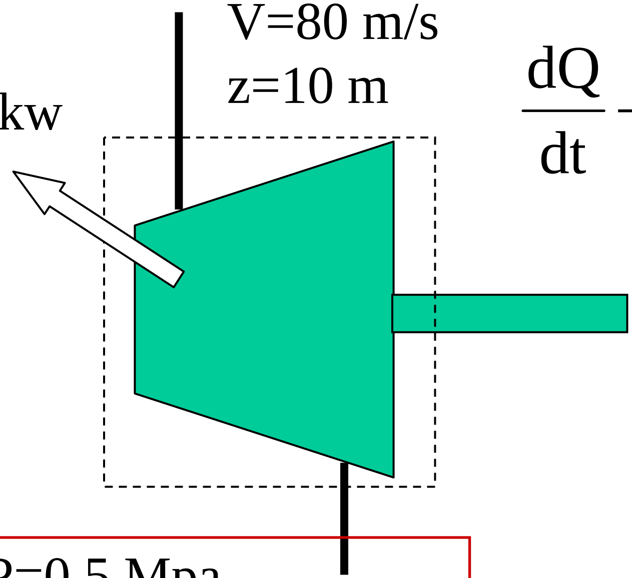
Energy Conservation(cont.)

Example: Superheated water vapor is entering the steam turbine with a mass flow rate of 1 kg/s and exhausting as saturated steamas shown. Heat loss from the turbine is 10 kW under the following operating condition. Determine the power output of the turbine.

P=1.4 Mpa
T=350° C
V=80 m/s
z=10 m

From superheated vapor table:
h_{in}=3149.5 kJ/kg

10 kw



P=0.5 Mpa
100% saturated steam
V=50 m/s
z=5 m

From saturated steam table: h_{out}=2748.7 kJ/kg

$$\frac{dQ}{dt}+\dot{m}\left(h+\frac{V^2}{2}+gz\right)_{in}=\dot{m}\left(h+\frac{V^2}{2}+gz\right)_{out}+\frac{dW}{dt}$$

$$\frac{dW}{dt}=(-10)+(1)[(3149.5-2748.7)+\frac{80^2-50^2}{2(1000)}+\frac{(9.8)(10-5)}{1000}]$$

$$=-10+400.8+1.95+0.049$$

$$=392.8(kW)$$

Appendix C

Saturated Steam

Thermodynamic Properties of Water (Steam Tables)

f-liquid phase g-vapor phase

Table C-1 Properties of Saturated H_2O—Temperature Table

		Volume, m^3/kg		Energy, kJ/kg		Enthalpy, kJ/kg			Entropy, kJ/kg · K		
T, °C	P, MPa	v_f	v_g	u_f	u_g	h_f	h_{fg}	h_g	s_f	s_{fg}	s_g
0.010	0.0006113	0.001000	206.1	0.0	2375.3	0.0	2501.3	2501.3	0.0000	9.1571	9.1571
2	0.0007056	0.001000	179.9	8.4	2378.1	8.4	2496.6	2505.0	0.0305	9.0738	9.1043
5	0.0008721	0.001000	147.1	21.0	2382.2	21.0	2489.5	2510.5	0.0761	8.9505	9.0266

- These properties are all dependent: specify one to determine all (because they are in a saturation state)
- Liquid and vapor phases coexist, the total mass of the mixture, m, is the sum of the liquid mass and the vapor mass: $m=m_f+m_g$, The ratio of the mass of vapor to the total mass is called the quality of the mixture: $x=m_g/m$

Total volume is the sum of liquid volume and vapor volume:

$V = V_f + V_g = m_f v_f + m_g v_g$, where v is the specific volume or 1/ρ.
$[V = m(1/\rho) = mv]$

$V/m = v = V_f/m + V_g/m = (m_f/m)v_f + (m_g/m)v_g$
$= [(m-m_g)/m]v_f + (m_g/m)v_g$
$= (1-x)v_f+xv_g= v_f + x(v_g-v_f) = v_f + xv_{fg}$, where $v_{fg} = v_g-v_f$

Similarly, all other saturated thermodynamic properties can be expressed in the same manner:

Ex: internal energy: $u = (1-x)u_f+xu_g= u_f + x(u_g-u_f) = u_f + xu_{fg}$

since $U = U_f + U_g = m_f u_f + m_g u_g$

Saturated Steam Table

p (Mpa) — h_f (kJ/kg) — h_{fg} (kJ/kg) — h_g (kJ/Kg)

140	0.3613	0.001080	0.5089	588.7	2550.0	589.1	2144.8	2733.9	1.7395	5.1912	6.9307
150	0.4758	0.001090	0.3928	631.7	2559.5	632.2	2114.2	2746.4	1.8422	4.9965	6.8387
160	0.6178	0.001102	0.3071	674.9	2568.4	675.5	2082.6	2758.1	1.9431	4.8079	6.7510
170	0.7916	0.001114	0.2428	718.3	2576.5	719.2	2049.5	2768.7	2.0423	4.6249	6.6672

h_g(p=0.5 Mpa) = 2746.4 + (2758.1-2746.4)/(0.6178-0.4758)*(0.5-0.4758)
=2748.4 kJ/kg for 100% quality saturated vapor

Example: If the quality is 50% and the temperature is 150° C

h_f = 632.2, h_{fg} = 2114.2, h_g = 2746.4

$h = (1-x)\, h_f + x\, h_g = (1-0.5)(632.2) + 0.5(2746.4)$

= 1689.3 (kJ/kg)

Superheated Steam

Table C-3 (*Continued*)

P, MPa (T_{sat}, °C)		Temperature °C 150	200	250	300	350	400	450	500	550	600	700	800
1	v, m³/kg		0.2060	0.2327	0.2579	0.2825	0.3066	0.3304	0.3541	0.3776	0.4011	0.4478	0.4943
(179.9)	u, kJ/kg		2621.9	2709.9	2793.2	2875.2	2957.3	3040.2	3124.3	3209.8	3296.8	3475.4	3660.5
	h, kJ/kg		2827.9	2942.6	3051.2	3157.7	3263.9	3370.7	3478.4	3587.5	3697.9	3923.1	4154.8
	s, kJ/kg · K		6.6948	6.9255	7.1237	7.3019	7.4658	7.6188	7.7630	7.8996	8.0298	8.2740	8.5005
1.5	v, m³/kg		0.1325	0.1520	0.1697	0.1866	0.2030	0.2192	0.2352	0.2510	0.2668	0.2981	0.3292
(198.3)	u kJ/kg		2598.1	2695.3	2783.1	2867.6	2951.3	3035.3	3120.3	3206.4	3293.9	3473.2	3658.7
	h, kJ/kg		2796.8	2923.2	3037.6	3147.4	3255.8	3364.1	3473.0	3582.9	3694.0	3920.3	4152.6
	s, kJ/kg · K		6.4554	6.7098	6.9187	7.1025	7.2697	7.4249	7.5706	7.7083	7.8393	8.0846	8.3118

h(p=1MPa, T=350°C)=3157.7 kJ/kg

h(p=1.5MPa, T=350°C)=3147.4 kJ/kg

h(p=1.4MPa, T=350°C)=3157.7+(3147.7-3157.7)*(0.4/0.5)
=3149.7 (kJ/kg)

Compressed Liquid

Table C-4 Compressed Liquid

	P = 5 MPa (263.99)				P = 10 MPa (311.06)			
T	v	u	h	s	v	u	h	s
0	0.000 997 7	0.04	5.04	0.0001	0.000 995 2	0.09	10.04	0.0002
20	0.000 999 5	83.65	88.65	0.2956	0.000 997 2	83.36	93.33	0.2945
40	0.001 005 6	166.95	171.97	0.5705	0.001 003 4	166.35	176.38	0.5686
60	0.001 014 9	250.23	255.30	0.8285	0.001 012 7	249.36	259.49	0.8258
80	0.001 026 8	333.72	338.85	1.0720	0.001 024 5	332.59	342.83	1.0688
100	0.001 041 0	417.52	422.72	1.3030	0.001 038 5	416.12	426.50	1.2992
120	0.001 057 6	501.80	507.09	1.5233	0.001 054 9	500.08	510.64	1.5189

- Similar to the format of the superheated vapor table
- In general, properties are not sensitive to pressure, therefore, can treat the compressed liquid as saturated liquid at the given TEMPERATURE.
- Given: P and T: $v \cong v_{f\,@T}, u \cong u_{f\,@T}, s \cong s_{f\,@T}$
- But not h, since h=u+pv, and it depends more strongly on p. It can be approximated as

$$h \cong h_{f\,@T} + v_f(p - p_{sat})$$