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ESE 2026 : Mains Test Series

UPSC ENGINEERING SERVICES EXAMINATION

Mechanical Engineering

Test-1 : Thermodynamics [All Topics]

IC Engine + Refrigeration and Air-conditioning [All Topics]

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	31
Q.2	32
Q.3	27
Q.4	—
Section-B	
Q.5	25
Q.6	40
Q.7	—
Q.8	—
Total Marks Obtained	155

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

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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

.1 (a) (i) A turbo compressor delivers 3.5 m^3/s of air at 0.5 MPa, 50°C The air is then heated at a constant pressure of 0.5 MPa to 450°C in a heater and finally expanded in a turbine which delivers 2 MW. During Expansion, there is a heat transfer of 0.05 MJ/s to the surroundings. Calculate the turbine exhaust temperature if changes in kinetic and potential energy in the turbine are negligible.

(ii) The Clausius inequality forms the basis of the second law of thermodynamics and provide a criterion for the direction of heat transfer and the feasibility of thermodynamic processes.

1. State the Clausius inequality and explain its physical significance.
2. Using Clausius inequality, drive the concept of entropy for a closed system.
3. Discuss how the entropy change differs for reversible and irreversible processes, with suitable thermodynamic reasoning.

[6 + 6 marks]

1) Given

$Q = 3.5\ m^3/s$

$P_2 = 0.5\ mPa$

$T_2 = 50^\circ C$

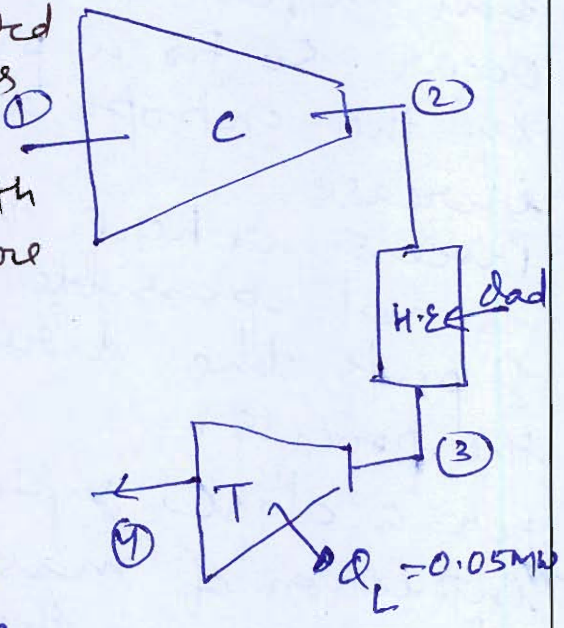
$P_3 = 0.5\ mpa$

$T_3 = 450^\circ C$

$W_T = 2MW$

Assumption:

- Air is treated as ideal gas
- Cp, Cv do not changes with temperature



Assuming turbine is a steady flow device

Apply SFEE in Turbine

$$Q - W = m(h_2 - h_1 + \frac{V_2^2 - V_1^2}{2000} + g(z_2 - z_1)$$

given, Neglecting K.E & P.E changes

$$Q - W = m(h_3 - h_4)$$

$$-50 - 2000 = \dot{m}\{cp(T_3 - T_4) \quad — ①$$

$$P_1 V_1 = mRT_1$$

$$500 \times 3.5 = \dot{m}_a \times 0.287 \times 323$$

$$\dot{m}_a = 18.877\ kg/s$$

$-2050 = 18{\cdot}877\{1{\cdot}005[-450+T_4]$

$-108{\cdot}0523 = -450 + T_4$

4

$T_4 - 450 = -108{\cdot}0523$

$T_4 = 341.9476$ K

or $68{\cdot}9476$°C

ii) Clausius inequality

$$ds = S_{gen} + \frac{dQ}{T} \quad -①$$

For a process to occur $ds \geq 0$ equality hold only for reversible process but in nature reversible process do not occur. So for a process to occur spontaneously the entropy during the process should increase.

Process where the entropy decreases is not possible in nature.

It puts the directional Constrain on the process.

3

For a closed system, there is no interaction of mass ie mass is fixed only energy in the form of work and heat can interact with system.

Heat added to system increases the entropy and vice versa

Work is a form of high grade energy. It cannot transfer entropy but can generate entropy within the system.

·Entropy is property thus it depends on initial and final location not on the path. So for both Rev. & Irr. process b/w 1 & 2 entropy change is same but entropy generation is different.

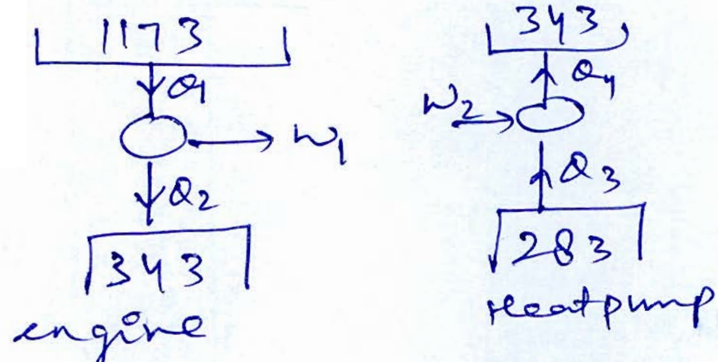
.1 (b) A heat pump working on the Carnot cycle extract heat from a reservoir at 10°C and delivers heat to a reservoir at 70°C. The heat pump is driven by a reversible heat engine operating between 900°C and 70°C. The reversible heat engine also drives a machine that absorbs 40 kW of work. If the heat pump extracts 20 kJ/s from the 10°C reservoir, determine:

(i) The rate of heat supply from 900°C source.

(ii) The rate of heat rejection to 70°C sink.

[12 marks]

Both the heat pump & Heat engine are reversible devices.



$\eta_{HE} = 1 - \frac{T_L}{T_H} \Rightarrow 1 - \frac{343}{1173} \rightarrow 0.70758$

$\eta_{HE} = \frac{W_1}{Q_1} \Rightarrow 0.70758\, Q_1 = W_1$

Heat engine does 40KW of work to some other m/c

Work Available for Heat pump $\Rightarrow (0.70758Q_1 - 40)$

$COP_{HP} = \frac{343}{343-283} \quad \left\{ \because \frac{T_H}{T_H - T_L} \right\}$

$= 5.7166 \Rightarrow \frac{Q_4}{W_2} \quad -①$

$\therefore W_2 = 0.70758Q_1 - 40 \quad -②$

given: $Q_3 = 20\,KW$

Ist law $Q_3 + W_2 = Q_4$

$20 + 0.70758Q_1 - 40 = Q_4$

$0.70758Q_1 - 20 = Q_4$

so $5.7166 = \frac{0.70758Q_1 - 20}{0.70758Q_1 - 40} \quad -③$

from Eq^n ③ Q_1 = ~~43.9101~~ ~~kw~~ 62.52344 kw

and W_1 = ~~31.0699~~ 44.24 kw

W_2 = 4.24 kw

Q_4 = $W_2 + Q_3$

= 24.24 kw

1) Rate of heat supply Q_1 = 62.52344 kw

2) Rate of Heat rejection = $Q_2 + Q_4$

⇒ 18.2834 + 24.24

⇒ 42.5234 kw

12

Q.1 (c) An ideal gas cycle is represented by a rectangle on a P-V diagram. If P_1 and P_2 are the lower and higher pressures; and V_1 and V_2, be the smaller and larger volumes, respectively. Then,

(i) Calculate the net work done per cycle.

(ii) Show that the thermal efficiency of the cycle is given by

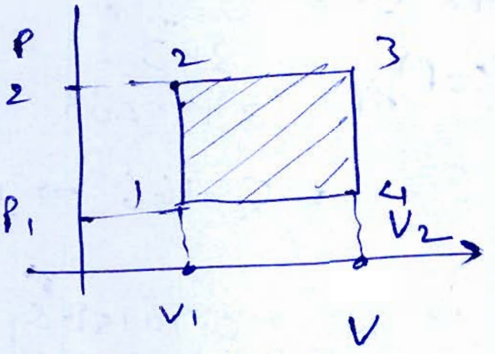
$$\eta = \frac{\gamma - 1}{\frac{\gamma P_2}{P_2 - P_1} + \frac{V_1}{V_2 - V_1}}$$ if the specific heat capacities are constant

[12 marks]

1) For Net workdone per cycle

we know that

The Area under the P-V digram represent the workdone during the process



Process 1→2: Isochoric heat addition

2→3: Isobaric expansion

3→4: Isochoric heat rejection

4→1: Isobaric compression

Process 1→2

$$Q_{1-2} = U_{1-2} + \cancel{W_{1-2}} \to 0$$

$W_{1-2} = 0$ {Isochoric process)

$Q_{dd} = C_v(T_2 - T_1)$ KJ/Kg

Process 2-3: $W_{2-3} = P_2(V_3 - V_2)$ KJ/Kg

$U_{2-3} = C_v(T_3 - T_2)$

Process 3-4: $W_{3-4} = 0$

$Q_{rej} = C_v(T_3 - T_4)$ KJ/Kg

Process 4→1: $W_{4-1} = P_1(V_4 - V_1)$

$U_{4-1} = C_v(T_4 - T_1)$

Now work done is Area under the curve so Net enclosed area is work

$W_{Net} = (P_2 - P_1) \times (V_2 - V_1)$

{Area of rectangle)

$= (P_2V_2 - P_2V_1 - P_1V_2 + P_1V_1)$

Qadd during Compression (4-1) = $C_p(T_1 - T_4)$

Total heat added ⇒ $C_p(T_1 - T_4) + C_v(T_2 - T_1)$

$$\eta = \frac{W_{Net}}{Q_{added}} \Rightarrow \frac{(P_2 - P_1)(V_2 - V_1)}{C_p(T_1 - T_4) + C_v(T_2 - T_1)}$$

Q.1 (d) In the temperature range between 0°C and 100°C a particular thermodynamic system maintained at constant volume has a temperature dependent heat capacity given by,

$C_v = A + 2BT$ [where 'T' is in Kelvin (K)]

and, the constant A and B are 0.019 J/K and $B = 5.8 \times 10^{-4}$ J/K^2

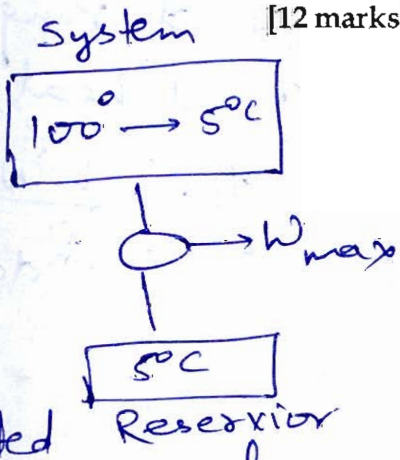
A heat reservoir at 5°C and a reversible work source are available. What is the maximum amount of work that can be transferred to the reversible work source as the system is cooled from 100°C to the temperature of the reservoir?

[12 marks]

$C_v = A + 2BT$ → given

$A = 0.019$ J/K

$B = 5.8 \times 10^{-4}$ J/K^2



Max Amont of work can be obtained when a reversible heat engine is installed between the thermodynamic system mainted at Constant volume and the thermal reservior.

$\therefore T_L = 5°C$ or 278 K

We know that

$$\eta_{HE} = 1 - \frac{T_L}{T_H}$$

Here $\left.\begin{matrix} T_1 = 373 K \\ T_2 = 273 \end{matrix}\right\}$ given.

$\eta = 1 - \frac{278}{T}$

dQ ⇒ let dQ be the small amont of heat extracted/rejected when system cools and we know

$$dw = \eta \times dQ$$

$$dw = \left(1 - \frac{278}{T}\right) dQ \quad -①$$

$$\text{and } dQ = C_v\, dT$$

Put in ①

$$dw = \left(1 - \frac{278}{T}\right) C_v\, dT$$

Integrate both side

$$\int dw = \int_{T_1}^{T_2} \left(1 - \frac{278}{T}\right)(A + 2BT)\, dT$$

$$W = \int_{T_1}^{T_2} (A + 2BT) - 278\left(\frac{A + 2BT}{T}\right) dT$$

$$= \left[AT + \frac{2BT^2}{2}\right]_{T_1}^{T_2} - 278\left\{A \ln T + 2BT\right\}_{T_1}^{T_2}$$

$$= A(T_2 - T_1) + B(T_2^2 - T_1^2] - 278\left\{A \ln \frac{T_2}{T_1} - 2B(T_2 - T_1)\right)$$

$$W \Rightarrow 0.019\{273 - 373\} + 5.8 \times 10^{-4}\{273^2 - 373^2]$$

$$-278\{0.019 \ln \frac{273}{373} - 2 \times 5.8 \times 10^{-4}\{273 - 373]$$

$$\Rightarrow -1.9 + (-37.468\} - 278\{-0.00593 + 0.116]$$

$$-39.368 - 30.59946$$

$$-69.96746\ J$$

Max Reversible work that can be transferred from system is <u>69.96746 J</u>

Q.1 (e) Air expands steadily through a turbine from 7 bar, 850 K to 1 bar, 500 K. During the expansion, heat transfer from air to the surroundings at 300 K is 15 kJ/kg. Neglect the change in kinetic and potential energies. Evaluate:

(i) The irreversibility per kg air

(ii) Actual Work

(iii) Maximum Work

Assume air to behave as an ideal gas with $c_p = 1.0$ kJ/kg.K and $R = 0.287$ kJ/kg.K.

[12 marks]

Given

$P_1 = 7$ bar

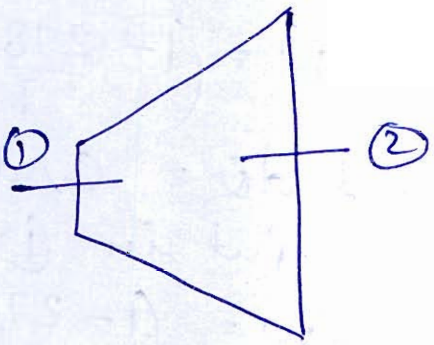
$T_1 = 850$K

$P_2 = 1$ bar

$T_2 = 500$K

$Q = 15$ KJ/kg

at 300 K



Given:- Neglect change in kinetic & potential energy changes

Assumption:

C_p, C_v, γ do not change with temperature

Atmospheric temperature = 300 K

Atm pressure = 1 bar

Now,

iii) Max. Work = $X_1 - X_2$

$$\rightarrow h_1 - h_2 - T_0(s_1 - s_2) + Q$$

$$C_p(T_1 - T_2) - 300(s_1 - s_2) + 300\left\{\frac{Q}{T_0}\right\}$$

$$1.00\{850 - 500) - 300\left\{1.00 \ln\frac{T_1}{T_2} - 0.287 \ln\frac{P_1}{P_2}\right\}$$

$$\left\{ \begin{array}{l} \text{Here} \\ s_1 - s_2 = mC_p \ln\frac{T_2}{T_1} - mR\ln\frac{P_1}{P_2} \end{array} \right.$$

$$350 - 300\left\{\ln\frac{850}{500} - 0.287 \ln 7\right\} + 15$$

$$350 - 300\{0.530628 - 0.558476\} + 15$$

$$350 + 8.35446 + 15$$

$$= 358.3544 \text{ KJ/kg} + 15 \Rightarrow \boxed{\underline{373.3544 \text{ KJ/kg}}}$$

ii) Actual work: Using SFEE

$\dot{Q} - W = (h_2 - h_1)$ $\{T_1 = 850K, T_2 = 500K\}$

$-15 - W = C_p(T_2 - T_1)$

$-15 - W = -850 + 500$

$-15 - W = -350$

$-W = -350 + 15$ ✓

$-W = -335$

$W_a = \underline{335\ KJ/kg}$

i) • Irreversibility $= W_{max} - W_{actual}$

$= 373.3544 - 335$

$= \underline{38.3544\ KJ/kg}$

4

2 (a) An air preheater is used to heat up the air used for combustion by cooling the outgoing products of combustion from a furnace. The rate of flow of the products is 20 kg/s and products are cooled from 400°C to 200°C and for the products at this temperature $c_p = 1.03$ kJ/kgK. The rate of air flow is 18 kg/s, the inlet air temperature is 30°C and for the air $c_p = 1005$ kJ/kgK.

(i) What is initial and final availability of the products?

(ii) What is the irreversibility for this process?

(iii) If heat transfer from the products were to take place reversibly through heat engines, what would be the final temperature of the air? What power would be developed by heat engine?

[Take surrounding temperature, $T_0 = 300$ K]

[20 marks]

a) Assuming Air preheater is a steady flow device & there is No heat loss to surrounding i.e it is perfectly insulated

Given: $\dot{m}_p = 20 kg/s$ $C_p = 1.03\ KJ/kgK$

$T_1 = 400°C$

$T_2 = 200°C$

$\dot{m}_a = 18 kg/s$ $C_p = 1.005$

$T_i = 30°C$

Energy Conservation

Heat lost by product = Heat gained by air

$mC_p(T_1 - T_2)\Big|_p = mC_p(T_i - T_f)_{air}$

$20 \times 1.03(400-200) = 18 \times 1.005(T-30)$

$T_f = 257.75^\circ C$

i) Initial Availability of products

$X_1 - X_0 = h_1 - h_0 - T_0(S_1 - S_0)$

Here Assuming pressure of air preheater is same as atmospheric pressure

$T_0 = 300K$ (given) or $27^\circ C$

$X_1 - X_0 = 1.03\{400-27) - 300(S_1 - S_0)$

Assuming products to be ideal gas and C_p, C_v of products do not vary with temperature.

$X_1 - X_0 = 384.19 - 300(C_p \ln T_1/T_0 - R \ln P_1/P_0)$

$P_1 = P_0$

$X_1 - X_0 = 384.19 - 300\{1.03 \ln 673/300]$

$384.19 - 249.66$

134.529 KJ/Kg

$(X_1 - X_0)_{init} = 134.529 \times \dot{m}$

$\rightarrow 2690.5895$ KW

Final Availability

$(X_2 - X_0) = h_2 - h_0 - T_0(S_2 - S_0)$

$= 1.03(200-27) - 300(1.03 \ln \frac{473}{300})$

$178.19 - 140.6916$

37.4984 KJ/Kg

$X_2 - X_0 = 749.968$

ii) Irreversibility for this process

$$Irr = T_0 (\dot{S}_{gen})_{Total}$$

$$\dot{S}_{gen}|_{Total} = \dot{S}_{gen}(prod) + \dot{S}_{gen}(air)$$

$$= (mC_p)_{pro} \ln T_2/T_1 + (mC_p)_{air} \ln \frac{T_f}{T_i}$$

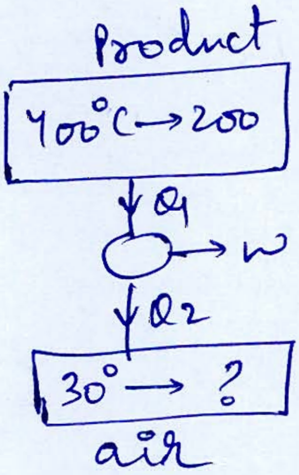
$$\Rightarrow 20 \times 1.03 \ln \frac{473}{673} + 18 \times 1.005 \ln \left(\frac{530.75}{303}\right)$$

$$-7.26458 + 10.140499 \quad \text{—} ①$$

$$\dot{S}_{gen}|_{Total} = 2.8759$$

$$Irr = T_0 \times \dot{S}_{gen} \Rightarrow 300 \times 2.8759$$

$$\Rightarrow 862.773 \text{ kW}$$



For Reversible (ΔS) for both the process = 0

$$\Delta S|_P + \Delta S|_{air} = 0$$

From eqn ① $\Delta S|_p = -7.26458$

$$-7.26458 + \Delta S|_{air} = 0$$

$$18 \times 1.005 \ln \frac{T_f}{303} = 7.26458$$

$$\ln T_f/303 = 0.401579$$

$$T_f = 452.737 \text{ K}$$

or 179.73°C

Power developed $= Q_1 - Q_2$

$$\dot{m}c_p(400-200)|_{prod} - mC_p(179.73-30)|_{air}$$

$$4120 - 2708.6157$$

1411.38 kW work/power

20

Q.2 (b) Air enters a compressor at 1 bar 27°C, which is also the state of the environment. It leaves at 4 bar, 164°C and 110 m/s. Neglecting inlet velocity and potential energy effect, determine:

(i) Whether the compression is adiabatic or polytropic.

(ii) If not adiabatic, the polytropic index.

(iii) Isothermal efficiency.

(iv) Minimum work input and irreversibility.

(v) The second law efficiency.

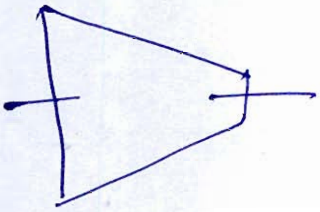
[Take c_p of air = 1.003 kJ/kgK, $\gamma = 1.4$]

[20 marks]

Assumption:

. Treating air as ideal gas

• C_p, C_v do not changes with temperature



Given

$P_1 = 1$ bar } Same as atmosphere

$T_1 = 27°C$

$P_2 = 4$ bar

$T_2 = 164$ °C

$V_2 = 110$ m/s

i) If $\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}}$

$$\frac{437}{300} = \left(\frac{4}{1}\right)^{\frac{n-1}{n}}$$

$$1.45666 = 4^{n-1/n}$$

$$ln(1.4566) = \frac{n-1}{n} \ln 4$$

$$0.271335 = 1 - 1/n$$

$$1/n = 0.72866$$

$$n = 1.3723$$

Process is polytropic with index

$n \Rightarrow 1.3723$

iii $W_{poly} = \frac{n}{n-1} R(T_1 - T_2)$ kJ/kg

$\frac{1.3723}{0.3723} \times 0.287 \times (27-164)$

$W_{poly} = -144.93$ → compression work

here isothermal work

$W_{iso} = mRT \ln P_1/P_2$

$0.287 \times 300 \ln 1/4$

$W_{iso} = -119.3599$ kJ/kg

isothermal eff = $\cancel{\frac{W_{poly}}{W_{iso}}} \Rightarrow \frac{W_{iso}}{W_{poly}}$

$\Rightarrow \frac{119.3599}{144.93} = 0.82356$

or 82.356%

iv) Minimum work $= X_1 - X_2$

$= \cancel{c_p}\ h_1 - h_2 - T_0(s_1 - s_2)$

3

$1.003\{27-164) - 300(s_1 - s_2)$

$-137.411 - 300\left(1.003 \ln \frac{300}{437} - 0.287 \ln \frac{1}{4}\right)$

$-137.411 - 300\{-0.377279 + 0.397866)$

$-137.411 + 6.176244 \Rightarrow -131.234$ kJ/kg

$W_{rev} = -143.5872$ kJ/kg

$W_{act} = ?$ $Q - W = \left(h_2 - h_1 + \frac{V_2^2 - V_1^2}{2000}\right)$

V_1 no given

$+137.411 + \frac{110^2}{2000}$

~~+198.461~~ 143.461 kJ/kg

Irreversibility $= |W_{rev} - W_{act}| \Rightarrow 143.461 - 131.234$

12.226 kJ/kg

5) second Law effⁿ : ($\frac{W_{rev}}{W_{act}}$

$$= \frac{131.324}{143.461}$$

91.530%

Q.2 (c) (i) An object of mass 20 kg falls down freely, starting from nest through a distance of 20 m. During this free fall it experience a resistance F, due to air which is given by

$$F = \frac{V^2}{200} \text{ Newton}$$

where V is the instantaneous velocity of the object in m/s. Assuming the process to be adiabatic, find the work transfer and the final velocity of the object. [Take g = 9.8 m/s]

(ii) Enumerate the different types of work encountered in thermodynamics. For each type, briefly explain its physical significance and state weather work is a point function or path function.

[15 + 5 marks]

Given data:

$m = 20\,kg$

$s = 20\,m$

$f = \frac{v^2}{2000}$

1

$g = 9.8$

Process is adiabatic

$$ma = -\frac{v^2}{2000} + mg$$

$$m\left(\cancel{\frac{dv}{ds}}\right)v = \cancel{\frac{v^2}{2000}}$$

$$20 v \frac{dv}{ds} = \frac{v^2}{200}$$

∵ v is final velocity
u is initial

$$\frac{dv}{ds} = \frac{v}{4000}$$

$$\int \frac{dv}{v} = \int \frac{ds}{4000}$$

Integrate both sides

$$\ln v \Big|_u^v = \frac{s_2 - s_1}{4000}$$

$$\ln v/u = \frac{s_2 - s_1}{4000}$$

ii Different types of work are:

- Boundary work
- Electrical work
- Displacement work
- Surface energy work

→ Boundary work is used to determine how much energy in the form of work is either coming in or out of the system

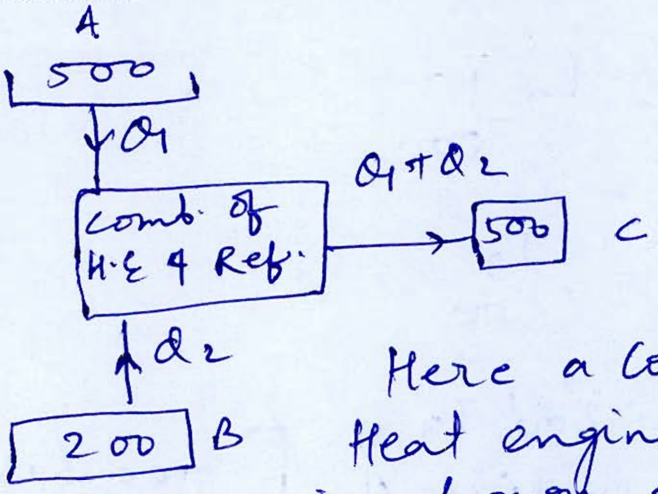
→ Electrical work is used to transfer high grade energy into the system. generally used for electrical appliances

→ Surface energy work: whenever we need to increase the surface area of the bubble we need to given certain amount of work in order to do it. That is surface energy work 3

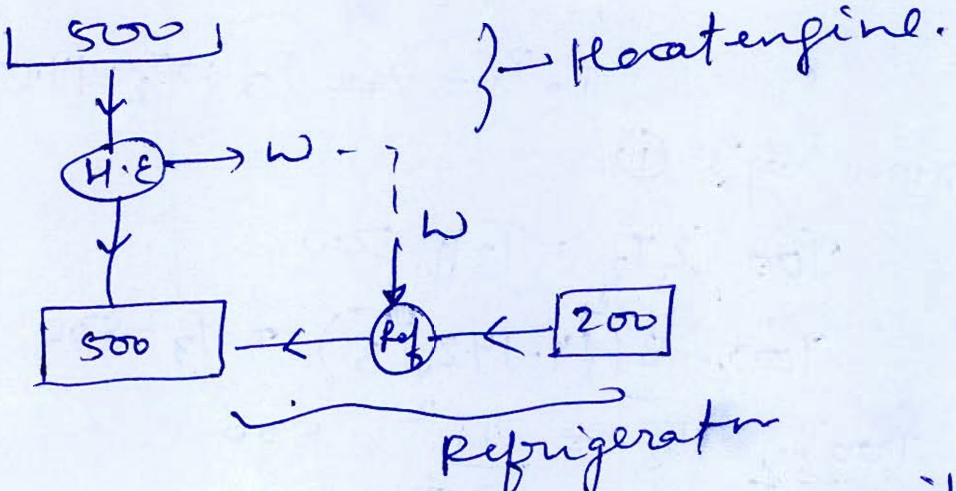
→ Work is a path function. It depends on the end points as well as the path taken between the end points.

Q.3 (a) Three identical finite bodies of constant heat capacity are at temperatures 500 K, 500 K and 200 K. If no work or heat is supplied from outside what is the highest temperature to which any one of the bodies can be raised by the operation of heat engines or refrigerators?

[20 marks]



Here a combination of Heat engine & Refrigerator is shown it can be shown like this also



Assuming all the process reversible
And they have same heat capacities

$$\Delta S_A + \Delta S_B + \Delta S_C = 0$$

& $Q_1 + Q_2$ is given to C

$$mc(500 - T_1) + mc(200 - T_2) \Rightarrow mc(T_3 - 500)$$

$$700 - T_1 - T_2 = T_3 - 500 \quad \text{①}$$

(energy conservation)

$$\Delta s|_A + \Delta s|_B + \Delta s|_C = 0$$

$$-\left(mc \ln \frac{T_1}{500} + mc \ln \frac{T_2}{200}\right) + mc \ln \frac{T_3}{500} = 0$$

$$\ln \frac{T_1 T_2}{500 \times 200} = \ln \frac{T_3}{500}$$

$$\frac{T_1 T_2}{500 \times 200} = \frac{T_3}{500}$$

$$T_1 T_2 = 200\, T_3$$

Assuming both bodies A, B reaches to same final temperature

$$T_1 = T_2$$

$$T_2^2 = 200\, T_3 \Rightarrow T_2 = 14.142\sqrt{T_3}$$

from eq^n ①

$$700 - 2T_2 = T_3 - 500$$

$$700 - 2(14.142\sqrt{T_3}) = T_3 - 500$$

or $$700 - 2T_2 = \frac{T_2^2}{200} - 500$$

$$140000 - 400\, T_2 + 100000 = T_2^2$$

$$T_2^2 + 400\, T_2 - 240000 = 0$$

$$T_2 = \frac{-400 \pm \sqrt{400^2 + 4 \times 240000}}{2}$$

$$T_2 = 82.8427 \text{ K} = T_1$$

3 (b) The internal energy of air is given, at ordinary temperature by

$u = u_0 + 0.718t$

where u is in kJ/kg, u_0 is any arbitrary value of u at 0°C, kJ/kg and t is temperature in °C.

Also for air, $pv = 0.287(t + 273)$

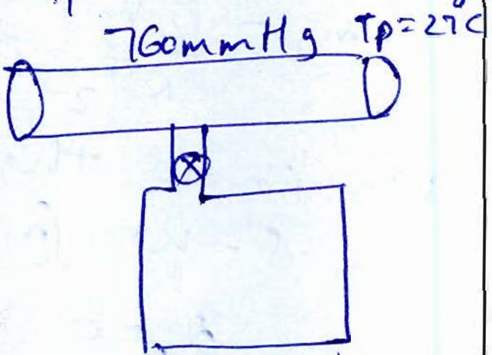
where, p is in kPa and v is in m^3/kg.

(i) An evacuated bottle is fitted with a valve through which air from the atmosphere, at 760 mm Hg and 27°C, is allowed to flow slowly to fill the bottle. If no heat is transferred to or from the air in the bottle, what will its temperature be when pressure in the bottle reaches 760 mm Hg?

(ii) If the bottle initially contains 0.04 m^3 of air at 500 mm Hg and 27°C, what will the temperature be when pressure in the bottle reaches 760 mm Hg?

[20 marks]

> Initially evacuated $m_1 = 0$



Assumption :-

- Properities inside the pipe do not change with time
- air is treated as ideal gas
- C_p, C_v, γ do not change with temperature

We know that, this is unsteady state

$$Q - W + (m_2 - m_1) h_p = m_2 U_2 - m_1 U_1$$

$m_1 = 0$ (given)

$Q = 0$ given

$W = 0$ (rigid)

$$\cancel{m_2} h_p = \cancel{m_2} U_2$$

$$h_p = U_2$$

$$c_p T_p = c_v T_2$$

$$T_2 = \gamma T_p$$

$$= 1.4 \times 300$$

$$T_2 = 420\,K$$ ✓

ii) Initial

$V_1 = 0.04$

$P_1 = 500\,mm\,Hg$ or $66.61184\,kPa$

$T_1 = 27^\circ C$

$T_2 = ?$

$P_2 = 760\,mm\,Hg$ or $101.325\,KPa$

$$m_1 = \frac{P_1 V_1}{R T_1} \Rightarrow \frac{66.611 \times 0.04}{0.287 \times 300} \Rightarrow 0.03096$$

$$m_2 = \frac{P_2 V_2}{R T_2} \Rightarrow \frac{101.325 \times 0.04}{0.287 \times T_2} = \frac{14.12195}{T_2}$$

We know that

$$Q - W + (m_2 - m_1) h_p = m_2 U_2 - m_1 U_1$$

$Q = 0$ given

$W = 0$ rigid

so,

$$\left[\frac{14.12195}{T_2} - 0.03096\right] 1.005 \times 300 = \frac{14.12195}{T_2} C_v T_2 - 0.03096 \times C_v \times 300$$

$$\frac{4257.7679}{T_2} - 9.3344 = 10.1395 - 6.6687$$

$$\frac{4257.7679}{T_2} = 3.4708 + 9.3344$$

$$\underline{T_2 = 332.503\,K}$$

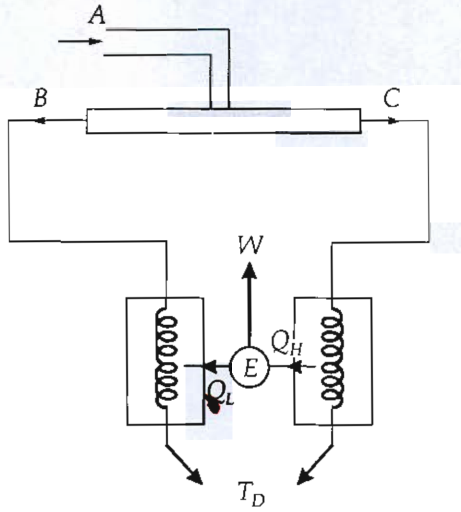
Here the properties are varying with respect to time so this has become a unsteady state problem.

20

Q.3 (c) Air enters a vortex tube tangentially near the center (Point A in figure) at 300 K and 15 bar. It bifurcates into two streams B and C leaving at a pressure of 1 bar and temperatures of 250 K and 315 K respectively.

A reversible engine E is used to extract power from these streams by using the hot stream C as a source and cold stream B as a sink. Such that both streams leave the engine at temperature T_D.

If flow rate of stream A is 1 kg/s, determine the flow rates of streams B and C, the temperature T_D and the power output from the reversible engine. How does it compare with the energy of stream A with respect to environment at temperature T_D?



Assume all streams as ideal gases with $c_p = 1$ kJ/kgK.

[20 marks]

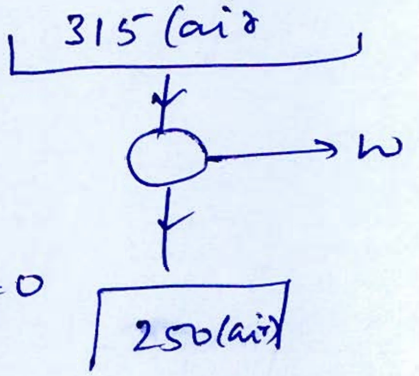
$\dot{m}_a = 1\ kg/s$

Assumptions:

- Treating air as an ideal gas
- C_p, C_v, γ do not changes with temperature

Point A	Point B	Point C
$P_1 = 15 bar$	$P_2 = 1 bar$	$P_3 = 1 bar$
$T_1 = 300 K$	$T_2 = 250 K$	$T_3 = 315K$
$\dot{m}_a = 1$	$m_2 = n$	$\dot{m}_3 = 1-n$

Both has final temp T_f same



Reversible engins

$$\Delta S\Big|_{hot\ air} + \Delta S\Big|_{cold} = 0$$

$$x \times C_p \ln \frac{T_f}{T_1}\Big|_{Hot} + (1-n)\ C_p \ln \frac{T_f}{T_1}\Big|_{cold} = 0$$

$C_p = 1$

$$x \ln \frac{T_F}{315} + (1-n) \ln \frac{T_f}{250} = 0$$

$$x \ln \frac{T_f}{315} = (1-n) \ln \frac{T_f}{250} \quad ①$$

and energy conservation

Heat lost by Hot air $= mC_p\Delta T$

$x \times 1\,(315 - T_f)$

Heat gained by cold air $= mC_p\Delta T$

$(1-n)\ (T_f - 250)$

.4(a) The equation of state of a certain gas is $v = \frac{RT}{P} + \frac{K}{RT}$ (where K is a constant). Show that the change in temperature during throttling (enthalpy before and after remains the same) of such a gas from an initial pressure P_1 to a final pressure P_2 is given by

$$\frac{T_2^2 - T_1^2}{4K} = \frac{P_1 - P_2}{C_p R}$$

where, C_p is assumed constant during the process 1-2.

[20 marks]

.4 (b) An ideal gas is compressed reversibly and adiabatically from state a to b. It then heated reversibly at constant volume to state c. After expanding reversibly and adiabatically to state d such that, $T_b = T_d$, the gas is again reversibly heated at constant pressure to state e such that $T_e = T_c$.

Heat is then rejected reversibly from the gas at constant volume till it returns to state a. Express T_a in terms of T_b and T_c. If $T_b = 500$ K and $T_c = 850$ K. Estimate T_a.

Take $\gamma = 1.4$

[20 marks]

Q.4 (c) A leakproof piston- cylinder arrangement contains 1 kg of water and steam at 2 bar and 0.35 dry. Heat is supplied at constant volume until pressure reaches 4 bar. The steam is then expanded according to law Pv = constant until the pressure reaches 2 bar. Calculate.

(i) Heat transferred during constant volume heating.

(ii) Heat transferred and work transferred during Pv = constant expansion.

(iii) Temperature and quality of steam after expansion process.

Also show the processes on P- V diagram.

[Use the steam table attached at the end]

[20 marks]

Do not write in this margin

Section B : IC Engine + Refrigeration and Air-conditioning

Q.5 (a) A air refrigeration system working on the Bell-Coleman cycle takes air into the compressor at 1 bar and -6°C. Air is compressed isentropically to 5.6 bar and then cooled at constant pressure to 19°C. Find the COP of the system if

(i) The expansion is isentropic

(ii) The expansion follows the law $pv^{1.26}$ = constant

Take for air $c_v = 0.7$ kJ/kg-K, $c_p = 1.0$ kJ/kg-kg, $\gamma = 1.4$

[12 marks]

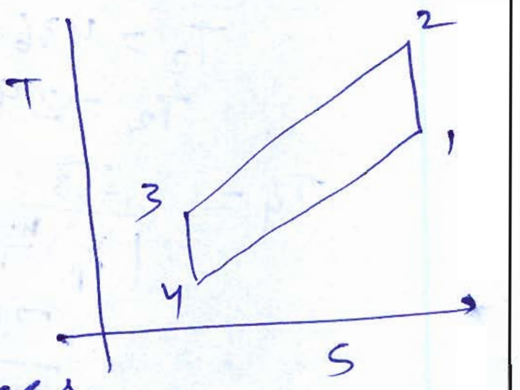
- Given:

$T_1 = -6°C$ or $267\,K$

$P_1 = 1$ bar

$P_2 = 5.6$ bar

$T_3 = 19°C$ or $292K$



Assumption:

- Air is assumed as ideal gas
- Cp, Cv, γ do not change with temperature

1) Now $r_p = 5.6$, given expansion is isentropic

$$T_2 = (r_p)^{\frac{\gamma-1}{\gamma}} \times T_1 \Rightarrow (5.6)^{\frac{1.4-1}{1.4}} \times 267$$

$$T_2 = 436.79K$$

$$T_4 = \frac{T_3}{(r_p)^{\gamma-1/\gamma}} \Rightarrow \frac{292}{(5.6)^{\frac{0.4}{1.4}}} \Rightarrow 178.49K$$

and we know

$$COP\Big|_{Bell\,coleman} = \frac{1}{(r_p)^{\frac{\gamma-1}{\gamma}} - 1}$$

$$\frac{1}{(5.6)^{\frac{1.4-1}{1.4}} - 1}$$

$$\frac{1}{0.63594}$$

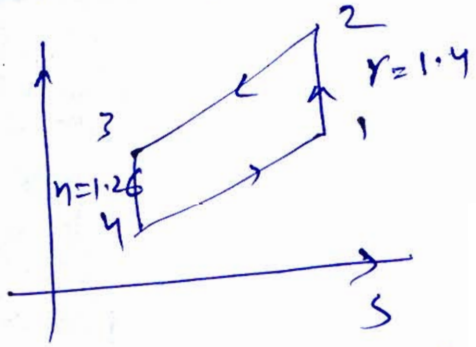
$$COP = 1.572469$$

ii) $C_p = 1$ and expansion is $PV^{1.26} = C$

$C_v = 0.7$

$\gamma = 1.4$

$T_2 = T_1 (r_p)^{\gamma-1/\gamma}$



$r_p = 5.6 \rightarrow$ given

$(5.6)^{\gamma-1/\gamma} \times T_1$

$T_2 = 436.79K$ $T_1 = 267K$

$T_3 = 292$

$T_4 = \dfrac{T_3}{(r_p)^{\frac{n-1}{n}}}$ } $n = 1.26$

$\dfrac{292}{(5.6)^{\frac{0.26}{1.26}}} = 204.642K$

8

$W_{comp} = C_p(T_2 - T_1)$

$= 1\{436.79 - 267\} = 169.79$ kJ/kg

$W_{Turb} = \dfrac{n}{n-1} R(T_3 - T_4)$ {Polytropic work}

$= \dfrac{1.26}{0.26} \times 0.3 \times \{292 - 204.642\}$

$W_T = 127.005$ kJ/kg

Qadd or Refrigeration effn $= C_p(T_1 - T_4)$

$= (267 - 204.642)$

$= 62.358$ kJ/kg

$COP = \dfrac{R.E}{W_{input}} \Rightarrow \dfrac{62.358}{169.79 - 127.005}$

$COP = 1.45747$

Q.5 (b) A refrigeration plant of 110 tons capacity uses R-22 as refrigerant. The condensing and evaporating pressure are 11.82 bar and 1.64 bar respectively. The refrigerant enters the condenser as dry-saturated and it leaves the condenser, sub cooled by 8°C. The actual COP is 70% of theoretical COP. Determine

(i) The theoretical and actual COP

(ii) The mass flow rate of refrigerant in kg/sec

(iii) The compressor power required

p (bar)	T_s (°C)	h_f (kJ/kg)	h_g (kJ/kg)	s_f (kJ/kg-K)	s_g (kJ/kg-K)
1.64	-30	116.1	393.1	0.8698	1.803
11.82	+30	236.7	414.5	1.125	1.712

C_p (vapour) = 0.55 kJ/kg°C; C_p (liquid) = 1.19 kJ/kg°C

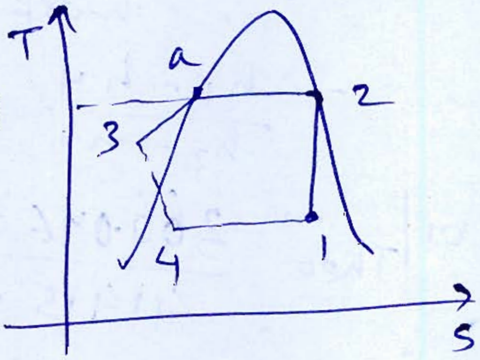
[12 marks]

Given:-

RC=110 tons

Entry to condensor i.e (2) is dry saturated

It is subcooled by 8°c inside the condensor



$T_2 = 30°C$

$T_3 = 30-8 \Rightarrow 22°C$

Now from table

$h_2 = h_g$ @ 11.82 bar

$h_2 =$ ~~236.7~~ 414.5 kJ/kg

$s_2 = s_f$ at 11.82 bar

$= 1.712$ kJ/kgK

Process 1-2 is isentropic compression

$s_1 = s_2$

$1.712 = s_f + x\, s_{fg}$ at 1.64 bar

$1.712 = 0.8698 + x\, 0.9332$

$x = 0.9024$

Now $h_1 = h_f + x\, h_{fg}$ at 01.64 bar

$\Rightarrow$ ~~236.7 + 0.9024 (177.8)~~

~~$\Rightarrow$ 397.146 kJ/kg~~

$h_a = h_f$ @ 11.82 bar and $h_1 = 116.1 + x\, h_{fg}$

$h_a = 236.7$ KJ/Kg $\Rightarrow 116.1 + 0.9024 \times 277$

$h_3 = h_a - C_L (T_a - T_3)$ $h_1 \Rightarrow 366.0648$ KJ/kg

$236.7 - 1.19\{8]$

$h_3 = 227.18$ KJ/Kg

Process 3-4 is isenthalpic

$h_3 = h_4 = 227.18$ KJ/Kg

$$COP = \frac{\text{Refrigeration effect}}{\text{Work input}}$$

$$= \frac{h_1 - h_4}{h_2 - h_1}$$

$$COP|_{Theo.} \Rightarrow \frac{366.046 - 227.18}{414.5 - 366.046} \Rightarrow \cancel{\frac{169.966}{17.354}} \quad \frac{138.88}{48.354}$$

$$COP_{Theoritical} = \underline{2.866}$$

$$COP_{act} = 0.7 \times COP_T$$
$$\Rightarrow 0.7 \times 2.866 = \underline{2.006}$$

ii) $\dot{m}_{Ref}$ RC = 110 tons

or 110×3.5 kW

$RC \Rightarrow 110 \times 3.5 = \dot{m}\{h_1 - h_4)$

$385 = \dot{m}\{138.88)$

$\dot{m} = \underline{2.772 \text{ kg/s}}$

12

iii) P_{comp}.

$= \dot{m}\{h_2 - h_1)$

$2.772\{414.5 - 366.046]$

$\Rightarrow \underline{134.045 \text{ kW}}$

Q.5 (c) Discuss the advantages of an SI engine with the multi-point fuel injection system over the carburetted engine. Also draw the performance curve for the fuel-injection and carburettor system.

[12 marks]

Q.5 (d) For an air standard otto cycle operating with initial pressure P_1 and T_1, derive an expression for the mean effective pressure (P_m) in terms of compression ratio (r), specific heat ratio (γ), pressure ratio (α). Sketch a neat plot of P_m versus α for different values of compression ratio, indicating the trend.

[12 marks]

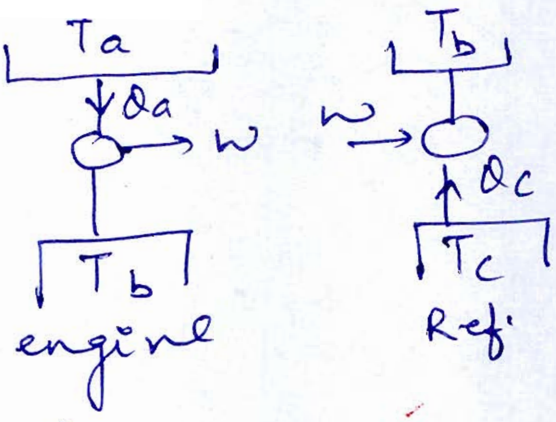
Q.5 (e) A Carnot engine receives heat at temperature, T_a and rejects heat to sink at temperature, T_b. This engine drives a Carnot refrigerator which removes the heat at T_c and rejects heat at T_b. Determine:

(i) The ratio $\frac{Q_c}{Q_a}$, where Q_c = Heat removed at T_c, Q_a = Heat received at T_a in terms of temperatures of reservoirs.

(ii) T_b, such that Q_a (Heat supplied to engine) = Q_c (Heat removed by refrigerator)
Given that T_a = 300°C and T_c = −20°C

(iii) η_{engine} and $(\text{COP})_{\text{refrigerator}}$ for the conditions given in part (ii).

[12 marks]



i) $\frac{Q_c}{Q_a}$ = ____

Since Both the devices are reversible so Q (heat ratio can be written in the form of temperature ratio)

effn of heat engine $= \left(1-\frac{T_b}{T_a}\right) = \frac{W}{Q_a}$

$$W = Q_a\left\{1-\frac{T_b}{T_a}\right\} \quad \text{—①}$$

COP of Refrigerator $= \frac{T_c}{T_b - T_c} = \frac{R\cdot E}{W_{input}}$

R·E → Refrigeration effect

$$\frac{T_c}{T_b - T_c} = \frac{Q_c}{W} \quad \text{—②}$$

Put the value of W from eqn ① in eqn ②

$$\frac{T_c}{T_b-T_c} = \frac{Q_c}{Q_a(1-T_b/T_a)}$$

$$\frac{Q_c}{Q_a} = \left(1-\frac{T_b}{T_a}\right)\left(\frac{T_c}{T_b-T_c}\right) \quad \text{— (A)}$$

ii) If $Q_c = Q_a$ and $T_a = 673\,K$

$T_c = 253\,K$

Put in (A)

5

$$1 = \left(1-\left(\frac{T_b}{673}\right)\right)\left\{\frac{253}{T_b-253}\right]$$

$$\left(\frac{-T_b+253}{253} = 1-\frac{T_b}{673}\right)$$

from here

T_b = ~~489.124K or 216.124°C~~ 367.75K

iii) $\eta_{engine} = 1 - \frac{\cancel{489.124}\ 367.75}{673} \Rightarrow \cancel{0.2732}$ $\Rightarrow 45.35\%$ & $(COP)_{Ref} = \frac{253}{\cancel{489}367.124-253}$ $\Rightarrow 2.204$

Here

$\eta_{engine} = 45.35\%$

$COP_{Ref} = 2.204$

$T_b = 367.75\,K$

.6 (a) A steam ejector water vapor system is supplied with motive steam at 8 bar and in saturated condition when the water in the flash chamber is at 6°C. Make up water is supplied to the cooling system at 18°C and condenser is operated at 5 cm of Hg absolute. The nozzle efficiency is 90%, entrainment efficiency is 66%, and thermocompressor efficiency is 83%. The quality of the motive steam and flashed vapour mixed together at the beginning of compression is 93% dry.

Take $(c_p)_{vapour} = 2.1$ kJ/kgK

Determine:

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

(ii) The refrigeration effect per kg of flash vapour.

[Use Steam Table attached at the end]

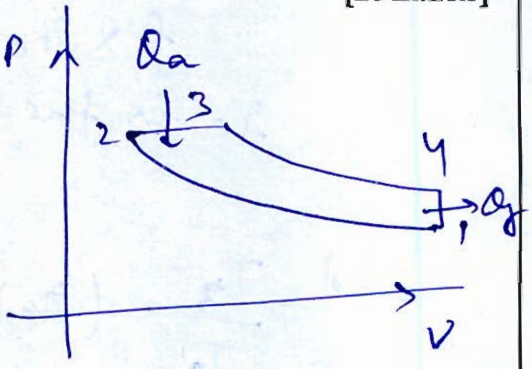
[20 marks]

Q.6 (b) An air- Standard Diesel cycle operates with a Compression ratio of 16, and the cut- off occurs at 5% of the stroke. Determine the percentage change in thermal efficiency if the specific heat at constant pressure increases by 3%. Take c_p = 1.004 kJ/kgK and R = 0.287 kJ/kgK.

[20 marks]

Given: $\gamma = 16$

Cutt off occur at 5% of stroke



We know that:

$(\rho - 1) = x\% (\gamma - 1)$

Here $\rho \rightarrow$ Cut off ratio

$x \rightarrow$ percent of stroke

$\gamma_c \rightarrow$ compression ratio

then $(\rho - 1) = 0.05\{16 - 1\}$

$\rho - 1 = 0.75$

$\rho = 1.75$

Assumptions:
- Air is working fluid
- C_p, C_v, γ do not change with temperature

$\gamma = 1.4$

$C_p = 1.004$

and we know $\eta = 1 - \frac{Q_{rej}}{Q_{add}}$

$1 - \frac{C_v(T_4 - T_1)}{C_p(T_3 - T_2)}$

$1 - \frac{(T_4 - T_1)}{\gamma(T_3 - T_2)}$ — (A)

T_1 is the inlet of compressor

$T_2 = (\gamma_c)^{\gamma-1} T_1$

$\rho = \frac{V_3}{V_2}$ since 2-3 is constant pressure process

$\frac{V_3}{V_2} = \frac{T_3}{T_2}$

$T_3 = T_2 \rho$

$T_3 = (r_c)^{\gamma-1} T_1 \rho$

We know that

$\rho \times r_e = r_c$

r_e is the expansion ratio

$r_e = \frac{V_4}{V_3}$

and $\frac{T_3}{T_4} = (r_e)^{\gamma-1}$

$$T_4 = \frac{T_3}{(r/\rho)^{\gamma-1}} \rightarrow \frac{\rho^{\gamma-1} T_3}{(r_c)^{\gamma-1}}$$

Put all the values of temperature in eq^n A

$$\eta = 1 - \frac{\left(\frac{\rho^{\gamma-1}}{(r)^{\gamma-1}} T_3 - T_1\right)}{\gamma((r_c)^{\gamma-1} T_1 \rho - (r_c)^{\gamma-1} T_1]}$$

$$\eta = 1 - \frac{\{\{ \rho^{\gamma-1} \{ r_c^{\gamma-1} T_1 \rho \} - T_1 \}}{\gamma \{(r_c)^{\gamma-1} T_1 \} \rho - 1\}}$$

$$\eta = 1 - \frac{(\rho^{\gamma} - 1)}{(r_c)^{\gamma-1} \{ \rho - 1) \gamma}$$

Now Put the values

$$\eta = 1 - \frac{(1.75)^{1.4} - 1}{(16)^{0.4} \times (0.75) \times 1.4}$$

$$1 - \{ \frac{1.18903}{3.183}$$

$\eta = 0.62644$ or 62.644%

If C_p is increased by 3%

$$C_p' = 1.03412$$

$$C_v' = C_p' - R$$

$$C_v' = 0.74712$$

$$\gamma = \frac{C_p'}{C_v} = 1.38414$$

$$\eta_{New} = 1 - \frac{\{1.75\}^{1.38414} - 1}{(16)^{0.38414} \times 0.75 \times 1.38414}$$

$$1 - \frac{1.169694}{3.011562}$$

$$\eta_{New} = 0.611599 \text{ or } 61.159\%$$

$$\% \text{ change} = \frac{|\eta_{New} - \eta_{old}|}{\eta_{old}} \rightarrow \frac{61.159 - 62.644}{62.644} \times 100 \Rightarrow -2.37\%$$

i.e 2.37% decrease

20

6 (c) A four cylinder four stroke SI engine has a bore of 50 mm and a stroke of 75 mm. It runs at 2500 rpm and is tested at this speed against a brake which has a torque arm of 0.30 m. The net brake load in 150 N and fuel consumption is 5.5 litre/hour. The specific gravity of the fuel used is 0.75 and it has a lower calorific value of 42000 kJ/kg. A morse test is carried out and the cylinders are cut out in the order 1, 2, 3, 4 with corresponding brake loads of 108N, 101N, 103N and 110N respectively. Calculate for this speed

(i) Brake power

(ii) Brake mean effective pressure

(iii) Brake thermal efficiency

(iv) Brake specific fuel consumption

(v) Indicated power

(vi) Mechanical efficiency

(vii) Indicated mean effective pressure

[20 marks]

Given

$D = 50\,mm$

$L = 75\,mm$

$N = 2500$

$K = 4$

$a = 0.3\,m$

$P_b = 150\,N$

$\dot{m}_f = \frac{5.5\,l}{hr}$

$\rho = 0.75 \times 1000 \Rightarrow 750\ kg/m^3$

$C_V = 42000\ kJ/kg$

$T_1 = 108N,\ T_2 = 101N\ T_3 = 103N\ T_4 = 110N$

1) Brake Power = Brake Torque × ω

$\Rightarrow$ Brake Load × arm × ω

$$\Rightarrow 150 \times 0.3 \times \frac{2\pi \times 2500}{60}$$

$$\Rightarrow 11780.97\,W \text{ or } 11.7809\,kW$$

ii) $$BP = P_{BMEP} \frac{LANK}{60 \times n}$$

$$11.7809 = P \times 0.075 \times \frac{\pi}{4} 0.05^2 \frac{\times 2500 \times 4}{60 \times 2}$$

$$P_{BMEP} = 959.994 \text{ kPa or } 9.59 \text{ bar}$$

iii) Brake thermal eff^n $= \frac{BP}{\dot{m}_f CV}$

$$\dot{m}_f = \rho \times \text{Vol flow rate}$$

$$= 750 \cancel{\rho} \times \frac{5.5 \times 10^{-3}}{3600} \text{ kg/s}$$

$$\dot{m}_f = 1.1458 \times 10^{-3} \text{ kg/s}$$

$$\eta_B = \frac{11.7809}{1.1458 \times 10^{-3} \times 42000}$$

$$\Rightarrow 0.24479 \text{ or } 24.479\%$$

iv) Brake specific fuel cons. $= \frac{m_f \text{ (kg/hr)}}{BP \text{ (kW)}}$

$$\Rightarrow \frac{1.1458 \times 10^{-3} \times 3600}{11.7809}$$

$$\Rightarrow 0.35013 \frac{\text{kg}}{\text{kWhr}}$$

v) Indicated power

$$IP = (4 \times BP - \Sigma BP_i)$$

$$BP_1 = 108 \times 0.3 \times 2\pi \times 2500/60$$

$$\left\{ BP_i = \frac{T_i a \times 2\pi N}{60} \right\}$$

$$\Rightarrow 8482.3 \text{ W or } 8.482 \text{ kW}$$

$$BP_2 = \frac{101 \times 0.3 \times 2\pi \times 2500}{60 \times 1000}$$

$$\Rightarrow 7.9325 \text{ kW}$$

$$BP_3 = \frac{103\times0.3\times2\pi\times2500}{60\times1000}$$

$$BP_3 = 8.0896 \text{ kw}$$

$$BP_4 = \frac{110\times0.3\times2\pi\times2500}{60\times1000}$$

$$BP_4 = 8.6393 \text{ kw}$$

$$IP = (4\times11.7809) - \{8.482 + 7.9325 + 8.0896 + 8.6393)$$

$$47.1236 - 33.14347$$

$$IP = 13.98013 \text{ kw}$$

vi) Mechanical efficiency $= \frac{BP}{IP}$

$$\Rightarrow \frac{11.7809}{13.98013}$$

$$\Rightarrow 0.84268 \text{ or } 84.268\%$$

vii) Indicated mean effective pressure

$$IP = P_{imep}\frac{LANK}{60\times n}$$

$$13.98013 = P\times0.075\times\frac{\pi}{4}0.05^2\frac{\times2500\times4}{60\times2}$$

$$P_{imep} = 1139.203$$

or 11.392 bar

20

Q.7 (a) The analysis of a fuel used in a SI engine found to be carbon 85%, hydrogen 6%, oxygen 1.8%, sulphur 0.6% by weight and the remaining is nitrogen. Determine the stoichiometric air-fuel ratio for complete combustion. If the actual supply of air is 20% in excess of stoichiometric, estimate the percentage composition of dry products of combustion by weight and volume.

[20 marks]

7 (b) (i) Describe the construction and working of a thermostatic expansion valve (TEV) with a neat sketch. Explain how superheat is maintained in the evaporator using a TEV.

(ii) Explain working of counterflow Ranque-Hilsch vortex tube refrigeration system with the help of a neat sketch. Also state its advantages.

[10 + 10 marks]

Q.7 (c) An injection system consists of a pump plunger moving with a velocity of 0.35 m/s and connected to a fuel pipe which is 0.6m long and has a cross-sectional area $\frac{1}{20}$ th of that of the plunger cylinder. The end of the pipe has an open nozzle having a hole of area which is $\frac{1}{50}$ th of that of the pipe. The initial pressure in the line is 27 bar and the compression pressure of the engine is 30 bar. If the bulk modulus of the fuel is 1.8 GPa and the specific gravity of the oil is 0.85, then determine:

(i) The velocity of the pressure disturbances.

(ii) The time taken by the disturbance to travel through the pipe line.

(iii) The pressure and velocity at the pump end of the pipeline as the plunger moves.

(iv) The magnitude of the first reflected pressure and velocity wave.

(v) The pressure and velocity at the orifice end of the pipe line after first reflection.

[20 marks]

Q.8 (a) Air flowing at the rate of 120 m^3/min at 42°C dry bulb temperature and 50% relative humidity is mixed with another stream flowing at the rate of 30 m^3/min at 25°C dry bulb temperature and 50% relative humidity. The mixture flows over a cooling coil whose apparatus dew point temperature is 11°C and bypass factor is 0.08. Find dry bulb temperature of air leaving the coil. If this air is supplied to an air conditioned room where dry bulb temperature of 25°C and relative humidity of 50% are maintained, estimate:

(i) Room sensible heat factor

(ii) Cooling load capacity of the coil in tonnes of refrigeration.

[Use psychrometric chart attached at the end]

[20 marks]

Q.8 (b) A single-cylinder two-stroke SI engine has 90 mm diameter bore and 120 mm stroke, and the compression ratio is 10. The exhaust port opens 55° before BDC and closes 55° after BDC. The air-fuel ratio is 14.8 : 1. The temperature of the fresh mixture entering the engine is 310K, and the pressure in the cylinder at the time of closing exhaust port is 1.02 bar. Air supplied to the engine is 190 kg/h. The engine runs at 4200 rpm. Take *R* for mixture = 287 J/kg·K. Considering the effective stroke, calculate:

(i) Scavenging ratio

(ii) Scavenging efficiency

(iii) Trapping efficiency

[20 marks]

Q.8 (c) Discuss the working principle of practical vapour absorption system with a neat sketch. Derive the expression for its COP. Also discuss the desirable properties of an ideal refrigerant-absorbent pair and list the commonly used refrigerant-absorbent combinations in VARS.

[20 marks]

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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 . . .

Saturated Water and Steam (Pressure-based)

p_{tp} = 611.657 Pa = 0.000611657 MPa

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}
p_{tp}	**0.01**	0.00100021	205.991	**0**	2374.9	0.00	2500.9	2500.9	**0**	9.1555	9.1555
0.0007	1.881	0.00100011	181.217	7.89	2377.4	7.89	2504.3	2496.5	0.02878	9.1058	9.0770
0.0008	3.761	0.00100008	159.640	15.81	2380.1	15.81	2507.8	2492.0	0.05748	9.0567	8.9992
0.0009	5.444	0.00100009	142.757	22.89	2382.4	22.89	2510.9	2488.0	0.08297	9.0135	8.9305
0.0010	6.970	0.00100014	129.178	29.30	2384.5	29.30	2513.7	2484.4	0.10591	8.9749	8.8690
0.0012	9.654	0.00100032	108.670	40.57	2388.2	40.57	2518.6	2478.0	0.14595	8.9082	8.7623
0.0014	11.969	0.00100054	93.899	50.28	2391.3	50.28	2522.8	2472.5	0.18015	8.8521	8.6719
0.0016	14.010	0.00100080	82.743	58.83	2394.1	58.83	2526.5	2467.7	0.21004	8.8035	8.5935
0.0018	15.837	0.00100108	74.011	66.49	2396.7	66.49	2529.9	2463.4	0.23662	8.7608	8.5241
0.0020	17.495	0.00100136	66.987	73.43	2398.9	73.43	2532.9	2459.4	0.26056	8.7226	8.4620
0.0024	20.414	0.00100193	56.375	85.65	2402.9	85.65	2538.2	2452.5	0.30239	8.6567	8.3544
0.0028	22.935	0.00100249	48.729	96.19	2406.4	96.19	2542.8	2446.6	0.33816	8.6012	8.2631
0.0032	25.158	0.00100305	42.952	105.49	2409.4	105.49	2546.8	2441.3	0.36945	8.5533	8.1838
0.0036	27.152	0.00100358	38.430	113.83	2412.1	113.83	2550.4	2436.6	0.39729	8.5110	8.1138
0.0040	28.960	0.00100410	34.791	121.39	2414.5	121.39	2553.7	2432.3	0.42239	8.4734	8.0510
0.0045	31.012	0.00100473	31.131	129.96	2417.3	129.96	2557.4	2427.4	0.45069	8.4313	7.9806
0.0050	32.874	0.00100533	28.185	137.74	2419.8	137.75	2560.7	2423.0	0.47620	8.3938	7.9176
0.0055	34.581	0.00100590	25.762	144.87	2422.1	144.88	2563.8	2418.9	0.49945	8.3599	7.8605
0.0060	36.159	0.00100645	23.733	151.47	2424.2	151.48	2566.6	2415.2	0.52082	8.3290	7.8082
0.0065	37.627	0.00100699	22.009	157.60	2426.2	157.61	2569.3	2411.6	0.54060	8.3007	7.7601
0.0070	39.000	0.00100750	20.524	163.34	2428.0	163.35	2571.7	2408.4	0.55903	8.2745	7.7154
0.0075	40.290	0.00100800	19.233	168.74	2429.8	168.75	2574.0	2405.3	0.57627	8.2501	7.6738
0.0080	41.509	0.00100848	18.099	173.83	2431.4	173.84	2576.2	2402.4	0.59249	8.2273	7.6348
0.0085	42.663	0.00100895	17.095	178.66	2433.0	178.67	2578.3	2399.6	0.60780	8.2060	7.5982
0.0090	43.761	0.00100940	16.199	183.24	2434.4	183.25	2580.2	2397.0	0.62230	8.1858	7.5635
0.0095	44.807	0.00100984	15.396	187.62	2435.8	187.63	2582.1	2394.5	0.63607	8.1668	7.5308
0.010	45.806	0.00101027	14.670	191.80	2437.2	191.81	2583.9	2392.1	0.64920	8.1488	7.4996
0.011	47.683	0.00101110	13.412	199.64	2439.7	199.65	2587.2	2387.5	0.67372	8.1154	7.4417
0.012	49.419	0.00101188	12.358	206.90	2442.0	206.91	2590.3	2383.4	0.69628	8.0849	7.3887
0.013	51.034	0.00101263	11.462	213.66	2444.1	213.67	2593.1	2379.4	0.71717	8.0570	7.3398
0.014	52.547	0.00101335	10.691	219.98	2446.1	219.99	2595.8	2375.8	0.73664	8.0311	7.2945
0.016	55.313	0.00101471	9.4306	231.55	2449.7	231.57	2600.6	2369.1	0.77201	7.9846	7.2126
0.018	57.798	0.00101597	8.4431	241.94	2453.0	241.96	2605.0	2363.0	0.80355	7.9437	7.1402
0.020	60.058	0.00101716	7.6480	251.40	2455.9	251.42	2608.9	2357.5	0.83202	7.9072	7.0752
0.024	64.053	0.00101934	6.4453	268.13	2461.2	268.15	2615.9	2347.7	0.88191	7.8442	6.9623
0.028	67.518	0.00102131	5.5778	282.63	2465.6	282.66	2621.8	2339.2	0.92472	7.7912	6.8664
0.032	70.586	0.00102312	4.9215	295.49	2469.6	295.52	2627.1	2331.6	0.96228	7.7453	6.7830
0.036	73.345	0.00102480	4.4072	307.05	2473.1	307.09	2631.8	2324.7	0.99579	7.7050	6.7092
0.040	75.857	0.00102638	3.9930	317.58	2476.4	317.62	2636.1	2318.4	1.0261	7.6690	6.6429
0.045	78.715	0.00102821	3.5759	329.57	2480.0	329.62	2640.9	2311.2	1.0603	7.6288	6.5686
0.050	81.317	0.00102993	3.2400	340.49	2483.2	340.54	2645.2	2304.7	1.0912	7.5930	6.5018

Continued . . .

Saturated Water and Steam (Pressure-based), Contd.

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}
0.050	81.317	0.00102993	3.2400	340.49	2483.2	340.54	2645.2	2304.7	1.0912	7.5930	6.5018
0.055	83.709	0.00103154	2.9635	350.53	2486.2	350.59	2649.2	2298.6	1.1194	7.5606	6.4412
0.060	85.926	0.00103307	2.7317	359.85	2489.0	359.91	2652.9	2292.9	1.1454	7.5311	6.3857
0.065	87.993	0.00103452	2.5346	368.53	2491.6	368.60	2656.3	2287.7	1.1696	7.5040	6.3345
0.070	89.932	0.00103590	2.3648	376.68	2493.9	376.75	2659.4	2282.7	1.1921	7.4790	6.2869
0.075	91.758	0.00103723	2.2170	384.36	2496.1	384.44	2662.4	2277.9	1.2132	7.4557	6.2425
0.080	93.486	0.00103850	2.0871	391.63	2498.2	391.71	2665.2	2273.5	1.2330	7.4339	6.2009
0.085	95.125	0.00103972	1.9720	398.53	2500.2	398.62	2667.8	2269.2	1.2518	7.4135	6.1617
0.090	96.687	0.00104091	1.8694	405.11	2502.1	405.20	2670.3	2265.1	1.2696	7.3943	6.1246
0.095	98.178	0.00104205	1.7772	411.38	2503.9	411.48	2672.7	2261.2	1.2866	7.3761	6.0895
0.10	99.606	0.00104315	1.6939	417.40	2505.5	417.50	2674.9	2257.4	1.3028	7.3588	6.0561
0.11	102.292	0.00104527	1.5495	428.73	2508.8	428.84	2679.2	2250.3	1.3330	7.3269	5.9938
0.12	104.784	0.00104727	1.4284	439.23	2511.7	439.36	2683.1	2243.7	1.3609	7.2977	5.9367
0.13	107.109	0.00104917	1.3253	449.05	2514.3	449.19	2686.6	2237.5	1.3868	7.2709	5.8840
0.14	109.292	0.00105099	1.2366	458.27	2516.9	458.42	2690.0	2231.6	1.4110	7.2461	5.8351
0.15	111.349	0.00105273	1.1593	466.97	2519.2	467.13	2693.1	2226.0	1.4337	7.2230	5.7893
0.16	113.297	0.00105440	1.0914	475.21	2521.4	475.38	2696.0	2220.7	1.4551	7.2014	5.7463
0.17	115.148	0.00105600	1.0312	483.04	2523.5	483.22	2698.8	2215.6	1.4753	7.1812	5.7059
0.18	116.911	0.00105756	0.97747	490.51	2525.5	490.70	2701.4	2210.7	1.4945	7.1621	5.6676
0.19	118.596	0.00105906	0.92924	497.65	2527.3	497.85	2703.9	2206.0	1.5127	7.1440	5.6313
0.20	120.210	0.00106052	0.88568	504.49	2529.1	504.70	2706.2	2201.5	1.5302	7.1269	5.5967
0.21	121.759	0.00106193	0.84614	511.07	2530.8	511.29	2708.5	2197.2	1.5469	7.1106	5.5638
0.22	123.250	0.00106330	0.81007	517.40	2532.4	517.63	2710.6	2193.0	1.5628	7.0951	5.5323
0.23	124.686	0.00106464	0.77704	523.50	2534.0	523.74	2712.7	2188.9	1.5782	7.0803	5.5021
0.24	126.072	0.00106594	0.74668	529.38	2535.4	529.64	2714.6	2185.0	1.5930	7.0661	5.4731
0.25	127.411	0.00106722	0.71866	535.07	2536.8	535.34	2716.5	2181.1	1.6072	7.0524	5.4452
0.26	128.708	0.00106846	0.69273	540.59	2538.2	540.87	2718.3	2177.4	1.6210	7.0394	5.4184
0.27	129.965	0.00106968	0.66865	545.95	2539.5	546.24	2720.0	2173.8	1.6343	7.0268	5.3925
0.28	131.185	0.00107086	0.64624	551.14	2540.8	551.44	2721.7	2170.3	1.6471	7.0146	5.3675
0.29	132.370	0.00107203	0.62533	556.19	2542.0	556.50	2723.3	2166.8	1.6596	7.0029	5.3433
0.30	133.522	0.00107317	0.60576	561.11	2543.2	561.43	2724.9	2163.5	1.6717	6.9916	5.3199
0.31	134.644	0.00107429	0.58741	565.89	2544.3	566.22	2726.4	2160.2	1.6835	6.9807	5.2972
0.32	135.737	0.00107539	0.57017	570.56	2545.3	570.90	2727.8	2157.0	1.6949	6.9701	5.2752
0.33	136.802	0.00107647	0.55395	575.10	2546.5	575.46	2729.3	2153.8	1.7060	6.9598	5.2538
0.34	137.842	0.00107753	0.53864	579.54	2547.5	579.91	2730.6	2150.7	1.7168	6.9498	5.2330
0.35	138.857	0.00107857	0.52418	583.88	2548.5	584.26	2732.0	2147.7	1.7274	6.9401	5.2128
0.36	139.849	0.00107960	0.51050	588.13	2549.4	588.52	2733.2	2144.7	1.7377	6.9307	5.1931
0.37	140.819	0.00108061	0.49753	592.28	2550.4	592.68	2734.5	2141.8	1.7477	6.9216	5.1739
0.38	141.769	0.00108161	0.48522	596.34	2551.3	596.75	2735.7	2139.0	1.7575	6.9126	5.1551
0.39	142.698	0.00108259	0.47352	600.32	2552.2	600.74	2736.9	2136.2	1.7671	6.9040	5.1369
0.40	143.608	0.00108355	0.46238	604.22	2553.1	604.65	2738.1	2133.4	1.7765	6.8955	5.1190

Continued . . .

Saturated Water and Steam (Pressure-based), Contd.

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

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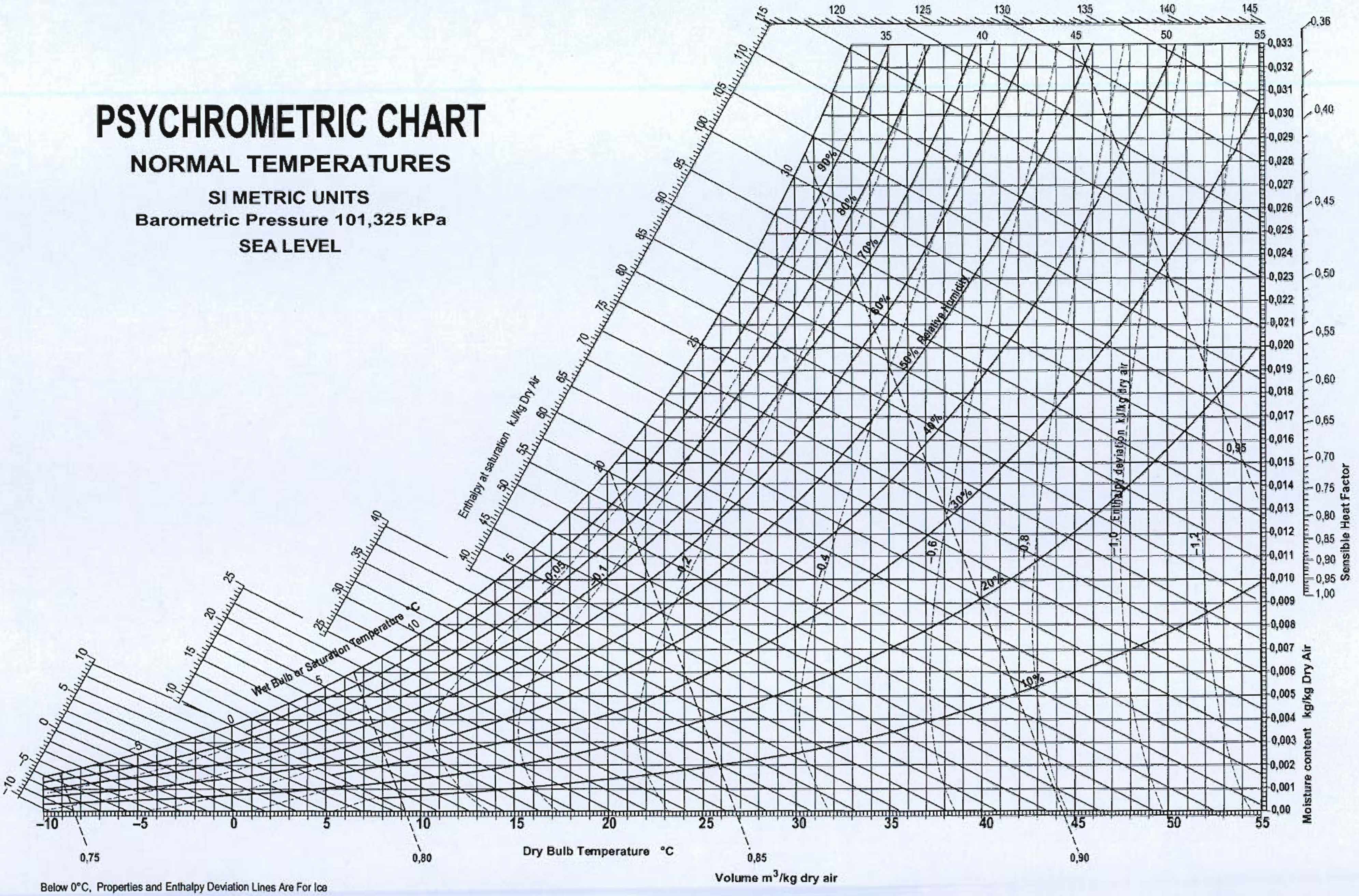
PSYCHROMETRIC CHART

NORMAL TEMPERATURES

SI METRIC UNITS
Barometric Pressure 101,325 kPa
SEA LEVEL



Below 0°C, Properties and Enthalpy Deviation Lines Are For Ice

Space for Rough Work

Space for Rough Work

Space for Rough Work

Space for Rough Work

Space for Rough Work

4.04499