MADE EASY

Leading Institute for ESE, GATE & PSUs

ESE 2025 : Mains Test Series

UPSC ENGINEERING SERVICES EXAMINATION

Mechanical Engineering

Test-1 : Thermodynamics + Refrigeration and Air-conditioning + IC Engine

Name : ....

Roll No :

Test Centres			Student's Signature
Delhi ☑	Bhopal ☐	Jaipur ☐	
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Instructions for Candidates

1. Do furnish the appropriate details in the answer sheet (viz. Name & Roll No).
2. There are Eight questions divided in TWO sections.
3. Candidate has to attempt FIVE questions in all in English only.
4. Question no. 1 and 5 are compulsory and out of the remaining THREE are to be attempted choosing at least ONE question from each section.
5. Use only black/blue pen.
6. The space limit for every part of the question is specified in this Question Cum Answer Booklet. Candidate should write the answer in the space provided.
7. Any page or portion of the page left blank in the Question Cum Answer Booklet must be clearly struck off.
8. There are few rough work sheets at the end of this booklet. Strike off these pages after completion of the examination.

FOR OFFICE USE

Question No.	Marks Obtained
Section-A	
Q.1	26
Q.2	46
Q.3	—
Q.4	23
Section-B	
Q.5	10
Q.6	20
Q.7	—
Q.8	—
Total Marks Obtained	125

Signature of Evaluator .... Cross Checked by ....

IMPORTANT INSTRUCTIONS

CANDIDATES SHOULD READ THE UNDERMENTIONED INSTRUCTIONS CAREFULLY. VIOLATION OF ANY OF THE INSTRUCTIONS MAY LEAD TO PENALTY.

DONT'S

1. Do not write your name or registration number anywhere inside this Question-cum-Answer Booklet (QCAB).
2. Do not write anything other than the actual answers to the questions anywhere inside your QCAB.
3. Do not tear off any leaves from your QCAB, if you find any page missing do not fail to notify the supervisor/invigilator.
4. Do not leave behind your QCAB on your table unattended, it should be handed over to the invigilator after conclusion of the exam.

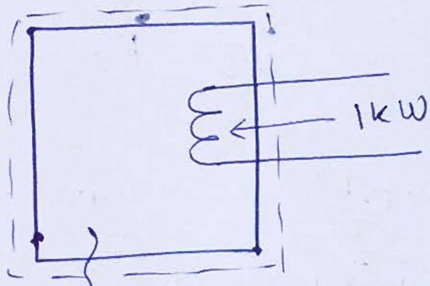
DO'S

1. Read the Instructions on the cover page and strictly follow them.
2. Write your registration number and other particulars, in the space provided on the cover of QCAB.
3. Write legibly and neatly.
4. For rough notes or calculation, the last two blank pages of this booklet should be used. The rough notes should be crossed through afterwards.
5. If you wish to cancel any work, draw your pen through it or write "Cancelled" across it, otherwise it may be evaluated.
6. Handover your QCAB personally to the invigilator before leaving the examination hall.

Section A : Thermodynamics + Refrigeration and Air-conditioning + IC Engine

Q.1 (a) Helium gas is contained in a closed rigid tank. An electric resistor in the tank transfers energy to the gas at constant rate of 1 kW. Heat transfer from the gas to its surroundings occurs at a rate of 50 *t* watts, where t is time in seconds. Plot the change in energy of the helium in kJ, for $t \geq 0$ and comment.

[12 marks]



(50t) watts. t is in seconds.

1st Law of thermodynamics

$$\left(\frac{dE}{dt}\right)_{cv} = \dot{Q} - \dot{W}$$

$$= \left[-50t - (-1000)\right] \text{ watts}$$

$$\left(\frac{dE}{dt}\right)_{cv} = (-50t + 1000) \text{ watts}$$

$$E_f - E_i = (\Delta E)_{HE} = \int_0^t (-50t + 1000)\, dt$$

Change in energy of He $= \left[-50\frac{t^2}{2} + 1000t\right]$

($\because$ tank is rigid, No boundary work done by He).

$(\Delta E)_{He}\ (t = 0) = 0$ kJ

$(\Delta E)_{He}\ (t = 40s) = 0$ kJ.

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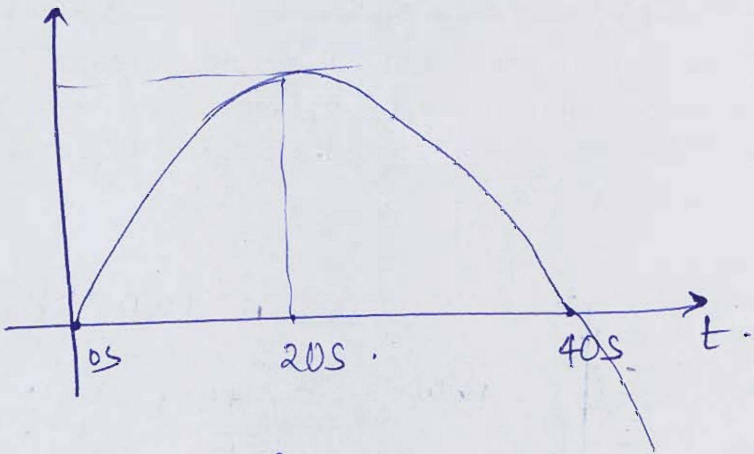

$\Delta E = -50\frac{t^2}{2} + 1000t$ 1000

$= (1000 - 25t)t$ → Convert into kJ as asked in the question

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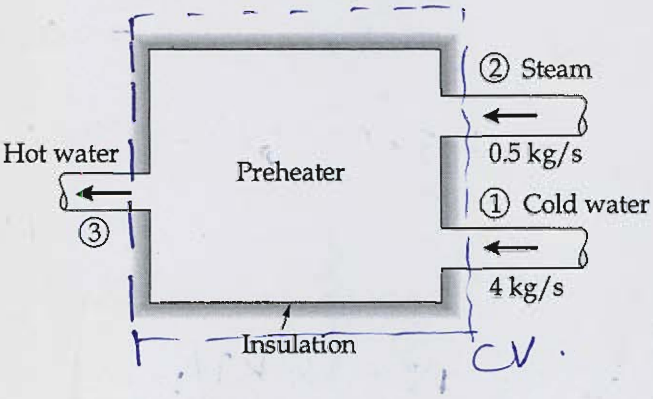
change in energy of He in kJ vs time.

Rises from zero parabolically till 20 s and decreases till 40s to become zero and goes to negative beyond 40 s time.

Q.1 (b) A preheater is used to preheat water in a power plant cycle, as shown in the figure below. The super heated steam is at a temperature of 250°C and the entering water is subcooled at 45°C. All the pressures are 600 kPa. Calculate the rate of entropy generation. Is the process reversible or irreversible. Explain why? (Neglect kinetic and potential energy changes) [Use Steam Table attached at the end]



[12 marks]

② steam

$T_2 = 250^\circ C$

$h_2 = 2957.6$

$s_2 = 7.1832$

① cold water.

$T_1 = 45^\circ C$

$h_1 = 188.95$

$s_1 = 0.63836$

③ Hot water (exit).

Assuming steady state, No heat loss to surrounding. 3

$$\dot{m}_1 h_1 + \dot{m}_2 h_2 = \dot{m}_3 h_3$$

$$4(188.95) + 0.5(2957.6) = 4.5\, h_3$$

$$h_3 = 2234.6 \text{ kJ/kg}$$

at 600 kPa, $h_f < h_3 < h_g$

$$2234.6 = 670.38 + x_3 (2085.8)$$

dryness at exit $x_3 = 0.7499 \approx 0.75$

$$s_3 = s_f + x_3 s_{fg}$$

$$= 1.9308 + x_3 (4.8284)$$

$$s_3 = 5.5518 \text{ kJ/kgK}$$

$$\dot{S}_{gen} = \dot{S}_e - \dot{S}_i$$

$$= 4.5\,kg/s\,(s_3) - (4\,kg/s\; s_1) - (0.5\,s_2)$$

$$= (4.5 \times 5.5568) - (4 \times 0.63836) - (0.5(7.1832))$$

$$\boxed{\dot{S}_{gen} = 18.838\ kJ/K}$$

$\because \dot{S}_{gen} > 0 \Rightarrow$ process is irreversible.

Q.1 (c) In the generator of an ammonia absorption refrigeration system, 10 kg of strong aqua solution at 82°C per minute is supplied for every kg of NH_3 driven out from the solution. The remaining weak solution leaves the generator at 100°C. Assuming the mass concentration of the aqua ammonia in the generator is 0.35.

(i) Find the quantity of heat supplied from the external source per kg of NH_3 generated.

(ii) The NH_3 generated in the generator is completely condensed to saturated liquid in the condenser and is completely evaporated in the evaporator. Using the P-h chart, find the ratio of refrigerating effect in the evaporator to the heat supplied in the generator per kg of NH_3.

Assume the pressure in the evaporator is 2 bar.

If the flow of anhydrous ammonia through the evaporator is 8 kg/min, find the capacity of the system in tons of refrigeration.

(iii) Compare the refrigerating effect produced from the amount of heat given to the generator is utilised in vapour-compression system working in the same pressure limit and having the same conditions of refrigerant in the inlet and outlet of the evaporator. Assume the compression machine of vapour compression system is driven by a prime-mover which has a thermal efficiency of 10%.

Assume the compression in the compressor is isentropic and transmission efficiency between the prime-mover and compressor is 100%.

Take the following data: Pressure in the generator = 10 bar. Enthalpy of NH_3 leaving the generator = 1860 kJ/kg

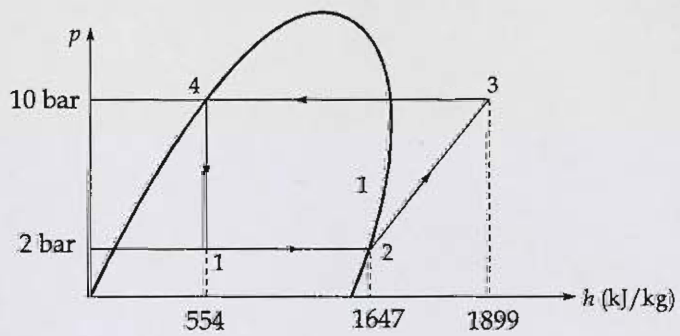
Mean specific heat of solution = 4.78 kJ/kg-°C

Heat loss from the generator to atmosphere = 79 kJ/kg of NH_3 generated.

Take the heat of aqua ammonia = 418 kJ/kg at 0°C

Use the following equation for the heat of absorption:

$Q_a = 802.5(1 - x_w) - 928x_w^2$, where x_w is the mean mass concentration of aqua ammonia.



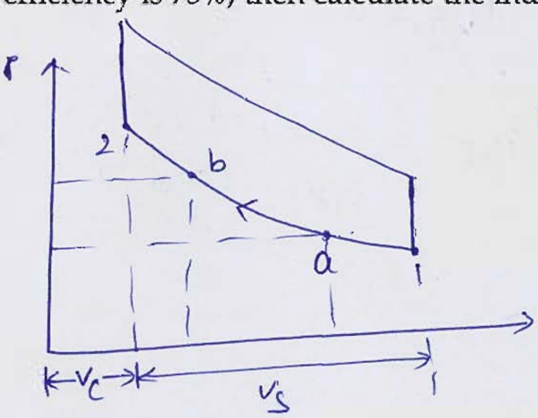
[12 marks]

Q.1 (d) Explain how does a complete HVAC system work to meet the heating, ventilating and air conditioning requirements of a large complex?

[12 marks]

1 (e) A petrol engine is supplied with fuel having calorific value 42000 kJ/kg. The pressure in the cylinder at 10% and 80% of the compression stroke are 1 bar and 4 bar respectively. Assume that the compression follows the law $PV^{1.3}$ = constant. Find the compression ratio of the engine. If the relative efficiency of the engine compared with the air standard efficiency is 75%, then calculate the indicated specific fuel consumption in kg/kWh.

[12 marks]



Compression

$$PV^{1.3} = C$$

$$1\,(V_C + 0.9V_S)^{1.3} = 4\,(V_C + 0.2V_S)^{1.3}$$

$$1\,(c + 0.9)^{1.3} = 4\,(c + 0.2)^{1.3}$$

where $c = \frac{V_C}{V_S}$

$$\frac{(c+0.9)^{1.3}}{(c+0.2)^{1.3}} = 4$$

$$\frac{c+0.9}{c+0.2} = 4^{\frac{1}{1.3}}$$

$$c = 0.1675$$

$$r = 1 + \frac{1}{c}$$

$$\boxed{r = 6.97}$$ * Compression Ratio *

$$\eta_{rel} = \frac{\eta_{actual}}{\eta_{air\,std}} = 0.75$$

$$\eta_{air\,std} = 1 - \frac{1}{r^{\gamma-1}} \qquad \{\gamma = 1.4\}.$$

$$= 1 - \frac{1}{6.97^{1.4-1}}$$

$$= 54\%$$

$$\Longrightarrow \eta_{actual} = 0.405$$

$$= 40.5\% = \frac{IP}{(\dot{m}_f \times CV)}$$

$$isfc = \frac{\dot{m}_f}{(IP)} = \frac{\dot{m}_f \times CV}{IP} \times \frac{1}{CV}$$

$$isfc = \frac{1}{0.405} \times \frac{1}{(42000\ kJ/kg)} \times 3600$$

$$\boxed{isfc = 0.2116\ kg/kW\,hr.}$$ *

isfc = indicated specific fuel consumption

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2 (a) A frictionless piston cylinder arrangement is loaded with a linear spring, having spring constant 100 kN/m and the piston cross-sectional area is 0.1 m^2. The cylinder initial volume of 20 L contains air at 200 kPa and 10°C. The cylinder has a set of stops that prevent its volume exceeding 50 L. A valve connects to a line flowing air at 800 kPa, 50°C. The valve is now opened, allowing air to flow in until the cylinder pressure reaches 800 kPa, at this point the temperature inside the cylinder is 80°C. The valve is then closed and the process ends.

(i) Is the piston at the stops at the final state?

(ii) Taking the inside of the cylinder as a control volume calculate the heat transfer during the process.

(iii) Calculate the net entropy change for this process.

Neglect the mass of the piston.

[For air, take c_p = 1.005 kJ/kgK, c_v = 0.718 kJ/kgK, R = 0.287 kJ/kgK]

[20 marks]

$K_{sp} = 100$ kN/m

$A_p = 0.1 \text{ m}^2$

$\forall_1 = 20\times10^{-3} \text{ m}^3$

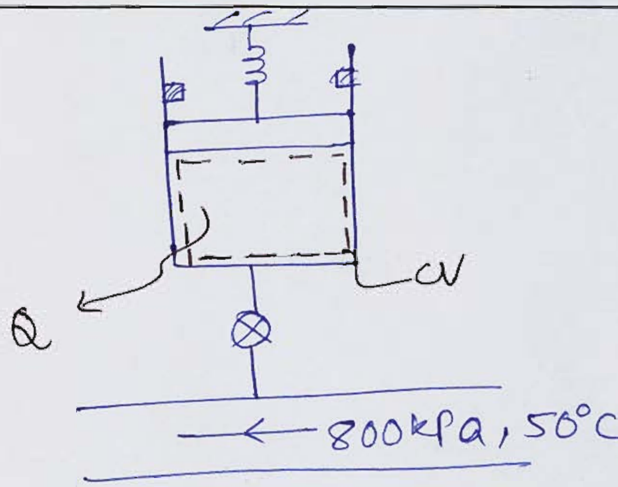
$P_1 = 200$ kPa.

$T_1 = 263$ K

$\forall_{@ \text{stops}} = 50$ L $= 50\times10^{-3} \text{ m}^3$.

$P_{final} = 800$ kPa

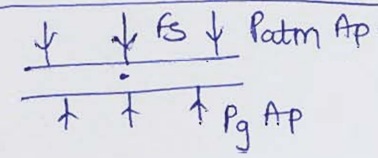
$T_{final} = 80°$C

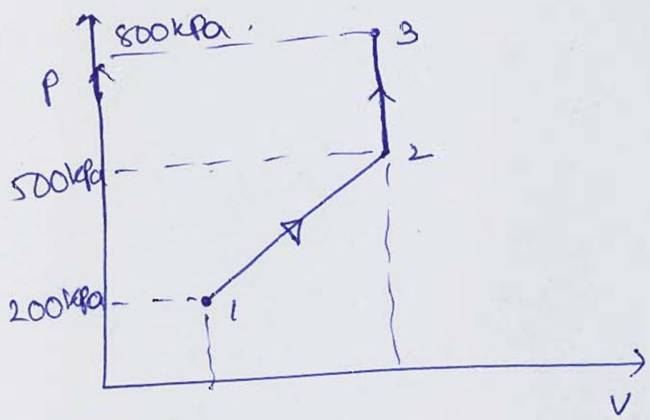


state 1

$$m_1 = \frac{200 \times 20 \times 10^{-3}}{0.287 \times 283}$$

$$m_1 = 0.04924\ kg$$





Assume a state where piston just touches the stops.

at state ①.

$P_{g_1} A_p = F_{s_1} + P_{atm} A_p$

$P_{g_2} A_p = F_{s_2} + P_{atm} A_p$

(Neglecting wt of piston).

$$P_{g_2} A_p = (F_{s_2} - F_1) + (P_{g_1} A_p)$$

$$P_{g_2} A_p = k(x_2 - x_1) + (P_{g_1} A_p)$$

$V_{@\,stops} = 50L \implies (x_2 - x_1) = \frac{30 \times 10^{-3}\ m^3}{0.1\ m^2}$

$$(x_2 - x_1) = 0.3m.$$

$$P_{g_2} = \frac{100\ kN/m \times 0.3\ m}{0.1\ m^2} + P_{g_1}$$

$$P_{g_1} = 200kPa.$$

$$P_{g_2} = 500\ kPa < 800kPa$$

final pressure

P_{g_2} → pressure when piston just touches stops.

∴ At final state, piston will be at the stops. (i)

$$m_2 = \frac{800 \text{ kPa} \times 50\times10^{-3} m^3}{0.287\times(273+80)}$$

$$\boxed{m_2 = 0.3948 \text{ kg}}$$

mass conservation $m_2 - m_1 = m_i - m_e$ ($m_e = 0$)

mass entered in CV. ← $\boxed{m_i = 0.3455 \text{ kg}}$

Energy Conservation

$$m_2 U_2 - m_1 U_1 = m_i h_i + Q - m_e h_e - W_{CV}$$ ($m_e = 0$)

$$\left[0.3948 \times 0.718\times(273+80)\right] - \left[0.04924\times0.718\,(283)\right]$$

$$= \left[0.3455\times1.005\times(323)\right] + Q - W_{CV}$$

$$W_{CV} = \frac{1}{2}(200+500)(30\times10^{-3}) \text{ kPa}\,m^3$$

$$= 10.5 \text{ kJ}$$

$$\boxed{Q = -11.5961 \text{ kJ}}$$

→ This amount of heat is lost from the CV

Net Entropy change for the C.V. $= m_1\left[c_p \ln\left(\frac{T_2}{T_1}\right) - R\ln\left(\frac{P_2}{P_1}\right)\right] + m_i\left[c_p \ln\left(\frac{T_2}{T_i}\right) - R\ln\left(\frac{P_2}{P_i}\right)\right]$

~~T_b be the boundary through which Q is leaving the CV.~~

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Net Entropy change $= 0.04924\left[1.005\ln\left(\frac{353}{283}\right) - 0.287\ln\left(\frac{800}{200}\right)\right] + 0.3455\left[1.005\ln\left(\frac{353}{323}\right) - 0.283\ln\left(\frac{800}{800}\right)\right]$

Net Entropy change for CV. $= 0.0221858$ kJ/k —— (iii)

Q.2 (b) A R-12 vapour compression system includes a liquid vapour heat exchanger in the system. A system of 80 kW refrigeration capacity operates between –8°C and 42°C respectively. Refrigerant is subcooled by 5°C before entering the throttle valve and superheated by 10°C before entering the compressor. If a two-cylinder single acting reciprocating compressor with bore to stroke ratio of 1 : 1.4 operates at 1250 rpm then, determine the following

(i) COP of the system

(ii) Mass flow rate of refrigerants

(iii) Theoretical piston displacement per minute

(iv) Bore and stroke of the compressor

Assume volumetric efficiency of the compressor = 85%

Take C_{pl} = 1.24 kJ/kg°C and C_{pg} = 0.74 kJ/kg°C for R-12

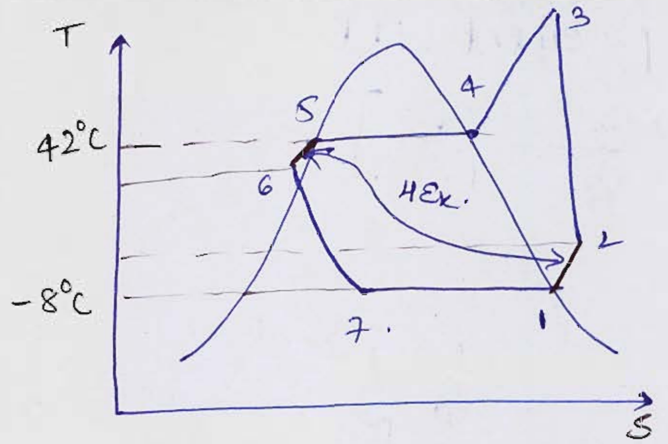
Use the following properties of R-12

Temp. (°C)	Enthalpy (kJ/kg)		Entropy kJ/kg-K		Specific volume (m³/kg)	
	Liquid	Vapour	Liquid	Vapour	Liquid	Vapour
–8	190.7	402.3	0.966	1.764	0.76×10^{-3}	0.064
+42	252.4	416.8	1.175	1.697	0.89×10^{-3}	0.014

[20 marks]

RC = 80 kW. K = 2 (2 cyl)

$\frac{D}{L} = \frac{1}{1.4}$ N = 1250 rpm



$h_1 = 402.3$ kJ/kg.

$h_2 = h_1 + C_{pg}(10)$.

$h_2 = 409.7$ kJ/kg.

$h_5 = 252.4$ kJ/kg

$h_4 = 416.8$ kJ/kg.

$h_6 = h_5 - (C_{pL} \times 5)$

$(h_6 = 246.2 = h_7) \Rightarrow$ isentropic exp.

$s_2 = 1.764 + 0.74 \ln\left(\frac{273-8+10}{273-8}\right) = s_3$.

$s_3 = 1.7914 = 1.697 + 0.74 \ln\left(\frac{T_3}{273+42}\right)$

$T_3 = 357.86$ K.

$h_3 = h_4 + C_{pv}(T_3 - T_4)$

$h_3 = 448.5197$ kJ/kg

$COP. = \frac{D.E}{W_{in}} = \frac{(h_1 - h_7)}{(h_3 - h_2)}$

$COP = 4.0211$ ⟶ (i).

$R.C = \dot{m}_{Ref}(R.E) = \dot{m}_{Ref}(h_1 - h_7)$

$\dot{m}_{Ref} = 0.5125$ kg/s ⟶ (ii)

Theoretical Piston Displacement (TPD)

$$= \frac{\pi}{4} D^2 L \frac{NK}{60} \quad \left[\frac{m^3}{s}\right].$$

~~$= \frac{\pi}{4} \times$~~

Given, $\eta_{vol} = 0.85 = \frac{m_{ref}(V_{entry})}{\left(\frac{\pi}{4} D^2 L \frac{NK}{60}\right)}$.

$$\left(\frac{\pi}{4} D^2 L \frac{NK}{60}\right) = \frac{0.5125 \times v_2}{0.85}$$

$$\frac{v_2}{v_1} = \frac{275}{265} = \frac{v_2}{0.064} \implies v_2 = 0.0664 \frac{m^3}{kg}.$$

$$TPD = 0.04004 \; m^3/s$$

$$\boxed{TPD = 2.4026 \; m^3/min} \text{ — (iii)}$$

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$$\frac{D}{L} = \frac{1}{1.4}$$

$$\frac{\pi}{4} \times D^2 \times 1.4 D \times \frac{1250 \times 2}{60} = 0.04004$$

$$D^3 = 8.74047 \times 10^{-4}$$

(iv)

Bore $\Rightarrow$ $\boxed{D = 95.612 \; mm}$

$L = 1.4D \implies \boxed{L = 133.85 \; mm}$

↑ stroke

Q.2 (c) A four cylinder tour stroke SI engine has a bore of 50 mm and stroke of 70 mm. It runs at 3200 rpm and is tested at this speed against a brake which has a torque arm of 0.35 m. The net brake load is 150 N and the fuel consumption is 6 litre per hour. The specific gravity of the fuel used is 0.78 and it has a lower calorific value of 44000 kJ/kg. A morse-test is carried out and the cylinders are cut out in the order 1, 2, 3 and 4 with the corresponding brake loads of 100, 95, 98, 104 N respectively.

For this speed calculate

(i) Brake power

(ii) Brake mean effective pressure (bmep)

(iii) Brake thermal efficiency and Brake specific fuel consumption (bsfc)

(iv) Indicated power

(v) Mechanical efficiency and Indicated mean effective pressure (imep)

[20 marks]

$k = 4$ (4 cyl) $\quad D = 0.05 m$

$n = 1$ (2 stroke) $\quad L = 0.07 m$

$N = 3200$ rpm.

$l = 0.35 m$. $\quad B_{1234} = 150 N$ (Net Brake load).

$\dot{V}_f = 6 \times 10^{-3} \frac{m^3}{hr}$ $\quad S = 0.78$

$\rho = 780 \, kg/m^3$.

$CV = 44000 \, kJ/kg$.

Morse Test brake loads 100N, 95N, 98N, 104N

(i) $BP = (\text{Brake Torque}) \times \omega$

$= (150N \times 0.35m) \times \left(\frac{2\pi \times 3200}{60}\right)$ rad/s

$BP = 17.5929 kW$ → Ans

(ii) $17.5929 = \frac{(bmep) L A N K}{60 n}$

$17.5929 = \frac{(bmep)(0.07) \frac{\pi}{4}(0.05)^2 \times 3200 \times 4}{60 \times 1}$

$bmep = 600 kPa$ → Ans

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(iii) $\dot{m}_f = \dot{V}_f \times \rho$

$= 6 \times 10^{-3} \frac{m^3}{hr} \times 780 \frac{kg}{m^3}$

$= 4.68 \ kg/hr$

$\dot{m}_f = 1.3 \times 10^{-3} \ kg/s$

$\eta_{bth} = \frac{BP}{HA/s} = \frac{17.5929}{1.3 \times 10^{-3} \times 44000}$

$\eta_{bth} = 30.7568\%$ brake Thermal efficiency → Ans

$$bsfc = \frac{\dot{m}_f (kg/hr)}{BP}$$

$$= \frac{4.8\ kg/hr}{17.5929\ kW}$$

$bsfc = 0.27284\ \frac{kg}{kW.hr}$ → Ans

(iv) Indicated load $= \Sigma 4 \times (\text{Brake load})_{1234} - \Sigma(\text{Brake load})_{1\ cyl\ cutoff}$

$$I.Load = 206\ N.$$

$$IP = (206 \times 0.35) \times \left(\frac{2\pi \times 3200}{60}\right)$$

$IP = 24.161\ kW.$ → Ans

$$24.161 = \frac{(imep)(0.07)\frac{\pi}{4}(0.05)^2 \times 3200 \times 4}{60 \times 1}$$

$imep = 8.24\ bar$
$= 824\ kPa$ → Ans

$$\eta_{mech} = \frac{BP}{IP}$$

$\eta_{mech} = 72.8152\ \%$ → Ans

mech. Efficiency

Q.3 (a) The steam at 7 bar saturated to a steam ejector water vapour refrigeration system. The temperature of the water in flash chamber is 5°C. Make up water is supplied at 20°C. The pressure in the condenser is 0.06 bar. The nozzle efficiency is 90%, the entrainment efficiency is 65% and the compression efficiency is 82%. Determine

(i) Mass of motive steam required per kg of flashed vapour.

(ii) Quality of flashed vapour from flash chamber.

(iii) Refrigeration effect per kg of flash vapour.

(iv) Mass of motive steam required per hour per ton of refrigeration.

Assume quality of mixture of motive steam and flashed vapour out the beginning of compression is 92% dry.

[Use Steam Tables attached at the end]

[20 marks]

Q.3 (b) An engine working on an Otto cycle having a compression ratio of 9, uses octane C_8H_{18} as a fuel. The lower heating value of the fuel is 44000 kJ/kg. The air fuel ratio is 14 : 1. Determine the maximum pressure and temperature reached in the cycle.

(i) Without considering the molar expansion

(ii) With molar expansion

Assume c_v = 0.71 kJ/kgK, compression follows the law $PV^{1.3}$ = constant, the pressure and temperature of the mixture at the beginning of the compression being 1.2 bar and 65°C respectively. Determine the percentage molecular expansion.

[20 marks]

.3 (c) A certain elastic balloon will support an internal pressure equal to $P_0 = 100$ kPa until the balloon becomes spherical at a diameter of $D_0 = 1$ m, beyond which $P = P_0 + C\left(1 - x^6\right)x;\ x = \dfrac{D_0}{D}$; because the offsetting effects of balloon curvature and elasticity. This balloon contains helium gas at 250 K, 100 kPa, with a 0.4 m^3 volume. The balloon is heated until the volume reaches 2 m^3. During the process the maximum pressure inside the balloon is 200 kPa.

(i) What is the temperature inside the balloon when pressure is maximum?

(ii) What are the final pressure and temperature inside the balloon?

(iii) Determine the work and heat transfer for the overall process.

[Take $R_{He} = 2.077$ kJ/kgK and $(C_V)_{\text{He}} = 3.1156$ kJ/kgK]

[20 marks]

Q.4 (a) **(i)** Atmospheric air at 35°C and 60% RH is conditioned to 22°C DBT and 55% RH. This is done first by cooling and dehumidifying and then heating. If the quantity of air flow is 50 m^3 per minutes. Find the following

1. Capacity of cooling air (in tons)
2. Capacity of heating coil (in kW)
3. Amount of water vapour added to the air per minute

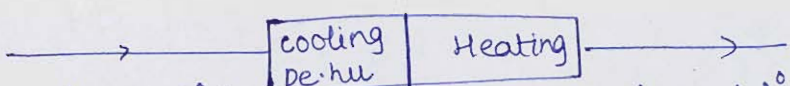
Take P_t = 1.033 bar

[Use Steam Table attached at the end]

(ii) Define the term 'bypass' factor used for cooling or heating coil and find the expression for that.

[15 + 5 marks]

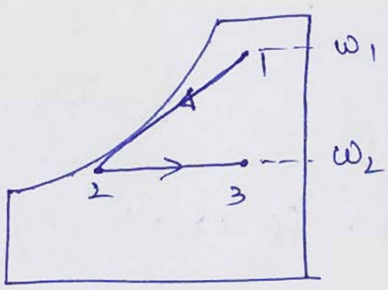
(i)



$t_1 = 35°C$ $t_3 = 22°C$

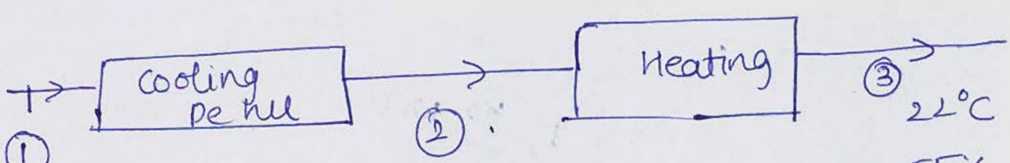
$\phi_1 = 60\%$ $\phi_3 = 55\%$

3



cmm = 50 m^3/min.

$\rho = \frac{(1.033 - P_{v1}) \times 100}{0.287 \times 308} = 1.13 \frac{kg}{m^3}$



35°C

60%

$(P_{vs})_1 = 0.05629$ Bar.

$P_{v1} = 0.03377$ Bar.

$\omega_1 = 0.622 \times \frac{P_{v1}}{P_t - P_{v1}}$

$\omega_1 = 0.021$ kg/kg da

$h_1 = 1.005 t_1 + \omega_1 (2500 + 1.88 t_1)$

$h_1 = 89.1176$ kJ/kg da.

$(P_{vs})_3 = 0.0026453$

$(P_{vs})_3 = 0.026453$ Bar.

$P_{v3} = 0.01455$ Bar

$\omega_3 = 0.622 \frac{P_{v3}}{P_t - P_{v3}}$

$\omega_3 = (8.8856 \times 10^{-3}$ kg/kg da$)$

$h_3 = 1.005(22) + \omega_3(1.88(22) + 2500)$

$h_3 = 44.69$ kJ/kg da.

$\dot{m} = \rho\left(\frac{cmm}{60}\right) = \left(1.13 \times \frac{50}{60}\right) = 0.942$ kg/s

1) capacity of cooling air $= \dot{m}(h_1 - h_3)$

$= 0.942(89.1176 - 44.69)$

$= 41.5965$ kW

$= 11.8847$ TonnR.

3. Amount of water vapour Removed.

$= \dot{m}(\omega_1 - \omega_2)$ $(\omega_2 = \omega_3)$

$= 0.942 \frac{kg}{s}(0.021 - (8.8856 \times 10^{-3}))\frac{kg}{kg\,da}$

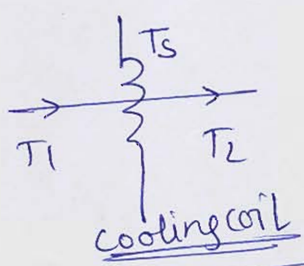
$= 0.1894 \frac{kg\ w.V}{s}$

(ii) Bypass factor (x).

consider a situation where air is passing over a coil.

3

x = Represents the fraction of air which has not come in contact with the coil.



T_s = surface temp of coil

T_1 = inlet temp.

T_2 = exit temp.

$$X = \frac{t_2 - t_s}{t_1 - t_s}$$

Q.4 (b) (i) A mixture is composed of 3 mol of CO_2 and 5 mol of N_2. It is compressed adiabatically in a cylinder from 110 kPa and 20°C to 2.2 MPa. Assuming constant specific heats for both the gases:

For CO_2 take, $c_v = 0.653$ kJ/kgK and $c_p = 0.842$ kJ/kgK

For N_2 take, $c_v = 0.745$ kJ/kgK and $c_p = 1.042$ kJ/kgK

Calculate :

1. The final temperature.
2. The work required.
3. The change in entropy.

(ii) The moment of inertia of a flywheel is 0.6 kg.m^2 and it rotates at a speed of 2100 rpm in a large insulated system at 18°C. The kinetic energy of the flywheel is distributed as frictional heat at the shaft bearings. The water equivalent of the shaft bearing is 0.8 kg. Find the rise in temperature of the shaft bearing when flywheel has come to rest. Determine the maximum possible heat which may return to the flywheel as high grade energy. Calculate how much amount of kinetic energy becomes unavailable. What would be the final rpm of the flywheel if it is set in motion with this available energy?

[10 + 10 marks]

(i) $n_{CO_2} = 3$

$n_{N_2} = 5$

Initially ①

$110\text{ kPa} = P_{total}$

$(P_{CO_2})_1 = \left(\frac{3}{3+5}\right) 110\text{ kPa}$

$(P_{CO_2})_1 = 41.25\text{ kPa}$

$(P_{N_2}) = 68.75\text{ kPa}$

$T = 293\text{ K}$

Final ②

$P_2 = 2.2\text{ MPa}$

$= 2.2 \times 1000\text{ kPa}$

$(P_{CO_2})_2 = \frac{3}{8} \times 2200$

$(P_{CO_2})_2 = 825\text{ kPa}$

$(P_{N_2})_2 = 1375\text{ kPa}$

~~$(P_{CO_2})_1$~~ $(C_p)_{mix} = \frac{3(0.842) + 5(1.042)}{8} = 0.967$

$(C_v)_{mix} = \frac{3(0.653) + 5(0.745)}{8}$

$= 0.7105$

7

$\left(\frac{T_2}{T_1}\right) = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}}$ $\gamma = \frac{(C_p)_{mix}}{(C_v)_{mix}}$ → γ of mix.

$\gamma = 1.361$

$\frac{T_2}{293} = \left(\frac{2200}{110}\right)^{\frac{0.361}{1.361}}$

$T_2 = 648.5759\text{ K}$ → final temp.

(2) work $= \frac{P_1 V_1 - P_2 V_2}{\gamma - 1}$

$= \frac{mRT_1 - mRT_2}{\gamma - 1} = \frac{n\bar{R}T_1 - n\bar{R}T_2}{\gamma - 1}$

$= \frac{(8 \times 10^{-3} \times 8.314)(293 - 648.5759)}{0.361}$

$= -65.51$ kJ.

work Required $= 65.51$ kJ.

MJ

(3) $(\Delta S) = (\Delta S)_{CO_2} + (\Delta S)_{N_2}$.

$(\Delta S)_{CO_2} = \left(\frac{3 \times 44}{1000} \text{ kg}\right)\left[0.842 \ln\left(\frac{648.5759}{293}\right) - 0.189 \ln\left(\frac{825}{41.25}\right)\right]$

$= 0.10286$ kJ/k.

$(\Delta S)_{N_2} = \left(\frac{5 \times 28}{1000} \text{ kg}\right)\left[1.042 \ln\left(\frac{648.5759}{293}\right) - 0.297 \ln\left(\frac{1375}{68.75}\right)\right]$

$(\Delta S)_{N_2} = -8.64 \times 10^{-3}$ kJ/k.

$(\Delta S) = 0.0942$ kJ/kg.

(ii) $I = 0.6\ kg\ m^2$

$N = 2100\ rpm \Rightarrow \omega = \frac{2\pi N}{60} = 219.91\ rad/s.$

$(KE)_{flywheel} = \frac{1}{2} I \omega^2$

$= 14.5083\ kJ$ = frictional heat @ shaft bearing

Let ΔT be rise in temp of shaft bearing.

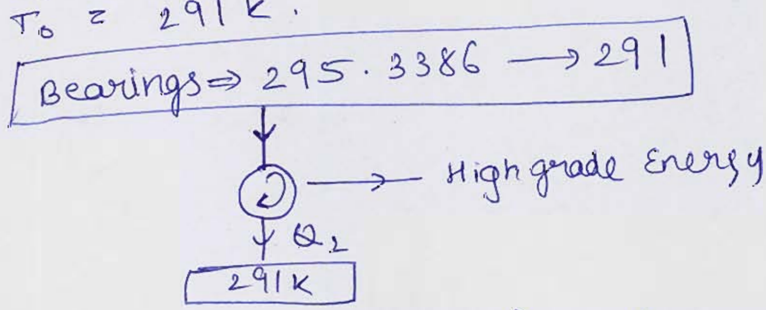
$14.5083 = 0.8 \times 4.18\ \frac{kJ}{k}\ (\Delta T)$

Rise in temp of shaft bearing. ← $\boxed{\Delta T = 4.3386\ k}$

$T_{bearing} =$

$T_0 = 273 + 18$

$T_0 = 291\ k.$



$0.8(4.18)\ \ln\left(\frac{291}{295.3386}\right) + \frac{Q_2}{291} = 0.$

Amount of Energy that becomes unavailable. ← $\boxed{Q_2 = 14.40118\ kJ.}$

max. possible heat that may return to flywheel as high grade Energy = 0.1069 kJ.

10

$0.1069 \times 1000 = \frac{1}{2} \times 0.6 \times \left(\frac{2\pi}{60}\right)^2 \times N^2.$

Final rpm of flywheel $\boxed{N = 180.2958\ rpm}$

Q.4 (c) (i) Discuss the various variables that affect the performance of an IC (Internal Combustion) engine. Also define scavenging efficiency, efficiency and combustion efficiency.

(ii) A single cylinder 4-stroke diesel engine running at 1400 rpm uses 2.3 kg of fuel per hour of specific gravity 0.88. It has an open type injector with a single orifice nozzle and the injection period of 25° crank angle. If the average injection pressure is 135 bar and the average pressure inside the cylinder is 25 bar, estimate the diameter of the fuel orifice. [Assume c_d for the nozzle = 0.88]

[10 + 10 marks]

Section B : Thermodynamics + Refrigeration and Air-conditioning + IC Engine

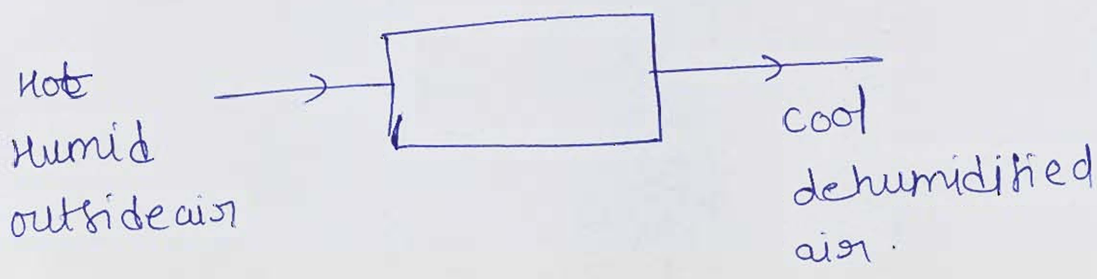
Q.5 (a) Draw a neat sketch of automatic expansion valve and explain its working.

[12 marks]

Q.5 (b) Show a systematic sketch of summer air conditioning for Hot and Humid outdoor conditions and explain its working.

[12 marks]

In summer



In summer air conditioning we perform cooling and dehumidification. in a cooling coil having ADP lower than the design room condition.

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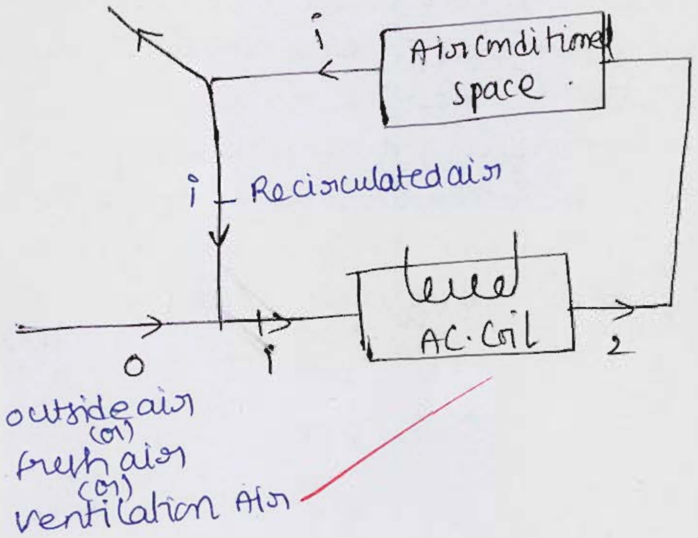

Q.5 (c) A single cylinder two stroke SI engine has 9 cm diameter bore and 12 cm stroke. The compression ratio is 9. The exhaust part opens 60° before BDC and closes 60° after BDC. The air/fuel ratio is 16 : 1. The temperature of the mixture entering into the engine is 300 K and the pressure in the cylinder at the time of closing the exhaust is 1 bar. The R for the mixture = 287 kJ/kgK. Air supplied to the engine is 180 kg/hr. The speed of the engine is 3800 rpm. Considering the effective stroke, calculate the scavenging ratio, the scavenging efficiency and the trapping efficiency.

[12 marks]

Q.5 (d) A closed rigid tank filled with water vapour, initially at 20.98 MPa, 633.22°C is cooled until its temperature reaches 439.03°C. Determine

(i) the specific volume of the water vapour in m^3/kg at the initial state.

(ii) the pressure in MPa at the final state

[Take molecular weight, critical temperature and critical pressure as 18.02 kg/Kmol, 647.3 K and 220.9 bar respectively]

[Use compressibility chart attached at the end]

[12 marks]

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Q.5 (e) A cylindrical copper rod of base area A and length L is insulated on its lateral surface. One end of the rod is in contact with a wall at temperature T_H. The other end is in contact with a wall at a lower temperature T_C. At steady state, the rate at which energy is conducted into the rod from hot wall is

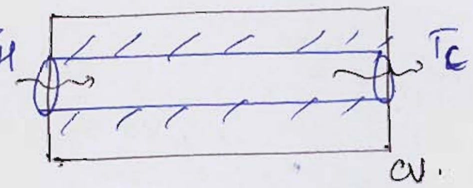
$$\dot{Q}_H = \frac{kA(T_H - T_C)}{L}$$

where K is the thermal conductivity of the copper rod.

(i) For the rod as the system, obtain an expression for the time rate of entropy production in terms of A, L, T_H, T_C and K.

(ii) If $T_H = 427°C$, $T_C = 127°C$, $k = 0.4$ kW/mK. $A = 0.1$ m^2, plot the heat transfer rate $\dot{Q}_H$ in kW, and the time rate of entropy production in kW/K, each versus L ranging from 0.2 to 1 m.

[12 marks]

(i) 

At steady state.

$$\dot{S}_{gen} = \dot{S}_e - \dot{S}_i$$

$$= \frac{Q_H}{T_L} - \frac{Q_H}{T_H}$$

$$= Q_H \left(\frac{1}{T_C} - \frac{1}{T_H}\right)$$

$$\dot{S}_{gen} = \frac{kA(T_H - T_C)}{L}\left(\frac{T_H - T_C}{T_C T_H}\right)$$

$$\boxed{\dot{S}_{gen} = \frac{kA(T_H - T_C)^2}{T_C T_H L}}$$ → Time Rate of change of entropy production

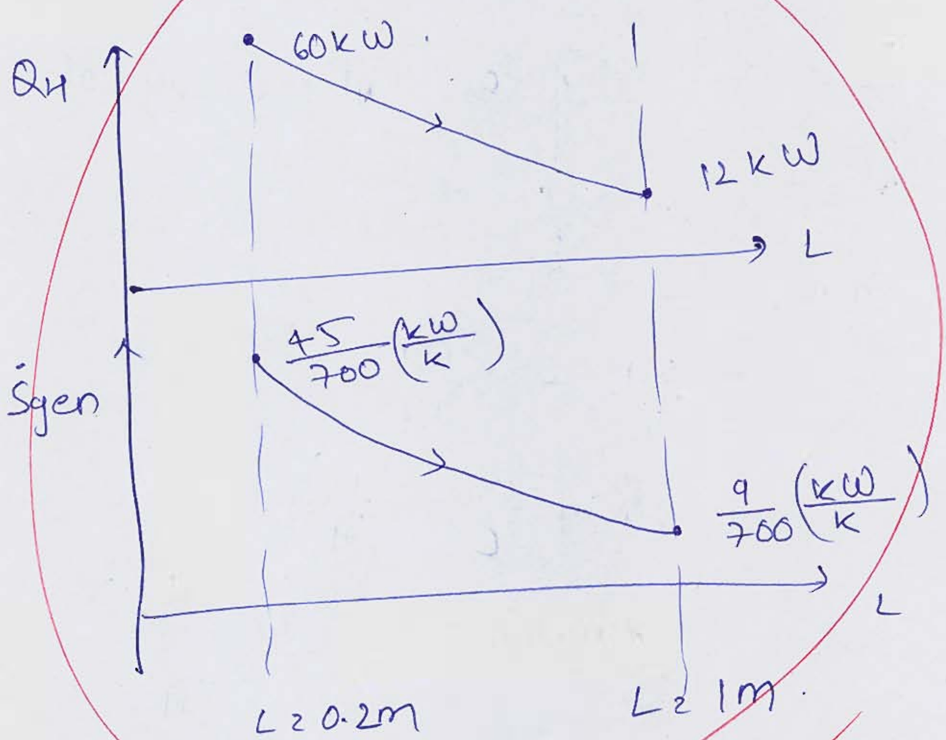
(ii) $$\dot{Q}_H = 0.4 \times 0.1 \times \frac{300}{L}$$

$$= \frac{12}{L} \text{ (kW)}$$ where L is in m.

$$\dot{S}_{gen} = \frac{KA\,(T_H - T_C)^2}{T_H T_C L} \qquad 0.2 \le L \le 1$$

$$= \frac{0.4 \times 0.1\,(300)^2}{700 \times 400 \times L} \frac{kW}{K}$$

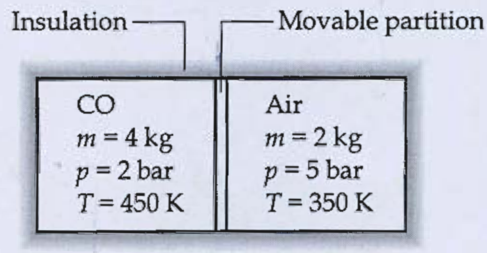
$$= \frac{9}{700 L} \frac{kW}{K}$$



(8)

Draw rectangular hyperbolic variation

Q.6 (a) Two kg of air, initially at 5 bar, 350 K and 4 kg of carbon monoxide (CO) initially at 2 bar, 450 K are confined to opposite sides of a rigid, well insulated container by a partition as shown in the figure. The partition is free to move and allows conduction from one gas to the other without energy storage in the partition itself. The air and CO each behave as ideal gases with constant specific heat ratio, $\gamma = 1.395$. Determine at equilibrium



(i) The temperature (in K)

(ii) The pressure (in bar)

(iii) The volume occupied by each gas (in m^3)

[20 marks]

T_f = common final temp. } at Eqm.

P_f = common final pressure

~~m Cv~~

$\delta Q = \Delta U + \delta W$ ($\delta Q \to 0$, $\delta W \to 0$)

both gases together with partitions as our control volume

$\Delta U = 0$

$$4 (C_v)_{CO} (T_f - 450) + 2 (C_v)_{Air} (T_f - 350) = 0$$

$$\left[4 \times \frac{1}{0.395}\left(\frac{8.314}{28}\right)(T_f - 450)\right] + \left[2 \times \cancel{\frac{1}{1.395}(8.314)}\; 0.718 \times (T_f - 350)\right] = 0$$

Cv :

T_f = ~~387.22 K~~ 417.67 K → (i)

$$(V_{CO})_1 = \frac{4 \times \frac{8.314}{28} \times 450}{200}$$

$(V_{CO})_1 = 2.6723 m^3$

$$(V_{Air})_1 = \frac{2 \times 0.287 \times 350}{500}$$

$(V_{air})_1 = 0.4018 m^3$

$V_{total} = 3.0741$

$$3.0741 = (V_{CO})_2 + (V_{air})_2$$

$$= \left[\frac{4 \times \left(\frac{8.314}{28}\right) \times \sout{387.22}\ 417.68}{P_f}\right] + \left[\frac{2 \times 0.287 \times \sout{387.22}\ 417.68}{P_f}\right]$$

~~$P_f = 221.9092$ kPa~~

$P_f = 239.36$ kPa

(ii) ← $P_f = 2.3936$ bar

(iii) $$(V_{CO})_2 = \frac{4 \times \frac{8.314}{28} \times 417.68}{2.3936 \times 100} = 2.0725\ m^3$$

$$(V_{air})_2 = \frac{2 \times 0.287 \times 417.68}{239.36} = 1.0016\ m^3$$

vol. occupied by CO $= 2.0725\ m^3$
vol. occupied by air $= 1.0016\ m^3$
} Finally.

20

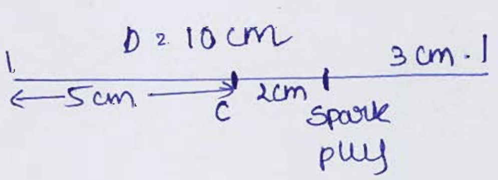
Q.6 (b) (i) List and explain the various losses that causes deviation of the actual internal combustion engine cycle from the ideal fuel-air cycle.

(ii) A spark-ignition engine runs at 2200 rpm. The compression ratio is 8, the cylinder bore is 10 cm and the engine is square. Connecting rod length is 18 cm. The spark plug is offset by 2 cm from the centre. The spark plug is offset by 2 cm from the centre. The spark plug is fired at 20° bTDC. It takes 7° of engine rotation for the combustion to develop and get into flame propagation mode. Flame termination occurs at 14° aTDC. Calculate:

1. Piston displacement from TDC position at the time of flame termination.
2. Flame travel distance.
3. Effective flame speed.

[10 + 10 marks]

(ii)



Q.6 (c) In a thermoelectric refrigeration system of 20 W cooling capacity, $T_c = -15°C$ and $T_n = 40°C$. Both the diameter and length of p-type material are 0.01 m. The length of the n-type material is also 0.01 m. The properties of thermoelectric material are as follows:

$\alpha_p = 0.00015$ V/K and $\alpha_n = -0.0002$ V/K

$\sigma_p = 1000\ \text{cm}^{-1}\ \text{Ohm}^{-1}$ and $\sigma_n = 1500\ \text{cm}^{-1}\ \text{Ohm}^{-1}$

$k_p = k_n = 1.2$ W/mK

For figure of merit to be maximum

(i) Find the area and the diameter of the n-type material, overall heat transfer coefficient U, the resistance R and the figure of merit z.

(ii) Find the COP, the current, refrigeration effect, the number of thermocouple pairs and the power for the case of maximum COP and for the case of maximum cooling.

[20 marks]

Q.7 (a) A car showroom is air-conditioned for sensible load of 58 kW and latent load of 14 kW. The inside design conditions are 25°C DBT and 50% RH and outside design conditions are 36.5°C DBT and 26°C WBT. The fresh (ventilation) air supplied to the showroom is 75 m^3/min. Determine

(i) The ventilation load

(ii) Total load to be taken by the plant

(iii) Effective sensible heat factor

(iv) Apparatus dew point

(v) Dehumidified air quantity

(vi) Conditions of air entering the apparatus.

Take bypass factor of cooling coil as 0.2.

[Use Psychrometric Chart attached at the end]

[20 marks]

Q.7 (b) Refrigerant 134a flows at steady state through a horizontal tube having an inside diameter of 0.07 m. The refrigerant enters the tube of quality of 0.1, temperature of 36°C, and velocity of 12 m/s. The refrigerant exits the tube at 9 bar as a saturated liquid. Determine

(i) The mass flow rate of the refrigerant, in kg/s.

(ii) The velocity of the refrigerant at the exit.

(iii) The rate of heat transfer, in kW, and its associated direction with respect to the refrigerant.

[Use Refrigerant Table attached at the end]

[20 marks]

Q.7 (c) A test on a single-cylinder, four stroke oil engine having bore of 16 cm and stroke 32 cm gave the following results; speed 280 rpm; brake torque 200 Nm; indicated mean effective pressure 8 bar; fuel consumption 2.5 kg/hr; cooling water flow 6 kg/min; cooling water temperature rise 35°C; air fuel ratio 20; exhaust gas temperature 400°C; barometric pressure 1 bar; room temperature 20°C. The fuel has calorific value of 42 MJ/kg and contains 16% weight of hydrogen. Take latent heat of vaporisation as 2250 kJ/kg. Determine:

(i) Indicated thermal efficiency.

(ii) Volumetric efficiency based on atmospheric conditions.

Draw up a heat balance in terms of kJ/min. Take c_p for dry exhaust gas = 1 kJ/kgK and super heated steam c_p = 2.1 kJ/kgK; R = 0.287 kJ/kgK.

[Assume that the exhaust steam is in superheated state]

[20 marks]

Q.8 (a) A dual combustion cycle operates with a compression ratio of 13 and with a cut-off ratio of 1.65. The maximum pressure is 50 bar. The pressure and temperature before compression are 1 bar and 59°C respectively. Assuming indices of compression and expansion to be 1.35. Determine

(i) The temperatures at cardinal points.

(ii) The cycle efficiency.

(iii) The mean effective pressure of the cycle.

[20 marks]

Q.8 (b) Explain the stages of combustion in Spark Ignition (SI) and Compression Ignition (CI) engines.

[20 marks]

Q.8 (c) (i) What are the design and operating variables which may decrease the formation of NO_x in the exhaust of an SI engine? Briefly explain the effect of injection timing, fuel/air ratio, type of fuel and intake air charge dilution on CI engine NO_x exhaust emission.

(ii) The compression ratio of an engine working an Diesel cycle is 22 and the air/fuel ratio is 28 : 1. The temperature at the end of compression is 970 K. The calorific value of the fuel is 42000 kJ/kg and the specific heat at constant volume of the products of combustion is given by $c_v = (0.74 + 25 \times 10^{-6}T)$ kJ/kgK and $P = 0.287$ kJ/kgK. Determine the percentage of stroke at which combustion is complete.

[10 + 10 marks]

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Thermodynamic Properties of R134a

Temp. (°C)	Pressure (MPa)	Density kg/m^3 (Liquid)	Volume m^3/kg (Vapour)	Enthalpy kJ/kg		Entropy kJ/kgK		Specific heat c_p, kJ/kgK		c_p/c_v
				Liquid	Vapour	Liquid	Vapour	Liquid	Vapour	Vapour
32.00	0.81543	1179.6	0.02513	244.62	415.78	1.1529	1.7138	1.456	1.080	1.257
34.00	0.85263	1171.6	0.02371	247.54	416.72	1.1623	1.7131	1.466	1.095	1.265
36.00	0.91185	1163.4	0.02238	250.48	417.65	1.1717	1.7124	1.476	1.111	1.273
38.00	0.96315	1155.1	0.02113	253.43	418.55	1.1811	1.7118	1.487	1.127	1.282
40.00	1.0166	1146.7	0.01997	256.41	419.43	1.1905	1.7111	1.498	1.145	1.292
42.00	1.0722	1138.2	0.01887	259.41	420.28	1.1999	1.7103	1.510	1.163	1.303
44.00	1.1301	1129.5	0.01784	262.43	421.11	1.2092	1.7096	1.523	1.182	1.314
46.00	1.1903	1120.6	0.01687	265.47	421.92	1.2186	1.7089	1.537	1.202	1.326
48.00	1.2529	1111.5	0.01595	268.53	422.69	1.2280	7.7081	1.551	1.223	1.339
50.00	1.3179	1102.3	0.01509	271.62	423.44	1.2375	1.7072	1.566	1.246	1.354
52.00	1.3854	1092.9	0.01428	274.74	424.15	1.2469	1.7064	1.582	1.270	1.369
54.00	1.4555	1083.2	0.01351	277.89	424.83	1.2563	1.7055	1.600	1.296	1.386
56.00	1.5282	1073.4	0.01278	281.06	425.47	1.2658	1.7045	1.618	1.324	1.405
58.00	1.6036	1063.2	0.01209	284.27	426.07	1.2753	1.7035	1.638	1.354	1.425
60.00	1.6818	1052.9	0.01144	287.50	426.63	1.2848	1.7024	1.660	1.387	1.448
62.00	1.7628	1042.2	0.01083	290.78	427.14	1.2944	1.7013	1.684	1.422	1.473
64.00	1.8467	1031.2	0.01024	294.09	427.61	1.3040	1.7000	1.710	1.461	1.501
66.00	1.9337	1020.0	0.00969	297.44	428.02	1.3137	1.6987	1.738	1.504	1.532
68.00	2.0239	1008.3	0.00916	300.84	428.36	1.3234	1.6972	1.769	1.552	1.567
70.00	2.1168	996.2	0.00865	304.28	428.65	1.3332	1.6956	1.804	1.605	1.607
72.00	2.2132	983.8	0.00817	307.78	428.86	1.3430	1.6939	1.843	1.665	1.653
74.00	2.3130	970.8	0.00771	311.33	429.00	1.3530	1.6920	1.887	1.734	1.705
76.00	2.4161	957.3	0.00727	314.94	429.04	1.3631	1.6899	1.938	1.812	1.766
78.00	2.5228	943.1	0.00685	318.63	428.98	1.3733	1.6876	1.996	1.904	1.838
80.00	2.6332	928.2	0.00645	322.39	428.81	1.3836	1.6850	2.065	2.012	1.924
85.00	2.9258	887.2	0.00550	332.22	427.76	1.4104	1.6771	2.306	2.397	2.232
90.00	3.2442	837.8	0.00461	342.93	425.42	1.4390	1.6662	2.756	3.121	2.820
95.00	3.5912	772.7	0.00374	355.25	420.67	1.4715	1.6492	3.938	5.020	4.369
100.00	3.9724	651.2	0.0268	373.30	407.68	1.5188	1.6109	17.59	25.35	20.81
101.06[c]	4.0593	511.9	0.00195	389.64	389.64	1.5621	1.5621	∞	∞	∞

[a]Triple point [b]NBP [c]Critical point

*Ashrae Handbook Fundamentals, 2005.

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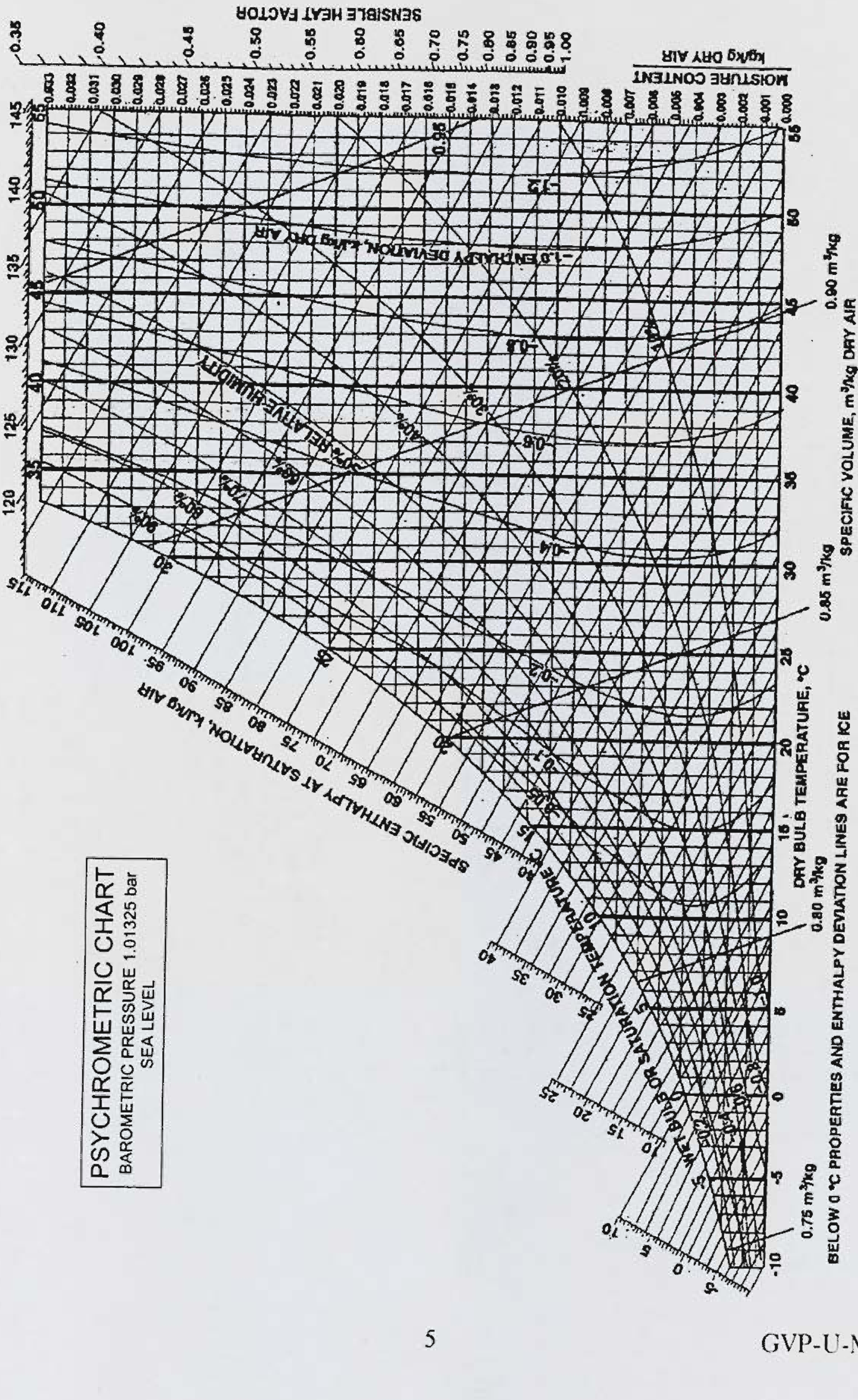
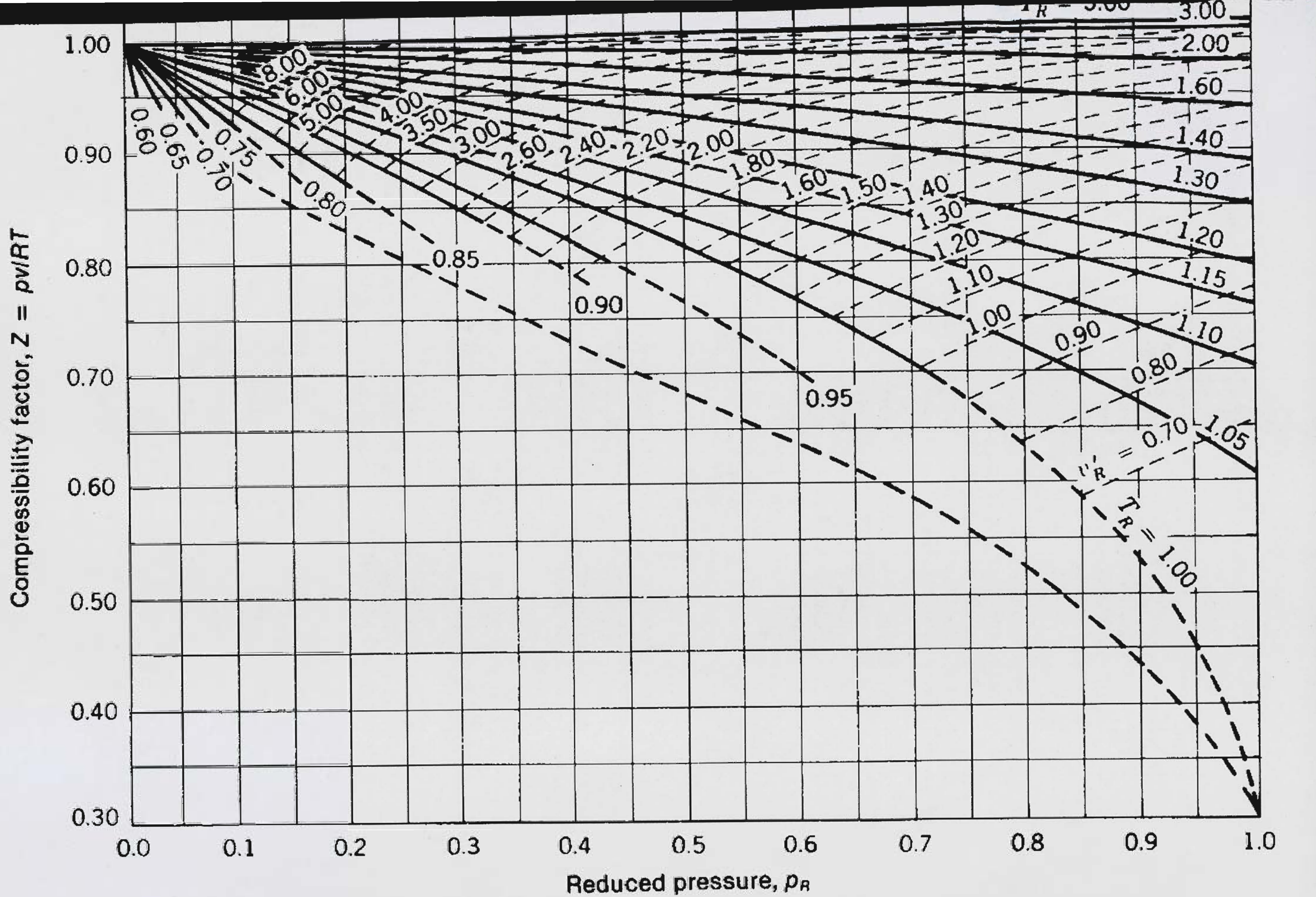
Ref. Point for S.H.F. is 25°C, 50% R.H.





Compressibility factor, Z = pv/RT
Reduced pressure, pR
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
3.00
2.00
1.60
1.40
1.30
1.20
1.15
1.10
1.05
TR = 1.00
v'R = 0.70
0.80
0.90
1.00
1.10
1.20
1.30
1.40
1.50
1.60
1.80
2.00
2.20
2.40
2.60
3.00
3.50
4.00
5.00
6.00
8.00
0.60
0.65
0.70
0.75
0.80
0.85
0.90
0.95

Saturated Water and Steam (Temperature-based)

T	p_{sat}	Volume, m^3/kg		Energy, kJ/kg		Enthalpy, kJ/kg			Entropy, kJ/(kg K)		
°C	MPa	v_f	v_g	u_f	u_g	h_f	h_g	h_{fg}	s_f	s_g	s_{fg}
0.01	0.0006117	0.00100021	205.991	0	2374.9	0.00	2500.9	2500.9	0	9.1555	9.1555
1	0.0006571	0.00100015	192.439	4.18	2376.2	4.18	2502.7	2498.6	0.01526	9.1291	9.1138
2	0.0007060	0.00100011	179.758	8.39	2377.7	8.39	2504.6	2496.2	0.03061	9.1027	9.0720
3	0.0007581	0.00100008	168.008	12.60	2379.0	12.60	2506.4	2493.8	0.04589	9.0765	9.0306
4	0.0008135	0.00100007	157.116	16.81	2380.4	16.81	2508.2	2491.4	0.06110	9.0505	8.9894
5	0.0008726	0.00100008	147.011	21.02	2381.8	21.02	2510.1	2489.0	0.07625	9.0248	8.9486
6	0.0009354	0.00100011	137.633	25.22	2383.2	25.22	2511.9	2486.7	0.09134	8.9993	8.9080
7	0.0010021	0.00100014	128.923	29.43	2384.5	29.43	2513.7	2484.3	0.10637	8.9741	8.8677
8	0.0010730	0.00100020	120.829	33.63	2386.0	33.63	2515.6	2481.9	0.12133	8.9491	8.8278
9	0.0011483	0.00100026	113.304	37.82	2387.3	37.82	2517.4	2479.6	0.13624	8.9243	8.7881
10	0.0012282	0.00100035	106.303	42.02	2388.6	42.02	2519.2	2477.2	0.15109	8.8998	8.7487
11	0.0013130	0.00100044	99.787	46.22	2390.0	46.22	2521.0	2474.8	0.16587	8.8754	8.7096
12	0.0014028	0.00100055	93.719	50.41	2391.4	50.41	2522.9	2472.5	0.18061	8.8513	8.6707
13	0.0014981	0.00100067	88.064	54.60	2392.8	54.60	2524.7	2470.1	0.19528	8.8274	8.6321
14	0.0015990	0.00100080	82.793	58.79	2394.1	58.79	2526.5	2467.7	0.20990	8.8037	8.5938
15	0.0017058	0.00100094	77.875	62.98	2395.5	62.98	2528.3	2465.4	0.22446	8.7803	8.5558
16	0.0018188	0.00100110	73.286	67.17	2396.9	67.17	2530.2	2463.0	0.23897	8.7570	8.5180
17	0.0019384	0.00100127	69.001	71.36	2398.2	71.36	2532.0	2460.6	0.25343	8.7339	8.4805
18	0.0020647	0.00100145	64.998	75.54	2399.6	75.54	2533.8	2458.3	0.26783	8.7111	8.4433
19	0.0021983	0.00100164	61.256	79.73	2400.9	79.73	2535.6	2455.9	0.28218	8.6884	8.4063
20	0.0023393	0.00100184	57.757	83.91	2402.3	83.91	2537.4	2453.5	0.29648	8.6660	8.3695
21	0.0024882	0.00100205	54.483	88.10	2403.7	88.10	2539.3	2451.2	0.31073	8.6437	8.3330
22	0.0026453	0.00100228	51.418	92.28	2405.1	92.28	2541.1	2448.8	0.32493	8.6217	8.2967
23	0.0028111	0.00100251	48.548	96.46	2406.4	96.46	2542.9	2446.4	0.33908	8.5998	8.2607
24	0.0029858	0.00100275	45.858	100.65	2407.8	100.65	2544.7	2444.0	0.35318	8.5781	8.2250
25	0.0031699	0.00100301	43.337	104.83	2409.1	104.83	2546.5	2441.7	0.36722	8.5566	8.1894
26	0.0033639	0.00100327	40.973	109.01	2410.5	109.01	2548.3	2439.3	0.38123	8.5353	8.1541
27	0.0035681	0.00100354	38.754	113.19	2411.8	113.19	2550.1	2436.9	0.39518	8.5142	8.1191
28	0.0037831	0.00100382	36.672	117.37	2413.2	117.37	2551.9	2434.6	0.40908	8.4933	8.0842
29	0.0040092	0.00100411	34.716	121.55	2414.5	121.55	2553.7	2432.2	0.42294	8.4725	8.0496
30	0.0042470	0.00100441	32.878	125.73	2415.9	125.73	2555.5	2429.8	0.43675	8.4520	8.0152
31	0.0044969	0.00100472	31.151	129.91	2417.2	129.91	2557.3	2427.4	0.45052	8.4316	7.9810
32	0.0047596	0.00100504	29.526	134.09	2418.7	134.09	2559.2	2425.1	0.46424	8.4113	7.9471
33	0.0050354	0.00100537	27.998	138.26	2420.0	138.27	2561.0	2422.7	0.47792	8.3913	7.9134
34	0.0053251	0.00100570	26.560	142.44	2421.4	142.45	2562.8	2420.3	0.49155	8.3714	7.8799
35	0.0056290	0.00100605	25.205	146.62	2422.6	146.63	2564.5	2417.9	0.50513	8.3517	7.8466
36	0.0059479	0.00100640	23.929	150.80	2424.0	150.81	2566.3	2415.5	0.51867	8.3321	7.8135
37	0.0062823	0.00100676	22.727	154.98	2425.3	154.99	2568.1	2413.1	0.53217	8.3127	7.7806
38	0.0066328	0.00100713	21.593	159.16	2426.7	159.17	2569.9	2410.8	0.54562	8.2935	7.7479
39	0.0070002	0.00100750	20.524	163.34	2428.0	163.35	2571.7	2408.4	0.55903	8.2745	7.7154
40	0.0073849	0.00100789	19.515	167.52	2429.4	167.53	2573.5	2406.0	0.57240	8.2555	7.6831

Continued . . .

p	T_{sat}	Volume, m^3/kg		Energy, kJ/kg		Enthalpy, kJ/kg			Entropy, kJ/(kg K)		
MPa	°C	v_f	v_g	u_f	u_g	h_f	h_g	h_{fg}	s_f	s_g	s_{fg}
0.40	143.608	0.00108355	0.46238	604.22	2553.1	604.65	2738.1	2133.4	1.7765	6.8955	5.1190
0.42	145.375	0.00108544	0.44165	611.79	2554.8	612.25	2740.3	2128.0	1.7946	6.8791	5.0846
0.44	147.076	0.00108729	0.42274	619.10	2556.4	619.58	2742.4	2122.8	1.8120	6.8636	5.0516
0.46	148.716	0.00108908	0.40542	626.14	2557.9	626.64	2744.4	2117.7	1.8287	6.8487	5.0199
0.48	150.300	0.00109084	0.38950	632.95	2559.3	633.47	2746.3	2112.8	1.8448	6.8344	4.9895
0.50	151.831	0.00109255	0.37481	639.54	2560.7	640.09	2748.1	2108.0	1.8604	6.8207	4.9603
0.52	153.314	0.00109423	0.36120	645.93	2562.1	646.50	2749.9	2103.4	1.8754	6.8075	4.9321
0.54	154.753	0.00109587	0.34858	652.13	2563.3	652.72	2751.5	2098.8	1.8899	6.7948	4.9049
0.56	156.149	0.00109748	0.33682	658.16	2564.5	658.77	2753.1	2094.4	1.9040	6.7825	4.8786
0.58	157.506	0.00109905	0.32585	664.01	2565.7	664.65	2754.7	2090.0	1.9176	6.7707	4.8531
0.60	158.826	0.00110060	0.31558	669.72	2566.8	670.38	2756.1	2085.8	1.9308	6.7592	4.8284
0.62	160.112	0.00110212	0.30596	675.28	2567.9	675.96	2757.6	2081.6	1.9437	6.7482	4.8045
0.64	161.365	0.00110362	0.29691	680.70	2568.9	681.41	2758.9	2077.5	1.9562	6.7374	4.7813
0.66	162.587	0.00110509	0.28840	686.00	2570.0	686.73	2760.3	2073.5	1.9684	6.7270	4.7587
0.68	163.781	0.00110654	0.28036	691.17	2570.9	691.92	2761.5	2069.6	1.9802	6.7169	4.7367
0.70	164.946	0.00110796	0.27277	696.22	2571.9	697.00	2762.8	2065.8	1.9918	6.7071	4.7153
0.72	166.086	0.00110936	0.26559	701.17	2572.7	701.97	2763.9	2062.0	2.0031	6.6975	4.6944
0.74	167.200	0.00111075	0.25879	706.02	2573.6	706.84	2765.1	2058.2	2.0141	6.6882	4.6741
0.76	168.291	0.00111211	0.25233	710.76	2574.4	711.61	2766.2	2054.6	2.0248	6.6791	4.6543
0.78	169.360	0.00111346	0.24618	715.41	2575.3	716.28	2767.3	2051.0	2.0354	6.6703	4.6349
0.80	170.406	0.00111478	0.24034	719.97	2576.0	720.86	2768.3	2047.4	2.0457	6.6616	4.6160
0.82	171.433	0.00111609	0.23477	724.44	2576.8	725.36	2769.3	2043.9	2.0557	6.6532	4.5975
0.84	172.440	0.00111739	0.22946	728.84	2577.6	729.78	2770.3	2040.5	2.0656	6.6449	4.5793
0.86	173.428	0.00111867	0.22438	733.15	2578.2	734.11	2771.2	2037.1	2.0753	6.6369	4.5616
0.88	174.398	0.00111993	0.21953	737.38	2578.9	738.37	2772.1	2033.8	2.0847	6.6290	4.5443
0.90	175.350	0.00112118	0.21489	741.55	2579.6	742.56	2773.0	2030.5	2.0940	6.6213	4.5272
0.92	176.287	0.00112242	0.21044	745.65	2580.3	746.68	2773.9	2027.2	2.1032	6.6137	4.5106
0.94	177.207	0.00112364	0.20617	749.67	2580.9	750.73	2774.7	2024.0	2.1121	6.6063	4.4942
0.96	178.112	0.00112485	0.20208	753.64	2581.5	754.72	2775.5	2020.8	2.1209	6.5991	4.4782
0.98	179.002	0.00112605	0.19814	757.55	2582.1	758.65	2776.3	2017.7	2.1296	6.5920	4.4624
1.00	179.878	0.00112723	0.19436	761.39	2582.7	762.52	2777.1	2014.6	2.1381	6.5850	4.4470
1.05	182.009	0.00113014	0.18552	770.75	2584.1	771.94	2778.9	2007.0	2.1587	6.5681	4.4095
1.10	184.062	0.00113299	0.17745	779.78	2585.4	781.03	2780.6	1999.6	2.1785	6.5520	4.3735
1.15	186.043	0.00113577	0.17006	788.51	2586.6	789.82	2782.2	1992.4	2.1976	6.5365	4.3390
1.20	187.957	0.00113850	0.16326	796.96	2587.8	798.33	2783.7	1985.4	2.2159	6.5217	4.3058
1.25	189.809	0.00114118	0.15699	805.15	2588.9	806.58	2785.1	1978.6	2.2337	6.5074	4.2737
1.30	191.605	0.00114380	0.15119	813.11	2590.0	814.60	2786.5	1971.9	2.2508	6.4936	4.2428
1.35	193.347	0.00114638	0.14580	820.84	2590.9	822.39	2787.7	1965.3	2.2674	6.4803	4.2129
1.40	195.039	0.00114892	0.14078	828.36	2591.7	829.97	2788.8	1958.9	2.2835	6.4675	4.1839
1.45	196.685	0.00115141	0.13609	835.68	2592.6	837.35	2789.9	1952.6	2.2992	6.4550	4.1559
1.50	198.287	0.00115387	0.13171	842.83	2593.4	844.56	2791.0	1946.4	2.3143	6.4430	4.1286

Continued ...

Water/Steam at $p = 0.60$ MPa ($T_{sat} = 158.826$°C)

T	v	u	h	s
°C	m^3/kg	kJ/kg	kJ/kg	kJ/kg K
0	0.00099990	-0.03	0.57	-0.00011
5	0.00099979	21.02	21.62	0.07624
10	0.00100006	42.01	42.61	0.15103
15	0.00100067	62.95	63.55	0.22437
20	0.00100157	83.88	84.48	0.29636
25	0.00100273	104.78	105.38	0.36707
30	0.00100415	125.68	126.28	0.43657
35	0.00100578	146.57	147.17	0.50492
40	0.00100762	167.46	168.06	0.57217
45	0.00100966	188.34	188.95	0.63836
50	0.00101189	209.24	209.85	0.70354
55	0.00101429	230.14	230.75	0.76773
60	0.00101687	251.06	251.67	0.83098
65	0.00101961	271.98	272.59	0.89333
70	0.00102251	292.92	293.53	0.95479
75	0.00102557	313.86	314.48	1.0154
80	0.00102879	334.83	335.45	1.0752
85	0.00103217	355.82	356.44	1.1342
90	0.00103569	376.83	377.45	1.1925
95	0.00103937	397.86	398.48	1.2500
100	0.00104321	418.91	419.54	1.3068
105	0.00104719	440.00	440.63	1.3630
110	0.00105134	461.12	461.75	1.4184
115	0.00105564	482.27	482.90	1.4733
120	0.00106010	503.45	504.09	1.5275
125	0.00106472	524.69	525.33	1.5812
130	0.00106951	545.97	546.61	1.6343
135	0.00107447	567.29	567.93	1.6869
140	0.00107961	588.67	589.32	1.7390
145	0.00108492	610.11	610.76	1.7905
150	0.00109042	631.61	632.26	1.8417
155	0.00109611	653.16	653.82	1.8923
158.826	0.00110060	669.72	670.38	1.9308
158.826	0.31558	2566.8	2756.1	6.7592
160	0.31668	2569.0	2759.0	6.7659
165	0.32129	2578.3	2771.1	6.7937
170	0.32583	2587.5	2783.0	6.8206
175	0.33032	2596.4	2794.6	6.8466
180	0.33475	2605.1	2806.0	6.8720
185	0.33915	2613.8	2817.3	6.8968
190	0.34350	2622.4	2828.5	6.9211
195	0.34783	2630.9	2839.6	6.9449
200	0.35212	2639.3	2850.6	6.9683
210	0.36063	2656.0	2872.4	7.0139
220	0.36905	2672.5	2893.9	7.0580
230	0.37740	2688.9	2915.3	7.1008
240	0.38568	2705.1	2936.5	7.1426
250	0.39390	2721.3	2957.6	7.1832
260	0.40208	2737.3	2978.5	7.2230
270	0.41021	2753.4	2999.5	7.2619

T	v	u	h	s
°C	m^3/kg	kJ/kg	kJ/kg	kJ/kg K
270	0.41021	2753.4	2999.5	7.2619
280	0.41831	2769.3	3020.3	7.3000
290	0.42638	2785.4	3041.2	7.3373
300	0.43442	2801.3	3062.0	7.3740
310	0.44243	2817.3	3082.8	7.4100
320	0.45042	2833.3	3103.6	7.4453
330	0.45839	2849.4	3124.4	7.4801
340	0.46634	2865.5	3145.3	7.5144
350	0.47427	2881.5	3166.1	7.5481
360	0.48219	2897.7	3187.0	7.5813
370	0.49010	2913.8	3207.9	7.6141
380	0.49799	2930.0	3228.8	7.6464
390	0.50587	2946.3	3249.8	7.6782
400	0.51374	2962.6	3270.8	7.7097
410	0.52160	2978.8	3291.8	7.7407
420	0.52945	2995.2	3312.9	7.7713
430	0.53729	3011.6	3334.0	7.8016
440	0.54513	3028.1	3355.2	7.8315
450	0.55296	3044.7	3376.5	7.8611
460	0.56078	3061.2	3397.7	7.8903
470	0.56859	3077.9	3419.1	7.9192
480	0.57640	3094.7	3440.5	7.9478
490	0.58420	3111.4	3461.9	7.9761
500	0.59200	3128.2	3483.4	8.0041
520	0.60758	3162.1	3526.6	8.0592
540	0.62315	3196.1	3570.0	8.1132
560	0.63870	3230.4	3613.6	8.1663
580	0.65424	3265.0	3657.5	8.2183
600	0.66976	3299.8	3701.7	8.2695
620	0.68528	3334.9	3746.1	8.3198
640	0.70078	3370.3	3790.8	8.3693
660	0.71628	3405.9	3835.7	8.4180
680	0.73176	3441.8	3880.9	8.4659
700	0.74725	3478.0	3926.4	8.5131
720	0.76272	3514.6	3972.2	8.5597
740	0.77819	3551.3	4018.2	8.6056
760	0.79365	3588.3	4064.5	8.6508
780	0.80911	3625.6	4111.1	8.6954
800	0.82457	3663.2	4157.9	8.7395
820	0.84002	3701.0	4205.0	8.7830
840	0.85547	3739.1	4252.4	8.8260
860	0.87091	3777.6	4300.1	8.8684
880	0.88635	3816.2	4348.0	8.9103
900	0.90178	3855.1	4396.2	8.9518
920	0.91722	3894.4	4444.7	8.9927
940	0.93265	3933.8	4493.4	9.0332
960	0.94808	3973.6	4542.4	9.0733
980	0.96351	4013.5	4591.6	9.1129
1000	0.97893	4053.7	4641.1	9.1521

Space for Rough Work

Space for Rough Work