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ENCH 501 Transport Phenomena

Final Examination, Fall 2014

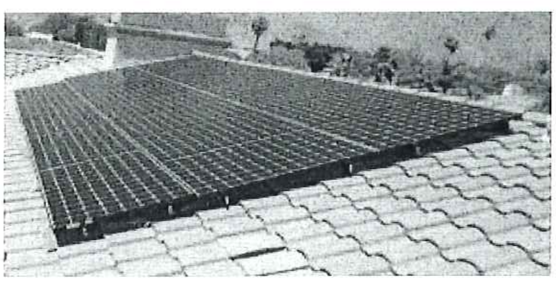
Time: 8.00 to 11.00 am **Monday, December 8, 2014**

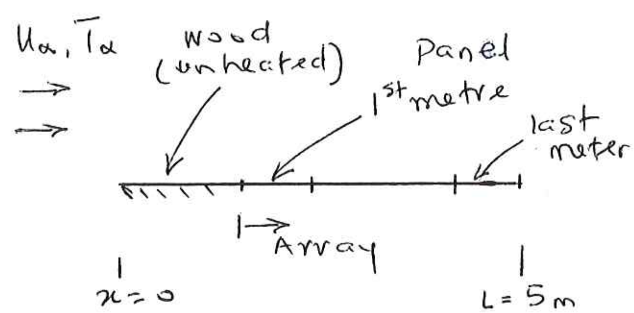
Instructions: Attempt All Questions. Use of Electronic Calculators Allowed; no other Electronic Device Allowed. Open Notes, Open Book Examination.

Question #1 (30 points)

Arrays of solar panels are composed of solar cells that contain photovoltaic material, such as silicon, aluminum alloy and cadmium telluride. The cells produce direct current electricity from sun light, and photovoltaic modules power orbiting satellites and spacecraft. The majority of the panels are used for small scale power generation. Like all semiconductor devices, solar cells are sensitive to temperature and the parameter that is reduced by a temperature increase is the open-circuit voltage. It therefore helps to keep the surface temperature below a specified operational value.
A roof array is as shown in the picture. It is 4.25m wide and 8m long. Air at 20°C (μ = 0.01813 mPa s; ρ =1.2047 kg/m^3; k=0.025 W/m K; C_p= 1.0056 kJ/kg K) flows over the surface at a steady rate in a direction perpendicular to the long side at a velocity of 1.32 m/s. The sun rays heated the panel surfaces and a constant temperature of 45°C was maintained. A flat piece of wood, 0.75 m wide and 8 m long was attached to the leading edge of the array (see sketch).

(a) Obtain an expression for temperature as a function of position T(x,y) in the boundary layer using the **integral method**. Use <u>only</u> three natural boundary conditions for each of the velocity and temperature profiles (e.g. for velocity – at y=0, u=0; y=δ, u=U_∞; y=δ, $\partial u/\partial y$=0). Show your steps.
(b) Estimate the drag force on the entire assembly.
(c) Compare the rate of heat transfer from the assembly into air in the first meter width of the array and the last meter. Show your steps.





Question #2 (20 points)

An inert gas mixture with carbon dioxide (CO_2) is brought in contact with the surface of a special gel of amines in a container. The inert components already saturates the gel and, therefore, does not diffuse.

CO_2 first dissolves at the interface and then diffuses into and reacts with the immobilized amines. The reaction is

$$CO_2 + RNH_2 \leftrightarrow RNH\ COOH$$

If the solubility of CO_2 at the interface is 10 moles/litre, the gel mixture concentration (with or without CO_2) is assumed constant at 72 moles/litre, the diffusivity of CO_2 through the gel is $1.5(10^{-6})\ m^2/s$, and the rate constant k_1 for the reaction (rate = $k_1\,[CO_2]$) equals $3.5(10^{-3})\ s^{-1}$,

(a) estimate the depth that CO_2 would have penetrated into the gel in 3 minutes? Show important steps?
(b) How much total CO_2 would have been taken up by the gel at this time?

Question #3 (25 points)

(a) ***15pts*** The rate of condensation of a saturated vapor on the outside surface of a vertical pipe through which a refrigerant flows is determined to depend on the average convective heat transfer coefficient **h** outside the pipe, the temperature difference between the vapor and the refrigerant **ΔT**, the length **L** of the pipe, the heat of vaporization per unit mass **λ**, the density of the condensate **ρ**, acceleration of gravity **g**, the viscosity of the condensate **μ** and the thermal conductivity of the condensate **k**.

Determine the dimensionless groups from the variables. Show your steps.

(b) ***10pts*** For a binary mixture of substances A and B, ω_A is the mass fraction and x_A is the mole fraction of A. Given that the molar masses are M_A and M_B, and

$$x_A = \frac{m_A/M_A}{m_A/M_A + m_B/M_B}$$, obtain a relationship between dx_A and $d\omega_A$.

Question #4 (25 points)

(a) ***10 pts.*** A concrete block is 50m long. The cross-section is rectangular, 50 x 20cm. A 6 cm i.d. hole is drilled through the axis along the entire length. Saturated steam at 200°C flows through the hole. The latent heat of vaporization of water is given as 1939 kJ/kg. The specific volume of the steam is 0.127 m^3/kg. The outside temperature of the block is maintained at -30°C. The thermal conductivity of the concrete is 1.1 W/mK.

Estimate the minimum rate, kg/hr, at which steam must be supplied at one end so that 3 m^3/s steam emerges at the other end.

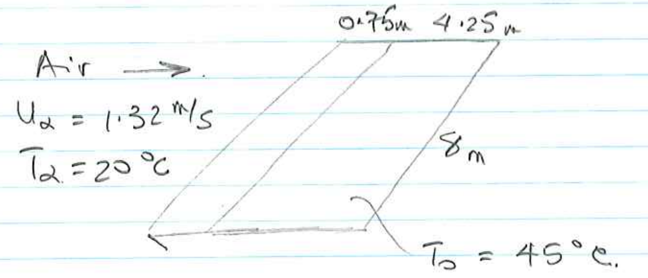
(b) ***15 pts.*** It is desired to estimate the volume rate of water through a cooling tower. Warm water from inside a large building is distributed equally over 60 boards of wood, each 5 m wide and 2 m long. The water flow perpendicularly to the 5 m wide edge. The flow is assume to be fully developed over the entire length (0 to 2m) and the film thickness δ is constant at 1.2 cm. The boards are at an angle of 60° to the horizontal. The average temperature of the water is 40°C (μ=0.653 mPa s; ρ=996 kg/m^3).

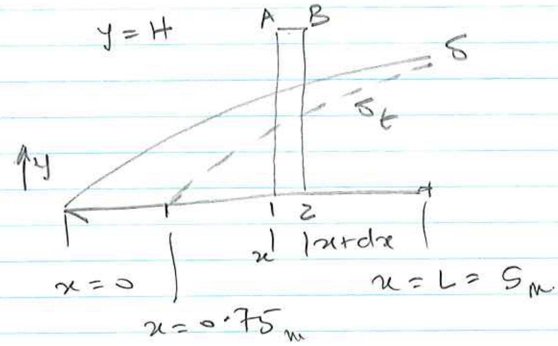
Estimate the total volume of water entering the cooling tower. Neglect any evaporation.

Dec. 8

ENCH 501 Solution - Final Exam Fall 2014

Q.1





Choose a control volume A12B – width dx and height H.

From

- Material balance, output at AB $= -\frac{d}{dx}\left[\int_0^H \rho u\, dy\right] dx.$

- Momentum balance, eq. 5.13 of Notes (integral)

$$\mu \left.\frac{du}{dy}\right|_{y=0} = \frac{d}{dx}\left[\int_0^\delta \rho U_\alpha^2 \left(1 - \frac{u}{U_\alpha}\right)\frac{u}{U_\alpha}\, dy\right] \quad (1)$$

Given conditions

$y = 0,\ u = 0$ (no slip); $y = \delta,\ u = U_\alpha$; $y = \delta,\ \frac{du}{dy} = 0$

Assume $u = a + by + cy^2$ and $\frac{du}{dy} = b + 2cy$

Apply conditions

$$\frac{u}{U_\alpha} = 2\left(\frac{y}{\delta}\right) - \left(\frac{y}{\delta}\right)^2 \quad \text{where } \delta(x) \quad (2)$$

Substitute into the integral equation

$$\mu \left.\frac{du}{dy}\right|_{y=0} = \frac{\mu U_\alpha}{\delta} \left.\frac{d(u/U_\alpha)}{d(y/\delta)}\right|_{y=0} = 2\mu\frac{U_\alpha}{\delta} =$$

$$\frac{d}{dx}\left[\rho U_\alpha^2 \delta \int_0^1 (1 - 2\eta + \eta^2)(2\eta - \eta^2)\, d\eta\right]$$

$$\frac{2\mu U_\alpha}{\delta} = \frac{2}{15}\rho U_\alpha^2 \frac{d\delta}{dx} \quad \text{or} \quad \frac{15\nu}{U_\alpha} = \delta \frac{d\delta}{dx} \qquad (3)$$

$$\frac{d\delta^2}{dx} = \frac{30\nu}{U_\alpha} \quad \text{with} \quad x=0,\ \delta=0$$

Integrate

$$\delta^2 = 30\frac{\nu x}{U_\alpha} \quad \text{or} \quad \delta = 5.477\sqrt{\frac{\nu x}{U_\alpha}} \qquad (4)$$

II Integral Energy balance equation is eq. 5.75, Notes

$$\alpha \left.\frac{dT}{dy}\right|_{y=0} = \frac{d}{dx}\left[\int_0^{\delta_t}(T_\alpha - T)\,u\,dy\right] \quad ; \quad \alpha = \frac{k}{\rho C_p} \qquad (5)$$

Conditions:

$$y=0,\ T=T_0 \ ; \quad y=\delta_t,\ T=T_\alpha \ ; \quad y=\delta_t,\ \frac{dT}{dy}=0$$

Define $\theta = T - T_0$

$$y=0,\ \theta=0 \ ; \quad y=\delta_t,\ \theta=\theta_\alpha = T_\alpha - T_0 \ ;$$

$$y=\delta_t,\ \frac{d\theta}{dy}=0$$

Assume $\theta = a' + b'y + c'y^2$ & subst. b.c.

$$\frac{\theta}{\theta_\alpha} = 2\left(\frac{y}{\delta_t}\right) - \left(\frac{y}{\delta_t}\right)^2 \quad \text{where } \delta_t(x) \qquad (6)$$

Define $\xi = \delta_t/\delta < 1$

substitute into integral energy eq.

$$\alpha \left.\frac{d(T-T_0)}{dy}\right|_{y=0} = \frac{\alpha\theta_\alpha}{\delta_t}\left.\frac{d\left(\frac{\theta}{\theta_\alpha}\right)}{d\left(y/\delta_t\right)}\right|_{y=0} = \frac{2\alpha\theta_\alpha}{\delta_t} =$$

$$\frac{d}{dx}\left[\int_0^{\delta_t}\left\{(T_\alpha - T_0) - (T - T_0)\right\} u\, dy\right] =$$

$$\frac{d}{dx}\left[U_\alpha \theta_\alpha \delta \int_0^{\delta_t/\delta}\left(1 - \frac{\theta}{\theta_\alpha}\right)\frac{u}{U_\alpha}\, d\left(\frac{y}{\delta}\right)\right] =$$

$$\frac{d}{dx}\left[U_\alpha \theta_\alpha \delta \int_0^{\xi}\left(1 - 2\frac{\eta}{\xi} + \left(\frac{\eta}{\xi}\right)^2\right)(2\eta - \eta^2)\, d\eta\right] =$$

$$\frac{d}{dx}\left[U_\alpha \theta_\alpha \delta \left\{\frac{1}{6}\xi^2 - \frac{1}{15}\xi^3\right\}\right]$$

$$\frac{2\alpha\theta_\alpha}{\xi\delta} = \frac{U_\alpha \theta_\alpha}{6}\frac{d}{dx}\left[\delta\xi^2\right], \quad \text{if } \frac{1}{15}\xi^3 << \frac{1}{6}\xi^2$$

$$\frac{12\alpha}{U_\alpha} = \xi\delta\frac{d}{dx}\left[\delta\xi^2\right] = \xi\delta^2\frac{d\xi^2}{dx} + \xi^3\delta\frac{d\delta}{dx} \qquad (7)$$

from earlier equations

$$\delta\frac{d\delta}{dx} = \frac{15\nu}{U_\alpha} \quad \text{and} \quad \delta^2 = \frac{30\nu x}{U_\alpha}.$$

Substitute.

$$\frac{12\alpha}{U_\alpha} = \xi\left(\frac{30\nu x}{U_\alpha}\right)\frac{d\xi^2}{dx} + \xi^3\left(\frac{15\nu}{U_\alpha}\right)$$

$$4\frac{\alpha}{\nu} = 10x\,\xi\frac{d\xi^2}{dx} + 5\xi^3 \qquad (8)$$

$$\frac{4}{5}\frac{\alpha}{\nu} = \frac{4}{3}x\frac{d\xi^3}{dx} + \xi^3 \quad \text{with} \quad x = x_0,\ \xi = \delta_t/\delta = 0$$

Solve to obtain

$$\xi^3 = \frac{4}{5}\frac{\alpha}{\nu}\left(1-\left(\frac{x_o}{x}\right)^{3/4}\right) \qquad (9)$$

or $$\xi = \left(\frac{4}{5}\right)^{1/3}\left(P_r^{-1/3}\right)\left(1-\left(\frac{x_o}{x}\right)^{3/4}\right)^{1/3}$$

$$\delta_t/\delta = 0.928\left(P_r^{-1/3}\right)\left(1-\left(\frac{x_o}{x}\right)^{3/4}\right)^{1/3} \qquad (10)$$

(a) The temperature profile is obtained from

$$\frac{\theta}{\theta_\alpha} = \frac{T(x,t)-T_o}{T_\alpha - T_o} = 2\left(y/\delta_t\right) - \left(y/\delta_t\right)^2 \qquad \text{eq. (6)}$$

where δ_t is given by eq. (4) and (10)

$\longrightarrow$

(b) The drag force

$$D = \int_0^L \tau\Big|_{y=0} W\,dx \quad ; \quad W = 8m,\ L = 5m$$

and $\tau\Big|_{y=0} = \mu \frac{du}{dy}\Big|_{y=0}$

$$D = W\int_0^L \frac{2\mu U_\alpha}{\delta}\,dx = 2\mu U_\alpha W\int_0^L \frac{1}{\beta}\frac{dx}{x^{1/2}}$$

write $\beta = 5.477\sqrt{\frac{\nu}{U_\alpha}}$

$$D = \frac{4\mu U_\alpha W}{5.477\sqrt{\nu/U_\alpha}} L^{1/2} = \frac{4}{5.477}\mu U_\alpha^{3/2} W \nu^{-1/2} L^{1/2}$$

$$= \frac{4}{5.477}\left[(1.813)(10^{-5})\right]^{1/2}(1.32)^{3/2}(8)(1.2047)^{1/2}(5)^{1/2}\ N$$

$$D = 0.0926 \text{ N} \longrightarrow$$

(c) From the condition that

$$h_x (T_0 - T_\alpha) = -k \left.\frac{dT}{dy}\right|_{y=0} = \frac{2k(T_0 - T_\alpha)}{\delta_t}$$

or $h_x = \dfrac{2k}{\delta_t}$ and $\delta_t = \varepsilon\, x^{\frac{1}{2}}\left(1 - \left(\frac{x_0}{x}\right)^{3/4}\right)^{\frac{1}{3}}$

where $\varepsilon = (0.928)\left(P_r^{-\frac{1}{3}}\right)(5.477)\left(\dfrac{\nu}{u_\alpha}\right)^{\frac{1}{2}}$

$$\therefore \quad h_x = \frac{2k}{\varepsilon}\, x^{-\frac{1}{2}}\left(1 - \left(\frac{x_0}{x}\right)^{3/4}\right)^{-\frac{1}{3}}$$

Heat loss over a distance from a to b is given by $Q_{ab} = W(T_0 - T_\alpha)\displaystyle\int_a^b h_x\, dx$

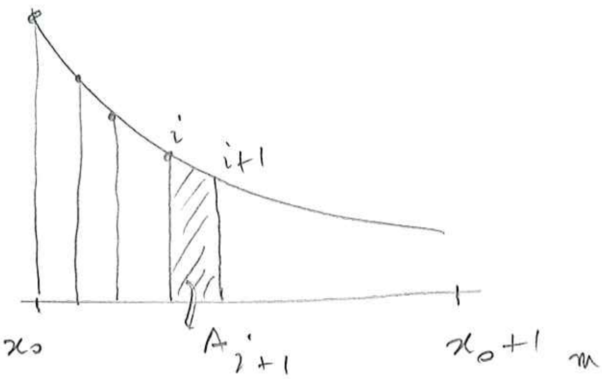
$\therefore$ Comparing the 1st heated to the last heated meter,

$$\frac{Q_{\text{first } m}}{Q_{\text{last } m}} = \frac{\displaystyle\int_{x_0=0.75}^{1.75} x^{-\frac{1}{2}}\left(1 - \left(\frac{x_0}{x}\right)^{3/4}\right)^{-\frac{1}{3}} dx}{\displaystyle\int_{3.25}^{4.25} x^{-\frac{1}{2}}\left(1 - \left(\frac{x_0}{x}\right)^{3/4}\right)^{-\frac{1}{3}} dx.}$$

solve numerically –

$$\frac{Q_{1^{st} m}}{Q_{last\, m}} \doteq \frac{1.685963}{0.583263} \doteq 2.891 \longrightarrow$$

$$\frac{f(x_i) + f(x_{i+1})}{2} \cdot (x_{i+1} - x_i)$$



1st meter

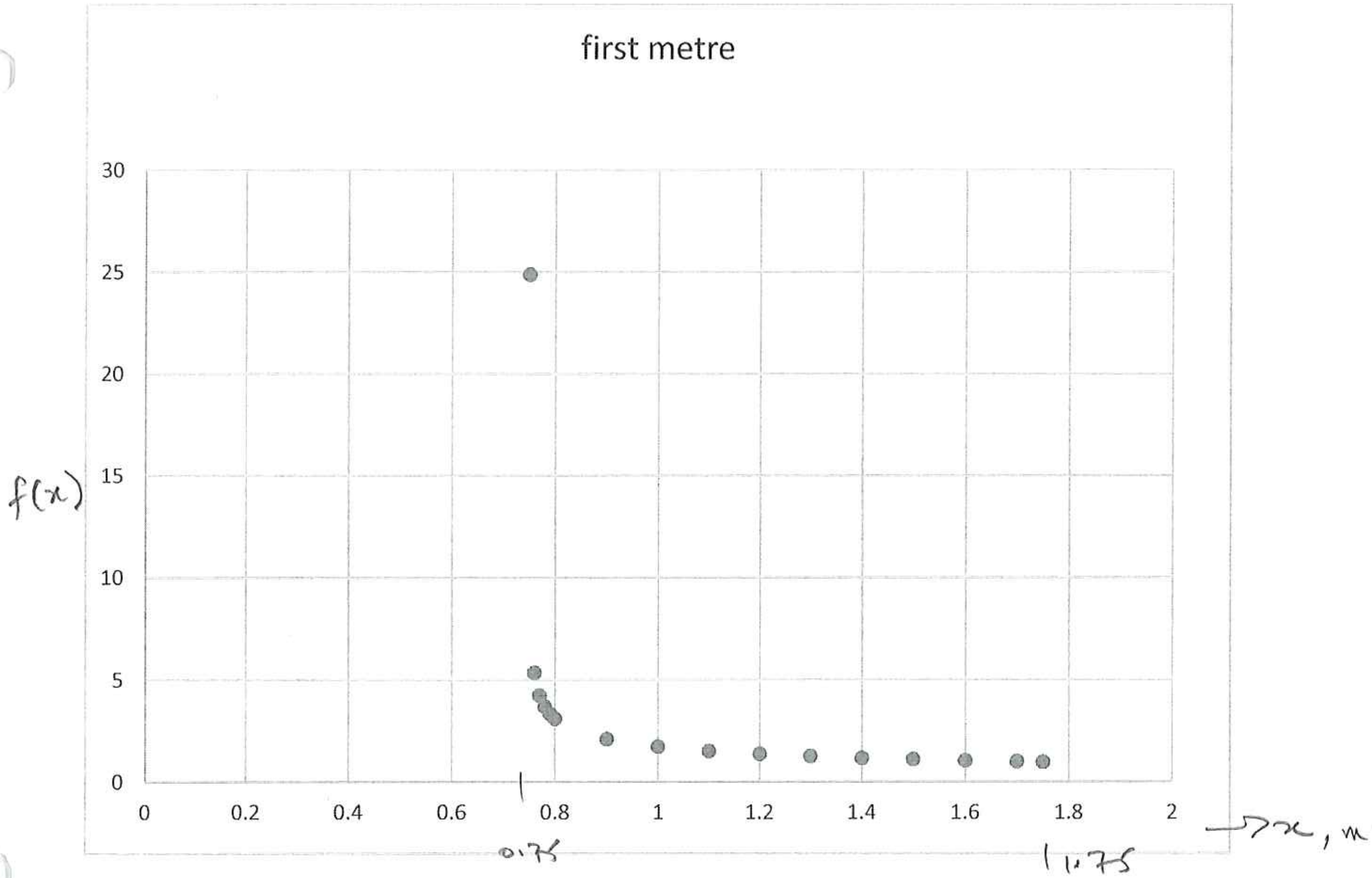
x	f(x)	
0.7501	24.86894	
0.76	5.344059	0.149554
0.77	4.230156	0.047871
0.78	3.685529	0.039578
0.79	3.339704	0.035126
0.8	3.092242	0.03216
0.9	2.092509	0.259238
1	1.727116	0.190981
1.1	1.514121	0.162062
1.2	1.368056	0.144109
1.3	1.259005	0.131353
1.4	1.173189	0.12161
1.5	1.103184	0.113819
1.6	1.044562	0.107387
1.7	0.994481	0.101952
1.75	0.972017	0.049162
		1.685963

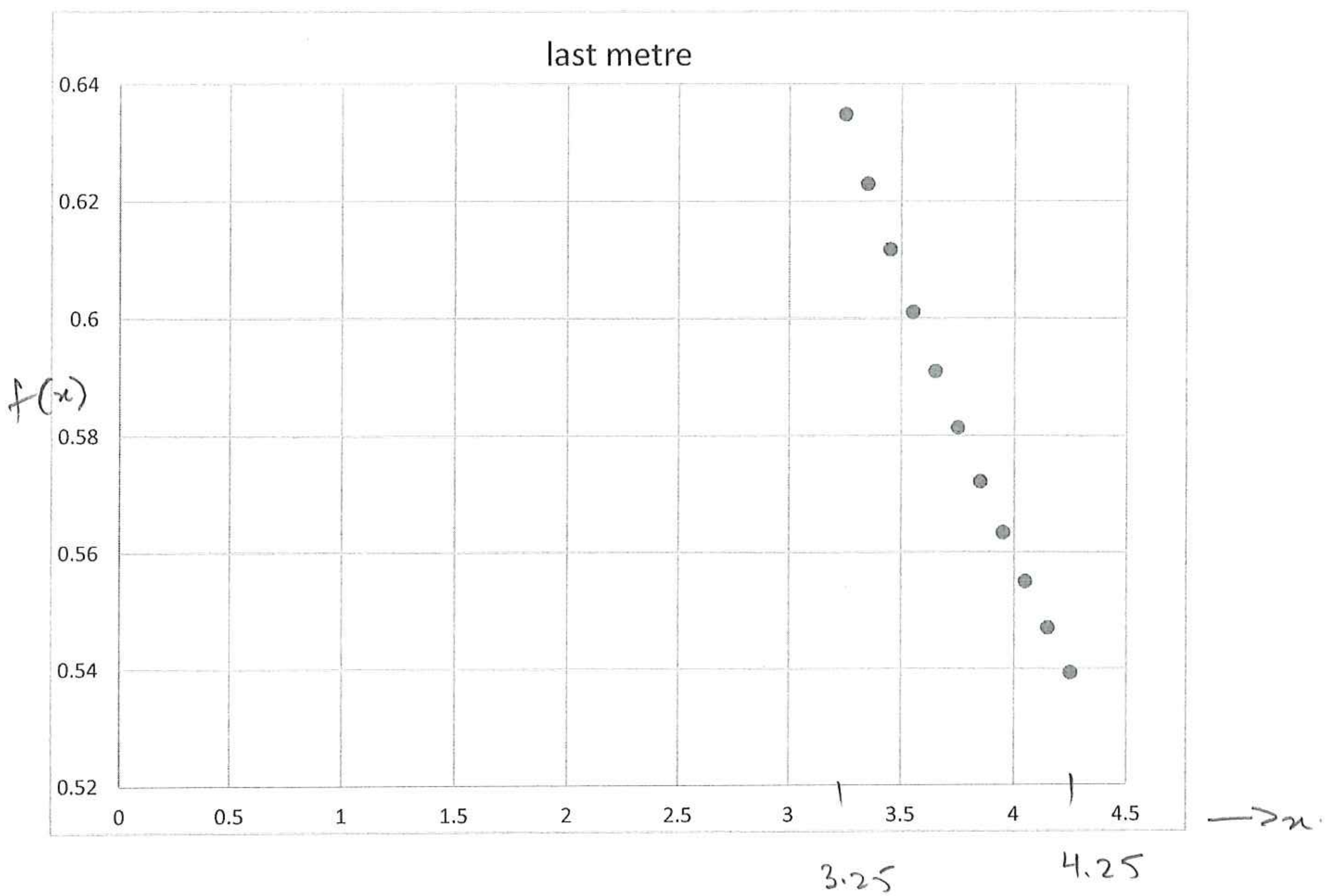
$1.685963 \;-\; \sum_{i=1}^{N-1} A_{i+1}$

last meter

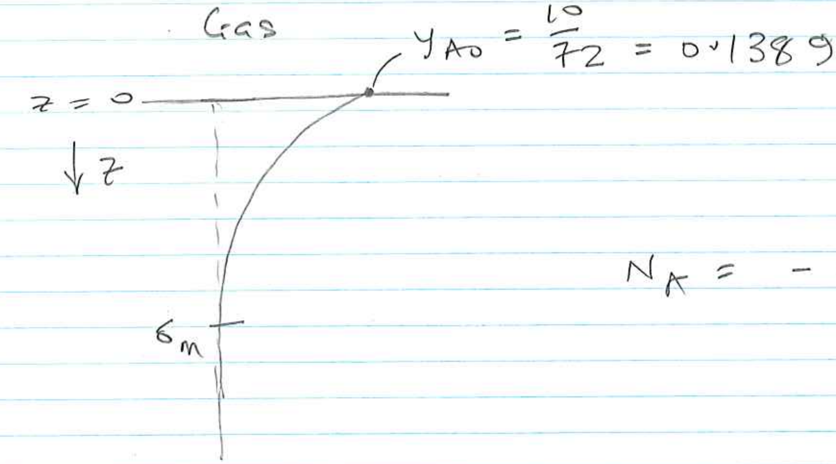
3.25	0.634844	
3.35	0.622977	0.062891
3.45	0.611742	0.061736
3.55	0.601087	0.060641
3.65	0.590963	0.059603
3.75	0.581328	0.058615
3.85	0.572142	0.057674
3.95	0.563374	0.056776
4.05	0.554991	0.055918
4.15	0.546967	0.055098
4.25	0.539276	0.054312
		0.583263

$$f(x) = x^{-\frac{1}{2}} \left(1 - \left(\frac{x_0}{x}\right)^{3/4}\right)^{-1/3} \quad ; \quad x_0 = 0.75\,\text{m}$$


first metre
30
25
20
15
10
5
0
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
f(x)
0.75
1.75
→ x, m.


last metre
0.64
0.62
0.6
0.58
0.56
0.54
0.52
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
f(x)
3.25
4.25
→ x.

Q. 2



This is a problem of diffusion with chemical reaction

$$N_A = -\frac{c\mathcal{D}_{AB}}{1-y_A}\frac{dy_A}{dz}$$, from Notes, since B is immobile

The integral mass transfer equation, with a first order reaction, is

$$N_A\Big|_{x=0} - \int_0^{\delta_m} k_1 C_A\,dz = \frac{d}{dt}\left[\int_0^{\delta_m} C_A\,dz\right] \quad (1)$$

where $C_A = c\,y_A$

The b.c.s are

$z = 0$, $y_A = y_{A0}$

$z = \delta_m$, $y_A = 0$ (assuming no CO_2 initially present)

$z = \delta_m$ $\frac{dy_A}{dz} = 0$

Assume $y_A = a + bz + cz^2$

Subst. conditions

$$\frac{y_A}{y_{A0}} = \left(1 - \frac{z}{\delta_m}\right)^2 \quad ; \quad \text{where } \delta_m(t) \quad (2)$$

Given fact c = constant = 72 moles/litre

substitute into integral eq.

$$\frac{12\,\mathcal{D}_{AB}}{1-y_{A0}} - 2k_1\delta_m^2 = \frac{d\delta_m^2}{dt} \quad \text{(also in Notes)} \quad (3)$$

with $t = 0$, $\delta_m = 0$ as i.c.,

$$\delta_m = \sqrt{\frac{12 D_{AB}}{1 - y_{A0}} \left[\frac{1 - e^{-2k_1 t}}{2k_1} \right]} \qquad (4)$$

(a) $k_1 = 3.5(10^{-3})\ s^{-1}$

$t = 180\,s$

$y_{A0} = 0.1389$

$$\delta_m = \left[\frac{(12)(1.5)(10^{-6})}{1 - 0.1389} \left[\frac{1 - e^{-180(3.5)(10^{-3})2}}{2(3.5)(10^{-3})} \right] \right]^{1/2}$$

$= 0.04625\ m$ or $4.625\ cm$ $\longrightarrow$

(b) The total uptake of CO_2 is given by

$$Q = \int_0^{180\,s} N_A\big|_{z=0}\, dt \quad \left[\text{not} \int_0^{\delta_m} C_A\, dx \ \text{since some A reacted} \right] \qquad (5)$$

$$N_A\big|_{z=0} = \left(- \frac{c D_{AB}}{1 - y_A} \frac{dy_A}{dz} \right)\bigg|_{z=0}$$

$$= \frac{c D_{AB}}{1 - y_{A0}} y_{A0} \cdot \frac{2}{\delta_m}$$

$$Q = 2 \frac{c D_{AB}}{1 - y_{A0}} y_{A0} \int_0^{t=180\,s} \frac{1}{\delta_m}\, dt \qquad (6)$$

where δ_m is from eq. (4)

$$Q = \frac{2c\,D_{AB}}{1-y_{A0}}\, y_{A0}\,(2k_1)^{1/2} \sqrt{\frac{1-y_{A0}}{12 D_{AB}}} \int_0^{180} \frac{dt}{(1-e^{-2k_1 t})^{1/2}}$$

$$= \overbrace{c\, y_{A0} \sqrt{\frac{2k_1 D_{AB}}{3(1-y_{A0})}}}^{\beta} \int_0^{180} \frac{dt}{(1-u)^{1/2}} \quad ; \quad u = e^{-2k_1 t}$$

$$du = -2k_1 e^{-2k_1 t}\, dt = -2k_1\, u\, dt$$

$$Q = -\frac{\beta}{2k_1} \int_1^{0.2836} \frac{du}{u(1-u)^{1/2}} \quad ; \quad e^{-2(3.5)(10^{-3})(180)} = u \text{ upper limit} = 0.2836$$

$$= -\frac{\beta}{2k_1} \ln \left| \frac{\sqrt{1-u} - 1}{\sqrt{1-u} + 1} \right|_1^{0.2836}$$

from Math table

$$= -\frac{\beta}{2k_1} \left\{ \ln \frac{-0.153628}{1.8464} - \ln \frac{-1}{1} \right\}$$

$$Q = \frac{2.486463}{2} \frac{\beta}{3.5(10^{-3})} \quad \frac{\text{moles}}{m^2 \text{ surface area}}$$

$$\beta = 72(10^3)(0.1389) \sqrt{\frac{2(3.5)(10^{-3})(1.5)(10^{-6})}{3(1-0.1389)}} = 0.63759$$

where $c = 72 \frac{\text{moles}}{\text{litre}}$ or $72(10^3) \frac{\text{moles}}{m^3}.$

$$Q = 226.48 \frac{\text{moles}}{m^2}$$

$\longrightarrow$

Q.3 (a) Variables $h, \Delta T, L, \lambda, \rho, g, \mu, k$

units. W/m^2K K m kJ/kg kg/m^3 m/s $Pa.s$ W/mK

Dimensions — M, L, t, T

Total 8 variables, 4 dimensions ∴ 4 dimensionless groups

By inspection $\frac{hL}{k} = \Pi_1$

& remove one of h or k. (say k)

Choose 4 repeating variables — e.g. $h, \Delta T, L, \rho$

$\Pi_2 = h^{a_0} \Delta T^{b_0} L^{c_0} \rho^{d_0} \lambda$ where a, b, c and d are coefficients

$\Pi_3 = h^{a_1} \Delta T^{b_1} L^{c_1} \rho^{d_1} g$

$\Pi_4 = h^{a_2} \Delta T^{b_2} L^{c_2} \rho^{d_2} \mu$

Apply dimensions

h	ΔT	L	λ	ρ	g	μ
$\frac{M}{t^3 T}$	T	L	$\frac{L^2}{t^2}$	$\frac{M}{L^3}$	$\frac{L}{t^2}$	$\frac{M}{Lt}$

$$\Pi_2 = \left[\frac{M}{t^3 T}\right]^{a_0} \left[T\right]^{b_0} \left[L\right]^{c_0} \left[\frac{M}{L^3}\right]^{d_0} \frac{L^2}{t^2}$$

$$\left.\begin{aligned} M \quad & 0 = a_0 + d_0 \\ L \quad & 0 = c_0 - 3d_0 + 2 \\ t \quad & 0 = -3a_0 - 2 \\ T \quad & 0 = -a_0 + b_0 \end{aligned}\right) \quad \begin{aligned} a_0 &= -2/3 \\ b_0 &= -2/3 \\ c_0 &= 0 \\ d_0 &= 2/3 \end{aligned}$$

$$\Pi_2 = \left(\frac{\rho}{h \Delta T}\right)^{2/3} \lambda$$

$$\Pi_3 = \left[\frac{M}{t^3 T}\right]^{a_1} \left[T\right]^{b_1} \left[L\right]^{c_1} \left[\frac{M}{L^3}\right]^{d_1} \left[\frac{L}{t^2}\right]$$

$$\left.\begin{array}{lll} M & 0 = & a_1 + d_1 \\ L & 0 = & c_1 - 3d_1 + 1 \\ t & 0 = & -3a_1 - 2 \\ T & 0 = & -a_1 + b_1 \end{array}\right) \quad \begin{array}{l} a_1 = -2/3 \\ b_1 = -2/3 \\ c_1 = 1 \\ d_1 = 2/3 \end{array}$$

$$\Pi_3 = \left(\frac{\rho}{h \Delta T}\right)^{2/3} L g$$

and
$$\Pi_4 = \left[\frac{M}{t^3 T}\right]^{a_2} \left[T\right]^{b_2} \left[L\right]^{c_2} \left[\frac{M}{L^3}\right]^{d_2} \left[\frac{M}{Lt}\right]$$

$$\left.\begin{array}{lll} M & 0 = & a_2 + d_2 + 1 \\ L & 0 = & c_2 - 3d_2 - 1 \\ t & 0 = & -3a_2 - 1 \\ T & 0 = & -a_2 + b_2 \end{array}\right) \quad \begin{array}{l} a_2 = -1/3 \\ b_2 = -1/3 \\ c_2 = 3 \\ d_2 = -2/3 \end{array}$$

$$\Pi_4 = \left(\frac{\rho^2}{h \Delta T}\right)^{1/3} L^3 \mu$$

(b)
$$x_A = \frac{m_A / M_A}{m_B / M_B + \frac{m_A}{M_A}} \times \frac{\frac{1}{m_A + m_B}}{\frac{1}{m_A + m_B}}$$

$$= \frac{w_A / M_A}{\frac{w_A}{M_A} + \frac{w_B}{M_B}} = \frac{w_A / M_A}{\frac{w_A}{M_A} + \frac{(1 - w_A)}{M_B}}$$

$$= \frac{w_A / M_A}{\frac{M_B w_A + M_A (1 - w_A)}{M_A M_B}}$$

$$= \frac{\omega_A M_B}{M_B \omega_A + M_A (1-\omega_A)}$$

$$dx_A = \left[M_B \omega_A + M_A (1-\omega_A)\right] M_B \, d\omega_A -$$

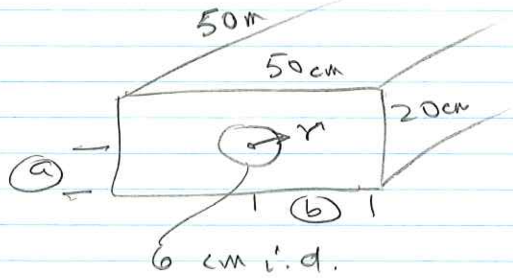
$$\frac{\omega_A M_B (M_B - M_A)\, d\omega_A}{(M_B \omega_A + M_A \omega_B)^2}$$

$$= \frac{M_A M_B \, d\omega_A}{(M_B \omega_A + M_A \omega_B)^2} \times \frac{\frac{1}{M_A M_B}}{\frac{M_A M_B}{(M_A M_B)^2}}$$

$$dx_A = \frac{d\omega_A}{M_A M_B \left(\frac{\omega_A}{M_A} + \frac{\omega_B}{M_B}\right)^2} \longrightarrow$$

Q 4

(a)



Steam is saturated.
∴ Inside wall is constant at 200 °C

Shape factor problem. Assume h is large.

$$Q = k S \Delta T$$

$$S = \frac{2\pi l}{\ln\left(\frac{4a}{\pi r} - 2K\right)}$$

from tables,
$K = 0.000078$
for $\frac{b}{a} = 2.5$
$l = 50\,m$; $r = 0.03\,m$

$$= 217.39\,m$$

Rate of heat loss $= 1.1\,(217.39)(230)$

$Q = 54{,}999.67\ W$ or $55\ kW$

Since $\Delta H_v = 1939\ kJ/kg$

Rate of condensation $= \frac{55}{1939}\ kg/s$

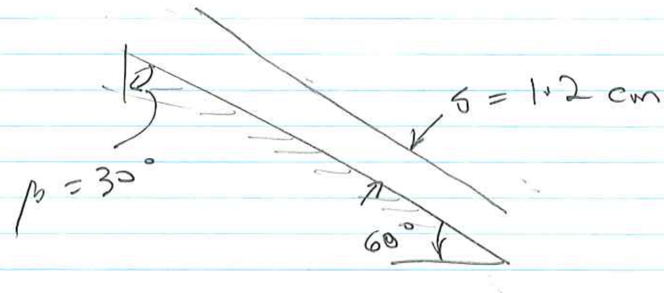
steam input rate (feed)

$$F = \frac{3}{0.127} + \frac{55}{1939} = 23.65\ kg/s.$$

vapor flowing out ; condensate.

→

(b)



Notes — eq. 6.7, laminar flow on an inclined wall

$$\frac{Q}{m \text{ width}} = \frac{\rho g \delta^3 \cos\beta}{3\mu}$$

Total flow rate = $\underbrace{(60)}_{\text{boards}}\underbrace{(5)}_{\text{width of each board}} Q$.

$$Q_{total} = \frac{(996)(9.81)(0.012)^3 \cos 30}{3\,(0.653)(10^{-3})} \cdot 60 \cdot 5 \quad m^3/s$$

$$= 2{,}239.18 \ m^3/s.$$

⟶

Check — is flow laminar?

$$Re = \frac{(4\delta)\bar{u}\rho}{\mu} \; ; \quad \bar{u} = \frac{\rho g \delta^2 \cos\beta}{3\mu} = \frac{Q}{\delta}$$

$$= \frac{4Q\rho}{\mu} = \frac{4(7.46394)(996)}{0.653(10^{-3})}$$

$$= 4.55(10^7)$$ Flow is definitely turbulent.