MCG 3110 - HEAT TRANSFER

Quiz #1 - Review of Thermodynamics
Tuesday, January 25, 2011

Part 1 - Short questions (35 marks)

1. Write the mass conservation equation and explain the meaning of every term. (5 marks)

2. Write the full energy conservation equation and explain the meaning of every term. (10 marks)

3. Explain the difference between Steady-State, Steady Flow and Uniform State, Uniform Flow. (5 marks)

4. Explain the difference between latent and sensible energy. (5 marks)

5. What is metabolism and why is it important for a thermal engineer? (5 marks)

6. Draw a P-T diagram and a T-v diagram and identify the phases, the triple point and the critical point (5 marks)

Part 2 - Problem (65marks)

a) You are probably familiar with the Iced Cappucino slush beverage from Tim Hortons, which is a very popular and refreshing treat during the summer. The slush is made by mixing crushed ice, water and a syrup called "base" that gives it the sweet taste, as well as preventing the ice from forming... a big ice cube!

A 500 ml glass of Iced Cappuccino slush contains approximately 80% in volume of ice and 20% in volume of water (neglect the sugar content). How much energy has to be transferred to the slush in order for it to reach a temperature of 5°C? Use the methodology presented in class and identify all your assumptions. (45marks)

You can use Siebel's formula:

$Cp_{fresh} = 3.35\ a + 0.84$ [kJ/kg °C]
$Cp_{frozen} = 1.26\ a + 0.84$ [kJ/kg °C]
$\Delta h_{latent} = 334\ a$ [kJ/kg]

Liquid water specific volume: 0.001 m^3/kg
Solid water specific volume: 0.0010908 m^3/kg

b) How long would it take to bring the initial mixture to 5°C, using a microwave oven that has an output power of 1500 Watts? (10 marks)

c) A slush beverage such as the Iced Cappuccino is a great drink from a thermal point of view because it has the ability to remain cold for a long time. Explain, from a thermodynamic perspective, why this is true. (10marks)

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SOLUTION - QUIZ 1 - MAY 14th 2008

PART 1:

1)

$$\underbrace{\frac{dm_{cv}}{dt}}_{\text{change of mass in CV in time}} = \underbrace{\sum \dot{m}_i}_{\text{mass flow rate in}} - \underbrace{\sum \dot{m}_e}_{\text{mass flow rate out}}$$

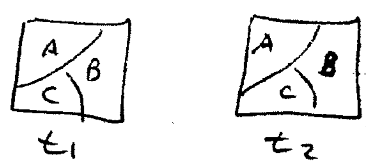
(-5) for every mistake

2)

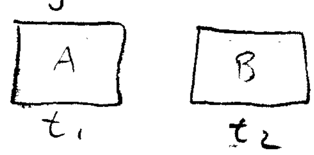
$$\underbrace{\dot{Q}_{cv}}_{\text{Heat transfer}} + \underbrace{\sum \dot{m}_i \left(h_i + \frac{V_i^2}{2} + g z_i\right)}_{\text{energy flow in}} = \underbrace{\dot{W}_{cv}}_{\text{work}} + \underbrace{\sum \dot{m}_e \left(h_e + \frac{V_e^2}{2} + g z_e\right)}_{\text{energy flow out}} + \underbrace{\left[\frac{m_2\left(u_2 + \frac{V_2^2}{2} + g z_2\right) - m_1\left(u_1 + \frac{V_1^2}{2} + g z_1\right)}{\Delta t}\right]}_{\text{change of energy in CV in time}} - \underbrace{\dot{E}_g}_{\text{energy generated}}$$

(-5) for every mistake

3) SSSF → no change in time



USUF → uniform at a given time, but changes in time



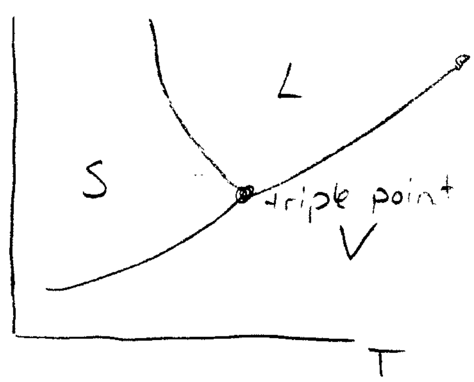
(-3) for every mistake

4) Latent energy variation: energy change associated to phase change (no change in temperature)
Sensible energy variation: energy change associated to change of temperature (no phase change)

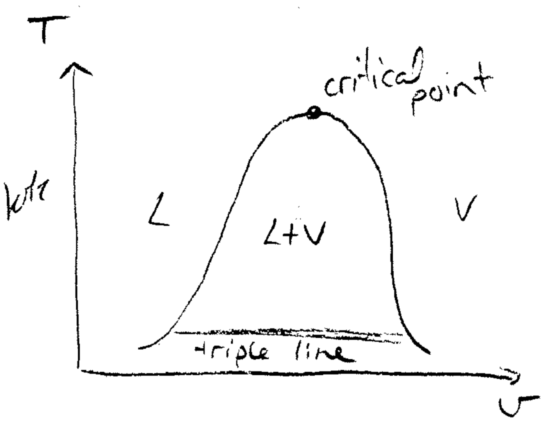
(-3) for every mistake

5) Metabolism is the result of cells acting as small power plants and generating heat as a result of the reaction of nutrients (carbohydrates, fat, proteins) and oxygen (breathing).

Metabolism is important for thermal engineers because it is an important source of heat gain in buildings. ⟹ needs to be considered.

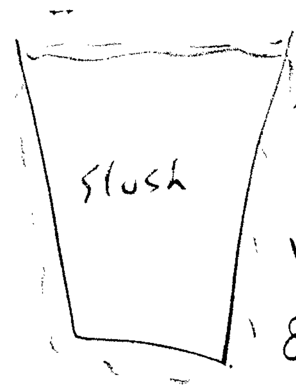
6) 

-3 persisted



QUIZ 1

a)



$V = 500\,mL$

80% ice, 20% water } vol %

$T_1 = 0°C$

Assumptions:
① Closed system
② $\Delta e_p = \Delta e_k = 0$
③ $\dot{W} = 0$
④ $\dot{E}_T = 0$
⑤ Mix water & ice is at 0°C

5

Cons. Mass: $\frac{dm_{cv}}{dt} = \cancel{\sum \dot{m}_i} - \cancel{\sum \dot{m}_e} \Rightarrow m$: constant 5

1st Law:

$$Q_{cv} + \sum m_i \left(h_i + \cancel{\frac{V_i^2}{2}} + \cancel{g z_i}\right) = \cancel{W_{cv}} + \cancel{\sum m_e \left(h_e + \frac{V_e^2}{2} + g z_e\right)} + \left[m_2\left(u_2 + \cancel{\frac{V_2^2}{2}} + \cancel{g z_2}\right) - m_1\left(u_1 + \frac{V_1^2}{2} + g z_1\right)\right] - \cancel{\dot{E}_T}$$

$$Q = m(u_2 - u_1) = m\,c_p(T_2 - T_1)$$ 5

$$m_{ice} = \frac{V_i}{v_i} = \frac{0.8 \cdot 0.0005}{0.0010908} = 0.3667\ kg$$

$$m_{wat} = \frac{V_w}{v_w} = \frac{0.2 \cdot 0.0005}{0.001} = 0.1\ kg$$

a = water content
a = 1 ①

$c_{p\,fresh} = 3.35(1) + 0.84 = 4.19$ ②
$\Delta h_{latent} = 334(1) = 334$ ②

10

$$Q = m_{ice}(\Delta h_{latent}) + (m_{ice} + m_{water}) \cdot c_{p\,Fresh}(T_f - T_i)$$

(T_f = 5°C, T_i = 0°C)

$$= 0.3667(334) + (0.4667) \cdot 4.19 \cdot (5 - 0)$$

$Q = 132.255\ kJ$ 5

b) $\frac{132\,255\ J}{1500\ J/s} = 88.2\ sec$ 5

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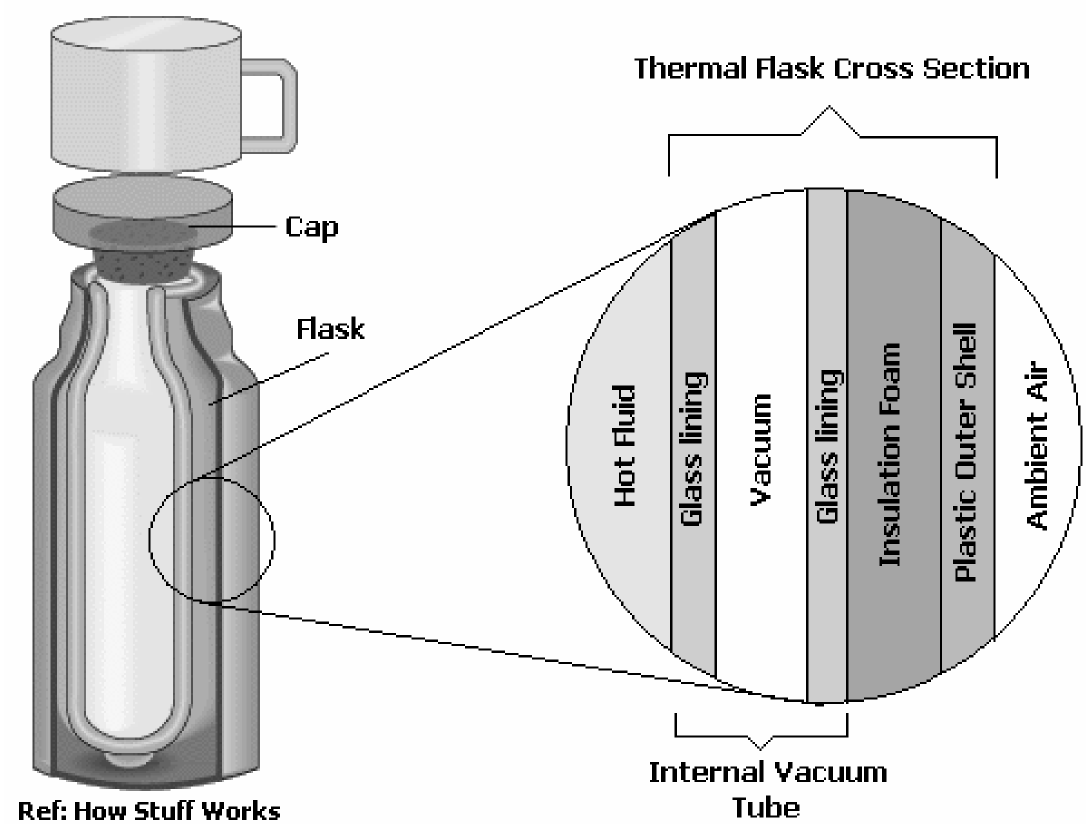
Quiz #2 – Introduction to Heat Transfer
Tuesday, February 1st, 2011

Part 1 - Short questions (30 marks)

1. Name the different heat transfer modes, and for each mode provide the following information:
   (a) The physical mechanism (*please... 3 or 4 lines max for each mode!*).
   (b) The governing law and appropriate units.
   (c) An example of the mode from your everyday life.
   (15 marks)

2. a) Explain how heat is transferred (which modes) from a hot fluid (ex: coffee) through the side walls of the thermal flask shown in the figure below. (10 marks)

   b) What is the advantage of including an internal vacuum tube in the design of a thermal flask? (5 marks)



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Part 2 - Problem (70 marks)

To be done in groups of 2:One Quiz book to be handed in - Include both names

A common heat transfer application involves the use of heating elements to transfer thermal energy to solid objects (ex: heating a frying pan on an electric stovetop) or to fluids (ex: heating air with a space heater). Many heating elements, including the one in the demonstration lamp used in class, are composed of Nichrome 80/20 (80% nickel, 20% chromium). This is an ideal heating element material because it has a relatively high electrical resistance and can therefore efficiently convert electrical power into heat. An important issue with this application however is to balance the electrical power input and heating element size to limit its surface temperature: the element must be large enough to dissipate sufficient energy so that it does not melt during operation when maximum current is applied. This would not only cause permanent damage to the heater, but it could also become a considerable fire and safety hazard. The following problem will allow you to develop a procedure to predict the surface temperature of the demonstration lamp's heating element under electrical load.

You must complete the following tasks

a) Predict the lamp's heating element surface temperature under electrical load.
b) Once the prediction is made, measure the heating element's surface temperature with an optical pyrometer. <u>Note: The T-A needs to initialize your Quiz book before doing this task.</u>
c) Explain any discrepancy between the predicted and measured temperatures.

Given:

1- The wire heating element used in the lamp has a diameter d_w=0.8mm. The total length L of the wire is 5525 mm. You can assume that 15% of the total wire surface area is in contact with the ceramic base of the lamp, and therefore this portion of the wire may be considered as perfectly insulated.

2- The demonstration lamp is in the front of the classroom if you need to access it. The voltage and current may be measured on the experimental setup.

Methodology

You must do the complete analysis as seen in class with assumptions and governing laws.
If some data is missing, make an educated guess and clearly justify your assumptions. Everything is to be written in the Quiz book.

Time limit

You get 50 minutes to complete this part of the Quiz. This includes all of the three tasks to complete. Manage your time properly as task c) is also worth some marks.

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QUIZ #2 - SOLUTIONS

PART 1:

1) • Conduction

a) Heat transfer mode caused by the transfer of kinetic energy through the collision of molecules

b) Fourrier's Law: $q''_x = -k \frac{dT}{dx}$ $\left[W/m^2\right] = \left[\frac{W}{mK}\right]\left[\frac{K}{m}\right.$

c) Heat transferred from stove top through an aluminum pa

• Convection

a) Heat tranfer mode based on the combined effect of conduction (collision of molecules) and advection (bulk fluid motion).

b) Newton's Law $q''_N = h(T_s - T_\infty)$ $\left[W/m^2\right] = \left[\frac{W}{m^2K}\right]\left[K\right.$

c) Blowing on soup to cool it down

• Radiation

a) Heat transfer mode between matter at finite temperat resulting from the release of electromagnetic waves.

b) Emissive Power Law $E = \varepsilon\sigma T_s^4$ $\left[\frac{W}{m^2}\right] = \left[1\right]\left[\frac{W}{m^2K^4}\right]\left[K^4\right.$

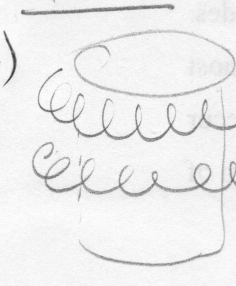
c) Sun transfers energy to the earth

2) a) - Convection from hot fluid to glass lining surface
- Conduction across glass lining
- Radiation across vacuum
- Conduction across glass lining
- Conduction across insulation foam
- Conduction across plastic outer shell
- Convection from outer shell surface to ambient air

b) The vacuum tube prevents conduction & convection heat transfer modes, thereby limiting the amount of heat transfer.

PART 2:

a)



C.V. = heating element

$L = 5525\ mm$

$d_w = 0.8\ mm$

Assumptions

1. Closed system
2. W = 0
3. Homogeneous
4. Steady state
5. $T_\infty = 20°C = 293\ K$

$V = 110\ V$

$A = 8.5\ A$

15% A_s = insulated.

1st Law

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

$$\cancel{q_{in}} - q_{out} = -\dot E_g \quad \therefore \quad q_{out} = \dot E_g = V \cdot I$$

$$q_{out} = P = VI = 110 \cdot 8.5 = 935\ W$$

q_{out} is by convection and radiation.

$$q_{out} = hA_s(T_s - T_\infty) + \varepsilon \sigma A (T_s^4 - T_\infty^4)$$

Engineering assumptions: $h \approx 10\ W/m^2K$ $\quad \varepsilon \approx 0.75$

$$A_s = \pi D_w L \cdot \underbrace{(1 - 0.15)}_{\text{insulated portion}} \qquad A_s = 0.011804\ m^2$$

$$935 = 10 \cdot 0.011804\,(T_s - 293) + 0.75 \cdot 5.67\times10^{-8} \cdot 0.011804\,(T_s^4 - 293^4)$$

Solve for T_s $\Rightarrow$ $\boxed{T_s = 864\ °C}$

b) Sources of error:

- Errors in voltage/current readings.
- Errors in T_∞, h, ε assumptions
- Errors in geometry (D_w and L)
- Error in pyrometer measurement

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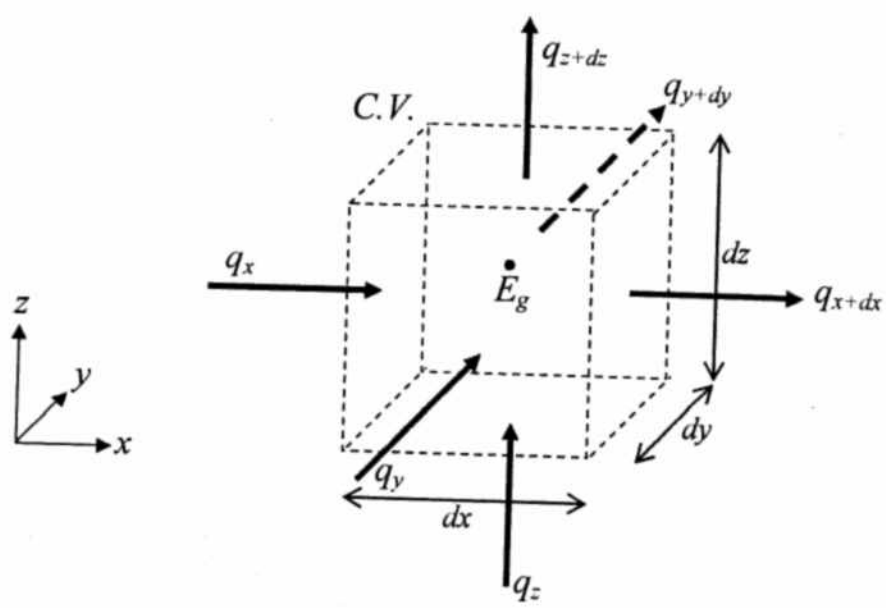
Quiz #3 – Introduction to Conduction
Tuesday, February 8, 2011

Part 1 - Short questions (60 marks)

1. Estimate the heat transfer rate trough a 100 mm thick wall of surface area $1m^2$ if the temperature on both sides of the wall are respectively 10°C and -5°C and if the wall is made of : (9 marks)

   a) Plastic
   b) Pure copper
   c) Air (neglect convection)

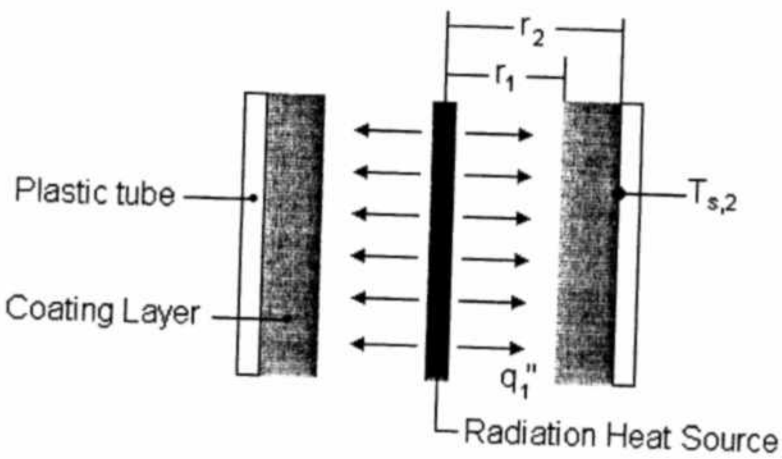
2. a) Using the 1st law applied on an infinitesimal control volume (shown below), develop the heat diffusion equation (HDE) in Cartesian coordinates. State all the assumptions required. (45 marks)



b) Explain the meaning of every term in the HDE. (6 marks)

Part 2 - Problem (40 marks)

A **cylindrical** coating, which is applied to the inner surface of a plastic **tube**, is cured by placing a cylindrical radiation heat source within the tube. The space between the coating and the source is evacuated and the source delivers a uniform heat flux q_1'', which is absorbed at the inner surface of the coating. The outer surface of the coating is maintained at a known uniform temperature $T_{s,2}$.



Develop an expression for the temperature distribution T(r) in the coating layer in terms of q_1'', $T_{s,2}$, r_1, r_2 and k.

Useful information:

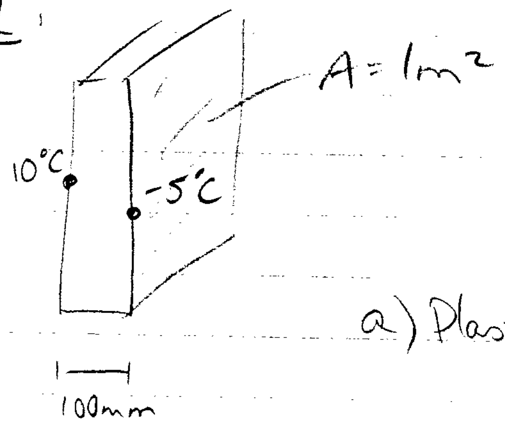
$$\frac{1}{r^2}\frac{\partial}{\partial r}\left(kr^2\frac{\partial T}{\partial r}\right)+\frac{1}{r^2\sin^2\theta}\frac{\partial}{\partial\phi}\left(k\frac{\partial T}{\partial\phi}\right)+\frac{1}{r^2\sin\theta}\frac{\partial}{\partial\theta}\left(k\sin\theta\frac{\partial T}{\partial\theta}\right)+\dot{q}=\rho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

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

MCG 3105 - HEAT TRANSFER - QUIZ 3 SOLUTIONS

PART 1:

1)



$$q_x = -kA\frac{dT}{dx} = k\left(-(1)\frac{(-5-10)}{0.1}\right)$$

$$q_x = 150K$$

a) Plastic $K \approx 1$ 3 (between 0.5 and 10)

$$q_x = 150W$$

b) Pure Copper $K = 400$

$q_x = 60\,000$ W 3

k between 300 - 500

c) Air $K = 0.05$ 3 (between 0.01 and 0.2)

$$q_x = 7.5W$$

2) Assumptions: 1 Closed system 5
2 Homogeneous
3 $W_{cv} = 0$
4 No flow inside cv.

1st Law: $$Q_{cv} + \cancel{\sum m_i E_i}^{1} = \cancel{W_{cv}}^{3} + \cancel{\sum m_e E_e}^{1} + \frac{dE_{cv}}{dt} - \dot{E}_g \quad 5$$

$$q_{in} - q_{out} + \dot{E}_g = \frac{dE_{cv}}{dt}$$

$$(q_x + q_y + q_z) - (q_{x+dx} + q_{y+dy} + q_{z+dz}) + \dot{E}_g = \frac{dE_{cv}}{dt} \quad 5$$

$$q_{x+dy} = q_x + \frac{\partial q_x}{\partial x}dx \qquad q_{y+dy} = q_y + \frac{\partial q_y}{\partial y}dy \qquad q_{z+dz} = q_z + \frac{\partial q_z}{\partial z}dz \quad 5$$

$$\cancel{q_x} + \cancel{q_y} + \cancel{q_z}) - \left(\cancel{q_x} + \frac{\partial q_x}{\partial x}dx + \cancel{q_y} + \frac{\partial q_y}{\partial y}dy + \cancel{q_z} + \frac{\partial q_z}{\partial z}dz\right) + \dot{E}_g = \frac{dE_{cv}}{dt}$$

$$q_x = -kA\frac{dT}{dx} = -k\,dy\,dz\frac{dT}{dx} \qquad \frac{\partial q_x}{\partial x} = -dy\,dz\frac{\partial}{\partial x}\left(k\frac{dT}{dx}\right)$$

Similarly: $$\frac{\partial q_y}{\partial y} = -dx\,dz\frac{\partial}{\partial y}\left(k\frac{dT}{dy}\right) \quad 5$$

$$\frac{\partial q_z}{\partial z} = -dx\,dy\frac{\partial}{\partial z}\left(k\frac{dT}{\partial z}\right)$$

$$\underbrace{dx\,dy\,dz}_{d\forall}\frac{\partial}{\partial x}\left(k\frac{\partial T}{\partial x}\right)+dx\,dy\,dz\frac{\partial}{\partial y}\left(k\frac{\partial T}{\partial y}\right)+dx\,dy\,dz\frac{\partial}{\partial z}\left(k\frac{\partial T}{\partial z}\right)+\dot{E}_g=\frac{dE_{cv}}{dt}$$ 5

$\div\, d\forall$ 5

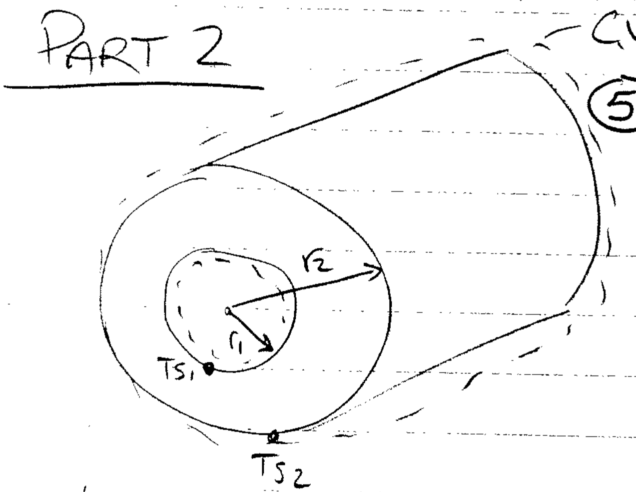
$$\dot{q}=\frac{\dot{E}_g}{d\forall} \qquad \frac{dE_{cv}}{dt}=\frac{d(mu)}{dt}=m\frac{du}{dt}=\rho\, d\forall\, c\frac{dT}{dt}$$

$$\therefore \boxed{\underbrace{\frac{\partial}{\partial x}\left(k\frac{\partial T}{\partial x}\right)+\frac{\partial}{\partial y}\left(k\frac{\partial T}{\partial y}\right)+\frac{\partial}{\partial z}\left(k\frac{\partial T}{\partial z}\right)}_{\text{Net heat flux along x, y and z } (q_{in}-q_{out})}+\underbrace{\dot{q}}_{\text{energy generated per unit volume}}=\underbrace{\rho c\frac{\partial T}{\partial t}}_{\text{change of energy of CV in time}}}$$ 10

2 2 2

b)

PART 2



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Assumptions 5

1. Closed system
2. $W=0$
3. Homogeneous
4. Steady state
5. No $\dot{E}_g$
6. T is function of r only
7. No flow

1st Law (HDE) — cylindrical

$$\frac{1}{r}\frac{\partial}{\partial r}\left(kr\frac{\partial T}{\partial r}\right)+\cancel{\frac{1}{r^2}\frac{\partial}{\partial \phi}\left(k\frac{\partial T}{\partial \phi}\right)}^{6}+\cancel{\frac{\partial}{\partial z}\left(k\frac{\partial T}{\partial z}\right)}^{6}+\cancel{\dot{q}}^{0}=\cancel{\rho c\frac{\partial T}{\partial t}}^{4}$$ 5

$$\frac{\partial}{\partial r}\left(kr\frac{\partial T}{\partial r}\right)=0 \qquad \int d\left(kr\frac{\partial T}{\partial r}\right)=\int 0\,dr$$

$$kr\frac{\partial T}{\partial r}=C_1 \qquad \frac{dT}{dr}=\frac{C_1}{r}$$

$\frac{C_1}{k}$ is still a constant... C_1

$$\int dT=\int\frac{C_1}{r}dr \qquad T(r)=C_1\ln r+C_2$$ 5 ⇒ general solution

Boundary conditions

1. @ $r=r_1$ $\quad q_r=q_1''$
2. @ $r=r_2$ $\quad T=T_{s,2}$

5

with 1 ⇒ $q_1''=-k\left.\frac{dT}{dr}\right|_{r_1}=-k\frac{C_1}{r_1}$ $\quad\therefore \boxed{C_1=-\frac{q_1''r_1}{k}}$

5

with (2) $\Rightarrow$ $$T_{s,2} = \frac{-q_1'' r_1}{k} \ln r_2 + C_2$$

$$\therefore \quad C_2 = T_{s,2} + \frac{q_1'' r_1}{k} \ln r_2 \quad (5)$$

Solution:

$$\boxed{T(r) = \frac{-q_1'' r_1}{k} \ln r + T_{s,2} + \frac{q_1'' r_1}{k} \ln r_2} \quad (5)$$

MCG 3110 HEAT TRANSFER

Quiz #4 - Chapter 3, part 1
Tuesday, February 15, 2011

Part 1 - Short questions (15 marks)

1. Explain what we mean when we assume one-dimensional steady-state conduction. (5 marks)

2. Explain the concept of thermal resistance. Why is it useful? (5 marks)

3. Explain why the concept of thermal resistances can't be used for solids with heat generated. (5 marks)

Part 2 - Problems (85 marks)

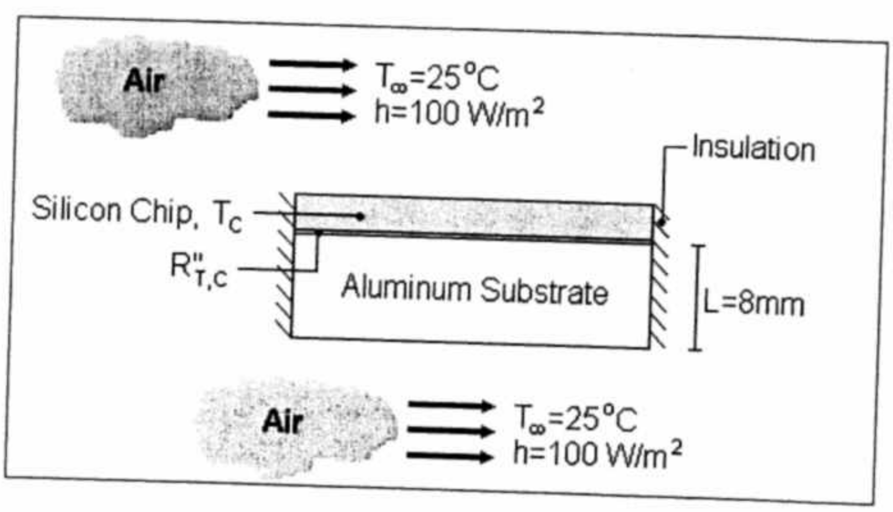
1. Clothing made of several thin layers of fabric with trapped air in between, often called ski clothing, is commonly used in cold climates because it is light, fashionable, and a very effective thermal insulator. So it is no surprise that such clothing has largely replaced thick and heavy old-fashioned coats. Consider a jacket made of five layers of 0.1 mm thick synthetic fabric (k=0.13 W/m.K) with 1.5 mm thick air space (k=0.026 W/m.K) between the layers.

   a) Assuming the inner surface temperature of the jacket to be 28 Celsius and the surface to be 1.1 m^2, determine the rate of heat loss through the jacket when the outside air temperature is -5 Celsius and the heat transfer coefficient at the outer surface is 25 W/ m^2 .K. (20 marks)

   b) What would be your response if the jacket is made of a single layer of 0.5 mm thick synthetic fabric (without air pockets)? (10 marks)

   c) What should be the thickness of a wool fabric (k=0.035 W/m.K) if the person is to achieve the same level of thermal comfort (as in part a)) wearing a thick wool coat instead of a ski jacket? (10 marks)

2. A thin silicon chip is mounted on an 8mm thick aluminium substrate (k_{Al} = 238 W/m°C) as shown in the figure below. Imperfections at the interface between the chip and the aluminium substrate causes a thermal contact resistance of $R''_{T.C.} = 0.9\times10^{-4}$ m^2·°C/W. The chip and aluminium substrate both have a surface area of 100mm^2, and their exposed surfaces are cooled by air at T_∞=25°C with a convection coefficient of h = 100 W/m^2 °C. The sides of the chip and substrate are perfectly insulated; as such heat losses through the sides of the chip and substrate can be neglected. Knowing that the chip dissipates 1 W under normal conditions, will it operate below its maximum allowable temperature of 85°C? (45 marks)



Note: You can assume the chip to have a uniform and constant temperature T_C.

MCG 3105 - HEAT TRANFER - QUIZ 4 SOLUTIONS
JUNE 4, 2008

PART 1:

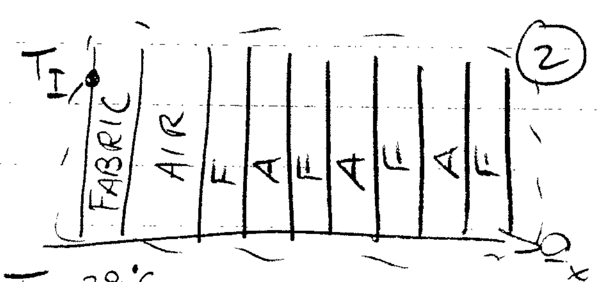
1) 1-dimensional: heat flux & temperature gradient are along 1 coordinate only.
5 Steady State: No changes of heat flux or temperature gradient in time.

2) A thermal system is like an electrical system in a sense that a heat flux (like current) is driven by a temperature
5 difference (difference of voltage) and is affected by what it must go through (matter = resistance)
i.e. ex: a wall acts like a resistance to heat transfer
$q \cdot R = \Delta T$ is like $I \cdot R = \Delta V$ (similar behavior)
It's useful for finding q through composite walls where there is no E_{gen}.

3) When heat is generated in an object, it affects the temperature distribution. Thermal resistances are
3 obtained based on the results of solving the HDE (getting the temperature distribution) when $\dot{E}_g = 0$. As such the thermal resistances can't be used in solids that have $\dot{E}_g$.

Part 2

1) a) 2



T_∞
$h_\infty = 25$

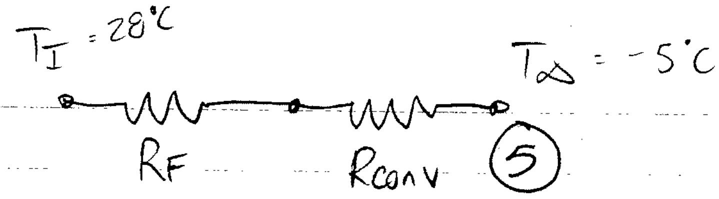
Assumptions: 3
1) Closed syst
2) SS, 1-D
3) $\dot{E}_g = 0$

$T_I = 28°C$ $T_\infty = -5°C$

5 R_F R_A R_F R_A R_F R_A R_F R_A R_F R_{conv}

$$R_{TOT} = 5\left(\frac{L_F}{K_F A}\right) + 4\left(\frac{L_A}{K_A A}\right) + \frac{1}{hA}$$

b)

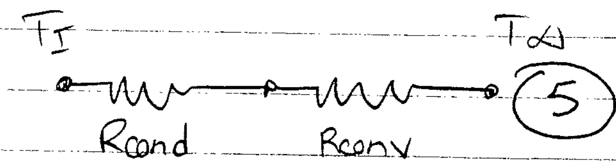


$$R_{TOT} = \frac{0,0005}{0,13 \cdot 1,1} + \frac{1}{25 \cdot 1,1} = 0,0399$$ 3

$0,003497 + 0,0364$

$$\boxed{q_x = 827,1\ W}$$ 2

c)



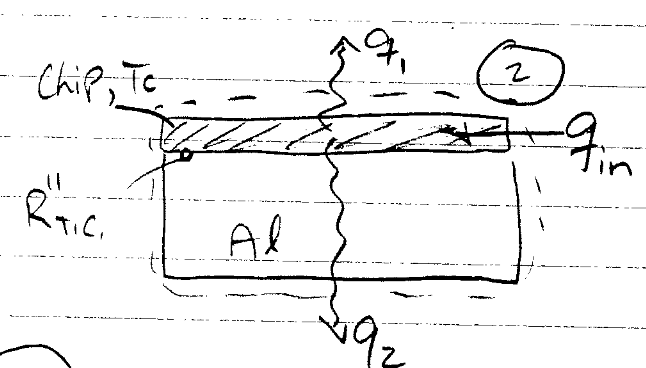
$$q_x = \frac{28-(-5)}{R_{cond} + 0,0364} \Rightarrow R_{cond} = 0,2496 = \frac{L_w}{K_w A}$$ 3

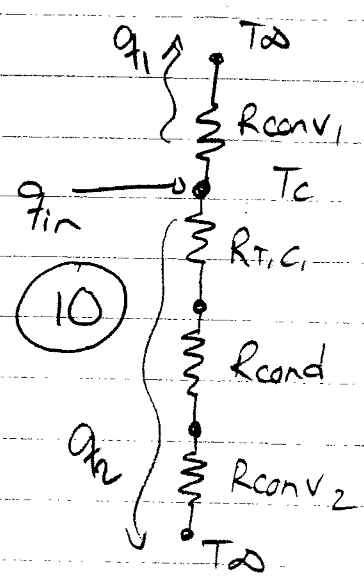
132,2 W

$L_w = 0,2496 \cdot 1,1 \cdot 0,035$

$$\boxed{L_w = 9,6mm}$$ 2

2)





3 Assumptions
① Closed System
② 1-D SS
③ $\dot{W} = 0$

10

$$R_{conv,1} = \frac{1}{hA} = \frac{1}{100 \times 10^{-4}} = 100$$

$$R_{T,C,1} = \frac{R''_{T,C,1}}{A} = 0,9$$

$$R_{cond} = \frac{L_{Al}}{K_{Al} \cdot A} = \frac{0,008}{238 \cdot 0,0001} = 0,3361$$

$$R_{conv\,2} = R_{conv,1} = 100$$

$\xrightarrow[R_{conv1}]{} q_1$

$q_x \cdot R_{TOT} = T_c - T_\infty$ 5

$T_c = q_x R_{TOT} + T_\infty$

$= 1(50.31) + 25$ 5

$\boxed{T_c = 75.3\,°C}$

Yes it's ok because it's less than 85 °C.

MCG 3110 HEAT TRANSFER

Quiz #5 -Chapter 3, Part 2
Tuesday, March 1st, 2011

To be done in groups of two - One quiz book per group - Write both names

Part 1 - Short questions (20 marks)

1. Explain what makes a good fin (at least two things...) (10 marks)
2. Define fin efficiency and fin effectiveness (in your words and mathematically). (10 marks)

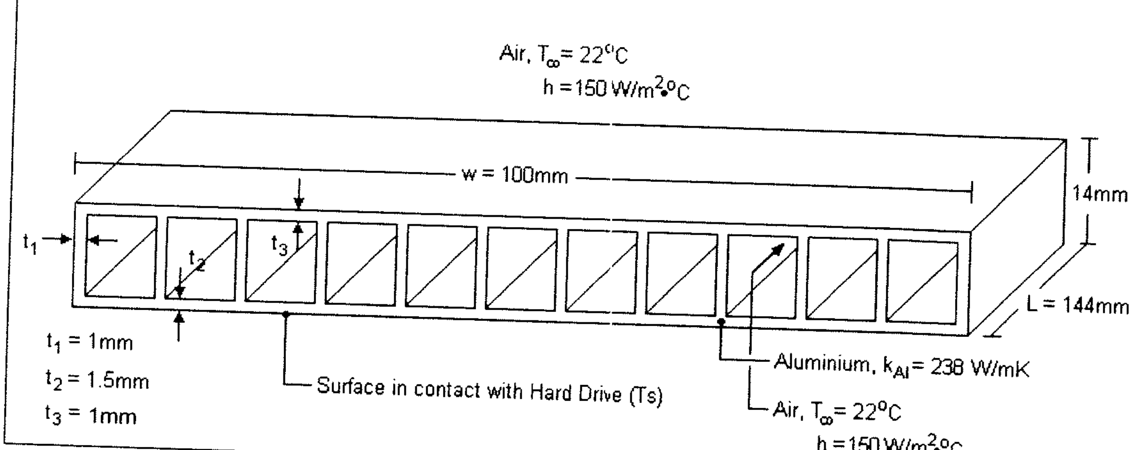
Part 2 - Problem (80 marks)

In order to get faster computers and data access, it is required not only to increase the CPU speed but also the hard drive speed. As we increase the hard drive speed, more power is dissipated through the hard drive and it must be evacuated adequately to prevent elevated hard drive temperatures that could damage it. One proposed solution to keep the hard drive temperature low is to use hard drive coolers; a combination of fins and fans that can reduce the hard drive surface temperature.

One such unit is branded as the Ultimate Hard Drive Cooler (see reverse for images). On the packaging, the manufacturer claims that a reduction of up to 40% of the hard drive surface temperature can be achieved when using this unit. The aim of this problem is to determine whether the manufacturer's claim is true or not.

To verify this claim, we will assume that the hard drive temperature **when only cooled by natural convection** ($h = 20$ W/m^{2}K) is 42°C. The power dissipated by the hard drive can also be assumed to be constant, with or without the presence of the hard drive cooler. For the purpose of this analysis, you may use the simplified hard drive cooler fin array geometry shown below. You can assume that the two outer sides of the fin array (14mm x 144mm) do not contribute to heat transfer (insulated).

Cross-Section view of Heat Sink (Fin Array)



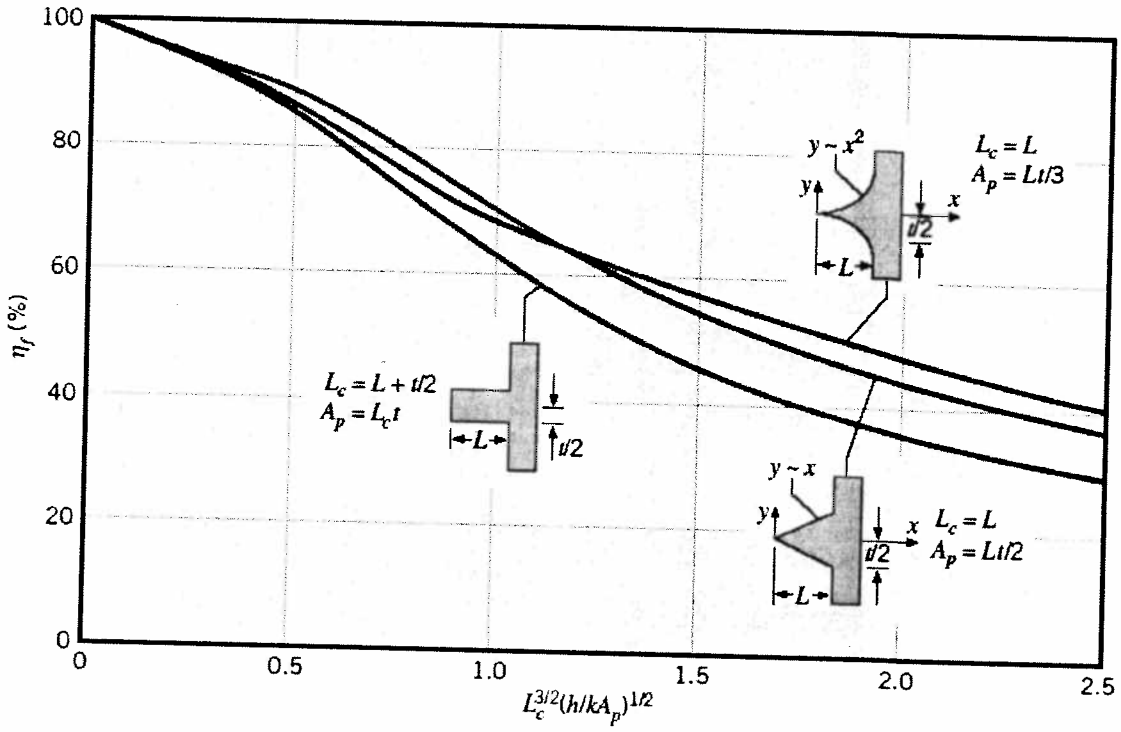
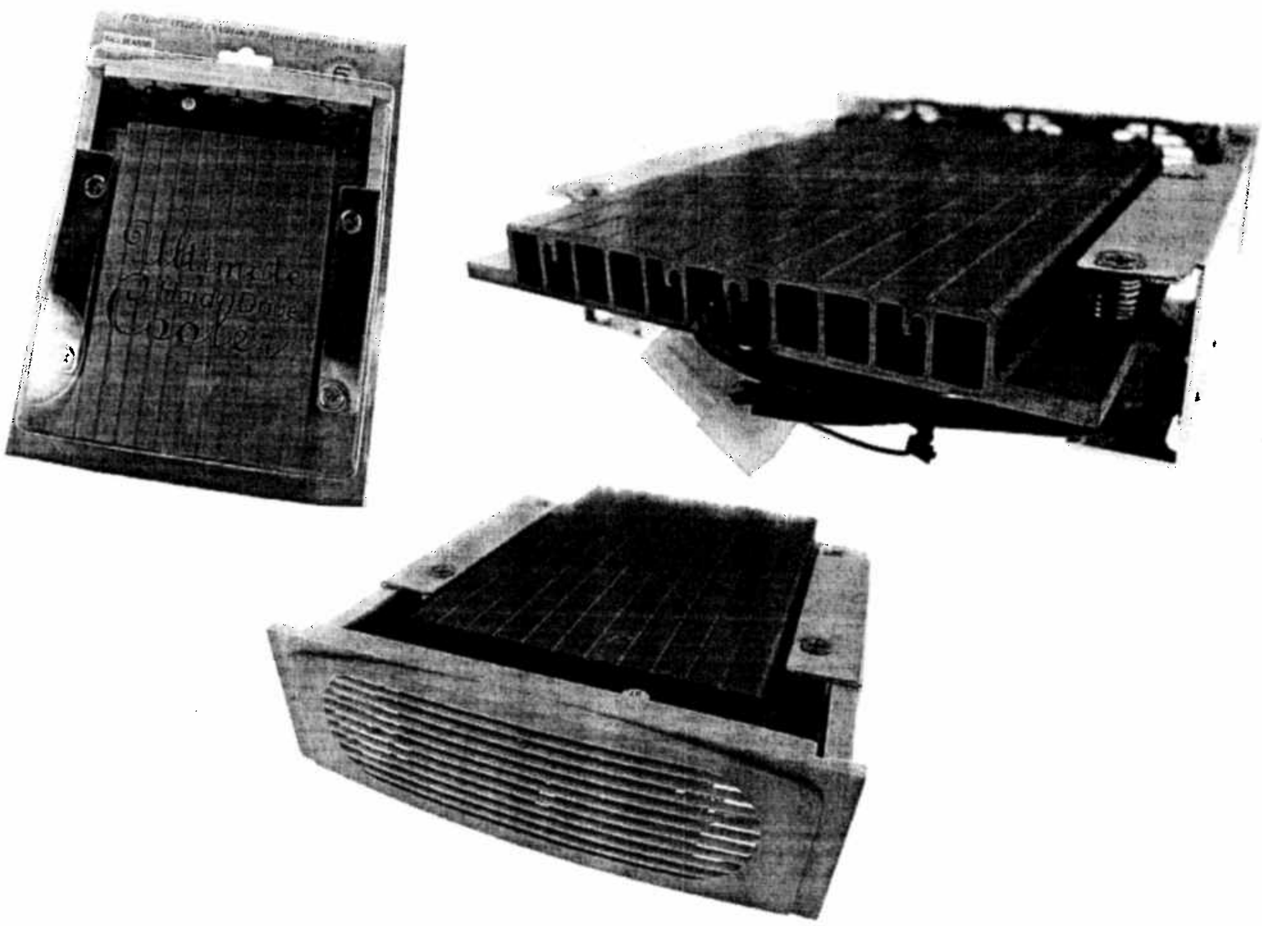


FIGURE 3.18 Efficiency of straight fins (rectangular, triangular, and parabolic profiles).



MCG 3105 - HEAT TRANSFER - QUIZ 5 SOLUTIONS

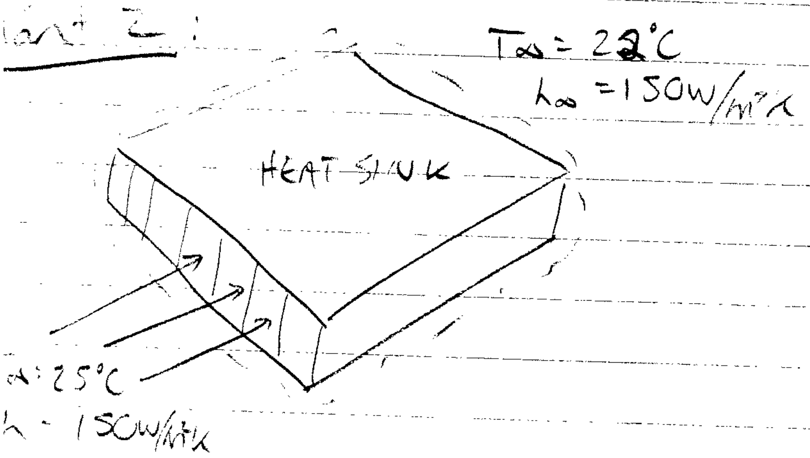
PART 1:

1) - Material with high thermal conductivity (T° inside fin increases with high k)
- Fins aren't too long (T inside $\downarrow$ with $L\uparrow$)
- Use thin fins (P/A_c small)

2) a) Fin efficiency: answers the question "is it a good fin design?".
$$\eta_{fin} = \frac{q_{fin}}{q_{fin\,max}}$$
$$\eta_{fin} = \frac{\text{heat transfer rate through fin}}{\text{heat transfer rate through fin if all the fin is at } T_b}$$

b) Fin effectiveness: answers the question "is it worth it";
$$\varepsilon_{fin} = \frac{q_{fin}}{q_{no\,fin}} = \frac{\text{heat transfer through fin}}{\text{heat transfer through base without fin}}$$

Part 2:



Assumptions:
1. Closed system
2. SS
3. $\dot{W} = 0$
4. $\dot{E}_g = 0$
5. homogeneous

1st of all, determine heat dissipated by Hard Drive:

$T_s = 42^{\circ}C$
$T_\infty = 22^{\circ}C$
$h = 20\ W/m^2k$
$A_s = 0.1 \times 0.144 = 0.0144\, m^2$

$$q = hA_s(T_s - T_\infty) = 5.76\,W$$

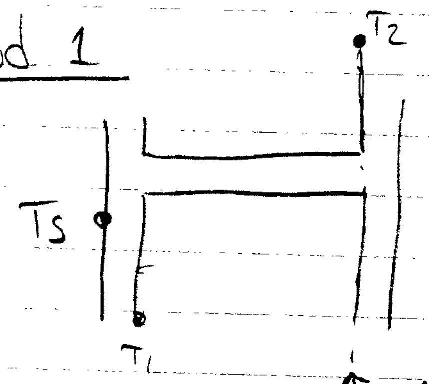
10

$$\boxed{q_{out} = 5.76\,W}$$

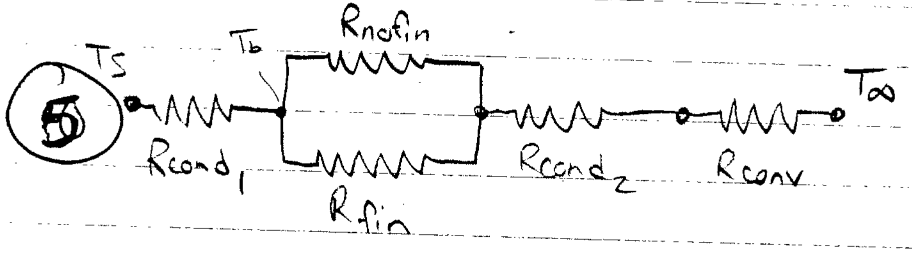
Now find a way to estimate Ts with the Heat Sink.

$\Rightarrow$ There are 2 approximate methods for doing this

Method 1



Assume T_2 is constant,,, and unknown...

5 

10 $R_{cond_1} = \dfrac{L}{kA} = \dfrac{0.0015}{238\,(0.0144)} = 0.00044 = R_{cond_2}$

10 $R_{conv} = \dfrac{1}{hA} = \dfrac{1}{150\,(0.0144)} = 0.463$

10 $R_{nofin} = \dfrac{1}{hA_{unfin}} = \dfrac{1}{h\,(11 \times 0.008 \times 0.144)} = 0.526$

5 $R_{fin} = \dfrac{T_b - T_\infty}{q_{fin}} = \dfrac{T_b - T_\infty}{\eta_{fin} \cdot q_{fin\,max}} = \dfrac{\cancel{T_b - T_\infty}}{\eta_{fin} \cdot h \cdot A_f \cdot \cancel{T_b - T_\infty}}$

$= \dfrac{1}{\eta_{fin} \cdot h \cdot A_f}$

$\eta_{fin} \Rightarrow$ fig 3.18 15

$L_c = L + t/2 = 0.011 + 0.0005 = 0.0115\,m$

$A_p = L_c t = 0.0115 \cdot 0.001 = 1.15 \times 10^{-5}\,m^2$

$L_c^{3/2} \left(\dfrac{h}{kA_p}\right)^{1/2} = 0.00123\,(234.1) = 0.289$

$\eta_{fin} \doteq 0.92$ $A_f = 22 \times \overset{L_c}{0.0115} \cdot 0.144 = 0.03643\,m^2$

$R_{fin} = 0.199$

$R_{TOT} = 0.6083$ 5

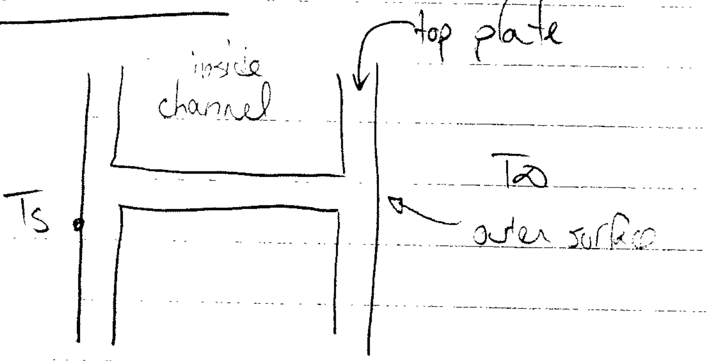
$T_s = T_\infty + R_{TOT}\, q_{out}$ 5

$= 22 + 0.6083 \cdot 5.76$

$\boxed{T_s = 25.5^\circ C}$

5 Temperature drop of $16.5^\circ C \Rightarrow \dfrac{16.5^\circ C}{42^\circ C} = \boxed{39\%}$ decrease in Ts...

Method 2:

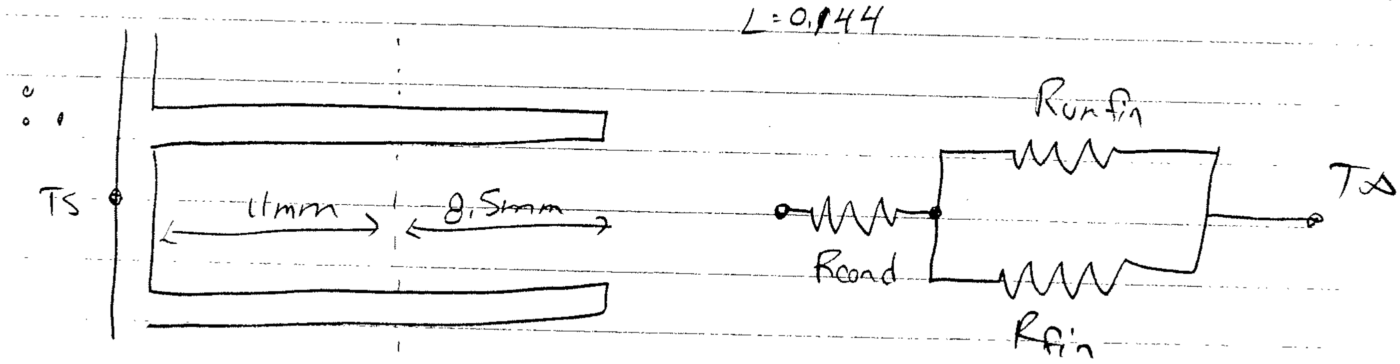


Since the flow conditions inside the channel is the same as the flow conditions on the outer surface, the top plate can be viewed as an extension of the fins.

* The total area exposed to the flow by this top plate is: $(0.1 \times 0.144) + 11(0.008 \times 0.144) = 0.0271 \, m^2$

Dividing by the number of surfaces on the fins (10 fins × 2 sides + 2 ends) $= 0.0271/22 = 0.00123$ = extra area per fin

extra length per fin $= \dfrac{0.00123}{L = 0.144} = 0.0085 \, m$ longer per fin



$R_{cond} = \dfrac{L}{kA} = 0.00044$

$R_{nofin} = 0.526$

$R_{fin} = \dfrac{1}{\eta_{fin} h A_{fin}}$ $\Rightarrow$ $L_c = L + t/2 = 0.011 + 0.0085 + 0.0005 = 0.02 \, m$

$A_p = L_c t = 2 \times 10^{-5}$

$R_{fin} = 0.2155$ $\qquad L_c^{3/2} \left(\dfrac{h}{kA_p}\right)^{1/2} = 0.0028(177.52) = 0.502$

$\eta_{fin} = 0.85$

$R_{TOT} = 0.153$

$A_{fin} = 22 \times 0.0115 \cdot 0.144 = 0.0364$

$T_s = T_\infty + R_{TOT} \cdot q_{out}$

$= 22 \cdot 0.153 \cdot 5.76$

$= 22.9°C$

$\Delta T = 19.1°C$ $\qquad$ Temperature drop $= \dfrac{19.1°C}{42°C} = 45.5\%$

$\Rightarrow$ Manufacturer's claim is a temperature drop of 40% is TRUE! ... Could depend on the