-1 High Stage Volumetric Flow Rate Per Ton



Sat Disch Temp

75 F	14.20	10.59	8.01	6.15	4.79	3.77	3.00	2.41	1.96
85 F	14.56	10.85	8.21	6.31	4.90	3.86	3.07	2.47	2.01
95 F	14.94	11.13	8.43	6.47	5.03	3.96	3.15	2.53	2.06
105 F	15.35	11.43	8.65	6.64	5.16	4.06	3.23	2.60	2.11

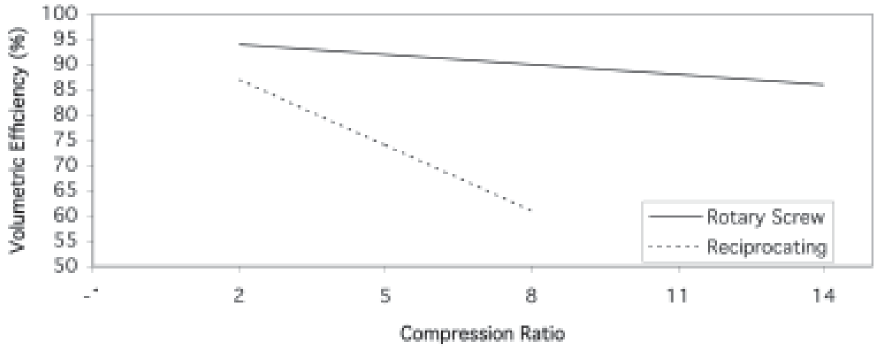
Figure B-2 Booster Volumetric Flow Rate Per Ton



Sat Disch Temp

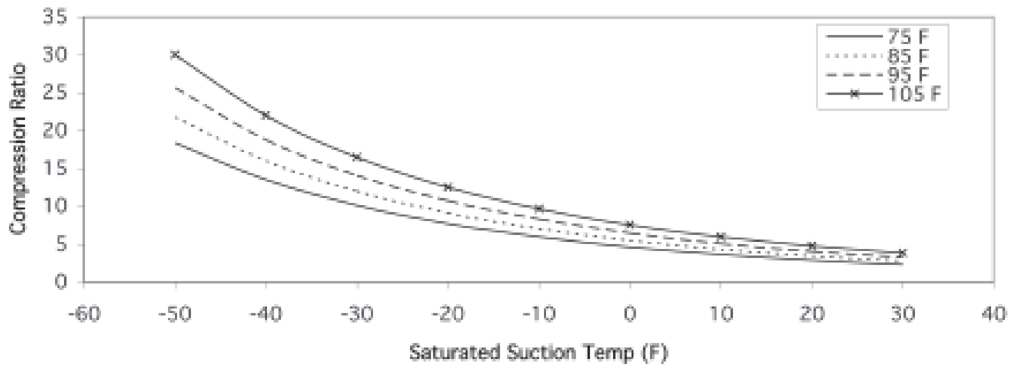
10 F	12.29	9.17	6.95	5.34
20 F	12.55	9.36	7.09	5.45
30 F	12.81	9.56	7.24	5.57
40 F	13.09	9.77	7.40	5.68

Figure B-3 Typical Compressor Volumetric Efficiency



Rotary Screw	94	92	90	88	86
Reciprocating	87	74	61		

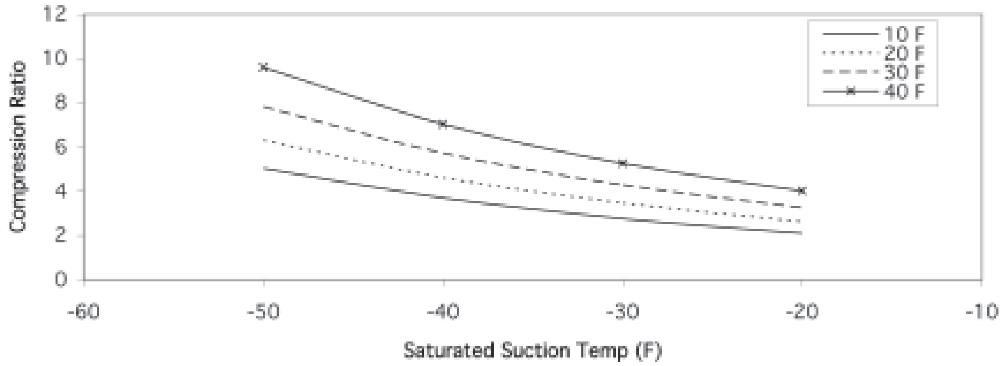
Figure B-4 High Stage Compression Ratio



Sat Disch Temp

75 F	18.41	13.50	10.11	7.69	5.92	4.62	3.65	2.92	2.35
85 F	21.81	16.00	11.98	9.10	7.02	5.48	4.33	3.45	2.79
95 F	25.66	18.82	14.09	10.71	8.26	6.44	5.09	4.06	3.28
105 F	30.00	22.01	16.48	12.52	9.65	7.53	5.95	4.75	3.84

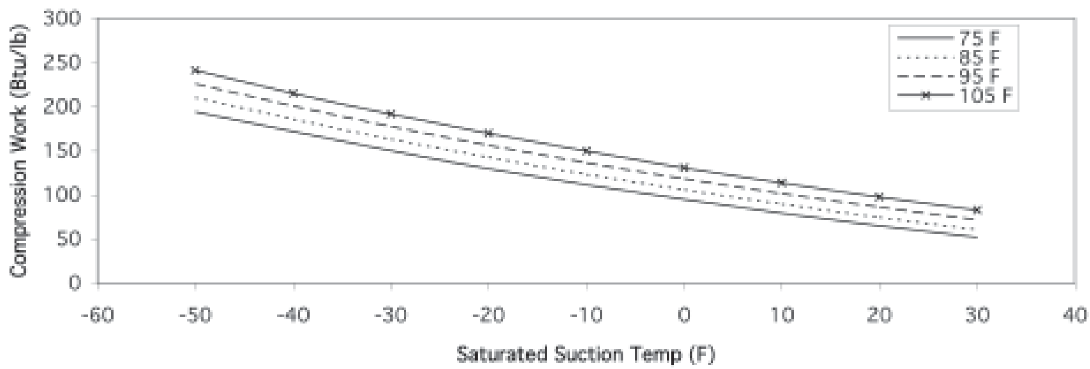
Figure B-5 Booster Compression Ratio



Sat Disch Temp

10 F	5.04	3.70	2.77	2.10
20 F	6.31	4.63	3.47	2.63
30 F	7.82	5.74	4.30	3.27
40 F	9.60	7.04	5.27	4.01

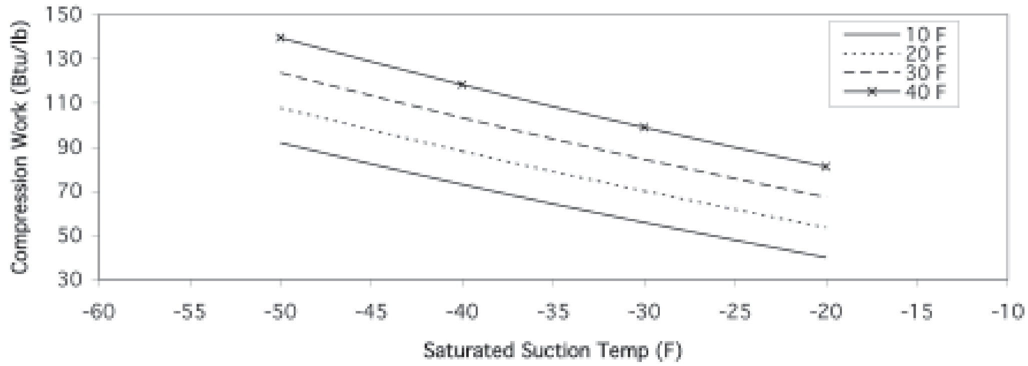
Figure B-6 High Stage Isentropic Work of Compression



Sat Disch Temp

75 F	193.99	171.78	150.07	130.20	111.96	95.18	79.69	65.39	52.16
85 F	210.34	185.79	163.33	142.74	123.79	106.30	90.11	75.10	61.15
95 F	225.86	200.57	177.46	156.25	136.73	118.72	102.05	86.58	72.20
105 F	241.26	215.27	191.51	169.70	149.63	131.10	113.95	98.03	83.23

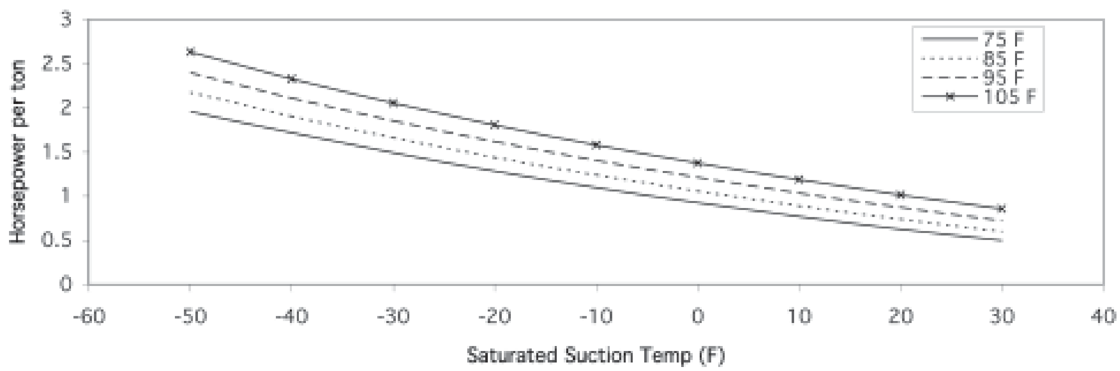
Figure B-7 Booster Isentropic Work of Compression



Sat Disch Temp

10 F	92.02	73.14	55.90	40.08
20 F	107.86	88.21	70.24	53.76
30 F	123.72	103.28	84.60	67.47
40 F	139.57	118.36	98.98	81.21

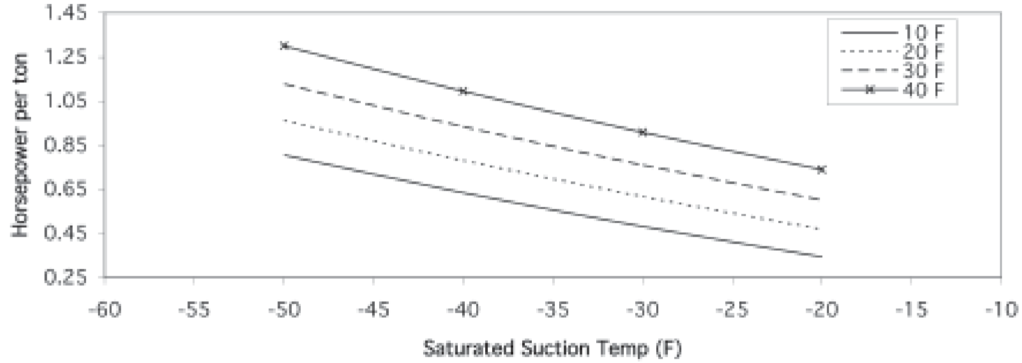
Figure B-8 High Stage Isentropic Power Per Ton



Sat Disch Temp

75 F	1.959	1.721	1.492	1.285	1.097	0.926	0.771	0.629	0.499
85 F	2.178	1.908	1.664	1.443	1.242	1.060	0.893	0.739	0.599
95 F	2.400	2.113	1.854	1.620	1.407	1.213	1.036	0.874	0.724
105 F	2.634	2.329	2.055	1.806	1.581	1.375	1.187	1.015	0.856

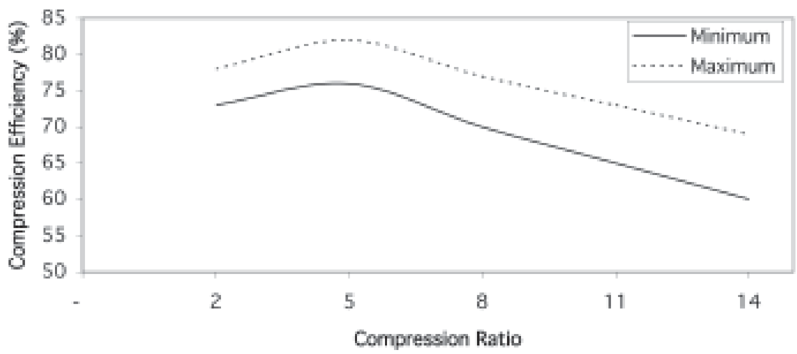
Figure B-9 Booster Isentropic Power Per Ton



Sat Disch Temp

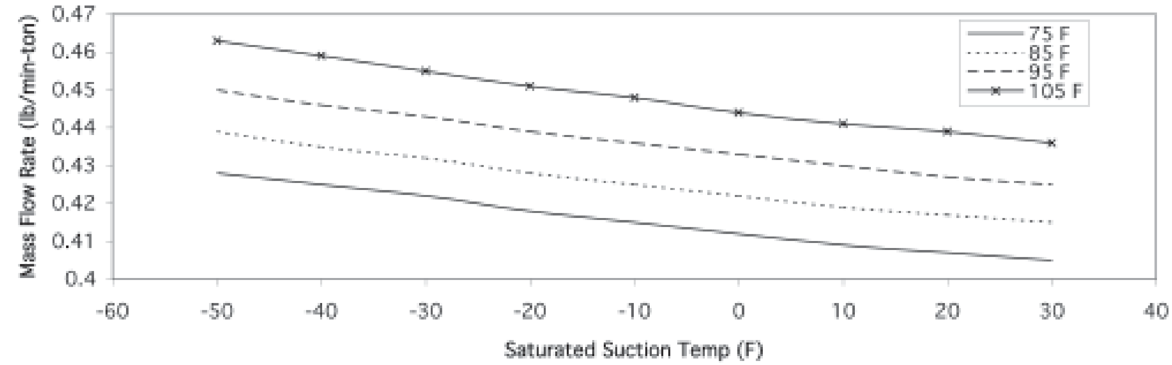
10 F	0.805	0.635	0.482	0.344
20 F	0.963	0.782	0.618	0.470
30 F	1.127	0.934	0.760	0.602
40 F	1.300	1.094	0.908	0.740

Figure B-10 Typical Adiabatic Compression Efficiency



Minimum	73	76	70	65	60
Maximum	78	82	77	73	69

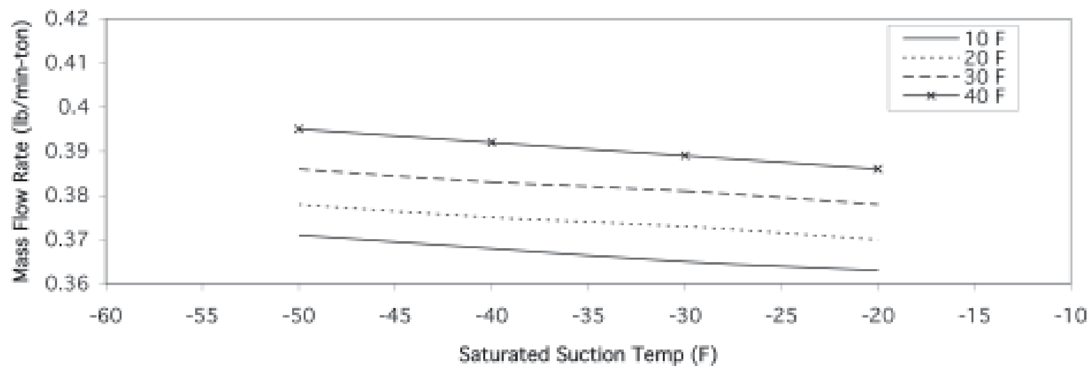
Figure B-11 High Stage Mass Flow Rate Per Ton



Sat Disch Temp

75 F	0.428	0.425	0.422	0.418	0.415	0.412	0.409	0.407	0.405
85 F	0.439	0.435	0.432	0.428	0.425	0.422	0.419	0.417	0.415
95 F	0.450	0.446	0.443	0.439	0.436	0.433	0.430	0.427	0.425
105 F	0.463	0.459	0.455	0.451	0.448	0.444	0.441	0.439	0.436

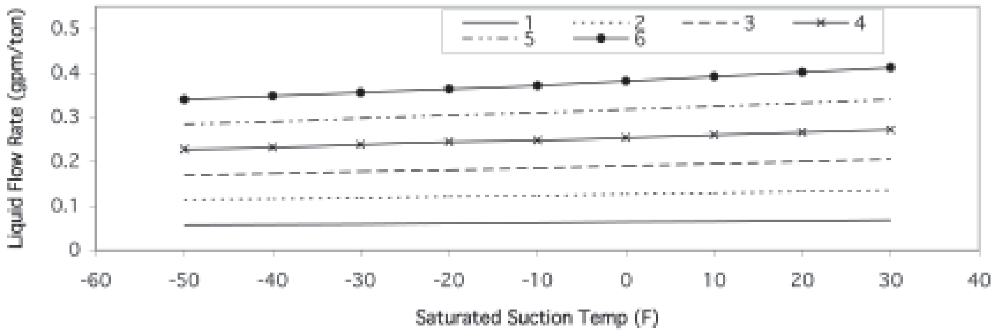
Figure B-12 Booster Mass Flow Rate Per Ton



Sat Disch Temp

10 F	0.371	0.368	0.365	0.363
20 F	0.378	0.375	0.373	0.370
30 F	0.386	0.383	0.381	0.378
40 F	0.395	0.392	0.389	0.386

Figure B-13 Liquid Overfeed Circulating Number



1	0.057	0.058	0.059	0.061	0.062	0.064	0.065	0.067	0.068
2	0.114	0.116	0.119	0.122	0.124	0.127	0.130	0.133	0.136
3	0.170	0.174	0.178	0.182	0.186	0.191	0.196	0.201	0.206
4	0.228	0.232	0.238	0.244	0.248	0.254	0.260	0.266	0.272
5	0.285	0.290	0.298	0.305	0.310	0.318	0.325	0.333	0.340
6	0.340	0.348	0.356	0.364	0.372	0.382	0.392	0.402	0.412