MET 440 Heat Exchanger Design Project

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Abstract:

We have been hired to engineer a heat exchanger to meet the demands laid forth by the custom. The customer requirements are to cool 320,000 lb/hr of liquid Ammonia from 122^{o}F to 86^{o}F. To accomplish this cooling the heat exchanger will using liquid water at an initial temperature of 50^{o}F. The owner has also listed some limits for the heat exchanger which we have to design around.

For our final design, we have a single-pass-in-shell, two-pass-in-tube, BEN Type Heat exchanger encompassing 574 tubes, 12 baffles, and meets all heat transfer and dimensional requirements.

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Appendix A. Table of Thermodynamic Properties

Pressure bar	Temp. °C	Specific volume Liquid cm^3/g	Specific volume Vapor cm^3/g	Free energy G/RT	Internal energy Liquid J/g	Internal energy Vapor J/g	Enthalpy Liquid J/g	Enthalpy Vapor J/g	Latent heat J/g	Entropy Liquid J/g K	Entropy Vapor J/g K
.10	−71.22	1.37611	9803.87	−25.76	−1079.91	294.03	−1079.90	392.07	1471.9725	4.3553	11.6446
.15	−65.59	1.38824	6705.39	−25.49	−1054.84	301.73	−1054.82	402.31	1457.1367	4.4777	11.4980
.20	−61.37	1.39767	5122.56	−25.30	−1036.36	307.39	−1036.33	409.84	1446.1715	4.5659	11.3946
.25	−57.96	1.40548	4157.58	−25.16	−1021.55	311.89	−1021.51	415.83	1437.3395	4.6353	11.3148
.30	−55.08	1.41224	3505.96	−25.05	−1009.02	315.63	−1008.98	420.81	1429.7879	4.6931	11.2498
.35	−52.58	1.41821	3035.50	−24.95	−998.16	318.84	−998.11	425.09	1423.1946	4.7426	11.1950
.40	−50.36	1.42359	2679.37	−24.87	−988.47	321.66	−988.42	428.83	1417.2519	4.7863	11.1476
.45	−48.35	1.42850	2400.12	−24.80	−979.76	324.17	−979.70	432.17	1411.8740	4.8252	11.1059
.50	−46.52	1.43303	2175.09	−24.73	−971.78	326.43	−971.71	435.19	1406.8936	4.8606	11.0686
.55	−44.84	1.43724	1989.76	−24.68	−964.44	328.49	−964.36	437.93	1402.2944	4.8929	11.0350
.60	−43.28	1.44118	1834.39	−24.63	−957.60	330.39	−957.51	440.45	1397.9643	4.9227	11.0043
.70	−40.45	1.44609	1500.31	−24.53	−945.21	333.77	−945.11	444.96	1390.0605	4.9763	10.9500
.80	−37.94	1.45491	1401.97	−24.46	−934.15	336.73	−934.03	448.89	1382.9212	5.0236	10.9031
.90	−35.67	1.46085	1255.81	−24.39	−924.15	339.36	−924.02	452.38	1376.4036	5.0659	10.8618
1.00	−33.60	1.46636	1137.99	−24.33	−914.98	341.72	−914.84	455.52	1370.3578	5.1043	10.8249
1.20	−29.91	1.47628	959.56	−24.23	−898.65	345.84	−898.47	460.99	1359.4575	5.1720	10.7610
1.40	−26.69	1.48512	830.63	−24.14	−884.32	349.34	−884.11	465.63	1349.7414	5.2306	10.7071
1.60	−23.83	1.49313	732.97	−24.07	−871.50	352.39	−871.27	469.67	1340.9334	5.2822	10.6605
1.80	−21.23	1.50050	656.35	−24.01	−859.88	355.08	−859.61	473.23	1332.8428	5.3286	10.6194
2.00	−18.86	1.50735	594.57	−23.95	−849.22	357.50	−848.91	476.42	1325.3286	5.3708	10.5826
2.50	−13.66	1.52270	482.11	−23.83	−825.76	362.61	−825.38	483.14	1308.5291	5.4621	10.5048
3.00	−9.24	1.53622	406.05	−23.74	−805.67	366.77	−805.21	488.58	1293.7924	5.5389	10.4412
3.50	−5.36	1.54842	351.06	−23.67	−787.98	370.25	−787.44	493.13	1280.5667	5.6054	10.3873
4.00	−1.89	1.55962	309.40	−23.60	−772.11	373.24	−771.48	497.01	1268.4875	5.6643	10.3406
4.50	1.25	1.57003	276.70	−23.55	−757.66	375.85	−756.95	500.37	1257.3152	5.7173	10.2993
5.00	4.13	1.57902	250.33	−23.50	−744.36	378.14	−743.57	503.31	1246.8000	5.7655	10.2623
5.50	6.80	1.58907	228.60	−23.46	−732.02	380.18	−731.15	505.92	1237.0629	5.8098	10.2288
6.00	9.28	1.59788	210.37	−23.42	−720.48	382.01	−719.52	508.24	1227.7588	5.8509	10.1980
6.50	11.61	1.60632	194.85	−23.38	−709.63	383.66	−708.59	510.32	1218.9063	5.8892	10.1697
7.00	13.80	1.61442	181.47	−23.35	−699.37	385.16	−698.24	512.19	1210.4369	5.9251	10.1434
7.50	15.88	1.62224	169.82	−23.32	−689.64	386.52	−688.43	513.89	1202.3129	5.9589	10.1188
8.00	17.85	1.62980	159.57	−23.30	−680.37	387.76	−679.06	515.42	1194.4869	5.9909	10.0957
8.50	19.73	1.63714	150.49	−23.27	−671.51	388.90	−670.12	516.82	1186.9347	6.0213	10.0739
9.00	21.52	1.64427	142.38	−23.25	−663.02	389.94	−661.54	518.08	1179.6217	6.0502	10.0533
9.50	23.25	1.65122	135.10	−23.23	−654.86	390.89	−653.29	519.24	1172.5316	6.0778	10.0338
10.00	24.90	1.65801	128.51	−23.21	−647.00	391.77	−645.35	520.29	1165.6381	6.1043	10.0152
10.50	26.49	1.66464	122.54	−23.19	−639.43	392.58	−637.68	521.25	1158.9300	6.1296	9.9974
11.00	28.03	1.67114	117.09	−23.17	−632.10	393.32	−630.26	522.12	1152.3867	6.1540	9.9803
11.50	29.51	1.67750	112.09	−23.16	−625.01	394.01	−623.08	522.92	1146.0001	6.1776	9.9640
12.00	30.94	1.68376	107.50	−23.14	−618.14	394.64	−616.11	523.64	1139.7630	6.2002	9.9483
12.50	32.33	1.68990	103.26	−23.13	−611.46	395.21	−609.35	524.29	1133.6419	6.2222	9.9331
13.00	33.68	1.69595	99.34	−23.11	−604.97	395.74	−602.77	524.89	1127.6510	6.2434	9.9185
13.50	34.99	1.70190	95.69	−23.10	−598.66	396.23	−596.36	525.42	1121.7766	6.2640	9.9044
14.00	36.26	1.70777	92.30	−23.09	−592.50	396.67	−590.11	525.90	1116.0077	6.2839	9.8908
14.50	37.50	1.71355	89.13	−23.07	−586.50	397.08	−584.02	526.33	1110.3408	6.3033	9.8775
15.00	38.71	1.71926	86.17	−23.06	−580.64	397.45	−578.06	526.71	1104.7667	6.3221	9.8646
15.50	39.89	1.72490	83.39	−23.05	−574.92	397.78	−572.24	527.04	1099.2826	6.3405	9.8522
16.00	41.04	1.73048	80.78	−23.04	−569.32	398.08	−566.55	527.33	1093.8808	6.3584	9.8400
16.50	42.16	1.73599	78.32	−23.03	−563.84	398.35	−560.98	527.58	1088.5591	6.3758	9.8282
17.00	43.26	1.74145	76.00	−23.02	−558.48	398.59	−555.52	527.79	1083.3108	6.3928	9.8166
17.50	44.33	1.74685	73.81	−23.01	−553.22	398.80	−550.16	527.97	1078.1341	6.4094	9.8054
18.00	45.38	1.75220	71.74	−23.00	−548.07	398.98	−544.91	528.11	1073.0233	6.4257	9.7944
18.50	46.41	1.75751	69.77	−22.99	−543.01	399.14	−539.76	528.22	1067.9769	6.4416	9.7836
19.00	47.41	1.76276	[illegible]	[illegible]	−538.04	[illegible]	[illegible]	528.30	[illegible]	6.4571	9.7731
19.50	48.40	1.76798	66.13	−22.98	−533.17	399.39	−529.72	528.34	1058.0612	6.4723	9.7628
20.00	49.37	1.77316	64.44	−22.97	−528.37	399.47	−524.83	528.36	1053.1863	6.4872	9.7527
21.00	51.25	1.78339	61.30	−22.96	−519.02	399.59	−515.28	528.31	1043.5911	6.5162	9.7331
22.00	53.07	1.79350	58.43	−22.94	−509.97	399.62	−506.02	528.16	1034.1857	6.5441	9.7143
23.00	54.83	1.80849	55.80	−22.93	−501.19	399.57	−497.04	527.91	1024.9537	6.5710	9.6961
24.00	56.53	1.81336	53.38	−22.92	−492.65	399.46	−488.30	527.58	1015.8805	6.5970	9.6785
25.00	58.18	1.82315	51.15	−22.91	−484.35	399.28	−479.79	527.16	1006.9531	6.6222	9.6614
26.00	59.78	1.83285	49.08	−22.90	−476.26	399.04	−471.50	526.66	998.1600	6.6467	9.6448
27.00	61.33	1.84248	47.17	−22.89	−468.37	398.74	−463.40	526.09	989.4904	6.6704	9.6287
28.00	62.84	1.85205	45.38	−22.88	−460.67	398.39	−455.48	525.45	980.9351	6.6934	9.6130
29.00	64.31	1.86156	43.71	−22.87	−453.14	397.98	−447.74	524.75	972.4852	6.7159	9.5976
30.00	65.75	1.87102	42.15	−22.86	−445.77	397.52	−440.15	523.98	964.1328	6.7378	9.5827
31.00	67.15	1.88045	40.69	−22.85	−438.55	397.02	−432.72	523.15	955.8708	6.7591	9.5680
32.00	68.51	1.88984	[illegible]	[illegible]	−431.40	396.47	−425.40	522.26	947.6924	6.7799	9.5537
33.00	69.84	1.89920	38.01	−22.84	−424.54	395.87	−418.27	521.32	939.5914	6.8003	9.5397
34.00	71.15	1.90855	36.79	−22.83	−417.73	395.23	−411.24	520.32	931.5621	6.8202	9.5259
35.00	72.42	1.91788	35.63	−22.82	−411.03	394.55	−404.32	519.28	923.5991	6.8397	9.5124
36.00	73.67	1.92720	34.54	−22.82	−404.45	393.83	−397.52	518.18	915.6975	6.8588	9.4991
37.00	74.89	1.93652	33.50	−22.81	−397.98	393.07	−390.82	517.04	907.8527	6.8775	9.4860
38.00	76.09	1.94585	32.52	−22.81	−391.61	392.28	−384.22	515.84	900.0601	6.8959	9.4731

for the Coexisting Phases of Liquid and Vapor

C_p Liquid J/g·K	C_p Vapor J/g·K	C_v Liquid J/g·K	C_v Vapor J/g·K	C_s Liquid J/g·K	C_s Vapor J/g·K	Isothermal compressibility Liquid bar^{-1}	Isothermal compressibility Vapor bar^{-1}	$(dP/dT)_\rho$ bar/K	Density Liquid g/cm^3	Density Vapor g/cm^3	Pressure bar
4.5330	2.0048	3.3051	1.4996	4.5327	−5.4437	.000054	10.189	.00733	.72668	.000102	.10
4.4049	2.0236	3.2346	1.5116	4.4037	−5.2204	.000063	6.806	.01033	.72033	.000149	.15
4.3603	2.0409	3.2045	1.5227	4.3596	−5.0635	.000068	5.113	.01316	.71548	.000195	.20
4.3468	2.0569	3.1893	1.5331	4.3460	−4.9432	.000072	4.097	.01587	.71150	.000241	.25
4.3441	2.0720	3.1797	1.5428	4.3431	−4.8454	.000075	3.419	.01848	.70809	.000285	.30
4.3477	2.0864	3.1734	1.5520	4.3466	−4.7635	.000078	2.935	.02100	.70512	.000329	.35
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.40
4.3598	2.1131	3.1639	1.5693	4.3583	−4.6312	.000081	2.289	.02586	.70004	.000417	.45
4.3663	2.1256	3.1598	1.5774	4.3647	−4.5762	.000083	2.062	.02820	.69782	.000460	.50
4.3739	2.1377	3.1561	1.5852	4.3721	−4.5268	.000084	1.877	.03050	.69578	.000503	.55
4.3805	2.1495	3.1523	1.5927	4.3785	−4.4819	.000085	1.723	.03276	.69387	.000545	.60
4.3943	2.1719	3.1452	1.6071	4.3920	−4.4032	.000087	1.480	.03716	.69042	.000630	.70
4.4064	2.1930	3.1379	1.6206	4.4038	−4.3302	.000088	1.298	.04141	.68733	.000713	.80
4.4182	2.2132	3.1309	1.6334	4.4153	−4.2766	.000089	1.156	.04561	.68453	.000796	.90
4.4286	2.2325	3.1237	1.6457	4.4254	−4.2192	.000091	1.042	.04964	.68196	.000879	1.00
4.4480	2.2688	3.1100	1.6686	4.4442	−4.1351	.000093	.872	.05757	.67738	.001042	1.20
4.4650	2.3026	3.0968	1.6897	4.4604	−4.0610	.000095	.750	.06517	.67335	.001204	1.40
4.4802	2.3345	3.0842	1.7095	4.4750	−3.9979	.000097	.658	.07254	.66973	.001364	1.60
4.4940	2.3646	3.0722	1.7280	4.4882	−3.9432	.000099	.587	.07971	.66644	.001524	1.80
4.5067	2.3933	3.0608	1.7455	4.5002	−3.8922	.000101	.530	.08666	.66342	.001682	2.00
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2.50
4.5607	2.5208	3.0124	1.8212	4.5508	−3.7174	.000109	.359	.11952	.65095	.002463	3.00
4.5837	2.5772	2.9925	1.8537	4.5719	−3.6554	.000114	.309	.13495	.64582	.002848	3.50
4.6048	2.6302	2.9747	1.8835	4.5912	−3.6041	.000118	.273	.14985	.64118	.003232	4.00
4.6247	2.6804	2.9588	1.9111	4.6092	−3.5610	.000122	.244	.16431	.63693	.003614	4.50
4.6434	2.7282	2.9444	1.9369	4.6260	−3.5244	.000126	.221	.17857	.63298	.003995	5.00
4.6613	2.7741	2.9314	1.9612	4.6420	−3.4917	.000130	.202	.19205	.62930	.004374	5.50
4.6783	2.8183	2.9195	1.9841	4.6570	−3.4658	.000134	.186	.20549	.62583	.004754	6.00
4.6949	2.8610	2.9086	2.0057	4.6715	−3.4405	.000138	.173	.21856	.62254	.005132	6.50
4.7107	2.9026	2.8986	2.0264	4.6852	−3.4219	.000142	.161	.23149	.61942	.005510	7.00
4.7262	2.9430	2.8894	2.0461	4.6986	−3.4020	.000146	.152	.24405	.61643	.005889	7.50
4.7412	2.9825	2.8808	2.0649	4.7114	−3.3888	.000150	.143	.25655	.61357	.006267	8.00
4.7559	3.0211	2.8728	2.0831	4.7240	−3.3730	.000154	.135	.26868	.61082	.006645	8.50
4.7702	3.0590	2.8654	2.1005	4.7360	−3.3639	.000158	.128	.28082	.60817	.007023	9.00
4.7843	3.0962	2.8585	2.1173	4.7479	−3.3515	.000163	.122	.29254	.60561	.007402	9.50
4.7981	3.1329	2.8521	2.1335	4.7593	−3.3456	.000167	.117	.30438	.60313	.007781	10.00
4.8118	3.1690	2.8460	2.1492	4.7707	−3.3358	.000171	.112	.31580	.60073	.008161	10.50
4.8252	3.2047	2.8404	2.1645	4.7817	−3.3326	.000175	.107	.32734	.59840	.008541	11.00
4.8386	3.2400	2.8351	2.1792	4.7926	−3.3251	.000179	.103	.33847	.59612	.008921	11.50
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	12.00
4.8648	3.3095	2.8254	2.2076	4.8138	−3.3185	.000187	.096	.36061	.59175	.009684	12.50
4.8777	3.3438	2.8209	2.2212	4.8241	−3.3192	.000192	.093	.37166	.58964	.010067	13.00
4.8906	3.3779	2.8168	2.2345	4.8345	−3.3154	.000196	.090	.38230	.58758	.010450	13.50
4.9034	3.4117	2.8128	2.2475	4.8446	−3.3175	.000200	.087	.39313	.58556	.010834	14.00
4.9163	3.4454	2.8092	2.2602	4.8548	−3.3153	.000204	.084	.40356	.58358	.011219	14.50
4.9290	3.4789	2.8056	2.2726	4.8647	−3.3187	.000209	.082	.41419	.58164	.011605	15.00
4.9418	3.5122	2.8024	2.2848	4.8747	−3.3179	.000213	.080	.42443	.57974	.011992	15.50
4.9545	3.5454	2.7992	2.2967	4.8846	−3.3223	.000217	.078	.43488	.57787	.012379	16.00
4.9672	3.5786	2.7963	2.3084	4.8945	−3.3228	.000222	.076	.44495	.57604	.012768	16.50
4.9799	3.6116	2.7935	2.3199	4.9043	−3.3282	.000226	.074	.45522	.57423	.013158	17.00
4.9928	3.6446	2.7909	2.3311	4.9141	−3.3298	.000231	.072	.46513	.57246	.013548	17.50
5.0055	3.6776	2.7884	2.3422	4.9239	−3.3560	.000235	.070	.47524	.57071	.013940	18.00
5.0184	3.7105	2.7861	2.3531	4.9337	−3.3587	.000240	.069	.48501	.56899	.014333	18.50
5.0313	3.7434	2.7838	2.3630	4.9434	3.3455	.000245	.067	.49497	.56729	.014727	19.00
5.0443	3.7763	2.7818	2.3743	4.9533	−3.3493	.000249	.066	.50461	.56562	.015122	19.50
5.0573	3.8093	2.7798	2.3847	4.9630	−3.3568	.000254	.065	.51441	.56397	.015518	20.00
5.0835	3.8753	2.7762	2.4050	4.9827	−3.3695	.000264	.062	.53360	.56073	.016314	21.00
5.1101	3.9414	2.7730	2.4248	5.0025	−3.3836	.000274	.060	.55254	.55757	.017115	22.00
5.1371	4.0079	2.7702	2.4440	5.0225	−3.3991	.000284	.058	.57126	.55448	.017922	23.00
5.1646	4.0748	2.7678	2.4628	5.0426	−3.4158	.000294	.056	.58976	.55146	.018733	24.00
5.1924	4.1421	2.7656	2.4812	5.0630	−3.4336	.000305	.054	.60805	.54850	.019550	25.00
5.2209	4.2100	2.7638	2.4992	5.0837	−3.4526	.000316	.053	.62615	.54560	.020373	26.00
5.2498	4.2785	2.7623	2.5168	5.1046	−3.4727	.000327	.051	.64407	.54275	.021202	27.00
5.2793	4.3476	2.7610	2.5340	5.1259	−3.4938	.000339	.050	.66181	.53994	.022037	28.00
5.3095	4.4175	2.7599	2.5510	5.1475	−3.5159	.000351	.049	.67939	.53718	.022877	29.00
5.3403	4.4882	2.7591	2.5677	5.1694	−3.5391	.000363	.048	.69682	.53447	.023725	30.00
5.3718	4.5598	2.7585	2.5840	5.1917	−3.5631	.000375	.047	.71409	.53179	.024578	31.00
5.4040	4.6323	2.7581	2.6002	5.2145	−3.5882	.000388	.046	.73122	.52915	.025439	32.00
5.4369	4.7059	2.7579	2.6161	5.2376	−3.6142	.000401	.045	.74821	.52654	.026306	33.00
5.4707	4.7805	2.7578	2.6317	5.2612	−3.6411	.000415	.044	.76507	.52396	.027181	34.00
5.5052	4.8562	2.7580	2.6472	5.2852	−3.6690	.000429	.043	.78181	.52141	.028063	35.00
5.5407	4.9332	2.7583	2.6624	5.3098	−3.6978	.000444	.042	.79843	.51889	.028952	36.00
5.5770	5.0114	2.7587	2.6775	5.3348	−3.7276	.000459	.042	.81494	.51639	.029848	37.00
5.6142	5.0910	2.7593	2.6923	5.3603	−3.7583	.000474	.041	.83134	.51391	.030753	38.00

List of Figures and Tables:

Report Body:

Job Site location:

Local shipyard.

Specifications and Design Philosophy:

This heat exchanger is based on criteria prescribed by the test prompt. It is designed to efficiently use water to cool down liquid ammonia from its heated state of 122°F to 86°F. The tube material is of aluminum, the layout angle is 90°, and the pitch is square.

Sources:

Bayazitoglu,Y., Ozisik, N., “A Textbook for Heat Transfer Fundamentals”, Begell House Inc (2012)

Kakaç, S., Liu, H., “Heat Exchangers Selection, Rating, and Thermal Design”, CRC Press

Haar, L., Gallagher, J. S., “Thermodynamic Properties of Ammonia”, National Measurement Laboratory

TABLE 8.1

Dimensional Data for Commercial Tubing

O.D. of Tubing (in.)	BWG Gauge	Thickness (in.)	Internal Flow Area (in.^{2})	External Surface per Foot Length (ft^2)	Internal Surface per Foot Length (ft^2)	Weight per Ft Length, Steel (lb)	I.D. Tubing (in.)	O.D./I.D. (in)
1/4	22	0.028	0.0295	0.0655	0.0508	0.066	0.194	1.289
1/4	24	0.022	0.0333	0.0655	0.0539	0.054	0.206	1.214
1/4	26	0.018	0.0360	0.0655	0.0560	0.045	0.214	1.168
3/8	18	0.049	0.0603	0.0982	0.0725	0.171	0.277	1.354
3/8	20	0.035	0.0731	0.0982	0.0798	0.127	0.305	1.233
3/8	22	0.028	0.0799	0.0982	0.0835	0.104	0.319	1.176
3/8	24	0.022	0.0860	0.0982	0.0867	0.083	0.331	1.133
1/2	16	0.065	0.1075	0.1309	0.0969	0.302	0.370	1.351
1/2	18	0.049	0.1269	0.1309	0.1052	0.236	0.402	1.244
1/2	20	0.035	0.1452	0.1309	0.1126	0.174	0.430	1.163
1/2	22	0.028	0.1548	0.1309	0.1162	0.141	0.444	1.126
5/8	12	0.109	0.1301	0.1636	0.1066	0.602	0.407	1.536
5/8	13	0.095	0.1486	0.1636	0.1139	0.537	0.435	1.437
5/8	14	0.083	0.1655	0.1636	0.1202	0.479	0.459	1.362

Figure 1. Table 8.1 Dimensional Data for Commercial Tubing.

Dimensional Data for Commercial Tubing

O.D. of Tubing (in.)	BWG Gauge	Thickness (in.)	Internal Flow Area (in.^{2})	External Surface per Foot Length (ft^2)	Internal Surface per Foot Length (ft^2)	Weight per Ft Length, Steel (lb)	I.D. Tubing (in.)	O.D./I.D. (in)
5/8	15	0.072	0.1817	0.1636	0.1259	0.425	0.481	1.299
5/8	16	0.065	0.1924	0.1636	0.1296	0.388	0.49s	1.263
5/8	17	0.058	0.2035	0.1636	0.1333	0.350	0.509	1.228
5/8	18	0.049	0.2181	0.1636	0.1380	0.303	0.527	1.186
5/8	19	0.042	0.2298	0.1636	0.1416	0.262	0.541	1.155
5/8	20	0.035	0.2419	0.1636	0.1453	0.221	0.555	1.136
3/4	10	0.134	0.1825	0.1963	0.1262	0.884	0.482	1.556
3/4	11	0.120	0.2043	0.1963	0.1335	0.809	0.510	1.471
3/4	12	0.109	0.2223	0.1963	0.1393	0.748	0.532	1.410
3/4	13	0.095	0.2463	0.1963	0.1466	0.666	0.560	1.339
3/4	14	0.083	0.2679	0.1963	0.1529	0.592	0.584	1.284
3/4	15	0.072	0.2884	0.1963	0.1587	0.520	0.606	1.238
3/4	16	0.065	0.3019	0.1963	0.1623	0.476	0.620	1.210
3/4	17	0.058	0.3157	0.1963	0.1660	0.428	0.634	1.183
3/4	18	0.049	0.3339	0.1963	0.1707	0.367	0.652	1.150
3/4	20	0.035	0.3632	0.1963	0.1780	0.269	0.680	1.103
7/8	10	0.134	0.2892	0.2291	0.1589	1.061	0.607	1.441
7/8	11	0.120	0.3166	0.2291	0.1662	0.969	0.635	1.378
7/8	12	0.109	0.3390	0.2291	0.1720	0.891	0.657	1.332
7/8	13	0.095	0.3685	0.2291	0.1793	0.792	0.685	1.277
7/8	14	0.083	0.3948	0.2291	0.1856	0.704	0.709	1.234
7/8	16	0.065	0.4359	0.2291	0.1950	0.561	0.745	1.174
7/8	18	0.049	0.4742	0.2291	0.2034	0.432	0.777	1.126
7/8	20	0.035	0.5090	0.2291	0.2107	0.313	0.805	1.087
1	8	0.165	0.3526	0.2618	0.1754	1.462	0.670	1.493
1	10	0.134	0.4208	0.2618	0.1916	1.237	0.732	1.366
1	11	0.120	0.4536	0.2618	0.1990	1.129	0.760	1.316
1	12	0.109	0.4803	0.2618	0.2047	1.037	0.782	1.279
1	13	0.095	0.5153	0.2618	0.2121	0.918	0.810	1.235
1	14	0.083	0.5463	0.2618	0.2183	0.813	0.834	1.199
1	15	0.072	0.5755	0.2618	0.2241	0.714	0.856	1.167
1	16	0.065	0.5945	0.2618	0.2278	0.649	0.870	1.119
1	18	0.049	0.6390	0.2618	0.2361	0.496	0.902	1.109
1	20	0.035	0.6793	0.2618	0.2435	0.360	0.930	1.075
1 1/4	7	0.180	0.6221	0.3272	0.2330	2.057	0.890	1.404
1 1/4	8	0.165	0.6648	0.3272	0.2409	1.921	0.920	1.359
1 1/4	10	0.134	0.7574	0.3272	0.2571	1.598	0.982	1.273
1 1/4	11	0.120	0.8012	0.3272	0.2644	1.448	1.010	1.238
1 1/4	12	0.109	0.8365	0.3272	0.2702	1.329	1.032	1.211
1 1/4	12	0.095	0.8825	0.3272	0.2773	1.173	1.060	1.179
1 1/4	14	0.083	0.9229	0.3272	0.2838	1.033	1.084	1.153
1 1/4	16	0.065	0.9852	0.3272	0.2932	0.823	1.120	1.116
1 1/4	18	0.049	1.042	0.3272	0.3016	0.629	1.152	1.085
1 1/4	20	0.035	1.094	0.3272	0.3089	0.456	1.180	1.059
1 1/2	10	0.134	1.192	0.3927	0.3225	1.955	1.232	1.218
1 1/2	12	0.109	1.291	0.3927	0.3356	1.618	1.282	1.170
1 1/2	14	0.083	1.398	0.3927	0.3492	1.258	1.334	1.124
1 1/2	16	0.065	1.474	0.3927	0.3587	0.996	1.370	1.095
2	11	0.120	2.433	0.5236	0.4608	2.410	1.760	1.136
2	13	0.095	2.573	0.5236	0.4739	1.934	1.810	1.105
2 1/2	9	0.148	3.815	0.6540	0.5770	3.719	2.204	1.134

Note: Courtesy of Tubular Exchanger Manufacturers Association.

Figure 2. Table 8.1 (Continued).

TABLE 8.3

Tube-Shell Layouts (Tube Counts)

Shell I.D. (in.)	1-P	2-P	4-P	6-P	8-P
3/4-in. O.D. Tubes on 1-in. Triangular Pitch					
8	37	30	24	24	
10	61	52	40	36	
12	92	82	76	74	70
13 1/4	109	106	86	82	74
15 1/4	151	138	122	118	110
17 1/4	203	196	178	172	166
19 1/4	262	250	226	216	210
21 1/4	316	302	278	272	260
23 1/4	384	376	352	342	328
25	470	452	422	394	382
27	559	534	488	474	464
29	630	604	556	538	508
31	745	728	678	666	640
33	856	830	774	760	732
35	970	938	882	864	848
37	1074	1044	1012	986	870
39	1206	1176	1128	1100	1078
1-in. O.D. Tubes on 1 1/4-in. Triangular Pitch					
8	21	16	16	14	
10	32	32	26	24	
12	55	52	48	46	44
13 1/4	68	66	58	54	50
15 1/4	91	86	80	74	72
17 1/4	131	118	106	104	94
19 1/4	163	152	140	136	128
21 1/4	199	188	170	164	160
23 1/4	241	232	212	212	202
25	294	282	256	252	242
27	349	334	302	296	286
29	397	376	338	334	316
31	472	454	430	424	400
33	538	522	486	470	454
35	608	592	562	546	532
37	674	664	632	614	598
39	766	736	700	688	672
3/4-in. O.D. Tubes on 1-in. Square Pitch					
8	32	26	20	20	
10	52	52	40	36	
12	81	76	68	68	60
13 1/4	97	90	82	76	70
15 1/4	137	124	116	108	108
17 1/4	177	166	158	150	142
19 1/4	224	220	204	192	188
21 1/4	277	270	246	240	234
23 1/4	341	324	308	302	292
25	413	394	370	356	346
27	481	460	432	420	408
29	553	526	480	468	456

Figure 3. Table 8.3 Tube-Shell Layouts.

TABLE 8.3 (CONTINUED)

Tube-Shell Layouts (Tube Counts)

Shell I.D. (in.)	1-P	2-P	4-P	6-P	8-P
31	657	640	600	580	560
33	749	718	688	676	648
35	845	824	780	766	748
37	934	914	886	866	838
39	1049	1024	982	968	948
1-in. O.D. Tubes on 1 1/4-in. Square Pitch					
8	21	16	14		
10	32	32	26	24	
12	48	45	40	38	36
13 1/4	61	56	52	48	44
15 1/4	81	76	68	68	64
17 1/4	112	112	96	90	82
19 1/4	138	132	128	122	116
21 1/4	177	166	158	152	148
23 1/4	213	208	192	184	184
25	260	252	238	226	222
27	300	288	278	268	260
29	341	326	300	294	286
31	406	398	380	368	358
33	465	460	432	420	414
35	522	518	488	484	472
37	596	574	562	544	532
39	665	644	624	612	600
3/4-in. O.D. Tubes on 15/16-in. Triangular Pitch					
8	36	32	26	24	18
10	62	56	47	42	36
12	109	98	86	82	78
13 1/4	127	114	96	90	86
15 1/4	170	160	140	136	128
17 1/4	239	224	194	188	178
19 1/4	301	282	252	244	234
21 1/4	361	342	314	306	290
23 1/4	442	420	386	378	364
25	532	506	468	446	434
27	637	602	550	536	524
29	721	692	640	620	594
31	847	822	766	722	720
33	974	938	878	852	826
35	1102	1068	1004	988	958
37	1240	1200	1144	1104	1072
39	1377	1330	1258	1248	1212
1 1/4-in. O.D. Tubes on 1 9/16-in. Square Pitch					
10	16	12	10		
12	30	24	22	16	16
13 1/4	32	30	30	22	22
15 1/4	44	40	37	35	31
17 1/4	56	53	51	48	44
19 1/4	78	73	71	64	56
21 1/4	96	90	86	82	78

Figure 4. Table 8.3 (Continued_1).

TABLE 8.3 (CONTINUED)

Tube-Shell Layouts (Tube Counts)

Shell I.D. (in.)	1-P	2-P	4-P	6-P	8-P
23 1/4	127	112	106	102	96
25	140	135	127	123	115
27	166	160	151	146	140
29	193	188	178	174	166
31	226	220	209	202	193
33	258	252	244	238	226
35	293	287	275	268	258
37	334	322	311	304	293
39	370	362	348	342	336
1 1/2-in. O.D. Tubes on 1 7/8-in. Square Pitch					
12	16	16	12	12	
13 1/4	22	22	16	16	
15 1/4	29	29	24	24	22
17 1/4	29	39	34	32	29
19 1/4	50	48	45	43	39
21 1/4	62	60	57	54	50
23 1/4	78	74	70	66	62
25	94	90	86	84	78
27	112	108	102	98	94
29	131	127	120	116	112
31	151	146	141	138	131
33	176	170	164	160	151
35	202	196	188	182	176
37	224	220	217	210	202
39	252	246	237	230	224
1 1/2-in. O.D. Tubes on 1 7/8-in. Triangular Pitch					
12	18	14	14	12	12
13 1/4	27	22	18	16	14
15 1/4	26	34	32	30	27
17 1/4	48	44	42	38	36
19 1/4	61	58	55	51	48
21 1/4	76	78	70	66	61
23 1/4	95	91	86	80	76
25	115	110	105	98	95
27	136	131	125	118	115
29	160	154	147	141	136
31	184	177	172	165	160
33	215	206	200	190	184
35	246	238	230	220	215
37	275	268	260	252	246
39	307	299	290	284	275
1 1/4-in. O.D. Tubes on 1 9/16-in. Triangular Pitch					
10					
10	20	18	14		
12 1/4	32	30	26	22	20
13 1/4	38	36	32	28	26
15 1/4	54	51	45	42	38
17 1/4	69	66	62	58	54
19 1/4	95	91	86	78	69
21 1/4	117	112	105	101	95

Figure 5. Table 8.3 (Continued_2).

TABLE 8.3 (CONTINUED)

Tube-Shell Layouts (Tube Counts)

Shell I.D. (in.)	1-P	2-P	4-P	6-P	8-P
23 1/4	140	136	130	123	117
25	170	164	155	150	140
27	202	196	185	179	170
29	235	228	217	212	202
31	275	270	255	245	235
33	315	305	297	288	275
35	357	348	335	327	315
37	407	390	380	374	357
39	449	436	425	419	407

From Kern, D. Q. (1950) *Process Heat Transfer*, McGraw Hill, New York. With permission.

Figure 6. Table 8.3 (Continued_3).

Materials and Specifications:

Establish the HX materials to use:

The tubes are made out of aluminum tubing to ensure that the ammonia and water do not mix. Using aluminum tubes instead of copper will also ensure that the tubes will last longer.

Fluid Characteristics:

Property	**Unit**	**WATER**	**AMMONIA**
Temperature (In)	°C	10	50
Temperature (Out)	°C	26.67	30
Bulk Temperature	°C	18.33	40
Density, ρ	Kg/m^3	580.99	999
Specific Heat, Cp	J/kg/K	4184.8	4999
Thermal Conductivity	W/m/K	0.493	0.593
Mass Flow Rate, ṁ	kg/s	57.8	40.32
Dynamic Viscosity	Pa*s	3.40E-7	1.07E-3
Film Dynamic Viscosity	Pa*s	-----	1.012E-3

Table 1. Fluid Characteristics.

Preliminary Drawings and Sketches:

Plot Plan:

Nothing is known of the location other than that it is a shipyard. The layout schematics were not given, so we did not create a plot plan.

Elevation:

Below is a preliminary drawing of the heat exchanger.

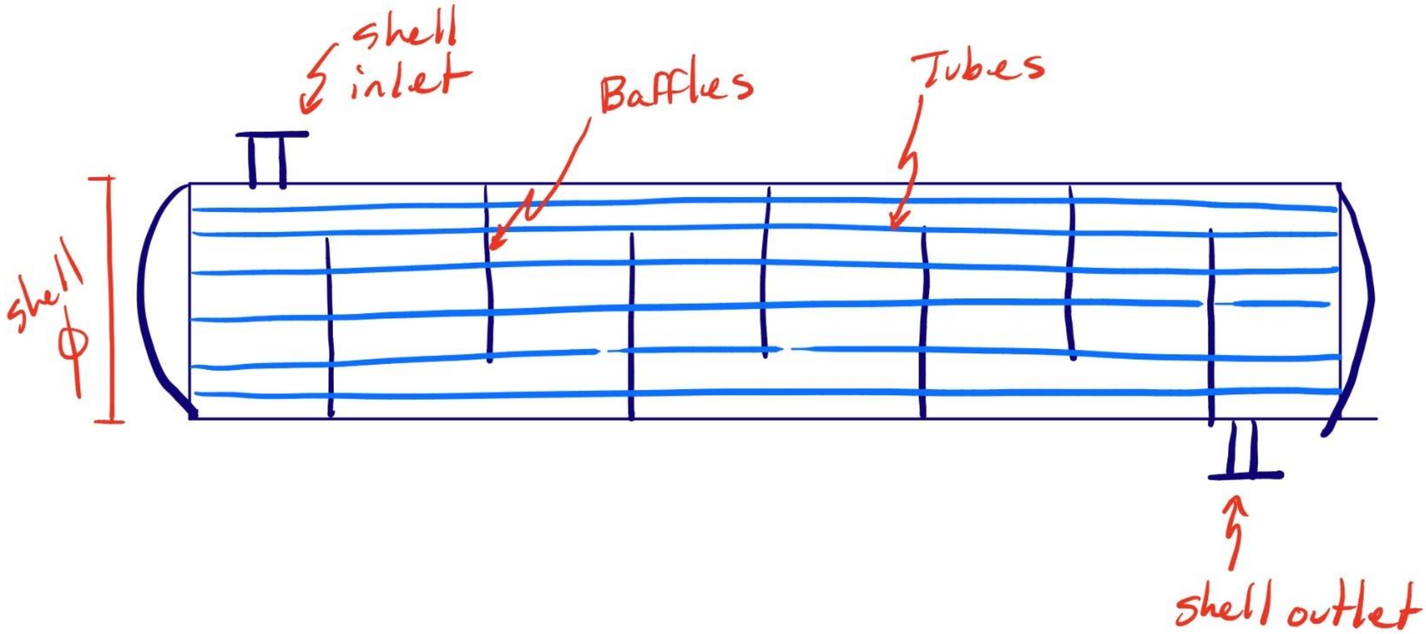

Figure 7.One Pass Shell Preliminary Elevation Drawing.

Methodology:

Start with the following equation:

$$Q = \dot{m} C_p \Delta T$$

The Q value solved for in the above equation is then put into the following equation:

$$Q = U_o A_o MLDT * F$$

Where:

$$U_o = assumed\ value\ from\ Table\ 8.5\ of\ Heat\ Exchanger\ Tables$$

$$(Ammonia\ to\ water\ is\ 1000\ to\ 2500)$$

$$A_o = Outer\ surface\ area\ of\ the\ tubes\ that\ we\ need\ to\ solve\ for$$

$$MLDT = \frac{\Delta T_1 - \Delta T_2}{\ln\left(\frac{\Delta T_1}{\Delta T_2}\right)} = computed\ based\ on\ counter\ flow\ HX$$

$$F = Correction\ factor$$

The correction factor above was located in *Supplemental Materials Bergman HEAT TRANSFER: Figure 11S.3*

Once A_o is solved for, use it to solve for the number of tubes required in the heat exchanger by using the following equation:

$$A_o = \pi D_o L * N_t$$

Where:

$$L = Selected\ length\ of\ the\ tubes$$

$$D_o = Selected\ outer\ diameter\ of\ the\ tubes\ from\ Table\ 8.1$$

$$N_t = Calculated\ number\ of\ tubes$$

From the number of tubes calculated (which is not a permanent number), we were directed to Table 8.3 where we selected a shell diameter and number of passes. The option we selected was 1-in. O.D. Tubes on 1 ¼-in. Square Pitch. We selected this size because it is the most common tube diameter in the industry. We then selected 23.25 inches for our shell I.D. and 208 as our number of tubes for a single pass of tubes in shell (these values were subject to change with the iterations to come). We initially designed the heat exchanger with a shell ID as close to 24 inches as possible because that is the maximum size in the industry before fabrication is required.

The baffle spacing was the next step in the design process. Using the equation below, we found a range for the distance between each baffle and from that range of numbers we selected a suitable value.

$$0.4D_s < B < 0.6D_s$$

Where:

$$D_s = Diameter\ of\ the\ shell\ selected\ in\ the\ above\ process\ (23.25\ in = 0.5906m)$$

The required number of baffles was also calculated from the range calculated above. We divided the overall length of the tubes by the selected baffle spacing of 0.343m and rounded up to the nearest whole number of baffles, which was 16 baffles (this was subject to change).

With the new number of tubes from Table 8.3, we recalculated A_o and A_i using the previous equations used:

$$A_o = \pi D_o L * N_t$$

$$A_i = \pi D_i L * N_t$$

Where:

$$A_i = \ Inner\ surface\ area\ of\ the\ tubes\ that\ we\ need\ to\ solve\ for$$

$$D_i = Inner\ tube\ diameter$$

The next step was to start calculating resistances, beginning with h_i. To do this, we needed the velocity of the ammonia inside of the tubes by using the following equations:

$$\dot{m}_{ammonia} = \rho_{ammonia} * V_{ammonia} * A_{internal\ flow}$$

$$A_{internal\ flow} = \frac{\pi}{4} D_i^2 * \left(\frac{N_{tubes}}{N_{passes}}\right)$$

Where:

$$d_i = 0.0221m, \qquad A_{internal\ flow} = 0.055m^2, \qquad \rho_{ammonia} = 580.99\frac{kg}{m^3}$$

With the above values, we computed the ammonia velocity inside the tubes to be $1.25\ m^2$. With this value, we are now able to calculate Reynold, Prandtl, and Nusselt numbers using the following equations:

$$Reynold's = \frac{Velocity_{ammonia} * D_i}{Viscosity_{ammonia}} = 81666$$

$$Nusselt's = 0.023Re^{0.8}\mathrm{Pr}^{0.3} = 240.8$$

Where:

$$Pr = 2.00 = Value\ obtained\ in\ the\ back\ of\ the\ textbook$$

Now that we have the above values, we can pair Nusselt's with the thermal conductivity (k) of ammonia to compute the heat transfer coefficient inside the tubes (h_i), using the following:

$$h_i = \frac{Nu * k_{ammonia}}{D_i} = 5372.4\frac{W}{m^2 * K}$$

With the discovery of h_i, the last piece we needed to solve for the resistances was h_o (the heat transfer coefficient outside the tubes).

To find h_o, we needed the following equation from the heat exchanger tables (equation 8.11):

$$\frac{h_o D_e}{k} = 0.36 \left(\frac{D_e G_s}{\mu}\right)^{0.55} \left(\frac{C_p \mu}{k}\right)^{\frac{1}{3}} \left(\frac{\mu_b}{\mu_w}\right)^{0.14}$$

Where:

$$D_e = \frac{4\left(P_T^2 - \frac{\pi D_o^2}{4}\right)}{\pi D_o} = 0.036m$$

$$G_s = \frac{\dot{m}}{A_s} = 1228.95 \frac{kg}{m^2 * s}$$

$$A_s = \frac{D_s CB}{P_T} = 0.047m^2$$

$$C = Clearance\ between\ tubes\ in\ the\ heat\ exchanger = Pitch\ size - Tube\ O.D.$$

$$D_s = Shell\ diameter$$

$$B = Baffle\ spacing$$

$$P_T = Pitch\ size$$

$$\dot{m} = Mass\ flow\ rate$$

$$C_p = Specific\ heat\ of\ water$$

$$\mu = Dynamic\ viscosity\ of\ water$$

$$k = Thermal\ conductivity\ of\ water$$

$$\mu_b = Bulk\ temperature\ viscosity$$

$$\mu_w = film\ temperature\ viscosity$$

Using the above equations and values, our initial value for h_o is:

$$h_o = 4025 \frac{W}{m^2 * K}$$

After finding h_o, we needed to find the wall resistance R_w.

$$R_w = \frac{\ln\left(\frac{D_o}{D_i}\right)}{2\pi k L} * \left(\frac{1}{N_{tubes}}\right) = 6.876 * 10^{-8}\ K/W$$

With our given fouling factors for water and ammonia () coupled with our computed values for h_o, h_i, A_o, A_i, and R_w, we can finally calculate a new value for U_o, which we will then use to compute a new value of Q, and compare that new Q value to the original Q calculated from the ammonia to the water at the beginning and reiterate the entire process above. We will do this till the Q percentage difference is less than 10%.

To compute $U_{o_{new}}$, use the following:

$$\frac{1}{U_{o_{new}}} = \frac{A_o}{A_i}\left(\frac{1}{h_i} + R_{f_i}\right) + A_o R_w + R_{f_o} + \frac{1}{h_o}$$

Where:

$$A_o = Tube\ outer\ surface\ area$$

$$A_i = Tube\ inner\ surface\ area$$

$$h_i = heat\ coefficient\ inside\ the\ tubes$$

$$R_{f_i} = Fouling\ factor\ inside\ tubes\ (ammonia)$$

$$R_w = Wall\ resistance$$

$$R_{f_o} = Fouling\ factor\ outside\ tubes\ (water)$$

$$h_o = heat\ coefficient\ outside\ the\ tubes$$

With this newly calculated value, $U_{o_{new}} = 974.9\frac{W}{m^2 * K}$, we were able to compute a new Q value using the equation stated at the beginning of this section:

$$Q_{new} = U_{o_{new}} A_o MLDT * F = 2245826\ W$$

With this new Q, we did a percent difference calculation between this Q and the Q that needs to be transferred from the ammonia to the water.

$$\%\ Diff = \frac{Q - Q_{new}}{Q} * 100\% = 44.3\%$$

With this percent difference, we knew that we needed to reiterate the process in order to get the percent difference as close to zero as we can.

Per requirements we had to calculate the pressure drop on the shell side and on the tube side. The equations used to determine these pressure drops are the following, respectively:

$$\Delta p_s = \frac{f G_s^2 (N_b + 1) \cdot D_s}{2 \rho D_e \varphi_s}$$

$$\Delta p_t = 4f \frac{L N_p}{D_i} \rho \frac{U_m^2}{2}$$

Where:

$$f = \exp(0.576 - 0.19 ln * Re_s)$$

$$400 < Re_s = \frac{G_s D_e}{\mu} \leq 1 * 10^6$$

$$\varphi_s = \left(\frac{\mu_b}{\mu_w}\right)^{0.14}$$

$$N_b = Number\ of\ baffles$$

$$L = Length\ of\ the\ heat\ exchanger$$

$$N_p = Number\ of\ tube\ passes$$

Design Calculations:

See the attached MS Excel Spreadsheet for the calculations done for this project.

Final Drawings:

Plot Plant:

Nothing is known of the location other than that it is a shipyard. The layout schematics were not given, so we did not create a plot plan.

Elevations View:

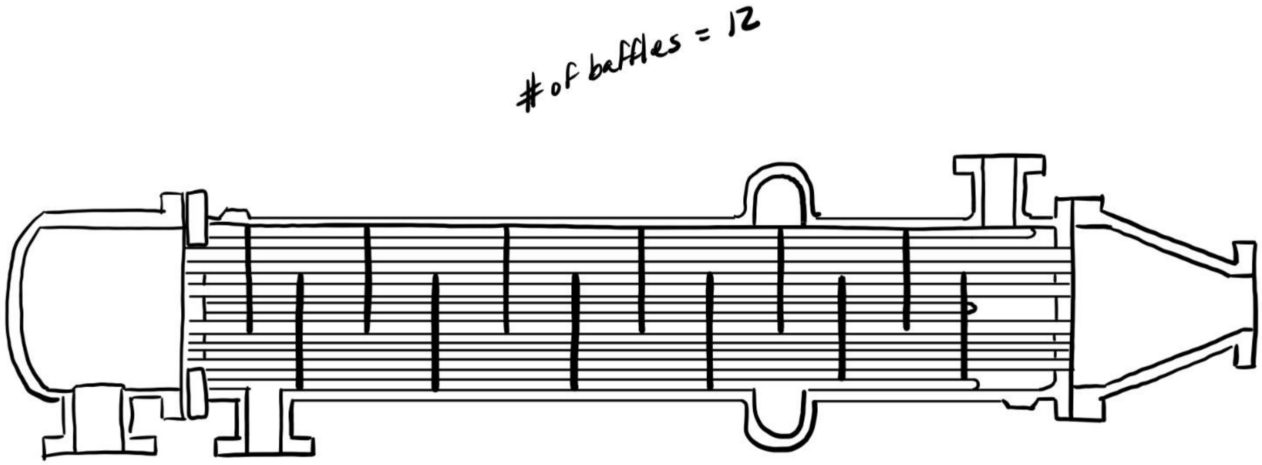

Figure 8. Final Elevations View.

Isometrics:

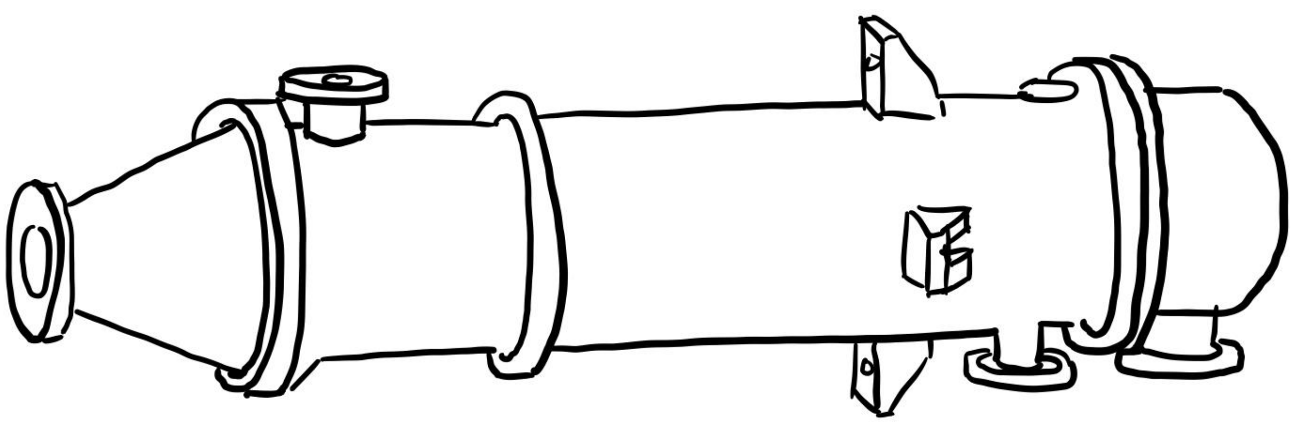

Figure 9. Final Isometrics View.

Heat Exchanger Data Sheet:

				SHELL-AND-TUBE HEAT EXCHANGER		
				CLIENT Shipyard	EQUIP. NO	PAGE 1
REV	PREPARED BY	DATE	APPROVAL	W.O.	REQUISITION NO.	SPECIFICATION NO.
0	12/12/19	12/12/19				
1				UNIT AREA	PROCURED BY	INSTALLED BY
2						

1	Size 24H	TEMA Type BEM				Connected in (series/parallel) N/A			
2	Surface per Unit 2880 ft²			Shells per Unit 1 shell		Surface per Shell 2160 ft²			
3	Performance of One Unit								
4	Fluid Allocation			Shell Side			Tube Side		
6	Fluid Name			Water			Ammonia		
7	Flow Total	lb/h		458711			320000		
8	Vapor	lb/h	(in/out)	—	—				
9	Liquid	lb/h	(in/out)	458711	458711		320,000	320,000	
10	Steam	lb/h	(in/out)	—	—		—	—	
11	Water	lb/h	(in/out)	—	—		—	—	
12	Noncondensable	lb/h	(in/out)	—	—		—	—	
13	Temperature (In/Out)	°F	(in/out)	50	80		122	86	
14	Density	lb/ft3		999			580.19		
15	Viscosity	cP		1.012			0.00034		
16	Molecular Weight, vapor			—	—		—	—	
17	Specific Heat	Btu/lb-°F		0.9995			1.1940		
18	Thermal Conductivity	Btu/h-ft-°F		0.343			0.285		
19	Latent Heat	Btu/lb		—	—		—	—	
20	Inlet Pressure	psigg	(inlet)						
21	Velocity	ft/s		2.07			2.15		
22	Press Drop Allow/Calc	psig		2.83			0.725		
23	Fouling Factor	ft²-h-°F/Btu		0.0002			0.0001		
24	Heat Exchanged	Btu/hr		13,784,270		LMTD (corrected) °F 67.03			
25	Service Coeff.	Btu/h-ft²-°F	Dirty			Clean			

26	Construction Data for One Shell						
27			Shell Side	Tube Side	Sketch		
28	Design/Test Press	psigg					
29	Design Temperature	°F					
30	No. Passes per Shell		1	2			
31	Corrosion Allowance	in					
32	Connections Size & Rating	In inches					
33		Out					
34		Intermediate					
35	Tubes No. 574	OD, in 1	Gauge 16		Length, ft. 18		Pitch layout, deg. Square, 90°
36	Type E			Material Aluminum			Pitch ratio 1.25
37	Shell	OD, in 38.2	ID, in 37		Material		
38	Channel or Bonnet B	OD, in 40	Thick 1.5 in		Channel Cover Integral		
39	Tubesheet Type M						
40	Floating Heat Cover				Impingement Protection		
41	Baffles Cross (number) 12		% Cut (d) 50				Spacing C/C, in 18.5
42	Baffles Long		Seal Type No				
43	Supports Tube		U-Bend 1				Type
44	Bypass Seal Arrangement				Tube-Tubesheet Joint		
45	Expansion Joint No.				Type		
46	Rho-V2-Inlet Nozzle		Bundle Entrance				Bundle Exit
47	Gaskets - Shell Side				Tube Side		
48	Floating Heat Cover				Supports		
49	Code Requirements				TEMA Class		
50	Weight per shell lb		Filled w/water				Bundle
51							
52	Notes						
53							
54							

Figure 10. Heat Exchanger Data Sheet.

Discussion:

We went through four different iterations of this heat exchanger. Our resulting percentage difference was well below the minimum threshold of 10%. Our pressure drop from the shell inlet to the shell outlet was 2.83 psi. The pressure drop from the tube inlet to the tube outlet was 0.725 psi.

Our effectiveness was computed once we were completely finished with the iterative process and we were satisfied with our results. We used the below chart to calculate our effectiveness:

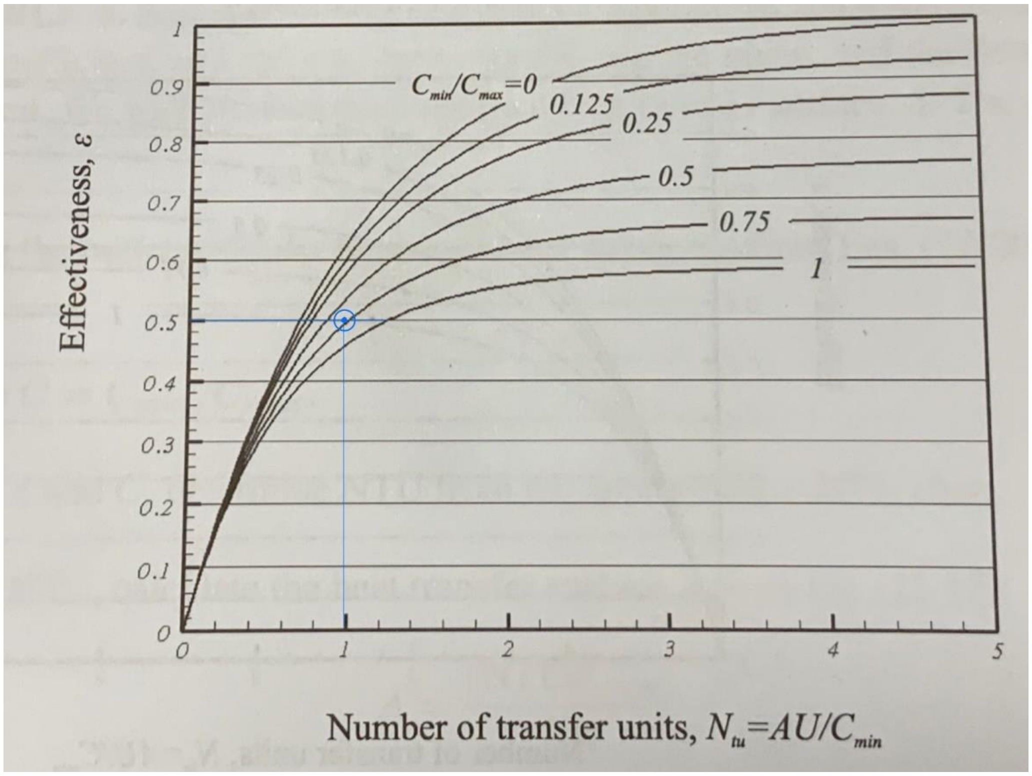

Figure 11. Heat Exchanger Effectiveness Graph.

Final Remarks:

The results told us that the effectiveness was average, which means we did it right. The overall heat transfer coefficient value went down, which caused the Q (heat transfer value) to increase and then level off with the target Q value.

Appendix:

- Do you think what you learn is important for your professional career?
    - Noah: Absolutely. It does not even have to be heat transfer material for it to be important for my professional career. Everything from sitting and listening in class, to networking with the professor and classmates is important for my professional career.
- Where do you think you will be using everything you learned?
    - Graham: In terms of heat transfer, I do not think that I will use all of the principles that I've learned in my life as soon as I leave college. I will certainly use the methods of critical thinking and perseverance that I learned in this class every day in my professional life.
- How would you explain the project and your contribution to the project in a job interview?
    - Noah: I would explain the project as a culmination of the principles learned in this course. I contributed by taking good notes and by pulling the report together in a clear and cohesive format.
- How would you explain how your strengths helped you contribute to the project in a job interview?
    - Graham: I don't have many strengths when it comes to this subject material. I know how to ask questions and am competent enough to understand this material, but it the understanding comes to me after lots of work and perseverance. It does not come to me naturally; I have to work very hard on it in order to make any headway.
- How would you explain in a job interview how your weaknesses affected your ability to work on this project and how did you address them (or what part of the class helped you address them)?
    - Noah:
- Explain the technical strengths and weaknesses in your project.
    - Graham: My technical strength was the report and overall formatting. I did contribute to the calculations, but I made a few mathematical mistakes when I was directly involved with the equations.
- If you were starting the class over again, what advice would you give yourself to ensure that you had a successful semester and a successful final project?
    - Noah: Take very detailed notes, go to every single class, and don't be afraid to ask questions of the professor or the other students. Make friends in the class and work on the homework assignments together, as this will help you complete them on time and helps build good working relations for the future.