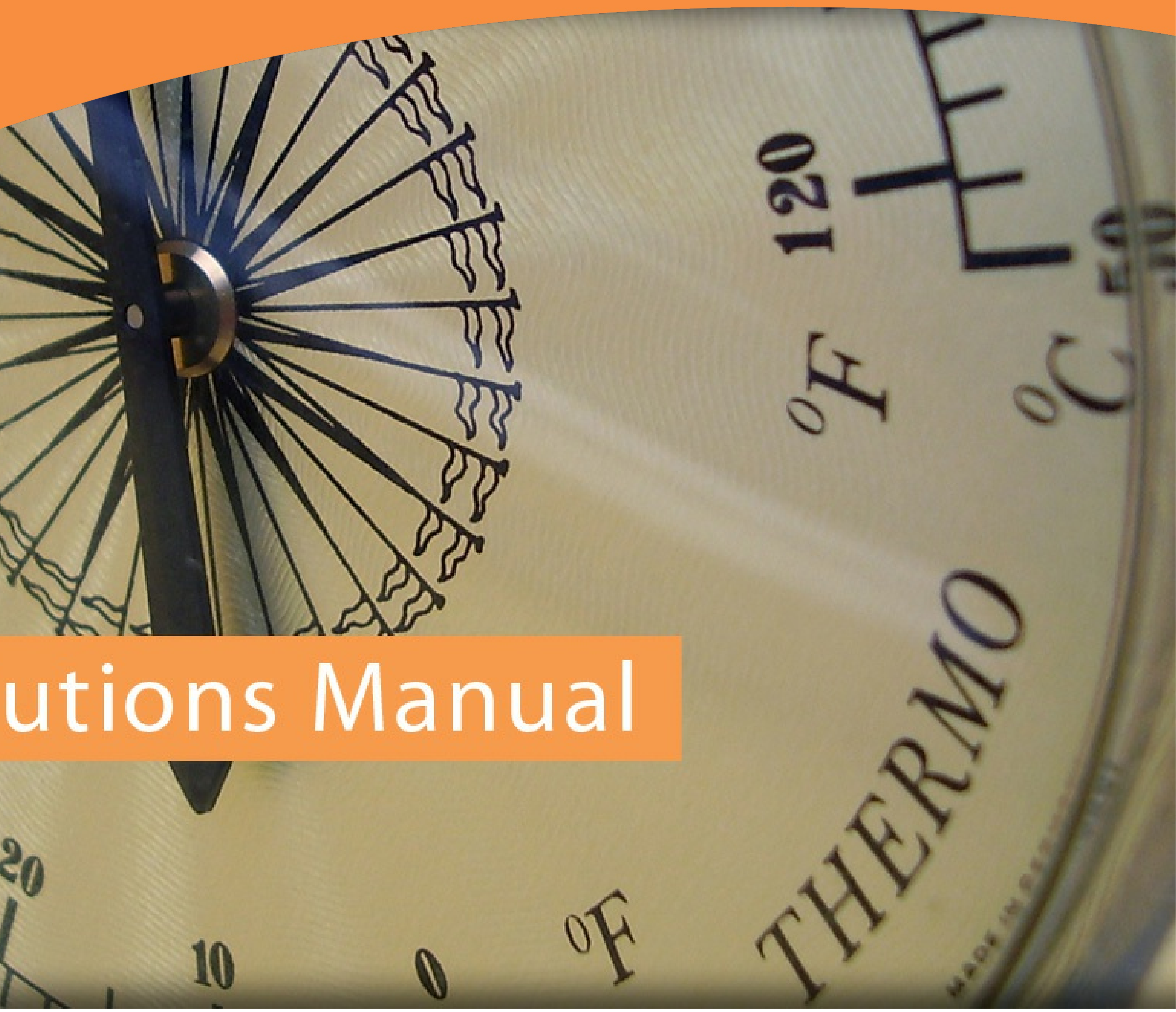
Engineering Thermodynamics Solutions Manual

Prof. T.T. Al-Shemmeri



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Foreword

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Thermodynamics is an essential subject in the study of the behaviour of gases and vapours in real engineering applications.

This book is a complimentary follow up for the book "Engineering Thermodynamics" also published on BOOKBOON, presenting the solutions to tutorial problems, to help students to check if their solutions are correct; and if not, to show how they went wrong, and change it to get the correct answers.

This solutions manual is a small book containing the full solution to all tutorial problems given in the original book which were grouped in chapter four, hence the sections of this addendum book follows the format of the textbook, and it is laid out in three sections as follows:

4.1 First Law of Thermodynamics N.F.E.E Applications

In this section there are 6 tutorial problems

4.2 First Law of Thermodynamics S.F.E.E Applications

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4.3 General Thermodynamics Systems

In this section there are 15 tutorial problems

4.1 First Law of Thermodynamics N.F.E.E Applications

1. In a non-flow process there is heat transfer loss of 1055 kJ and an internal energy increase of 210 kJ. Determine the work transfer and state whether the process is an expansion or compression.

[Ans: -1265 kJ, compression]

Solution:

Closed system for which the first law of Thermodynamics applies,

$Q - W = \Delta U$

$1055 - W = 210$

Hence the work done can be found as:

$W = -1265$ kJ

Since negative, it must be work input, ie compression.

2. In a non-flow process carried out on 5.4 kg of a substance, there was a specific internal energy decrease of 50 kJ/kg and a work transfer from the substance of 85 kJ/kg. Determine the heat transfer and state whether it is gain or loss.

[Ans: 189 kJ, gain]

Solution:

Closed system for which the first law of Thermodynamics applies,

$Q - W = \Delta U$

$$Q = \Delta U + W$$
$$= 5.4x\ (-50) + 5.4 \times 85$$
$$= +\ 189 \text{ kJ},$$

Since Q is positive, it implies heat is entering the control volume, ie Gain.

3. During the working stroke of an engine the heat transferred out of the system was 150 kJ/kg of the working substance. If the work done by the engine is 250 kJ/kg, determine the change in internal energy and state whether it is decrease or increase.

[Ans: -400 kJ/kg, decrease]

Solution:

Closed system for which the first law of Thermodynamics applies,

$Q - W = \Delta U$

Hence

$$\begin{aligned}\Delta U &= Q - W \\ &= (-150) - 250 \\ &= -400 \text{ kJ/kg}\end{aligned}$$

Since the sign is negative, there is a decrease in internal energy.

4. Steam enters a cylinder fitted with a piston at a pressure of 20 MN/m^2 and a temperature of 500 deg C. The steam expands to a pressure of 200 kN/m^2 and a temperature of 200 deg C. During the expansion there is a net heat loss from the steam through the walls of the cylinder and piston of 120 kJ/kg. Determine the displacement work done by one kg of steam during this expansion.

[Ans: 168.6 kJ/kg]

Solution:

State 1
at 20 MPa, 500 C: u = 2942.9 kJ/kg

State 2
at 200 kPa, 200C: u = 2654.4 kJ/kg

Closed system for which the first law of Thermodynamics applies,

$Q - W = \Delta U$

Rearranging to determine the work done:

$W = Q - \Delta U = (-120) - (2654.4 - 2942.9) = 168.5$ kJ/kg

5. A closed rigid system has a volume of 85 litres contains steam at 2 bar and dryness fraction of 0.9. Calculate the quantity of heat which must be removed from the system in order to reduce the pressure to 1.0 bar. Also determine the change in enthalpy and entropy per unit mass of the system.

[Ans: -38 kJ]

Solution:

Closed system for which the first law of Thermodynamics applies,

T	*p* = 0.2 MPa (120.23 C)			
	v	*u*	*h*	*s*
deg-C	m^3/kg	kJ/kg	kJ/kg	kJ/kg K
Sat. liquid	0.00106	504.5	504.7	1.5300
Sat. vapour	0.8857	2529.5	2706.7	7.1272

$Q - W = \Delta U$

For a rigid system W=0,

hence $Q = \Delta U$

At 2bar, x=0.9, the properties are:

Hence:

h = hf + x.(hg-hf) = 504.7 + 0.9 (2706.7 – 504.7) = 2486.5 kJ/kg

u = uf +x.(ug – uf) = 504.5 + 0.9 (2529.5-504.5) = 2327.0 kJ/kg

v = vf +x.(vg – vf) = 0.00106 + 0.9 (0.8857 -0.00106) = 0.797 kJ/kg

mass = volume/specific volume = 85 litres x 10^{-3} / 0.797 = 0.1066 kg

T	*p* = 0.10 MPa (99.63 C)			
	v	*u*	*h*	*s*
deg-C	m^3/kg	kJ/kg	kJ/kg	kJ/kg K
Sat. liquid	0.00104	417.3	417.4	1.3030
Sat. vapour	1.694	2506.1	2675.5	7.3594

at 1 bar

v = vf +x.(vg – vf)

x = (v-vf)/(vg-vf) = (0.797-0.00104)/(1.694-0.00104) = 0.470

h = 417.4 + 0.470 (2675.5-417.4) = 1479.06 kJ/kg

u = 417.3 + 0.470 (2506.1 – 417.3) = 1399.36 kJ/kg

Q = m (u2-u1) = 0.1066 x (2327.0 – 1399.36) = 98.9 kJ not the answer given in the text, please accept this as the correct answer.

6. 2 kg of air is heated at constant pressure of 2 bar to 500 °C. Determine the initial temperature and the change in its entropy if the initial volume is 0.8 m³.

[Ans: 2.04 kJ/kgK]

Solution:

$$T_1 = \frac{P_1 x V_1}{m x R}$$

$$= \frac{2x10^5 x0.8}{2x287}$$

$$= 278.746\ K$$

$$\Delta S = m.Cp.\ln\frac{T_2}{T_1}$$

$$= 2x1005x\ln\frac{500+273}{278.7}$$

$$= 2.05\ kJ/kgK$$

4.2 First Law of Thermodynamics S.F.E.E Applications

1. A boiler is designed to work at 14 bar and evaporate 8 kg/s of water. The inlet water to the boiler has a temperature of 40 deg C and at exit the steam is 0.95 dry. The flow velocity at inlet is 10 m/s and at exit 5 m/s and the exit is 5 m above the elevation at entrance. Determine the quantity of heat required. What is the significance of changes in kinetic and potential energy on the result?

[Ans: 20.186 MW]

Solution:

1. SFEE : $Q - W = m[(h_2 - h_1) + \frac{V_2^2 - V_1^2}{2} + g(z_2 - z_1)]$

W =0 (since constant pressure process),

ignoring Δke and ΔPe: the SFEE reduces to

$Qs = m_s (h_2 - h_1)$

State 1- h_1 is hf at T=40C, closest to this is Ts=45, h1=191.83 kJ/kg

State 2, $h=h_f+0.95h_{fg}$ at 14 bar.

h_2=830.30+0.95x1959.7 = 2692 kJ/kg

hence

Qs= $m_s (h_2 - h_1)$ = 8 x(2692 – 191.83) = 2000136 kW= 20 MW

2. Taking into account changes in KE and PE

The KE and PE contribution is calculated

$$X = m[\frac{V_2^2 - V_1^2}{2}] + g(Z_2 - Z_1)]$$

$$= 8x[\frac{5^2 - 10^2}{2000} + 9.81x(\frac{5}{1000})]$$
$$= -0.3 + 0.049$$
$$= -0.251\,kW$$

This is tiny (0.001%) in comparison to 20 MW.

2. Steam flows along a horizontal duct. At one point in the duct the pressure of the steam is 1 bar and the temperature is 400°C. At a second point, some distance from the first, the pressure is 1.5 bar and the temperature is 500°C. Assuming the flow to be frictionless and adiabatic, determine whether the flow is accelerating or decelerating.

[Ans: Decelerating]

Solution:

1. SFEE :

$$Q - W = m[(h_2 - h_1) + \frac{V_2^2 - V_1^2}{2} + g\,(z_2 - z_1)]$$

W =0 (since constant pressure process),

Q = 0 adiabatic

PE = 0 horizontal layout

Hence

$$(h_2 - h_1) = -\frac{V_2^2 - V_1^2}{2}$$

Find enthalpy values at 1 and 2:

State 1- 1.0 bar and the temperature is 400°C, hence h_1= 3263.9 kJ/kg

State 2- 1.5 bar and the temperature is 500°C, h_2 = 3473 kJ/kg

Hence $(h_2 - h_1) = 3473 - 3263.9 = 209.1$ kJ/kg

Since this is positive, then $V_1 > V_2$, ie decelerating

3. Steam is expanded isentropically in a turbine from 30 bar and 400°C to 4 bar. Calculate the work done per unit mass flow of steam. Neglect changes in Kinetic and Potential energies.

[Ans: 476 kJ/kg]

Solution:

1. SFEE : $$Q - W = m[(h_2 - h_1) + \frac{V_2^2 - V_1^2}{2} + g(z_2 - z_1)]$$

Q = 0 isentropic expansion

KE=PE = 0

Hence $W = m[(h_2 - h_1)$

State 1- 30 bar and the temperature is 400°C,

T	p = 3.00 MPa (233.90 C)			
	v	u	h	s
deg-C	m^3/kg	kJ/kg	kJ/kg	kJ/kg K
Sat. liquid	0.001216	1004.8	1008.4	2.6457
Sat. vapour	0.06668	2604.1	2804.2	6.1869
400	0.09936	2932.8	3230.9	6.9212

Hence

h_1= 3230.9 kJ/kg,

s_1= 6.9212 kJ/kgK

Expanding at constant entropy, to 4 bar,

Slightly superheated,

h_2= 2750 kJ/kg (approximately)

T	p = 0.40 MPa (143.63 C)			
	v	u	h	s
deg-C	m^3/kg	kJ/kg	kJ/kg	kJ/kg K
Sat. liquid	0.00108	604.3	604.7	1.7766
Sat.Vapour	0.4625	2553.6	2738.6	6.8959
150	0.4708	2564.5	2752.8	6.9299
200	0.5342	2646.8	2860.5	7.1706

Hence

$$W = m(h_2 - h_1)$$
$$= 1x(3230.9 - 2750)$$
$$= 480.9 \text{ kJ/kg}$$

4. A compressor takes in air at 1 bar and 20°C and discharges into a line. The average air velocity in the line at a point close to the discharge is 7 m/s and the discharge pressure is 3.5 bar. Assuming that the compression occurs isentropically, calculate the work input to the compressor. Assume that the air inlet velocity is very small.

[Ans: -126.6 kW/kg]

Solution:

$$Q - W = m[(h_2 - h_1) + \frac{V_2^2 - V_1^2}{2} + g(z_2 - z_1)]$$

Assume adiabatic condition, Q=0, and horizontally mounted, (PE=0), SFEE reduces to

$$-W = m[Cp(T_2 - T_1) + \frac{V_2^2 - V_1^2}{2}]$$

$$T_2 = T_1\left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}} = 293\left(\frac{3.5}{1}\right)^{\frac{0.4}{1.4}} = 419.1K$$

$$\frac{W}{m} = -[1005(419.1-293)+\frac{7^2-0}{2}]$$

$$= -[126728+24.5]$$

$$= -126.7\ kW/kg$$

5. Air is expanded isentropically in a nozzle from 13.8 bar and 150°C to a pressure of 6.9 bar. The inlet velocity to the nozzle is very small and the process occurs under steady-flow, steady-state conditions. Calculate the exit velocity from the nozzle knowing that the nozzle is laid in a horizontal plane and that the inlet velocity is 10 m/s.

[Ans: 390.9 m/s]

Solution:

The situation is an open system for which the SFEE applies:

$$Q - W = m\left[C_p(T_2 - T_1) + \frac{V^2{}_2 - V^2{}_1}{2} + g(Z_2 - Z_1)\right]$$

Q = 0 adiabatic

$g(Z_2 - Z_1) = 0$ (Assumed)

And W=0 no moving parts

Hence SFEE reduces to $0 = m\left[C_p(T_2 - T_1) + \frac{V^2{}_2 - V^2{}_1}{2000}\right]$

$$T_2 = T_1\left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}} = (273 + 150)x\left(\frac{6.9}{13.8}\right)^{\frac{0.4}{1.4}} = 347K$$

The SFEE can now be used to determine the mass flow rate

$$0 = m\left[1.005(347 - 423) + \frac{V_2{}^2 - 10^2}{2000}\right]$$

$$m = 1$$

$$hence$$

$$V_2 = \sqrt{100 + 2000x1.005x76} = 390\ m/s$$

4.3 General Thermodynamics Systems

1. A rotary air compressor takes in air (which may be treated as a perfect gas) at a pressure of 1 bar and a temperature of 20°C and compresses it adiabatically to a pressure of 6 bar. The isentropic efficiency of the processes is 0.85 and changes in kinetic and potential energy may be neglected. Calculate the specific entropy change of the air. Take R = 0.287 kJ/kg K and C_p = 1.006 kJ/kg K.

[Ans: 0.07 kJ/kg K]

Solution:

Closed system for which the first law of Thermodynamics applies,

$dQ - dW = \Delta U$

$dQ = T.dS$; $dW= -pdV$; $Cv = du/dT$,

Hence

$Tds - pdV = Cv.dT$

$dS = (P/T)dV + Cv(dT/T)$

integrating

$(S_2-S_1)=R \ln(V_2/V_1) +Cv \ln(T_2/T_1)$

For isentropic process

$V_2/V_1=(P_1/P_2)^{\wedge}1/n$

$T_2/T_1=(P_2/P_1)^{\wedge}(n-1)/n$

Hence

$S_2-S_1 = R \ln(P_1/P_2)^{\wedge}1/n +Cv \ln(T_2/T_1)$

T2s = T2 (P2/P1)^(1-n)/n =488.5 K

T2 = T1 + (T2s-T1)/effc = 293+ (488.5-293)/0.85 = 523 K

$S_2-S_1 = R \ln(P_1/P_2)^{\wedge}1/n +Cv \ln(T_2/T_1)$

S_2-S_1 =0.287xln(1/6)^(1/1.4) + (1.006-0.287) ln(523/293)

= -0.3673 + 0.4166

= 0.05 kJ/kgK

Very small quantity, note that if the process is 100% isentropic, the change in entropy would be zero.

2. An air receiver has a capacity of 0.86m^3 and contains air at a temperature of 15°C and a pressure of 275 kN/m^2. An additional mass of 1.7 kg is pumped into the receiver. It is then left until the temperature becomes 15°C once again. Determine,

a) the new pressure of the air in the receiver, and
b) the specific enthalpy of the air at 15°C if it is assumed that the specific enthalpy of the air is zero at 0°C.
Take C_p = 1.005 kJ/kg, C_v = 0.715 kJ/kg K

[Ans: 442 kN/m^2, 15.075 kJ/kg]

Solution:

$$m_1 = \frac{PV}{RT}$$
$$= \frac{275x10^3 \text{ x } 0.86}{(2005\text{-}715)\text{x } 288}$$
$$= 2.8316\ kg$$

added

$$dm = 1.7\ kg$$

hence

$$m_2 = m_1 + dm = 2.8316 + 1.7 = 4.5316\ kg$$

a)

$$P_2 = \frac{mRT_2}{V}$$
$$= \frac{4.5316\text{x } (2005\text{-}715)\text{x } 288}{0.86}$$
$$= 440\ kPa$$

b) h =Cp.dT = 1005 x(288-273) = 15.075 kJ/kg.

3. Oxygen has a molecular weight of 32 and a specific heat at constant pressure = 0.91 kJ/kg K.

a) Determine the ratio of the specific heats.
b) Calculate the change in internal energy and enthalpy if the gas is heated from 300 to 400 K.

[Ans: 1.4, 65 kJ/kg, 91 kJ/kg]

Solution:

a) $R = \frac{\text{Ro}}{\text{M}} = \frac{8314.3}{32} = 0.2598\ kJ/kgK$

Cv = Cp – R = 0.91 – 0.2598 = 0.65 kJ/kgK

n = Cp/Cv = 0.91 /0.65 = 1.3996

b) du = Cv (T2-T1) = 0.65 (400 – 300) = 65 kJ/kg

dh = Cp (T2-T1) = 0.91 (400 – 300) = 91 kJ/kg

4. A steam turbine inlet state is given by 6 MPa and 500°C. The outlet pressure is 10 kPa. Determine the work output per unit mass if the process:-

a) is reversible and adiabatic (ie 100% isentropic),
b) such that the outlet condition is just dry saturated,
c) such that the outlet condition is 90% dry.

[Ans: 1242.7 kJ/kg, 837.5 kJ/kg, 1076.8 kJ/kg]

Solution:

a) when 100% isentropic
h_1 = 3422.2 kJ/kg, S_1=6.8803 kJ/kgK
$S_{2'} = s_1$ and $x_{2'}$ is found using

Then 6.8803 = 0.6493 + $x_{2'}$(7.5009), from which $x_{2'}$ = 0.8307

Thus $h_2 = h_f + x\,h_{fg}$ = 191.83 + 0.8307 x 2392.87 = 2179.6 kJ/kg

Hence
W = $h_1 - h_2$ = 3422.2 – 2179.6 = 1242.6 kJ/kg

b) if x=1,
h_2 = 2584.7 kJ/kg
W = $h_1 - h_2$ = 3422.2 – 2584.7= 837.5 kJ/kg

c) if x=0.9
$h_2 = h_f + x\,h_{fg}$ = 191.83 + 0.9 x 2392.87 = 2345.4 kJ/kg

Hence
W = $h_1 - h_2$ = 3422.2 – 2345.4 = 1076.8 kJ/kg

5. Determine the volume for carbon dioxide contained inside a cylinder at 0.2 MPa, 27°C:-

a) assuming it behaves as an ideal gas
b) taking into account the pressure and volume associated with its molecules

[Ans: 0.2833m³/kg]

Substance	Chemical Formula	Molar Mass M (kg/kmol)	Gas constant R (J/kgK)	Critical Temp TC (K)	Critical Pressure PC (MPa)	Van der Waals Constants	
						a	b
Carbon Dioxide	CO_2	44.01	188.918	304.20	7.386	188.643	0.00097

Solution:

a) Assuming perfect gas behaviour:

$$R = \frac{\text{Ro}}{\text{M}} = \frac{8314.3}{44} = 188.96$$

$$V = \frac{mRT}{P}$$

$$= \frac{1x188.96x300}{0.2x10^6}$$

$$= 0.2834\ m^3/kg$$

b) using Van Der Vaal's equation

$$P = \frac{RT}{v-b} - \frac{a}{v^2}$$

$$0.2x10^6 = \frac{1889.96x300}{v-0.00097} - \frac{188.643}{v^2}$$

solve

$$V = 0.2833\ m^3/kg$$

6. A cylindrical storage tank having an internal volume of 0.465 m^3 contains methane at 20°C with a pressure of 137 bar. If the tank outlet valve is opened until the pressure in the cylinder is halved, determine the mass of gas which escapes from the tank assuming the tank temperature remains constant.

[Ans: 20.972 kg]

Solution:

$$R = \frac{Ro}{M} = \frac{8314.3}{16} = 519.644\ J/kgK$$

$$m_1 = \frac{PV}{RT}$$

$$= \frac{137x10^5 \text{ x } 0.465}{519.644 \text{x} 293}$$

$$= 41.841\ kg$$

$$P_2 = 0.5P_1$$

hence

$$m_2 = 0.5m_1 = 20.920\ kg$$

so

$$dm = 20.920\ kg$$

7. Find the specific volume for H_20 at 1000 kN/m^2 and 300°C by using:-

a) the ideal gas equation assuming R = 461.5 J/kg K
b) steam tables

[Ans: 0.264m^3/kg, 0.258 m^3/kg]

Solution:

a) for a perfect gas

$$v = \frac{RT}{P}$$
$$= \frac{461.5x573}{1x10^6}$$

$$= 0.2644\ m^3/kg$$

b) using the steam Tables

V=0.2579 m^3/kg

The difference = 2.4% under-estimation if assumed ideal gas.

8. Determine the specific volume of steam at 6 MPa using the steam tables for the following conditions:-

a) dryness fraction x = 0
b) dryness fraction x = 0.5
c) dryness fraction x = 1
d) its temperature is 600°C

[Ans: 0.001319, 0.01688, 0.03244, 0.06525 m³/kg]

T	p = 6.0 Mpa (257.64 deg-C)			
	v	*u*	*h*	*s*
deg-C	m^3/kg	kJ/kg	kJ/kg	kJ/kg K
Sat. liquid	0.00132	1205.4	1213.3	3.0267
Sat. vapour	0.03244	2589.7	2784.3	5.8892
300	0.03616	2667.2	2884.2	6.0674
350	0.04223	2789.6	3043.0	6.3335
400	0.04739	2892.9	3177.2	6.5408
450	0.05214	2988.9	3301.8	6.7193
500	0.05665	3082.2	3422.2	6.8803
550	0.06101	3174.6	3540.6	7.0288
600	0.06525	3266.9	3658.4	7.1677
700	0.07352	3453.1	3894.2	7.4234
800	0.0816	3643.1	4132.7	7.6566
900	0.08958	3837.8	4375.3	7.8727
1000	0.09749	4037.8	4622.7	8.0751
1100	0.10536	4243.3	4875.4	8.2661
1200	0.11321	4454.0	5133.3	8.4474
1300	0.12106	4669.6	5396.0	8.6199

Solution:

a) v=vf=0.001319 m³/kg
b) v=vf+X(vg-vf) =0.00132+0.5(0.03244-0.00132)
 = 0.01688 m³/kg
c) v=vg = 0.03244 m³/kg
d) v = 0.06525 m³/kg

9. Steam at 4 MPa, 400°C expands at constant entropy till its pressure is 0.1 MPa. Determine:

a) the energy liberated per kg of steam
b) repeat if the process is 80% isentropic

[Ans: 758 kJ/kg, 606 kJ/kg]

T	p = 4.0 MPa (250.4 deg C)			
	v	*u*	*h*	*s*
deg-C	m^3/kg	kJ/kg	kJ/kg	kJ/kg K
Sat. liquid	0.00125	1082.3	1087.3	2.7964
Sat. vapour	0.04978	2602.3	2801.4	6.0701
275	0.05457	2667.9	2886.2	6.2285
300	0.05884	2725.3	2960.7	6.3615
350	0.06645	2826.7	3092.5	6.5821
400	0.07341	2919.9	3213.6	6.7690

T	*p* = 0.10 MPa (99.63 C)			
	v	*u*	*h*	*s*
deg-C	m^3/kg	kJ/kg	kJ/kg	kJ/kg K
Sat. liquid	0.00104	417.3	417.4	1.3030
Sat. vapour	1.694	2506.1	2675.5	7.3594

Solution:

a) h_1 = 3213.6 kJ/kg, S1=6.769 kJ/kgK

$$X_2 = \frac{S_1 - S_f}{S_g - S_f} = \frac{6.7690 - 1.303}{7.3594 - 1.303} = 0.9024$$

$$h_2 = h_f + X_2(h_g - h_f) = 417.4 + 0.9024(2675.5 - 417.4) = 2455.4\ kJ/kg$$

$W = h_1 - h_2 = 3213.6 - 2455.4 = 758.2$ kJ/kg

b) if efficiency = 80%

$W = 0.8(h_1 - h_2)$
$= 0.8(3213.6 - 2455.39)$
$= 606.6$ kJ/kg

10. a) Steam (1 kg) at 1.4 MPa is contained in a rigid vessel of volume 0.16350 m^3. Determine its temperature.

b) If the vessel is cooled, at what temperature will the steam be just dry saturated?

c) If cooling is continued until the pressure in the vessel is 0.8 MPa; calculate the final dryness fraction of the steam, and the heat rejected between the initial and the final states.

[Ans: 250°C, 188°C, 0.678; 8181 kJ]

Solution:

a) at 1.4 MPa and v =0.16350 m^3/kg, from steam tables, it can be verified that the condition of the fluid is superheated, at 250 C.

h_1 =2927.2 kJ/kg

T	***p* = 1.40 MPa (195.07*C)**			
	v	*u*	*h*	*s*
deg-C	m^3/kg	kJ/kg	kJ/kg	kJ/kg K
Sat. liquid	0.00115	828.7	830.3	2.2842
Sat. Vapour	0.14084	2592.8	2790.0	6.4693
200	0.14302	2603.1	2803.3	6.4975
250	0.16350	2698.3	2927.2	6.7467
300	0.18228	2785.2	3040.4	6.9534

b) now if the vessel is cooled, at constant volume, till x=1, then the temperature is equal to the saturation value at a new pressure of 1.2 MPa, T=Ts=187.99C

T	*p* = 1.20 MPa (187.99 C)			
	v	*u*	*h*	*s*
deg-C	m^3/kg	kJ/kg	kJ/kg	kJ/kg K
Sat. liquid	0.00114	797.3	798.6	2.2166
Sat. vapour	0.16333	2588.8	2784.4	6.5233

c) further cooling, to a reduced pressure of 0.8MPa, the fluid is in the wet region, as v lies between vf and vg at this pressure.

T	*p* = 0.80 MPa (170.43 C)			
	v	*u*	*h*	*s*
deg-C	m^3/kg	kJ/kg	kJ/kg	kJ/kg K
Sat. liquid	0.00111	720.2	721.1	2.0462
Sat. vapour	0.2404	2576.8	2769.1	6.6628

Then $0.16333 = 0.00111 + x_{2'}(0.2404-0.00111)$,

from which $x_{2'} = 0.678$

$h_2 = h_f + x\,h_{fg}$
$= 721.1+0.678x(2769.1-721.1)$
$=2109.5$ kJ/kg

$h_1=2927.2$ kJ/kg

Q =m (h1-h2) = 1x(2927.2-2109.5) = 818 kJ

11. Steam (0.05 kg) initially saturated liquid, is heated at constant pressure of 0.2 MPa until its volume becomes 0.0658 m^3. Calculate the heat supplied during the process.

[Ans: 128.355 kJ]

Solution:

T	*p* = 0.2 MPa (120.23 C)			
	v	*u*	*h*	*s*
deg-C	m^3/kg	kJ/kg	kJ/kg	kJ/kg K
Sat. liquid	0.00106	504.5	504.7	1.5300
Sat. vapour	0.8857	2529.5	2706.7	7.1272
150	0.9596	2576.9	2768.8	7.2795
200	1.0803	2654.4	2870.5	7.5066
250	1.1988	2731.2	2971.0	7.7086
300	1.3162	2808.6	3071.8	7.8926
400	1.5493	2966.7	3276.6	8.2218

at 0.2 MPa and x=0,

h_1= 504.70 kJ/kg

v_2 = 0.0658 / 0.05 = 1.316 m^3/kg,

P_2 =0.2 MPa,
h_2 = 3071.48 kJ/kg

hence the heat supplied during the process 1-2 is calculated as follows:

$Q = m\ (h_1 - h_2)$
$= 0.05x(3071.80 - 504.70)$
$= 128.355$ kJ

12. Steam at 0.6 MPa and dryness fraction of 0.9 expands in a cylinder behind a piston isentropically to a pressure of 0.1 MPa. Calculate the changes in volume, enthalpy and temperature during the process.

[Ans: 1.1075 m^3, -276 kJ/kg, -59°C]

Solution:

T	*p* = 0.60 MPa (158.85 C)			
	v	*u*	*h*	*s*
deg-C	m^3/kg	kJ/kg	kJ/kg	kJ/kg K
Sat. liquid	0.00110	669.4	670.6	1.9312
Sat. vapour	0.3175	2567.4	2756.8	6.7600

at 0.6 MPa and x=0.9,

T=158.85 C

$h_1 = h_f + x\ h_{fg}$

$= 670.6+0.9x(2756.8-670.6)$

$=2548.18$ kJ/kg

$V_1 = V_f + x\, V_{fg}$
$= 0.0011+0.9x(0.3715-0.0011)$
$= 0.28424\ m^3/kg$

$S_1 = S_f + x\, S_{fg}$
$= 1.9312+0.9x(6.7600-1.9312)$
$= 6.2771$ kJ/kgK

T	*p* = 0.10 MPa (99.63 C)			
	v	*u*	*h*	*s*
deg-C	m^3/kg	kJ/kg	kJ/kg	kJ/kg K
Sat. liquid	0.00104	417.3	417.4	1.3030
Sat. vapour	1.694	2506.1	2675.5	7.3594

at 0.1 MPa, constant entropy,
$S_2=S_1=6.2771$ kJ/kgK
T=99.63 C

$$X_2 = \frac{S_1 - S_f}{S_g - S_f} = \frac{6.2771 - 1.303}{7.3594 - 1.303} = 0.821$$

$$h_2 = h_f + X_2(h_g - h_f) = 417.4 + 0.821(2675.5 - 417.4) = 2272.2\ kJ/kg$$

$$v_2 = v_f + X_2(v_g - v_f) = 0.00104 + 0.821(1.694 - 0.00104) = 1.3909\ m^3/kg$$

hence

dT = 158.85 – 99.63 = 59.22 C

dv = 1.3909- 0.28424 = 1.107 m^3/kg

dh = 2548.18 – 2272.2 = 276.0 kJkg

13. The pressure in a steam main pipe is 1.2 MPa; a sample is drawn off and throttled where its pressure and temperature become 0.1 MPa, 140°C respectively. Determine the dryness fraction of the steam in the main stating reasonable assumptions made!

[Ans: 0.986, assuming constant enthalpy]

Solution:

state 2, at 0.1 MPa and T=140C

h_2= 2756.36 kJ/kg
S_2=7.5630 kJ/kgK

T	*p* = 0.10 MPa (99.63 C)			
	v	*u*	*h*	*s*
deg-C	m^3/kg	kJ/kg	kJ/kg	kJ/kg K
Sat. liquid	0.00104	417.3	417.4	1.3030
Sat. vapour	1.694	2506.1	2675.5	7.3594
100	1.6958	2506.7	2676.2	7.3614
150	1.9364	2582.8	2776.4	7.6143

at 1.2 MPa, constant enthalpy, h_1=h_2= 2756.36 kJ/kg

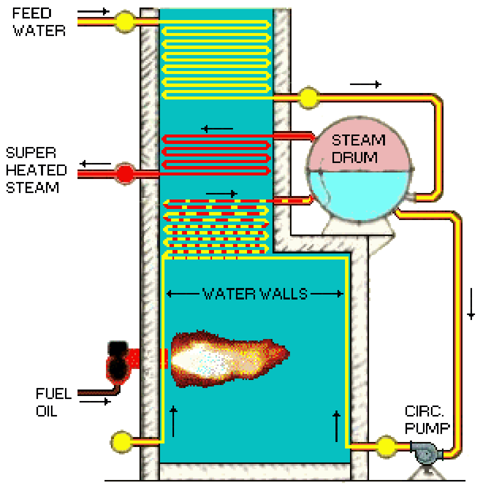
T	*p* = 1.20 MPa (187.99 C)			
	v	*u*	*h*	*s*
deg-C	m^3/kg	kJ/kg	kJ/kg	kJ/kg K
Sat. liquid	0.00114	797.3	798.6	2.2166
Sat. vapour	0.16333	2588.8	2784.4	6.5233

$$X_1 = \frac{h_1 - h_f}{h_g - h_f} = \frac{2756.36 - 798.6}{2784.4 - 798.6} = 0.9858$$

14. A boiler receives feed water at 20 kPa as saturated liquid and delivers steam at 2 MPa and 500°C. If the furnace of this boiler is oil fired, the calorific value of oil being 42000 kJ/kg; determine the efficiency of the combustion when 4.2 tonnes of oil was required to process 42000 kg of steam.

[Ans: 76%]

Solution:



a) Constant pressure process.

$h_1 = h_{f@20}$ kPa = 251.40 kJ/kg

h_2 = 3467.6 kJ/kg

SFEE ignoring W, Δke and ΔPe:

$Qs \quad = m_s (h_2 - h_1) \quad = 42000\,(3467.6 - 251.4) \qquad = 135 \times 10^6$ kJ

b) The heat generated by burning oil in the furnace is

= mass of oil burned x calorific value

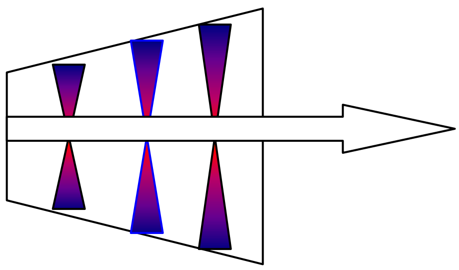
= 4200 x 42000 = 176 x 10^6 kJ

$$\therefore\ Efficiency = \frac{\text{Energy Output}}{\text{Energy Input}} = \frac{135}{176} = 76.7\%$$

15. 10 kg/s steam at 6 MPa and 500°C expands isentropically in a turbine to a pressure of 100 kPa. If the heat transfer from the casing to surroundings represents 1 per cent of the overall change of enthalpy of the steam, calculate the power output of the turbine. Assume exit is 5 m above entry and that initial velocity of steam is 100 m/s whereas exit velocity is 10 m/s.

[Ans: 9 MW]

Solution:



At 6 MPa, 500 °C

h_1 = 3422.2 kJ/kg

s_1 = 6.8803 kJ/kgK

at 100 kPa,

s_f = 1.303, s_{fg} = 6.056 kJ/kgK

h_f = 417, h_{fg} = 2258 kJ/kg

$x_2 = x_2 = \dfrac{6.8803 - 1.303}{6.056} = 0.921$

h_2 = 417 + 0.921 x 2258 = 2496.5 kJ/kg

The Steady Flow Energy Equation applies to this situation:

$$Q - W = m[(h_2 - h_1) + \frac{V_2^2 - V_1^2}{2} + g\,(z_2 - z_1)]$$

but $Q = -\dfrac{m}{100}(h_2 - h_1)$ Heat loss (negative sign)

$$W = -m[\,1.01\,(h_2 - h_1) + \frac{V_2^2 - V_1^2}{2} + g\,(z_2 - z_1)]$$

$$W = 10x\left[1.01(3422.2 - 2496.5) + \frac{10^2 - 100^2}{2\text{ x }1000} + \frac{9.8\text{ x }5}{1000}\right] = 9\ MW$$