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WEDNESDAY, JUNE 29TH 2011

Harry Potter

AND THE

HEAT TRANSFER MIDTERM EXAM

MCG 3110 - HEAT TRANSFER
MIDTERM EXAMINATION - DURATION: 90 MINUTES
INSTRUCTOR: DR. PATRICK RICHER

CLOSED BOOKS – CALCULATORS ALLOWED – IMPORTANT INFORMATION ON LAST PAGES

<u>QUESTION SHEETS MUST BE HANDED IN WITH EXAM</u>

HARRY POTTER NEEDS YOUR HELP!!

GIVEN YOUR EXPERTISE IN THE FIELD OF HEAT TRANSFER, YOU HAVE BEEN ASKED TO ASSIST THE YOUNG WIZARD AND HIS FRIENDS IN THEIR MULTIPLE ADVENTURES.

PLEASE NOTE THAT "BECAUSE IT'S MAGIC" WILL NOT BE ACCEPTED AS A VALID ANSWER!

ATTEMPT ALL QUESTIONS – GOOD LUCK!

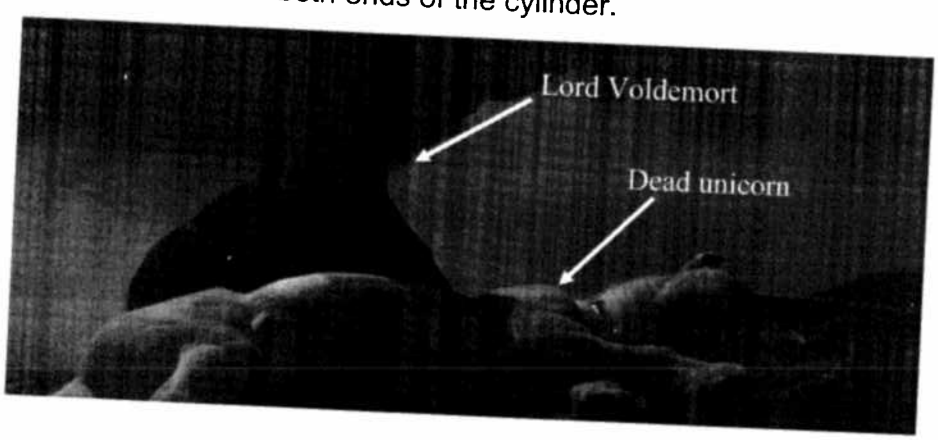
PROBLEM 1: (30 MARKS)

In the movie *Harry Potter and the Philosopher's Stone*, Harry and his friends are ordered to accompany Hagrid (the school's groundskeeper) into the forbidden forest as part of their detention. Unexpectedly, they stumble upon a dead unicorn as well as a creepy hooded figure crouched over top. They later discover this hooded figure to be the wounded and weakened dark wizard known as Lord Voldemort, who had been drinking the unicorn's blood in order to gain sufficient strength to carry out his evil plans and return to full health.

To assist Harry Potter and estimate how much strength Lord Voldemort may have gained from drinking the unicorn blood, you are required to determine how much time (in minutes) the unicorn has been dead before Harry found it.

The following information is to be used for this problem:

1. The skin surface temperature of the unicorn at the moment when Harry discovered it was of $T_{skin} = 27°C$
2. The unicorn can be modelled as a cylinder with a diameter of $d = 74\ cm$, a uniform conductivity of $k = 6.7\ W/mK$, density $\rho = 340\ kg/m^3$ and specific heat $C_p = 1200\ J/kgK$.
3. The air in the forest is at a temperature of $T_\infty = 14°C$ with a convection coefficient of $h = 18\ W/m^2K$.
4. You can assume that at the moment of its death, the unicorn was at a uniform initial temperature of $T_i = 38°C$.
5. Neglect heat loss at both ends of the cylinder.



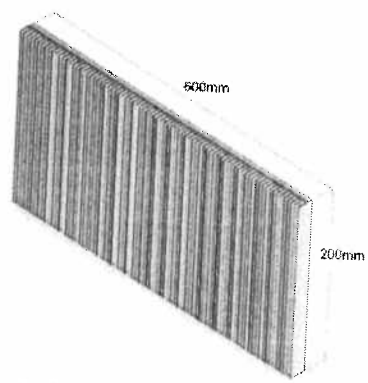
PROBLEM 2: (30 MARKS)

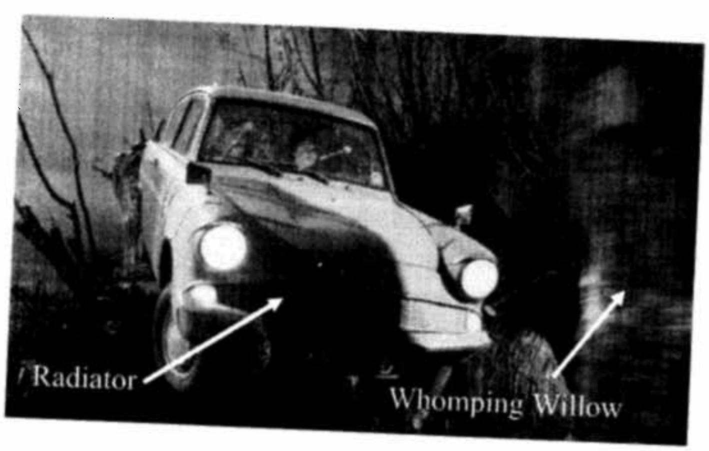
At the start of their second year, as seen in the movie *Harry Potter and the Chamber of Secrets,* Harry and Ron are forced to use an enchanted flying car to get to Hogwarts (School of Witchcraft and Wizardry) rather than taking the usual Hogwarts Express train ride. The flying car is a light blue Ford Anglia that was heavily modified by Ron's father (Arthur Weasley). Just as they arrive on school grounds, the car starts breaking down and they end up crashing into the Whomping Willow, a magical tree that pummels anything (or anyone!) that gets too close...

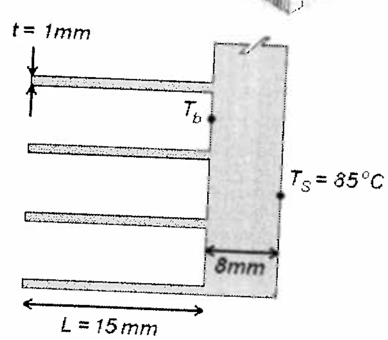
The stock radiator on the Ford Anglia consists of a fin array with 80 rectangular fins and is designed to draw heat from the engine block in order to keep it sufficiently cool during operation. The newly added flying feature provides added strain on the engine, and as a result a minimum of 3.0 kW must be removed from the engine block during operation; otherwise the engine will overheat and the car will break down. The fin array is constructed from aluminum (k_{Al} = *238 W/mK*), with dimensions shown below. The radiator fin array has an inner surface temperature T_S = *85°C*.

a) Determine whether the car failure experienced by Harry and Ron was attributed to overheating of the engine (i.e. find the heat transfer rate from the radiator fin array). The ambient air conditions are T_∞ = *20°C* and h_∞ = *100W/m²K*.

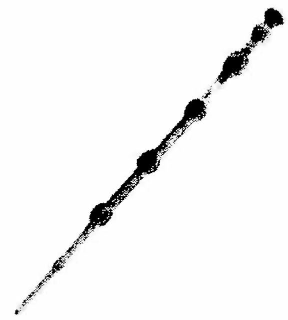
b) If the Whomping Willow smashes the radiator and tears it off from the car, could it still operate without the risk of overheating?







PROBLEM 3: (40 MARKS)



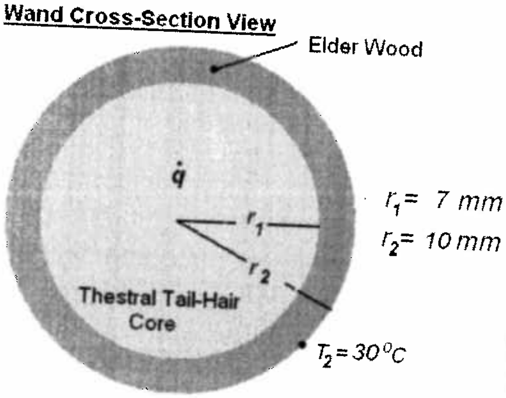
In the latest movie, *Harry Potter and the Deathly Hallows – Part 1*, it is revealed that the late Professor Dumbledore was the last known owner of the Elder Wand. The Elder Wand, also known as the Wand of Destiny, is said to be the most powerful magic wand that has ever existed, able to perform feats of magic that would normally be considered impossible. The movie ends on a cliff-hanger with Lord Voldemort stealing the Elder Wand from Professor Dumbledore's tomb, setting the tone for the upcoming grand finale: *Harry Potter and the Deathly Hallows – Part 2.*

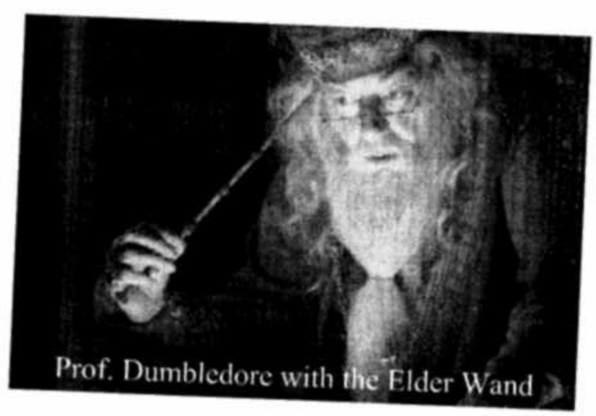
The Elder Wand is made of an elder wood shell, k_{wood} = 0.012 W/mK, and a thestral tail-hair core, k_{core} = 0.038 W/mK (see diagram below). When the wand is being used, the thestral tail-hair core produces a uniform energy generation rate per unit volume of $\dot{q}$ = *32,000 W/m*^{3}. For the current analysis, the Elder Wand is to be modeled as a <u>cylinder</u> with outer radius r_2 = *10mm* and length L = *300mm*. The wand's core has a radius of r_1 = *7mm*. Under normal operating conditions, the outer surface temperature of the wand T_2 is measured to be 30°C.

a) Evaluate the steady state temperature at the interface $T(r_1)$ between the wood shell and the thestral tail-hair core. *(Hint: You don't need to solve the HDE for this part of the problem.)*

b) Find an expression for the steady state temperature distribution <u>in the thestral tail-hair core</u> as a function of the radius *r*. Neglect any heat transfer along the length (*z-axis*) of the wand. *(Hint: You need to solve the HDE in the core with the proper boundary conditions.)*

<u>Wand Cross-Section View</u>





Prof. Dumbledore with the Elder Wand

IMPORTANT INFORMATION

$$\frac{1}{r^2}\frac{\partial}{\partial r}\left(kr^2\frac{\partial T}{\partial r}\right)+\frac{1}{r^2\sin^2\theta}\frac{\partial}{\partial\phi}\left(k\frac{\partial T}{\partial\phi}\right)+\frac{1}{r^2\sin\theta}\frac{\partial}{\partial\theta}\left(k\sin\theta\frac{\partial T}{\partial\theta}\right)+\dot{q}=\rho c_p\frac{\partial T}{\partial t}$$

$$\frac{1}{r}\frac{\partial}{\partial r}\left(kr\frac{\partial T}{\partial r}\right)+\frac{1}{r^2}\frac{\partial}{\partial\phi}\left(k\frac{\partial T}{\partial\phi}\right)+\frac{\partial}{\partial z}\left(k\frac{\partial T}{\partial z}\right)+\dot{q}=\rho c_p\frac{\partial T}{\partial t}$$

$$R_{cond}=\frac{\ln\left(r_2/r_1\right)}{2\pi LK}$$

TABLE 3.4 Temperature distribution and heat loss for fins of uniform cross section

Case	Tip Condition ($x = L$)	Temperature Distribution θ/θ_b	Fin Heat Transfer Rate q_f
A	Convection heat transfer: $h\theta(L) = -kd\theta/dx\vert_{x=L}$	$\frac{\cosh m(L-x) + (h/mk)\sinh m(L-x)}{\cosh mL + (h/mk)\sinh mL}$ (3.70)	$M\frac{\sinh mL + (h/mk)\cosh mL}{\cosh mL + (h/mk)\sinh mL}$ (3.72)
B	Adiabatic $d\theta/dx\vert_{x=L} = 0$	$\frac{\cosh m(L-x)}{\cosh mL}$ (3.75)	$M\tanh mL$ (3.76)
C	Prescribed temperature: $\theta(L) = \theta_L$	$\frac{(\theta_L/\theta_b)\sinh mx + \sinh m(L-x)}{\sinh mL}$ (3.77)	$M\frac{(\cosh mL - \theta_L/\theta_b)}{\sinh mL}$ (3.78)
D	Infinite fin ($L \rightarrow \infty$): $\theta(L) = 0$	e^{-mx} (3.79)	M (3.80)

$\theta \equiv T - T_\infty$ $\quad m^2 \equiv hP/kA_c$

$\theta_b = \theta(0) = T_b - T_\infty$ $\quad M \equiv \sqrt{hPkA_c}\,\theta_b$

IMPORTANT INFORMATION – CONTINUED

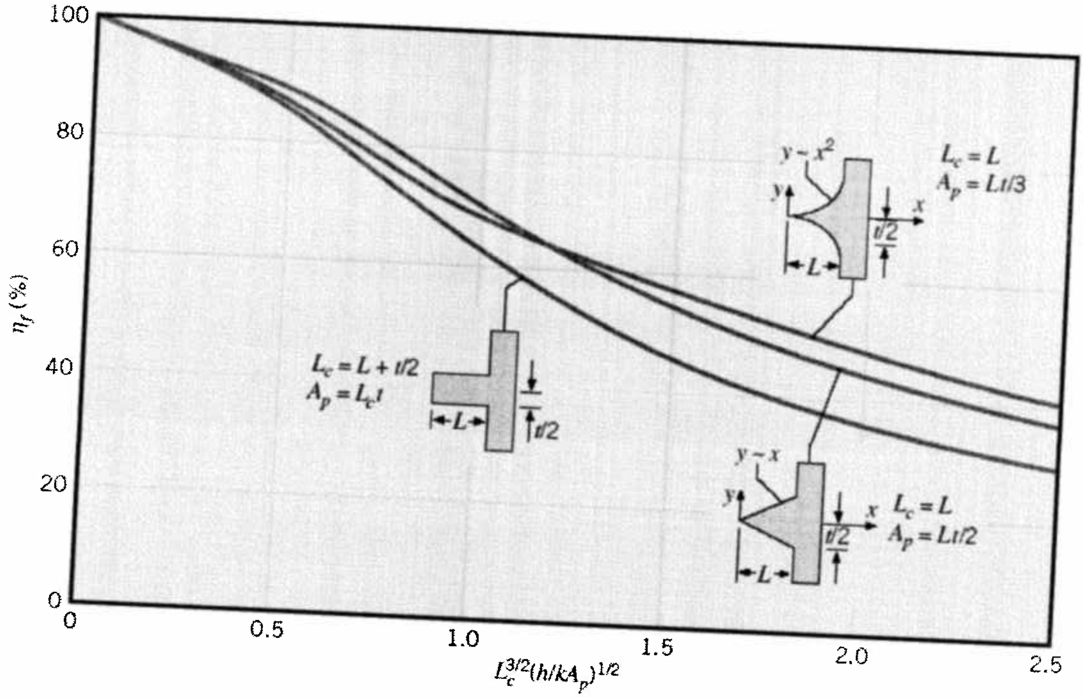


FIGURE 3.18 Efficiency of straight fins (rectangular, triangular, and parabolic profiles).

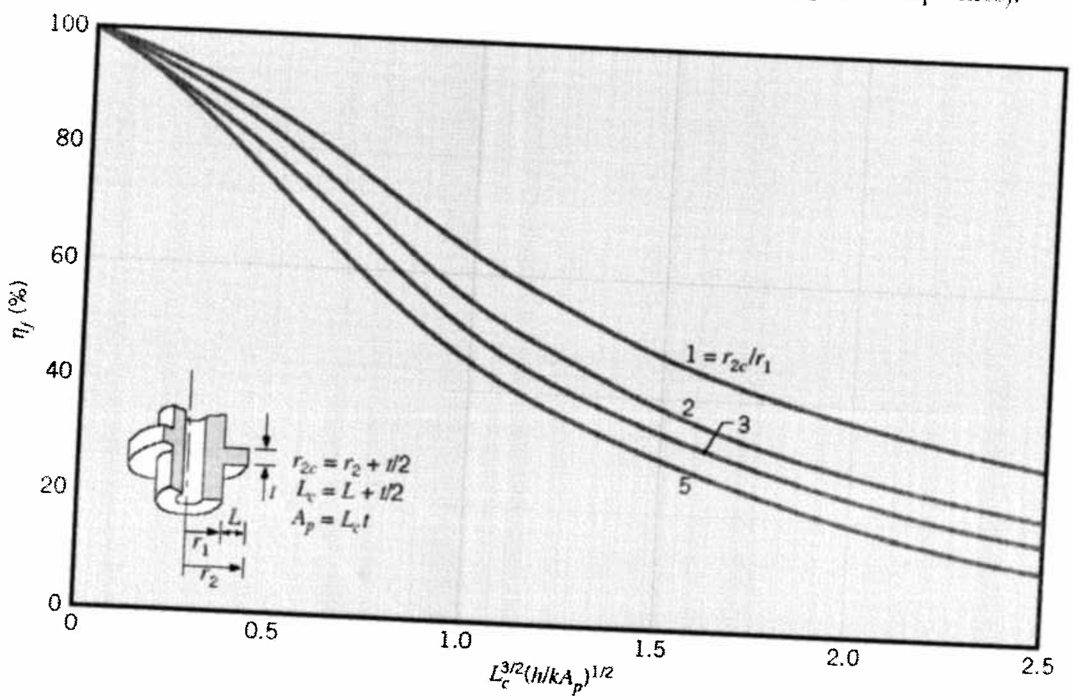
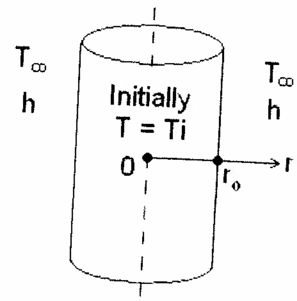
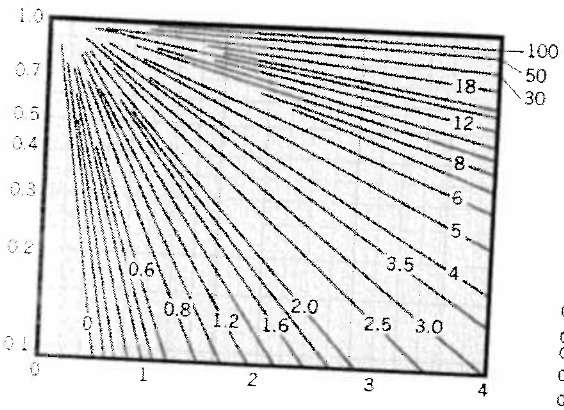


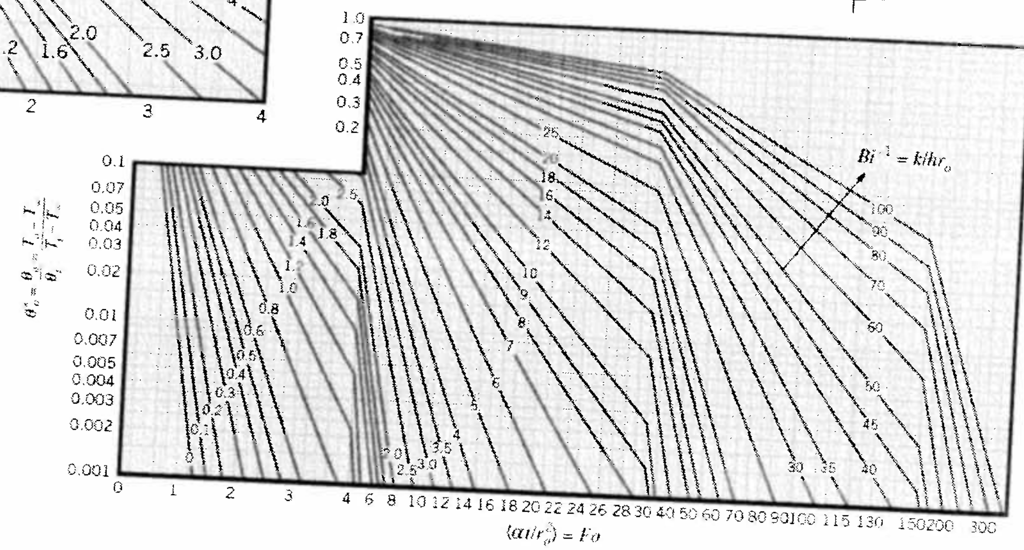
FIGURE 3.19 Efficiency of annular fins of rectangular profile.

IMPORTANT INFORMATION – CONTINUED

$$\frac{\theta}{\theta_i} = \frac{T - T_\infty}{T_i - T_\infty} = e^{\left(-\frac{hA_s t}{\rho V c}\right)}$$







$$\alpha = \frac{k}{\rho C_p}$$

FIGURE 58.4 Centerline temperature as a function of time for an infinite cylinder of radius r_o [1]. Used with permission.

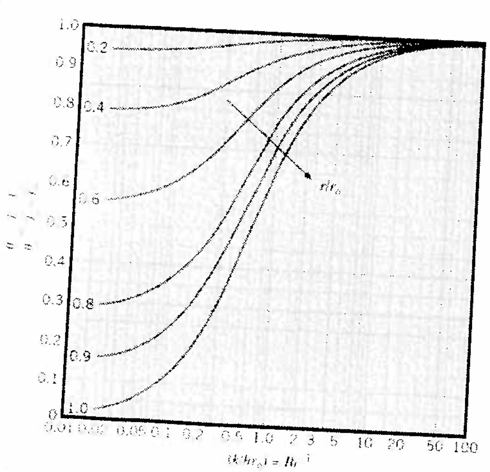


FIGURE 58.5 Temperature distribution in an infinite cylinder of radius r_o.

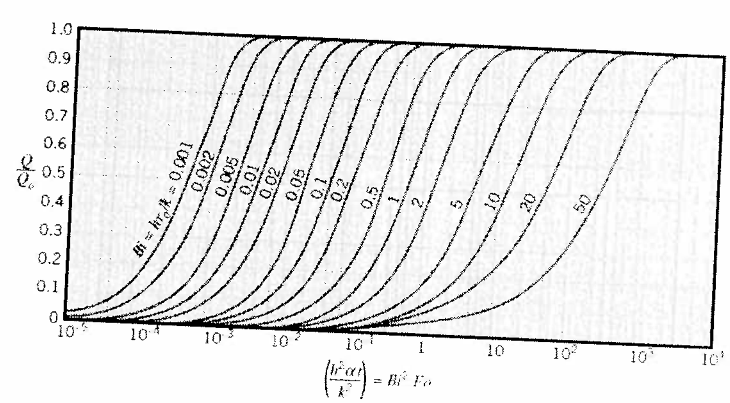


FIGURE 58.6 Internal energy change as a function of time for an infinite cylinder of radius r_o [2]. Adapted with permission.

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Engineering

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COTE DU COURS - *COURSE CODE*

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1. $T_{skin} = 27°C$

$d = 74 cm$

$k = 6.7 W/mK$

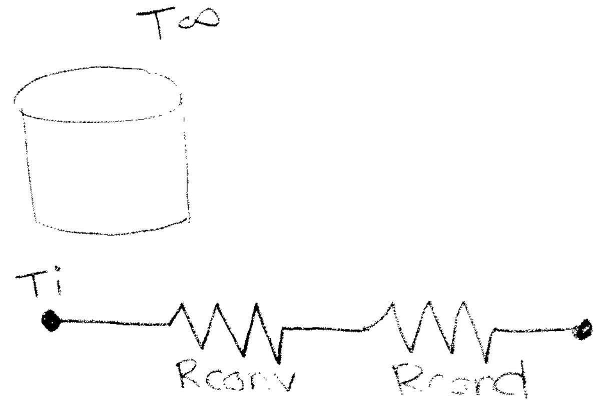
$\rho = 340 kg/m^3$

$C_p = 1200 J/kgK$

$T_\infty = 14°C$

$h = 18 W/m^2K$

$T_i = 38°C$



Can we use LMC?

$$L_c = \frac{\cancel{V}}{A_s} = \frac{\pi r^2 \cdot L}{2\pi r \cdot L} = \frac{r}{2} = \frac{0.37m}{2} = 0.185m$$

$$Bi = \frac{hL_c}{k} = \frac{18 W/m^2K \cdot 0.185m}{6.7 W/mK} = 0.49$$

0.49 > 0.1 ∴ LMC is not valid

Using fig 5S.4

$$Bi = \frac{hr_0}{k} = \frac{18 W/m^2 \cdot K (0.37m)}{6.7 W/mK} = 0.994$$

$$\frac{1}{Bi} = 1.0$$

$$\frac{\theta_o}{\theta_i} = \frac{T_o - T_\infty}{T_i - T_\infty}$$

$T_s \neq T_o$ -9

$$\frac{\theta_o}{\theta_i} = \frac{27^\circ C - 14^\circ C}{38^\circ C - 14^\circ C}$$

$$\frac{\theta_o}{\theta_i} = 0.541$$

Using fig 5 5.4

$\frac{\theta_o}{\theta_i} = 0.541$, ~~ok~~ $Bi^{-1} = 1.0$, $\Rightarrow Fo \approx \cancel{2}$ -2

with these values, $Fo = 0.5\ldots$

$$Fo = \frac{\alpha t}{r_o^2}$$ ✓

$$t = \frac{Fo\, r_o^2}{\alpha}$$

$$t = \frac{2(0.37)^2}{1.6422 \times 10^{-5}}$$

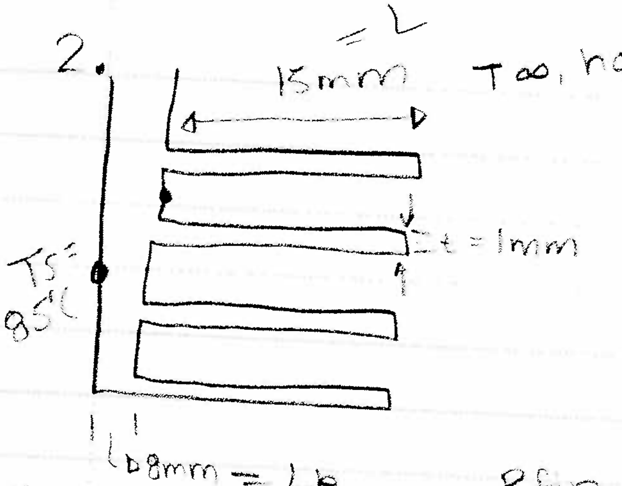
$$t = 16673s$$

$$\boxed{t = 277.9 \text{ min}}$$ -1

$$\alpha = \frac{K}{\rho C_p} = \frac{6.7}{340 \cdot 1200}$$

$$\alpha = 1.6422 \times 10^{-5}$$

2.



8 rectangular fins.

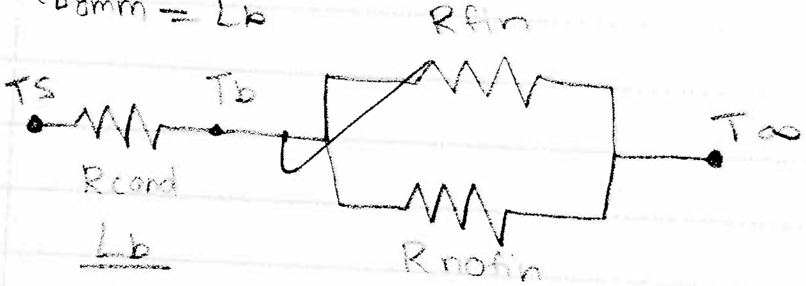
$q = 3.0 kW$

$k_{Al} = 238\ W/mK$

$T_\infty = 20°C$

$h_\infty = 100\ W/m^2K$

12/30



$\frac{L_b}{KA_b}$

Using Fig. 3.18

$L_c = L + t/2$

$L_c = 0.015m + 0.001m/2$

$L_c = 0.0155m$

$A_p = L_c t$

$A_p = 0.0155m \cdot 0.001m$

$A_p = 1.55 \times 10^{-5} m^2$

$L_c^{3/2}(h/kA_p)^{1/2} = (0.0155m)^{3/2}(100\ W/m^2K / 238 W/mK \cdot 1.55 \times 10^{-5} m^2)^{1/2}$

$= 0.317$

$\therefore \eta_f \approx 10\%$ X (-2)

$q_{fin} = \eta_{fin}\, q_{fin\,max}$

$R_{unfin} = \frac{1}{100 W/m^2K \cdot (0.2m \cdot 0.6m - \cancel{(0.001m)^2 \cdot 80})}$ (-2) X

$R_{unfin} = 0.0833$ X

Rcond -2

Runfin ok

Rfdn -5

$$R_{TOT} = \frac{L_b}{kA_b} + \left[\frac{1}{R_{fin}} + \frac{1}{R_{unfin}}\right]^{-1}$$

$$q_{tot} = \frac{T_s - T_\infty}{R_{TOT}}$$

$$q_{fin\,max} = M \frac{\sinh mL + (h/mk)\cosh mL}{\cosh mL + (h/mk)\sinh mL}$$

$$m = \sqrt{hP/kA_c} \qquad M = \sqrt{hPkA_c}\,\theta_b$$

$$M = \sqrt{hPkA_c}\;T_b - T_\infty$$

$$\frac{T_s - T_b}{\frac{L_b}{kA_b}} = \frac{T_b - T_\infty}{\left[\frac{1}{R_{fin}} + \frac{1}{R_{unfin}}\right]^{-1}}$$

incomplete

-2

b)

-5

DIRECTIVES

1. Le silence est de rigueur dans la salle d'examen.
2. Le surveillant ou la surveillante se réserve le droit de vérifier les cartes d'identité universitaire.
3. Il est interdit de quitter la salle d'examen avant qu'une heure ne se soit écoulée.
4. Il est interdit de se présenter à la salle d'examen ou d'en sortir en possession d'un cahier d'examen.
5. Écrire lisiblement.
6. L'ordre des réponses est facultatif, mais en tête de chaque réponse doit figurer le numéro (chiffre et lettre) correspondant à la question.
7. À moins d'indication contraire donnée par le surveillant ou la surveillante, les réponses doivent être écrites sur les deux côtés des pages lignées.
8. À moins d'indication contraire, il faut inclure le détail des opérations aussi bien que les réponses.
9. On numérotera chaque cahier d'examen. Si l'on utilise plus d'un cahier, on insérera le cahier n° 1 sous la page couverture du cahier n° 2, le cahier n° 2 sous la page couverture du cahier n° 3 et ainsi de suite.
10. À moins d'indication contraire, il est interdit de se servir de livres, de notes, de tables de mathématiques, de dictionnaires ou de tout autre aide-mémoire.
11. Les étudiants et étudiantes ne doivent pas avoir en leur possession les objets suivants: appareil photo, appareil radio (radio avec écouteurs), magnétophone, téléavertisseur, montre-calculatrice, téléphone cellulaire, ni tout autre dispositif de communication qui n'a pas été autorisé au préalable.

    Il revient à l'étudiant ou l'étudiante de vérifier quel genre de calculatrice est autorisé pour chaque test ou examen.

    Quiconque contrevient au présent règlement est jugé avoir commis une fraude scolaire.

CONSERVATION DES CAHIERS D'EXAMEN

1. Les étudiants et étudiantes ont le droit de voir, sur demande, après notation, leurs propres cahiers d'examen et leurs travaux écrits.
2. L'Université se réserve le droit de détruire les cahiers d'examen et les autres travaux écrits six mois après la communication de la note à l'étudiant ou l'étudiante.

INSTRUCTIONS

1. *Silence is compulsory in the examination room.*
2. *Students must produce their student identity card on request.*
3. *Students may not leave until one hour after the examination has begun.*
4. *Students may not take any examination booklet into or away from the examination room.*
5. *Write legibly.*
6. *Questions may be answered in any order, but each answer must be preceded by the appropriate question number, including both figure and letter where applicable.*
7. *Unless otherwise indicated, answers must be written on both sides of the ruled pages.*
8. *Unless otherwise indicated, the detailed operations and the final answers must be shown in the examination booklet.*
9. *Each examination booklet must be numbered. Booklet 1 is inserted inside the cover page of booklet 2, booklet 2 inside the cover page of booklet 3, and so on.*
10. *Unless otherwise specified in the examination questionnaire, the use of books, notes, mathematical tables, dictionaries or other study aids is forbidden.*
11. *Students must not have in their possession: cameras, radios (radios with head sets), tape recorders, pagers, calculator watches, cellular phones or any other communication device which has not been previously authorized.*

    It is the responsibility of the student to find out what type of calculators are allowed for each examination or test.

    Any student who contravenes this regulation will be deemed to have committed academic fraud.

RETENTION OF EXAMINATION BOOKLETS

1. *All students have the right to see their examination booklets and written work after they have been marked.*
2. *The University reserves the right to destroy examination booklets and other written work six months after the grade has been communicated to the student.*

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$k_{wood} = 0.012\ W/mK$

$k_{core} = 0.038\ W/mK$

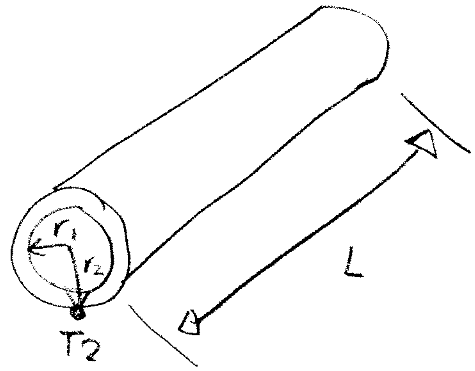
$\dot{q} = 32{,}000\ W/m^3$

$r_2 = 10mm$

$L = 300mm$

$r_1 = 7mm$

$T_2 = 30°C$



Assumptions

1. Steady State
2. $W = 0$

$$-k\frac{dT}{dx}\bigg|_{r=1} = k\frac{dT}{dx}\bigg|_{r=2}$$

$$Q_{cv} + \cancel{\sum m_i E_i} = \cancel{W_{cv}} + \cancel{\sum m_e E_e} + \cancel{\frac{dE_{cv}}{dt}} - \dot{E}_g$$

$$Q_{cv} = -\dot{E}_g$$

$$Q_{cv} = 32\,000\ W/m^3 \times V$$ -3

$$\dot{q} = \frac{T_1 - T_0}{\frac{r_1}{k_{core} A}} = \frac{T_2 - T_1}{\frac{(r_2 - r_1)}{k_{wood} A}}$$

cylindrical resistances -4

$$32\,000 = \frac{T_2 - T_1}{\frac{(r_2 - r_1)}{k_{wood} A}}$$ ok

Solve for T_1?

Assumptions
1. ~~Steady~~ State
2. In r direction only

(b) HDE cylindrical

$$\frac{1}{r}\frac{\partial}{\partial r}\left[kr\frac{\partial T}{\partial r}\right]+\cancel{\frac{1}{r^2}\frac{\partial}{\partial \phi}\left[k\frac{\partial T}{\partial \phi}\right]}+\cancel{\frac{\partial}{\partial z}\left[k\frac{\partial T}{\partial z}\right]}+\dot{q}=\rho c_p\cancel{\frac{\partial T}{\partial t}}$$

2 2 1

$$\frac{1}{r}\frac{\partial}{\partial r}\left[kr\frac{\partial T}{\partial r}\right]=\dot{q}$$

$$\frac{d}{dr}\left[kr\frac{dT}{dr}\right]=\dot{q}r$$

X

-3

$$kr\frac{dT}{dr}=\dot{q}r+C_1$$

$$dT=\frac{\dot{q}}{k}+\frac{C_1}{r}$$

$$T(r)=\frac{\dot{q}r}{k}+\ln C_1+C_2$$ (general equation).

X

$$T_2=\frac{\dot{q}r_2}{k}\ln C_1+C_2$$

-10

B.C not valid in core

~~$@r=r_2 \quad T=T_2$~~

$@r=r_1 \quad T=T_1$ ✓

$$T_1=\frac{\dot{q}r_1}{k}\ln C_1+C_2$$

$$T_2-T_1=\frac{q}{k}(r_2-r_1)\ln C_1$$

$$C_1=e^{\left(\frac{T_2-T_1}{qk(r_2-r_1)}\right)} \qquad \therefore C_2=T_1-\frac{q}{k}\left[\frac{T_2-T_1}{qk(r_2-r_1)}\right]$$

$$T(r)=\frac{\dot{q}r}{k}+\ln\left[e^{\frac{T_2-T_1}{qk(r_2-r_1)}}\right]+T_1-\frac{q}{k}\left[\frac{T_2-T_1}{qk(r_2-r_1)}\right]$$

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54/100

VEUILLEZ COMPLÉTER LES DEUX SECTIONS - *PLEASE COMPLETE BOTH SECTIONS*

5192141 M663110

N° D'ÉTUDIANT/E - *STUDENT NO* CAHIER N° - *BOOKLET NO*

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NOM DU PROFESSEUR - *PROFESSOR'S NAME* COTE DU COURS - *COURSE CODE*

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Gabriel Mak

NOM DE L'ÉTUDIANT/E - *STUDENT'S NAME*

COTE DU COURS - *COURSE CODE*

Cahier d'examen

Université d'Ottawa

DIRECTIVES AU DOS DU CAHIER

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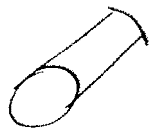
1.



$T_s = 27°C$

$T_\infty = 14°C$

$T_i = 38°C$

10/30

$$Bi = \frac{h(r/2)}{K} = \frac{18(0.7414)}{6.7}$$

$= 0.5$

cannot use LCM

$$\frac{\theta}{\theta_i} = e^{-\frac{hA_s t}{\rho V c}}$$

$$\frac{A}{V} = \frac{D\pi L}{\frac{D^2}{4}\pi L}$$

$$\ln\left(\frac{T - T_\infty}{T_i - T_\infty}\right) = -\frac{hAt}{\rho V c}$$

$$\ln\left(\frac{27-14}{38-14}\right) = -\frac{18 \quad 4 \quad t}{340 \quad 1200 \quad D}$$

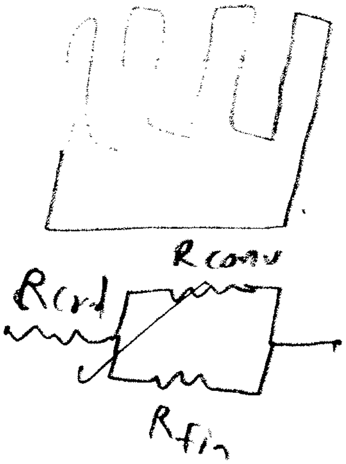
$t = 2571 \text{ s} = 43 \text{ minutes}$

-20

LCM not valid!

0.072
0.12 -

2 a)



$T_\infty = 20°C$

$T_s = 85°C$

$q \geq 3.0\,kW$

$\frac{29}{30}$

$R_{cond} = \frac{L}{KA} = \frac{0.008}{238(0.2 \times 0.6)} = 2.8 \times 10^{-4}$

$R_{no\,fin} = \frac{1}{hA} = \frac{1}{100(\cancel{(0.6 \times 0.2) - (0.001 \times 80 \times 0.2)}}$

$((0.6 \times 0.2) - 0.001 \times 80 \times 0.2)$

$\frac{1}{100\;0.104} = \cancel{0.130}\;0.096$

$R_{fin} = \frac{T_b - T_\infty}{q_{max}} = \frac{\cancel{T_b - T_\infty}}{\eta\, h A_{fin} \cancel{T_b - T_\infty}}$

$L_c = L + t/2 = 0.015 + 0.0005$
$= 0.0155\,m$

$A_p = L_c t = 1.55 \times 10^{-5}\,m$

$L_c^{3/2} (h/KA_p)^{1/2} = 0.0155^{3/2} \left(\frac{100}{238(1.55 \times 10^{-5})}\right)^{1/2}$

$= 0.32$

$\eta = 0.95$ $A_{fin} = 0.2 \times 0.015 \times 80$

$= 0.48\;L_c$ -1

$$R_{fin} = \frac{1}{0.45\ 100\ 0.40}$$

$$= 0.022$$

$$\frac{1}{R_{eq}} = \frac{1}{0.022} + \frac{1}{\cancel{0.150}\ 0.096}$$

$$R_{eq} = 0.018$$

$$R_{total} = 0.018 + 2.0\times10^{-4} = 0.0183$$

$$q = \frac{T - T_\infty}{0.0183} = \frac{85-20}{0.0183}$$

$$= 3.6\,\text{KW}$$

radiator is good

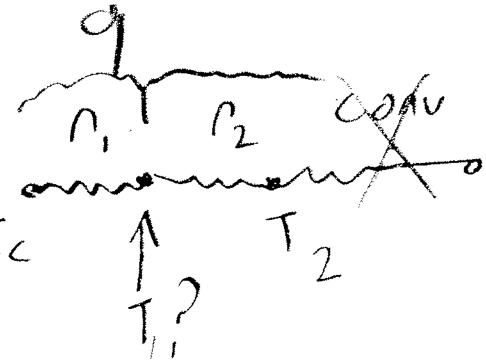
b) ~~No~~, with no radiator ~~Q w~~
~~is removed. Maximum is~~ 3.0KW

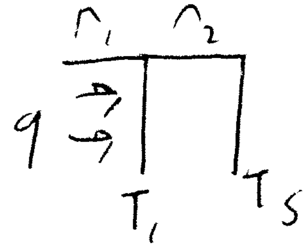
$$q = hA(T - T_\infty) = 100\ 0.2\times0.6(85-20)$$

$$= 0.780\,\text{KW} < 3.0\,\text{KW}$$

too low

3 a)





15/40

$$res_1 = \frac{r_1}{KA} = \frac{0.007}{0.038(2\pi \; /12)} = \frac{1}{0.038 \cdot 2\pi \; 0.3}$$

$= 14$

$$res\ 2 = \frac{\ln\left(\frac{r_2}{r_1}\right)}{2\pi LK} = \frac{\ln\left(\frac{0.01}{0.007}\right)}{2\pi \; 0.3 \; 0.012}$$

$= 15.8$

$q = 32000\ W/m^3$

volume $= 0.07^2 \times 2 \times \pi \times 0.3$

-2 $= 0.0188\ m^3$

$q = 32000 \times 0.0188 = 603\ W$

$$\frac{T_1 - 30}{15.8} = 603\ W$$

-1

$$\frac{T_1 - T_1}{R_1} = q$$

$T_1 = 9557.4\ C$

$T_1 = 15 \; 30 - q R_1 = \quad - 603(14)$

$= \quad C$

SS, no change in Z or ϕ

write in full, then simplify ... -2

b) $$\frac{1}{r}\frac{\partial}{\partial r}\left(kr\frac{\partial T}{\partial r}\right) = -\dot{q}\left(\cancel{-\frac{r^2}{x}\pi L}\right) \quad (q=32000)$$

$$\frac{\partial}{\partial r}\left(kr\frac{\partial T}{\partial r}\right) = -\dot{q}r\,(r^2\pi L)$$

$$\frac{kr\,\partial T}{\partial r} = -\dot{q}3r^2\pi l + c_1$$

$$\cancel{\frac{\partial T}{\partial r} = \frac{-\dot{q}+c_1}{kr}}$$

$$\cancel{T = \left(\frac{-\dot{q}+c_1}{k}\right)\ln r} + c_2$$

B.C.#1 @ $r = 0.007\,m$ $T = \cancel{1557}$ C ok

$-\dot{q}\,\Sigma\,603$

B.C.#2: $\frac{\partial T}{\partial r} \cancel{=} 603$ @ $r = 0.007$

-5 $$\frac{\partial T}{\partial r} = -\dot{q}3r\pi l + \frac{c_1}{r}$$

-5

$$T = -\dot{q}3\cancel{\pi l} + c_1\ln r + c_2$$

$$\frac{\partial T}{\partial r} = 60\cancel{3}$$

$$603 = -32000\,(0.007)\,2\,0.3 + \frac{C_1}{0.007}$$

$$C_1 = 5.7$$

$$T @ r = 0.007$$

$$9557 \cancel{At} = T = -32000(3)\,2(0.3) + 5.7 \ln 0.007 + C_2$$

$$C_2 = 106063$$

-10

$$T = -937 r^2 + 5.7 \ln r + 100063$$

It might make more sense to say the core generates a constant q though

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5210728

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$\frac{88}{100}$

Daniel Carmeles

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MCG 3110

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Problem 1

$@\ t_i = 0 \Rightarrow T_i$

$@\ t = t \Rightarrow T_0$

$T_0 = 27°C$

$k = 6.7\ W/mK$

$\rho = 340\ kg/m^3$

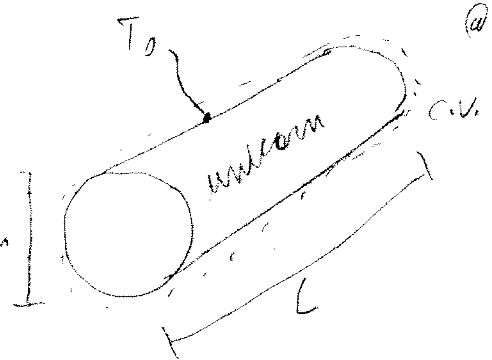
$d = 0.74m = 74cm$

$C_p = 1200\ J/kgK$

$T_\infty = 14°C$

$h = 18\ W/m^2K$

$T_i = 38°C$



20/30

Assumptions:
- Homogenous
- uniform temperature (unicorn) initially
- negligeable heat loss at ends
- no Work
- no E_g
- $\Delta E_k = \Delta E_p = 0$
- area of unicorn is surrounded by T_∞

$$Bi = \frac{hL_c}{k} = \frac{h V}{k A_s} = \frac{h}{k}\frac{\pi r^2 L}{2\pi r L} = \frac{hr}{k2} = \frac{hD}{k4} = \frac{(18)(0.74)}{6.7 \cdot 4}$$

$Bi = 0.497 > 0.1 \Rightarrow \therefore$ temperature of the unicorn cannot be assumed uniform at $t > 0$

$\therefore$ can't use LCM $\Rightarrow$ use Heisler Grober charts for cylinder

Chart 1

$$\alpha = \frac{k}{\rho C_p} = \frac{6.7}{340 \cdot 1200} = 0.000016422$$

$T_S \neq T_0$ -9

$$\frac{\theta_0}{\theta_i} = \frac{T_0 - T_\infty}{T_i - T_\infty} = \frac{27 - 14}{38 - 14} = \frac{13}{24} = 0.5416$$

$$Bi^{-1} = \frac{k}{h r_0} = \frac{6,7}{18 \cdot \left(\frac{d}{2}\right)} = \frac{6,7}{18 \left(\frac{0,74}{2}\right)} = 1,00\overline{6} \approx 1$$

from chart

$$Fo = \tau \approx 0,55 = \frac{\alpha t}{r_0^2} = \frac{(0,00016422)\, t}{(0,74/2)^2}$$

OK

$$0,55 = 0,000119956\, t$$

$$\boxed{\begin{aligned} t &= 4585,014505 \text{ sec} \\ &\approx 1,27 \text{ hours} \end{aligned}}$$

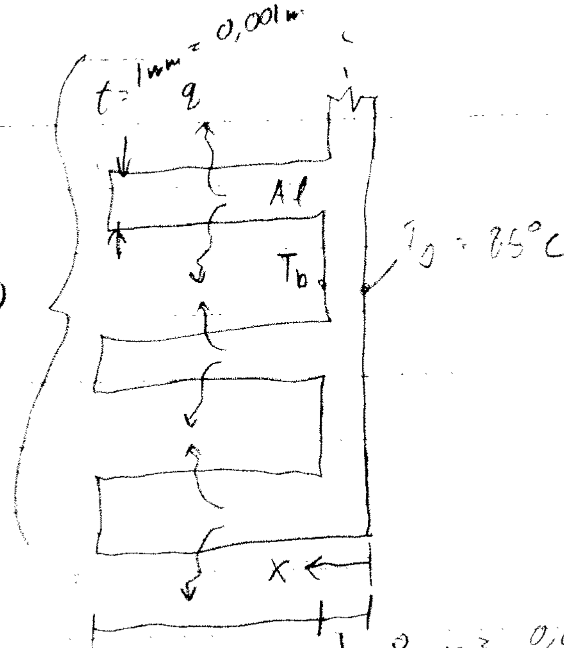
-1

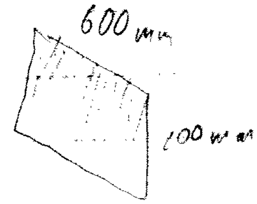
Problem 2

$q_{min} = 3{,}0 + W$

$k_{Al} = 238\ W/mK$

x 80 fins





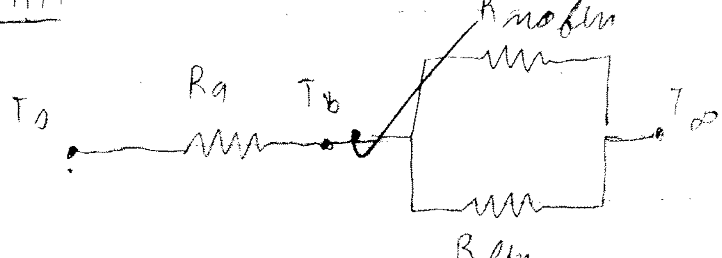
$T_\infty = 20°C$

$h_\infty = 100\ W/m^2K$

a) $q = ?$

Assumptions: ① 1-D along x
② $\dot{E}_g = 0$
③ $W = 0$
④ $\Delta E_k = \Delta E_p = 0$
⑤ Homogenous
⑥ SS
⑦ sides are perfectly insulated
⑧ no contact resistance
⑨ h constant everywhere on surface

TRM



$$R_a = \frac{l_a}{k_a A} = \frac{(0{,}008)}{(238)(0{,}6 \times 0{,}2)} = 0{,}000280112\ K/W$$

$$R_{nofin} = \frac{1}{h A_{nofin}} = \frac{1}{(100)(0{,}6 - \underbrace{80}_{\#fins} \times \underbrace{0{,}001}_{fin\ thickness})(0{,}2)} = \frac{1}{10{,}4} = 0{,}096154$$

nofin thickness

28/30

$$R_{fin} = \frac{T_b - T_\infty}{q_{fin}} = \frac{T_b - T_\infty}{\eta\, q_{fin\,max}} = \frac{T_b - T_\infty}{\eta\, h A_{fin} (T_b - T_\infty)} = \frac{1}{\eta\, h A_{fin}}$$

$$A_{fin} = (\underbrace{80}_{\#fins} \times \underbrace{L_c}_{fin\ length})\underbrace{2}_{\#faces/fin} \times \underbrace{0{,}2}_{fin\ width} = 32\, L_c$$

$\underline{\eta = ?}$

Fig 3.18

$$L_c = L + t/2 = 15mm + \frac{(t/2)}{2} = 15mm + \frac{1mm/2}{2} = 15{,}25mm$$

? -2

$$= 0{,}01525m$$

$$A_p = L_c t = (0{,}01525)(0{,}001) = 0{,}00001525\ m^2$$

$$L_c^{3/2}(h/kA_p)^{1/2} = (0{,}01525)^{3/2}\left(\frac{100}{238 \cdot 0{,}00001525}\right)^{1/2} = 0{,}312594524$$ OK

$\Rightarrow \eta \approx 95\%$ OK

$\therefore A_{fin} = 32 L_c = 32(0{,}01525m) = 0{,}488\ m^2$

$$R_{fin} = \frac{1}{\eta\, h A_{fin}} = \frac{1}{(0{,}95)(100)(0{,}488)} = 0{,}021570319\ K/W \quad // \frac{1}{46{,}36}\ K/W$$

$$R_{eq} = \left(\frac{1}{R_{nofin}} + \frac{1}{R_{fin}}\right)^{-1} = (10{,}4 + 46{,}36)^{-1} = 0{,}017618041\ K/W$$

$R_{tot} = R_a + R_{eq} = 0{,}00028\,0112 + 0{,}017618041 = 0{,}017898153\ K/W$

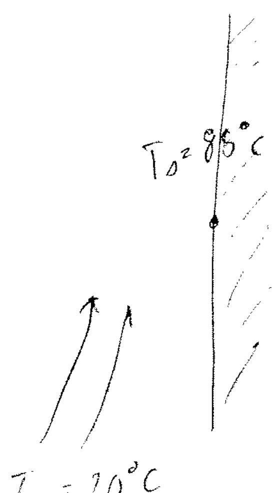
$q_{fin} = \dfrac{T_0 - T_\infty}{R_{tot}} = \dfrac{T_0 - T_\infty}{R_{tot}} = \dfrac{85 - 20}{0{,}017898} = 3631{,}659672\ W$

$\boxed{q_{fin} = 3{,}632\ kW}$

$\therefore\ q_{fin} > q_{min}$, So the failure is not due to over heating of the engine since the radiator is capable of extracting 3.632 kW of heat and the engine only needs to dissipate 3kW

$\underline{3{,}632\,kW > 3{,}0\,kW}$

b) $q_{without\ fin} = ?$



$R_{conv} = \dfrac{1}{hA} = \dfrac{1}{(100)(0{,}6 \times 0{,}2)} = \dfrac{1}{12}$

$= 0{,}083\ K/W$

$q_{without\ fin} = \dfrac{T_0 - T_\infty}{R_{conv}} = \dfrac{85 - 20}{(1/12)} = 780\ W$

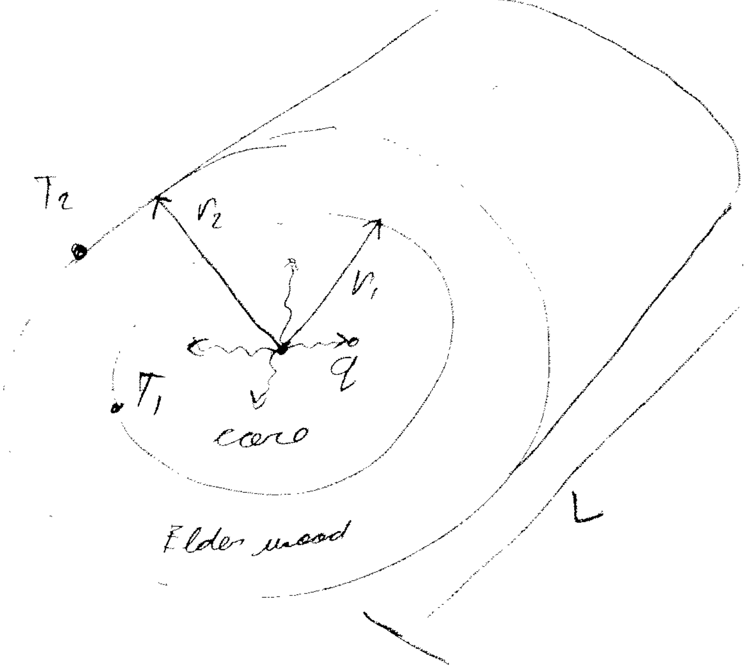
$q_{without\ fin} < q_{min}$

$780\,W < 3000\,W$

$\therefore$ No , it would overheat!!!
since the heat transfer do to convection is only 780 W and the engine needs to dissipate a minimum of 3000 W

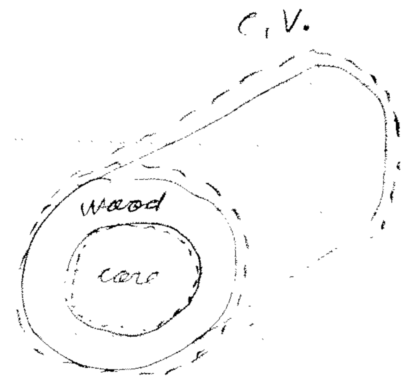
Problem 3

$k_{wood} = 0.012\ W/mK$
$k_{core} = 0.038\ W/mK$
$\dot{q} = 32\,000\ W/m^3$



$r_2 = 10mm = 0.010m$
$r_1 = 7mm = 0.007m$
$L = 300mm = 0.3m$
$T_2 = 30°C$

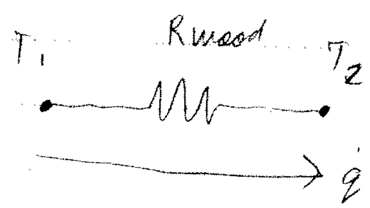
a)



Assumptions: (1) SS
(2) no Work
(3) $\dot{E}_g = 0$
(4) $\Delta E_k = \Delta E_p = 0$
(5) 1-D along r

40/40

$T_1 = ?$



$$q = \frac{T_1 - T_2}{R_{wood}} \Rightarrow T_1 = \cancel{q R_{wood} + T_2}$$

$$= \dot{q} \forall R_{wood} + T_2$$

$$= \dot{q} \left(\pi r_1^2 L \right) \left(\frac{\ln(r_2/r_1)}{2\pi L k_{wood}} \right) + T_2$$

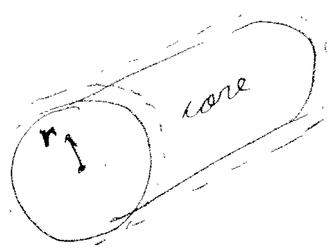
$$= \dot{q} \left(\pi r_1^2 L \right) \left(\frac{\ln(r_2/r_1)}{2\pi L k_{wood}} \right) + T_2$$

$$T_1 = \left(32\,000 \frac{W}{m^3}\right)\left[\pi (0{,}007m)^2 (0{,}3m)\right]\left(\frac{\ln\left({}^{0{,}01}/_{0{,}007}\right)}{2\pi\,(0{,}3m)\,(0{,}012\ {}^{W}/_{mK})}\right) + 30°C$$

$$= 23{,}302763 + 30°C$$

$$\boxed{T_1 = 53{,}302763°C}$$

b)



assumptions:
1. SS
2. no Work
3. 1-D along r
4. k constant
5. ρ constant

HDE

$$\frac{1}{r}\frac{\partial}{\partial r}\left(k r \frac{\partial T}{\partial r}\right) + \cancel{\frac{1}{r^2}\frac{\partial}{\partial \phi}\left(k\frac{\partial T}{\partial \phi}\right)} + \cancel{\frac{\partial}{\partial z}\left(k\frac{\partial T}{\partial z}\right)} + \dot{q} = \cancel{\rho c_p \frac{\partial T}{\partial t}}$$

$$\frac{1}{r}\frac{d}{dr}\left(k r \frac{dT}{dr}\right) + \dot{q} = 0$$

$$\frac{d}{dr}\left(k r \frac{dT}{dr}\right) = -\dot{q} r$$

$$k r \frac{dT}{dr} = -\frac{\dot{q} r^2}{2} + C_0$$

new constant: C_1

$$\frac{dT}{dr} = -\dot{q}\frac{r^{\cancel{2}}}{2}\frac{1}{k\cancel{r}} + \frac{C_0}{kr}$$

$$\frac{dT}{dr} = -\frac{1}{2k}\dot{q}\, r + \frac{C_1}{r}$$

$$T = -\frac{1}{4k}\dot{q}\, r^2 + C_1 \ln r + C_2$$

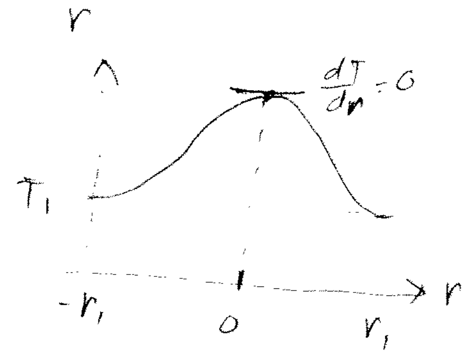
general equation

B.C.

@ $r = r_1 \Rightarrow T = T_1$

@ $r = 0 \Rightarrow \frac{dT}{dr} = 0$

axisymmetric



$$\left.\frac{dT}{dr}\right|_{r=0} = 0 = \frac{-1}{2k}\dot{q}\,r + \frac{C_1}{r}$$

$$0 = \frac{-1}{2k}\dot{q}\,r^2 + C_1$$

$$\boxed{0 = C_1}$$

$$T_1 = \frac{-1}{4k}\dot{q}(r_1)^2 + C_1 \ln(r_1) + C_2$$

$$T_1 = \frac{-1}{4k}\dot{q}\,r_1^2 + C_2$$

$$\boxed{C_2 = T_1 + \frac{1}{4k}\dot{q}\,r_1^2}$$

$$T = \frac{-1}{4k}\dot{q}\,r^2 + C_2$$

$$= \frac{-1}{4k}\dot{q}\,r^2 + \left(T_1 + \frac{1}{4k}\dot{q}\,r_1^2\right)$$

$$\boxed{T = \frac{1}{4k}\dot{q}\left(r_1^2 - r^2\right) + T_1}$$

$$T = \frac{1}{4(0{,}038)} \, 32\,000 \left(0{,}007^2_m - r^2\right) + 53{,}3\,^\circ C$$

$$= 210526{,}3158\,(0{,}007 - r) + 53{,}3\,^\circ C$$

$$= -210526{,}3158r + 1473{,}68211 + 53{,}3$$

$$= -20526{,}3158r + 1526{,}986971$$

$$\boxed{T \approx -20526{,}3\,r + \cancel{1527}}$$ OK

In celsius

In metres

$+273{,}15$

$$\boxed{T \approx -20526{,}3r + 1800}$$

In metres

In kelvin

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93/100

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N° D'ÉTUDIANT/E - *STUDENT NO.*

CAHIER N° - *BOOKLET NO.*

FACULTÉ, ÉCOLE, COLLÈGE - *FACULTY, SCHOOL, COLLEGE*

NOM DU PROFESSEUR - *PROFESSOR'S NAME*

COTE DU COURS - *COURSE CODE*

DATE

HEURE - *TIME*

N° RANGÉE / SIÈGE - *ROW / SEAT NO.*

NOM DE L'ÉTUDIANT/E - *STUDENT'S NAME*

COTE DU COURS - *COURSE CODE*

Guillaume Archambault

5197529

Heat - Transfer

Mid Term

Cahier d'examen

Université d'Ottawa

DIRECTIVES AU DOS DU CAHIER

Examination Booklet

University of Ottawa

FOR INSTRUCTIONS, SEE BACK COVER

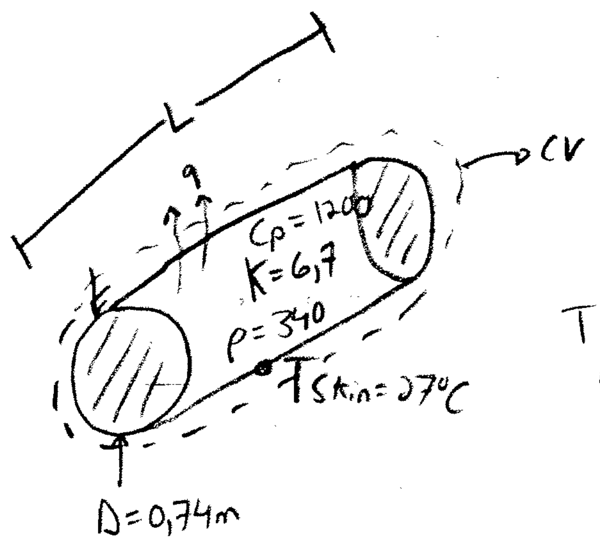
uOttawa

L'Université canadienne

Canada's university

#1

DCL:



$T_\infty = 14°C$
$h = 18$

23/30

$T_i = 38°C$ Find $t = ?$

Assumptions

① Closed system ② $\Delta W = \Delta E_K = \Delta E_p = 0$ ③ $\dot{E}_g = 0$
④ Homogenous ⑤ $K = cst$

① Biot #

$$Bi = \frac{h}{K} L_c = \frac{h}{K} \cdot \frac{V}{A} = \frac{h}{K} \cdot \frac{\frac{\pi}{4}(D^2) L}{\pi D \cdot L}$$

$$= \frac{h}{K} \frac{D}{4} = \frac{18}{6{,}7} \cdot \frac{0{,}74}{4}$$

$Bi = 0{,}49 \Rightarrow$ Cannot use LCM since $Bi > 0{,}1$

② graphs

$$\alpha = \frac{K}{\rho C_p} = \frac{6{,}4}{340 \cdot 1200} = 1{,}5686 \times 10^{-5}$$

-1

$$Bi^{-1} = \frac{K}{h r_0} = \frac{6{,}7}{18} \cdot \frac{1}{0{,}74/2} = 1{,}006 \approx 1$$

$\frac{r}{r_0} = 1 \Rightarrow$ check at the skin $T = 27°C$

From Figure 55,5 w/ $Bi^{-1} = 1$ $r/r_0 = 1$ w/ $T_0 = 27$

this is T_s $\frac{T - T_\infty}{T_0 - T_\infty} = 0,6$

this is middle temp...

-3

$$\frac{T-14}{27-14} = 0,6 \Rightarrow T = \cancel{21,8} \Rightarrow \text{center line } T^0$$

From Fig 55,4 $\Rightarrow$ $\frac{T - T_\infty}{T_i - T_\infty} = \frac{21,8 - 14}{38 - 14} = \cancel{0,325}$ ok

y axis $\rightarrow$ 0,325 $Bi^{-1} = 1$

x $\rightarrow$ $\cancel{1}$ ok

$$\therefore \frac{\alpha t}{r_0^2} = 1$$

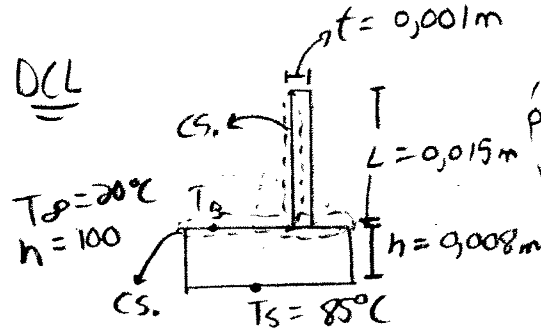
$$t = \frac{r_0^2}{\alpha} = \frac{\left(\frac{0,74}{2}\right)^2}{1,5686 \times 10^{-5}} = 8336,597 \text{ sec}$$

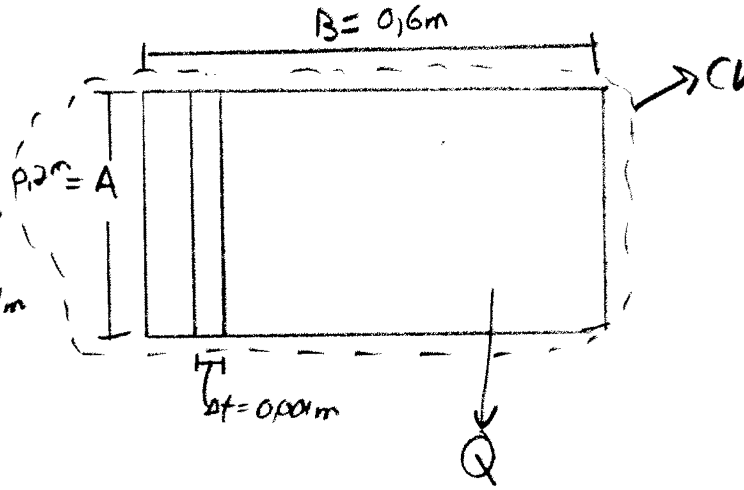
$$\boxed{t = 138,94 \text{ min}}$$

-1

#2

DCL





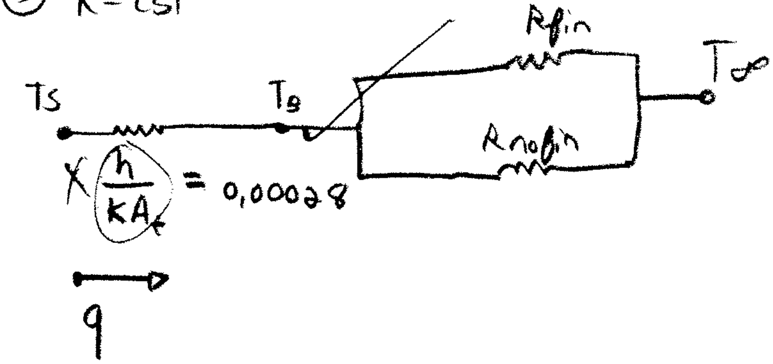
30/30

$Q_{MAX} = 3000\ W$ 80 fins $k_{fin} = 238$ Find $q = ?$

Assumptions

① S.S ② $\Delta W = \Delta E_K = \Delta E_p = 0$ ③ $\dot{E}_g = 0$ ④ Homogeneous
⑤ $k = cst$

a) ①



i) $R_{nofin} = \frac{1}{hA_{nofin}} = \frac{1}{h\cdot(0{,}6\cdot 0{,}2 - 80\cdot 0{,}001\cdot 0{,}2)} = 0{,}09615$

$h \to 100$

ii) $R_{fin} = \frac{T_B - T_\infty}{q_{fin}} = \frac{T_B - T_\infty}{\eta\, q_{fin\,MAX}} = \frac{T_B - T_\infty}{\eta A_{fin}\cdot h(T_B - T_\infty)} = \frac{1}{\eta h A_{fin}}$

$\rightarrow \frac{1}{\eta h\cdot(2\cdot 80\cdot L_c\cdot 0{,}2)}$ ↘ for L_c & η.

Fig 3,18 i) $L_c = L + t/2 = 0{,}015 + \frac{0{,}001}{2} = 0{,}0155$

$A_p = L_c t = 1{,}55\times10^{-5}$

$x : L_c^{3/2}(h/kA_p)^{1/2} = 0{,}0155^{3/2}\left(\frac{100}{238\cdot 1{,}55\times10^{-5}}\right)^{1/2} = 0{,}3177$

from graph $x : 0{,}3177$ $\eta \doteq 0{,}925$

Back to $R_{fin} \Rightarrow R_{fin} = \frac{1}{\eta h(2\cdot 80 L_c\cdot 0{,}2)} = \frac{1}{0{,}925\cdot 100(2\cdot 80\cdot 0{,}0155\cdot 0{,}2)}$

$R_{fin} = 0{,}021796$

$R_{eq} = (R_{fin}^{-1} + R_{nofin}^{-1})^{-1} + \frac{r}{hA}$ ok

$\therefore$

$R_{eq} = \left(\underbrace{0{,}021796^{-1} + 0{,}09615^{-1}}_{0{,}017768}\right)^{-1} + \frac{0{,}008}{238\cdot(0{,}6\cdot 0{,}2)} \to 2{,}80\times10^{-}$

$R_{eq} = 0{,}018048$

$q = \frac{\Delta T}{R_{eq}} = \frac{T_s - T_\infty}{R_{eq}} = \frac{85-20}{0{,}018048} \doteq \boxed{3601{,}48\ W}$ $> 3000\ W$

~~Always~~ not break because of overheat!
it evacuates more than 3000 W

b) if no fins no base $\Rightarrow$ $q = hA(T_s - T_\infty)$ (works)

$q = 100\cdot 0{,}2\cdot 0{,}6\cdot(85-20)$

$\boxed{q = 780\ W}$ $< 3000\ W$

It would break since it evacuates $< 3000\ W$

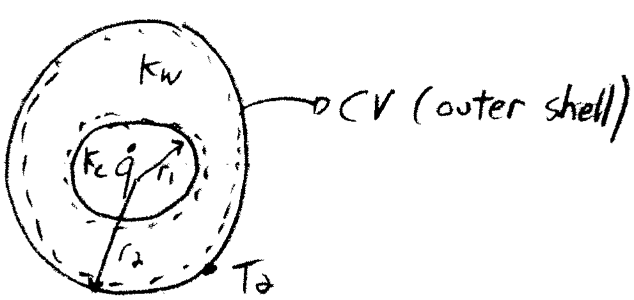
#3. Data: $K_w = 0{,}012$

$K_{core} = 0{,}038$

$\dot{q} = 32\,000 \ W/m^3$

$r_1 = 0{,}007m \quad r_2 = 0{,}01m \qquad T_a = 30\,°C$

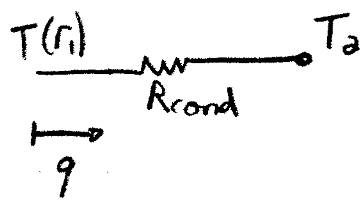
DCL



Assumptions

① S.S ② No $\dot{E}_{gen}$ by wood ③ $\Delta W = \Delta E_K = \Delta E_P = 0$ ④ Homogenous. ⑤ Along one direction (radial) ⑥ $K = cst$

)①



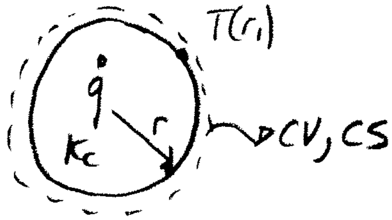
$$R_{cond} = \frac{\ln r_2/r_1}{2\pi L K} = \frac{\ln\left(\frac{0{,}01}{0{,}007}\right)}{2\pi \underbrace{K_w}_{0{,}012} \cdot L} = \frac{4{,}7305}{L}$$

② $\dot{q}\overset{\text{inner shell}}{\forall} = q = \dot{q} \cdot \pi r_1^2 \cdot L = 32000 \cdot \pi \cdot 0{,}007^2 \cdot L = 4{,}926L$

③ $q = \frac{\Delta T}{R} \Rightarrow 4{,}926\cancel{L} = \frac{T(r_1) - T_a}{\frac{4{,}7305}{\cancel{L}}}$

$$T(r_1) = 4{,}926 \cdot 4{,}7305 + \overset{30°C}{T_a}$$

$$\boxed{T(r_1) = 53{,}3°C}$$

b) 

$\frac{40}{40}$

Assumptions

① 1D (along r) ② $\Delta W = \Delta E_k = \Delta E_p = 0$ ③ Homogenous ④ $k = cst$
⑤ S.S

① Cyl HDE

$$\frac{1}{r}\frac{d}{dr}\left(kr\frac{dT}{dr}\right) + \cancel{\frac{1}{r^2}\frac{d}{d\phi}\left(k\frac{\partial T}{\partial \phi}\right)}_{①} + \cancel{\frac{\partial}{\partial z}\left(k\frac{\partial T}{\partial z}\right)}_{①} + \dot{q} = \cancel{\rho c_p \frac{\partial T}{\partial t}}_{⑤}$$

$$\frac{1}{r}\frac{d}{dr}\left(kr\frac{dT}{dr}\right) = -\dot{q}$$

$$\int d\,kr\frac{dT}{dr} = \int -\dot{q}\,r\,dr$$

$$kr\frac{dT}{dr} = \frac{-\dot{q}r^2}{2} + C_1$$

$$\frac{dT}{dr} = \frac{-\dot{q}r}{2k} + \frac{C_2}{r}$$

general sol $\rightarrow$ $$T(r) = \frac{-\dot{q}r^2}{4k} + C_2 \ln r + C_3$$

B.C @ $r = r_1$ $T = T(r_1) = 53,3°C$

@ $r = r_1$ $\left.\frac{dT}{dr}\right|_{r_1} = \frac{-q}{k_c A}$ from $q = -kA\frac{dT}{dr}$

$\Downarrow$

$$q = -k_c A \frac{\partial T}{\partial r}\Big|_{r_1} \rightsquigarrow \dot{q} \cdot V = \dot{q} \cdot 2\pi r_1 \cdot L$$

$$\frac{dT}{dr}\Big|_{r_1} = \frac{-4{,}926L}{k_c \cdot 2\pi r_1 L} = \frac{-4{,}926}{\underset{0{,}038}{k_c}\, 2\pi \underset{0{,}007}{r_1}} = -2947{,}358$$

from BC2 $\longrightarrow$ $$\frac{dT}{dr} = \frac{-\dot{q} r}{2k_c} + \frac{C_2}{r} \Big|_{r=r_1}$$

same or very similar $\Rightarrow$ neglect

$$-2947{,}358 = -\frac{32000 \cdot 0{,}007}{2 \cdot 0{,}038} + \frac{C_2}{0{,}007}$$

$$0 = 0 + \frac{C_2}{0{,}007} \Rightarrow \boxed{C_2 = 0}$$

from $$T(r) = \frac{-\dot{q} r^2}{4k_c} + C_3$$

BC I $$T_{r_1} = \frac{-\dot{q} r_1^2}{4k_c} + C_3 \qquad C_3 = T_{r_1} + \frac{\dot{q} r_1^2}{4k_c}$$

$$\boxed{\therefore\ T(r) = \frac{-\dot{q} r^2}{4k_c} + T_{r_1} + \frac{\dot{q} r_1^2}{4k_c}}$$

$$T(r) = -\frac{32000 \cdot r^2}{4 \cdot 0{,}038} + 53{,}3 + \frac{32000 \cdot 0{,}007^2}{4 \cdot 0{,}038}$$

$$\boxed{T(r) = -210526\, r^2 + 63{,}616}$$

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4576408

N° D'ÉTUDIANT/E - *STUDENT NO.*

CAHIER N° - *BOOKLET NO.*

FACULTÉ, ÉCOLE, COLLÈGE - *FACULTY, SCHOOL, COLLEGE*

MCG 3110

NOM DU PROFESSEUR - *PROFESSOR'S NAME*

COTE DU COURS - *COURSE CODE*

29/06/11

DATE

HEURE - *TIME*

N° RANGÉE / SIÈGE - *ROW / SEAT NO.*

81/100

Parthipan Nadarajah

NOM DE L'ÉTUDIANT/E - *STUDENT'S NAME*

COTE DU COURS - *COURSE CODE*

Cahier d'examen

Université d'Ottawa

DIRECTIVES AU DOS DU CAHIER

Examination Booklet

University of Ottawa

FOR INSTRUCTIONS, SEE BACK COVER

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Canada's university

(1) $T_{skin} = 27°C$ $T_\infty = 14°C$ $h = 18 \frac{W}{m^2 K}$

$r = 0.37m$

$d = 74cm$

$K = 6.7 \frac{W}{mK}$

$\rho = 340 \frac{Kg}{m^3}$ $C_p = 1200 \frac{J}{Kg K}$

$\frac{25}{30}$

$T_i = 38°C$

$Bi = \frac{hL}{K}$ $L = \frac{V}{A} = \frac{\pi r^2 L}{2\pi r L} = \frac{r}{2} = \frac{0.37}{2} = 0.185$

$= \frac{18 \cdot 0.185}{6.7} = 0.49 > 0.1$ can't use L.C.

from 55.5

$\frac{r}{r_0} = 1$, $\frac{\theta}{\theta_0} = 0.8$, $Bi = 2.04$

$\frac{\theta}{\theta_0} = \frac{T_s - T_\infty}{T_0 - T_\infty}$

X Need to recheck Bi.... (-3)

$T_0 = \frac{(27-14)}{0.8} + 14$ (-1)

$T_0 = 24.4$ X ok

$\frac{\theta_0}{\theta_i} = \frac{T_0 - T_\infty}{T_i - T_\infty} = \frac{24.4 - 14}{38 - 14} = 0.43$ ok

from figure 55.4 $F_0 = 1.1$ ok

$\alpha = \frac{K}{\rho C_p} = \frac{6.7}{340 \times 1200} = 1.64$

$\frac{\alpha t}{r_0^2} = F_0$

$t = \frac{F_0 r_0^2}{\alpha} = \frac{1.1 \times 0.37^2}{1.64} = 0.092$ sec $\times 60$

$=$ 5.51 mins X (-1)

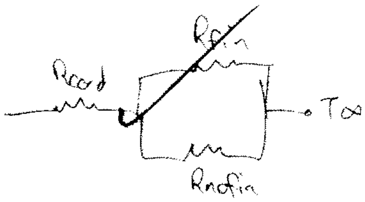
(2) $q = 3.0\,kW$ $T_\infty = 20°C$

$K_{Al} = 238\ W/mK$ $h_\infty = 100\ W/m^2K$

$T_s = 85°C$

$A_{rad} = 0.2 \times 0.6 = 0.12\,m^2$

20/30



$$R_{cond} = \frac{L}{KA} = \frac{0.008}{238 \times 0.12} \quad 2.8 \times 10^{-4}$$

$$R_{nofin} = \frac{1}{hA} = \frac{1}{100 \times 1.5 \times 10^{-3}} = 6.67$$

OK

A_{nofin} $\frac{0.2}{80}$ $2.5 \times 10^{-3} \times 0.6 = 1.5 \times$

-2

minus fin thickness.

$$R_{fin} = \frac{\cancel{T_b - T_\infty}}{\eta_{fin} h A \cancel{(T_b - T_\infty)}} \quad \frac{1}{\eta_{fin} h A}$$

$$L_c = L + t/2 = 0.015 + \frac{0.001}{2} = 0.0155$$

$$A_p = L_c t = 0.0155 \times 0.001 = 1.55 \times 10^{-05}$$

$$L_c^{3/2}\left(\frac{h}{K A_p}\right)^{1/2} = (0.0155)^{3/2}\left(\frac{100}{238 \times 1.55 \times 10^{-5}}\right)^{1/2} = 0.3177$$

from figure 3.18 $\eta_f = 90\%$

$$R_{fin} = \frac{1}{90 \times 100 \times 0.06} = 1.85 \times 10^{-3}$$

-2 $A_{fin} = 0.001 \times 0.6 = 0.06$

$$R_{Tot} = R_{cond} + \left(\frac{1}{R_{fin}} + \frac{1}{R_{nofin}}\right)^{-1} = 2.8 \times 10^{-4} + \left(\frac{1}{6.67} + \frac{1}{1.85 \times 10^{-3}}\right) = 2.13 \times 10^{-3}$$

OK

$$q = \frac{T_s - T_\infty}{R_{Tot}} = \frac{85 - 20}{2.13 \times 10^{-3}} = 30\,497\ W = 30.5\ kW$$

-1

it was not due to overheating as the radiator fin array take more heat than the minimum engine operation

R_{conv} R_{rad}

T_s — T_∞

b)

$q = \varepsilon \sigma h (T_i^4 - T_\infty^4)$

?

-5

$\dot{q} = \frac{T - T_\infty}{R_\infty}$

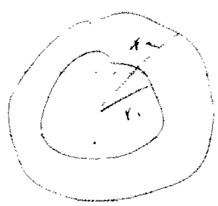
$\sigma = 5.67 \times 10^{-8}$

- Assume car operate normally 20-40%

$\varepsilon = 0.3$

- T_i is very high in the engine

③



$k_{wood} = 0.0012$ $r_2 = 10$ mm $L = 300$ mm

$k_{core} = 0.038$ $r_1 = 7$ mm $T_2 = 30°C$

$\dot{q} = 32\,000$ W/m³

36/40

a)

$R_{con} = \frac{\ln(r_2/r_1)}{2\pi L k}$

$q = \dot{q}A$
$= 32000 \times \pi r^2 L$
$= 32000 \times \pi (0.007)^2 \cdot 0.3) = 1.48$ W

$$q = \frac{T_{si} - T_2}{\frac{\ln(r_2/r_1)}{2\pi L k}} = 1.48\left(\frac{\ln\left(\frac{0.01}{0.007}\right)}{2\pi \times 0.3 \times 0.038}\right) + 30$$

$T_{si} = 37.37°C$ X −2

b) Assume
① steady state
② closed system
③ along r and 1-D

$$\frac{1}{r}\frac{\partial}{\partial r}\left(kr\frac{\partial T}{\partial r}\right) + \frac{1}{r^2}\frac{\partial}{\partial \phi}\left(k\frac{\partial T}{\partial \phi}\right) + \frac{\partial}{\partial z}\left(k\frac{\partial T}{\partial z}\right) + \dot{q} = \cancel{\rho c_p \frac{\partial T}{\partial t}}$$

$$\frac{1}{r}\frac{\partial}{\partial r}\left(kr\frac{\partial T}{\partial r}\right) = -\dot{q}$$

$$\int d\left(kr\frac{\partial T}{\partial r}\right) = \int -\dot{q}r\,dr$$

$$kr\frac{dT}{dr} = -\dot{q}\frac{r^2}{2} + c_1$$

$$\frac{dT}{dr} = -\frac{\dot{q}r}{2k} + \frac{c_1}{kr}$$ k = constant

$$\int dT = dr\int -\frac{\dot{q}r}{2k} + \frac{c_1}{kr}$$

$$T(r) = -\frac{\dot{q}r^2}{4k} + c_1\ln r + c_2$$

BC ① $r = r_1$ $T = T_{s1} = 37.37$
② $r = 0$ $\frac{dT}{dr}$ → $c_1 = 0$

① $37.37 = -\frac{1.48(0.007)^2}{4(0.0038)} + c_2$

$c_2 = 37.374$ ok

$\therefore T(r) = \ldots\ldots$ −2

DIRECTIVES

1. Le silence est de rigueur dans la salle d'examen.
2. Le surveillant ou la surveillante se réserve le droit de vérifier les cartes d'identité universitaire.
3. Il est interdit de quitter la salle d'examen avant qu'une heure ne se soit écoulée.
4. Il est interdit de se présenter à la salle d'examen ou d'en sortir en possession d'un cahier d'examen.
5. Écrire lisiblement.
6. L'ordre des réponses est facultatif, mais en tête de chaque réponse doit figurer le numéro (chiffre et lettre) correspondant à la question.
7. À moins d'indication contraire donnée par le surveillant ou la surveillante, les réponses doivent être écrites sur les deux côtés des pages lignées.
8. À moins d'indication contraire, il faut inclure le détail des opérations aussi bien que les réponses.
9. On numérotera chaque cahier d'examen. Si l'on utilise plus d'un cahier, on insérera le cahier n° 1 sous la page couverture du cahier n° 2, le cahier n° 2 sous la page couverture du cahier n° 3 et ainsi de suite.
10. À moins d'indication contraire, il est interdit de se servir de livres, de notes, de tables de mathématiques, de dictionnaires ou de tout autre aide-mémoire.
11. Les étudiants et étudiantes ne doivent pas avoir en leur possession les objets suivants: appareil photo, appareil radio (radio avec écouteurs), magnétophone, téléavertisseur, montre-calculatrice, téléphone cellulaire, ni tout autre dispositif de communication qui n'a pas été autorisé au préalable.

    Il revient à l'étudiant ou l'étudiante de vérifier quel genre de calculatrice est autorisé pour chaque test ou examen.

    Quiconque contrevient au présent règlement est jugé avoir commis une fraude scolaire.

CONSERVATION DES CAHIERS D'EXAMEN

1. Les étudiants et étudiantes ont le droit de voir, sur demande, après notation, leurs propres cahiers d'examen et leurs travaux écrits.
2. L'Université se réserve le droit de détruire les cahiers d'examen et les autres travaux écrits six mois après la communication de la note à l'étudiant ou l'étudiante.

INSTRUCTIONS

1. *Silence is compulsory in the examination room.*
2. *Students must produce their student identity card on request.*
3. *Students may not leave until one hour after the examination has begun.*
4. *Students may not take any examination booklet into or away from the examination room.*
5. *Write legibly.*
6. *Questions may be answered in any order, but each answer must be preceded by the appropriate question number, including both figure and letter where applicable.*
7. *Unless otherwise indicated, answers must be written on both sides of the ruled pages*
8. *Unless otherwise indicated, the detailed operations and the final answers must be shown in the examination booklet.*
9. *Each examination booklet must be numbered. Booklet 1 is inserted inside the cover page of booklet 2, booklet 2 inside the cover page of booklet 3, and so on.*
10. *Unless otherwise specified in the examination questionnaire, the use of books, notes, mathematical tables, dictionaries or other study aids is forbidden.*
11. *Students must not have in their possession: cameras, radios (radios with head sets), tape recorders, pagers, calculator watch, cellular phones or any other communication device which has not been previously authorized.*

    It is the responsibility of the student to find out what type of calculators are allowed for each examination or test.

    Any student who contravenes this regulation will be deemed to have committed academic fraud

RETENTION OF EXAMINATION BOOKLETS

1. *All students have the right to see their examination booklets and written work after they have been marked.*
2. *The University reserves the right to destroy examination booklet and other written work six months after the grade has been communicated to the student.*