Homework 13

Due <u>Wednesday11/9</u> at the end of class with your exam

1. (5 points) After the ingredients are mixed at 20°C, ice cream (85% water by mass) is frozen by mixing the liquid in a continuous freezer that is cooled by passing liquid ammonia through stainless steel tubes surrounding the freezer. Heat from the ice cream mix is transferred to the ammonia through the stainless steel. Your process makes 100 kg of ice cream per minute and is supplied with saturated ammonia at 120kPa and 25% quality (see tables below). If the resulting ice cream is -20°C and the ammonia leaving the freezer is saturated vapor at 120kPa, how much ammonia is required per minute?

2. (15 points) Your process will need to recycle the ammonia. An equipment vendor has a process to return the ammonia to the thermodynamic state that supplies the freezer in a three-step process. First, the ammonia vapor is isentropically compressed to 1200kPa. Second, the ammonia is passed through a heat exchanger where it is cooled and condensed to saturated liquid at 1200kPa. Third, the liquid is adiabatically throttled to 120kPa.
   a. Assuming no changes in kinetic or potential energy and that the process is adiabatic, how much work must be supplied to compress the vapor in the first step?
   b. How much heat must be removed by the condenser?
   c. Calculate the final quality of the throttled ammonia.
   d. Will this equipment work for your process? How might it be modified to make it work if it doesn't meet your needs?

Properties of Saturated Ammonia – Pressure Table

P_{sat} kPa	T_{sat} °C	Specific Volume m³/kg		Specific Internal Energy kJ/kg			Specific Enthalpy kJ/kg			Specific Entropy kJ/kgK		
		V_f	V_g	U_f	U_{fg}	U_g	H_f	H_{fg}	H_g	S_f	S_{fg}	S_g
90.0	-35.7	0.001460	1.2560	36.30	1265.9	1302.2	36.4	1378.8	1415.2	0.3605	5.8057	6.1661
95.0	-34.6	0.001463	1.1940	41.22	1262.2	1303.4	41.4	1375.5	1416.8	0.3812	5.7660	6.1471
100.0	-33.6	0.001466	1.1381	45.92	1258.6	1304.6	46.1	1372.3	1418.4	0.4008	5.7284	6.1292
120.0	-29.9	0.001476	0.9596	62.87	1245.8	1308.7	63.0	1360.8	1423.8	0.4710	5.5943	6.0654
140.0	-26.7	0.001485	0.8307	77.55	1234.6	1312.2	77.8	1350.7	1428.5	0.5310	5.4805	6.0115
160.0	-23.8	0.001493	0.7330	90.59	1224.6	1315.2	90.8	1341.7	1432.5	0.5836	5.3813	5.9649
180.0	-21.2	0.001500	0.6564	102.36	1215.6	1317.9	102.6	1333.5	1436.1	0.6306	5.2932	5.9237
200.0	-18.9	0.001507	0.5946	113.12	1207.2	1320.4	113.4	1325.9	1439.3	0.6731	5.2139	5.8870
220.0	-16.7	0.001513	0.5437	123.05	1199.5	1322.5	123.4	1318.8	1442.2	0.7120	5.1418	5.8538
240.0	-14.6	0.001519	0.5010	132.30	1192.2	1324.5	132.7	1312.1	1444.8	0.7479	5.0755	5.8230
1200	30.9	0.001684	0.1058	344.98	1012.6	1357.6	347.0	1139.6	1486.6	1.5054	3.7475	5.2530

Properties of Saturated Ammonia – Temperature Table

T_{sat} °C	P_{sat} kPa	Specific Volume m³/kg		Specific Internal Energy kJ/kg			Specific Enthalpy kJ/kg			Specific Entropy kJ/kgK		
		V_f	V_g	U_f	U_{fg}	U_g	H_f	H_{fg}	H_g	S_f	S_{fg}	S_g
-50	40.7	0.001424	2.6371	-33.62	1318.5	1284.9	-33.6	1425.8	1392.3	0.0566	6.3895	6.4461
-48	45.8	0.001429	2.3621	-23.45	1310.9	1287.4	-23.4	1419.0	1395.6	0.1020	6.3023	6.4043
-46	51.4	0.001434	2.1206	-13.47	1303.3	1289.9	-13.4	1412.3	1398.9	0.1461	6.2173	6.3635
-44	57.5	0.001439	1.9081	-3.65	1296.0	1292.3	-3.6	1405.7	1402.1	0.1892	6.1344	6.3236
-42	64.3	0.001444	1.7207	6.03	1288.7	1294.7	6.1	1399.2	1405.3	0.2312	6.0533	6.2845
-40	71.6	0.001449	1.5545	15.86	1281.3	1297.1	16.0	1392.5	1408.5	0.2736	5.9727	6.2463
-38	79.7	0.001454	1.4075	25.33	1274.1	1299.5	25.4	1386.2	1411.6	0.3140	5.8948	6.2089
-36	88.4	0.001460	1.2768	34.71	1267.1	1301.8	34.8	1379.9	1414.7	0.3538	5.8185	6.1723
-34	97.9	0.001465	1.1604	44.01	1260.1	1304.1	44.2	1373.6	1417.7	0.3928	5.7436	6.1365
-32	108.3	0.001470	1.0566	53.25	1253.1	1306.3	53.4	1367.3	1420.7	0.4313	5.6701	6.1014
-30	119.5	0.001476	0.9637	62.44	1246.1	1308.6	62.6	1361.1	1423.7	0.4692	5.5977	6.0670
-28	131.6	0.001481	0.8805	71.58	1239.2	1310.8	71.8	1354.8	1426.6	0.5067	5.5265	6.0332
-26	144.6	0.001487	0.8058	80.70	1232.2	1312.9	80.9	1348.5	1429.5	0.5437	5.4564	6.0001
-24	158.7	0.001492	0.7386	89.79	1225.3	1315.0	90.0	1342.2	1432.3	0.5804	5.3873	5.9677
-22	173.9	0.001498	0.6780	98.87	1218.3	1317.1	99.1	1335.9	1435.0	0.6167	5.3192	5.9358

Properties of Superheated Ammonia

P kPa	T °C	v m3/kg	u kJ/kg	h kJ/kg	s kJ/(kg·K)
1200					
	(Tsat=30.9°C)	(0.1075)	(1357.6)	(1486.6)	(5.2530)
	40	0.1129	1379.8	1515.2	5.3458
	60	0.1238	1424.6	1573.1	5.5251
	80	0.1339	1465.9	1626.6	5.6810
	100	0.1435	1505.5	1677.7	5.8219
	120	0.1528	1544.4	1727.7	5.9523
	140	0.1618	1583.0	1777.2	6.0751
	160	0.1707	1621.8	1826.7	6.1921
	180	0.1795	1661.0	1876.5	6.3044