Technological University (Toungoo)

ME-1013
Basic Engineering Thermodynamic
Sample Questions
1. During a test on a four-stroke cycle oil engine the following data and results were obtained:

- Mean height of indicator diagram 21mm
- Indicator spring number, 27 kN/m$^2$/mm
- Swept volume of cylinder, 14 litres
- Speed of engine, 6.6 rev/sec
- Effective brake load, 77kg
- Effective brake radius, 0.7m
- Fuel consumption, 0.002kg/s
- Calorific value of fuel, 44000 kJ/kg
- Cooling water circulating, 0.15 kg/s
- Cooling water inlet temperature, 38°C
- Cooling water outlet temperature, 71°C
- Specific heat capacity of water, 4.18 kJ/kg
- Energy to exhaust gases, 33.6 kJ/s

Determine the indicated and brake outputs and the mechanical efficiency. Draw up an overall energy balance in kJ/s and as a percentage. (20 marks)

Solution,

Mean height of indicator diagram 21mm
Indicator spring number, 27 kN/m$^2$/mm

\[ V_{st} = 14 \text{ litres} = 14 \times 10^{-3} \text{ m}^3/\text{s} \]

\[ N = 6.6 \text{ rev/s} \]

\[ m = 77 \text{ kg} \]

\[ F = 77 \times 9.81 \text{ N} = 0.7 \text{ m} \]

\[ m^o_r = 0.002 \text{ kg/s} \]

\[ CV = 44000 \text{ kJ/kg} \]

\[ m_w = 0.15 \text{ kg/s} \]

\[ T_1 = 38^\circ \text{C} \]

\[ T_2 = 71^\circ \text{C} \]

\[ c_{pw} = 4.18 \text{ kJ/kg} \]

\[ Q_{ex} = 33.6 \text{ kJ/s} \]

\[ ip=? \quad bp=? \quad \eta_{mech}=? \]

Indicated mean effective pressure
Pm = mean height of diagram × indicator spring number
   = 21 × 27
   = 567 kN/m²
Indicated power \( ip = Pm \times LANn \)
   = 567 × 14 × 10³ × 3.3 × 1
   = 26.19 kW
Brake power \( bp = \frac{2 \times \pi \times N \times T}{\pi} \)
   = 2 × π × 6.6 × 77 × 9.81 × 0.7
   = 21927.12 Watt
   = 21.927 kW
Mechanical efficiency = \( \frac{bp}{ip} \) × 100%
   = \( \frac{21.927}{26.19} \) × 100%
   = 83.72% = 83.72%

Energy balance
Energy from fuel, \( Q_f \) = \( m_r \times CV \)
   = 0.002 × 44000 = 88 kJ/s
Energy to brake power = 21.927 kW = 21.927 kJ/s
Energy to coolant = \( m_w \times C_{pw} \times (\Delta T) \)
   = 0.15 × 4.18 × (71 - 38)
   = 20.69 kJ/s
Energy to exhaust = 33.6 kJ/s
Energy lost to surroundings = Energy from fuel - (Energy to bp + Energy to bp
   + Energy to coolant + Energy to exhaust)
   = 88 - (21.927 + 20.69 + 33.6)
   = 11.78 kJ/s

<table>
<thead>
<tr>
<th>Energy balance</th>
<th>kJ/s</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy from fuel</td>
<td>88</td>
<td>100</td>
</tr>
<tr>
<td>Energy to brake power</td>
<td>21.927</td>
<td>24.92</td>
</tr>
<tr>
<td>Energy to coolant</td>
<td>20.69</td>
<td>23.5</td>
</tr>
<tr>
<td>Energy to exhaust</td>
<td>33.6</td>
<td>39.2</td>
</tr>
<tr>
<td>Energy to surroundings</td>
<td>11.78</td>
<td>13.3</td>
</tr>
</tbody>
</table>
2. The diameter and stroke of single cylinder gas engine, working on the constant volume cycle, are 200mm and 300mm, respectively, and the clearance volume is 2.78 litres.

When running at 300 rev/min, the number of firing cycle/min was 135, the indicated mean effective pressure was 518 kN/m² and the gas consumption 8.8 m³/hr. Calorific value of the gas used = 16350 kJ/m³.

Determine
(a) the air standard efficiency;
(b) the indicated power developed by the engine;
(c) the indicated thermal efficiency of the engine;

Assume $\gamma = 1.4$ (20 marks)

Solution

$D = 200 \text{ mm} = 200 \times 10^{-3} \text{ m}$

$L = 300 \text{ mm} = 300 \times 10^{-3} \text{ m}$

$V_{cl} = 2.78 \text{ L} = 2.78 \times 10^{-3} \text{ m}^3$

$N = 135 \text{ rpm}$

$m^2_r = \frac{8.8}{3600} \text{ m}^3/\text{s}$

$\text{imep} = 518 \text{ kN/m}^2$

$CV = 16350 \text{ kJ/m}^3$

$ip = ?$

$\eta_{air} = ?$

$\eta_{th} = ?$

(a) Stroke volume, $V_{st} = \frac{\pi}{4}d^2 \times L$

$$= \frac{\pi}{4}(200 \times 10^{-3})^2 \times (300 \times 10^{-3})$$

$$= 9.242 \times 10^{-3} \text{ m}^3/\text{s}$$

$$= 9.421 \text{ L}$$

$V_1 = V_{st} + V_{cl}$

$$= 9.42 + 2.78$$

$$= 12.2 \text{ L}$$

$V_2 = V_{cl} = 2.78 \text{ L}$

$$r = \frac{V_1}{V_2} = \frac{12.2}{2.78} = 4.3$$
\[ \eta_{\text{air}} = 1 - \frac{1}{r^{1.41}} \]
\[ = 1 - \frac{1}{(4.3)^{1.41}} \]
\[ = 0.442 \times 100\% \]
\[ = 44.2\% \]

(b) indicated power \( ip = P_m \times \text{LAN} \times n \)

\[ = 518 \times 300 \times 10^{-3} \times \frac{\pi}{4} \left( 200 \times 10^{-3} \right)^2 \times \frac{135}{60} \times 1 \]
\[ = 11 \text{ kW} \]

(c) \[ \eta_{\text{ih}} = \frac{ip}{m_0 \times CV} = \frac{11}{\frac{8.8}{3600} \times 16350} = 0.275 \times 100\% = 27.5\% \]

3. During a trial on a six cylinder petrol engine, a Morse test was carried out to estimate the indicated power of the engine. When running at full load, all cylinders in, the brake power output was 52 kW. The measured brake power outputs, in kW, were as follows:

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>40.5</td>
<td>40.2</td>
<td>40.1</td>
<td>40.6</td>
<td>40.7</td>
<td>40.0</td>
</tr>
</tbody>
</table>

For this data, estimate

(a) the indicated power of the engine;

(b) the mechanical efficiency of the engine.

(20 marks)

Solution

(a) \( ip \) cylinder 1 = 52 - 40.5 = 11.5

ip cylinder 2 = 52 - 40.2 = 11.8

ip cylinder 3 = 52 - 40.1 = 11.9

ip cylinder 4 = 52 - 40.7 = 11.3

ip cylinder 6 = 52 - 40.0 = 12.0

Total ip = 69.9 kW
(b) Mechanical efficiency = \( \frac{bp}{ip} \)

\[ \frac{52}{69.9} = 0.744 \times 100\% = 74.4\% \]

4. In a test on a single-cylinder oil engine operating on the four-stage cycle and fitted with a simple rope brake, the following readings were taken:

- Brake wheel diameter: 600 mm
- Rope diameter: 25.4 mm
- Speed: 50 rpm
- Dead weight on rope: 20 kg
- Spring balance reading: 3.25 kg
- Area of indicator diagram: 410 mm\(^2\)
- Length of indicator diagram: 64 mm
- Spring constant: 100 kN/m\(^2\)/mm
- Bore: 120 mm
- Stroke: 150 mm
- Brake specific fuel consumption: 0.30 kg/kW-hr of oil CV = 41700 kJ/kg.

Calculate the bp, ip, mechanical efficiency and indicated thermal efficiency of the engine. (20 marks)

Solution,

Four stage cycle,

\( n = 1, \)

\( D_w = 600\text{ mm} = 600 \times 10^{-3} \text{ mm} \)

\( d = 25.4\text{ mm} = 25.4 \times 10^{-3} \text{ mm} \)

\( N = 450\text{ rpm}, \)

\( M = 20\text{ kg} \)

Spring balance reading, \( m_s = 3.25 \text{ kg} \),

Area of indicator diagram = 410 mm\(^2\),

Length of indicator diagram = 64 mm

Spring constant = 100 kN/m\(^2\)/mm,

bore \( D = 120 \text{ mm} = 120 \times 10^{-3} \text{ m} \)

stroke \( L = 150 \text{ mm} = 150 \times 10^{-3} \text{ m} \)

b.s. f.c. = 0.30 kg/kW-hr,
CV = 41700kJ/kg

\[ \text{bp} = ?, \quad \text{ip} = ?, \quad \eta_{\text{mech}} = ?, \quad \eta_{\text{th}} = ? \]

\[ \text{bp} = \frac{2\pi NT}{60} \]

\[ T = F \times r \]

\[ F = (M - m_s) \times 9.81 = (20 - 3.25) \times 9.81 = 164.3175 \text{N} \]

\[ R = \frac{D + d}{2} = \frac{600 + 25.4}{2} = 312.7 \text{mm} = 0.3127 \text{m} \]

\[ T = F \times r \]

\[ = 164.3175 \times 0.3127 \text{m} = 51.382 \text{Nm} \]

\[ \therefore \text{bp} = \frac{2\pi \times 450 \times 51.382}{60} = 2421.3 \text{W} = 2.42 \text{kW} \]

\[ \text{ip} = P_m \times \text{LAN} \times \text{n} \]

\[ P_m = \frac{\text{Area of Indicator}}{\text{Length of Indicator}} \times \text{Sprig Calibration} \]

\[ = \frac{410}{64} \times 100 \]

\[ = 640.625 \text{kN/m}^2 \]

\[ A = \frac{\pi}{4} (D)^2 = \frac{\pi}{4} \left(120 \times 10^{-3}\right)^2 = 0.0113 \text{m}^2 \]

\[ \text{ip} = P_m \times \text{LAN} \times \text{n} \]

\[ = 640.625 \times 150 \times 10^{-3} \times 0.0113 \times \frac{450}{60 \times 2} \times 1 = 4.07 \text{kW} \]

\[ \eta_{\text{mech}} = \frac{\text{bp} \times 2.24}{\text{ip} \times 4.07} = 0.594 \times 100\% = 59.4\% \]

\[ \text{m}^o\text{f} = \text{b.s.f.c} \times \text{bp} = 0.3 \times \frac{2.42}{3600} = 2.0167 \times 10^{-4} \text{kg/s} \]

\[ \eta_{\text{th}} = \frac{\text{ip}}{\text{m}^o\text{f} \times \text{CV}} = \frac{4.07}{2.016 \times 10^{-4} \times 41700} \]

\[ = 0.483 \times 100\% = 48.3\% \]

5. During a trial on a four-cylinder, compression ignition oil engine, a Morse test was carried out in order to estimate the indicated power of the engine. At full load; with all
cylinders working, the engine developed a brake power of 45 kW. The measured brake power outputs, when each cylinder was cut in turn and the load reduced to bring the engine back to the original speed, were, as follows:

<table>
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<th>3</th>
<th>4</th>
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</thead>
<tbody>
<tr>
<td>kW</td>
<td>31</td>
<td>32</td>
<td>31.8</td>
<td>31.2</td>
</tr>
</tbody>
</table>

Form this data, estimate:
(a) the indicated power of the engine;
(b) the mechanical efficiency of the engine;

Solution

bp = b = 45 kW

\[ b_1 = 31 \text{ kW} \]
\[ b_2 = 32 \text{ kW} \]
\[ b_3 = 31.8 \text{ kW} \]
\[ b_4 = 31.2 \text{ kW} \]

\[ (a) \; i_{ip} = ? \quad (b) \; \eta_{mech} = ? \]

\[ (a) \; i_1 = b - b_1 = 54 - 31 = 14 \text{ kW} \]
\[ i_2 = b - b_2 = 45 - 32 = 13 \text{ kW} \]
\[ i_3 = b - b_3 = 45 - 31.8 = 13.2 \text{ kW} \]
\[ i_4 = b - b_4 = 45 - 31.2 = 13.8 \text{ kW} \]

\[ \text{total } i_{ip} = 54 \text{ kW} \]

\[ (b) \; \eta_{mech} = \frac{bp}{ip} = \frac{45}{54} = 0.83 \times 100\% = 83.3\% \]

6. During a test on a four-stroke, single cylinder gas engine, the following observations were made:

- Calorific Value of gas, 18850 kJ/m³
- Gas consumption 4.95 m³/h
- Speed 5 rev/s
- Effective brake diameter 0.9 m
- Dead weight on brake 400 N
- Spring balance reading 40 N
- Jacket cooling water 204 kg/h
- Temperature rise of jacket 30°C
Cooling water
Indicated men effective pressure 455kN/m²
Cylinder diameter 165 mm
Piston stroke 305 mm
Determine
(a) the mechanical efficiency
(b) the indicated thermal efficiency
(c) the brake thermal efficiency
(d) Draw up an energy balance for the engine in kJ/s.

Solution
Four stroke gas engine, single cylinder, n = 1
CV = 18850 kJ/m³,
N = 5 rev/s,
D = 0.9 m,
M = 400 N,
m_a = 40 N
m_w = 204 kg/hr
ΔT = 30°C
P_m = imep = 455 kN/m²,
D = 165 mm = 165 × 10⁻³ m
L = 305 mm = 305 × 10⁻³ m

(a) \( \eta_{\text{mech}} = ? \)
(b) \( \eta_{\text{ith}} = ? \)
(c) \( \eta_{\text{bth}} = ? \)
(d) Draw up energy balance

\[
ip = P_m L A n, \quad A = \frac{\pi}{4} (D)^2
\]
\[
= 455 \times 305 \times 10^{-3} \times \frac{\pi}{4} \left(165 \times 10^{-3}\right)^2 \times \frac{5}{2} \times 1
\]
\[
= 7.418 \text{ kW}
\]

\[
T = F \times r = (M - m_a) \times r = (400 - 40) \times \frac{0.9}{2} = 162 \text{ Nm}
\]
bp = 2π NT = 2 × π × 0.5 × 162 = 508.94W = 5.089kW

(a) \( \eta_{\text{mech}} = \frac{bp}{ip} = \frac{5.086}{7.401} = 68.72\% \)

(b) \( \eta_{\text{th}} = \frac{ip}{m^6f \times CV} = \frac{7.419}{1.375 \times 10^{-3} \times 18850} = 0.286 \times 100 = 28.6\% \)

(c) \( \eta_{3bth} = \frac{bp}{m^6f \times CV} = \frac{5.086}{1.375 \times 10^{-3} \times 18850} = 19.6\% \)

(d) Draw up energy balance,

Energy from fuel, \( Q_f = m^6f \times CV = 1.375 \times 10 - 3 \times 18850 = 25.92kW \)

Energy to bp = 5.08 kW

\( C_{pw} = 4.18 \text{ kJ/kgK} \)

Energy to cooling water, \( Q_w = m^6_w C_{pw} (\Delta T) = \frac{204}{3600} \times 4.18 \times 30 = 7.1kW \)

Energy lost to surrounding, \( Q = Q_f - [bp + Q_w] = 25.2 - [5.08 + 7.1] = 13.73kW \)

Energy balance

<table>
<thead>
<tr>
<th>Energy component</th>
<th>KJ/sec</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy from fuel</td>
<td>25.9</td>
<td>100</td>
</tr>
<tr>
<td>Energy to brake power</td>
<td>5.08</td>
<td>19.6</td>
</tr>
<tr>
<td>Energy to Coolant</td>
<td>7.1</td>
<td>27.4</td>
</tr>
<tr>
<td>Energy to exhaust</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Energy to surroundings</td>
<td>13.73</td>
<td>53</td>
</tr>
</tbody>
</table>

7. In a trial on a single-cylinder, four stroke cycle oil engine:

Stroke cycle oil engine:

250 mm bore by 450 mm stroke; the following results were recorded;

Duration of trial, 30 min

Total revolution, 7962;

Average dead load on brake, 940 N

Average spring balance reading, 110 N

Brake radius, 1m

Average indicated mean effective pressure, 565kN/m²

Total fuel used, 2.9 kg of calorific value, 44000 kJ/kg

Total jacket water, 200 kg;

Inlet temperature, 17°C

Outlet temperature, 67°C; specific heat capacity of water 4.18 kJ/kg K
Calculate:
(a) the indicated power;
(b) the brake power;
(c) the mechanical efficiency;
(d) the brake thermal efficiency;
(e) the percentage energy loss to the jacket.

Solution

Four stroke oil engine

d = 250 mm = 250×10⁻³ m
L = 450 mm = 450×10⁻³ m
N = 7962 rev/30 min
M × 9.81 = 940 N
mₚ × 9.81 = 110 N
r = 1 m
m²p = 2.9 kg/30 min
imep = 565 kN/m²
CV = 44000 kJ/kg
m_w = 200 kg
T₁ = 17°C
T₂ = 67°C
cpw = 4.18 kJ/kg

(a) ip = ?
(b) bp = ?
(c) η_mech = ?
(d) η_bth = ?
(e) % of energy loss

(a) A = \frac{\pi}{4} (250×10⁻³)² = 0.049 m²

N = \frac{7962}{\frac{(30×60)}{2}} = 2.2116 rev/sec

ip = PₘLANn
= 565×450×10⁻³×0.049×2.2116×1
= 27.55 kW
(b) \[ \text{bp} = 2\pi \frac{NT}{T} \]
\[ T = F \times r \]
\[ F = (940 - 110) = 830 \text{ N} \]
\[ T = F \times r = 830 \times 1 = 830 \text{ Nm} \]
\[ \text{bp} = 2\pi \frac{NT}{T} = 2 \pi \times 4.423 \times 830 = 23.054 \text{ kW} \]

(c) \[ \eta_{\text{mech}} = \frac{\text{bp}}{\text{ip}} = \frac{23.054}{27.55} = 0.8368 \times 100\% = 83.6\% \]

(d) \[ \eta_{\text{bth}} = \frac{\text{bp}}{m_i \times CV} = \frac{23.054}{\frac{2.9}{30 \times 60} \times 4400} = 0.325 \times 100\% = 32.5\% \]

Energy from fuel, \( Q_f = m_i \times CV = \frac{2.9}{30 \times 60} \times 44000 = 70.88 \text{ kW} \)

Energy to water \( Q_w = m_w \times c_{pw} \times (T_2 - T_1) \)
\[ = \frac{200}{30 \times 60} \times 4.18 \times (67 - 17) \]
\[ = 23.22 \text{ kW} \]

\% loss to jacket = \[ \frac{23.22}{70.88} = 0.3275 \times 100\% = 32.75\% \]

8. A six cylinder, four-stroke cycle, marine oil engine has cylinder diameter of 610 mm and a piston stroke of 1250 mm. When the engine speed is 2 rev/s it uses 340 kg of fuel oil of calorific value 44200 kJ/kg in one hour. The cooling water amounts to 19200 kg/h, entering at 15°C and leaving at 63°C. The torque transmitted at the engine coupling is 108 kN.m and the indicated mean effective pressure is 775 kN/m². Determine:

(a) the indicated power
(b) the brake power
(c) the percentage of the energy supplied/kg of fuel lost to the cooling water;
(d) the brake thermal efficiency;
(e) the brake mean effective pressure;
(f) the mechanical efficiency;
(g) the fuel used/kW-h, on a brake power basis.

Solution

Six-cylinder, four stroke Engine

n = 6
D = 610 mm
L = 1250 mm
N = 2 rev/s
m = 340 kg
T = 108 kN.m
CV = 44200 kJ/kg
m_w = 19200 kg/h
T_1 = 15°C
T_2 = 63°C
imep = 775 kN/m^2

(a) ip =?
(b) bp = ?
(c) %
(d) η_{bth} = ?
(e) bmep =?
(f) η_{mech} = ?
(g) b.s.f.c = ?

(a) ip = P_m/LANn
= 775 \times 1250 \times 10^{-3} \times \pi \times 4 \times (610 \times 10^{-3})^2 \times \frac{2}{2} \times 6
= 1697.25 kW

(b) bp = 2πNT
= 2 \times π \times 2 \times 108
= 1357.168 kW

(c) Energy from fuel, Q_f = m_f \times CV
= 0.09 \times 44200
= 4154.8 kJ/kg
Energy to coolant, \( Q_w = m_w \times c_{pw} \times (\Delta T)_c \)

\[
= \frac{19200}{3600} \times 4.18 \times (63 - 15) \\
= 1070.8 \text{ kW}
\]

\% loss to cooling water = \[
\frac{1069.4}{4154.8} \times 100 \\
= 25.73 \%
\]

(d) \( \eta_{\text{th}} = \frac{bp}{m^2 \times CV} \)

\[
= \frac{1356.48}{0.094 \times 44200} \\
= 0.326 \times 100\% \\
= 32.6\%
\]

(f) \( \eta_{\text{mech}} = \frac{bp}{ip} \times \frac{1357.168}{1697.25} = 0.799 \times 100\% = 79.9\% \\
\eta_{\text{mech}} = \frac{b.m.e.p}{i.m.e.p} \\
\]

9. In a test on a two-stroke, heavy-oil engine, the following observations were made:

- Oil consumption, 4.05 kg/h
- Calorific value of oil, 43000 kJ/kg;
- Net brake load, 579N;
- Mean brake diameter, 1m;
- Mean effective pressure, 275 kN/m²
- Cylinder diameter, 0.02m
- Stroke, 0.250m;
- Speed, 6 rev/s;

Calculate;

(a) the mechanical efficiency;
(b) the indicated thermal efficiency;
(c) the brake thermal efficiency;
(d) the quantity of jacket water required per minute if 30% of the energy supplied by the fuel is absorbed by this water. Permissible rise in temperature is 25°C.

Solution
Two-Stroke Engine,

\[ m^o_r = 4.05 \text{ kg/hr} \]
\[ = \frac{4.05}{3600} = 1.125 \times 10^{-3} \text{ kg/s} \]

CV = 43000 kJ/kg

\[ F = M - m_b = 579 \text{ N} \]

\[ D_b = 1 \text{ m} \]

\[ P_m = 275 \text{ kN/m}^2 \]

\[ D_c = 0.20 \text{ m} \]

\[ L = 0.250 \text{ m} \]

\[ N = 6 \text{ rev/s} \]

(a) \[ \eta_{mech} = ? \]

(b) \[ \eta_{ith} = ? \]

(c) \[ \eta_{bth} = ? \]

(d) \[ m^o_{w} = ? \]

\[ T = F \times r \]
\[ = 579 \times 0.5 \]
\[ = 289.5 \text{ Nm} \]

\[ b_p = 2\pi NT \]
\[ = 2 \times \pi \times 6 \times 289.5 \]
\[ = 10913.89 \text{ W} \]
\[ = 10.913 \text{ kW} \]

\[ i_p = P_m \times \text{LANn} \]
\[ = 275 \times 0.250 \times \frac{\pi}{4} \times (0.20)^2 \times 6 \times 1 \]
\[ = 12.9525 \text{ kW} \]

(a) \[ \eta_{mech} = \frac{b_p}{i_p} = \frac{10.908}{12.95} = 0.8423 \times 100\% = 0.842\% \]
(b) \( \eta_{in} = \frac{ip}{m^o r \times CV} = \frac{12.95}{1.125 \times 10^{-3} \times 43000} = 0.267 \times 100\% = 26.7\% \)

(c) \( \eta_{bth} = \frac{bp}{m^o r \times CV} = \frac{10.908}{1.125 \times 10^{-3} \times 43000} = 0.2254 \times 100\% = 22.54\% \)

(d) Energy to coolant = 30% of Energy from fuel

\[
= 0.3 \times m^o r \times CV \\
= 0.3 \times (1.125 \times 10^{-3} \times 43000) \\
= 14.51 \text{ kW}
\]

Energy to coolant = \( m^o_w \times c^w_p \times (\Delta T) \)

\[
14.1 = m^o_w \times 4.18 \times 25 \\
m^o_w = 0.1388 \text{kJ/s} \\
= 0.1388 \times 60 \\
= 8.328\text{kg/min}
\]

10. A four cylinder four stroke cycle, petrol engine 75 mm bore by 90 mm stroke operates on the constant volume cycle and has a compression ratio of 6 to 1, the efficiency ratio being 55%. Calculate the indicated thermal efficiency. Take \( \gamma = 1.4 \), when running at 40 rev/s the engine developed a brake mean effective pressure of 725 kN/m\(^2\) and uses 9.2 kg of fuel/hr of calorific value 44000 kJ/kg. Calculate the brake thermal efficiency, the mechanical efficiency and the specific fuel consumption is kg/kW-hr.

Solution

Four cylinder four stroke cycle

Constant volume cycle

\( D = 75 \text{ mm} = 75 \times 10^{-3} \text{ m} \)

\( L = 90 \text{ mm} = 0.09 \text{ m} \)

\( r = 6 \)

efficiency ratio = 55%

\( \eta_{in} = \) ?

\( \gamma = 1.4 \)

Speed \( N = 40 \text{ rev/s} \)
bmep = P_m = 725 kN/m^2

\[ m_o = 9.2 \text{ kg/hr} = \frac{9.2}{3600} \text{ kg/s} \]

CV = 44000 kJ/kg

\( \eta_{\text{mech}} = ? \)
\( \eta_{\text{bth}} = ? \)
\( \text{b..s.f.c} = ? \)

\[ \eta_{\text{air}} = 1 - \frac{1}{\eta_{\text{air}}} = 1 - \frac{1}{6^{1.4-1}} = 0.5116 \]

efficiency ratio = \( \frac{\eta_{\text{bth}}}{\eta_{\text{air}}} \)

\[ 0.55 = \frac{\eta_{\text{bth}}}{0.5116} \]
\[ \eta_{\text{bth}} = 0.2814 \times 100\% = 28.14\% \]

\[ ip = 0.2814 \times \frac{9.2}{3600} \times 44000 \]
\[ = 31.64 \text{ kJ/kg} \]

bp = P_m LANn
\[ = 725 \times \frac{\pi}{4} (0.075)^2 \times 0.09 \times \frac{40}{2} \times 4 \]
\[ = 23.06125 \text{ kJ/kg} \]
\[ \eta_{\text{mech}} = \frac{bp}{ip} \times 100\% \]
\[ = \frac{23.06125}{31.641} \times 100 = 72.88\% \]

\[ \eta_{\text{bth}} = \frac{bp}{m_o \times CV} \]
\[ = \frac{23.06125}{9.2} \times 44000 \]
\[ = 20.51\% \]
11. A single cylinder four stroke oil engine has a bore of 18 cm and a stroke of 36 cm. The clearance volume is 590 cm³. During a test the fuel consumption was 3 kg/hr, the engine speed is 308 rpm, the indicator card area 420 mm², the indicator card spring rating 108 kN/m²/mm. If the fuel has calorific value of 42650 kJ/kg. Calculate the efficiency relative to that of the constant volume air standard cycle. Assume \( \gamma = 1.4 \).

Solution

Single cylinder 4 stroke

d = 18 cm

L = 36 cm

\( V_c = 590 \text{ cm}^3 \)

\( m^o_f = 3 \text{ kg/hr} \)

N = 380 rpm

indicator card Area = 420 mm²

indicator card Length = 63 mm

spring rating = 108 kN/m²/mm

CV = 42650 kJ/kg

relative efficiency =?

\( \gamma = 1.4 \)
\[ V_s = A \times L \]
\[ = \frac{\pi}{4} \times (18)^2 \times 36 = 9160 \text{cm}^3 \]

\[ r = \frac{V_c + V_s}{V_c} = \frac{9160 + 590}{590} = 16.53 \]

\[ \eta_{\text{air}} = 1 - \frac{1}{r^{1.5}} = 1 - \frac{1}{(16.53)^{1.5}} = 0.6743 \times 100\% = 67.43\% \]

\[ \text{i.m.e.p} = \frac{420}{63} \times 108 = 720 \text{kN/m}^2 \]

\[ \text{ip} = \text{i.m.e.p} \times A \times L \times N \times n \]
\[ = 720 \times \frac{\pi}{4} \times (0.18)^2 \times 0.36 \times \frac{380}{2 \times 60} \times 1 = 20.89 \text{kW} \]

\[ \eta_{\text{th}} = \frac{\text{ip}}{m_{\text{c}} \times CV} \]
\[ = \frac{20.89}{3 \times 42650} = 0.5878 \times 100\% = 58.75\% \]

Efficiency ratio = \[ \frac{\eta_{\text{th}}}{\eta_{\text{air}}} = \frac{0.5878}{0.6743} \times 100\% = 87.17\% \]
12. Determine the specific liquid enthalpy, specific enthalpy of evaporation and specific enthalpy of dry saturated stream at 0.5 MN/m².

Looking up stream tables, the various values will appear as follows,

<table>
<thead>
<tr>
<th>P (MN/m²)</th>
<th>Sat.temp°C</th>
<th>h̄</th>
<th>Specific enthalpy h fg</th>
<th>Kj/kg h g</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.50</td>
<td>151.8</td>
<td>640.1</td>
<td>2107.4</td>
<td>2747.5</td>
</tr>
</tbody>
</table>

Thus

Specific liquid enthalpy = 640.1 kJ/kg

Specific enthalpy of evaporation = 2107.4 kJ/kg

Specific enthalpy of dry saturated stream = 2747.5 kJ/kg

Note that,

\[ h_g = h_\parallel + h_{fg} \]

\[ = 640.1 + 2107.4 = 2747.5 \text{ kJ/kg} \]

Note also that saturation temperature = 151.8 °C

13. Determine the saturation temperature, specific liquid enthalpy, specific enthalpy of evaporation and specific enthalpy enthalpy of dry saturated stream at pressure of 2.04 MN/m².

\[ p = 2.04 \text{ MN/m}^2 \]

\[ t_s = ? \]

\[ h_\parallel s = ? \]

\[ h_{fg} = ? \]

\[ h_g = ? \]

<table>
<thead>
<tr>
<th>P MN/m²</th>
<th>Sat.temp °C</th>
<th>Specific enthalpy h̄</th>
<th>Kj/kg h g</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>h̄</td>
<td>h fg</td>
</tr>
</tbody>
</table>
Hence, at 2.04 MN/m²
Saturation temperature = 213.4 °C
Specific liquid enthalpy = 913.16 kJ/kg
Specific enthalpy of evaporation = 1884.44 kJ/kg
Specific enthalpy of dry saturated steam = 2797.6 kJ/kg

13. Determine the specific enthalpy of stream at 2MN/m² and with a temperature of 275 °C
p = 2N/m²
t = 275 °C
h = ?

At 2 MN/m², from tables, t_f = 212.4 °C
The steam must, therefore, be superheated since its temperature is above t_f
Degree of superheated = 275 - 212.4 °C = 62.6 °C
The specific enthalpy can be looked up in steam tables under the heading superheated states.
Looking up tables,
Specific enthalpy of steam at 2MN/m² with a temperature of 275 °C = 2965 kJ/kg.
Alternatively,
h = h_g + c_p (t - t_f)
= 2797.2 + 2.0934 × 62.6 = 2797 + 132
= 2929.2 kJ/kg.

It will be observed that this gives only an approximation.
14. Determine the specific enthalpy of stream at 2.5 MN/m² and with a temperature of 320 °C.

Looking up steam tables shows that at 2.5 MN/m² the saturation temperature is 223.9 °C. The steam is therefore superheated.

Degree of superheat = 320 – 223.9 = 96.1 K

The specific enthalpy could be estimated using the equation,

\[ h = h_g + c_v(t - t_r) \]

\[ = 2800.9 + 2.0934 \times 96.1 \]

\[ = 2800.9 + 201 = 3001.9 \text{ kJ/kg} \]

However, a more accurate value can be interpolated from tables giving specific enthalpy against temperature. Looking up this table will show that neither the pressure of 2.5 MN/m² nor the temperature of 320 °C are given. Interpolation for both pressure and temperature is therefore required.

A note is made of values of specific enthalpy on either side of the pressure and temperature as follows.

<table>
<thead>
<tr>
<th>Pressure MN/m²</th>
<th>2</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temp °C</td>
<td>Spec. enthalpy kJ/kg</td>
<td></td>
</tr>
<tr>
<td>325</td>
<td>3083</td>
<td>3031</td>
</tr>
<tr>
<td>300</td>
<td>3025</td>
<td>2962</td>
</tr>
</tbody>
</table>

Pressure MN/m² | Temp °C | Spec. enthalpy kJ/kg |
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Require +25</td>
<td>+58</td>
<td>+69</td>
</tr>
<tr>
<td>Adding 320</td>
<td>3071.4</td>
<td>3017.2</td>
</tr>
</tbody>
</table>

This gives values of specific enthalpy at the temperature of 320 °C. An interpolation is now required for the pressure.

<table>
<thead>
<tr>
<th>Pressure MN/m²</th>
<th>Specific enthalpy, kJ/kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>3017.2</td>
</tr>
<tr>
<td>2</td>
<td>3071.4</td>
</tr>
</tbody>
</table>

Difference +2

\[ +0.5 \times -54.2 = -13.6 \]
22

Thus, the specific enthalpy of steam at a pressure of 2.5 MN/m² and with a temperature of 320 °C = 3057.8 kJ/kg
Note that the estimated value of 3001 kJ/kg was not very accurate.

16. Determine the specific enthalpy of wet stream at a pressure of 70 kN/m² and having a dryness fraction of 0.85.

\[ x = 0.85 \]

\[ 0.7\text{bar} \Rightarrow h_f = 376.8 \text{ kJ/kg} \]
\[ 0.7\text{bar} \Rightarrow h_{fg} = 2283.3 \text{ kJ/kg} \]

\[ h = h_f + xh_{fg} \]
\[ = 376.8 + 0.85 \times 2283.3 \]
\[ = 376.8 + 1975 \]
\[ = 2321.8 \text{ kJ/kg} \]

17. Determine the specific volume of water at saturation temperature for a pressure of 4.0 MN/m².

\[ p = 4.0 \text{ MN/m}² \]
\[ v_f = ? \]
Looking up steam tables, values will appear as follows,

<table>
<thead>
<tr>
<th>Pressure MN/m²</th>
<th>Sat.Temp. °C</th>
<th>Specific Volume m³/kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.0</td>
<td>250.3</td>
<td>0.001252</td>
</tr>
</tbody>
</table>

This shows that at a pressure of 4.0 MN/m², saturation temperature is 250.3 °C and the specific volume of water is 0.001252 m³/kg

18. 1.5 kg of stream originally at a pressure of 1 MN/m² and temperature 225°C is expanded until the pressure becomes 0.28 MN/m². The dryness fraction of the stream is then 0.9. Determine the change of internal energy which occurs.

Solution

\[ m = 1.5 \text{ kg} \]
\( p_1 = 1 \text{ MN/m}^2 \)
\( T_1 = 225 \degree \text{C} \)
\( p_2 = 0.28 \text{ MN/m}^2 \)
\( x = 0.9 \)
\( \Delta u = ? \)

At 1 MN/m\(^2\) and 225 \degree\text{C}

\( h_1 = 2886 \text{ kJ/kg} \)
\( v_1 = 0.22 \text{ m}^3/\text{s} \)
\( u_1 = h_1 - p_1 v_1 \)
\[
= 2886 - 1 \times \frac{10^6}{10^3} \times 0.22 \\
= 2886 - 220 = 2666 \text{kJ/kg} 
\]

At 0.28 MN/m\(^2\) and dryness fraction 0.9,

\( h_2 = h_n + x h_g \)
\[
= 551.4 + 0.9 \times 2170.1 \\
= 551.4 + 1953.09 \\
= 2504.49 \text{kJ/kg} 
\]

\( v_2 = x v_g \)
\[
= 0.9 \times 0.646 = 0.5814 \text{ m}^3/\text{kg} 
\]

\( u_2 = h_2 - p_2 v_2 \)
\[
= 2504.49 - .28 \times \frac{10^6}{10^3} \times 0.5814 \\
= 2504.49 - 162.8 \\
= 2341.69 \text{kJ/kg} 
\]

Hence

\( u_2 - u_1 = 2341.69 - 2666 \)
\[
= -324.31 \text{kJ/kg} 
\]

This is a loss.

For 1.5 kg.

Loss of internal energy = 234.31 \times 1.5
\[
= 486.47 \text{kJ/kg} 
\]
19. A closed vessel of 0.6 m$^3$ capacity contains dry saturated stream at 350 kN/m$^2$. The vessel is cooled until the pressure is reduced to 200 kN/m$^2$.

Calculate

(a) the mass of stream in the vessel,

(b) the final dryness of the stream,

(c) the amount of heat transferred during the cooling process

Solution

(a) At 350 kN/m$^2$, $v_g = 0.5241$ m$^3$/kg

\[
\text{mass of steam in vessel} = \frac{0.6}{0.5241} = 1.1448 \text{ kg}
\]

(c) At 200 kN/m$^2$, $v_g = 0.885$ m$^3$/kg

Since the volume remains constant,

Specific volume after cooling

Specific volume before cooling

\[
x = \frac{0.5241}{0.885} = 0.592 = \text{final dryness of steam}
\]

(d) For a non-flow process, $Q = \Delta u + W$, and for a constant volume change

$W = 0$

$Q = \Delta u$

Hence in this case the heat transferred is equal to the change of internal energy.

Now, $h = u + pv$

$u = h - pv$

at 350 kN/m$^2$, dry saturated,

$u_1 = 2732 - 350 \times 0.5241 = 2732 - 183.4 = 2548.6$ kJ/kg

At 200 kN/m$^2$, dryness 0.592

$h_2 = 504.7 + 0.592 \times 2201.6$

$= 504.7 + 1303.3$

$= 1808$ kJ/kg

\[
u_2 = 1808 - 200 \times 0.5241
\]

$= 1808 - 104.8$

$= 1703.2$ kJ/kg
Change in specific internal energy
\[ = u_2 - u_1 \]
\[ = 1703.2 - 2548.6 \]
\[ = -845.4 \text{ kJ/kg} , \text{ a loss} \]

But there are 1.1448 kg of steam in the vessel.

Hence the amount of heat transferred during the cooling process
\[ = -845.4 \times 1.1448 \]
\[ = -967.8 \text{ kJ} \text{ a loss} \]

20. Stream at 4 MN/m² and dry fraction 0.95 received heat at constant pressure until its temperature becomes 350 °C. Determine the heat received by the stream/kg.

Solution

At 4 MN/m² and 0.95 dry,
\[ h_1 = 1087.4 + 0.95 \times 1712.9 \]
\[ = 1087 + 1627.3 = 2714.7 \text{ kJ/kg} \]

At 4 MN/m² and temperature 350 °C
\[ h_2 = 3095 \text{ kJ/kg} \]

Note that the steam in this case is superheated since saturation temperature at 4 MN/m²
\[ = 250.3 °C \]

Heat received = \( h_2 - h_1 \)
\[ = 3095 - 2714.7 \]
\[ = 380.3 \text{ kJ/kg} \]

21. A quantity of dry saturated stream occupies 0.2634 m³ at 1.5 MN/m². Determine the final condition of the stream if it is compressed until the volume is halved;

(a) if the compression is carried out in an isothermal manner;

(b) if the compression follows the law \( PV = \text{constant} \).

In case (a) determine the heat rejected during the compression.

Solution
Extract from Steam Tables

<table>
<thead>
<tr>
<th>Press MN/m²</th>
<th>Sat.Temp t°C</th>
<th>Spec.enthalpy h_f kJ/kg</th>
<th>Spec.enthalpy h_g kJ/kg</th>
<th>Spec.Vol, v_g m³/kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5</td>
<td>198.3</td>
<td>844.7</td>
<td>1945.2</td>
<td>2789.9</td>
</tr>
<tr>
<td>3.0</td>
<td>233.8</td>
<td>1008.4</td>
<td>1793.9</td>
<td>2902.3</td>
</tr>
</tbody>
</table>

(a) \( v_g \) at 1.5 MN/m² = 0.1317 m³/kg

\[
\frac{v_g}{2} = 0.1317 = 0.0659 \text{ m³/kg} \text{ = final specific volume}
\]

Hence, final condition is at 1.5 MN/m² with a dryness fraction of

\[
\frac{0.0659}{0.1317} = 0.5
\]

specific enthalpy = 844.7 + 0.5 \times 1945.2 = 1817.3 kJ/kg

For 2 kg

Enthalpy = 2 \times 1817.3 = 3634.6 kJ

The loss of heat during this process will be the loss of enthalpy of evaporation, changing from dry saturated steam to wet steam of dryness fraction 0.5 at constant pressure.

Heat loss = 0.5f_g = 0.5 \times 1945.2 = 972.6 kJ/kg

For 2 kg

Heat loss = 972.6 \times 2 = 1945.2 kJ

(b) If the compression is according to the law \( pv = \text{constant} \) then

\[
p_1v_1 = p_2v_2
\]

\[
\therefore \quad p_2 = p_1 \frac{v_1}{v_2} = 1.5 \times 2 = 3.0 \text{ MN/m}^2
\]

Specific volume after compression = 0.0659 m³/kg.

At 3.0 MN/m²

\( v_g = 0.0666 \text{ m³/kg} \)

dryness fraction after compression
\[
\frac{0.0659}{0.0666} = 0.989
\]

Specific enthalpy = 1008.4 + 0.989 \times 1793.9

= 1008.4 + 1774.2

= 2782.6 \text{ kJ/kg}

For 2 kg, Enthalpy = 2 \times 2782.6

= 5565.2 \text{ kJ}

22A quantity of stream at a pressure of 2.1 MN/m\(^2\) and 0.9 dry occupies a volume of 0.2562 m\(^3\). It is expanded according to the law \(P V^{1.25} =\) constant to a pressure of 0.7 MN/m\(^2\). Determine

(a) the mass of stream present

(b) the external work done

(c) the change of internal energy

(d) the heat exchange between the stream and surroundings, stating the direction of transfer.

Extract from steam tables

<table>
<thead>
<tr>
<th>Press MN/m(^2)</th>
<th>Sat. tem (t_{c}^\circ\text{C})</th>
<th>Spec.enthalpy hf kJ/kg</th>
<th>Spec.enthalpy hfg kJ/kg</th>
<th>Spec.enthalpy hg kJ/kg</th>
<th>Spec. vol. m(^3)/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.7</td>
<td>165</td>
<td>697.1</td>
<td>2064.9</td>
<td>2762.2</td>
<td>0.273</td>
</tr>
<tr>
<td>2.1</td>
<td>214.9</td>
<td>920.0</td>
<td>1878.2</td>
<td>2798.2</td>
<td>0.0949</td>
</tr>
</tbody>
</table>

(a) specific volume of steam at 2.1 MN/m\(^2\) and 0.9 dry.

\[
v_{1} = x_{i} v_{g1} = 0.9 \times 0.0949 = 0.0854 \text{ m}^3/\text{kg}
\]

\[
\therefore \text{ mass of steam present} = \frac{0.2562}{0.0854} = 3 \text{ kg}
\]

(b) For the expansion, \(p_{1} V_{1}^{1.25} = p_{2} V_{2}^{1.25}\)
\[ v_2 = v_1 \times \left( \frac{p_1}{p_2} \right)^{1/1.25} = 0.0854 \times \left( \frac{2.1}{0.7} \right)^{1/1.25} \]

\[ = 0.0854 \times (3)^{1/1.25} = 0.0854 \times 2.41 \]

\[ = 0.2058 \text{m}^3/\text{kg} \]

Steam is wet after expansion

\[ v = \frac{v_2}{v_{g2}} = \frac{0.2058}{0.273} = 0.754 \]

External work done \[ = \frac{p_1 v_1 - p_2 v_2}{n - 1} \]

\[ = \frac{10^6(2.1 \times 0.0854 - 0.7 \times 0.2058)}{1.25 - 1} \]

\[ = 10^6 \times \frac{0.0352}{0.251} \]

\[ = 10^6 \times 0.1408 \]

\[ = 140.8 \text{kJ/kg} \]

External work done for 3 kg = 140.8 \times 3 = 422.4 \text{kJ}

(b) \[ u_1 = h_1-p_1 v_1 = 920.0 + 0.9 \times 1878.2 \]

\[ = 920.0 + 1690.4 \]

\[ = 2610.4 \text{kJ/kg} \]

\[ u_2 = h_2-p_2 v_2 \]

\[ h_2 = h_{i2} - x_2 h_{f2} = 697.1 + 0.754 \times 2064.9 \]

\[ = 679.1 + 1556.9 \]

\[ = 2254.0 \text{kJ/kg} \]

\[ u_2 = 2254.0 - \frac{10^6}{10^3} \times 0.7 \times 0.2058 \]

\[ = 2254.0 - 144.1 = 2109.9 \text{kJ/kg} \]

\[ \therefore \text{Change in internal energy} = u_2 - u_1 = 2109.9 - 2431.1 = -321.2 \text{kJ/kg, a loss} \]

For 3 kg of steam,

\[ \text{loss of internal energy} = 3 \times 321.2 = 963.6 \text{kJ} \]

(d) \[ Q = \Delta U + W \]
\[ \begin{align*}
= -963.6 + 422.4 \\
= -541.2 \text{ kJ} \quad \text{a loss to the surroundings.}
\end{align*} \]

23. Determine the volume occupied by 1 kg of at a pressure of 0.85 MN/m\(^2\) and having a dryness fraction of 0.95.

(b) This is expanded adiabatically to a pressure of 0.17 MN/m\(^2\); the law of expansion being \( PV^{1.13} = \text{constant} \). Determine,

(i) the final dryness fraction of the stream,

(ii) the change of internal energy of the stream during the expansion.

Extract from steam Table

<table>
<thead>
<tr>
<th>Press MN/m(^2)</th>
<th>Spec.vol. m(^3)/kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.17</td>
<td>1.031</td>
</tr>
<tr>
<td>0.85</td>
<td>0.2263</td>
</tr>
</tbody>
</table>

(a) \( v_1 = x_1 v_{gf} = 0.95 \times 0.2263 = 0.2150 \text{ m}^3/\text{kg} \)

(b) (i) \( p_1 v_1^{1.13} = p_2 v_2^{1.13} \)

\[
v_2 = v_1 \left[ \frac{p_1}{p_2} \right]^{1/1.13}
\]

\[
= 0.2150 \times \left[ \frac{0.85}{0.17} \right]^{1/1.13}
\]

\[
= 0.2150 \times (5)^{1/1.13}
\]

\[
= 0.2150 \times 4.15 = 0.8923 \text{ m}^3/\text{kg}
\]

At 0.17 MN/m\(^2\), \( v_{g2} = 1.031 \text{ m}^3/\text{kg} \)

\[
x_2 = \frac{v_2}{v_{g2}} = \frac{0.8923}{1.031} = 0.865
\]

(ii) For an adiabatic expansion

\[
u = - W,
\]

\[
u_2 - u_1 = \frac{-(p_1 v_1 - p_2 v_2)}{n - 1}
\]
= \frac{10^6 \times (0.85 \times 0.2150 - 0.17 \times 0.8923)}{10^3 \times 1.13 - 1} \\
= -10^3 \times \frac{(0.1828 - 0.1517)}{0.13 - 1} = -10^3 \times \frac{0.0311}{0.13} \\
= -10^3 \times 0.2392 \\
= -239.2 \text{ kJ/kg, a loss of internal energy.}

24. A vessel of volume 0.03 m$^3$ contains dry saturated steam at 17 bar. Calculate the mass of steam in the vessel and the enthalpy of this steam.

Solution

$V_1 = 0.03 \text{ m}^3$ (dry saturated steam)

$P_1 = 17 \text{ bar}$

$m = \? \text{ kg}$

$h = \? \text{ kJ/kg}$

$V_1 = v_g = 0.1167$

$V_1 = m \times v_1$

$0.03 = m \times 0.1167$

$m = 0.257 \text{ kg}$

$h_1 = h_g = 2793 \text{ kJ/kg}$

$H_1 = mh_1$

$= 0.257 \times 2795$

$= 718.5 \text{ kJ}$

25. Steam at 7 bar and 250°C enters a pipeline and flows along it at constant pressure. If the steam rejects heat steady to the surrounding, at what temperature will droplets of water begin to form in the vapor?

Solution

$P_1 = 7 \text{ bar}$

$t_2 = \? \text{ °C}$

$t_1 = 250 \text{ °C}$

$p_2 = 7 \text{ bar}$

$Q_{12} = \? \text{ kJ}$

$t_2 = t_3 = 165 \text{ °C}$

$h_1 = h_{\text{super}} (p_1 = 7 \text{ bar}, t_s = 165 < t_1 = 250 \text{ °C (steam is superheat)})$
2955 kJ/kg

\[ h_2 = h_{g2} \text{ (p}_2 = 7 \text{ bar)} \]

\[ = 2764 \text{ kJ/kg} \]

\[ Q_{12} = (h_2 - h_1) \]

\[ = 2764 - 2955 \]

\[ = -191 \text{ kJ/kg} \]

26. Determine the enthalpy, volume and density of 1 kg of steam at a pressure of 20 bars and a temperature of 300°C.

Solution

\[ h =? \]

\[ v =? \]

\[ \rho =? \]

m = 1 kg

p = 20 bar

t = 300 °C

p = 20 bar \Rightarrow t_s = 212.4 < 300°C, steam is superheated.

h = 3025 kJ/kg

\[ H = h \times m \]

\[ = 3025 \times 1 = 3025 \text{ kJ} \]

\[ v = 0.1255 \text{ m}^3/\text{kg} \]

\[ V = v \times m \]

\[ = 0.1255 \times 1 = 0.1255 \text{ m}^3 \]

\[ \rho = \frac{1}{v} = \frac{1}{0.1255} = 7.97 \text{ kg/m}^3 \]

27. Steam at a pressure of 28 Kpa is passed into a condensser and it leaves as condensate at a temperature of 59°C. Cooling water circulates through the condenser at the rate of 45 kg/min. It enters at 15°C and leaves at 30°C. If the steam flow rate is 1.25 kg/min, determine the quality of the steam as it enters the condenser.

Solution

p_1 = 0.28 \text{ bar}
\[ t_2 = 59 \, ^\circ C \, , \, m^\circ = 1.25 \, \text{kg/min}, \, x_1 = ? \]
\[ m^\circ_{cw} = 45 \, \text{kg/min} \]
\[ T_{in} = 15 \, ^\circ C, \, T_{out} = 30 \, ^\circ C \]

Steam leave at condenser

\[ h_2 = h_{t2} (p = 0.28 \, \text{bar}, \, t_2 = 59 \, ^\circ C) \]
\[ = 247.36 \, \text{kJ/kg} \]

Heat lost of steam = heat gain of water

\[ m^\circ_s (h_1 - h_2) = m^\circ_{cw} c_{pw} (T_{out} - T_{in}) \]
\[ 1.25(h_1 - 247.36) = 45 \times 4.187(30 - 15) \]
\[ h_1 = 2508.34 \, \text{kJ/kg} \]

\[ h_1 = (h_f + x_i h_{fg}) \]
\[ 2508.34 = 283 + x_i \times 2339 \]
\[ x_i = 0.95 \]

28. Determine the enthalpy volume and density of 1 kg of steam at a pressure of 50 bar and with a quality of 0.9.

Solution

\[ h = ? \]
\[ v = ? \]
\[ \rho = ? \]
\[ m = 1 \, \text{kg} \]
\[ p = 50 \, \text{bar} \]
\[ x = 0.9 \]

\[ h = (h_f + x h_{fg}) \]
\[ = 1155 + 0.9 \times 1639 \]
\[ = 2630.1 \, \text{kJ/kg} \]

For \( m = 1 \, \text{kg} \)
\[ H = 2630.1 \times 1 = 2630.1 \, \text{kg} \]
\[ v = x v_g \]
\[ = 0.9 \times 0.03944 = 0.0354 \, \text{m}^3/\text{kg} \]
29. 0.05 kg of steam at 10 bar is contained in a rigid vessel of volume 0.0076 m³. What is the temperature of the steam? If the vessel is cooled, at what temperature will the steam be just dry saturated? Cooling is contained until the pressure in the vessel is 11 bar, calculate the final quality of the steam, and the heat rejected between the initial and the final states.

Solution

\( m = 0.05 \text{ kg} \)

\( p_1 = 15 \text{ bar} \)

\( V_1 = 0.0076 \text{ m}^3 \)

\( t = ? \)

\[ V_1 = m v_1 \]

\[ v_1 = \frac{V_1}{m} = \frac{0.0076}{0.05} = 0.152 \text{ m}^3/\text{kg} \]

\[ v_g (15 \text{ bar}) = 0.1317 < v_1 \text{ : steam is superheated} \]

\( \therefore \) \( v_1 = 0.152 \text{ m}^3/\text{kg} \Rightarrow t_1 = 250 \degree \text{C} \)

\( P_2 = 15 \text{ bar} \text{ , (steam is dry saturated)} \)

\( t_2 = ? \)

\( t_2 = t_s = 198.3 \degree \text{C} \)

\( p_3 = 11 \text{ bar} \text{ , } x_3 = ? \text{ } Q_{1-3} = ? \)

\[ v_3 = v_2 = v_1 = 0.152 \text{ m}^3/\text{kg} \]

\[ x_3 = \frac{v_3}{v_g} \]

\[ = \frac{0.152}{0.1774} = 0.856 \]

\[ Q_{1-2} = (u_3 - u_1)m (\because v = c) \]

\[ u_1 = u_{\text{superheat}} (p_1 = 15 \text{ bar}, t_1 = 250 \degree \text{C}) \]

\[ = 2697 \text{ kJ/kg} \]
\[ u_3 = \left[ u_r + x_3 \left( u_g - u_r \right) \right] \text{ at } p_3 = 11\text{bar} \]
\[ = 780 + 0.856(2586 - 780) \]
\[ = 1547.42 \text{ kJ/kg} \]

\[ Q_{1,3} = (u_3 - u_1)m \]
\[ = (1547.42 - 2697) \times 0.05 \]
\[ = -57.48 \text{ kJ} \]

30. A quality of steam 0.7 dry, occupied a volume of 0.197 m³ at a pressure of 109 MN/m². If the pressure is kept constant, determine the heat to be supplied to make the steam just dry and the percentage of this heat which appears as external work. If now, the volume is kept constant while heat is extracted until the pressure fails to 1.25 MN/m², find the dryness fraction and the heat transferred from the steam.

Solution

Wet steam
\[ x_1 = 0.7 \quad p = c \quad \text{Dry saturated steam} \]
\[ V_1 = 0.197 \text{ m}^3 \quad p_2 = 14 \text{ bar} \]
\[ p_1 = 1.4 \text{ MN/m}^2 \quad Q_{1-2} = ? \]
\[ = 14 \text{ bar} \quad \% \text{ heat} = ? \]
\[ h_1 = (h_f + x h_{fg})_{1/4\text{bar}} \]
\[ = 830 + 0.7 \times 1960 \]
\[ = 2202 \text{ kJ/kg} \]
\[ h_2 = h_g = 2790 \text{ kJ/kg} \]

\[ x_1 = \frac{V_1}{V_{fg}} \]
\[ V_1 = x V_g \]
\[ = 0.7 \times 0.1408 \]
\[ = 0.09856 \text{ m}^3/\text{kg} \]
\[ m = \frac{V_1}{V_{fg}} = \frac{0.197}{0.0985} = 1.9988 \text{ kg} \]
\[ Q_{1-2} = (h_2 - h_1)m \]
\[ = (2790 - 2202) \times 1.9988 \]
\[ = 1175.4 \text{ kJ/kg} \]
\[ w_{1-2} = (p_2 v_2 - p_1 v_1) m \\
= p(v_2 - v_1) m \\
= 1.4 \times 10^3 (0.1408 - 0.09856) \times 1.9988 \\
= 118.21 \text{ kJ} \]

\[
\% \text{ of heat} = \frac{w_{1-2}}{Q_{1-2}} = \frac{118.21}{1175.4} = 10.05\%
\]

\[ v_2 = 0.1408 \text{ m}^3/\text{kg} \quad v = c \quad v_3 = 0.1408 \text{ m}^3/\text{kg} \]

\[ p_2 = 14 \text{ bar} \quad x_3 = ? \]

\[ Q_{2-3} = ? \]

\[ p_3 = 1.25 \text{ MN/m}^2 = 12.5 \text{ bar} \]

\[ v_3 = x_3 v_{g3} \]

\[ x_3 = \frac{v_3}{v_{g3}} = \frac{0.1408}{0.1572} = 0.89 \]

\[ u_2 = u_{g2} = 2593 \text{ kJ/kg} \]

\[ u_3 = u_i + x_3 (u_g - u_f) \]

\[ = 805 + 0.89(2589 - 805) \]

\[ = 2398.85 \text{ kJ/kg} \]

\[ v = c \rightarrow w = 0 \]

\[ Q_{2-3} = (u_3 - u_2) \]

\[ = (2392.76 - 2593) \times 1.9988 \]

\[ = -400.24 \text{ kJ} \]