Case – 2 P-H Diagram Analysis for Multiple Refrigeration Loads Compound System

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Case Background:

The purpose of this case is to illustrate:

(I) Use of P-H diagram method to analysis the refrigeration system in accordance with the specification given for a compound refrigeration system with multiple refrigeration loads.

(II) Layout the refrigerant flow diagram conforms to the P-H diagram.

(III) How to calculate the refrigerant flows and power consumption based on the P-H diagram to meet the refrigeration loads as specified.

The Refrigeration System Specifications:

This refrigeration unit is with water cooled condenser, R-717 refrigerant, 460-3-60 power supply for Class 1, Group D, Division II area installation.

The unit is to be designed to handle three evaporative loads and is to be designed in accordance with the parameters and requirements as indicated below; all the evaporators are provided by the user and are remote mounted:

Evaporator No. 1:

The refrigeration capacity is 260 TR at evaporative temperature of -40°F.

Evaporator No. 2:

The evaporator is located at the same area as evaporator #1; same external piping pressure drop and superheat as the evaporator #1.

The refrigeration load is 30 TR to cool special brine from -20°F to -26°F leaving. The evaporative temperature required for this heat exchanger is to be -35°F.

Evaporator No. 3:

The refrigeration load is 80 TR to cool Ethylene Glycol Brine from 37°F to 30°F with an ET of 20°F, The external piping suction pressure drop and suction superheat allowed it to be given to the user to allow the user to make proper design of the suction piping for the heat exchanger.

Screw compressors are to be used for the compound system; no economizing is allowed for the compressors. Flash type intermediate intercooler with coil for liquid subcooling is to be used; 15°F approach to the intermediate temperature for the design is 15°F.

The screw compressor is with liquid injection oil cooling; assuming no power and capacity penalties for the oil cooling arrangement; pre-lube oil pump is used.

Assume compressor adiabatic efficiency is as the following:

For the booster compressor:	75%
For the high stage compressor:	75%

The mechanical efficiencies of the compressors for the calculation are 97%.

Remote water cooled condenser is used. The condenser is supplied by the user. The design condensing temperature is 105°F. The ambient design temperature is 91°FDB and 82°FWB.

Piping pressure drops and superheats limitations are as the following:

Booster compressor suction: Minimum piping pressure drop is 1.6 Psi; the maximum pressure drop for the suction valve, strainer and the check valve assembly of the compressor is 0.8 Psi; the suction superheat is 10°F.

High stage compressor suction: Piping pressure drop is 0.5 Psi; the pressure drop for the suction valve, strainer and the check valve assembly is.6 Psi; the suction superheat is 5°F.

High stage compressor discharge: The external piping pressure drop is 2.8 Psi; oil separator and discharge valve pressure drop is 4.3 Psi.

Low stage compressor discharge: The external piping pressure drop is 0.4 Psi; oil separator and discharge valve pressure drop is 3.5 Psi.

The information from this system design exercise as the following:

A. A report to outline the design concept, approach and consideration for the refrigeration system.

B. A detail P-H diagram to show all the operating conditions, enthalpy points and the refrigerant flows.

C. A detail refrigerant diagram showing all the operating conditions and the refrigerant flow rates in Lbs/Min on the flow diagram.

D. Fill in the Summary Data Sheet show below:

Maximum superheat and pressure drop for the Evaporator #3,	
Max. pres. drop, Psi	
Max. superheat, °F	
Booster Compressor Suction:	
Suction Pressure, Psia	
Suction Temp., °F	
Suction Flow, Lbs/Min	
Suction Flow, ACFM	
High Stage Compressor Suction Conditions:	
Suction Pressure, Psia	
Suction Temp., °F	
Suction Flow, Lbs/Min	
Suction Flow, ACFM	
Power Consumption Conditions:	
Booster Compressor, BHP	
High Stage Comp., BHP	
Heat Rejection from condenser, MBH	
Refrigerant flow to the condenser: Lbs/Min.	

Related Technical and Engineering Data for the Calculation:

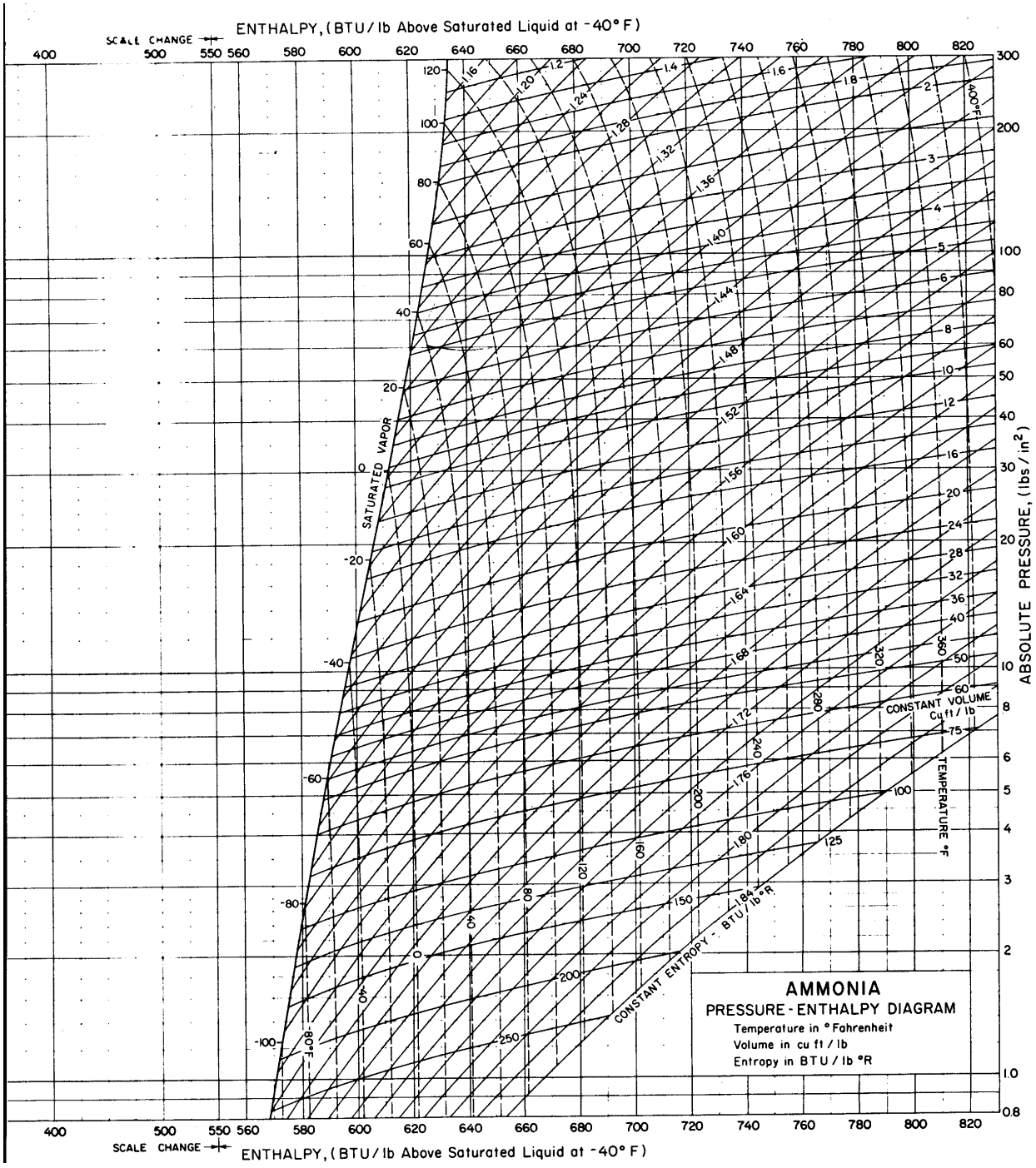


Figure-2-1 Pressure-Enthalpy Diagram of Ammonia

TEMP F	PRESSURE lb per sq in		VOLUME cu ft per lb		DENSITY lb per cu ft		ENTHALPY ** Btu per lb			ENTROPY ** Btu per (lb) (^{o}R)		TEMP F
t	Absolute P	Gage p	Liquid v_f	Vapor v_g	Liquid $1/v_f$	Vapor $1/v_g$	Liquid h_f	Latent h_{fg}	Vapor h_g	Liquid s_f	Vapor s_g	t
-45	8.95	11.7*	0.02310	28.62	43.28	0.03494	- 5.3	600.9	595.6	-0.0127	1.4368	-45
-44	9.23	11.1*	.02313	27.82	43.24	.03595	- 4.3	600.3	596.0	- .0102	1.4342	-44
-43	9.51	10.6*	.02315	27.04	43.20	.03698	- 3.2	599.6	596.4	- .0076	1.4317	-43
-42	9.81	10.0*	.02317	26.29	43.16	.03804	- 2.1	598.9	596.8	- .0051	1.4292	-42
-41	10.10	9.3*	.02320	25.56	43.11	.03912	- 1.1	598.3	597.2	- .0025	1.4267	-41
-40	10.41	8.7*	0.02322	24.86	43.07	0.04022	0.0	597.6	597.6	0.0000	1.4242	-40
-39	10.72	8.1*	.02324	24.18	43.03	.04135	1.1	596.9	598.0	.0025	1.4217	-39
-38	11.04	7.4*	.02326	23.53	42.99	.04251	2.1	596.2	598.3	.0051	1.4193	-38
-37	11.37	6.8*	.02328	22.89	42.95	.04369	3.2	595.5	598.7	.0076	1.4169	-37
-36	11.71	6.1*	.02331	22.27	42.90	.04489	4.3	594.8	599.1	.0101	1.4144	-36
-35	12.05	5.4*	0.02333	21.68	42.86	0.04613	5.3	594.2	599.5	0.0126	1.4120	-35
-34	12.41	4.7*	.02335	21.10	42.82	.04739	6.4	593.5	599.9	.0151	1.4096	-34
-33	12.77	3.9*	.02338	20.54	42.77	.04868	7.4	592.8	600.2	.0176	1.4072	-33
-32	13.14	3.2*	.02340	20.00	42.73	.04999	8.5	592.1	600.6	.0201	1.4048	-32
-31	13.52	2.4*	.02343	19.48	42.69	.05134	9.6	591.4	601.0	.0226	1.4025	-31
-30	13.90	1.6*	0.02345	18.97	42.65	0.05271	10.7	590.7	601.4	0.0250	1.4001	-30
-29	14.30	0.8*	.02347	18.48	42.61	.05411	11.7	590.0	601.7	.0275	1.3978	-29
-28	14.71	0.0	.02350	18.00	42.56	.05555	12.8	589.3	602.1	.0300	1.3955	-28
-27	15.12	0.4	.02352	17.54	42.52	.05701	13.9	588.6	602.5	.0325	1.3932	-27
-26	15.55	0.8	.02355	17.09	42.48	.05850	14.9	587.9	602.8	.0350	1.3909	-26
-25	15.98	1.3	0.02357	16.66	42.44	0.06003	16.0	587.2	603.2	0.0374	1.3886	-25
-24	16.42	1.7	.02360	16.24	42.39	.06158	17.1	586.5	603.6	.0399	1.3863	-24
-23	16.88	2.2	.02362	15.83	42.35	.06317	18.1	585.8	603.9	.0423	1.3840	-23
-22	17.34	2.6	.02364	15.43	42.31	.06479	19.2	585.1	604.3	.0448	1.3818	-22
-21	17.81	3.1	.02367	15.05	42.26	.06644	20.3	584.3	604.6	.0472	1.3796	-21
-20	18.30	3.6	0.02369	14.68	42.22	0.06813	21.4	583.6	605.0	0.0497	1.3774	-20
-19	18.79	4.1	.02371	14.32	42.18	.06985	22.4	582.9	605.3	.0521	1.3752	-19
-18	19.30	4.6	.02374	13.97	42.13	.07161	23.5	582.2	605.7	.0545	1.3729	-18
-17	19.81	5.1	.02376	13.62	42.09	.07340	24.6	581.5	606.1	.0570	1.3708	-17
-16	20.34	5.6	.02378	13.29	42.05	.07522	25.6	580.8	606.4	.0594	1.3686	-16
-15	20.88	6.2	0.02381	12.97	42.00	0.07709	26.7	580.0	606.7	0.0618	1.3664	-15
-14	21.43	6.7	.02383	12.66	41.96	.07898	27.8	579.3	607.1	.0642	1.3643	-14
-13	21.99	7.3	.02386	12.36	41.91	.08092	28.9	578.6	607.5	.0666	1.3621	-13
-12	22.56	7.9	.02388	12.06	41.87	.08289	30.0	577.8	607.8	.0690	1.3600	-12
-11	23.15	8.5	.02391	11.78	41.82	.08490	31.0	577.1	608.1	.0714	1.3579	-11
-10	23.74	9.0	0.02393	11.50	41.78	0.08695	32.1	576.4	608.5	0.0738	1.3558	-10
- 9	24.35	9.7	.02395	11.23	41.74	.08904	33.2	575.6	608.8	.0762	1.3537	- 9
- 8	24.97	10.3	.02398	10.97	41.69	.09117	34.3	574.9	609.2	.0786	1.3516	- 8
- 7	25.61	10.9	.02401	10.71	41.65	.09334	35.4	574.1	609.5	.0809	1.3495	- 7
- 6	26.26	11.6	.02403	10.47	41.60	.09555	36.4	573.4	609.8	.0833	1.3474	- 6
- 5	26.92	12.2	0.02406	10.23	41.56	0.09780	37.5	572.6	610.1	0.0857	1.3454	- 5
- 4	27.59	12.9	.02408	9.991	41.52	.1001	38.6	571.9	610.5	.0880	1.3433	- 4
- 3	28.28	13.6	.02411	9.763	41.47	.1024	39.7	571.1	610.8	.0904	1.3413	- 3
- 2	28.98	14.3	.02414	9.541	41.43	.1048	40.7	570.4	611.1	.0928	1.3393	- 2
- 1	29.69	15.0	.02416	9.326	41.38	.1072	41.8	569.6	611.4	.0951	1.3372	- 1
0	30.42	15.7	0.02419	9.116	41.34	0.1097	42.9	568.9	611.8	0.0975	1.3352	0
1	31.16	16.5	.02422	8.912	41.29	.1122	44.0	568.1	612.1	.0998	1.3332	1
2	31.92	17.2	.02424	8.714	41.25	.1148	45.1	567.3	612.4	.1022	1.3312	2
3	32.69	18.0	.02427	8.521	41.20	.1174	46.2	566.5	612.7	.1045	1.3292	3
4	33.47	18.8	.02429	8.333	41.16	.1200	47.2	565.8	613.0	.1069	1.3273	4
5	34.27	19.6	0.02432	8.150	41.11	0.1227	48.3	565.0	613.3	0.1092	1.3253	5
6	35.09	20.4	.02435	7.971	41.07	.1254	49.4	564.2	613.6	.1115	1.3234	6
7	35.92	21.2	.02438	7.798	41.02	.1282	50.5	563.4	613.9	.1138	1.3214	7
8	36.77	22.1	.02440	7.629	40.98	.1311	51.6	562.7	614.3	.1162	1.3195	8
9	37.63	22.9	.02443	7.464	40.93	.1340	52.7	561.9	614.6	.1185	1.3176	9
10	38.51	23.8	0.02446	7.304	40.89	0.1369	53.8	561.1	614.9	0.1208	1.3157	10
11	39.40	24.7	.02449	7.148	40.84	.1399	54.9	560.3	615.2	.1231	1.3137	11
12	40.31	25.6	.02451	6.996	40.80	.1429	56.0	559.5	615.5	.1254	1.3118	12
13	41.24	26.5	.02454	6.847	40.75	.1460	57.1	558.7	615.8	.1277	1.3099	13
14	42.18	27.5	.02457	6.703	40.71	.1492	58.2	557.9	616.1	.1300	1.3081	14
15	43.14	28.4	0.02460	6.562	40.66	0.1524	59.2	557.1	616.3	0.1323	1.3062	15
16	44.12	29.4	.02463	6.425	40.62	.1556	60.3	556.3	616.6	.1346	1.3043	16
17	45.12	30.4	.02466	6.291	40.57	.1590	61.4	555.5	616.9	.1369	1.3025	17
18	46.13	31.4	.02468	6.161	40.52	.1623	62.5	554.7	617.2	.1392	1.3006	18
19	47.16	32.5	.02471	6.034	40.48	0.1657	63.6	553.9	617.5	0.1415	1.2988	19

* Inches of mercury below one standard atmosphere.

Figure 2-2A Properties of Saturated Liquid and Vapor of R-717

TEMP F	PRESSURE lb per sq in		VOLUME cu ft per lb		DENSITY lb per cu ft		ENTHALPY ** Btu per lb			ENTROPY ** Btu per (lb) (^{O}R)		TEMP F
t	Absolute P	Gage p	Liquid v_f	Vapor v_g	Liquid $1/v_f$	Vapor $1/v_g$	Liquid h_f	Latent h_{fg}	Vapor h_g	Liquid s_f	Vapor s_g	t
20	48.21	33.5	0.02474	5.910	40.43	0.1692	64.7	553.1	617.8	0.1437	1.2969	20
21	49.28	34.6	.02477	5.789	40.38	.1728	65.8	552.2	618.0	.1460	1.2951	21
22	50.36	35.7	.02480	5.671	40.34	.1763	66.9	551.4	618.3	.1483	1.2933	22
23	51.47	36.8	.02483	5.556	40.29	.1800	68.0	550.6	618.6	.1505	1.2915	23
24	52.59	37.9	.02485	5.443	40.25	.1837	69.1	549.8	618.9	.1528	1.2897	24
25	53.73	39.0	0.02488	5.334	40.20	0.1875	70.2	548.9	619.1	0.1551	1.2879	25
26	54.90	40.2	.02491	5.227	40.15	.1913	71.3	548.1	619.4	.1573	1.2861	26
27	56.08	41.4	.02494	5.123	40.11	.1952	72.4	547.3	619.7	.1596	1.2843	27
28	57.28	42.6	.02497	5.021	40.06	.1992	73.5	546.4	619.9	.1618	1.2825	28
29	58.50	43.8	.02500	4.922	40.01	.2032	74.6	545.6	620.2	.1641	1.2808	29
30	59.74	45.0	0.02503	4.825	39.96	0.2073	75.7	544.8	620.5	0.1663	1.2790	30
31	61.00	46.3	.02506	4.730	39.92	.2114	76.8	543.9	620.7	.1686	1.2773	31
32	62.29	47.6	.02509	4.637	39.87	.2156	77.9	543.1	621.0	.1708	1.2755	32
33	63.59	48.9	.02512	4.547	39.82	.2199	79.0	542.2	621.2	.1730	1.2738	33
34	64.91	50.2	.02515	4.459	39.77	.2243	80.1	541.4	621.5	.1753	1.2721	34
35	66.26	51.6	0.02518	4.373	39.72	0.2287	81.2	540.5	621.7	0.1775	1.2704	35
36	67.63	52.9	.02521	4.289	39.68	.2332	82.3	539.7	622.0	.1797	1.2686	36
37	69.02	54.3	.02524	4.207	39.63	.2377	83.4	538.8	622.2	.1819	1.2669	37
38	70.43	55.7	.02527	4.126	39.59	.2423	84.6	537.9	622.5	.1841	1.2652	38
39	71.87	57.2	.02530	4.048	39.54	.2470	85.7	537.0	622.7	.1863	1.2635	39
40	73.32	58.6	0.02533	3.971	39.49	0.2518	86.8	536.2	623.0	0.1885	1.2618	40
41	74.80	60.1	.02536	3.897	39.44	.2566	87.9	535.3	623.2	.1908	1.2602	41
42	76.31	61.6	.02539	3.823	39.39	.2616	89.0	534.4	623.4	.1930	1.2585	42
43	77.83	63.1	.02542	3.752	39.34	.2665	90.1	533.6	623.7	.1952	1.2568	43
44	79.38	64.7	.02545	3.682	39.29	.2716	91.2	532.7	623.9	.1974	1.2552	44
45	80.96	66.3	0.02548	3.614	39.24	0.2767	92.3	531.8	624.1	0.1996	1.2535	45
46	82.55	67.9	.02551	3.547	39.20	.2819	93.5	530.9	624.4	.2018	1.2519	46
47	84.18	69.5	.02554	3.481	39.15	.2872	94.6	530.0	624.6	.2040	1.2502	47
48	85.82	71.1	.02557	3.418	39.10	.2926	95.7	529.1	624.8	.2062	1.2486	48
49	87.49	72.8	.02560	3.355	39.05	.2981	96.8	528.2	625.0	.2083	1.2469	49
50	89.19	74.5	0.02564	3.294	39.00	0.3036	97.9	527.3	625.2	0.2105	1.2453	50
51	90.91	76.2	.02567	3.234	38.95	.3092	99.1	526.4	625.5	.2127	1.2437	51
52	92.66	78.0	.02570	3.176	38.90	.3149	100.2	525.5	625.7	.2149	1.2421	52
53	94.43	79.7	.07574	3.119	38.85	.3207	101.3	524.6	625.9	.2171	1.2405	53
54	96.23	81.5	.02577	3.063	38.80	.3265	102.4	523.7	626.1	.2192	1.2389	54
55	98.06	83.4	0.02581	3.008	38.75	0.3325	103.5	522.8	626.3	0.2214	1.2373	55
56	99.91	85.2	.02584	2.954	38.70	.3385	104.7	521.8	626.5	.2236	1.2357	56
57	101.8	87.1	.02587	2.902	38.65	.3446	105.8	520.9	626.7	.2257	1.2341	57
58	103.7	89.0	.02590	2.851	38.60	.3508	106.9	520.0	626.9	.2279	1.2325	58
59	105.6	90.9	.02594	2.800	38.55	.3571	108.1	519.0	627.1	.2301	1.2310	59
60	107.6	92.9	0.02597	2.751	38.50	0.3635	109.2	518.1	627.3	0.2322	1.2294	60
61	109.6	94.9	.02600	2.703	38.45	.3700	110.3	517.2	627.5	.2344	1.2278	61
62	111.6	96.9	.02604	2.656	38.40	.3765	111.5	516.2	627.7	.2365	1.2262	62
63	113.6	98.9	.02607	2.610	38.35	.3832	112.6	515.3	627.9	.2387	1.2247	63
64	115.7	101.0	.02611	2.565	38.30	.3899	113.7	514.3	628.0	.2408	1.2231	64
65	117.8	103.1	0.02614	2.520	38.25	0.3968	114.8	513.4	628.2	0.2430	1.2216	65
66	120.0	105.3	.02618	2.477	38.20	.4037	116.0	512.4	628.4	.2451	1.2201	66
67	122.1	107.4	.02621	2.435	38.15	.4108	117.1	511.5	628.6	.2473	1.2186	67
68	124.3	109.6	.02625	2.393	38.10	.4179	118.3	510.5	628.8	.2494	1.2170	68
69	126.5	111.8	.02628	2.352	38.05	.4251	119.4	509.5	628.9	.2515	1.2155	69
70	128.8	114.1	0.02632	2.312	38.00	0.4325	120.5	508.6	629.1	0.2537	1.2140	70
71	131.1	116.4	.02636	2.273	37.95	.4399	121.7	507.6	629.3	.2558	1.2125	71
72	133.4	118.7	.02639	2.235	37.90	.4474	122.8	506.6	629.4	.2579	1.2110	72
73	135.7	121.0	.02643	2.197	37.85	.4551	124.0	505.6	629.6	.2601	1.2095	73
74	138.1	123.4	.02647	2.161	37.79	.4628	125.1	504.7	629.8	.2622	1.2080	74
75	140.5	125.8	0.02650	2.125	37.74	0.4707	126.2	503.7	629.9	0.2643	1.2065	75
76	143.0	128.3	.02654	2.089	37.69	.4786	127.4	502.7	630.1	.2664	1.2050	76
77	145.4	130.7	.02657	2.055	37.64	.4867	128.5	501.7	630.2	.2685	1.2035	77
78	147.9	133.2	.02661	2.021	37.58	.4949	129.7	500.7	630.4	.2706	1.2020	78
79	150.5	135.8	.02665	1.988	37.53	.5031	130.8	499.7	630.5	.2728	1.2006	79
80	153.0	138.3	0.20668	1.955	37.48	0.5115	132.0	498.7	630.7	0.2749	1.1991	80
81	155.6	140.9	.02672	1.923	37.43	.5200	133.1	497.7	630.8	.2769	1.1976	81
82	158.3	143.6	.02676	1.892	37.37	.5287	134.3	496.7	631.0	.2791	1.1962	82
83	161.0	146.3	.02680	1.861	37.32	.5374	135.4	495.7	631.1	.2812	1.1947	83
84	163.7	149.0	.02683	1.831	37.26	0.5462	136.6	494.7	631.3	0.2833	1.1933	84

Figure 2-2B Properties of Saturated Liquid and Vapor of R-717

TEMP F	PRESSURE lb per sq in		VOLUME cu ft per lb		DENSITY lb per cu ft		ENTHALPY ** Btu per lb			ENTROPY ** Btu per (lb) (^{o}R)		TEMP F
t	Absolute P	Gage p	Liquid v_f	Vapor v_g	Liquid $1/v_f$	Vapor $1/v_g$	Liquid h_f	Latent h_{fg}	Vapor h_g	Liquid s_f	Vapor s_g	t
85	166.4	151.7	0.02687	1.801	37.21	0.5552	137.8	493.6	631.4	0.2854	1.1918	85
86	169.2	154.5	.02691	1.772	37.16	.5643	138.9	492.6	631.5	.2875	1.1904	86
87	172.0	157.3	.02695	1.744	37.10	.5735	140.1	491.6	631.7	.2895	1.1889	87
88	174.8	160.1	.02699	1.716	37.05	.5828	141.2	490.6	631.8	.2917	1.1875	88
89	177.7	163.0	.02703	1.688	36.99	.5923	142.4	489.5	631.9	.2937	1.1860	89
90	180.6	165.9	0.02707	1.661	36.94	0.6019	143.5	488.5	632.0	0.2958	1.1846	90
91	183.6	168.9	.02711	1.635	36.89	.6116	144.7	487.4	632.1	.2979	1.1832	91
92	186.6	171.9	.02715	1.609	36.83	.6214	145.8	486.4	632.2	.3000	1.1818	92
93	189.6	174.9	.02719	1.584	36.78	.6314	147.0	485.3	632.3	.3021	1.1804	93
94	192.7	178.0	.02723	1.559	36.72	.6415	148.2	484.3	632.5	.3041	1.1789	94
95	195.8	181.1	0.02727	1.534	36.67	0.6517	149.4	483.2	632.6	0.3062	1.1775	95
96	198.9	184.2	.02731	1.510	36.62	.6620	150.5	482.1	632.6	.3083	1.1761	96
97	202.1	187.4	.02735	1.487	36.56	.6725	151.7	481.1	632.8	.3104	1.1747	97
98	205.3	190.6	.02739	1.464	36.51	.6832	152.9	480.0	632.9	.3125	1.1733	98
99	208.6	193.9	.02743	1.441	36.45	.6939	154.0	478.9	632.9	.3145	1.1719	99
100	211.9	197.2	0.02748	1.419	36.40	0.7048	155.2	477.8	633.0	0.3166	1.1705	100
101	215.2	200.5	.02752	1.397	36.34	.7159	156.4	476.7	633.1	.3187	1.1691	101
102	218.6	203.9	.02756	1.375	36.29	.7270	157.6	475.6	633.2	.3207	1.1677	102
103	222.0	207.3	.02760	1.354	36.23	.7384	158.7	474.6	633.3	.3228	1.1663	103
104	225.4	210.7	.02764	1.334	36.18	.7498	159.9	473.5	633.4	.3248	1.1649	104
105	228.9	214.2	0.02769	1.313	36.12	0.7615	161.1	472.3	633.4	0.3269	1.1635	105
106	232.5	217.8	.02773	1.293	36.07	.7732	162.3	471.2	633.5	.3289	1.1621	106
107	236.0	221.3	.20778	1.274	36.01	.7852	163.5	470.1	633.6	.3310	1.1607	107
108	239.7	225.0	.20782	1.254	35.96	.7972	164.6	469.0	633.6	.3330	1.1593	108
109	243.3	228.6	.02786	1.235	35.90	.8095	165.8	467.9	633.7	.3351	1.1580	109
110	247.0	232.3	0.02790	1.217	35.84	0.8219	167.0	466.7	633.7	0.3372	1.1566	110
111	250.8	236.1	.02794	1.198	35.79	.8344	168.2	465.6	633.8	.3392	1.1552	111
112	254.5	239.8	.02799	1.180	35.73	.8471	169.4	464.4	633.8	.3413	1.1538	112
113	258.4	243.7	.02804	1.163	35.67	.8600	170.6	463.3	633.9	.3433	1.1524	113
114	262.2	247.5	.02808	1.145	35.61	.8730	171.8	462.1	633.9	.3453	1.1510	114
115	266.2	251.5	0.02813	1.128	35.55	0.8862	173.0	460.9	633.9	0.3474	1.1497	115
116	270.1	255.4	.02817	1.112	35.50	.8996	174.2	459.8	634.0	.3495	1.1483	116
117	274.1	259.4	.02822	1.095	35.44	.9132	175.4	458.6	634.0	.3515	1.1469	117
118	278.2	263.5	.02826	1.079	35.38	.9269	176.6	457.4	634.0	.3535	1.1455	118
119	282.3	267.6	.02831	1.063	35.32	.9408	177.8	456.2	634.0	.3556	1.1441	119
120	286.4	271.7	0.02836	1.047	35.26	0.9549	179.0	455.0	634.0	0.3576	1.1427	120
121	290.6	275.9	.02840	1.032	35.20	0.9692	180.2	453.8	634.0	.3597	1.1414	121
122	294.8	280.1	.02845	1.017	35.14	0.9837	181.4	452.6	634.0	.3618	1.1400	122
123	299.1	284.4	.02850	1.002	35.08	0.9983	182.6	451.4	634.0	.3638	1.1386	123
124	303.4	288.7	.02855	0.987	35.02	1.0132	183.9	450.1	634.0	.3659	1.1372	124
125	307.8	293.1	0.02860	0.973	34.96	1.028	185.1	448.9	634.0	0.3679	1.1358	125

Figure 2-2C Properties of Saturated Liquid and Vapor of R-717

Temp F	Abs Pressure 5.0 psi Gage Pressure 19.8 in. Vac (Sat'n Temp -63.11 F)			Abs Pressure 6.0 psi Gage Pressure 17.7 in. Vac (Sat'n Temp -57.64 F)			Abs Pressure 7.0 psi Gage Pressure 15.7 in. Vac (Sat'n Temp -52.88 F)			Abs Pressure 8.0 psi Gage Pressure 13.6 in. Vac (Sat'n Temp -48.64 F)		
t	v	h	s	v	h	s	v	h	s	v	h	s
(Sat'n)	(49.31)	(588.3)	(1.4857)	(41.59)	(590.6)	(1.4703)	(36.01)	(592.5)	(1.4574)	(31.79)	(594.2)	(1.4462)
- 50	51.05	595.2	1.5025	42.44	594.6	1.4803	36.29	594.0	1.4611	....	....	....
- 40	52.36	600.3	.5149	43.55	599.8	.4928	37.25	599.3	.4739	32.52	598.8	1.4573
- 30	53.67	605.4	.5269	44.64	604.9	.5049	38.19	604.5	.4861	33.36	604.1	.4697
- 20	54.97	610.4	.5385	45.73	610.0	.5166	39.13	609.6	.4979	34.19	609.3	.4816
- 10	56.26	615.4	.5498	46.82	615.1	.5280	40.07	614.7	.5094	35.01	614.4	.4932
0	57.55	620.4	1.5608	47.90	620.1	1.5391	41.00	619.8	1.5206	35.83	619.5	1.5044
10	58.84	625.4	.5716	48.98	625.2	.5499	41.93	624.9	.5314	36.64	624.6	.5154
20	60.12	630.4	.5821	50.05	630.2	.5605	42.85	629.9	.5421	37.45	629.7	.5261
30	61.41	635.4	.5925	51.12	635.2	.5708	43.77	635.0	.5525	38.26	634.7	.5365
40	62.69	640.4	.6026	52.19	640.2	.5810	44.69	640.0	.5627	39.07	639.8	.5467
50	63.96	645.5	1.6125	53.26	645.2	1.5910	45.61	645.0	1.5727	39.88	644.8	1.5568
60	65.24	650.5	.6223	54.32	650.3	.6008	46.53	650.1	.5825	40.68	649.9	.5666
70	66.51	655.5	.6319	55.39	655.3	.6104	47.44	655.2	.5921	41.48	655.0	.5763
80	67.79	660.6	.6413	56.45	660.4	.6199	48.36	660.2	.6016	42.28	660.1	.5858
90	69.06	665.6	.6506	57.51	665.5	.6292	49.27	665.3	.6110	43.08	665.2	.5952
100	70.33	670.7	1 6598	58.58	670.6	1.6384	50.18	670.4	1.6202	43.88	670.3	1.6044
110	71.60	675.8	.6689	59.64	675.7	.6474	51.09	675.5	.6292	44.68	675.4	.6135
120	72.87	680.9	.6778	60.70	680.8	.6563	52.00	680.7	.6382	45.48	680.5	.6224
130	74.14	686.1	.6865	61.76	685.9	.6651	52.91	685.8	.6470	46.27	685.7	.6312
140	75.41	691.2	.6952	62.82	691.1	.6738	53.82	691.0	.6557	47.07	690.9	.6399
150	76.68	696.4	1.7038	63.87	696.3	1.6824	54.73	696.2	1.6643	47.87	696.1	1.6485
160	77.95	701.6	.7122	64.93	701.5	.6909	55.63	701.4	.6727	48.66	701.3	.6570
170	79.21	706.8	.7206	65.99	706.7	.6992	56.54	706.6	.6811	49.46	706.5	.6654
180	80.48	712.1	1.7289	67.05	712.0	1.7075	57.45	711.9	1.6894	50.25	711.8	1.6737

Temp F	Abs Pressure 9.0 psi Gage Pressure 11.6 in. Vac (Sat'n Temp -44.38 F)			Abs Pressure 10.0 psi Gage Pressure 9.6 in. Vac (Sat'n Temp -41.34 F)			Abs Pressure 11.0 psi Gage Pressure 7.5 in. Vac (Sat'n Temp -38.14 F)			Abs Pressure 12.0 psi Gage Pressure 5.5 in. Vac (Sat'n Temp -35.16 F)		
(Sat'n)	(28.48)	(595.7)	(1.4363)	(25.81)	(597.1)	(1.4276)	(23.61)	(598.3)	(1.4196)	(21.77)	(599.4)	(1.4124)
- 40	28.85	598.3	1.4426	....	....	....	....	....	....	....	....	....
- 30	29.59	603.6	.4551	26.58	603.2	1.4420	24.12	602.7	1.4300	22.07	602.3	1.4190
- 20	30.34	608.9	.4672	27.26	608.5	.4542	24.74	608.1	.4423	22.64	607.7	.4314
- 10	31.07	614.0	.4788	27.92	613.7	.4659	25.35	613.3	.4542	23.20	613.0	.4434
0	31.80	619.2	1.4902	28.58	618.9	1.4773	25.95	618.5	1.4656	23.75	618.2	1.4549
10	32.53	624.3	.5012	29.24	624.0	.4884	26.55	623.7	.4768	24.31	623.4	.4661
20	33.26	629.4	.5119	29.90	629.1	.4992	27.15	628.9	.4876	24.86	628.6	.4770
30	33.98	634.5	.5224	30.55	634.2	.5097	27.74	634.0	.4982	25.41	633.7	.4877
40	34.70	639.5	.5327	31.20	639.3	.5200	28.34	639.1	.5085	25.95	638.9	.4980
50	35.42	644.6	1.5427	31.85	644.4	1.5301	28.93	644.2	1.5187	26.49	644.0	1.5082
60	36.13	649.7	.5526	32.49	649.5	.5400	29.52	649.3	.5286	27.03	649.1	.5182
70	36.85	654.8	.5623	33.14	654.6	.5497	30.10	654.4	.5383	27.57	654.3	.5279
80	37.56	659.9	.5718	33.78	659.7	.5593	30.69	659.6	.5479	28.11	659.4	.5375
90	38.27	665.0	.5812	34.42	664.8	.5687	31.28	664.7	.5573	28.65	664.5	.5470
100	38.98	670.1	1.5904	35.07	670.0	1.5779	31.86	669.8	1.5666	29.19	669.7	1.5562
110	39.70	675.3	.5995	35.71	675.1	.5870	32.44	675.0	.5757	29.72	674.8	.5654
120	40.40	680.4	.6085	36.35	680.3	.5960	33.03	680.1	.5847	30.26	680.0	.5744
130	41.11	685.6	.6173	36.99	685.4	.6049	33.61	685.3	.5936	30.79	685.2	.5833
140	41.82	690.7	.6260	37.62	690.6	.6136	34.19	690.5	.6023	31.33	690.4	.5920
150	42.53	695.9	1.6346	38.26	695.8	1.6222	34.77	695.7	1.6109	31.86	695.6	1.6006
160	43.24	701.2	.6431	38.90	701.1	.6307	35.35	700.9	.6194	32.39	700.8	.6092
170	43.95	706.4	.6515	39.54	706.3	.6391	35.93	706.2	.6278	32.92	706.1	.6176
180	44.65	711.7	1.6598	40.17	711.6	.6474	36.51	711.5	.6362	33.46	711.4	.6259
190	....	....	....	40.81	716.9	.6556	37.09	716.8	.6444	33.99	716.7	.6341
200	....	....	....	41.45	722.2	1.6637	37.67	722.1	1.6525	34.52	722.0	1.6422

Figure 2-3 Properties of Superheated Vapor for R-717

Cogitation:

Summary of Given Conditions from the Specifications and P-H Diagram Composition for the Sstem:

Refrigerant: R-717

Evaporators:

Load No. 1:	260 TR,	-40°F (10.4 Pisa)
Load No. 2:	30 TR,	-35°F (12.05 Psia)
Load No. 3:	80 TR,	20°F (48.2 Psia)

Condensing Temperature: 105°F (228.9 Psia**)**

This system shall be compound system by using screw compressors with no economizer.

Flash type intermediate Intercooler with coil for liquid subcooling shall be used:

Intermediate temperature:	15°F (43.1 Psia)
Approach:	15°F

All the temperatures indicated are saturated temperature; the saturated refrigerant pressures are obtained from the refrigerant property chart of Figure 2-2.

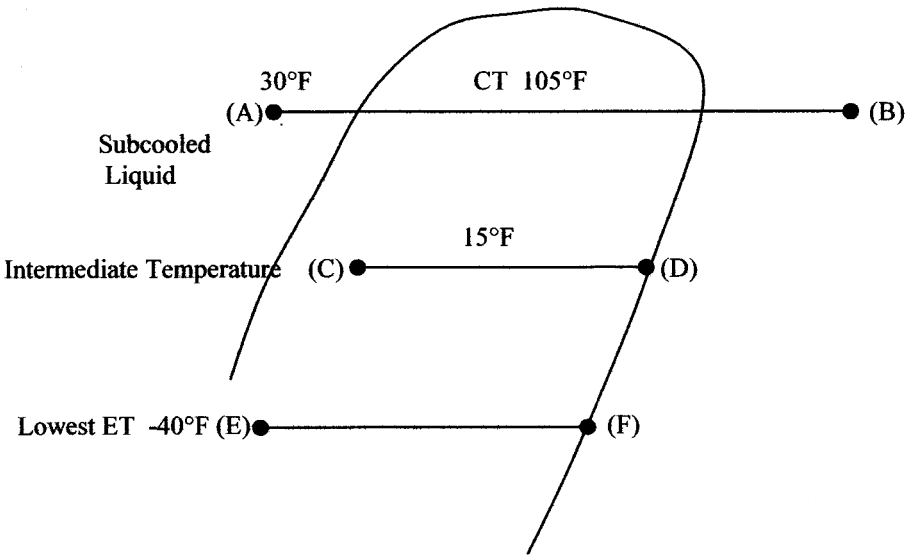


Figure-2-4 Determination of CT, ET and Intermediate Temperature Lines on P-H Diagram

Three (3) basic lines for this compound system is shown on Figure 2-4; one is the condensing condenser line of (A)-(B) at 105°F; one is the intermediate temperature line of (C)-(D) at 15°F and another line of (E)-(F) represents the lowest evaporative temperature at -40°F.

The specification indicates that a coil type liquid subcool flash intermediate intercooler is to be used and the approach is 15°F, that means the liquid leaving the subcooler shall be 15°F higher than the intermediate temperature (15°F), that is the liquid is subcooled from 105°F to 30°F by the liquid subcooling coil, it is the point (A) leaving the intermediate intercooler as shown in the Figure 2-4.

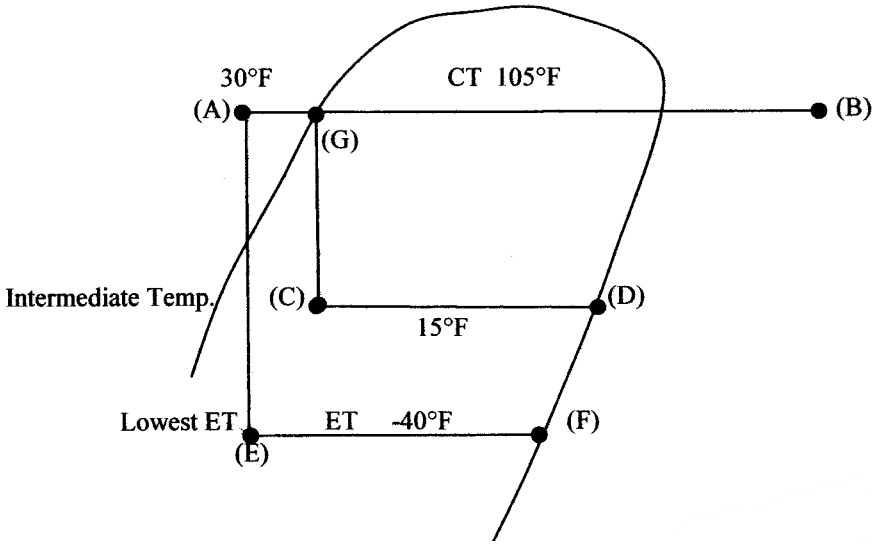


Figure 2-5 Liquid Subcooling and
Liquid Feed Lines on P-H Diagram

From Figure 2-5, the saturated liquid to intermediate intercooler shall be from the condenser (or high pressure receiver), (G)-(C) represents the throttling line for the intermediate intercooler; the liquid for the lowest temperature evaporator No.1 shall be from the subcooled liquid leaving the intermediate intercooler, which is from point (A); the throttling process is represented by line (A)-(E) as shown in the P-H diagram of Figure 2-5.

Figure 2-6 shows the ET line of (J)-(K) for ET of -35°F for the Evaporator No. 2 and the line of (H)-(I) for ET 20°F for Evaporator No. 3. It is more logical to direct the liquid for 20°F evaporator from the point (G) and the liquid for the -35°F evaporator shall be from the subcooled liquid of point (A) as shown in the P-H diagram.

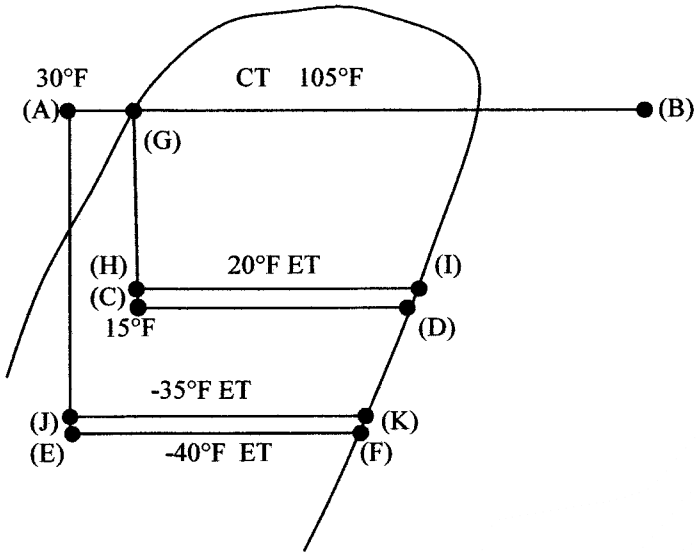


Figure 2-6 No. 2 and No. 3 Refrigeration Load Lines

See the Figure 2-6 and 2-7, draw a line (O)-(Q), it represents the discharge pressure drop for the high stage screw compressor; line (D)-(N) is the suction pressure drop and suction superheat penalties for the suction for the high stage compressor; the line (O)-(N) is the adiabatic compression line of the high stage compressor.

Likewise, the lines (M)-(P) and (F)-(L) are the penalties for the low stage compressor and the line (M)-(L) is the adiabatic compression line for the low stage compressor as shown in Figure 2-7..

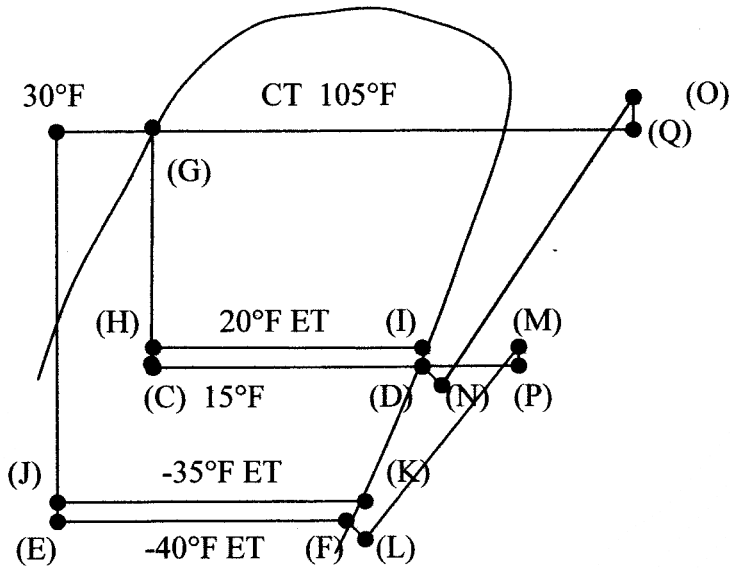


Figure 2-7 High Stage and Low Stage Compressor Lines and Penalties

The suction gas from the evaporator No. 3 is to be returned to the high stage compressor and the suction gas from evaporator No. 2 is to be combined with the suction gas from evaporator No. 1 and returned to the suction of the low stage compressor at point (L).

Composing the Refrigerant Flow Diagram:

Refrigerant flow diagram starts from the major components needed for the system. The refrigerant flow diagram is structured, composed and laying out exactly by following with the system design concepts and thermodynamic bases which were used to develop the P-H diagram for the system. The first step is to arrange the components to a relative array position as shown in Figure 2-8.

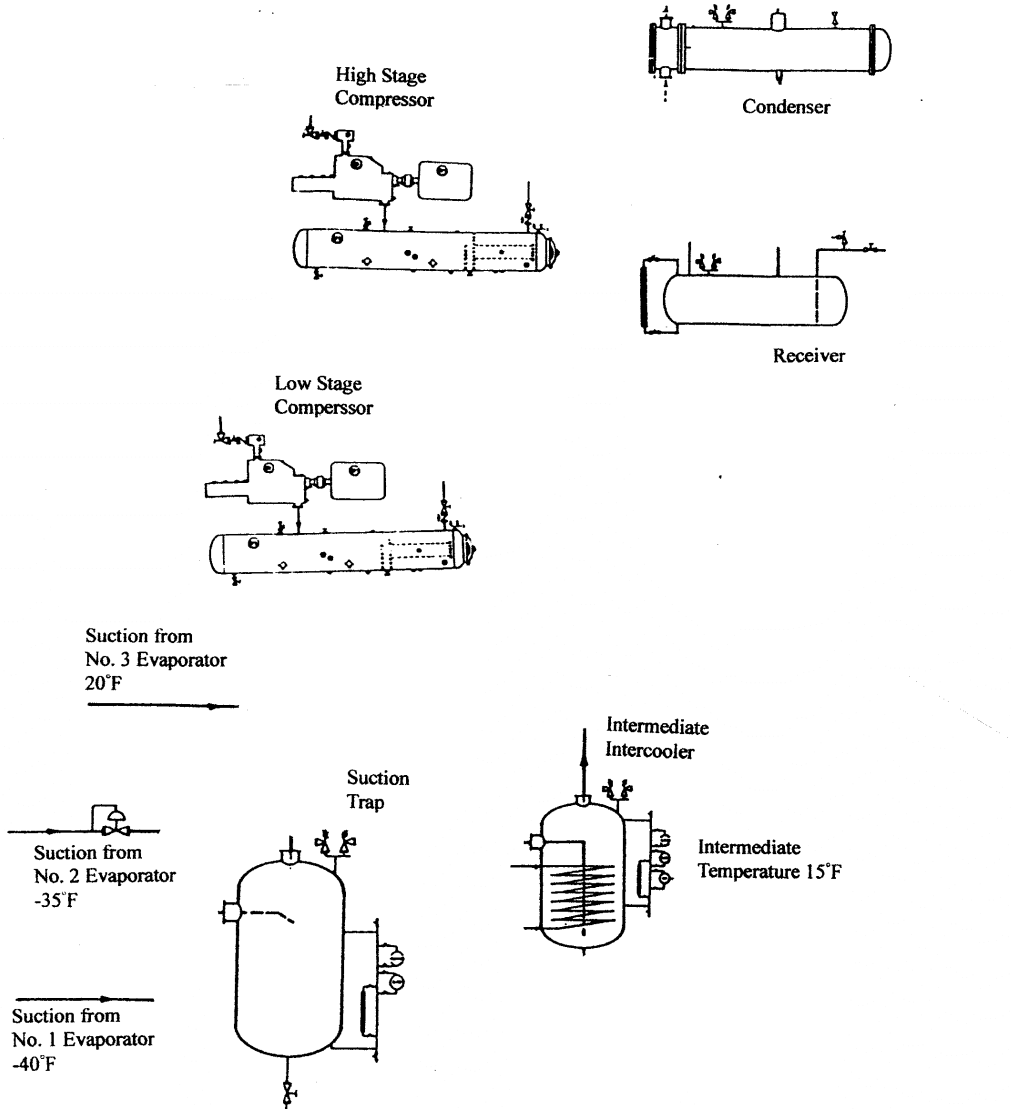


Figure 2-8 Major Components Array for the Refrigeration System

The major components shown in Figure 2-8 are water cooled condenser, high stage compressor, booster compressor and intermediate coil type intercooler for this compound refrigeration system as indicated in the P-H diagram of Figure 2-7; plus high pressure receiver and suction trap. Three suction lines from three evaporators are also shown.

Some of the components such as receiver, suction trap, valves and etc. are the hidden items and it is not shown in the P-H diagram, because it does not affect the thermodynamic property of the refrigeration system. But, it is important for the good application practice and operation if these items are included in the refrigeration system design. These items are to be shown in the refrigerant flow diagram.

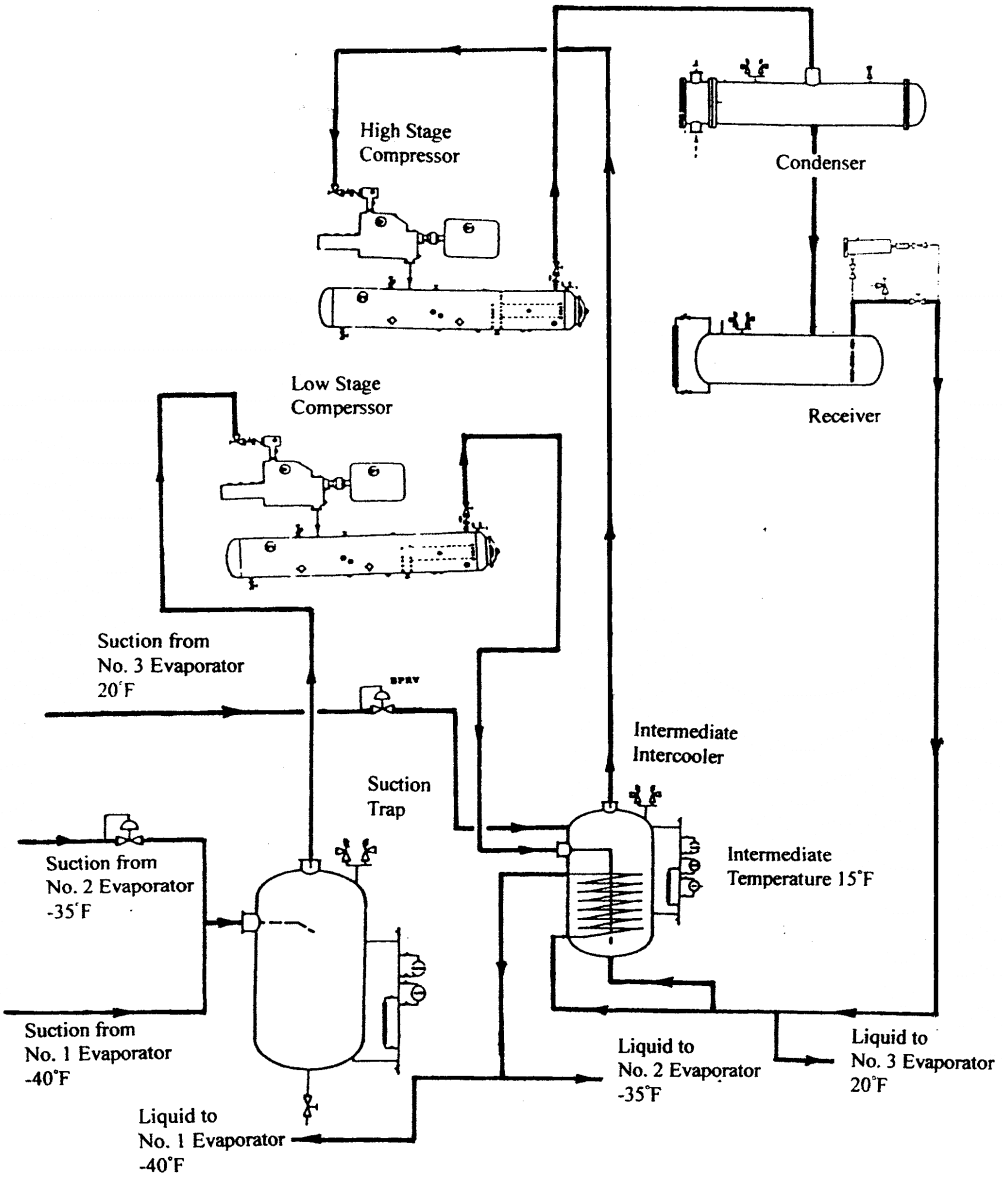


Figure 2-9 Composing the Refrigerant Flow Diagram for the System

Connecting the components in accordance with the design logics established by the P-H diagram of Figure 2-7, the refrigerant flow diagram for system is completed and it is shown in Figure 2-9, this is the simplified version of the refrigerant flow diagram for the system conforming to the functions outlined in the P-H diagram. Suction pressure regulating valve is used for suction line from the evaporator No. 2 and No. 3 to regulate the pressure difference when merge to the compressor suction.

P-H diagram is to show if the system designed meets with thermodynamic feasibilities and the refrigerant flow diagram is to show if the mechanical working system reflects the thermodynamic theory and is in compliance to the P-H diagram; the refrigerant flow diagram is also to show the functions of the refrigeration system.

Calculating the Refrigerant Flows and the Power Consumptions:

Compressor Efficiency:

Adiabatic Efficiency: 75%
Mechanical Efficiency: 97%

Booster Compressor Suction Conditions:

Suction Pressure: 10.4 – 1.6 – 0.8 = 8 Psia
Suction Temperature: -40 + 10 = -30°F

Booster Compressor Discharge Pressure: 43.1 + 3.5 + 0.4 = 47 Psia

High Stage Suction Conditions:

Suction Pressure: 43.1 – 0.5 – 0.6 = 42 Psia
Suction Temperature: 15 + 5 = 20°F

High Stage Discharge Pressure: 228.90 + 2.8 + 4.3 = 236 Psia

Booster (Low Stage) Compressor Calculation:

See Figure 2-10, the enthalpy values are shown for points (K), (F), (G) and (A).

FLOW (1) = Refrigerant Flow from Evaporator No. 1, 260 TR at ET of -40°F

$$= \frac{200}{(H_F - H_E)} \times TR$$

$$= \frac{200}{597.6 - 75.7} \times 260$$

= 99.64 Lbs/Min

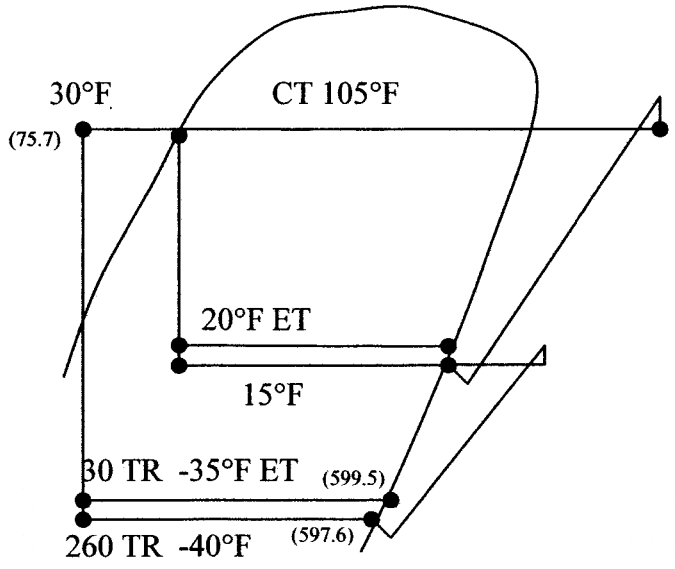


Figure 2-10 Enthalpy Values for Refrigerant for Evaporator Load No. 1 and No. 2

FLOW (2) = Refrigerant Flow from 30 TR load at -35°F, Evaporator No. 2.

$$= \frac{200}{(H_K - H_J)} \times TR$$

$$= \frac{200}{599.5 - 75.7} \times 30$$

= 11.45 LBS/MIN

FLOW (B) = Total Refrigerant Flow for the Booster Compressor

= FLOW (1) + FLOW (2)

= 99.64 + 11.45

= 111.09 Lbs/Min

Adiabatic head for the booster compressor, HEAD(B):

$$\begin{aligned} HEAD(B) &= (H_M - H_L) \times 778 \\ &= (712 - 604.1) \times 778 \\ &= 107.8 \times 778 \\ &= 83{,}868 \text{ FT.} \end{aligned}$$

Power consumption for the booster compressor, BHP (B):

Adiabatic EFF. = 75%
Mechanical EFF.= 97%.

FLOW(B) `= 111.09 Lbs/Min
HEAD(B) `= 83,868 Ft.

$$BHP(B) = \frac{FLOW(B) \times HEAD(B)}{33000 \times EFF}$$

$$= \frac{FLOW(B) \times HEAD(B)}{33000 \times 0.75 \times 0.97}$$

$$= \frac{111.09 \times 83868}{33000 \times 0.75 \times 0.97} = 388.1 \text{ BHP}$$

Refrigerant Flow to High Stage Compressor and Power Consumption Calculation:

See Figure 2-11, the enthalpy values are shown for points (I) and (D). From the Figure 2-11, it shows that the gas flows to the suction of the high stage compressor comes from four sources as the following:

(1) First is the refrigerant flow from the discharge from the booster compressor:

$$= 99.64 + 11.45 = 111.09 \text{ Lbs/Min}$$

(2) Second refrigerant flow is from the evaporator #3 of 80 TR load at ET 20°F:

$$= \frac{200}{617.8 - 161.1} \times 80$$

$$= 35.03 \text{ Lbs/Min}$$

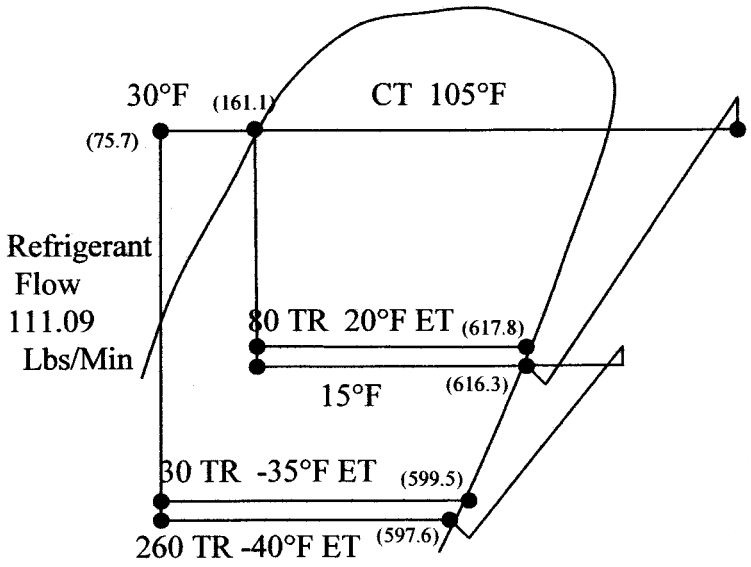


Figure 2-11 Enthalpy Values for Refrigerant for Evaporator Load No. 3 & Intermediate Temperature

(3) The third source is the refrigerant flow required to subcool the liquid 105°F to 30°F from the intermediate intercooler:

Liquid to be subcooled = 111.09 Lbs/Min.

Heat load for the subcooling:

$$= \frac{111.09 \times (161.1 - 75.7)}{200}$$

$$= 47.8 \text{ TR}$$

$$\text{Refrigerant flow} = \frac{200}{616.3 - 161.1} \times 47.8$$

$$= 20.8 \text{ Lbs/Min}$$

(4) The fourth source is the refrigerant flow required to desuperheat the discharge gas from low stage compressor to saturation point (D):

Gas to be desuperheated = 111.09 Lbs/Min.

Enthalpy at the point of low stage compressor discharge = H_X

$$H_X = H_L + \frac{H_M - H_L}{0.75 \times 0.97}$$

$$= 604.1 + \frac{712 - 604.1}{0.75 \times 0.97}$$

$$= 752.42 \text{ Btu/Lb}$$

Refrigerant load for desuperheating:

$$= \frac{111.09 \times (752.42 - 616.3)}{200}$$

$$= 75.6 \text{ TR}$$

$$\text{Refrigerant flow} = \frac{200}{616.3 - 161.1} \times 75.6$$

$$= 33.6 \text{ Lbs/Min}$$

Total Suction flow for the high stage compressor = FLOW (H):

$$\text{FLOW (H)} = 111.09 + 35.03 + 20.8 + 33.22$$

$$= 200.14 \text{ Lbs/Min}$$

Cross check & verification by using heat rejection method:

Heat rejection from booster compressor:

= BHP x 2545 + TR x 12000

= 388.1 x 2545 + (30 + 260) x 12000
= 4,467,715 Btu/Hr

Or 372.3 TR for the high stage compressor.

Total approximate refrigerant flow from low stage compressor to the high stage compressor.

$$= \frac{200}{616.3 - 161.1} \times (372.3 + 80) = 198.7 \text{ Lbs/Min} \quad (\text{O.K.})$$

Adiabatic head for the high stage compressor, HEAD(H):

$$\text{HEAD(H)} = (H_O - H_N \times 778$$
$$= (727 - 619.8) \times 778$$
$$= 107.2 \times 778$$
$$= 83{,}402 \text{ Ft.}$$

Power consumption for the high stage compressor, BHP (H):

Adiabatic EFF. = 75%
Mechanical EFF.= 97%.

FLOW = 200.14 Lbs/Min
HEAD = 83,402 Ft.

$$\text{BHP(H)} = \frac{\text{FLOW(H)} \times \text{HEAD(H)}}{33000 \times 0.75 \times 0.97}$$

$$= \frac{200.14 \times 83402}{33000 \times 0.75 \times 0.97} = 695 \text{ BHP}$$

Condenser heat rejection:

The enthalpy value for the gas discharged from the high stage compressor = H_Y

$$H_Y = H_N + \frac{H_O - H_N}{0.75 \times 0.97}$$

$$= 619.8 + \frac{727 - 619.8}{0.75 \times 0.97}$$

= 767.15 Btu/Lb

Refrigerant flow = 200.14 Lbs/Min

Condenser heat rejection:

= 200.14 x (H_Y- H_G)

= 200.1 x (767.15 - 161.1)

= 7,277,691 Btu/Hr

= 7,278 MBH

Cross check and verification:

Condenser heat rejection:

= (260 + 30 + 80) x 12000 + (388 + 678) x 2545

= 4,440,000 + 2,712,970

= 7,152,970 Btr/Hr

= 7,153 MBH

The oil cooling is by oil injection instead of water cooled without capacity and power input penalties as indicated by the specification. Therefore, the heat rejection from the compressor is the total heat input to the compressor.

Summary of design approach and consideration:

(A) Design considerations:

The brine coolers for evaporator No. 2 and No.3 are provided by the user, therefore it shall be the user's responsibility to design the brine cooler to meet the requirements to cool the brine from the entering and leaving temperatures as required. The refrigeration unit is to provide the ammonia liquid for the brine cooler to fulfill the refrigeration load with the design evaporative temperature for each of the brine cooler.

The condenser is also provided by the user, therefore, no need to worry about this item. However, the refrigeration unit is to be designed for condensing temperature of 105°F.

2-stage compression screw refrigeration is used. The low stage booster compressor is to handle the -40°F load. The -35°F load shall be combined with the -40°F load with a back pressure regulating valve (BPRV).

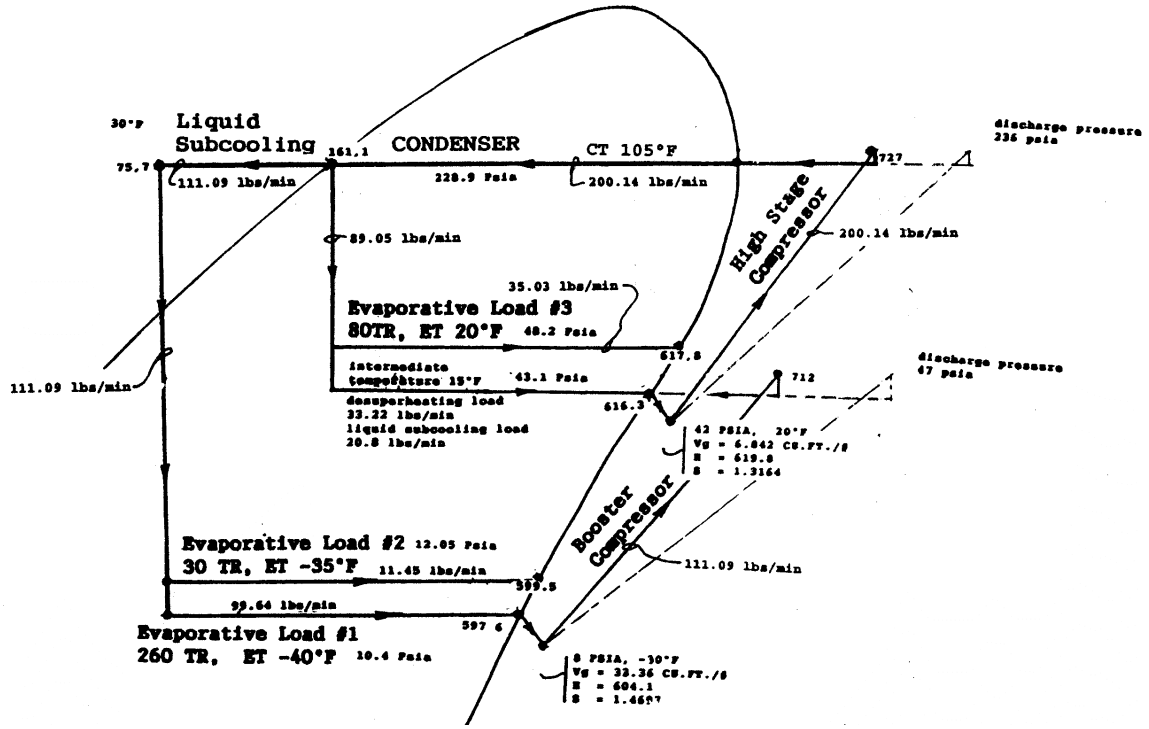
The 20°F load shall be channeled to the intermediate intercooler before entering into the suction of the high stage compressor for liquid vapor separation. A BPRV is to be installed for the 20°F evaporative temperature control.

The compressor discharge from the high stage shall be 236 Psia with the discharge pressure drop of 3.5 Psi.

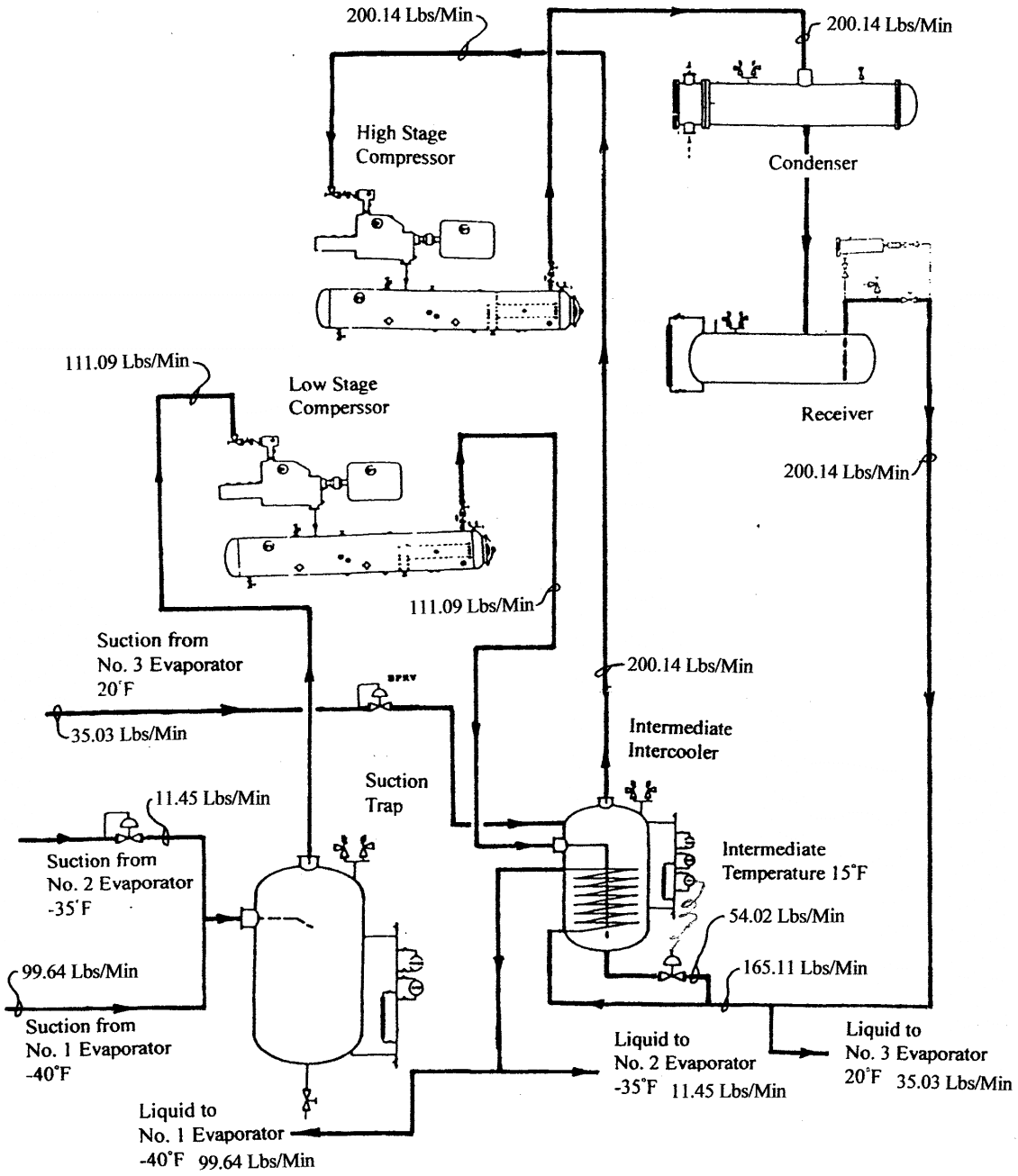
The booster compressor suction shall be 8 Psia and -30°F. 0.81 Psi suction pressure drop and 10°F superheat are included.

A suction scrubber is recommended for the -40°F and -35°F loads before the booster compressor.

(B) Detailed P-H diagram for the compound system is shown below



(C) Detail refrigerant flow diagram for the compound refrigeration system is shown below:



This is a simplified version of the flow diagram, a complete P&ID shall include the instrumentations and controls for the system.

(D) Summary Data Sheet:

Maximum superheat and pressure drop for the Evaporator #3:	
Max. pres. drop, Psi	5.1 Psi
Max. superheat, °F	15 °F
Booster Compressor Suction Conditions:	
Suction Pressure, Psia	8 Psia
Suction Temp., °F	-30°F
Suction Flow, Lbs/Min	111.09 Lbs/Min
Suction Flow, ACFM	3,706 ACFM
High Stage Compressor Suction Conditions:	
Suction Pressure, Psia	42Psia
Suction Temp., °F	20°F
Suction Flow, Lbs/Min	200.14 Lbs/Min
Suction Flow, ACFM	1,369 ACFM
Power Consumption:	
Booster Compressor, BHP	388 BHP
High Stage Comp., BHP	695 BHP
Heat Rejection from condenser:	7,277,691 Btu/Hr Or 7,278 MBH
Refrigerant flow to the condenser: Lbs/Min	200.14 Lbs/Min