Department of Energy and Process Engineering
EP8110 Exergy Analysis

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Exercise 8

Problem 1 – Separation of gases

A gas mixture (stream 1), for instance flue gas from combustion, enters a separation process (SP). The process has two outflowing streams: In one of these (stream 2), some of the gases are concentrated, while the other (stream 3) comprises the remaining gases. Normally stream 2 will have one or a few main components and small amounts of the other components.
The SP is a steady flow, steady state process. There are no chemical reactions and no other flows of matter.

Assume that the composition (mole fractions $x_{i,1}$) is known for stream 1, that the degree of separation, $\beta_i = n_{i,2} / n_{i,1}$ is known (or specified) for all gases, that the inflow and outflow occurs at the temperature of the environment (T_0), and that the flows are ideal gases

a) Develop an expression for the theoretical minimum work input for the separation process (i.e., the increase in chemical exergy or, alternatively, the decrease in entropy). The model should be suitable for implementation in a spreadsheet or other program (needed in b).

Hint: calculate per mole of something, e.g. per mole of stream 1 or per mole of a certain species in stream 2.

b) Use your model to calculate the minimum work input for separation of 1 kmol pure CO_2 from from a flue gas containing 1) 3,5% CO_2 (typically gas turbine) 2) 11% CO2 (typically gas engine or coal-fired power plant), when in both cases the degree of separation (β_{CO_2}) ranges from 0,3 to 0,9. The environmental temperature is 15 ºC.
Repeat the calculations for ambient temperatures -20 ºC and (+)40 ºC

Hint: Unless you think you will find the model in a) useful in later work, make the additional simplifications that are relevant for b) before implementing it in the spreadsheet/program. Notice that for ideal gases, it does not matter which gases other than CO_2 that are present.

Problem 2- Utilization of low-temperature energy

A developer/inventor seeks your organization for funding for the development of a device that will utilize the thermal energy of discharge gases and water to produce electricity. The thermal efficiency should be 15-20%, for discharge flows at 70 ºC (when a large amount of seawater is available for cooling 10 ºC).

Your manager asks you to evaluate the request – based on thermodynamics. Is the invention possible - theoretically and realistically?

Problem 3 – the Air Car

The Air Car uses compressed air as “fuel”. It has 4 containers, each 90 liter, of compressed air. Fully charged, the pressure is 300 bar. For simplicity of calculations, we can assume that the state of atmospheric air is 300 K and 1 atm (1.01325 bar). For calculations the attached table can be used.

--Estimate the range of the car (max. driving distance before refilling).

hint: determining the exergy of the compressed air is a sub-task of the problem; in addition you have to think a bit practically.

Table excerpt from
W.C. Reynolds: “Thermodynamic properties in SI”, Dept. Mech. Engr., Stanford University, 1979

PROPERTIES OF GASEOUS AIR

P, MPa (T_{sat},K)		T,K 200	300	400	500	600	700	800	900	1000
0.050	v,m³/kg	1.147	1.722	2.297	2.871	3.445	4.020	4.594	5.168	5.742
(76.24)	h,kJ/kg	359.56	459.96	560.79	662.81	766.71	872.87	981.41	1092.23	1205.16
	s,kJ/(kg·K)	4.3298	4.7368	5.0269	5.2544	5.4438	5.6074	5.7523	5.8828	6.0018
	u,kJ/kg	302.22	373.86	445.95	519.25	594.44	671.89	751.72	833.83	918.04
0.101325	v,m³/kg	0.5653	0.8497	1.133	1.417	1.701	1.984	2.267	2.551	2.834
(81.82)	h,kJ/kg	359.31	459.85	560.73	662.79	766.70	872.88	981.43	1092.26	1205.19
	s,kJ/(kg·K)	4.1261	4.5337	4.8239	5.0516	5.2410	5.4046	5.5495	5.6800	5.7990
	u,kJ/kg	302.03	373.75	445.88	519.20	594.40	671.86	751.69	833.81	918.03
0.14	v,m³/kg	0.4088	0.6149	0.8204	1.026	1.231	1.436	1.641	1.846	2.051
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

P, MPa		T,K 200	300	400	500	600	700	800	900	1000
14.	v,m³/kg	0.00328	0.00617	0.00859	0.01084	0.01302	0.01515	0.01726	0.01936	0.02144
	h,kJ/kg	292.25	433.18	548.32	658.05	766.80	876.27	987.19	1099.80	1214.08
	s,kJ/(kg·K)	2.4561	3.0353	3.3672	3.6121	3.8104	3.9791	4.1272	4.2598	4.3802
	u,kJ/kg	246.28	346.76	428.10	506.28	584.54	664.12	745.50	828.81	913.95
20.	v,m³/kg	0.00244	0.00444	0.00618	0.00780	0.00935	0.01086	0.01235	0.01383	0.01529
	h,kJ/kg	277.13	425.39	544.95	657.23	767.64	878.29	990.07	1103.34	1218.14
	s,kJ/(kg·K)	2.2967	2.9053	3.2501	3.5008	3.7021	3.8727	4.0219	4.1553	4.2763
	u,kJ/kg	228.33	336.54	421.27	501.25	580.66	661.04	743.02	826.78	912.29
30.	v,m³/kg	0.00193	0.00318	0.00436	0.00546	0.00651	0.00753	0.00854	0.00953	0.01052
	h,kJ/kg	267.96	417.41	541.77	657.30	769.98	882.29	995.34	1109.58	1225.16
	s,kJ/(kg·K)	2.1437	2.7549	3.1136	3.3716	3.5771	3.7502	3.9012	4.0357	4.1575
	u,kJ/kg	209.97	322.16	411.12	493.61	574.68	656.26	739.13	823.59	909.66
50.	v,m³/kg	0.00159	0.00226	0.00295	0.00362	0.00426	0.00489	0.00550	0.00610	0.00670
	h,kJ/kg	269.73	414.72	542.54	661.80	777.54	892.28	1007.28	1123.10	1239.97