Saket Centre

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# ESE 2024 : Mains Test Series

UPSC ENGINEERING SERVICES EXAMINATION

## Mechanical Engineering

**Test-2 : Heat Transfer + Refrigeration and Air-Conditioning [All Topics]**
**Thermodynamics-1 + Strength of Materials & Mechanics-1 [Part Syllabus]**

Name :

Roll No

| Test Centres | | | Student's Signature |
|---|---|---|---|
| Delhi ☑ | Bhopal ☐ | Jaipur ☐ | |
| Pune ☐ | Kolkata ☐ | Hyderabad ☐ | |

### 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 | 24 |
| Q.2 | — |
| Q.3 | 40 |
| Q.4 | 29 |
| Section-B | |
| Q.5 | 27 |
| Q.6 | — |
| Q.7 | — |
| Q.8 | 54 |
| **Total Marks Obtained** | 174 |

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.

Remarks:-

- Accuracy is very good.
- Presentation is also better, but try to work on increasing the attempt.

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## Section : A

Q.1 (a) In a 25 tonnes absorption refrigeration system the heating in generator is carried out by using steam at 3 bar and 90% dry. The refrigeration temperature is –15°C. The condensation of the refrigerant is carried out at 40°C using cooling water. Determine:

(i) Maximum possible C.O.P. of the system and

(ii) Quantity of steam required per hour to run the plant if the steam leaves the generator as saturated water at same pressure. Assume relative C.O.P. = 0.35.

From steam tables we have

At 3 bar, $T_{sat}$ = 133.5°C, $h_{fg}$ = 2163.2 kJ/kg

**[12 marks]**

given, $RC = 25TR = 87.5$ kW

steam, $x = .9$, $T_E = -15°C = 258K$

$T_G = 133.5°C = 406.5K$

$T_O = 40°C = 313K$

(i) $$\text{Max. COP} = \left(1 - \frac{T_O}{T_G}\right)\left(\frac{T_E}{T_O - T_E}\right)$$

$$= \left(1 - \frac{313}{406.5}\right)\left(\frac{258}{313-258}\right) = 1.0789$$ Ans

(ii) Actual COP $= .35 \times \text{Max COP} = 0.3776$

$$\text{Actual COP} = \frac{RC}{\dot{m} \times x h_{fg}}$$

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$$.3776 = \frac{87.5}{\dot{m}_s \times .9 \times 2163.2}$$

$\dot{m}_s = .119$ kg/s or 428.445 kg/hr

Ans

**Q.1 (b)** Air at 12°C flows past a flat plate 1.2 m wide and 1.6 m long. The plate is maintained at 88°C temperature and dissipates 3.95 kW of energy. Determine the convective heat transfer coefficient and the velocity at which air flows along the length of the plate. At the mean temperature of 50°C, the thermo-physical properties of air are:

$\rho = 1.09$ kg/m³; $k = 0.028$ W/m°C; Pr = 0.73; $c_p = 1007.5$ J/kgK

and $\mu = 2.029 \times 10^{-5}$ kg/m-s

Use the following correlations if required:

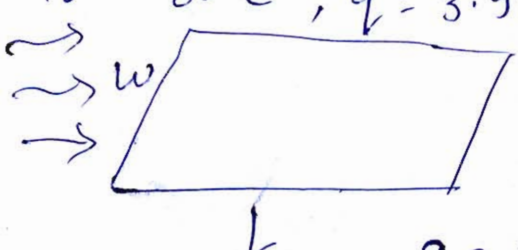
$$Nu = \frac{hl}{k} = 0.664(\text{Re})^{0.5}(\text{Pr})^{0.33} \text{ for laminar flow}$$

$$= \frac{hl}{k} = \left[0.036(\text{Re})^{0.8} - 836\right](\text{Pr})^{0.33} \text{ for turbulent flow}$$

**[12 marks]**

$T_\infty = 12°C$, $w = 1.2$ m, $L = 1.6$ m

$T_o = 88°C$, $q = 3.95$ kW, find $h, V$




$q = 3.95 = \dot{m} C_p (\Delta T)$ ($\dot{m} \to \rho A V$)

$3.95 = 1.09 \times 1.2 \times 1.6 \times V \times 1.0075 \times (88-12)$

$V = 0.0246$ m/s Ans

$$Re = \frac{\rho V L}{\mu} = \frac{1.09 \times .0246 \times 1.6}{2.029} \times 10^5$$

$$Re = 2118.727 < 5 \times 10^5$$

flow is Laminar, use given relation,

$$\frac{h \times 1.6}{.028} = .664 (2118.727)^{.5} (.73)^{.33}$$

$$\boxed{h = 0.4821 \, W/m^2K}$$ Ans

1

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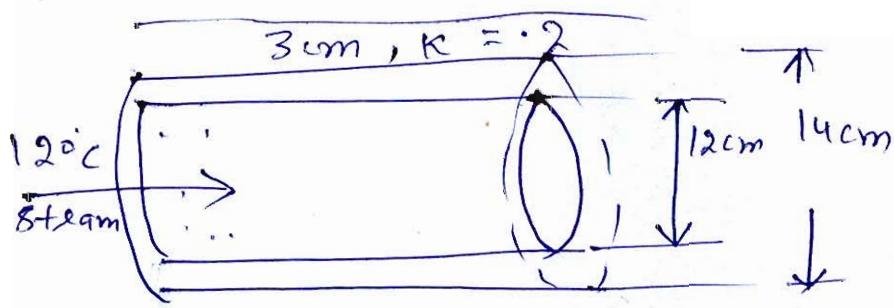
**Q.1 (c)** What are the functions of condenser in a refrigerating machine? Name different types of condensers. Describe with neat sketch the evaporative condenser.

**[12 marks]**

**Q.1 (d)** Saturated steam at 120°C flows inside a copper pipe of thermal conductivity 450 W/mK, having an internal diameter of 12 cm and external diameter of 14 cm. The surface resistance on the steam side is 11500 W/m²K and that on the outside surface of pipe is 20 W/m²K. Determine the heat loss from the pipe if it is located in space at 30°C. How this heat loss would be affected if the pipe is lagged with 3 cm thick insulation of thermal conductivity 0.20 W/mK?

**[12 marks]**

$T_\infty = 30°C$




$K = 450\ W/mK$

$R_i = 11500\ W/m^2K$

$R_o = 20\ W/m^2K$

$\frac{1}{U} = \frac{1}{R_i} + \frac{1}{R_o} \Rightarrow \frac{1}{U} = \frac{1}{11500} + \frac{1}{20}$

$U = 19.965\ W/m^2K$

$$q = \frac{2\pi K L (T - T_\infty)}{\ln(r_2/r_1)}$$

$$\dot{q} = \frac{120 - 30}{\frac{1}{11500 \times \pi \times .12 \times L} + \frac{\ln(\frac{7}{6})}{2\pi \times 450 \times L} + \frac{1}{20 \times \pi \times .14 L}}$$

$$q/L = \frac{90}{2.3065 \times 10^{-4} + 5.4519 \times 10^{-5} + .1136}$$

$q = 789.7$ watt/m **Ans**

If 3cm thick insulation is used

$$q/L = \frac{120 - 30}{\frac{1}{11500 \times \pi \times .12 \times 2} + \frac{\ln(7/6)}{2\pi \times 450} + \frac{\ln(10/7)}{2\pi \times .2} + \frac{1}{20 \times .2 \times \pi}}$$

$$q/L = \frac{90}{2.3065 \times 10^{-4} + 5.4519 \times 10^{-5} + .2838 + .0795}$$

$$\boxed{q/L = 247.48 \text{ Watt/m}}$$

heat loss is reduced by = $\boxed{542.217 \text{ watt/m}}$ Ans.

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**Q.1 (e)** Saturated air at 5°C is required to be supplied to a room where the temperature must be held at 21°C with a relative humidity of 55%. The air is heated and then water is sprayed to give the required humidity. Determine the mass of spray water required per $m^3$ of air at room conditions. Assume that the total pressure is constant at 1.0132 bar. (Refer steam table for the properties of water vapour in moist air)

**[12 marks]**

Q.2 (a) The following data refer to a steam jet refrigeration system:

Condition of the motive steam = 10 bar, dry saturated

Temperature of water in the flash chamber = 6°

Temperature at which the make up water is supplied = 22°

The pressure at which condenser is operated = 0.06 bar

Nozzle efficiency = 0.85

Entrainment efficiency = 0.65

Compression efficiency = 0.8

The quality of steam and flash vapour at beginning of compression = 0.9

Determine the following:

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

(ii) Refrigerating effect per kg of flash vapour.

(iii) The coefficient of performance of the system.

[Refer steam table for properties of steam]

**[20 marks]**

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Q.2 (b) A hemispherical cavity of radius 0.8 m is covered with a plate having a hole of 0.3 m diameter. The inner surface of the plate is maintained at 560 K by a heater embedded in the surface. Assuming the surfaces to be black and the hemisphere to be well insulated. Calculate:

(1) the temperature of the surface of the hemisphere

(2) the power input to the heater.

**[20 marks]**

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Q.2 (c) Ambient conditions for an aircraft cruising at 1200 km/h are 0.35 bar and –15°C. The cabin temperature is 25°C and turbine exit pressure is 1.06 bar. The pressure ratio of compressor is 5.0. Assuming 100 percent efficiency of ram effect, compressor and turbine and ideal heat exchanger, determine for simple gas refrigeration cycle of 30 tonnes capacity.

**(i)** Temperatures and pressures at all points of cycle.

**(ii)** Mass flow rate and volume flow rate at compressor inlet and turbine outlet.

**(ii)** Work requirement

**(iv)** Coefficient of performance of cycle.

Assume : $c_p$ = 1.005 kJ/kgK, $R_{air}$ = 0.286 kJ/kgK, $\gamma$ = 1.4

**[20 marks]**

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**Q.3 (a)** (i) List the assumptions made while analysing the heat flow from a finned surface.

(ii) A turbine blade 6 cm long, 4.8 $cm^2$ cross-sectional area and 12 cm perimeter is made of stainless steel of thermal conductivity 110 kJ/m-hr-deg. The temperature at the root of the blade is 520°C and it is exposed to products of combustion passing through the turbine at 880°C. The film coefficient between the blade and the combustion gases is 1200 kJ/$m^2$-hr-deg. Determine the temperature at the middle of blade and the rate of heat flow from it. The blade may be treated as a fin losing heat at the tip.

**[6 + 14 marks]**

(ii) $L = 6\,cm$, $A_{cs} = 4.8\,cm^2$, $P = 12\,cm$

$K = 110\,KJ/m\text{-}hr\,°C$ $T_0 = 520°C$

$T_\infty = 880°C$, $U = 1200\,KJ/m^2hr\,°C$

Find tempr at middle, rate of heat flow

Assume, ~~fin~~ blade is uninsulated at tip.

$$m = \sqrt{\frac{hP}{KA_{cs}}}$$

$K = 30.555\,W/m°C$

$h = 333.333\,W/m^2°C$

$$m = \sqrt{\frac{333.333 \times .12}{30.555 \times 4.8 \times 10^{-4}}} = 52.2237$$

$$L_c = L + \frac{A_{cs}}{P} = 6 + \frac{4.8}{12} = 6.4\,cm$$

We know that, $$\frac{\theta}{\theta_b} = \frac{\cosh\{m(L_c - x)\}}{\cosh(mL_c)}$$

$x = 3\,cm = .03\,m$

$$\frac{T - 880}{520 - 880} = \frac{\cosh\{52.2237(.064 - .03)\}}{\cosh(52.2237 \times .064)}$$

$$\frac{T - 880}{-360} = \frac{3.03661}{14.15996}$$

$$\boxed{T = 802.797°C}$$ Ans.

Tempr at Mid of blade.

$$\dot{q} = \sqrt{hPKA_{cs}} \cdot \tanh(mL_c) \times (\theta_b)$$

$= \sqrt{333.333 \times .12 \times 30.555 \times 4.8 \times 10^{-4}} \cdot \tanh$

$(52.2237 \times .064)\,(520 - 880)$

$0.765934 \times 14.159967 \times (-360)$

$= -3904.416$ watt $= -3.904$ kW

Ans

–ve sign shows heat is entering into the turbine blade,

$Q = 3.904$ kW

Ans

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**Q.3 (b)** A Freon-12 VCRS installation has the following data:

Refrigeration capacity = 20 tons

Evaporator temperature = –10°C

Condenser temperature = 30°C

Temperature of refrigerant superheated as gas in evaporator = –5°C

Temperature of refrigerant subcooled as liquid in condenser = 25°C

**Compressor particulars:**

Number of cylinders = 2

Stroke = 1.5 times the bore

r.p.m. = 1200

Determine the following:

**(i)** refrigerating effect per kg

**(ii)** theoretical power

**(ii)** coefficient of performance

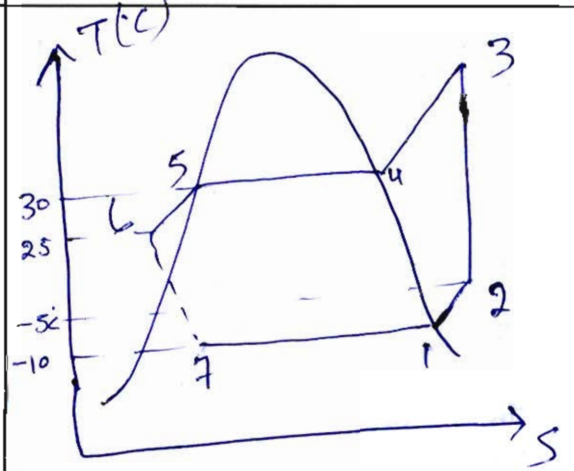
**(iv)** bore and stroke and compressor

| Saturation temperature $t_s$ °C | Absolute pressure $p$ bar | Specific volume $v_g$ m³/kg | Enthalpy of liquid $h_f$ kJ/kg | Enthalpy of vapour $h_g$ kJ/kg | Entropy of liquid $s_f$ kJ/kg°K | Entropy of vapour $s_g$ kJ/kg°K |
|---|---|---|---|---|---|---|
| –10 | 2.1928 | 0.07702 | 190.72 | 347.96 | 0.96561 | 1.5632 |
| +30 | 7.4457 | 0.02372 | 229.11 | 364.96 | 1.0999 | 1.5481 |

Take: Liquid specific heat, $c_{pl}$ = 0.963 kJ/kgK

Vapour specific heat $c_{pv}$ = 0.615 kJ/kgK

**[20 marks]**




$RC = 20\ TR = 70\ kW$

$h_1 = 347.96\ kJ/kg$

$h_2 = h_1 + C_{pv}(T_2 - T_1)$

$h_2 = 347.96 + .615 \times 5$

$h_2 = 351.035\ kJ/kg$

$h_4 = 364.96\ kJ/kg$

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

$s_2 = s_3$

$$s_1 + C_{pv} \ln \frac{T_2}{T_1} = s_4 + C_{pv} \ln \frac{T_3}{T_4}$$

$$1.5632 + .615 \ln \frac{268}{263} = 1.5481 + .615 \ln \frac{T_3}{303}$$

$T_3 = 316.435\ K$

$h_3 = 364.96 + .615(316.435 - 303) = 373.222\ kJ/kg$

$h_5 = 229.11\ kJ/kg$

$h_6 = h_7 = h_5 - C_{pl}(T_5 - T_6) \Rightarrow 229.11 - .963 \times 5 =$
$= 224.295\ kJ/kg$

(i) $RE = h_2 - h_7 = 351.035 - 224.295 = 126.74\ kJ/kg$ Ans

$70 = \dot m_R \times 126.74 \Rightarrow \dot m_{Ref} = 0.5523\ kg/s$

(ii) Power $= \dot m_R(h_3 - h_2) = .5523(373.222 - 351.035)$
$= 12.254\ kW$

(iii) $COP = \frac{RC}{Power} = \frac{70}{12.254} = 5.712$

Ans.

Assuming volumetric efficiency to be 100 %.
clearance ratio & swept volume is not given.

$\eta_V = \frac{\dot{m}_R \times v_{entry}}{\frac{\pi}{4} D^2 L \times \frac{N}{60} \times \frac{K}{n}}$

$v_1 = .02372 \ m^3/kg$

we know that
$PV = mRT$
$Pv = RT$
$v \propto T$

$\frac{v_1}{v_2} = \frac{T_1}{T_2} = \frac{.02372}{v_2} = \frac{263}{268}$

$v_2 = v_{entry} = 0.02417 \ kg/m^3$

$1 = \frac{0.5523 \times .02417 \times 4 \times 60}{\pi \times 1.5 \times D^3 \times 1200 \times 2}$

bore diameter

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$D = 0.06567 m = 65.676 mm$

Ans.

$L = 1.5D = 98.514 mm$ stroke length.

Ans.

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Q.3 (c) An existing heat exchanger of 24 $m^2$ surface area is to be used to condense low pressure steam. The cooling medium will be feed water available at 42°C, its flow rate being 0.94 kg/s. The overall heat transfer coefficient is estimated at 130 $W/m^2K$.

Calculate the quantity of steam condensed and the exit temperature of the feed water. At the condensing pressure steam has saturation temperature of 100°C and latent heat of vapourisation is 2257 kJ/kgK. Assume that the steam is initially just saturated and that the condensate leaves the exchanger without sub-cooling. How would the performance of the exchanger be affected if the overall heat transfer coefficient can be doubled by a modification of feed water flow through the exchanger? Take $C_p$ of water 4.187 kJ/kgK.

**[20 marks]**

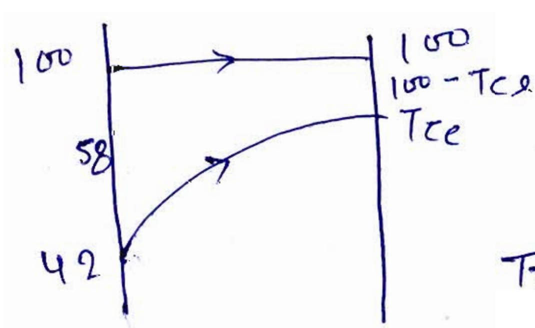
Ans - $A_s = 24 m^2$, $T_{ci} = 42°C$

$U = 130 W/m^2K$  $\dot{m}_c = .94 kg/s$

Find $\dot{m}_s$, $T_{ce}$, $T_{sat} = 100°C$

$h_{fg} = 2257 KJ/Kg$

~~Assume speci fic heat of water is 4.18 KJ/kgK~~




$Q = U A_s T_m = \dot{m}_c C_{pc} (T_{ce} - T_{ci})$

$$T_m = \frac{58 - (100 - T_{ce})}{\ln\left(\frac{58}{100 - T_{ce}}\right)}$$

$$130 \times 24 \times \frac{(T_{cl} - 42)}{\ln \frac{58}{100 - T_{cl}}} = .94 \times 4.187 \times (T_{cl} - 42) \times 1000$$

$$\frac{130 \times 24}{.94 \times 4.187 \times 1000} = \ln \frac{58}{100 - T_{cl}}$$

$$2.212 = \frac{58}{100 - T_{cl}} \Rightarrow 100 - T_{cl} = 26.216$$

$$T_{cl} = 73.783^\circ C$$

Ans

Exit tempr of feed water is $73.783^\circ C$

$$Q = \dot{m}_s \times h_{fg} = .94 \times 4.187 \times (73.783 - 42)$$

$\dot{m}_s = 0.05533$ kg/sec or $199.194$ kg/hr

Ans

If U is doubled $\Rightarrow U = 130 \times 2 = 260\ W/m^2 K$

Apply heat balance :

$$260 \times 24 \frac{(T_{cl} - 42)}{\ln \frac{58}{100 - T_{cl}}} = .94 \times 4.187 (T_{cl} - 42) \times 1000$$

$$\frac{260 \times 24}{.94 \times 4.187 \times 1000} = \ln \frac{58}{100 - T_{cl}}$$

$$4.8815 = \frac{58}{100 - T_{cl}} \Rightarrow T_{cl} = 88.118^\circ C$$

Ans

$$\dot{m}_s \times 2257 = .94 \times 4.187 (88.118 - 42)$$

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$\dot{m}_s = 0.08042 \text{ kg/s}$ or $289.518 \text{ kg/hr}$

Ans.

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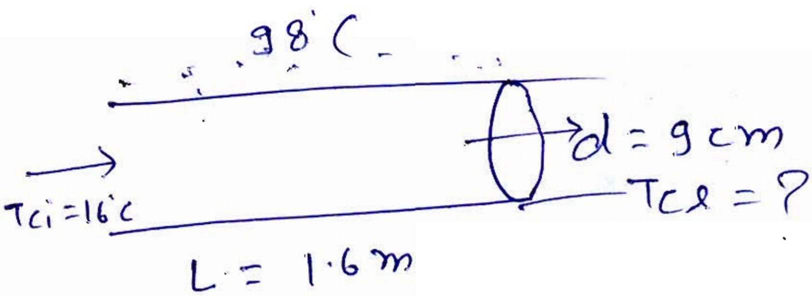
**Q.4 (a)** 900 kg/hr of cream cheese at 16°C is pumped through 1.6 m length of 9 cm inner diameter tube which is maintained at 98°C. Determine the temperature of cheese leaving the heated section and the rates of heat transfer from the tube to the cheese. The relevant thermo-physical properties of cheese are : $\rho$ = 1150 kg/m$^3$; $\mu$ = 22.5 kg/m-s; $c_p$ = 2750 J/kgK; $k$ = 0.42 W/mK.

Use the following correlation for laminar flow inside a tube

$$Nu = \frac{h\,d}{k} = 3.65 + \frac{0.067\frac{d}{l}\mathrm{Re\,Pr}}{1+0.04\left(\frac{d}{l}\mathrm{Re\,Pr}\right)^{0.67}}$$

**[20 marks]**




Find Tcl & Q

$\rho$ = 1150 kg/m3, $\mu$ = 22.5 kg/m-s, Cp = 2750 J/kgK

K = .4

$Re = \frac{\rho V D}{\mu}$

$\dot{m}$ = 900 kg/h = $\rho A V$

$\frac{900}{3600} = 1150 \times \frac{\pi}{4}(.09)^2 \times V$

$V = 0.03417\ m/s$

$$Re = \frac{1150 \times .03417 \times .09}{22.5} = 0.15719$$

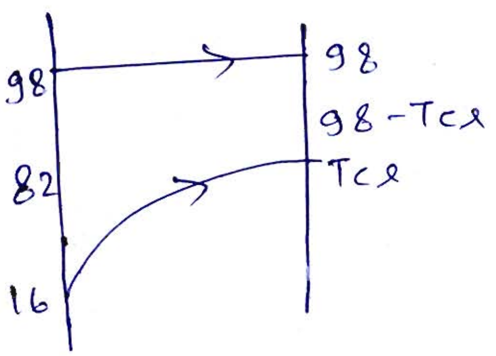
flow is laminar, so use the given relation.

$$\frac{h \times .09}{.42} = 3.65 + \frac{.067\left(\frac{.09}{1.6}\right) \times \frac{.15719 \times 22.5 \times 2750}{.42}}{1 + .04\left(\frac{.09}{1.6} \times \frac{.15719 \times 22.5 \times 2750}{.42}\right)^{.67}}$$

(302.607421)

$$= 3.65 + \frac{87.27469}{5.88635}$$

$h = 86.2242\ W/m^2K$




$$\Delta T_m = \frac{82 - (98 - T_{ce})}{\ln\left(\frac{82}{98 - T_{ce}}\right)}$$

$$\Delta T_m = \frac{T_{ce} - 16}{\ln\left(\frac{82}{98 - T_{ce}}\right)}$$

Apply heat balance,

$Q = UA\Delta T_m = \dot{m}_{Chem} \times C_{Chem}(T_{ce} - 16)$

* External diameter of tube is not given, so we use only internal diameter.

$$86.2242 \times \pi \times .09 \times 1.6 \times \frac{\cancel{T_{ce} - 16}}{\ln\left(\frac{82}{98 - T_{ce}}\right)} = \frac{9}{36} \times 2750 \times \cancel{(T_{ce} - 16)}$$

$$1.0583 = \frac{82}{98 - T_{ce}} \Rightarrow 98 - T_{ce} = 77.482$$

$T_{ce} = 20.51°C$

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Exit tempr of Chease is 20.51°C
Ans

$Q = \frac{900}{3600} \times 2750 \times (20.51 - 16) = 3.1056\,kW$
Ans.

heat transfer from tube to Chease.

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Q.4 (b) Air flowing at the rate of 120 $m^3/min$ at 40°C DBT and 50% RH is mixed with another stream flowing at the rate of 60 $m^3/min$ at 26°C DBT and 50% RH. The mixture flows over a cooling coil, whose ADP temperature is 10°C and by-pass factor is 0.2. Determine DBT and RH of air leaving the coil. If this air is supplied to an air-conditioned room where DBT of 26°C and RH of 50% are maintained estimate room sensible heat factor and cooling load capacity of the coil in tonnes of refrigeration.
[Refer Pschrometric chart attached]

**[20 marks]**

**Q.4 (c) (i)** During heat treatment, cylindrical pieces of 26 mm diameter, 32 mm height and at 30°C are placed in a furnace at 760°C with convection coefficient 84 W/m$^2$-K. Calculate the time required to heat the pieces to 620°C. What will be the shortfall in temperature if the pieces are taken out from the furnace after 270 seconds? Assume the following property values : $\rho = 7850$ kg/m$^3$; $C_p = 480$ J/kgK; $K = 42$ W/m-K.

**(ii)** Draw a typical boiling curve for pool boiling of water at saturation temperature and atmospheric pressure. Mark each boiling regime and explain briefly its various regimes.

**[10 + 10 marks]**

(i) $D = 26$ mm  $T_i = 30°C$  $h = 84$ W/m$^2$K

$h = 32$ mm  $T_\infty = 760°C$

Find time to reach 620°C

$\rho = 7850$ Kg/m3, $C_P = 480$ J/Kg K

$K = 42$ W/mK

We Know,

$$\frac{T - T_\infty}{T_i - T_\infty} = e^{\frac{-hA}{\rho V C_P} \times t}$$

$$\frac{620 - 760}{30 - 760} = e^{-\frac{84 \times 2\pi \times .013(.013 + .032) \times t}{7850 \times \pi (.013)^2 \times .032 \times 480}}$$

$$\frac{t-140}{t-730} = e^{-\frac{7.56t}{1567.488}}$$

$$1.6514 = \frac{7.56t}{1567.488} \Rightarrow t = \underline{\underline{342.4011 \text{ sec}}}$$

Ans.

Time 342.4011 sec or 5.70 minutes takes to reach to 620°C.

If, t = 270 sec, then what is shortfall in temp.

$$\frac{T-760}{30-760} = e^{-\frac{7.56 \times 270}{1567.488}}$$

$$\frac{T-760}{-730} = .2719 \Rightarrow T = \underline{\underline{561.4911\,^\circ C}}$$

Shortfall is $620 - 561.4911 = \underline{\underline{58.508\,^\circ C}}$ Ans

10

(ii)

? 0

### Saturated Water and Steam (Pressure-based)

$p_{tp}$ = 611.657 Pa = 0.000611657 MPa

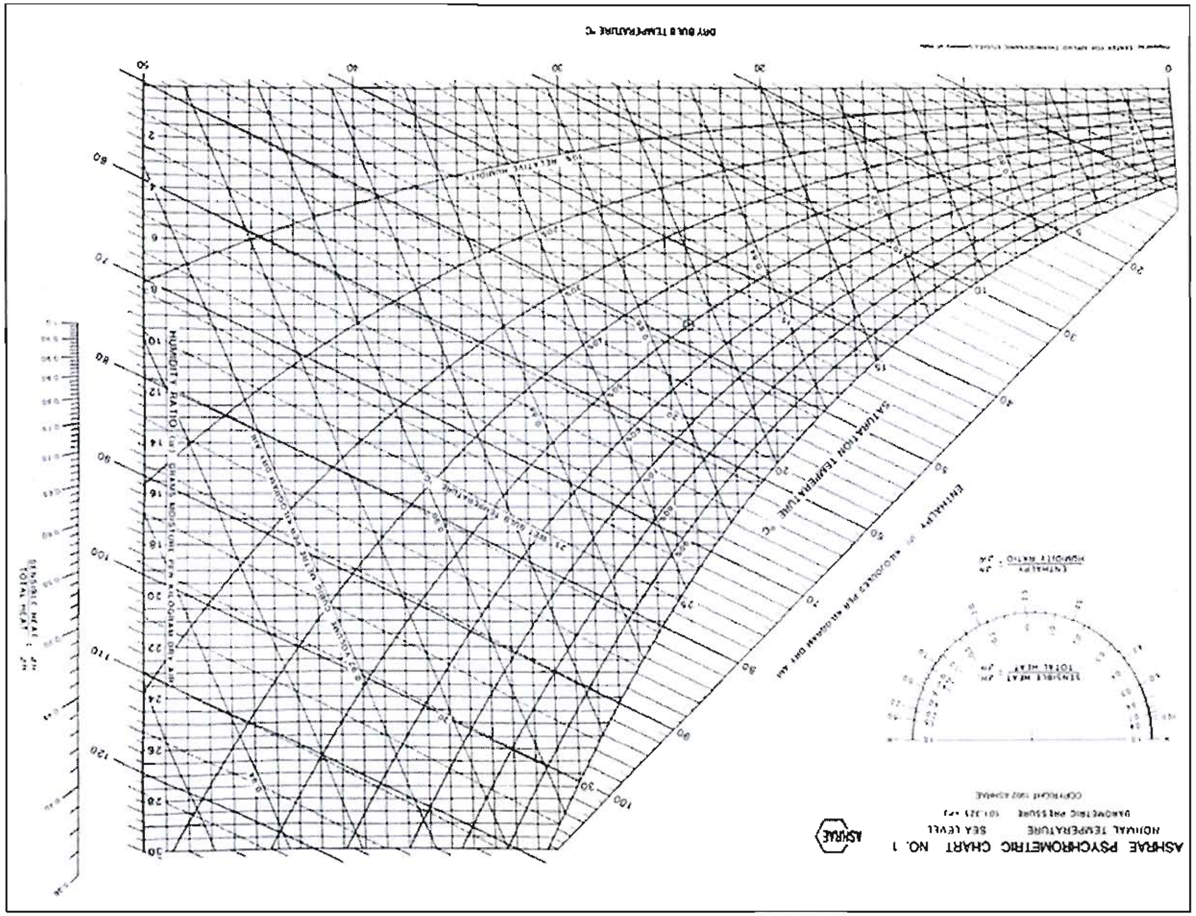
| p MPa | $T_{sat}$ °C | Volume, m³/kg $v_f$ | $v_g$ | Energy, kJ/kg $u_f$ | $u_g$ | Enthalpy, kJ/kg $h_f$ | $h_g$ | $h_{fg}$ | Entropy, kJ/(kg K) $s_f$ | $s_g$ | $s_{fg}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $p_{tp}$ | 0.01 | 0.00100021 | 205.991 | 0 | 2374.9 | 0.00 | 2500.9 | 2500.9 | 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 | 2481.4 | 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 | 93.809 | 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 |

### Saturated Water and Steam (Temperature-based)

| T °C | $p_{sat}$ MPa | Volume, m³/kg $v_f$ | $v_g$ | Energy, kJ/kg $u_f$ | $u_g$ | Enthalpy, kJ/kg $h_f$ | $h_g$ | $h_{fg}$ | Entropy, kJ/(kg K) $s_f$ | $s_g$ | $s_{fg}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 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 |

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

| $p$ MPa | $T_{sat}$ °C | Volume, m³/kg $v_f$ | $v_g$ | Energy, kJ/kg $u_f$ | $u_g$ | Enthalpy, kJ/kg $h_f$ | $h_g$ | $h_{fg}$ | Entropy, kJ/(kg K) $s_f$ | $s_g$ | $s_{fg}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 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 | 0.00108541 | 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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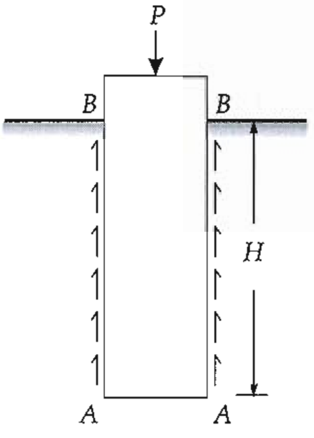
## Section : B

**Q.5 (a)** A pile of uniform section is embedded in soil by a depth $H$. The pile supports a structural load $P$ at its top which is transferred to the soil entirely by friction as shown in figure below. The variation of friction ($f$) along the depth of the pile is given by $f = ky^2$, where $y$ is the elevation above the bottom of the pile. Determine the shortening of the pile.



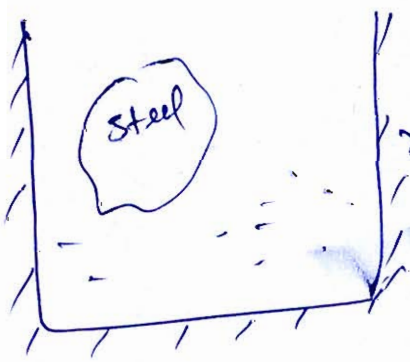

**[12 marks]**

**Q.5 (b)** A lump of steel of mass 15 kg at 800°C is dropped in 10 kg of water at 30°C contained in an insulated container which is open to the atmosphere. If the specific heat of steel and water are 0.5 kJ/kgK and 4.27 kJ/kgK respectively and latent heat of vaporization of water at 100°C is 2257 kJ/kg, then calculate the change in entropy of steel, water and the universe.

**[12 marks]**

$m = 15$ kg, $T_i = 800$°C, $C_s = .5$ kJ/kgK

$C_w = 4.27$ kJ/kg K




$m_w = 10$ kg, $T_{wi} = 30$°C

$(h_{fg})_{100} = 2257$ kJ/kg

Find $(\Delta S)$ steel, water & universe.

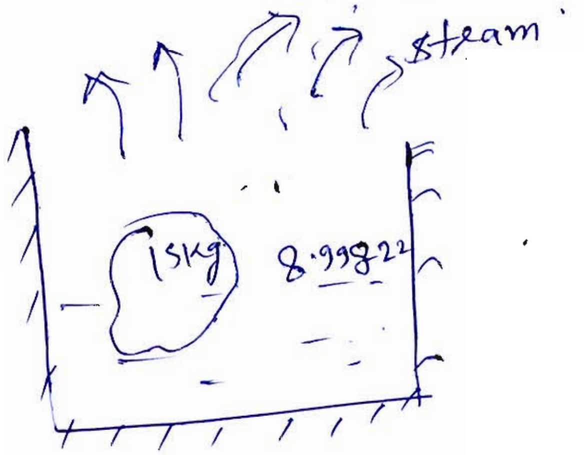
Steel loose → $15 \times .5 \times (800-100) = 5250$ kJ to reach upto 100°C,

water require to reach 100°C = $10 \times 4.27 \times (100-30)$
$= 2989$ kJ

remaining $5250 - 2989 = 2261$ kJ is used for vaporising the water so, 1.00177 kg water convert into steam. & tank is open to the atmosphere, so steam will be evaporated out

Finally in the tank water is remaining is

8.99822 Kg at 100°C




$$(\Delta S)_{steel} = 15 \times .5 \ln \frac{373}{1073} = -7.9247 \text{ KJ/K}$$

Ans.

$$(\Delta S)_{water} = 10 \times 4.27 \ln \frac{373}{303} + \frac{1.00177 \times 2257}{373}$$

$$8.875 + 6.0616 = 14.9366 \text{ KJ/K}$$

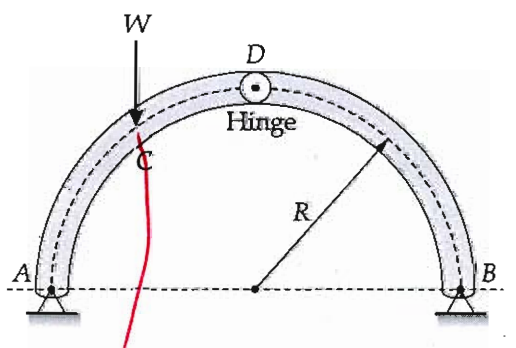
Ans

$$(\Delta S)_{universe} = 14.9366 - 7.9247 = 7.0119 \text{ KJ/K}$$

Ans

12

Q.5 (c) A 3-hinged arch loaded at $C$, at a distance $\frac{R}{2}$ from $A$. Find the resultant forces at $A$ and $B$ as shown in figure below.




**[12 marks]**

Do not write in this margin

Q.5 (d) State and prove Clausius inequality.

**[12 marks]**

$$\oint \frac{\delta Q}{T} \leq 0$$

Cyclic integral of Net heat supplied is divided by Absolute temp is less then or equals to 0 is known as clasius inequality.

$$\oint \frac{\delta Q}{T} = 0 \rightarrow \text{for Reversible Process}$$

3

$$\oint \frac{\delta Q}{T} < 0 \rightarrow \text{for irreversible Process}$$

**Q.5 (e)** A rectangular strain rosette strain gauge records the following values for linear strain at a point in two dimensional stress system : $e_x = 520 \times 10^{-6}$, $e_y = -140 \times 10^{-6}$, and $e_{45°} = 270 \times 10^{-6}$, the later being at 45° to the $x$ and $y$ axes. Calculate the principal strain and stresses. Take $E = 205$ GPa and $\mu = 0.32$.

**[12 marks]**

$\varepsilon_x = 520 \times 10^{-6}$, $\varepsilon_y = -140 \times 10^{-6}$, $\varepsilon_{45} = 270 \times 10^{-6}$

$E = 205$ GPa, $\mu = .32$, find principal stress & strain.

$$\varepsilon_{45} = \frac{\varepsilon_x + \varepsilon_y}{2} + \frac{\varepsilon_x - \varepsilon_y}{2}\cos 2\theta + \frac{\gamma_{xy}}{2}\sin 2\theta$$

$$270 = \frac{520 - 140}{2} + \frac{520 + 140}{2}\cos 90 + \frac{\gamma_{xy}}{2}\sin 90$$

$\gamma_{xy} = 160 \times 10^{-6}$

$$\varepsilon_1 = \frac{1}{2}\left[(\varepsilon_x + \varepsilon_y) + \sqrt{(\varepsilon_x - \varepsilon_y)^2 + (\gamma_{xy})^2}\right]$$

$$\varepsilon_1 = \frac{1}{2}\left[(520 - 140) + \sqrt{(520 + 140)^2 + (160)^2}\right]$$

Do not write in this margin

$\varepsilon_1 = 529.5585 \times 10^{-6}$ Ans.

$\varepsilon_1 + \varepsilon_2 = \varepsilon_x + \varepsilon_y$

$\varepsilon_2 = 520 - 140 - 529.5585 = -149.5585 \times 10^{-6}$ Ans

The Principal strains are $529.5585 \times 10^{-6}$ & $-149.5585 \times 10^{-6}$

We know, for Plain stress Problems,

$$\sigma_1 = \frac{E}{1-\mu^2}(\varepsilon_1 + \mu\varepsilon_2)$$

$$\sigma_1 = \frac{205 \times 10^3}{(1-(.32)^2) \times 10^3}(529.5585 + .32 \times (-149.5585)) \times 10^{-6}$$

$$= \frac{98.74845}{(1-(.32)^2) = .8976}$$

$\sigma_1 = 110.013$ MPa Ans

$$\sigma_2 = \frac{E}{1-\mu^2}(\varepsilon_2 + \mu\varepsilon_1)$$

$$\sigma_2 = \frac{205 \times 10^3}{(1-(.32)^2) \times 10^3}(-149.5585 + .32 \times 529.5585) \times 10^{-6}$$

12

$\sigma_2 = 4.544$ MPa Ans.

The Principal stresses are 110.013 MPa & 4.544 MPa Ans

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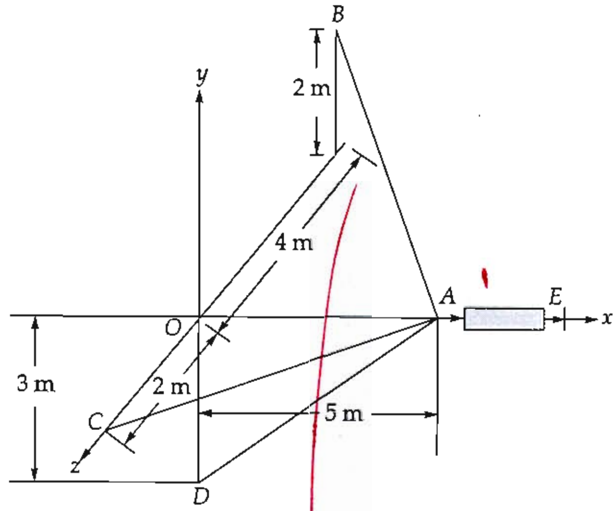
**Q.6 (a)** A compound cylinder, formed by shrinking one tube on to another, is subjected to an internal pressure of 60 MPa. Before the fluid is admitted, the internal and external diameters of the compound cylinder are 120 mm and 220 mm, and the diameter at the junction is 180 mm. If after shrinkage, the radial pressure at the common surface is 10 MPa, calculate the final stresses set-up by the section.

**[20 marks]**

Do not write in this margin

Do not write in this margin

**Q.6 (b)** A system of 3 cables *AB*, *AC* and *AD* shown in figure below is subjected to a force of 800 kN along the *x*-direction by turn buckle *AE*. Calculate the forces developed in the cables.




**[20 marks]**

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**Q.6 (c)** (i) Show that the first law of thermodynamics leads to the fact that heat interaction is a path function.

(ii) A perfect gas undergoes a cycle comprises of three processes. It is first compressed isothermally from 1 bar and 27°C to one-fifth of its initial volume. The energy is than added at constant pressure, increasing the temperature of gas and the cycle is completed by isentropic expansion to original conditions. Take $c_p$ = 1.25 kJ/kgK and $R$ = 0.5 kJ/kgK. Calculate the maximum cycle temperature and pressure. Also find the net work transfer.

**[10 + 10 marks]**

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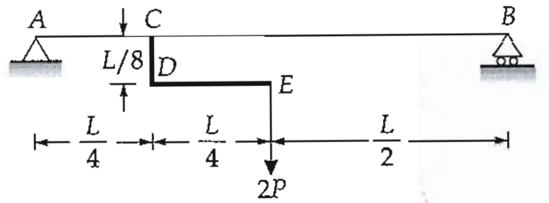
**Q.7 (a)** A rigid and insulated tank of volume 2.5 $m^3$ contains an ideal gas at 1 bar and 320 K. The tank is connected to a line carrying the same gas at 25 bar and 550 K. The valve in between the tank and the line is opened allowing the gas to enter the tank till the gas pressure in the tank rises to 25 bar and then closed. Determine the final temperature of the gas in the tank and the amount of gas that entered the tank. Neglect the effects of kinetic energy and potential energy.

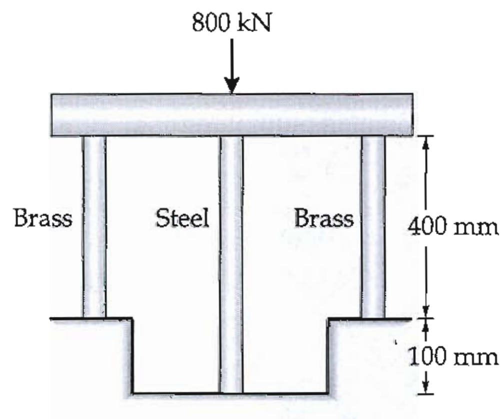
[Assume $R = 0.287$ kJ/kgK; $c_p = 1.005$ kJ/kgK and $\gamma = 1.4$ for ideal gas]

**[20 marks]**

**Q.7 (b)** (i) A simply supported beam ACB supports a vertical load 2P by means of a bracket CDE, as shown in figure below. Draw SFD and BMD for the beam.




(ii) A steel rod and two brass rods, together support a load of 800 kN as shown in figure below. Young's modulus of steel and brass are 200 GPa and 100 GPa, respectively. Cross-sectional area of steel and brass rod are 2500 $mm^2$ and 1500 $mm^2$, respectively. Calculate the stresses in the rods.




**[10 + 10 marks]**

**Q.7 (c)** **(i)** Sketch the Mollier diagram and briefly explain its essential features.

**(ii)** A rigid and sealed tank of volume 1 $m^3$ is initial filled with dry saturated steam at 230°C and left in the room. After a while the temperature of the steam is reduced to 190°C. Determine the final conditions of steam in the tank and the amount of energy transferred as heat. (Refer steam table attached)

**[8 + 12 marks]**

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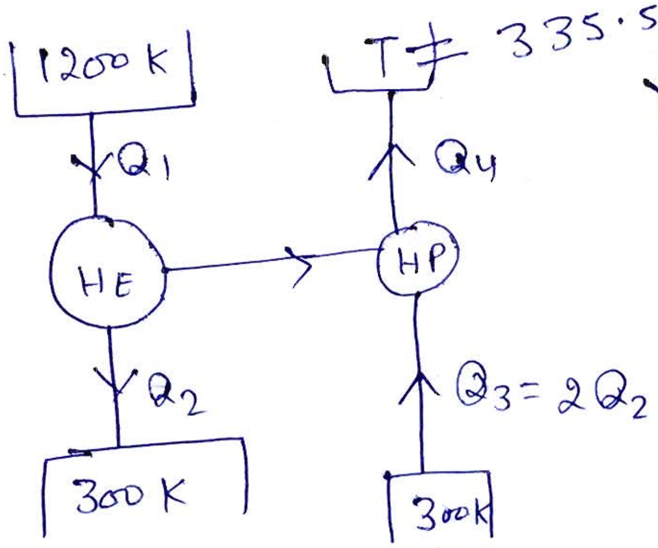
**Q.8 (a)** A heat engine operating between two reservoirs at 1200 K and 300 K is used to drive a heat pump which extracts heat from the rerservoir at 300 K at a rate twice that at which the engine rejects heat to it. If the efficiency of the engine is 40% of the maximum possible and the COP of the heat pump is 60% of the maximum possible, then determine:

(i) the temperature of the reservoir to which the heat pump rejects heat.

(ii) the rate of heat rejection from the heat pump if the rate of heat supply to the engine is 100 kW.

**[20 marks]**




$\eta_{HE} = .4\,\eta_C$

$COP_{HP} = .6\, COP_{Rev}$

Find T

$\eta_{HE} = .4 \times \left(1 - \frac{300}{1200}\right) = .3 = \frac{W}{Q_1}$

$(COP)_{HP} = .6 \times \frac{T}{T-300}$

$(COP)_{HP} = \frac{Q_4}{W = Q_1 - Q_2} \Rightarrow \frac{W + Q_3}{\cancel{Q_1 - Q_2}\ W} = 1 + \frac{Q_3}{W}$

$(COP)_{HP} = 1 + \frac{2Q_2}{W}$ $\quad (\because Q_2 + W = Q_1 \Rightarrow Q_2 = Q_1 - W)$

$= 1 + \frac{2(Q_1 - W)}{W} = 1 + \frac{2Q_1}{W} - 2$

$(COP)_{HP} = 1 + \frac{2}{.3} - 2 = 5.6667 = .6 \times \frac{T}{T-300}$

$9.444 = \frac{T}{T-300} \Rightarrow 9.444\,T - 2833.33 = T$

Do not write in this margin

$T = 335.528\,K = 62.528^\circ C$ Ans

(ii) $Q_1 = 100\,kW$, $Q_4 = ?$

$Q_2 = 70\,kW$, $W = 30\,kW$

$Q_3 = 70 \times 2 = 140\,kW$

$Q_4 = Q_3 + W = 140 + 30 = 170\,kW$ Ans

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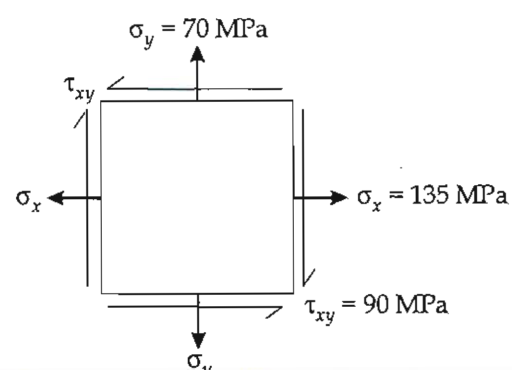
**Q.8 (b)** At a certain point in a piece of elastic material, there are normal tensile stresses of magnitude 135 MPa (in $x$-direction), 70 MPa acting orthogonally to each other. In addition, there is a shearing stress of 90 MPa acting normal to the normal stresses.

Calculate : (i) the magnitude and direction of the principal stresses, (ii) the magnitude and direction of the maximum shearing stress. (iii) the normal and shearing stress on a plane inclined at 30° to the direction of 135 MPa stress.




**[20 marks]**

given, $\sigma_x = 135$ MPa, $\sigma_y = 70$ MPa, $\tau_{xy} = 90$ MPa

(i)

$$\sigma_{1,2} = \frac{1}{2}\left[(\sigma_x + \sigma_y) \pm \sqrt{(\sigma_x - \sigma_y)^2 + 4\,\tau_{xy}^2}\right]$$

$$\sigma_1 = \frac{1}{2}\left[(135 + 70) + \sqrt{(135-70)^2 + 4(90)^2}\right]$$

$$\sigma_1 = \underline{198.188 \text{ MPa}}$$

Ans

$\sigma_1 + \sigma_2 = \sigma_x + \sigma_y$

$\sigma_2 = 135 + 70 - 198.188$

$\sigma_2 = 6.812$ MPa

Ans

$\tan 2\theta_P = \frac{2\tau_{xy}}{\sigma_x - \sigma_y} \Rightarrow \frac{2 \times 90}{135 - 70}$ Principal Plain angle.

$2\theta_P = 70.144 \Rightarrow \theta_P = 35.072° \;\&\; 125.072°$

Ans

(iii) $\tau_{max} = \frac{\sigma_1 - \sigma_2}{2} = \frac{198.188 - 6.812}{2}$

$= 95.688$ MPa

Ans

dirn of $\tau_{max}$ Plains is 45° ahead of Principal Plains

$\theta_{\tau max} = 80.072° \;\&\; 170.072°$ Ans.

14

(iii) $\sigma_n$ & $\tau_s$ from x face to θ of 30°

$(\sigma_n)_{\theta=30°} = \frac{\sigma_x + \sigma_y}{2} + \frac{\sigma_x - \sigma_y}{2} \cos 2\theta + \tau_{xy} \sin 2\theta$

$(\sigma_n)_{\theta=30} = \frac{135 + 70}{2} + \frac{135 - 70}{2} \cos 60 + 90 \times \sin 60$

$= 102.5 + 16.25 + 77.9422 = 196.692$ MPa

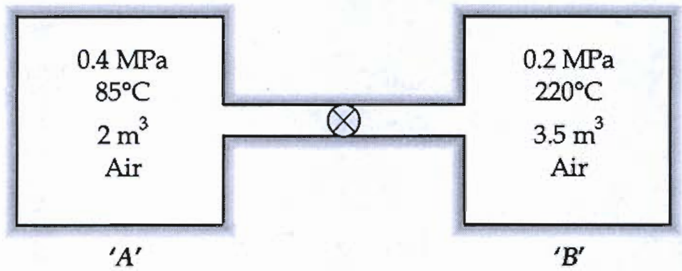
Ans

$(\tau_s)_{30} = -\frac{1}{2}(\sigma_x - \sigma_y) \sin 2\theta + \tau_{xy} \cos 2\theta$

$= \frac{-1}{2}(135 - 70) \sin 60 + 90 \times \cos 60$

$= -28.145 + 45 = 16.855$ MPa Ans.

(c) Two vessels, $A$ and $B$ of volume 2 m$^3$ and 3.5 m$^3$ respectively, are connected by a tube of negligible volume through a valve as shown below. Vessel $A$ contains air at 0.4 MPa, 85°C while vessel $B$ contains air at 0.2 MPa, 220°C. Determine the total change of entropy, when the valve is opened and assuming the mixing to be complete and adiabatic. For air take $R$ = 0.287 kJ/kgK; $c_p$ = 1.005 kJ/kgK; $c_v$ = 0.717 kJ/kgK.




**[20 marks]**

$P_A V_A = m_A R T_A$

$\frac{400 \times 2}{.287 \times 358} = m_A = 7.786\ kg$

$\frac{200 \times 3.5}{.287 \times 493} = m_B = 4.9473\ kg$

Total mass of air $= m = m_A + m_B = 12.733\ kg$

Total Volume $= 5.5\ m^3$

$P_{total} \times V_{total} = m_{total} \times R \times T_{final}$ (~~$T_{total}$~~)

From I$^{st}$ law,

$7.786 \times$ ~~1.005~~ $(T_f - 85) = 4.9473 \times$ ~~1.005~~ $(220 - T_f)$

$1.5737\ T_f - 133.77195 = 220 - T_f$

$2.5737\ T_f = 353.7719$

$T_f = 137.456°C = 410.4565 K$

$P_{final} \times 5.5 = 12.733 \times .287 \times 410.4565$

$P_{final} = 272.72\ kPa$

Entropy change of A

$$m_A\left\{C_P \ln \frac{T_f}{T_A} - R \ln \frac{P_f}{P_A}\right\}$$

$$= 7.786\left\{1.005 \ln \frac{410.4565}{358} - .287 \ln \frac{272.72}{400}\right\}$$

$$7.786(.13742 + .109926)$$

$$= 1.92583 \text{ kJ/K}$$

Entropy change of B

$$4.9473\left\{1.005 \ln \frac{410.4565}{493} - .287 \ln \frac{272.72}{200}\right\}$$

$$4.9473(-.18415 - .089068)$$

$$= -1.3514 \text{ kJ/K}$$

20

Total change in Entropy = $1.92583 - 1.3514$

$$= 0.5744 \text{ kJ/K}$$

Ans

**Saturated Water and Steam (Temperature-based), Contd.**

| T °C | $p_{sat}$ MPa | Volume, m³/kg $v_f$ | $v_g$ | Energy, kJ/kg $u_f$ | $u_g$ | Enthalpy, kJ/kg $h_f$ | $h_g$ | $h_{fg}$ | Entropy, kJ/(kg K) $s_f$ | $s_g$ | $s_{fg}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 160 | 0.61823 | 0.00110199 | 0.30678 | 674.79 | 2567.7 | 675.47 | 2757.4 | 2082.0 | 1.9426 | 6.7491 | 4.8066 |
| 161 | 0.63412 | 0.00110318 | 0.29951 | 679.12 | 2568.6 | 679.82 | 2758.5 | 2078.7 | 1.9525 | 6.7406 | 4.7880 |
| 162 | 0.65033 | 0.00110438 | 0.29245 | 683.45 | 2569.4 | 684.17 | 2759.6 | 2075.5 | 1.9625 | 6.7320 | 4.7695 |
| 163 | 0.66686 | 0.00110559 | 0.28559 | 687.78 | 2570.3 | 688.52 | 2760.7 | 2072.2 | 1.9725 | 6.7235 | 4.7511 |
| 164 | 0.68373 | 0.00110680 | 0.27892 | 692.12 | 2571.1 | 692.88 | 2761.8 | 2068.9 | 1.9824 | 6.7150 | 4.7327 |
| 165 | 0.70093 | 0.00110803 | 0.27243 | 696.46 | 2571.8 | 697.24 | 2762.8 | 2065.6 | 1.9923 | 6.7066 | 4.7143 |
| 166 | 0.71848 | 0.00110926 | 0.26612 | 700.80 | 2572.7 | 701.60 | 2763.9 | 2062.3 | 2.0022 | 6.6982 | 4.6960 |
| 167 | 0.73638 | 0.00111050 | 0.25999 | 705.14 | 2573.4 | 705.96 | 2764.9 | 2058.9 | 2.0121 | 6.6898 | 4.6778 |
| 168 | 0.75462 | 0.00111175 | 0.25403 | 709.49 | 2574.2 | 710.33 | 2765.9 | 2055.6 | 2.0220 | 6.6815 | 4.6596 |
| 169 | 0.77322 | 0.00111300 | 0.24823 | 713.85 | 2575.0 | 714.71 | 2766.9 | 2052.2 | 2.0318 | 6.6732 | 4.6414 |
| 170 | 0.79219 | 0.00111427 | 0.24259 | 718.20 | 2575.7 | 719.08 | 2767.9 | 2048.8 | 2.0417 | 6.6650 | 4.6233 |
| 171 | 0.81152 | 0.00111554 | 0.23710 | 722.55 | 2576.5 | 723.46 | 2768.9 | 2045.4 | 2.0515 | 6.6567 | 4.6053 |
| 172 | 0.83122 | 0.00111682 | 0.23176 | 726.92 | 2577.3 | 727.85 | 2769.9 | 2042.0 | 2.0613 | 6.6485 | 4.5872 |
| 173 | 0.85130 | 0.00111811 | 0.22656 | 731.28 | 2577.9 | 732.23 | 2770.8 | 2038.6 | 2.0711 | 6.6404 | 4.5693 |
| 174 | 0.87176 | 0.00111941 | 0.22150 | 735.65 | 2578.7 | 736.63 | 2771.8 | 2035.1 | 2.0809 | 6.6322 | 4.5514 |
| 175 | 0.89260 | 0.00112072 | 0.21658 | 740.02 | 2579.4 | 741.02 | 2772.7 | 2031.7 | 2.0906 | 6.6241 | 4.5335 |
| 176 | 0.91384 | 0.00112204 | 0.21179 | 744.39 | 2580.1 | 745.42 | 2773.6 | 2028.2 | 2.1004 | 6.6161 | 4.5157 |
| 177 | 0.93547 | 0.00112336 | 0.20712 | 748.77 | 2580.7 | 749.82 | 2774.5 | 2024.7 | 2.1101 | 6.6080 | 4.4979 |
| 178 | 0.95751 | 0.00112470 | 0.20258 | 753.15 | 2581.4 | 754.23 | 2775.4 | 2021.2 | 2.1198 | 6.6000 | 4.4802 |
| 179 | 0.97995 | 0.00112604 | 0.19815 | 757.54 | 2582.1 | 758.64 | 2776.3 | 2017.7 | 2.1296 | 6.5920 | 4.4625 |
| 180 | 1.0028 | 0.00112740 | 0.19384 | 761.92 | 2582.8 | 763.05 | 2777.2 | 2014.2 | 2.1392 | 6.5840 | 4.4448 |
| 181 | 1.0261 | 0.00112876 | 0.18964 | 766.31 | 2583.5 | 767.47 | 2778.1 | 2010.6 | 2.1489 | 6.5761 | 4.4272 |
| 182 | 1.0498 | 0.00113013 | 0.18555 | 770.71 | 2584.1 | 771.90 | 2778.9 | 2007.0 | 2.1586 | 6.5682 | 4.4096 |
| 183 | 1.0739 | 0.00113151 | 0.18157 | 775.10 | 2584.8 | 776.32 | 2779.8 | 2003.4 | 2.1683 | 6.5603 | 4.3921 |
| 184 | 1.0985 | 0.00113290 | 0.17769 | 779.51 | 2585.4 | 780.75 | 2780.6 | 1999.8 | 2.1779 | 6.5525 | 4.3746 |
| 185 | 1.1235 | 0.00113430 | 0.17390 | 783.92 | 2586.0 | 785.19 | 2781.4 | 1996.2 | 2.1875 | 6.5447 | 4.3571 |
| 186 | 1.1489 | 0.00113571 | 0.17021 | 788.33 | 2586.6 | 789.63 | 2782.2 | 1992.6 | 2.1971 | 6.5369 | 4.3397 |
| 187 | 1.1748 | 0.00113713 | 0.16662 | 792.73 | 2587.3 | 794.07 | 2783.0 | 1988.9 | 2.2067 | 6.5291 | 4.3223 |
| 188 | 1.2011 | 0.00113856 | 0.16311 | 797.15 | 2587.9 | 798.52 | 2783.8 | 1985.3 | 2.2163 | 6.5213 | 4.3050 |
| 189 | 1.2280 | 0.00114000 | 0.15969 | 801.57 | 2588.4 | 802.97 | 2784.5 | 1981.6 | 2.2259 | 6.5136 | 4.2877 |
| 190 | 1.2552 | 0.00114145 | 0.15636 | 806.00 | 2589.0 | 807.43 | 2785.3 | 1977.9 | 2.2355 | 6.5059 | 4.2704 |
| 191 | 1.2830 | 0.00114291 | 0.15311 | 810.42 | 2589.6 | 811.89 | 2786.0 | 1974.1 | 2.2450 | 6.4982 | 4.2532 |
| 192 | 1.3112 | 0.00114438 | 0.14994 | 814.86 | 2590.1 | 816.36 | 2786.7 | 1970.4 | 2.2546 | 6.4906 | 4.2360 |
| 193 | 1.3399 | 0.00114586 | 0.14685 | 819.29 | 2590.6 | 820.83 | 2787.4 | 1966.6 | 2.2641 | 6.4830 | 4.2188 |
| 194 | 1.3691 | 0.00114736 | 0.14383 | 823.74 | 2591.2 | 825.31 | 2788.1 | 1962.8 | 2.2736 | 6.4754 | 4.2017 |
| 195 | 1.3988 | 0.00114886 | 0.14089 | 828.18 | 2591.7 | 829.79 | 2788.8 | 1959.0 | 2.2832 | 6.4678 | 4.1846 |
| 196 | 1.4290 | 0.00115037 | 0.13802 | 832.64 | 2592.3 | 834.28 | 2789.5 | 1955.2 | 2.2926 | 6.4602 | 4.1676 |
| 197 | 1.4597 | 0.00115189 | 0.13522 | 837.09 | 2592.7 | 838.77 | 2790.1 | 1951.4 | 2.3021 | 6.4527 | 4.1505 |
| 198 | 1.4909 | 0.00115343 | 0.13248 | 841.54 | 2593.3 | 843.26 | 2790.8 | 1947.5 | 2.3116 | 6.4451 | 4.1335 |
| 199 | 1.5227 | 0.00115497 | 0.12982 | 846.00 | 2593.7 | 847.76 | 2791.4 | 1943.6 | 2.3211 | 6.4376 | 4.1166 |
| 200 | 1.5549 | 0.00115653 | 0.12721 | 850.47 | 2594.2 | 852.27 | 2792.0 | 1939.7 | 2.3305 | 6.4302 | 4.0996 |

**Saturated Water and Steam (Temperature-based), Contd.**

| T °C | $p_{sat}$ MPa | Volume, m³/kg $v_f$ | $v_g$ | Energy, kJ/kg $u_f$ | $u_g$ | Enthalpy, kJ/kg $h_f$ | $h_g$ | $h_{fg}$ | Entropy, kJ/(kg K) $s_f$ | $s_g$ | $s_{fg}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 200 | 1.5549 | 0.00115653 | 0.12721 | 850.47 | 2594.2 | 852.27 | 2792.0 | 1939.7 | 2.3305 | 6.4302 | 4.0996 |
| 201 | 1.5877 | 0.00115809 | 0.12467 | 854.94 | 2594.7 | 856.78 | 2792.6 | 1935.8 | 2.3400 | 6.4227 | 4.0827 |
| 202 | 1.6210 | 0.00115967 | 0.12218 | 859.42 | 2595.1 | 861.30 | 2793.2 | 1931.9 | 2.3494 | 6.4152 | 4.0658 |
| 203 | 1.6549 | 0.00116126 | 0.11976 | 863.90 | 2595.5 | 865.82 | 2793.7 | 1927.9 | 2.3588 | 6.4078 | 4.0490 |
| 204 | 1.6893 | 0.00116286 | 0.11739 | 868.39 | 2596.0 | 870.35 | 2794.3 | 1923.9 | 2.3683 | 6.4001 | 4.0322 |
| 205 | 1.7243 | 0.00116448 | 0.11508 | 872.87 | 2596.4 | 874.88 | 2794.8 | 1919.9 | 2.3777 | 6.3930 | 4.0154 |
| 206 | 1.7598 | 0.00116610 | 0.11282 | 877.37 | 2596.8 | 879.42 | 2795.3 | 1915.9 | 2.3871 | 6.3856 | 3.9986 |
| 207 | 1.7959 | 0.00116774 | 0.11061 | 881.86 | 2597.3 | 883.96 | 2795.9 | 1911.9 | 2.3964 | 6.3783 | 3.9819 |
| 208 | 1.8326 | 0.00116939 | 0.10846 | 886.37 | 2597.5 | 888.51 | 2796.3 | 1907.8 | 2.4058 | 6.3710 | 3.9651 |
| 209 | 1.8698 | 0.00117105 | 0.10635 | 890.88 | 2597.9 | 893.07 | 2796.8 | 1903.7 | 2.4152 | 6.3636 | 3.9484 |
| 210 | 1.9077 | 0.00117272 | 0.10429 | 895.39 | 2598.3 | 897.63 | 2797.3 | 1899.6 | 2.4245 | 6.3563 | 3.9318 |
| 211 | 1.9461 | 0.00117441 | 0.10228 | 899.91 | 2598.7 | 902.20 | 2797.7 | 1895.5 | 2.4339 | 6.3490 | 3.9151 |
| 212 | 1.9851 | 0.00117611 | 0.10031 | 904.44 | 2599.0 | 906.77 | 2798.1 | 1891.4 | 2.4432 | 6.3417 | 3.8985 |
| 213 | 2.0247 | 0.00117782 | 0.098394 | 908.97 | 2599.3 | 911.35 | 2798.5 | 1887.2 | 2.4526 | 6.3345 | 3.8819 |
| 214 | 2.0650 | 0.00117954 | 0.096516 | 913.50 | 2599.6 | 915.94 | 2798.9 | 1883.0 | 2.4619 | 6.3272 | 3.8653 |
| 215 | 2.1058 | 0.00118128 | 0.094679 | 918.04 | 2599.9 | 920.53 | 2799.3 | 1878.8 | 2.4712 | 6.3200 | 3.8488 |
| 216 | 2.1473 | 0.00118303 | 0.092884 | 922.58 | 2600.3 | 925.12 | 2799.7 | 1874.6 | 2.4805 | 6.3128 | 3.8323 |
| 217 | 2.1894 | 0.00118479 | 0.091129 | 927.14 | 2600.5 | 929.73 | 2800.0 | 1870.3 | 2.4898 | 6.3056 | 3.8158 |
| 218 | 2.2322 | 0.00118657 | 0.089413 | 931.69 | 2600.7 | 934.34 | 2800.3 | 1866.0 | 2.4991 | 6.2984 | 3.7993 |
| 219 | 2.2756 | 0.00118836 | 0.087734 | 936.26 | 2601.1 | 938.96 | 2800.7 | 1861.7 | 2.5084 | 6.2912 | 3.7828 |
| 220 | 2.3196 | 0.00119017 | 0.086092 | 940.82 | 2601.2 | 943.58 | 2800.9 | 1857.4 | 2.5177 | 6.2840 | 3.7663 |
| 221 | 2.3643 | 0.00119198 | 0.084486 | 945.39 | 2601.4 | 948.21 | 2801.2 | 1853.0 | 2.5269 | 6.2768 | 3.7499 |
| 222 | 2.4096 | 0.00119382 | 0.082916 | 949.97 | 2601.7 | 952.85 | 2801.5 | 1848.6 | 2.5362 | 6.2697 | 3.7335 |
| 223 | 2.4556 | 0.00119567 | 0.081379 | 954.55 | 2601.9 | 957.49 | 2801.7 | 1844.2 | 2.5455 | 6.2625 | 3.7171 |
| 224 | 2.5023 | 0.00119753 | 0.079875 | 959.14 | 2602.0 | 962.14 | 2801.9 | 1839.8 | 2.5547 | 6.2554 | 3.7007 |
| 225 | 2.5497 | 0.00119940 | 0.078403 | 963.74 | 2602.2 | 966.80 | 2802.1 | 1835.4 | 2.5640 | 6.2483 | 3.6843 |
| 226 | 2.5978 | 0.00120130 | 0.076964 | 968.34 | 2602.4 | 971.46 | 2802.3 | 1830.9 | 2.5732 | 6.2412 | 3.6680 |
| 227 | 2.6466 | 0.00120320 | 0.075551 | 972.95 | 2602.5 | 976.13 | 2802.5 | 1826.4 | 2.5824 | 6.2341 | 3.6516 |
| 228 | 2.6960 | 0.00120512 | 0.074175 | 977.56 | 2602.7 | 980.81 | 2802.7 | 1821.8 | 2.5917 | 6.2270 | 3.6353 |
| 229 | 2.7462 | 0.00120706 | 0.072825 | 982.19 | 2602.8 | 985.50 | 2802.8 | 1817.3 | 2.6009 | 6.2199 | 3.6190 |
| 230 | 2.7971 | 0.00120902 | 0.071503 | 986.81 | 2602.9 | 990.19 | 2802.9 | 1812.7 | 2.6101 | 6.2128 | 3.6027 |
| 231 | 2.8487 | 0.00121098 | 0.070210 | 991.44 | 2603.0 | 994.89 | 2803.0 | 1808.1 | 2.6193 | 6.2057 | 3.5864 |
| 232 | 2.9010 | 0.00121297 | 0.068943 | 996.08 | 2603.1 | 999.60 | 2803.1 | 1803.5 | 2.6285 | 6.1987 | 3.5702 |
| 233 | 2.9541 | 0.00121497 | 0.067702 | 1000.7 | 2603.1 | 1004.3 | 2803.1 | 1798.8 | 2.6377 | 6.1916 | 3.5539 |
| 234 | 3.0080 | 0.00121699 | 0.066488 | 1005.3 | 2603.2 | 1009.0 | 2803.2 | 1794.1 | 2.6469 | 6.1845 | 3.5376 |
| 235 | 3.0625 | 0.00121902 | 0.065298 | 1010.1 | 2603.2 | 1013.8 | 2803.2 | 1789.4 | 2.6561 | 6.1775 | 3.5214 |
| 236 | 3.1179 | 0.00122108 | 0.064133 | 1014.7 | 2603.2 | 1018.5 | 2803.2 | 1784.7 | 2.6653 | 6.1704 | 3.5052 |
| 237 | 3.1740 | 0.00122315 | 0.062991 | 1019.4 | 2603.2 | 1023.3 | 2803.1 | 1779.9 | 2.6745 | 6.1634 | 3.4890 |
| 238 | 3.2308 | 0.00122523 | 0.061873 | 1024.0 | 2603.2 | 1028.0 | 2803.1 | 1775.1 | 2.6836 | 6.1564 | 3.4727 |
| 239 | 3.2885 | 0.00122734 | 0.060778 | 1028.8 | 2603.1 | 1032.8 | 2803.0 | 1770.3 | 2.6928 | 6.1493 | 3.4565 |
| 240 | 3.3469 | 0.00122946 | 0.059705 | 1033.5 | 2603.2 | 1037.6 | 2803.0 | 1765.4 | 2.7020 | 6.1423 | 3.4103 |

**Space for Rough Work**

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