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ESE 2024 : Mains Test Series

UPSC ENGINEERING SERVICES EXAMINATION

Mechanical Engineering

Test-3 : Section A: Fluid Mechanics and Turbo Machinery [All Topics]

Section B : Heat Transfer-1 + Refrigeration and Air-Conditioning-1 [Part Syllabus]

Thermodynamics-2 + Strength of Materials & Mechanics-2 [Part Syllabus]

Name : RAJESH KASANIYA

Roll No : M E 2 4 M B L 1 0 0 4 4

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Student's Signature Rajesh

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

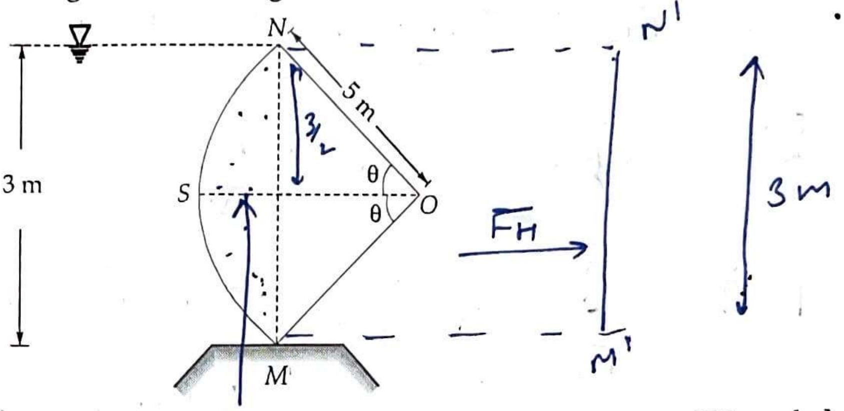
Question No.	Marks Obtained
Section-A	
Q.1	
Q.2	
Q.3	
Q.4	
Section-B	
Q.5	
Q.6	
Q.7	
Q.8	
Total Marks Obtained	

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

Corp. office : 44 - A/1, Kalu Sarai, New Delhi-110016 | **Ph:** 9021300500 | **Web:** www.madeeasy.in

Section : A

Q.1 (a) A sector gate in the form of circular arc of radius 5 m retains water to a height of 3 m above its sill as shown in figure. Calculate the magnitude and direction of the resultant force per unit length of the gate. Assume a gate width of 1 m.



[12 marks]

Horizontal Force

$F_H = (P \text{ @ CG of projected area}) \times \text{Projected area}(N'M')$

$= (\rho g \bar{h})(3 \times 1)$

$= 10^3 \times 9.81 \times 3/2 \times 3$

$\Rightarrow \boxed{F_H = 44145 N}$

Vertical Force

$F_V = \text{wt of liq in arc upto free surface}$

$= \left(1 \times \pi r^2 \times \frac{\theta}{2\pi}\right) \gamma$ rad

degree

$\left\{ \begin{array}{l} \sin\theta = \frac{3/2}{5} \\ \Rightarrow \theta = 17.4576^\circ \end{array} \right.$

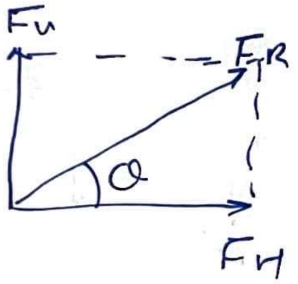
$= \left(\pi \times (5)^2 \times \frac{17.4576}{360}\right) \rho g$

$\Rightarrow F_V = 3.808 \times 9810$

$\Rightarrow \boxed{F_V = 37312.93 N}$

So, $F_H = 44.145$ kN
$F_V = 37.362$ kN

$\Rightarrow$ $\boxed{F_R = 57.833 \text{ kN}}$ Ans



$\tan\theta = \dfrac{F_H}{F_V}$

$\Rightarrow$ $\boxed{\theta = 49.757^\circ}$ Ans

from horizontal.

Q.1 (b) With the aid of a schematic diagram, explain the working principle of pulse jet engine and also draw the ideal and actual P-V diagrams.

[12 marks]

Q.1 (c) A liquid jet issues out of a nozzle into atmosphere at an angle of 60° above the horizontal and with a velocity of 10 m/s. At the nozzle exit the jet has a diameter of 8 cm. Assuming the jet to be unbroken throughout the trajectory, determine

(i) the equation of the jet trajectory.

(ii) the maximum height attained by the jet and its size at that location.

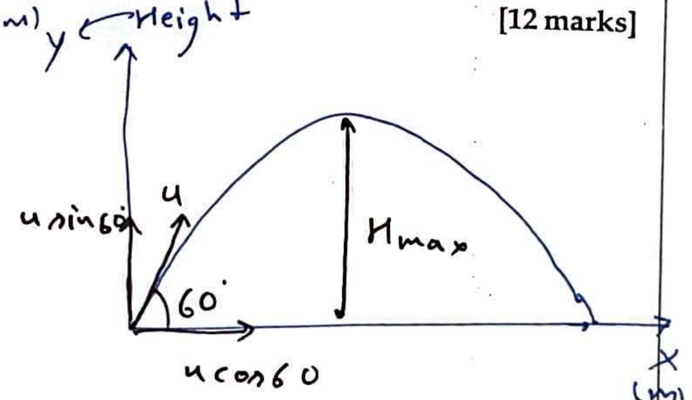
[12 marks]

A -

(i) Given

$u = 10 m/s$

$D_i = 8 cm$



in x - dirⁿ -

$\therefore S_x = u_x t + \frac{1}{2} \cancel{a_x} t^2$ (0)

$\Rightarrow x = u \cos 60 \, t$

$\Rightarrow \boxed{x = \frac{ut}{2}}$ — (1)

in y - dirⁿ

$S_y = u_y t + \frac{1}{2} a_y t^2$

$\Rightarrow y = u \sin 60 \, t - \frac{1}{2} g t^2$

from equⁿ (1) $t = \frac{2x}{u}$

$$\Rightarrow y = \frac{\sqrt{3}u}{2}\left(\frac{2x}{u}\right) - \frac{1}{2}g\left(\frac{2x}{u}\right)^2$$

$$\Rightarrow \boxed{y = \sqrt{3}x - \frac{2g}{u^2}x^2} \quad \text{An}$$

equ^n of jet tracjectory.

(ii) at max. hight, $V_y = 0$

So, $V_y^2 = u_y^2 + 2a_y s_y$

$$\Rightarrow 0 = (u\sin 60)^2 + 2(-g)H_{max}$$

$$\Rightarrow H_{max} = \frac{u^2 \sin^2 60}{2g}$$

$$\Rightarrow \boxed{H_{max} = \frac{3u^2}{8g}} \quad \text{An}$$

max height attained by jet

from continuity equ^n (1 → initial, 2 → at highest pnt)

$$A_1 V_1 = A_2 V_2$$

$$\Rightarrow \frac{\pi}{4} D_i^2 \times u = \frac{\pi}{4} D_2^2 \times \sqrt{V_{2y}^2 + V_{2x}^2} \qquad \left(\because V_x = u_x + a_x t\right)$$

$$\Rightarrow 64 \times 10 = D_2^2 \times \sqrt{0 + u^2\cos^2 60} \qquad \Rightarrow V_x = u_x \cos 60$$

$$\Rightarrow \cancel{D_2 = 128\text{ cm}} \Rightarrow \boxed{D_2 = 11.3137\text{ cm}} \quad \text{An}$$

So
$$\boxed{\begin{aligned} H_{max} &= 3.8226\text{ m} \\ \& \quad D_2 &= 11.3137\text{ cm} \end{aligned}} \quad \text{An}$$

Q.1 (d) A single acting reciprocating pump has its piston executing a simple harmonic motion. Show that the ratio of the work done against friction when the air vessels are fitted to that in the absence of air vessels is $3/2\pi^2$.

[12 marks]

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Q.1 (e) Examine whether or not the following velocity profiles satisfy the essential boundary conditions for velocity distribution in laminar boundary layer on a flat plate.

(i) $\frac{u}{U_o} = 1 + \left(\frac{y}{\delta}\right) - 2\left(\frac{y}{\delta}\right)^2$

(ii) $\frac{u}{U_o} = \sin\left(\frac{\pi y}{2\delta}\right)$

where u is the velocity at height y above the surface, U_0 is the free stream velocity and δ is the nominal boundary layer thickness.

[12 marks]

Ans

(i) $\frac{u}{U_\infty} = 1 + \frac{y}{\delta} - 2\left(\frac{y}{\delta}\right)^2$

BC (1) at $y = 0$; $u = 0$

$RHS = 1 + \frac{0}{\delta} - 2\left(\frac{0}{\delta}\right)^2 = 1 \neq 0$

So $\frac{u}{U_\infty} = 1 + \left(\frac{y}{\delta}\right) - 2\left(\frac{y}{\delta}\right)^2$

not satisfying essential BC.

(ii) $\frac{u}{U_\infty} = \sin\left(\frac{\pi}{2}\frac{y}{\delta}\right) \Rightarrow \frac{du}{dy} = U_\infty \cos\left(\frac{\pi}{2}\frac{y}{\delta}\right)\cdot\frac{\pi}{2\delta}$

$\frac{d^2u}{dy^2} = -U_o \sin\left(\frac{\pi}{2}\frac{y}{\delta}\right)\left(\frac{\pi}{2\delta}\right)^2$

BC (1) at $y = 0$; $u = 0$

$\frac{0}{U_\infty} = \sin(0) \Rightarrow 0 = 0$ (1) satisfied

BC (2) at $y = \delta$; $u = U_\infty$

$\frac{U_o}{U_o} = \sin\left(\frac{\pi}{2}\frac{\delta}{\delta}\right) \Rightarrow 1 = 1$ (2) satisfied

BC (3) at $y = \delta$; $\frac{du}{dy} = 0$

$\therefore \frac{du}{dy} = U_o \cos\left(\frac{\pi}{2}\cdot\frac{\delta}{\delta}\right)\frac{\pi}{2\delta} = 0$ (3) satisfied

BC (4) at $y = 0$; $\frac{d^2u}{dy^2} = 0$

$\frac{d^2u}{dy^2} = -U_o \sin\left(\frac{\pi}{2}\frac{0}{\delta}\right)\left(\frac{\pi}{2\delta}\right)^2 = 0$ (4) satisfied

~~BC (5) at $y = \delta$; $\frac{d^2u}{dy^2}$~~

So $\frac{U}{U_o} = \sin\left(\frac{\pi}{2}\frac{y}{\delta}\right)$ satisfy all (3) (1,2,3) essential Boundary cond^n.

Q.2 (a) A Pelton wheel has 4 nozzles each 52 mm in diameter with coefficient of velocity 0.98. Bucket speed is 0.46 times the jet speed and bucket mean diameter is 0.85 m. Reduction in relative velocity due to bucket friction is 16% with jet deflection of 165° and having mechanical efficiency of 94%. The water is supplied through a pipeline 360 m long from a reservoir, the level of which is 300 m above the nozzles. If the friction coefficient is 0.0058 and the head lost in friction amounts to 32 m. Calculate :

(i) the diameter of the pipeline,

(ii) the bucket power, hydraulic and overall efficiencies of the wheel,

(iii) the unit speed, the unit power and specific speed.

[20 marks]

Q.2 (b) **(i)** Explain the phenomenon of boundary layer separation. Describe four methods of controlling of boundary layer separation.

(ii) Two pipes each of length L and diameters D_1 and D_2 are arranged in parallel. The loss of head when a total quantity of water Q flows through them being h_1. If the pipes are arranged in series the same quantity of water 'Q' flows through them, the loss of head is h_2. If $D_1 = 1.5D_2$, determine the ratio of h_1 to h_2. Neglect minor losses and assume the friction factor f to be constant and to have the same value of for both the pipes.

[8 + 12 marks]

Q.2 (c) A nozzle of the impulse stage of a turbine receive steam at 20 bar and 300°C and discharge it at 12 bar and 240°C. The efficiency of nozzle is 96% and nozzle angle is 18°. The blade speed is that required for maximum work, and the inlet angle of the blades is that required for entry of the steam without shock. The blade exit angle is 6° less than the inlet blade angle. The blade friction factor is 0.88. For a steam flow rate of 1440 kg/hr, calculate (a) Axial thrust, (b) Diagram power, and (c) Diagram efficiency. [Refer Steam table attached]

Water/Steam at $p = 1.2$ MPa ($T_{sat} = 187.957$°C)

T °C	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg K
0	0.00099960	-0.02	1.18	-0.00008
5	0.00099949	21.01	22.21	0.07623
10	0.00099977	41.99	43.19	0.15098
15	0.00100039	62.93	64.13	0.22428
20	0.00100129	83.84	85.04	0.29623
25	0.00100246	104.74	105.94	0.36692
30	0.00100388	125.62	126.82	0.43639
35	0.00100551	146.50	147.71	0.50471
40	0.00100736	167.38	168.59	0.57194
45	0.00100939	188.27	189.48	0.63811
50	0.00101162	209.16	210.37	0.70326
55	0.00101402	230.04	231.26	0.76743
60	0.00101660	250.95	252.17	0.83067
65	0.00101933	271.87	273.09	0.89299
70	0.00102223	292.79	294.02	0.95444
75	0.00102529	313.74	314.97	1.0150
80	0.00102851	334.70	335.93	1.0748
85	0.00103188	355.67	356.91	1.1338
90	0.00103540	376.67	377.91	1.1921
95	0.00103907	397.69	398.94	1.2496
100	0.00104290	418.74	419.99	1.3064
105	0.00104688	439.81	441.07	1.3625
110	0.00105102	460.92	462.18	1.4179
115	0.00105531	482.06	483.33	1.4728
120	0.00105976	503.25	504.52	1.5270
125	0.00106438	524.46	525.74	1.5806
130	0.00106916	545.73	547.01	1.6337
135	0.00107410	567.04	568.33	1.6863
140	0.00107923	588.41	589.71	1.7383
145	0.00108453	609.83	611.13	1.7899
150	0.00109001	631.32	632.63	1.8410
155	0.00109569	652.87	654.18	1.8916
160	0.00110157	674.49	675.81	1.9419
165	0.00110765	696.19	697.52	1.9917
170	0.00111395	717.97	719.31	2.0411
175	0.00112047	739.84	741.18	2.0902
180	0.00112723	761.80	763.15	2.1390
185	0.00113424	783.87	785.23	2.1874
187.957	0.00113850	796.96	798.33	2.2159
187.957	0.16326	2587.8	2783.7	6.5217
190	0.16432	2592.2	2789.4	6.5340
195	0.16686	2602.8	2803.0	6.5631
200	0.16934	2612.9	2816.1	6.5909
210	0.17417	2632.3	2841.3	6.6437
220	0.17887	2651.1	2865.7	6.6937
230	0.18346	2669.3	2889.5	6.7414
240	0.18797	2687.1	2912.7	6.7872
250	0.19241	2704.7	2935.6	6.8313
260	0.19679	2722.1	2958.2	6.8740
270	0.20111	2739.2	2980.5	6.9155

T °C	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg K
270	0.20111	2739.2	2980.5	6.9155
280	0.20540	2756.1	3002.6	6.9558
290	0.20964	2772.9	3024.5	6.9951
300	0.21386	2789.7	3046.3	7.0335
310	0.21804	2806.4	3068.0	7.0710
320	0.22220	2823.0	3089.6	7.1078
330	0.22634	2839.6	3111.2	7.1438
340	0.23045	2856.2	3132.7	7.1792
350	0.23455	2872.7	3154.2	7.2139
360	0.23863	2889.2	3175.6	7.2480
370	0.24270	2905.8	3197.0	7.2816
380	0.24675	2922.3	3218.4	7.3147
390	0.25079	2939.0	3239.9	7.3472
400	0.25482	2955.5	3261.3	7.3793
410	0.25883	2972.1	3282.7	7.4109
420	0.26284	2988.8	3304.2	7.4421
430	0.26684	3005.5	3325.7	7.4728
440	0.27083	3022.2	3347.2	7.5032
450	0.27482	3038.9	3368.7	7.5332
460	0.27879	3055.8	3390.3	7.5628
470	0.28276	3072.6	3411.9	7.5921
480	0.28673	3089.4	3433.5	7.6210
490	0.29069	3106.4	3455.2	7.6496
500	0.29464	3123.3	3476.9	7.6779
520	0.30253	3157.5	3520.5	7.7336
540	0.31041	3191.8	3564.3	7.7881
560	0.31826	3226.4	3608.3	7.8416
580	0.32611	3261.3	3652.6	7.8940
600	0.33394	3296.3	3697.0	7.9455
620	0.34177	3331.6	3741.7	7.9961
640	0.34958	3367.1	3786.6	8.0459
660	0.35739	3402.9	3831.8	8.0948
680	0.36518	3439.0	3877.2	8.1430
700	0.37297	3475.3	3922.9	8.1904
720	0.38076	3511.9	3968.8	8.2371
740	0.38853	3548.8	4015.0	8.2832
760	0.39631	3585.9	4061.5	8.3286
780	0.40407	3623.3	4108.2	8.3734
800	0.41184	3661.0	4155.2	8.4176
820	0.41959	3698.9	4202.4	8.4612
840	0.42735	3737.1	4249.9	8.5042
860	0.43510	3775.6	4297.7	8.5468
880	0.44285	3814.3	4345.7	8.5888
900	0.45059	3853.3	4394.0	8.6303
920	0.45834	3892.6	4442.6	8.6713
940	0.46608	3932.1	4491.4	8.7119
960	0.47381	3971.9	4540.5	8.7520
980	0.48155	4011.9	4589.8	8.7917
1000	0.48928	4052.3	4639.4	8.8310

Q.3 (a) A centrifugal compressor running at 10500 rpm delivers 840 m^3/min of free air. The air is compressed from 100 kPa and 7°C to a compression ratio of 4 with an isentropic efficiency of 84%. Impeller has radial blade at outlet and flow velocity of 62 m/s may be assumed to be constant throughout. The slip factor is 0.92. At inlet, blade area coefficient is 0.86. The outer radius of impeller is twice the inner. Determine (i) Final temperature of air, (ii) Theoretical power required, (iii) Diameter of impeller at inlet and outlet, (iv) Breadth of impeller at inlet (v) Blade angle of impeller at inlet and (vi) Blade angle diffuser at inlet. [For air take: C_p = 1.005 kJ/kgK, γ = 1.4]

[20 marks]

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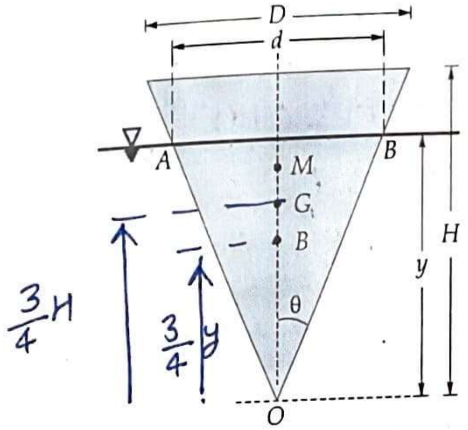
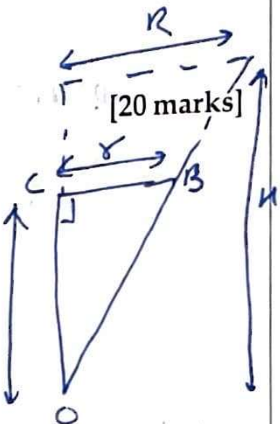
Q.3 (b) A solid cone of diameter 30 cm and height 20 cm float with its vertex downwards in water as shown in figure. Analyze whether the cone would be stable and float in water with its axis vertical if the specific gravity of cone material is 0.8.



[20 marks]



Given

$D = 30\,cm$

$H = 20\,cm$

$SG = 0.8$

Now $mg = F_B$ (for equil)

$\rho_{cone}\, \cancel{g}\left(\frac{1}{3}\cancel{\pi} R^2 H\right) = \rho_w\, \cancel{g}\left(\frac{1}{3}\cancel{\pi} r^2 y\right)$

$\Rightarrow \frac{r}{R} = \frac{y}{H}$

$\Rightarrow 0.8 \times (0.15)^2 \times 0.2 = \frac{R^2}{H^2} y^3$

$\Rightarrow y^3 = 0.8 \times 0.2 \times (0.2)^2$

$\Rightarrow \boxed{y = 0.1856\,m}$

So $BG = \frac{3}{4}H - \frac{3}{4}y$

$\boxed{BG = 0.0108\,m = 1.08\,cm}$

& we know

$BM = \frac{I}{Vol}$

$I = \frac{\pi}{64} d^4 = 2.9488 \times 10^{-4}\,m^4$

$d = 2\frac{Ry}{H} = \frac{Dy}{H} = 0.2784\,m$

$$BM = \frac{2.9488 \times 10^{-4}}{\frac{1}{3}\pi r^2 y} = \cancel{2.948}$$

$$= \frac{2.9488 \times 10^{-4} \times 3}{\pi \times \left(\frac{0.2784}{2}\right)^2 \times 0.1856}$$

$$\Rightarrow \boxed{BM = 0.07829\ m}$$

So $GM = BM - BG$

$$\Rightarrow GM = (7.83 - 1.08)\,cm$$

$$\Rightarrow \boxed{GM = 6.75\ cm}$$

$\because$ GM (metacentric height) > 0

So the cone would be stable float in water with $y = 18.56\,cm$

Ans

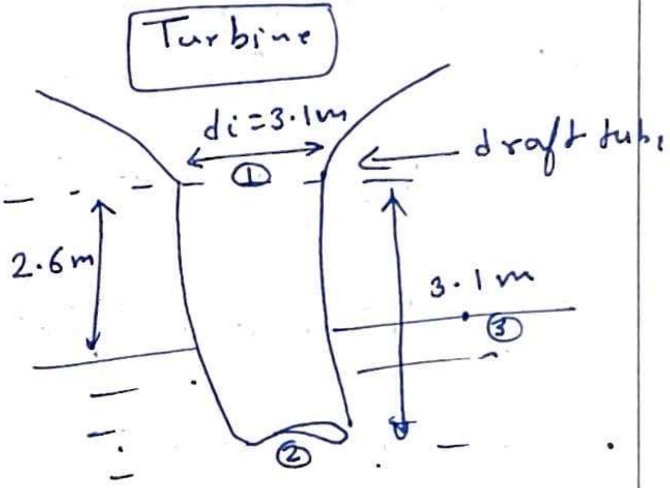
Q.3 (c) Explain briefly the function of a draft tube. How Kaplan turbine differs with francis turbine. A Kaplan turbine operating under a head of 7.6 m develops 1835 kW with an overall efficiency of 88%. The turbine is set 2.6 m above the tail water level and vacuum gauge inserted at turbine outlet records a suction head of 3.17 m. Calculate the efficiency of the draft tube if it has an inlet diameter of 3.1 m and the loss of head due to friction in the draft tube equals 25% of kinetic head at outlet.

[20 marks]

Function of draft tube -

↳ discharge water to tail race.

↳ Use kinetic energy head to obtain more work ~~more efficiently~~.



Given

$$h_f = 0.25 \frac{V_2^2}{2g}$$

$H = 7.6$ m

Power = 1835 kW

$\eta_{ov} = 88\%$

We know,

$$\text{Power} = (\gamma Q H)\, \eta_{overall}$$

$$\Rightarrow Q = \frac{1835 \times 10^3}{9.8 \times 10^3 \times 7.6 \times 0.88}$$

$$\Rightarrow \boxed{Q = 27.9971 \text{ m}^3/\text{s}}$$

at s/c 1 $\quad Q = A_1 V_1$

$$\Rightarrow V_1 = \frac{27.9971}{\frac{\pi}{4} \times 3.1^2} \quad \Rightarrow \boxed{V_1 = 3.709 \text{ m/s}}$$

Do not write in this margin

- Efficiency of draft tube –

$$\eta = \frac{\text{change in kinetic head}}{\text{Inlet kinetic head}}$$

$$\eta = \frac{\frac{V_1^2}{2g} - \frac{V_2^2}{2g} - h_f}{\frac{V_1^2}{2g}} \quad \text{—(1)}$$

Bernaulli equ^n b/w (1) & (2)

$$\cancel{\frac{P_1}{\gamma}}^{0} + \frac{V_1^2}{2g} + \cancel{Z_1}^{3.1} = \frac{P_2}{\gamma} + \frac{V_2^2}{2g} + \cancel{Z_2}^{0} + h_f$$

$$\frac{V_1^2}{2g} = 0.5 + \frac{V_2^2}{2g} + 0.25\frac{V_2^2}{2g}$$

$$\Rightarrow \frac{V_1^2}{2g} = 1.25\frac{V_2^2}{2g} + 0.5$$

$$\Rightarrow V_1^2 = 1.25 V_2^2 + g$$

$$\Rightarrow V_2^2 = \frac{(3.109)^2 - 9.81}{1.25}$$

$$\Rightarrow \boxed{V_2 = 1.777 m/s}$$

- from equ^n (1)

$$\eta = \frac{0.5}{V_1^2/2g} = \frac{g}{V_1^2} = \frac{g}{3.109^2}$$

$$\Rightarrow \boxed{\eta = 0.7131} \text{ Ans}$$

So the efficiency of draft tube is 71.31%.

Q.4 (a) An axial flow compressor is required to deliver air at the rate 48 kg/s and provide a total pressure ratio of 5 : 1. The inlet stagnation conditions being 290 K and 1 bar. The isentropic efficiency is 88%. The compressor shall have 10 stages with equal rise in total temperature in each stages. The axial velocity of flow is 160 m/s and blade speed is kept at 210 m/s to minimise noise generation. The stage degree of reaction at mean blade height is 50%. Assuming workdone factor as 0.86, calculate all the fluid angles of the first stage. Also, calculate the tip and hub diameter, if hub-tip diameter ratio is 0.82. Also, determine the blade height of the first stage and the speed in rpm. Draw velocity diagram at inlet and outlet of moving blade.
Take R = 0.287 kJ/kgK and c_p = 1.005 kJ/kgK.

[20 marks]

Q.4 (b) Laminar flow of a fluid of viscosity 0.8 kg/ms and density 1300 kg/m^3 occurs between a pair of plates of extensive width. The plates are 15 mm apart and are inclined at 45° to the horizontal. Pressure guages mounted at two points 1.2 m vertically apart on the upper plate record a pressure of 75 kPa and 250 kPa. The upper plate moves with a velocity of 2 m/s relative to the lower plate but in a direction opposite the fluid flow. Determine

(i) the velocity and shear stress distribution between the plate.

(ii) the maximum flow velocity, and

(iii) the shear stress on the upper plate.

[20 marks]

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Q.4 (c) What are the advantages of using a 50% reaction stage, obtain the maximum blading efficiency of a 50% reaction stage. Show that the diagram work per unit mass of steam for maximum blading efficiency of a 50% reaction stage is U^2, where U is the mean blade efficiency. Also, draw the velocity diagram of a 50% reaction turbine operating with maximum blading efficiency.

[20 marks]

Section : B

Q.5 (a) A nuclear reactor with its core constructed of parallel vertical plate 2.4 m high and 1.50 m wide has been designed on free convection heating of liquid bismuth. The maximum temperature of the plate surface is limited to 970°C, while the lowest allowable temperature of bismuth is 330°C. Calculate the maximum possible heat dissipation from both sides of each plate. For convective coefficient the appropriate correlation is,

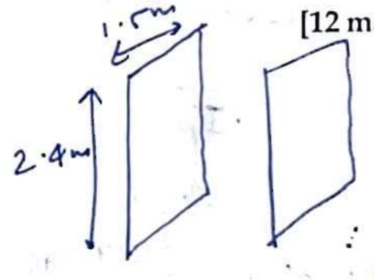
$Nu = 0.13(Gr \cdot Pr)^{1/3}$

The thermo-physical properties at mean film temperature of 650°C for bismuth are : $\rho = 10^4$ kg/m³; $\mu = 3.12$ kg/m-h; $c_p = 150.7$ J/kgK; $k = 13.02$ W/mK

[12 marks]

- $T_s = 970°C$
- $T_\infty = 330°C$

for max heat transfer



- Grashoff no,

$$Gr = \frac{g\beta(T_s - T_\infty)L_c^3}{\nu^2}$$

$$\left(\beta = \frac{1}{T_f} = \frac{1}{650+273} = \frac{1}{923}\right)$$

$$= \frac{9.81 \times 1 \times 640 \times 2.4^3}{923 \times (8.666\times10^{-8})^2}$$

$$\nu = \frac{\mu}{\rho} = \frac{3.12}{3600} \times \frac{1}{10^4} \ m^2/s$$

$$\Rightarrow \boxed{Gr = 1.252\times10^{16}}$$

$$\Rightarrow \nu = 8.666\times10^{-8} \ m^2/s$$

- $Nu = 0.13 (Gr Pr)^{1/3}$ $\quad\left[Pr = \frac{\mu c_p}{k} = \frac{3.12}{3600} \times \frac{150.7}{13.02} \right.$

$= 0.13 (1.252 \times 10^{16} \times 10^{-2})^{1/3}$ $\quad \Rightarrow \boxed{Pr = 0.01}$

$Nu = 6510.2287 = \frac{h L_c}{k}$

$\Rightarrow \boxed{h = 1200.042 \, W/m^2K}$

- So heat transfer from each plate both side -

$q = 2 h A \Delta T$

$q = 2 \times 1200.042 \times (2.4 \times 1.5) \times 640$

$\Rightarrow q = 5529794.305 \, W$

$\Rightarrow \boxed{q = 5529.794 \, kW}$ — from each plate on both side Ans

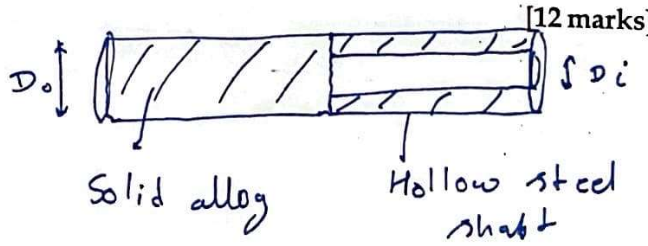
Q.5 (b) A solid alloy shaft of 80 mm in diameter is coupled with a hollow steel shaft of same external diameter in series. If the angle of twist of the steel shaft per unit length is 72% of that of the alloy shaft, then find the inner diameter of the steel shaft. What will be the speed to transmit 720 kW, if the limiting shear stresses in the alloy and the steel are to be 64 MPa and 80 MPa, respectively? Take $G_{steel} = 1.8 \, G_{alloy}$.

[12 marks]

Given

$D_o = 80 mm$

$\left(\frac{\theta_{st}}{L}\right) = 0.72 \left(\frac{\theta_{All}}{L}\right)$



- We know

$\frac{\theta}{L} = \frac{T}{G I_p}$

$(I_p)_{all} = \frac{\pi}{32} D_o^4$

$(I_p)_{st} = \frac{\pi}{32} (D_o^4 - D_i^4)$

$\left(\frac{T}{G I_p}\right)_{st} = 0.72 \left(\frac{T}{G I_p}\right)_{All}$

$\Rightarrow G_{st} I_{p st} = \frac{G_{all} I_{p all}}{0.72}$ $\quad (\because T_{st} = T_{all} \text{ in series})$

$\Rightarrow 1.8 \times \frac{\pi}{32} (D_o^4 - D_i^4) = 1 \times \frac{\pi}{32} D_o^4 \times \frac{1}{0.72}$

$\Rightarrow D_i^4 = \frac{0.296}{1.296} D_o^4$ $\quad \Rightarrow \boxed{D_i = 55.3047 \, mm}$

Ans

· Now given

Power = 720 kW $\quad \omega = ?$

$(\tau_p)_{alloy} = 64\ MPa$

$(\tau_p)_{steel} = 80\ MPa$

· $\frac{T}{I_p} = \frac{\tau}{r} \Rightarrow T = \tau \frac{I_p}{r}$

· $T_{max} = \tau \frac{I_p}{R} = \tau Z_p$

for alloy

$T_{max,1} = 64 \times 10^6 \times \frac{\pi}{16} D_o^3 = \cancel{5114.7185\ N}$ 6433.9817 Nm

for steel

$T_{max2} = 80 \times 10^6 \times \frac{\pi}{16} D_o^3 \left[1 - \left(\frac{D_i}{D_o}\right)^4\right]$

$\Rightarrow \boxed{T_{max_2} = 6205.6087\ Nm}$

So for safety

$T = \min(T_{max1}, T_{max2})$

$\Rightarrow \boxed{T = 6205.6087\ Nm}$

· Now $P = T\omega$

$\Rightarrow \omega = \frac{720 \times 10^3}{6205.6087} \Rightarrow \boxed{\omega = 116.024\ rad/s}$ Ans

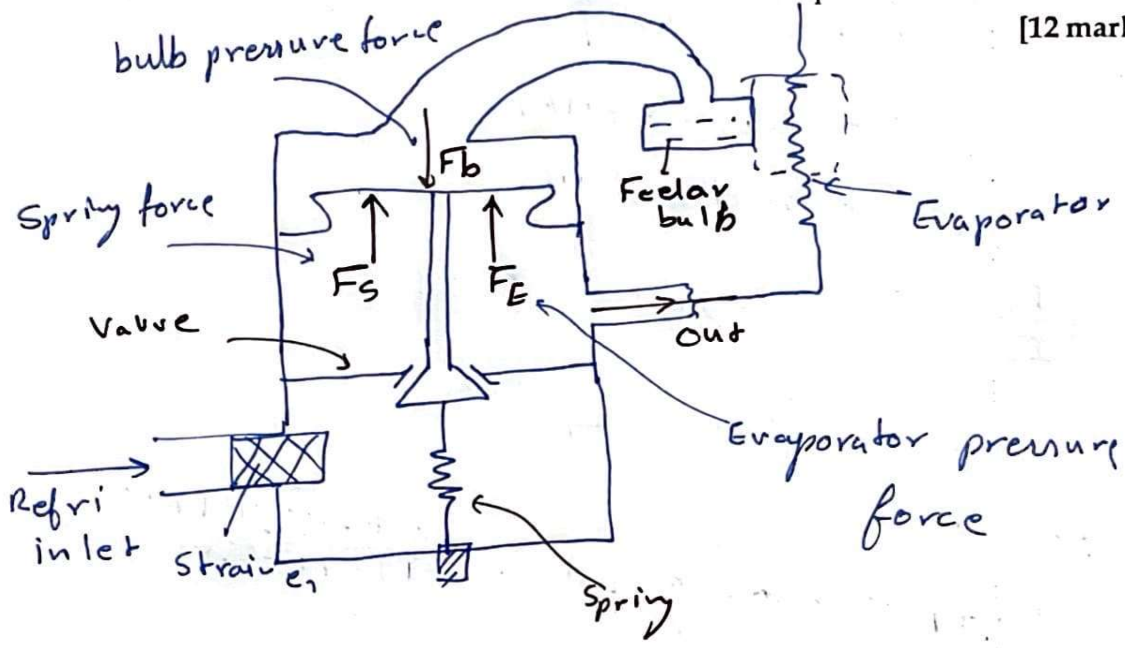
Or $\frac{2\pi N}{60} = \omega$

$\Rightarrow N = 1107.9 \Rightarrow \boxed{N = 1108\ rpm}$ Ans

Do not write in this margin

Q.5 (c) Briefly explain the working of thermostatic expansion valve for refrigerant flow control. Draw a neat sketch and write the functions of thermostatic expansion valve.

[12 marks]



- Functions of TEV
  - Reduce pressure from condenser to evaporator
  - Regulate mass flow rate.

- Working —

→ TEV work on maintaining constant superheat at ~~evap~~ evaporator.

→ At equilibrium

$$\boxed{F_b = F_S + F_E}$$

→ when load ↑ → compressor sucks more refrigerant then normal

↳ evaporator Pressure $P_E \uparrow \Rightarrow$ superheat ↑

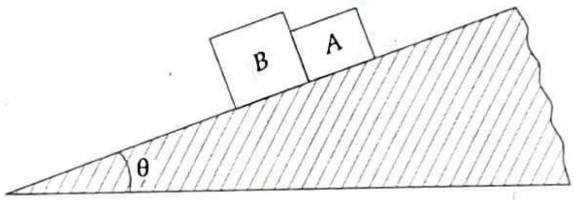
↳ To maintain constant superheat valve tends to open more & more mass flow rate will be passed

So when Load ↑ ⇒ $\dot{m}$ ↑

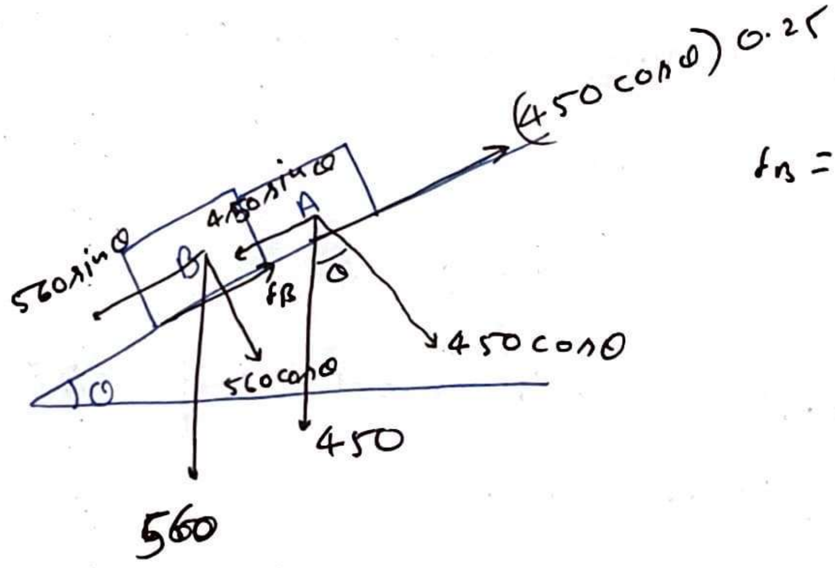
& similarily Load ↓ ⇒ $\dot{m}$ ↓

Thus TEV maintain constant superheat at evaporator exit.

Q.5 (d) Two blocks A and B are placed on an inclined plane. Weights of blocks A and B are 450 N and 560 N, respectively. Coefficients of friction between block A and plane is 0.25 and between block B and plane is 0.32 as shown in figure. To what angle θ, the plane should be raised so that bodies start slipping down the plane?

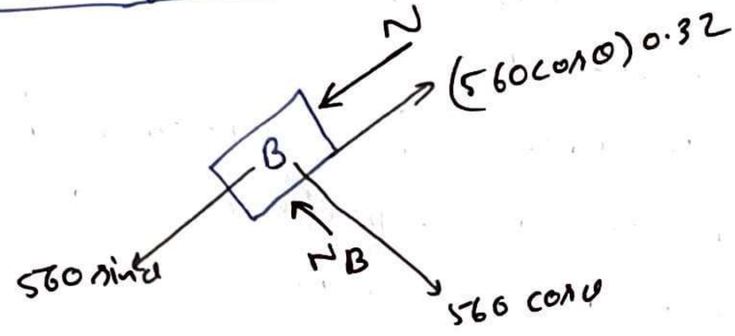


[12 marks]

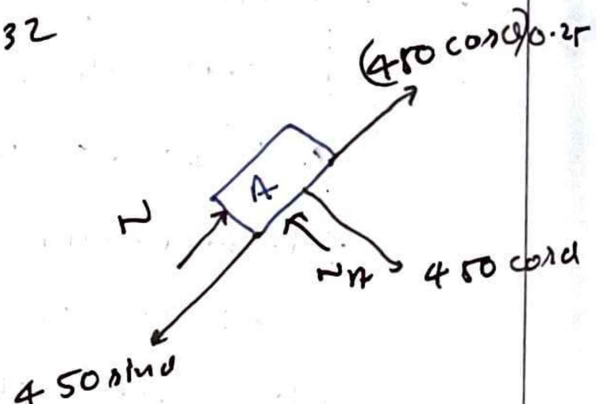


$f_B = (560\cos\theta)\,0.32$

FBD of B



(A)



(C1)

Only B start slipping

(N = 0)

$560\sin\theta = 560\cos\theta \cdot 0.32$

$\Rightarrow \tan\theta = 0.32$

$\Rightarrow \boxed{\theta = 17.745^\circ}$

in this case for A

$F_D = 450\sin\theta = 137.149\,N$

$F_{up} = (450\cos\theta)0.25 = 107.147\,N$

$\therefore F_D > F_{up}$

So this case is not Possible

both block will move together

(C2) both together

$560\sin\theta + 450\sin\theta = (560 \times 0.32 + 450 \times 0.25)\cos\theta$

$\Rightarrow \tan\theta = 0.2888$

$\Rightarrow \boxed{\theta = 16.109^\circ}$ Ans

So at 16.109° both block will slipp down simultaneously.

Q.5 (e) A piston cylinder assembly contains 0.2 kg superheated steam at 30 bar and 300°C. This assembly is placed in thermal contact with a reservoir at 300°C and the steam is allowed to expand to 1 bar and 300°C, calculate the maximum work that can be obtained from the steam. (Refer steam table attached)

Water/Steam at $p = 0.10$ MPa ($T_{sat} = 99.606$°C)

T °C	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg K
0	0.00100016	-0.04	0.06	-0.00015
5	0.00100003	21.02	21.12	0.07625
10	0.00100030	42.02	42.12	0.15108
15	0.00100090	62.98	63.08	0.22445
20	0.00100180	83.91	84.01	0.29646
25	0.00100296	104.82	104.92	0.36720
30	0.00100437	125.72	125.82	0.43673
35	0.00100600	146.62	146.72	0.50510
40	0.00100785	167.52	167.62	0.57237
45	0.00100988	188.41	188.51	0.63858
50	0.00101211	209.32	209.42	0.70377
55	0.00101452	230.23	230.33	0.76798
60	0.00101709	251.15	251.25	0.83125
65	0.00101984	272.08	272.18	0.89361
70	0.00102274	293.02	293.12	0.95509
75	0.00102581	313.98	314.08	1.0157
80	0.00102903	334.95	335.05	1.0755
85	0.00103241	355.95	356.05	1.1346
90	0.00103594	376.96	377.06	1.1928
95	0.00103962	398.00	398.10	1.2504
99.606	0.00104315	417.40	417.50	1.3028
99.606	1.6939	2505.5	2674.9	7.3588
100	1.6959	2506.2	2675.8	7.3610
105	1.7204	2514.1	2686.1	7.3885
110	1.7447	2521.8	2696.3	7.4155
115	1.7690	2529.6	2706.5	7.4418
120	1.7932	2537.3	2716.6	7.4678
125	1.8172	2545.0	2726.7	7.4932
130	1.8412	2552.6	2736.7	7.5183
135	1.8652	2560.2	2746.7	7.5429
140	1.8891	2567.8	2756.7	7.5672
145	1.9129	2575.4	2766.7	7.5911
150	1.9367	2582.9	2776.6	7.6148
155	1.9604	2590.5	2786.5	7.6380
160	1.9841	2598.0	2796.4	7.6610
165	2.0077	2605.5	2806.3	7.6838
170	2.0313	2613.1	2816.2	7.7062
175	2.0549	2620.6	2826.1	7.7284
180	2.0785	2628.1	2836.0	7.7503
185	2.1020	2635.6	2845.8	7.7719
190	2.1255	2643.1	2855.7	7.7934
195	2.1490	2650.7	2865.6	7.8146
200	2.1724	2658.3	2875.5	7.8356
210	2.2193	2673.3	2895.2	7.8769
220	2.2661	2688.4	2915.0	7.9174
230	2.3128	2703.5	2934.8	7.9572
240	2.3595	2718.7	2954.6	7.9962
250	2.4062	2733.9	2974.5	8.0346
260	2.4528	2749.1	2994.4	8.0723
270	2.4993	2764.5	3014.4	8.1094

T °C	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg K
270	2.4993	2764.5	3014.4	8.1094
280	2.5459	2779.8	3034.4	8.1459
290	2.5924	2795.2	3054.4	8.1818
300	2.6388	2810.6	3074.5	8.2172
310	2.6853	2826.2	3094.7	8.2520
320	2.7317	2841.7	3114.9	8.2864
330	2.7782	2857.3	3135.1	8.3202
340	2.8246	2873.0	3155.5	8.3536
350	2.8710	2888.7	3175.8	8.3866
360	2.9173	2904.6	3196.3	8.4191
370	2.9637	2920.3	3216.7	8.4512
380	3.0100	2936.3	3237.3	8.4829
390	3.0564	2952.3	3257.9	8.5142
400	3.1027	2968.3	3278.6	8.5452
410	3.1490	2984.4	3299.3	8.5757
420	3.1953	3000.6	3320.1	8.6059
430	3.2416	3016.7	3340.9	8.6358
440	3.2879	3033.1	3361.9	8.6653
450	3.3342	3049.4	3382.8	8.6946
460	3.3805	3065.8	3403.9	8.7235
470	3.4267	3082.3	3425.0	8.7521
480	3.4730	3098.9	3446.2	8.7804
490	3.5193	3115.5	3467.4	8.8084
500	3.5655	3132.1	3488.7	8.8361
520	3.6580	3165.8	3531.6	8.8908
540	3.7505	3199.6	3574.7	8.9445
560	3.8430	3233.7	3618.0	8.9972
580	3.9354	3268.2	3661.7	9.0489
600	4.0279	3302.8	3705.6	9.0998
620	4.1203	3337.8	3749.8	9.1499
640	4.2127	3373.0	3794.3	9.1991
660	4.3052	3408.5	3839.0	9.2476
680	4.3976	3444.2	3884.0	9.2954
700	4.4900	3480.4	3929.4	9.3424
720	4.5824	3516.8	3975.0	9.3888
740	4.6747	3553.4	4020.9	9.4345
760	4.7671	3590.3	4067.0	9.4797
780	4.8595	3627.6	4113.5	9.5242
800	4.9519	3665.0	4160.2	9.5681
820	5.0443	3702.8	4207.2	9.6115
840	5.1366	3740.8	4254.5	9.6544
860	5.2290	3779.2	4302.1	9.6968
880	5.3213	3817.8	4349.9	9.7386
900	5.4137	3856.6	4398.0	9.7800
920	5.5061	3895.8	4446.4	9.8209
940	5.5984	3935.2	4495.0	9.8613
960	5.6908	3974.8	4543.9	9.9013
980	5.7831	4014.8	4593.1	9.9408
1000	5.8754	4055.1	4642.6	9.9800

Water/Steam at $p = 3.0$ MPa ($T_{sat} = 233.853$°C)

T °C	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg K
0	0.00099869	0.01	3.01	0.00003
5	0.00099861	21.00	24.00	0.07619
10	0.00099892	41.94	44.91	0.15081
15	0.00099955	62.85	65.85	0.22400
20	0.00100047	83.73	86.73	0.29586
25	0.00100165	104.60	107.60	0.36645
30	0.00100307	125.45	128.46	0.43584
35	0.00100471	146.31	149.32	0.50409
40	0.00100656	167.16	170.18	0.57124
45	0.00100860	188.02	191.05	0.63734
50	0.00101082	208.89	211.92	0.70243
55	0.00101322	229.75	232.79	0.76654
60	0.00101579	250.63	253.68	0.82971
65	0.00101852	271.52	274.58	0.89198
70	0.00102141	292.43	295.49	0.95336
75	0.00102446	313.35	316.42	1.0139
80	0.00102766	334.28	337.36	1.0736
85	0.00103101	355.23	358.32	1.1326
90	0.00103452	376.21	379.31	1.1908
95	0.00103818	397.20	400.31	1.2482
100	0.00104199	418.21	421.34	1.3050
105	0.00104595	439.26	442.40	1.3610
110	0.00105006	460.35	463.50	1.4164
115	0.00105433	481.46	484.62	1.4712
120	0.00105876	502.60	505.78	1.5254
125	0.00106334	523.80	526.99	1.5790
130	0.00106809	545.03	548.23	1.6320
135	0.00107301	566.31	569.53	1.6845
140	0.00107810	587.64	590.87	1.7365
145	0.00108336	609.03	612.28	1.7880
150	0.00108881	630.47	633.74	1.8390
155	0.00109444	651.99	655.27	1.8896
160	0.00110027	673.57	676.87	1.9397
165	0.00110630	695.22	698.54	1.9895
170	0.00111255	716.95	720.29	2.0388
175	0.00111901	738.77	742.13	2.0878
180	0.00112571	760.68	764.06	2.1365
185	0.00113265	782.69	786.09	2.1849
190	0.00113984	804.81	808.23	2.2329
195	0.00114731	827.04	830.48	2.2807
200	0.00115506	849.39	852.86	2.3282
210	0.00117149	894.50	898.01	2.4227
220	0.00118931	940.19	943.76	2.5164
230	0.00120873	986.60	990.23	2.6097
233.853	0.00121669	1004.6	1008.3	2.6455
233.853	0.0666640	2603.2	2803.2	6.1856
240	0.0682300	2619.8	2824.5	6.2274
250	0.0706270	2644.6	2856.5	6.2893
260	0.0728950	2667.7	2886.4	6.3459
270	0.0750660	2689.7	2914.9	6.3987

T °C	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg K
270	0.0750660	2689.7	2914.9	6.3987
280	0.0771620	2710.7	2942.2	6.4486
290	0.0791960	2731.0	2968.6	6.4959
300	0.0811790	2750.8	2994.3	6.5412
310	0.0831190	2770.1	3019.5	6.5847
320	0.0850220	2789.1	3044.2	6.6266
330	0.0868930	2807.7	3068.4	6.6672
340	0.0887370	2826.2	3092.4	6.7066
350	0.0905560	2844.4	3116.1	6.7449
360	0.0923550	2862.4	3139.5	6.7823
370	0.0941340	2880.4	3162.8	6.8187
380	0.0958970	2898.2	3185.9	6.8544
390	0.0976450	2915.9	3208.8	6.8892
400	0.0993790	2933.6	3231.7	6.9234
410	0.10110	2951.1	3254.4	6.9570
420	0.10281	2968.7	3277.1	6.9900
430	0.10451	2986.2	3299.7	7.0224
440	0.10620	3003.7	3322.3	7.0542
450	0.10789	3021.1	3344.8	7.0856
460	0.10956	3038.6	3367.3	7.1165
470	0.11123	3056.1	3389.8	7.1470
480	0.11289	3073.6	3412.3	7.1770
490	0.11455	3091.1	3434.8	7.2066
500	0.11620	3108.6	3457.2	7.2359
520	0.11948	3143.8	3502.2	7.2933
540	0.12274	3179.0	3547.2	7.3493
560	0.12599	3214.3	3592.3	7.4041
580	0.12922	3249.8	3637.5	7.4577
600	0.13245	3285.4	3682.8	7.5103
620	0.13566	3321.3	3728.3	7.5618
640	0.13886	3357.4	3774.0	7.6124
660	0.14205	3393.8	3819.9	7.6621
680	0.14523	3430.3	3866.0	7.7109
700	0.14841	3467.0	3912.2	7.7590
720	0.15157	3504.0	3958.7	7.8062
740	0.15474	3541.2	4005.4	7.8528
760	0.15790	3578.7	4052.4	7.8987
780	0.16105	3616.4	4099.5	7.9439
800	0.16420	3654.3	4146.9	7.9885
820	0.16734	3692.6	4194.6	8.0325
840	0.17048	3731.0	4242.4	8.0759
860	0.17362	3769.6	4290.5	8.1187
880	0.17675	3808.6	4338.9	8.1610
900	0.17988	3847.9	4387.5	8.2028
920	0.18301	3887.3	4436.3	8.2441
940	0.18613	3927.0	4485.4	8.2849
960	0.18925	3967.0	4534.8	8.3252
980	0.19237	4007.2	4584.3	8.3651
1000	0.19549	4047.6	4634.1	8.4045

[12 marks]

Ans

Given

$T_0 = 300°C$

$m = 0.2 kg$

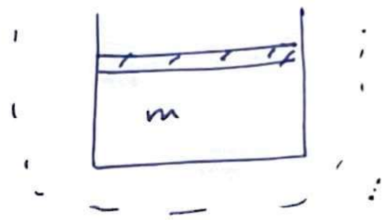
$T_1 = 300°c = 573 k$

$P_1 = 30 bar$

$P_2 = 1 bar$

$T_2 = 300°C = 573 K$

Max work that can obtained = ?



Assumptions

① $P_0 = 1 bar$

Max useful work = $AE_1 - AE_2$

$$= (U_1 - U_2) - T_0(S_1 - S_2) + P_0(V_1 - V_2) \quad —①$$

from steam table

$U_1 = 0.2 \times 2750.8$

$\Rightarrow U_1 = 550.16 \; kJ$

$U_2 = 0.2 \times 2810.6$

$= 562.12 \; kJ$

$\cancel{S_1 - S_2 = m\left[C_p \ln \frac{T_2}{T_1} - R \ln \frac{P_2}{P_1}\right]}$ 0 (∵ $T_1 = T_2$)

$\cancel{= 0.2}$

$S_1 = 0.2 \times 6.5412 = 1.30824 \; kJ/K$

$S_2 = 0.2 \times 8.2172 = 1.64344 \; kJ/K$

$V_1 = 0.2 \times 0.0811790 = 0.0162358 \; m^3$

$V_2 = 0.2 \times 2.6388 = 0.52776 \; m^3$

from equ^n ①

$$(W_{max})_{useful} = (550.16 - 562.12) - 300(1.30824 - 1.64344) + 100(0.0162358 - 0.52776)$$

$$\Rightarrow (W_{max})_{useful} = -11.96 + 100.56 - 51.15242$$

$$\boxed{W_{max\,useful} = 37.44758 \; kJ}$$ Ans

So max useful work that can be obtained from steam during this process is 37.45 kJ.

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Q.6 (a) In an aqua-ammonia absorption refrigeration system of 10 tonnes refrigeration capacity the vapour leaving the generator are 100% pure NH_3 saturated at 40°C. The evaporator, absorber, condenser and generator temperatures are –20°C, 30°C, 40°C and 170°C respectively. At absorber exit (strong solution) the concentration of ammonia in solution is 0.4 and enthalpy of 25 kJ/kg. At generator exit (weak solution) the concentration of ammonia in solution is 0.2 and enthalpy of 700 kJ/kg. The enthalpy of saturated liquid and saturated vapour ammonia at 40°C are 371.9 kJ/kg and 1473.3 kJ/kg respectively. The enthalpy of saturated vapour ammonia from evaporator exit at –20°C is 1420 kJ/kg.

(i) Determine the mass flow rate of ammonia in the evaporator.

(ii) Carry out overall mass conservation and mass conservation of ammonia in absorber to determine mass flow rates of weak and strong solution.

(iii) Determine the heat rejection in absorber and condenser, heat added in generator and C.O.P.

[20 marks]

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Q.6 (b) 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 12 kg/sec, and the products are cooled from 600°C to 450°C and the specific heat at constant pressure for products and for air are 1.09 kJ/kgK and 1.005 kJ/kgK respectively. The rate of air flow is 8 kg/sec and the initial air temperature is 40°C. Determine the following :

(i) the initial and final availability of the products.

(ii) the irreversibility of the process.

(iii) if the heat transfer from the products were to take place reversibly through heat engine, what would be the final temperature of the air and the power developed by heat engine? Take ambient temperature T_0 = 300 K.

[20 marks]

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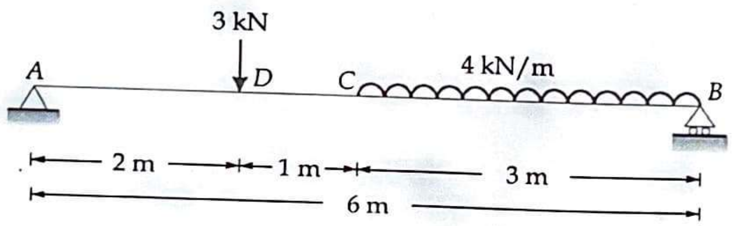
Q.6 (c) A beam AB of 6 m span is simply supported at the ends and is loaded as shown in figure below. Determine : (i) Deflection at C, (ii) Maximum deflection and (iii) Slope at end A. Take $E = 2 \times 10^5$ N/mm^2 and $I = 2500$ cm^4.



[20 marks]

Q.7 (a) An ammonia ice plant operates between condenser temperature of 35°C and an evaporator temperature of –15°C. It produces 10 tons of ice per day from water at 27°C to ice at -5°C. The NH_3 enters the compressor as dry saturated vapour and leaves the condenser as saturated liquid. Determine,

(i) The capacity of the refrigerating plant.

(ii) Mass flow rate of the refrigerant.

(iii) Power of the compressor motor if the isentropic efficiency of the compressor is 82% and mechanical efficiency of the compressor is 94%.

(iv) Relative efficiency

Take latent heat of ice = 335 kJ/kg

Specific heat of ice = 1.94 kJ/kgK

Specific heat of water = 4.2 kJ/kgK

Use the following properties of NH_3

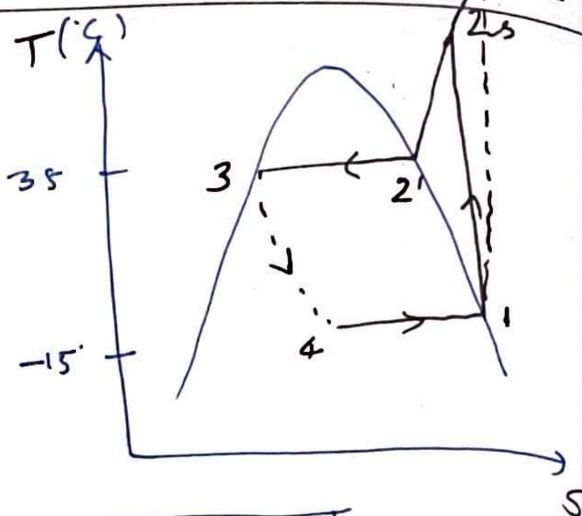
Saturation	Enthalpy (kJ/kg)		Entropy kJ/kg-K		Specific heat (kJ/kg-K)	
Temp. (°C)	h_f	h_g	s_f	s_g	Liquid, C_{pf}	Vapour, C_{pg}
-15	112.3	1426	0.457	5.549	–	–
35	347.5	1471	1.282	4.930	4.6	2.8

[20 marks]

Given

~~RC = 10 tons = 35 kW~~

$\dot m_{ice} = 10\,\text{tons/day} = 10^4\,\text{kg/day}$



(i) 27°C water $\xrightarrow{Q_1}$ 0°C water $\xrightarrow{Q_2}$ 0°C ice $\xrightarrow{Q_3}$ −5°C ice

$Q = 10^4[4.2\times27 + 335 + 1.94\times5]$

$\Rightarrow Q = 4581\times10^3\ \text{kJ}$

$\Rightarrow \boxed{Q = 4581\ \text{MJ}}$ — Perday

Assumption

① 1 tonnes = 3.5 kW

$\Rightarrow \dot Q = \dfrac{4581\times10^3}{24\times3600}\ \text{kJ/s}$

$\Rightarrow \boxed{\dot Q = 53.02\ \text{kW}}$

So capacity of refrigeration plant

$\boxed{RC = 53.02\,\text{kW} = 15.148\,TR}$ Ans

(ii) $\dot m = ?$

$RC = \dot m\, RE = \dot m(h_1 - \cancel{h_4})$ h_3

$\Rightarrow 53.02 = \dot m(1426 - 347.5)$

$\Rightarrow \boxed{\dot m = 0.04916\ \text{kg/s}}$ Ans

mass flow rate of refrigerand

(iii) $S_{2s} = S_1 = 5.549 = S_{2'} + C_{pv}\ln\left(\dfrac{T_{2s}}{T_{2'}}\right)$

$\Rightarrow 5.549 = 4.930 + 2.8\ln\left(\dfrac{T_{2s}}{308}\right)$

$\Rightarrow \boxed{T_{2s} = 384.203\,K}$

$\cdot\ h_{2s} = h_{2'} + C_{pv}(T_{2s} - T_{2'})$

$\Rightarrow h_{2s} = 1471 + 2.8(384.203 - 308)$

$\Rightarrow \boxed{h_{2s} = 1684.3685\ kJ/kg}$

$(\eta_{isen})_{comp} = \dfrac{h_{2s} - h_1}{h_2 - h_1} = \dfrac{1684.3685 - 1426}{h_2 - 1426}$

$\Rightarrow \boxed{h_2 = 1741.084\ kJ/kg}$

So, Power of comp. motor

$Power = \dfrac{W_{comp}}{\eta_{mech}} = \dfrac{\dot{m}(h_2 - h_1)}{\eta_{mech}}$

$\Rightarrow Power = \dfrac{0.04916(1741.084 - 1426)}{0.94}$

$\Rightarrow \boxed{Power = 16.4782\ kW}$ Ans

(iv) $\eta_{rel} = \dfrac{(COP)_{act}}{(COP)_{max}}$ — ①

$COP_{act} = \dfrac{RC}{Power} = \dfrac{53.02}{16.4782} = 3.2175$

$(COP)_{max} = \dfrac{h_1 - h_4}{h_{2s} - h_1} = \cancel{\dfrac{1684.3685 - 1426}{1426 - 347.5}}$

$= \dfrac{1426 - 347.5}{1684.368 - 1426} = 4.1742$

$\Rightarrow \boxed{\eta_{rel} = \dfrac{3.2175}{4.1742} = 0.7708}$ Ans

So relative efficiency 77.08 %.

Q.7 (b) Calculate the temperature difference between outer and inner surface of a thin hollow tube having 4 mm and 6 mm inside and outside radius, respectively, when a current of 2.1 kA flows through it. For cooling the tube, the coolant water at temperature 20°C circulates inside the tube. The heat transfer coefficient of water side is 12500 W/m^2K. The outer surface of the tube is insulated. The electrical resistivity of material is 0.11 $\Omega mm^2/m$. The thermal conductivity of the material is 18 W/m^2K. Find the heat flow rate. Also obtain the expression for temperature difference between inner and outer radius.

[20 marks]

Q.7 (c) Two vessels, A and B both containing nitrogen, are connected by a valve which is opened to allow the contents to mix and achieve an equilibrium temperature of 25°C. Before mixing the following information is known about the gases in the two vessels.

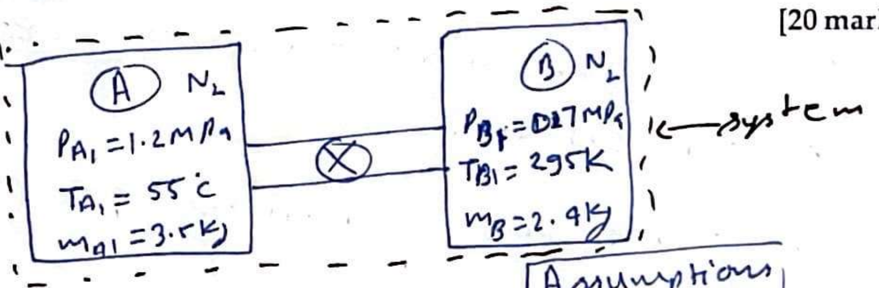
	Pressure	Temperature	Content
Vessel '*A*'	1.2 MPa	55°C	3.5 kg
Vessel '*B*'	0.7 MPa	22°C	2.4 kg

Calculate the final equilibrium pressure and the amount of heat transferred to the surroundings. If the vessel had been perfectly insulated. Calculate the final temperature and pressure which would have been reached. Take $\gamma = 1.4$

[20 marks]

$R_{N_2} = \frac{8.314}{28}$

$R_{N_2} = 0.2969$ kJ/kg K



Assumptions

(1) N_2 work as Ideal gas.

$T_f = 25°C = 298\,K$

(a) $P_f = ?$

$Q_{surr} = ?$

by $PV = mRT$

for (A) $V_A = \frac{m_A R T_A}{P_A}$

$= \frac{3.5 \times 0.2969 \times 328}{1200}$

$\Rightarrow \boxed{V_A = 0.284\ m^3}$

(B) $V_B = \frac{2.4 \times 0.2969 \times 295}{700}$

$\Rightarrow \boxed{V_B = 0.3003\ m^3}$

So Total vol $V_T = V_A + V_B = \boxed{0.5843\,m^3}$

for final condn

$P_f V_f = m_T R T_f$

$\Rightarrow P_f = \frac{5.9 \times 0.2969 \times 298}{0.5843}$

$\Rightarrow \boxed{P_f = 893.393\ kPa = 0.893\ MPa}$ Ans

↳ final equil pressure.

from 1st law

$Q = \Delta U + \cancel{W}^{0}$

$\Rightarrow Q = \Delta U_A + \Delta U_B$ $\left(c_v = \frac{R}{\gamma - 1}\right)$

$Q = m_A c_v (T_f - T_A) + m_B c_v (T_f - T_B)$

$\Rightarrow Q = [3.5(298 - 328) + 2.4(298 - 295)] \times \frac{0.2969}{1.4 - 1}$

$\Rightarrow \boxed{Q = -72.592 \text{ kJ}}$ Ans

So 72.592 kJ heat transferred to the surrounding from system.

(b) If vessels perfect insulated ($Q = 0$)

$\Rightarrow \cancel{Q}^{0} = \Delta U + \cancel{W}^{0}$

$\Rightarrow \Delta U_A + \Delta U_B = 0$

$3.5(T_f - 328) + 2.4(T_f - 295) = 0$

$\Rightarrow 5.9 T_f = 1856$

$\Rightarrow \boxed{T_f = 314.576 \text{ K}}$ Ans

by $P_f V_f = m_T R T_f$

$\Rightarrow P_f = \frac{5.9 \times 0.2969 \times 314.576}{0.5843}$

$\Rightarrow \boxed{P_f = 943.087 \text{ kPa}}$ Ans

So final Ans

before insulation	After insulation
$P_f = 893.393$ kPa	$T_f = 314.576$ K
$Q = 72.592$ kJ to surrounding	$P_f = 943.087$ kPa

Q.8 (a) A simply supported beam beam of span L carries a uniformly distributed load W per unit length on the whole span. Find the shape of beam of uniform strength, if

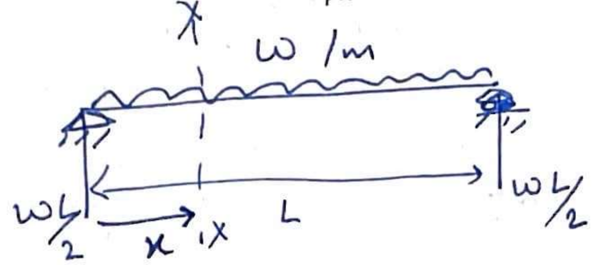
(i) the width is to be maintained constant, and

(ii) the depth is to be maintained constant.

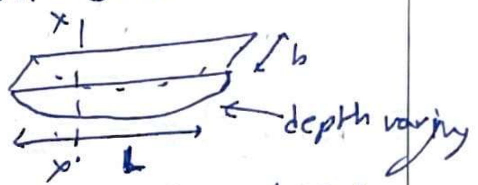
Also, determine depth in case (i) and width in case (ii) at the mid-span. Take permissible bending stress of beam as σ_{per}.

[20 marks]

(i)



assume width = b = const.



beam of uniform strength → max permisible stress at each x-c/s is same.

at distance x from left support

$$M_x = \left(\frac{wL}{2}\right)x - \frac{wx^2}{2} \quad \text{—(1)}$$

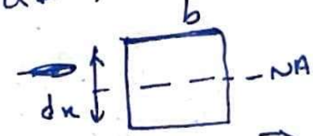
& we know,

$$\frac{M}{I} = \frac{\sigma_{per}}{y_{max}}$$

$$\Rightarrow M = \sigma_{per} Z$$

$$\Rightarrow M_x = \frac{\sigma_{per}}{6} b\, d_x^2 \quad \text{—(2)}$$

at x – x



$$Z = \frac{\frac{1}{12} b d_x^3}{d_x/2}$$

$$\Rightarrow Z = \frac{1}{6} b d_x^2$$

from equ^n (1) & (2)

$$\left(\frac{\sigma_{per}}{6} b\right) d_x^2 = \left(\frac{wL}{2}\right)x - \frac{wx^2}{2}$$

$$\Rightarrow \boxed{\frac{d_x^2}{K_1} + \frac{(x-K_2)^2}{K_3} = K_4} \longrightarrow \text{equ}^n \text{ of ellipse}$$

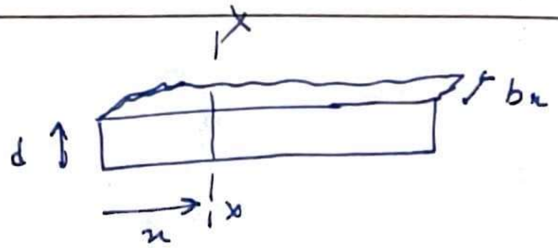
So elliptical shape.

at mid s/c ($x = L/2$)

$$\frac{\sigma_{per}\, b\, d^2}{3} = \frac{wL}{2}\left(\frac{L}{2}\right) - \frac{w}{2}\frac{L^2}{4}$$

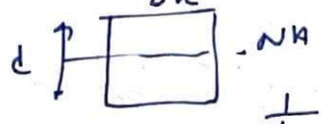
$$\Rightarrow \boxed{d = \sqrt{\frac{3wL^2}{4\sigma_{per} b}}} \quad \text{Ans} \longrightarrow \text{depth at mid s/c.}$$

(ii) depth = d = const.



$M_x = \sigma_{per} Z_x$

$M_x = \sigma_{per} \times \dfrac{b_x d^2}{6}$ — (3) at x - x



$Z = \dfrac{\frac{1}{12} b_x d^3}{d/2}$

from equ^n (1) & (3)

$$\boxed{\left(\frac{\sigma_{per} d^2}{6}\right) b_x = \left(\frac{wL}{2}\right)x - \frac{wx^2}{2}}$$

↳ equ^n of parabola.

So width will very as $\boxed{\text{parabolic}}$ Ans

At mid s/c - ($x = L/2$)

$$\left(\frac{\sigma_{per} d^2}{6}\right) b = \frac{wL^2}{4} - \frac{wL^2}{8} = \frac{wL^2}{8}$$

$$\Rightarrow \boxed{b = \frac{3}{4} \frac{wL^2}{\sigma_{per} d^2}} \text{ Ans}$$

↓ width at mid s/c

Q.8 (b) (i) Explain harmful effects of R-12 and R-22 refrigerant. Also suggest new eco-friendly substitutes of these two refrigerants.

(ii) Define availability of a thermodynamic system. Also, derive the expression for availability function or availability for a non flow process.

[10 + 10 marks]

Ans (1) R-012 $\Rightarrow$ $\boxed{CF_2Cl_2}$

$m-1=0$
$m=1$
$n+1=1$
$n=0$

cloro - floro carbon

R-22 $\Rightarrow$ $\boxed{CHF_2Cl}$

$m=1$
$n=1$

harmful effects

(1) Flourine is a global warming agent
↳ so it will ↑ global warming

(2) Cl is responsible for ozone diplition that will result in many health problems

↳ skin cancer.
↳ Eye problems
↳ depletion of soil quality etc.

• $\boxed{\text{Substitutes}}$
↳ R-134a C_xH_y (Hydrocarbon) or any inorganic refrigerant like (NH_3)

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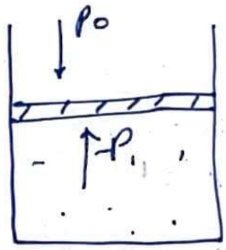
(ii) Availability — max Amount of useful work that can be obtained from system when it will achieve dead state (equilibrium with surroundig)

$$\boxed{AE = \text{max useful work}}$$

For Non Flow process

Assume a piston cyl arrangement.

state 1 — Pressure $= P_1$, Volume $= V_1$



state 2 (0) (dead state) — Pressure $= P_0$, Volume $= V_0$

~~max work done by gas from state 1 to state 2 = W~~

∵ from 1^{st} law

$$\delta Q = dU + \delta W$$

max work will be for reversible process

so $\int_1^0 T\,ds = \int_1^0 dU + \int_1^0 \delta W$

$$\Rightarrow T_0(S_0 - S_1) = U_0 - U_1 + W_{max} \quad \text{--- (1)}$$

. Wmax will be equal to work against atmosphere & to raise piston.

∵ work against atmosphere will no use

so $W_{max\,useful} = W_{max} - W_{atm}$

$$= W_{max} - P_0(V_0 - V_1)$$

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from equ^n (1)

$$T_0 (S_0 - S_1) = (U_0 - U_1) + P_0 (V_0 - V_p) + (W_{max})_{useful} \quad \text{;; } AE$$

$$\Rightarrow \quad AE = (U_1 - U_0) + T_0 (S_0 - S_1) - P_0 (V_0 - V_p)$$

$$\Rightarrow \quad AE = (U_1 - U_0) - T_0 (S_1 - S_0) + P_0 (V_1 - V_0)$$

$$\phi_f - \phi_0$$

$$\Rightarrow \quad \boxed{\phi = U - T_0 S + P_0 V}$$

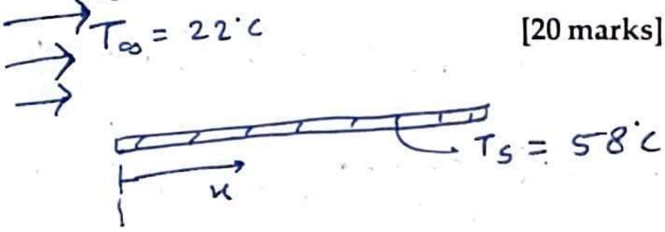
Availability f^n

Q.8 (c) Air at 22°C and at atmospheric pressure flows at a velocity of 4.8 m/s past a flat plate with a sharp leading edge. The entire plate is maintained at a temperature of 58°C. Assuming that transition occurs at critical Reynolds number of 5×10^5, find the distance from the leading edge at which the boundary layer changes from laminar to turbulent. At the location also calculate:

(i) Thickness of hydrodynamic boundary layer
(ii) Thickness of thermal boundary layer
(iii) Local and average convective heat transfer coefficient
(iv) Heat transfer from both side of plate per unit width of plate
(v) Mass entrainment in the boundary layer

Assume cubic velocity profile and approximate method. Thermo-physical properties of air at mean film temperature of 40°C are: ρ = 1.128 kg/m^3; ν = 16.96 × 10^{-6} m^2/s; k = 0.02755 W/mK; Pr = 0.7

[20 marks]



$$Re_{cr} = \frac{U_\infty x_{cr}}{\nu}$$

$$\Rightarrow \quad 5 \times 10^5 = \frac{4.8 \, x_{cr}}{16.96 \times 10^{-6}}$$

$$\Rightarrow \quad \boxed{x_{cr} = 1.7667 \text{ m}}$$

distance from leading edge at which Boundary Layer changes from Laminar to Turb.

(i) from blausius results

$$\delta_h = \frac{5x}{\sqrt{Re_x}} = \frac{5\times1.7667}{\sqrt{5\times10^5}} = 0.01249\text{ m}$$

$\Rightarrow \boxed{\delta_h = 12.49\text{ mm}}$ Ans

(ii) $\frac{\delta_h}{\delta_t} = (P_r)^{1/3} = (0.7)^{1/3}$

$$\Rightarrow \delta_{th} = \frac{12.49}{(0.7)^{1/3}}$$

$\Rightarrow \boxed{\delta_{th} = 14.06\text{ mm}}$ Ans

(iii) from blausius results

$$C_{fx} = \frac{0.664}{\sqrt{Re_x}} = \frac{0.664}{\sqrt{5\times10^5}} \quad \& \quad C_D = \frac{1.328}{\sqrt{Re_x}}$$

$\Rightarrow \boxed{C_{fx} = 9.3903\times10^{-4}}$ Local friction coeff. $\boxed{C_D = 18.78\times10^{-4}}$ Avg friction coeff

- for Laminar flow over flate plat.

- $Nu_x = 0.332(Re_x)^{0.5} P_r^{1/3}$

$$\Rightarrow Nu_x = 0.332(5\times10^5)^{0.5}(0.7)^{1/3} = \frac{h_x\times1.7667}{0.02755}$$

$\Rightarrow \boxed{h_x = 3.25\text{ W/m}^2\text{K}}$ Local Heat ransfer coff

& ~~Nu = 0.66~~ we know that $\bar{h} = 2h_x$

$\Rightarrow \boxed{\bar{h} = 6.5\text{ W/m}^2\text{K}}$ avg heat transfer coeff.

(iv) both side HT

$q = 2\times\bar{h}\,A\Delta T$

$= 2\times6.5\times(1.7667\times1)\times(58-22)$

$\Rightarrow \boxed{q = 826.8186\text{ W}}$ 0000

from both side of plate