Case – 15 Refrigeration System for Chemical Fertilizer Plant Ammonia Storage

Case Background:

Ammonia is one of the important elements to make nitrogen fertilizer for agricultural crops in a fertilizer plant. In a fertilizer plant, ammonia in liquid form is produced and stored until it is used for production. Ammonia is usually stored in a storage tank. The physical property of ammonia requires the storage tank to be designed for high pressure vessel or the tank is to be design for 0 to 1 Psig DWP with a refrigeration system. Ammonia storage temperature for 0 Psig is about -28° F.

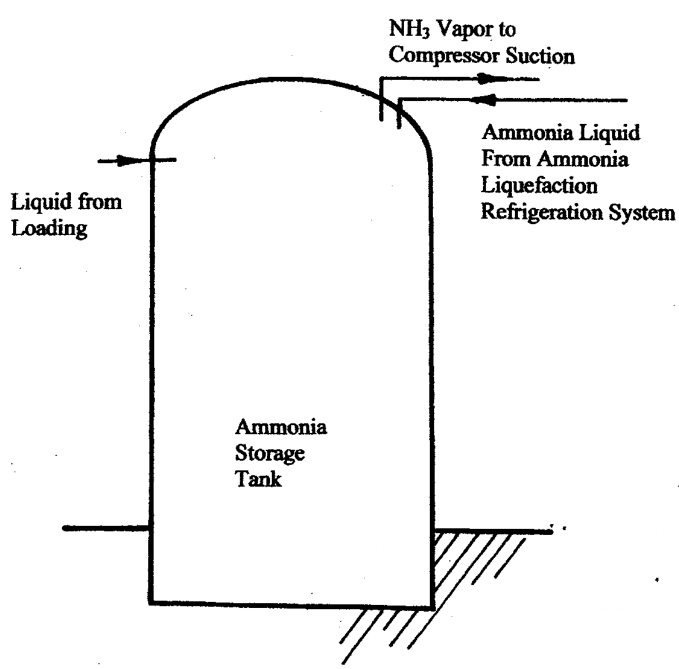

Figure 15-1 Ammonia Storage Tank

Ammonia pressure in the tank increases if the temperature increases. In order to keep the pressure inside the storage tank within the design working pressure which is close to atmospheric pressure, a vapor recovery and refrigeration system must be provided to recycle the boiled off ammonia vapor and return the liquefied ammonia gas back to the storage tank.

This case is to discuss the provisions as how to design the refrigeration system for the ammonia storage tank.

The property tables and pressure-enthalpy chart for ammonia are shown in the section of Related Technical and Engineering Information for the Case.

Figure 15-2 Pressure-Enthalpy Diagram for Ammonia (R-717)
Figure 15-3A Properties of Saturated Liquid and Vapor of Ammonia, -45^{o} F to 19^{o} F
Figure 15-3B Properties of Saturated Liquid and Vapor of Ammonia 20^{o} F to 84^{o} F
Figure 15-3C Properties of Saturated Liquid and Vapor of Ammonia 85^{o} F to 125^{o} F
Figure 15-4 Properties of Superheated Vapor of Ammonia

Related Technical Data and Engineering Information for the Case:

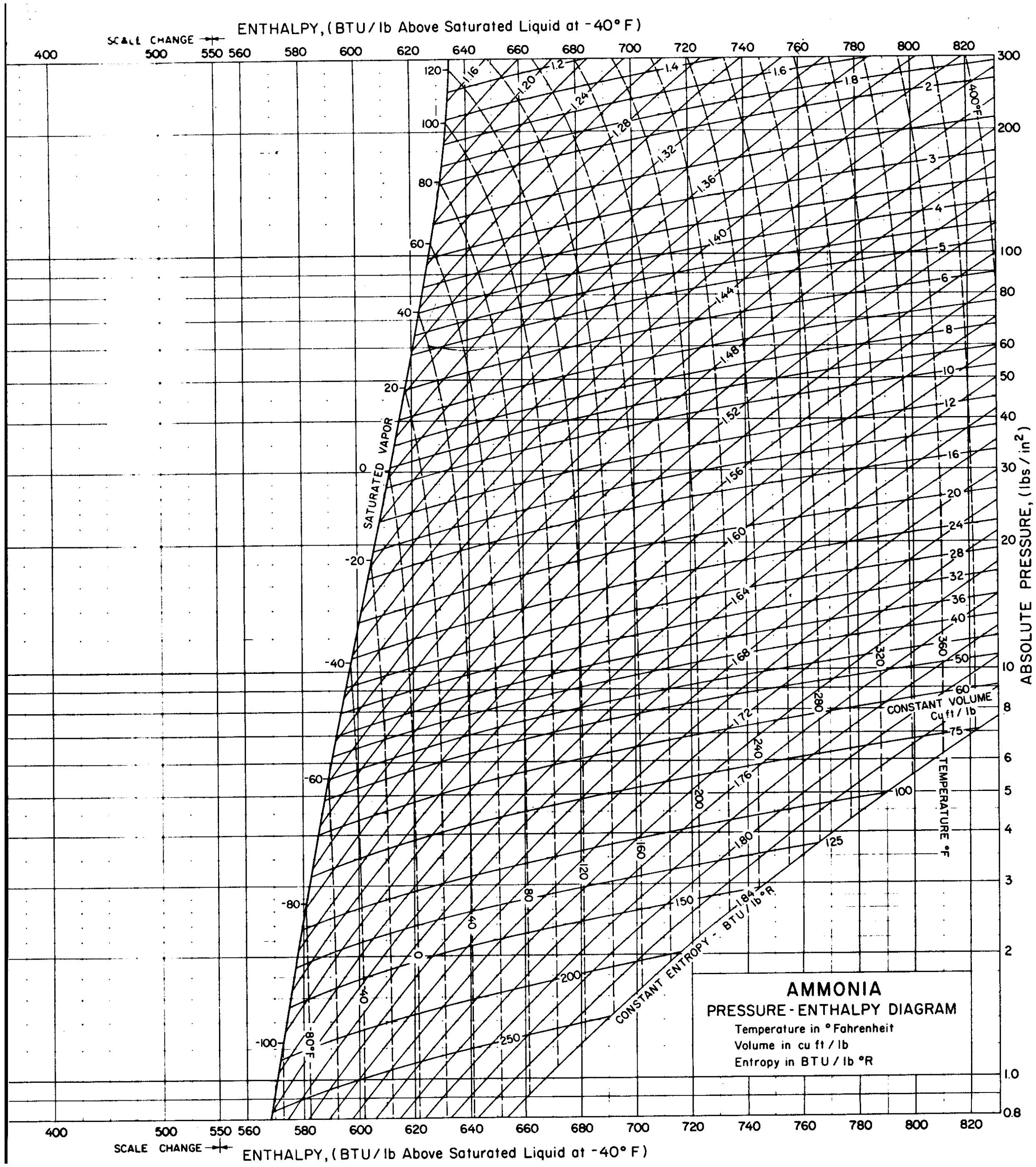

Figure 15-2 Pressure-Enthalpy Diagram for Ammonia (R-717)

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) (°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 15-3A Properties of Saturated Liquid and Vapor 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
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 15-3B Properties of Saturated Liquid and Vapor 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) (°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 15-3C Properties of Saturated Liquid and Vapor of Ammonia

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 15-4 Properties of Superheated Vapor of Ammonia

Cogitation

Ammonia produced in chemical fertilizer plant is actually the same as the R-717 refrigerant; the properties are shown in Figures 15-2, 15-3A, 15-3B, 15-3C and 15-4.

The pressure inside the storage tank will gradually increase due to heat gain from high ambient temperature. The flash gas from liquid loading process will help to build up the pressure inside the storage tank if the loading liquid is not subcooled. It is very expensive to construction a large tank with high design working pressure; therefore most ammonia storage tanks are constructed for storage design working pressure close to atmospheric pressure with vapor recovery and refrigeration system to maintain the pressure inside the storage tank. The refrigeration system is to recover the ammonia, liquefy the ammonia gas and return the liquid back to the storage tank. The compressor load of the refrigeration system is determined by the amount of vapor flow from the ammonia storage tank as shown in Figure 15-5

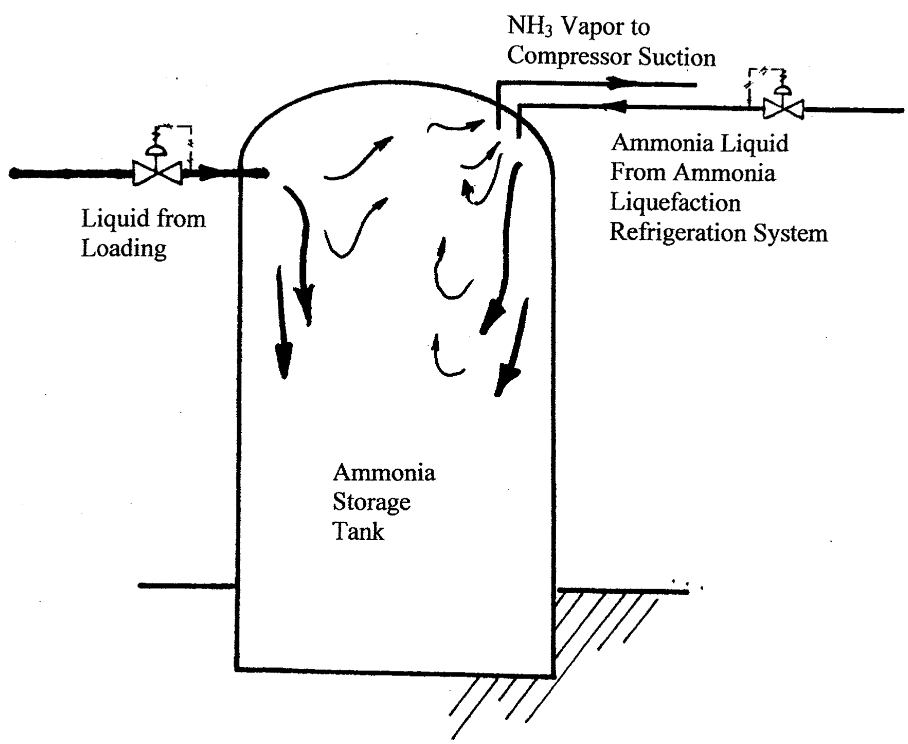

Figure 15-5 Liquid from Loading and from Recycling

The total ammonia vapor flow from the storage tank to compressor suction comes from three sources as the following:

(1) Vapor generated by heat gain from the tank.
(2) Flash gas from ammonia liquid loading into the storage tank.
(3) Flash gas from liquefied ammonia being throttling back to the storage tank.

The Figure 15-5 shows the throttling valves for both liquid lines from loading and liquid return from liquefaction refrigeration system. This throttling valve is to be located as close as possible to the storage tank.

When designing a refrigeration system for ammonia storage tank, it is important to include the flash gas from loading and the flash gas from the liquid throttling back to the storage tank. If the flow from loading is large and/or the liquid pressure is substantially higher, a separate refrigeration system as shown in Chapter 9 of the book of Engineered Industrial Refrigeration Systems Application should be considered, the compressors can be changed to screw instead of centrifugal.

See Figure 15-6, if the liquefied ammonia gas is at 113℉ saturated pressure; it is throttling back to a storage tank with DWP at 0.5 Psig, the flash gas represents 27.7% of the total flow, this portion flash gas is to be recycled back to the compressor suction. Same thing happen, the flash gas is generated when the loading liquid is throttling into the storage tank, unless the liquid is under subcooled status.

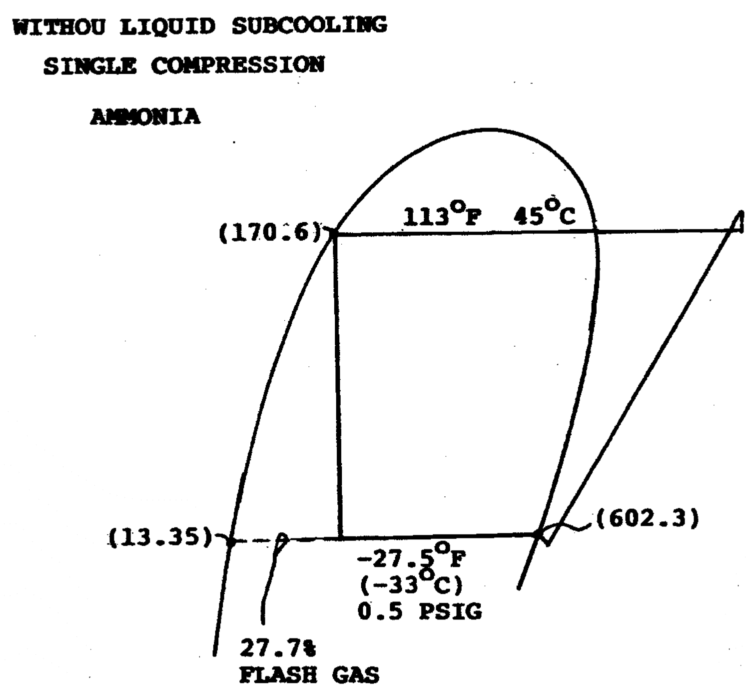

Figure 15-6 P-H Diagram for Single Compression Without Subcooling

For most ammonia storage tank installation, the liquefied ammonia from the refrigeration system is connected to the top of the tank. If it is in this case, the liquid should be subcooled before leaving the refrigeration system in order to offset the piping friction loss and the vertical liquid column penalty as shown in Figure 15-7.

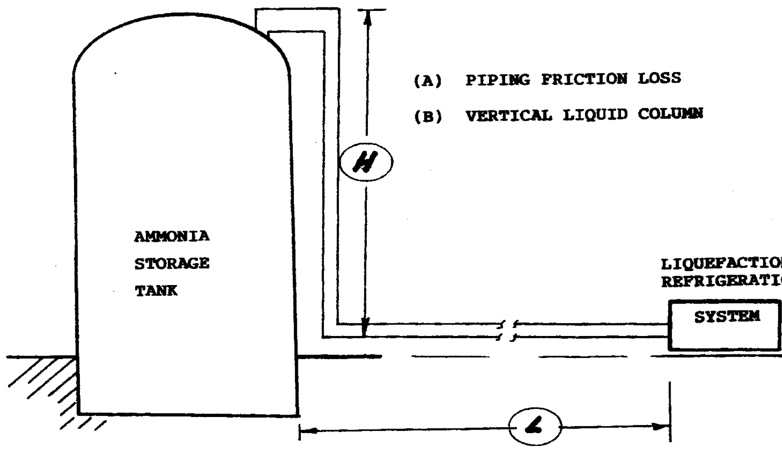

Figure 15-7 Liquid Column and Piping Friction Loss

If single compression screw compressor is used for the refrigeration system, it is suggested to use liquid subcooling economizer as shown in the P-H diagram of Figure 15-8. Based on condensing temperature of 113℉ and the storage tank design working pressure of 0.5 Psig, this system provides 110℉ liquid subcooling, which is enough to offset the vertical liquid column penalty and the external piping pressure drop for most installations.

Pressure reduction due to vertical liquid column can be calculated as the following:

$$\Delta P\ (\text{Psi}) = \frac{\text{Liquid Density (Lbs/Ft}^3\text{) x Column (Ft.)}}{144}$$

See Figure 15-6, the density of the saturated liquid at 113° F is 35.67 Lbs/ Ft^3, if the height of the storage tank is 100 Ft, the pressure drop due to the liquid column is:

$$\Delta P\ (\text{Psi}) = \frac{35.67\ (\text{Lbs/Ft}^3) \times 100\ (\text{Ft.})}{144} = 24.77\ \text{Psi}$$

If the liquid return from the refrigeration system is at saturated status instead of subcooled, flash gas is generated in the liquid due to pressure drops from friction loss and the liquid column penalty, the liquid will become two-phase; this will create great deal of problem for the refrigeration system. For a 2-phase flow, the pressure drops will be even greater, which will cause further greater pressure drop, and so on. This creates a great deal of problem for the refrigeration system.

Compare the P-H diagram in Figure 15-6, the compressor is without economizing and Figure 15-8, the compressor is with liquid subcooling economizer for the refrigeration system, the flash gas is 27.7% as compare to 5.7%. The refrigeration system using liquid subcooling economizer provides two advantages for the application:

(A) Subcooled liquid eliminates 2-phase flow problem.

(B) Liquid subcooling minimizes flash gas.

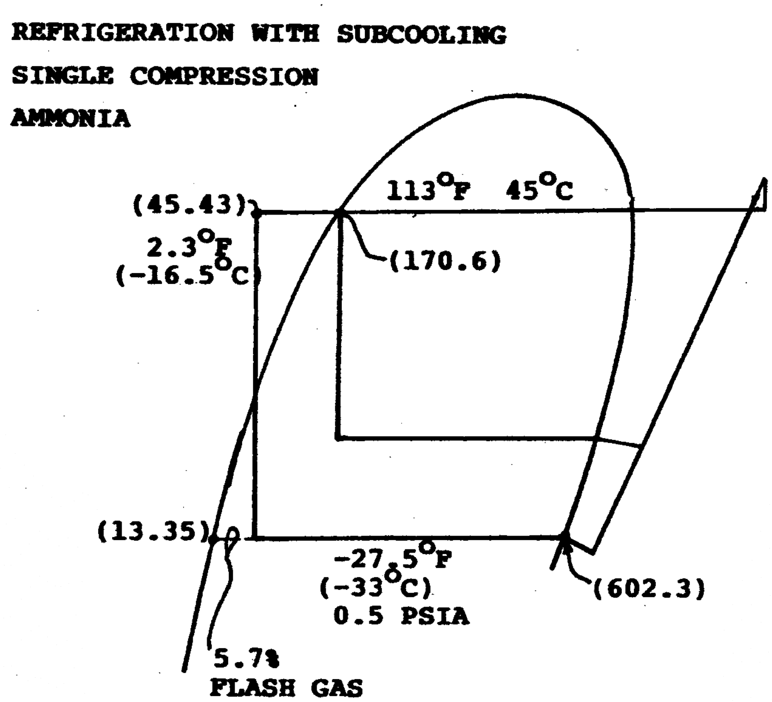

Figure 15-8 Single Compression Screw with
Liquid Subcooling Economizer

The Figure 15-9 shows a typical screw ammonia vapor recovery and refrigeration system with liquid subcooling feature for an ammonia storage tank. This refrigeration system has a 100% stand-by condensing system. The stand-by compressor drive line is equipped with an engine in addition to electrical driving motor for emergency operation in case of power interruption. The condensers are interconnected, so that the refrigeration system can be still in operation while the other is in service or when the other condenser is for tubes cleaning during continuous year round operation. This system is also designed to provide partial load operation down to 0% load.

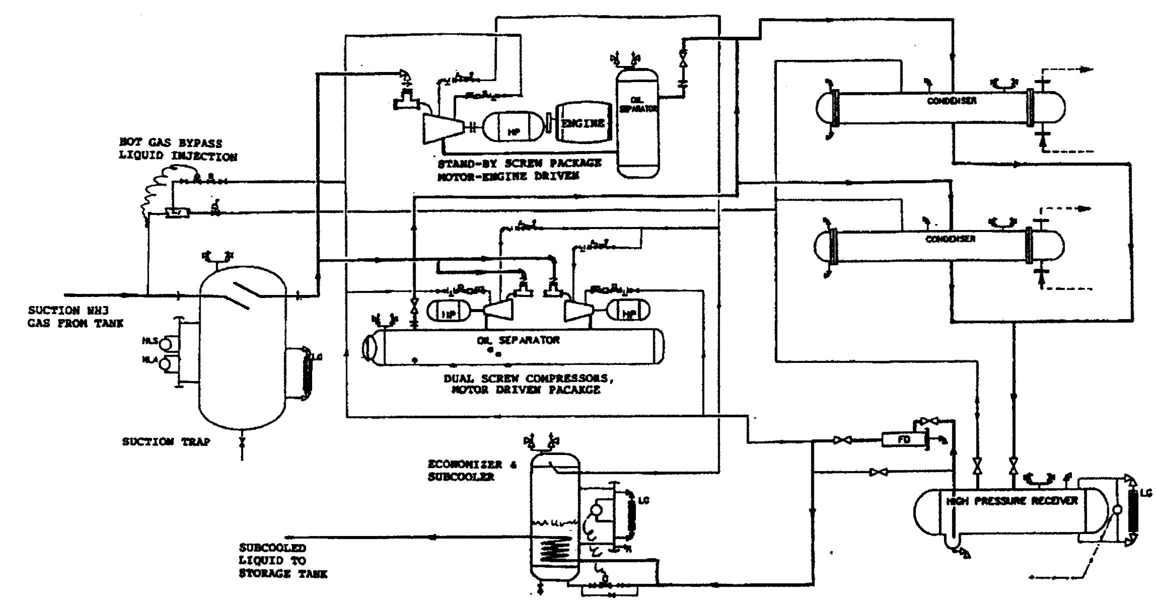

Figure 15-9 Ammonia Vapor Recovery & Refrigeration System

The Figure 15-10 shows the typical connection between the refrigeration system and the ammonia storage tank.

The refrigeration system design must allow suction pressure drop for the suction piping line between the storage tank and the compressor to allow the ammonia gas flow to the compressor suction. Suction superheat for suction line also must be allowed for proper selection of the compressor.

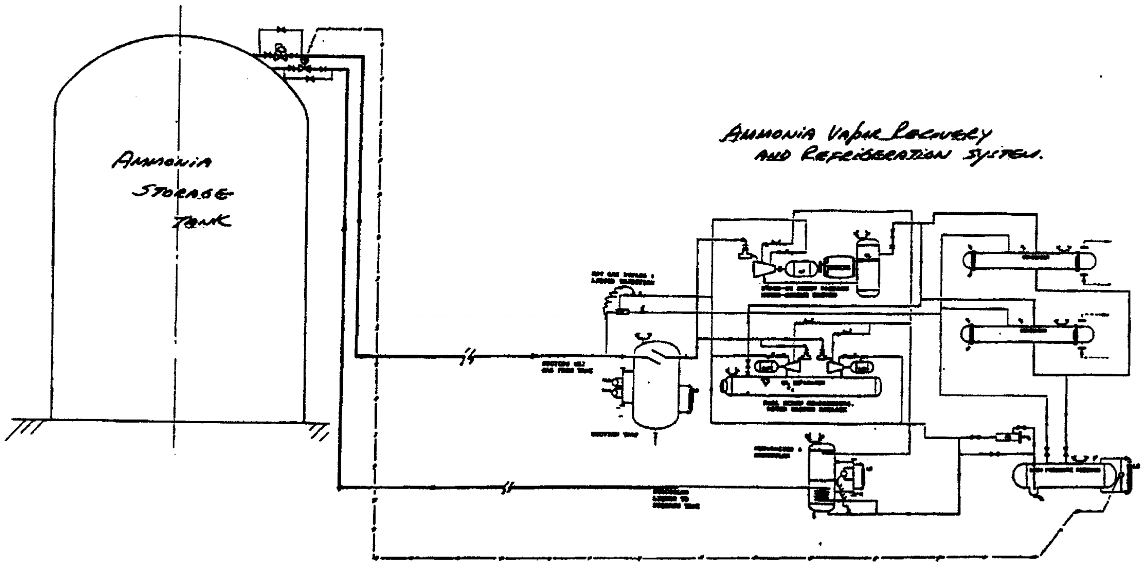

Figure 15-10 Ammonia Refrigeration System & Ammonia Storage Tank