KENYATTA UNIVERSITY

UNIVERSITY EXAMINATIONS 2011/2012

FIRST SEMESTER EXAMINATION FOR THE DEGREE OF BACHELOR OF SCIENCE (ENERGY ENGINEERING)

SET 331: HEAT TRANSFER

DATE: Thursday 8th December 2011 TIME: 11.00a.m -1.00p.m

INSTRUCTIONS:

This Paper consists of FIVE QUESTIONS

Answer Question ONE (COMPULSORY) and any other TWO questions.

Tables are provided

QUESTION ONE

(a) A furnace wall consists of 250mm firebrick, 125mm insulating brick, and 250mm building brick. The inside wall is at a temperature of 600^0C and the atmospheric temperature is 20^0C. Calculate the heat loss per m^2 of wall area and the temperature of the outside wall surface of the furnace. The heat transfer coefficient for the outside surface is $10W/m^2K$, and the thermal conductivities of the firebrick, insulating brick and building brick are 1.4, 0.2, and 0.7 W/mK, respectively. Neglect radiation. (8 Marks)

(b) A steam main of 200mm outside diameter containing wet steam at 30 bar is insulated with an inner layer of diatomaceous earth, 50mm thick, and an outer layer of magnesia, 35 mm thick. Calculate the heat loss per m length of the pipe and the temperature of the outside surface of the lagging, when the room temperature is 22^0C. Neglect the thermal resistance of the pipe itself. Assume that the inside surface of the pipe is at the steam temperature, and take the heat transfer coefficient for the outside surface of the lagging as $19W/m^2K$. The thermal conductivities of diatomaceous earth and magnesia are 0.09, and 0.06W/mK, respectively. Take the satuaration temperature of steam at 30bar as 234^0C. Neglect radiation. (9Marks)

(c) A spherical pressure vessel of 1m inside diameter is made of 20mm steel plate. The vessel is lagged with a 30mm thickness of vermiculite held in position by 15mm thick asbestos. Calculate the heat loss from the sphere when the inside surface is at 600^0C, and the room temperature is 20^0C. The heat transfer coefficient for the outside surface is $20W/m^2K$, and the thermal conductivities of steel, vermiculite and asbestos are 48, 0.047, and 0.21W/mK; respectively. Neglect radiation. (9 Marks)

(d) State and explain Fourier's law of conduction and explain two mechanisms through which heat transfer by conduction in solids takes place (4Marks)

QUESTION TWO

(a) With aid of sketches, discuss the following:

i) Parallel heat exchanger

ii) Counter flow heat exchanger (4Marks)

(b) Exhaust gases flowing through a tubular heat exchanger at a rate of 0.3kg/s are cooled from 500°C to 100°C by water initially at 10°C. The specific heat of the exhaust gases and water may be taken as 1.13 and 4.9kJ/kgK respectively. The overall heat transfer coefficient from the gases to the water is 140W/m^{2}K. Calculate the surface area required when the cooling water flow is 0.5kg/s for:

i) Parallel flow

ii) Counter flow (8Marks)

(c) A single pass shell and tube counter flow heat exchanger uses waste gas on the shell side to heat a liquid in the tubes. The waste gas enters at a temperature of 400°C at a mass flowrate of 50kg/s. The liquid enters at 100°C at a mass flowrate of 3kg/s. Assuming that the velocity of the liquid does not exceed 1m/s, calculate using the data below:

i) The required number of tubes

ii) The effectiveness of the heat exchanger

iii) The exit temperature of the liquid. Neglect the thermal resistance of the wall. (8Marks)

Data:

Tube inside diameter 10mm

Tube outside diameter 12.7mm

Tube length = 4m

Specific heat of waste gas 1.04kJ/kgK

Specific heat of the liquid = 1.5kJ/kgK

Density of the liquid = 500kg/m^3

Heat transfer coefficient of shell side = 260W/m^{2}k

Heat transfer coefficient of the tube side = 580 W/m^{2}K

QUESTION 3

(a) In an air cooler the air is blown across a bank of tubes at the rate of 240 kg/h at a velocity of 24m/s, the air entering at 97^{0}C and leaving at 27^{0}C. The cooling water enters the tubes at 10^{0}C and leaves at 20^{0}C, at a mean velocity of 0.6m/s. The tubes are 6mm diameter and the wall thickness may be neglected. The heat transfer coefficient from the air to the tubes may be calculated from

$$Nu = 0.33(\mathrm{Re})^{0.6} \times (\mathrm{Pr})^{0.33}$$

With properties at mean bulk temperature.

The heat transfer coefficient from the water to the tubes is given by,

$$St = \frac{f/2}{1 + (\Pr)^{-1/6}(\mathrm{Re})^{-1/8}(\Pr - 1)}$$

Where $f = 0.0791\,(Re)^{-1/4}$ and properties are at mean bulk temperature. Assuming that the tubes are arranged in 6 passes, and that the logarithmic mean temperature difference for counter – flow can be used, calculate the number of tubes required in each pass and the necessary tube length. (10 Marks)

(b) An exhaust pipe of 75mm outside diameter is cooled by surrounding it by an annular space containing water. The exhaust gas enters the exhaust pipe at 350^0C, and the water enters from the mains at 10^0C. The heat transfer coefficients for the gases and water may be taken as 0.3 and 1.5kW/m^{2}K, respectively and the pipe thickness may be taken to be negligible. The gases are required to be cooled to 100^0C and the mean specific heat at constant pressure is 1.13kJ/kgK. The gas flow is 200kg/h and the water flow is 1400kg/h. Calculate the required length of pipe, (i) for parallel – flow; (ii) for counter – flow. Take the specific heat of water as 4.19kJ/kgK. (10 Marks)

QUESTION FOUR

(a) Differentiate between forced convection and natural convection giving examples (2Marks)

(b) Calculate the heat transfer coefficient for water flowing through a 25mm diameter tube at a rate of 2.5kg/s when the bulk temperature is 60^0C. For turbulent flow of the liquid take:

$$Nu = 0.03Re^{0.8}(Pr)^{0.6}$$

Where the characteristic dimension of length is the tube diameter and all properties are evaluated at mean bulk temperature. (7Marks)

(c) Calculate the heat loss by natural convection per m length from a horizontal pipe of 150mm diameter, the surface of which is at 280^0C. The room temperature is 18^0C.

Take for horizontal pipe

$\mathrm{Nu} = 0.527(\Pr)^{0.5}(\Pr + 0.952)^{-0.25}(\mathrm{Gr})^{0.25}$

Where properties are evaluated at surface temperature.

Take Grashof number as Gr = 1.51 x 10^6 (6Marks)

(d) A double pipe heat exchanger has an effectiveness of 0.5 when the flow is counter – current and the thermal capacity of one fluid is twice that of the other fluid. Calculate the effectiveness of the heat exchanger if the direction of flow of one of the fluids is reversed with the same mass flow rates as before. (5Marks)

QUESTION FIVE

a) Explain the following terms as used in radiation heat transfer

i) Emissive power and Emissivity

ii) Kirchoff's law

iii) Stefan – Boltzman law

iv) Absorbtivity (6 Marks)

b) A body at 1300°C in black surrounding at 650°C has an emmisivity of 0.4 at 1300°C and an emissivity of 0.7 at 650°C. Calculate the rate of heat loss by radiation per m^2

i) When body is grey with $\varepsilon = 0.4$

ii) When body is not grey (8Marks)

c) Calculate the heat transferred per m^2 of surface area by radiation between two brick wall at a short distanc apart when the temperature of the surfaces are 30°C and 15°C. The emissivity of the brick may be taken as 0.93 and the surfaces may be assumed to be grey. (6Marks)

Attachment : SFT 331

Appendix A. Properties of Gases and Vapors

TABLE A.1 Properties of Dry Air at Atmospheric Pressure

Symbols and Units:

K = absolute temperature, degrees Kelvin
deg C = temperature, degrees Celsius
deg F = temperature, degrees Fahrenheit
ρ = density, kg/m^3
c_p = specific heat capacity, kJ/kg·K
c_p/c_v = specific heat capacity ratio, dimensionless
μ = viscosity, N·s/m^2 × 10^6 (For N·s/m^2 (= kg/m·s) multiply tabulated values by 10^{-6})
k = thermal conductivity, W/m·k × 10^3 (For W/m·K multiply tabulated values by 10^{-3})
Pr = Prandtl number, dimensionless
h = enthalpy, kJ/kg
V_s = sound velocity, m/s

Temperature			Properties							
K	deg C	deg F	ρ	c_p	c_p/c_v	μ	k	Pr	h	V_s
100	−173.15	−280	3.598	1.028		6.929	9.248	.770	98.42	198.4
110	−163.15	−262	3.256	1.022	1.4202	7.633	10.15	.768	108.7	208.7
120	−153.15	−244	2.975	1.017	1.4166	8.319	11.05	.766	118.8	218.4
130	−143.15	−226	2.740	1.014	1.4139	8.990	11.94	.763	129.0	227.6
140	−133.15	−208	2.540	1.012	1.4119	9.646	12.84	.761	139.1	236.4
150	−123.15	−190	2.367	1.010	1.4102	10.28	13.73	.758	149.2	245.0
160	−113.15	−172	2.217	1.009	1.4089	10.91	14.61	.754	159.4	253.2
170	−103.15	−154	2.085	1.008	1.4079	11.52	15.49	.750	169.4	261.0
180	−93.15	−136	1.968	1.007	1.4071	12.12	16.37	.746	179.5	268.7
190	−83.15	−118	1.863	1.007	1.4064	12.71	17.23	.743	189.6	276.2
200	−73.15	−100	1.769	1.006	1.4057	13.28	18.09	.739	199.7	283.4
205	−68.15	−91	1.726	1.006	1.4055	13.56	18.52	.738	204.7	286.9
210	−63.15	−82	1.684	1.006	1.4053	13.85	18.94	.736	209.7	290.5
215	−58.15	−73	1.646	1.006	1.4050	14.12	19.36	.734	214.8	293.9
220	−53.15	−64	1.607	1.006	1.4048	14.40	19.78	.732	219.8	297.4
225	−48.15	−55	1.572	1.006	1.4046	14.67	20.20	.731	224.8	300.8
230	−43.15	−46	1.537	1.006	1.4044	14.94	20.62	.729	229.8	304.1
235	−38.15	−37	1.505	1.006	1.4042	15.20	21.04	.727	234.9	307.4
240	−33.15	−28	1.473	1.005	1.4040	15.47	21.45	.725	239.9	310.6
245	−28.15	−19	1.443	1.005	1.4038	15.73	21.86	.724	244.9	313.8
250	−23.15	−10	1.413	1.005	1.4036	15.99	22.27	.722	250.0	317.1
255	−18.15	−1	1.386	1.005	1.4034	16.25	22.68	.721	255.0	320.2
260	−13.15	8	1.359	1.005	1.4032	16.50	23.08	.719	260.0	323.4
265	−8.15	17	1.333	1.005	1.4030	16.75	23.48	.717	265.0	326.5
270	−3.15	26	1.308	1.006	1.4029	17.00	23.88	.716	270.1	329.6
275	+1.85	35	1.285	1.006	1.4026	17.26	24.28	.715	275.1	332.6
280	6.85	44	1.261	1.006	1.4024	17.50	24.67	.713	280.1	335.6
285	11.85	53	1.240	1.006	1.4022	17.74	25.06	.711	285.1	338.5
290	16.85	62	1.218	1.006	1.4020	17.98	25.47	.710	290.2	341.5
295	21.85	71	1.197	1.006	1.4018	18.22	25.85	.709	295.2	344.4
300	26.85	80	1.177	1.006	1.4017	18.46	26.24	.708	300.2	347.3
305	31.85	89	1.158	1.006	1.4015	18.70	26.63	.707	305.3	350.2
310	36.85	98	1.139	1.007	1.4013	18.93	27.01	.705	310.3	353.1
315	41.85	107	1.121	1.007	1.4010	19.15	27.40	.704	315.3	355.8
320	46.85	116	1.103	1.007	1.4008	19.39	27.78	.703	320.4	358.7

*Condensed and computed from: "Tables of Thermal Properties of Gases", National Bureau of Standards Circular 564, U.S. Government Printing Office, November 1955.

TABLE A.1 (continued) Properties of Dry Air at Atmospheric Pressure

Temperature			Properties							
K	deg C	deg F	ρ	c_p	c_p/c_v	μ	k	Pr	h	V_s
325	51.85	125	1.086	1.008	1.400 6	19.63	28.15	.702	325.4	361.4
330	56.85	134	1.070	1.008	1.400 4	19.85	28.53	.701	330.4	364.2
335	61.85	143	1.054	1.008	1.400 1	20.08	28.90	.700	335.5	366.9
340	66.85	152	1.038	1.008	1.399 9	20.30	29.28	.699	340.5	369.6
345	71.85	161	1.023	1.009	1.399 6	20.52	29.64	.698	345.6	372.3
350	76.85	170	1.008	1.009	1.399 3	20.75	30.03	.697	350.6	375.0
355	81.85	179	0.994 5	1.010	1.399 0	20.97	30.39	.696	355.7	377.6
360	86.85	188	0.980 5	1.010	1.398 7	21.18	30.78	.695	360.7	380.2
365	91.85	197	0.967 2	1.010	1.398 4	21.38	31.14	.694	365.8	382.8
370	96.85	206	0.953 9	1.011	1.398 1	21.60	31.50	.693	370.8	385.4
375	101.85	215	0.941 3	1.011	1.397 8	21.81	31.86	.692	375.9	388.0
380	106.85	224	0.928 8	1.012	1.397 5	22.02	32.23	.691	380.9	390.5
385	111.85	233	0.916 9	1.012	1.397 1	22.24	32.59	.690	386.0	393.0
390	116.85	242	0.905 0	1.013	1.396 8	22.44	32.95	.690	391.0	395.5
395	121.85	251	0.893 6	1.014	1.396 4	22.65	33.31	.689	396.1	398.0
400	126.85	260	0.882 2	1.014	1.396 1	22.86	33.65	.689	401.2	400.4
410	136.85	278	0.860 8	1.015	1.395 3	23.27	34.35	.688	411.3	405.3
420	146.85	296	0.840 2	1.017	1.394 6	23.66	35.05	.687	421.5	410.2
430	156.85	314	0.820 7	1.018	1.393 8	24.06	35.75	.686	431.7	414.9
440	166.85	332	0.802 1	1.020	1.392 9	24.45	36.43	.684	441.9	419.6
450	176.85	350	0.784 2	1.021	1.392 0	24.85	37.10	.684	452.1	424.2
460	186.85	368	0.767 7	1.023	1.391 1	25.22	37.78	.683	462.3	428.7
470	196.85	386	0.750 9	1.024	1.390 1	25.58	38.46	.682	472.5	433.2
480	206.85	404	0.735 1	1.026	1.389 2	25.96	39.11	.681	482.8	437.6
490	216.85	422	0.720 1	1.028	1.388 1	26.32	39.76	680	493.0	442.0
500	226.85	440	0.705 7	1.030	1.387 1	26.70	40.41	.680	503.3	446.4
510	236.85	458	0.691 9	1.032	1.386 1	27.06	41.06	.680	513.6	450.6
520	246.85	476	0.678 6	1.034	1.385 1	27.42	41.69	.680	524.0	454.9
530	256.85	494	0.665 8	1.036	1.384 0	27.78	42.32	.680	534.3	459.0
540	266.85	512	0.653 5	1.038	1.382 9	28.14	42.94	680	544.7	463.2
550	276.85	530	0.641 6	1.040	1.381 8	28.48	43.57	680	555.1	467.3
560	286.85	548	0.630 1	1.042	1.380 6	28.83	44.20	.680	565.5	471.3
570	296.85	566	0.619 0	1.044	1.379 5	29.17	44.80	.680	575.9	475.3
580	306.85	584	0.608 4	1.047	1.378 3	29.52	45.41	.680	586.4	479.2
590	316.85	602	0.598 0	1.049	1.377 2	29.84	46.01	.680	596.9	483.2
600	326.85	620	0.588 1	1.051	1.376 0	30.17	46.61	680	607.4	486.9
620	346.85	656	0.569 1	1.056	1.373 7	30.82	47.80	.681	628.4	494.5
640	366.85	692	0.551 4	1.061	1.371 4	31.47	48.96	682	649.6	502.1
660	386.85	728	0.534 7	1.065	1.369 1	32.09	50.12	.682	670.9	509.4
680	406.85	764	0.518 9	1.070	1.366 8	32.71	51.25	683	692.2	516.7
700	426.85	800	0.504 0	1.075	1.364 6	33.32	52.36	.684	713.7	523.7
720	446.85	836	0.490 1	1.080	1.362 3	33.92	53.45	685	735.2	531.0
740	466.85	872	0.476 9	1.085	1.360 1	34.52	54.53	686	756.9	537.6
760	486.85	908	0.464 3	1.089	1.358 0	35.11	55.62	.687	778.6	544.6
780	506.85	944	0.452 4	1.094	1.355 9	35.69	56.68	688	800.5	551.2
800	526.85	980	0.441 0	1.099	1.354	36.24	57.74	.689	822.4	557.8
850	576.85	1 070	0.415 2	1.110	1.349	37.63	60.30	693	877.5	574.1
900	626.85	1 160	0.392 0	1.121	1.345	38.97	62.76	696	933.4	589.6
950	676.85	1 250	0.371 4	1.132	1.340	40.26	65.20	699	989.7	604.9
1 000	726.85	1 340	0.352 9	1.142	1.336	41.53	67.54	702	1 046	619.5
1 100	826.85	1 520	0.320 8	1.161	1.329	43.96			1 162	648.0
1 200	926.85	1 700	0.294 1	1.179	1.322	46.26			1 279	675.2
1 300	1 026.85	1 880	0.271 4	1.197	1.316	48.46			1 398	701.0
1 400	1 126.85	2 060	0.252 1	1.214	1.310	50.57			1 518	725.9
1 500	1 220.85	2 240	0.235 3	1.231	1.304	52.61			1 640	749.4
1 600	1 326.85	2 420	0.220 6	1.249	1.299	54.57			1 764	772.6
1 800	1 526.85	2 780	0.196 0	1.288	1.288	58.29			2 018	815.7
2 000	1 726.85	3 140	0.176 4	1.338	1.274				2 280	855.5
2 400	2 126.85	3 860	0.146 7	1.574	1.238				2 853	924.4
2 800	2 526.85	4 580	0.124 5	2.259	1.196				3 599	983.1

*Further Properties of Water and Steam

T [°C]	p_s [bar]	v_f 10^{-2}[m³/kg]	c_{pf} [kJ/kg K]	c_{pg} [kJ/kg K]	μ_f 10^{-6}[kg/m s]	μ_g 10^{-6}[kg/m s]	k_f 10^{-6}[kW/m K]	k_g 10^{-6}[kW/m K]	$(Pr)_f$	$(Pr)_g$
0.01	0.006112	0.10002	4.210	1.86	1752	8.49	569	16.3	12.96	0.97
5	0.008719	0.10001	4.204	1.86	1501	8.66	578	16.7	10.92	0.96
10	0.01227	0.10003	4.193	1.86	1300	8.83	587	17.1	9.29	0.96
15	0.01704	0.10010	4.186	1.87	1136	9.00	595	17.5	7.99	0.96
20	0.02337	0.10018	4.183	1.87	1002	9.18	603	17.9	6.95	0.96
25	0.03166	0.10030	4.181	1.88	890	9.35	611	18.3	6.09	0.96
30	0.04242	0.10044	4.179	1.88	797	9.52	618	18.7	5.39	0.96
35	0.05622	0.10060	4.178	1.88	718	9.70	625	19.1	4.80	0.96
40	0.07375	0.10079	4.179	1.89	651	9.87	632	19.5	4.30	0.96
45	0.09582	0.10099	4.181	1.89	594	10.0	638	19.9	3.89	0.95
50	0.1233	0.1012	4.182	1.90	544	10.2	643	20.4	3.54	0.95
55	0.1574	0.1015	4.183	1.90	501	10.4	648	20.8	3.23	0.95
60	0.1992	0.1017	4.185	1.91	463	10.6	653	21.2	2.97	0.95
65	0.2501	0.1020	4.188	1.92	430	10.7	658	21.6	2.74	0.95
70	0.3116	0.1023	4.191	1.93	400	10.9	662	22.0	2.53	0.96
75	0.3855	0.1026	4.194	1.94	374	11.1	666	22.5	2.36	0.96
80	0.4736	0.1029	4.198	1.95	351	11.3	670	22.9	2.20	0.96
85	0.5780	0.1032	4.203	1.96	330	11.4	673	23.3	2.06	0.96
90	0.7011	0.1036	4.208	1.97	311	11.6	676	23.8	1.94	0.96
95	0.8453	0.1040	4.213	1.99	294	11.8	678	24.3	1.83	0.97
100	1.01325	0.1044	4.219	2.01	279	12.0	681	24.8	1.73	0.97
105	1.208	0.1048	4.226	2.03	265	12.2	683	25.3	1.64	0.98
110	1.433	0.1052	4.233	2.05	252	12.4	684	25.8	1.56	0.99
115	1.691	0.1056	4.240	2.07	241	12.6	686	26.3	1.49	0.99
120	1.985	0.1060	4.248	2.09	230	12.8	687	26.8	1.42	1.00
125	2.321	0.1065	4.26	2.12	220	13.0	687	27.3	1.36	1.01
130	2.701	0.1070	4.27	2.15	211	13.2	688	27.8	1.31	1.02
135	3.131	0.1075	4.28	2.18	203	13.4	688	28.3	1.26	1.03
140	3.614	0.1080	4.29	2.21	195	13.5	688	28.8	1.22	1.04
145	4.155	0.1085	4.30	2.25	188	13.7	687	29.4	1.18	1.05
150	4.760	0.1091	4.32	2.29	181	13.9	687	30.0	1.14	1.07
160	6.181	0.1102	4.35	2.38	169	14.2	684	31.3	1.07	1.09
170	7.920	0.1114	4.38	2.49	159	14.6	681	32.6	1.02	1.12
180	10.03	0.1128	4.42	2.62	149	15.0	676	34.1	0.97	1.15
190	12.55	0.1142	4.46	2.76	141	15.3	671	35.7	0.94	1.18
200	15.55	0.1157	4.51	2.91	134	15.7	665	37.5	0.91	1.22
210	19.08	0.1173	4.56	3.07	127	16.0	657	39.4	0.88	1.25
220	23.20	0.1190	4.63	3.25	121	16.3	648	41.5	0.86	1.28
230	27.98	0.1209	4.70	3.45	116	16.7	639	43.9	0.85	1.31
240	33.48	0.1229	4.78	3.68	111	17.1	628	46.5	0.84	1.35
250	39.78	0.1251	4.87	3.94	107	17.5	616	49.5	0.85	1.39
260	46.94	0.1276	4.98	4.22	103	17.9	603	52.8	0.85	1.43
270	55.05	0.1302	5.10	4.55	99	18.3	589	56.6	0.86	1.47
280	64.19	0.1332	5.24	4.98	96	18.8	574	61.0	0.88	1.53
290	74.45	0.1366	5.42	5.46	93	19.3	558	66.0	0.90	1.60
300	85.92	0.1404	5.65	6.18	90	19.8	541	72.0	0.94	1.70
320	112.9	0.1499								
340	146.1	0.1639								
360	186.7	0.1894								
370	210.5	0.2225								
374.15	221.2	0.317								

The values for saturated water can be used with good accuracy above saturation pressure. The values for saturated steam can be used with only moderate accuracy below saturation pressure at temperatures greater than 200 °C.

General Information for H_2O

Triple point: Thermodynamic temperature (by definition) =

273.16 K ≘ 0.01 °C ≘ 491.688 R ≘ 32.018 °F

(hence 0 °C ≘ 273.15 K, 0 °F ≘ 459.67 R, 32 °F ≘ 491.67 R)

Gas constant: $R = \tilde{R}/\tilde{m} = 8.3145/18.015 \doteq 0.4615$ kJ/kg K

Compressed Water*

p/[bar] (T_s/[°C])		T/[°C] 0.01	100	200	250	300	350	374.15
	p_s	0.006112	1.01325	15.55	39.78	85.92	165.4	221.2
	$v_f/10^{-2}$	0.1000	0.1044	0.1157	0.1251	0.1404	0.1741	0.317
	h_f	0	419	852	1086	1345	1671	2084
	s_f	0	1.307	2.331	2.793	3.255	3.779	4.430
100 (311.0)	$(v-v_f)/10^{-2}$	−0.0005	−0.0006	−0.0009	−0.0011	−0.0007		
	$(h-h_f)$	+10	+7	+4	0	−2		
	$(s-s_f)$	0.000	−0.008	−0.013	−0.014	−0.007		
221.2 (374.15)	$(v-v_f)/10^{-2}$	−0.0011	−0.0012	−0.0020	−0.0029	−0.0051	−0.0107	0
	$(h-h_f)$	+22	+17	+9	+1	−12	−34	0
	$(s-s_f)$	+0.001	−0.017	−0.031	−0.040	−0.053	−0.071	0
500	$(v-v_f)/10^{-2}$	−0.0023	−0.0024	−0.0042	−0.0064	−0.0117	−0.0298	−0.161
	$(h-h_f)$	+49	+38	+23	+8	−21	−94	−369
	$(s-s_f)$	0.000	−0.037	−0.068	−0.091	−0.134	−0.235	−0.670
1000	$(v-v_f)/10^{-2}$	−0.0044	−0.0044	−0.0075	−0.0111	−0.0191	−0.0427	−0.180
	$(h-h_f)$	+96	+76	+51	+28	−17	−119	−415
	$(s-s_f)$	−0.007	−0.070	−0.124	−0.164	−0.235	−0.385	−0.853

* See footnote on p. 6.

Saturated Ice and Steam

T [°C]	p_s [bar]	v_i 10^{-2}[m³/kg]	v_g [m³/kg]	u_i [kJ/kg]	u_g [kJ/kg]	h_i [kJ/kg]	h_g [kJ/kg]	s_i [kJ/kg K]	s_g [kJ/kg K]
0.01	0.006112	0.1091	206.1	−333.5	2374.7	−333.5	2500.8	−1.221	9.155
−10	0.002598	0.1089	467.5	−354.2	2360.8	−354.2	2482.2	−1.298	9.481
−20	0.001038	0.1087	1125	−374.1	2346.8	−374.1	2463.6	−1.375	9.835
−30	0.0003809	0.1086	2946	−393.3	2332.9	−393.3	2445.1	−1.452	10.221
−40	0.0001288	0.1084	8354	−411.8	2319.0	−411.8	2426.6	−1.530	10.644

Isentropic Expansion of Steam—Approximate Relations

Wet equilibrium expansion:

pv^n = constant, with $n \approx 1.035 + 0.1x_1$ for steam with an initial dryness fraction $0.7 < x_1 < 1.0$

Superheated and supersaturated expansion:

pv^n = constant and $p/T^{n/(n-1)}$ = constant, with $n \approx 1.3$

$$\text{Enthalpy drop}\ \frac{(h_2-h_1)}{[\text{kJ/kg}]} = \left(\frac{h_1}{[\text{kJ/kg}]} - 1943\right)\left[\left(\frac{p_2}{p_1}\right)^{(n-1)/n} - 1\right]$$

Specific volume of supersaturated steam:

$$\frac{p}{[\text{bar}]} \times \frac{v}{[\text{m}^3/\text{kg}]} \times 10^2 = \frac{0.3}{1.3}\left(\frac{h}{[\text{kJ/kg}]} - 1943\right)$$