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UNIVERSITI TUN HUSSEIN ONN MALAYSIA

FINAL EXAMINATION
SEMESTER I
SESSION 2017/2018

COURSE NAME	:	HEAT TRANSFER
COURSE CODE	:	BDA 30603
PROGRAMME	:	BDD
EXAMINATION DATE	:	DECEMBER 2017/JANUARY 2018
DURATION	:	3 HOURS
INSTRUCTIONS	:	

A) ANSWER **ONLY** FIVE (5) QUESTIONS FROM SIX (6) QUESTIONS
B) SYMBOLS HAVE COMMON DEFINITION UNLESS STATED OTHERWISE
C) STATE RELEVANT ASSUMPTIONS WHERE NECESSARY

THIS QUESTION PAPER CONSISTS OF **TEN (10)** PAGES

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Q1 The engine cylinder of a motorcycle is constructed of 2024-T6 aluminum alloy and is of height $H = 0.15\ m$ and outside diameter $D = 50\ mm$ as shown in **Figure Q1**. Under typical operating conditions the outer surface of the cylinder is at a temperature of $500\ K$ and is exposed to ambient air at $300\ K$, with a convection coefficient of $50\ W/m^2\ K$. Annular fins are integrally cast with the cylinder to increase heat transfer to surroundings. Consider five such fins, which are of thickness $t = 6\ mm$, $L = 20\ mm$ and equally spaced.

(i) Determine annular fin efficiency.
(ii) What is the increase in heat transfer due to use of the fins.
(iii) Determine the overall effectiveness of the fins.

(20 marks)

Q2 (a) The equation for constant thermal conductivity for a cylinder can be written as

$$\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial T}{\partial r}\right)+\frac{1}{r^2}\frac{\partial^2 T}{\partial \phi^2}+\frac{\partial^2 T}{\partial z^2}+\frac{\dot{e}_{gen}}{k}=\frac{1}{\alpha}\frac{\partial T}{\partial t}$$

where, k – thermal conductivity, [$W \cdot m^{-1} \cdot K^{-1}$]
please re-write the equation based on these specified conditions:

(i) Steady-state condition.
(ii) Steady-state with no heat generation.
(iii) Transient with no heat generation.
(iv) Transient with heat generation.

(8 marks)

(b) One approach to achieving high operating temperatures in gas turbine engines involves application of a Thermal Barrier Coating (TBC) to the exterior surface of blade as shown in **Figure Q2(b)**. Typically the blade is made from a high temperature alloy, such as Inconel with $k = 24\ W/mK$, while a ceramic such as zirconia ($K = 1.3\ W/mK$) is used as TBC. Consider conditions for which hot gases at $T_{\infty,o} = 1700\ K$ and cooling air at $T_{\infty,i} = 400\ K$ provide outer and inner surface convection coefficient of $h_o = 1000\ W/m^2K$ and $h_i = 500\ W/m^2K$ respectively. If a $0.5\ mm$ thick zirconia TBC is attach to a $5\ mm$ thick Inconel blade wall by means of a metallic bonding agent, which provides an interfacial thermal resistant of $R_{t,c} = 10^{-4}\ m^2K/W$, can the Inconel be maintained at a temperature that is below its minimum allowable value of $1250\ K$? Radiation effects may be neglected, and the turbine blade may be approximated as plane wall.

(12 marks)

Q3 (a) Give definition of the Nusselt number and its significant.

(5 marks)

(b) Water is to be heated from 10 °C to 80 °C as it flows through a 2 cm internal diameter, 7 m long tube. The tube is equipped with an electric resistance heater, which provides uniform heating throughout the surface of the tube. The outer surface of the heater is well insulated, so that in steady operation all the heat generated in the heater is transferred to the water in the tube. If the system is to provide hot water at a rate of 8 L/min, determine;

(i) the power rating of the resistance heater, and
(ii) the inner surface temperature of the pipe at the exit.

(15 marks)

Q4 (a) Give definition of Rayleigh number and the Grashof number.

(3 marks)

(b) Consider a 15cm x 20cm thin rectangular plate in a room at 20 °C. The plate surface temperature is 45 °C. The heat loss from the back surface of the plate is negligible. Assume the surrounding surfaces to be at the same temperature as the air in the room, determine the rate of heat transfer from the plate by natural convection if the plate is,

(i) vertical,
(ii) horizontal with hot surface facing up, and
(iii) horizontal with hot surface facing down.

(17 marks)

Q5 (a) For parallel and counter-flow heat exchangers:

(i) sketch the variation of fluid temperatures for parallel and counter-flow heat exchangers and indicate the hot and cold inlet and outlet temperatures in the diagram; and

(ii) state the conditions required for the fluids in a heat exchanger to experience the same temperature change.

(8 marks)

(b) An automotive engine utilizes a forced induction system where intake air is compressed by a turbocharger compressor as shown in **Figure Q5(b)**. The compressed air is cooled by a heat exchanger labeled as "Intercooler" in the figure. The Intercooler is an air-to-air compact heat exchanger with both hot and cold air unmixed. This heat exchanger has 20 tubes on the hot side with 0.5 cm internal diameter and 70 cm length. The cold flow side of the heat exchanger consist of finned plate matrix. During operation, the engine requires the air to be at 45 °C for combustion. At this engine operating condition, hot air from the compressor enters the heat exchanger tubes at 111 °C and a flow rate of 130 g/s. The cooling air is heated from 28 °C to 50 °C in the intercooler. For the case described above, determine:

(i) the heat transfer rate from hot air to the cooling air;

(ii) the log mean temperature difference (LMTD) for the heat exchanger;

(iii) the overall heat transfer coefficient; and

(iv) the percentage error in calculation of the overall heat transfer coefficient if the arithmetic mean temperature difference is used rather than the LMTD.

(12 marks)

Q6 (a) Consider a 20 cm x 20 cm x 20 cm cubical body at 1000 K suspended in the air. Assuming the body closely approximates a blackbody, determine

(i) the rate at which the cube emits radiation energy, in W, and
(ii) the spectral blackbody emissive power at a wavelength of 4 m.

(4 marks)

(b) A 3 mm thick glass window transmits 90 percent of the radiation between λ = 0.3 and 3.0 m and is essentially opaque for radiation at other wavelengths. Determine the rate of radiation transmitted through a 2 m x 2 m glass window from blackbody sources at

(i) 5800 K and
(ii) 1000 K.

(6 marks)

(c) Consider an enclosure consisting of 12 surfaces.

(i) How many view factors does this geometry involve?
(ii) How many of these view factors can be determined by the application of the reciprocity and the summation rules?

(2 marks)

(d) A furnace is of cylindrical shape with $R = H = 2\ m$ as shown in **Figure Q6(d)**. The base, top, and side surfaces of the furnace are all black and are maintained at uniform temperatures of 500, 700 and 1200K, respectively. Determine the net rate of radiation heat transfer to or from the top surface during steady operation.

(8 marks)

- END OF QUESTIONS –

FINAL EXAMINATION

SEMESTER/SESSION: SEM I/2017/2018 PROGRAMME CODE: BDD
COURSE NAME : HEAT TRANSFER COURSE CODE: BDA30603

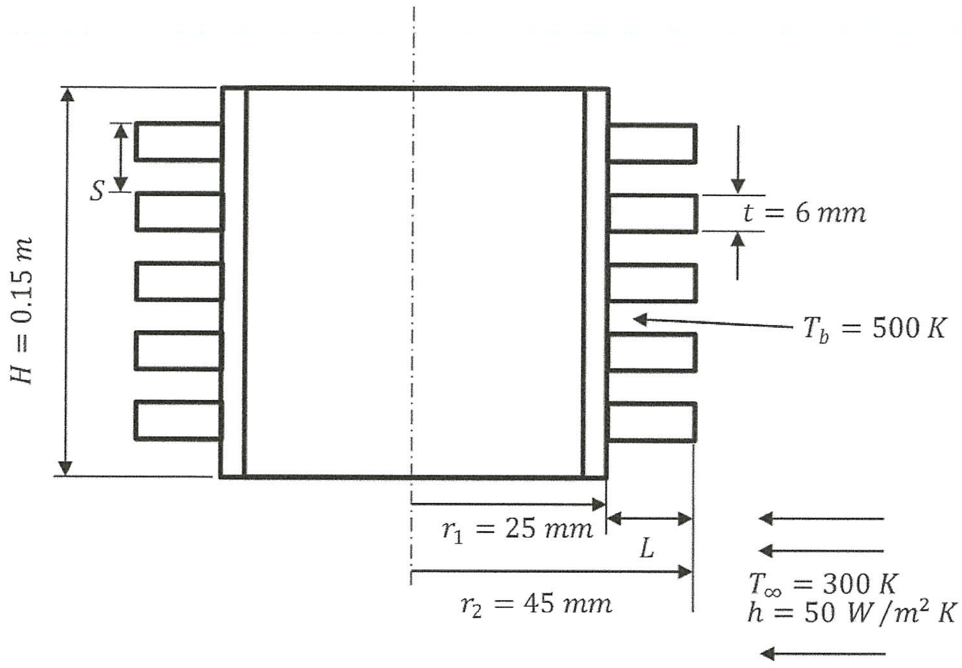

Figure Q1

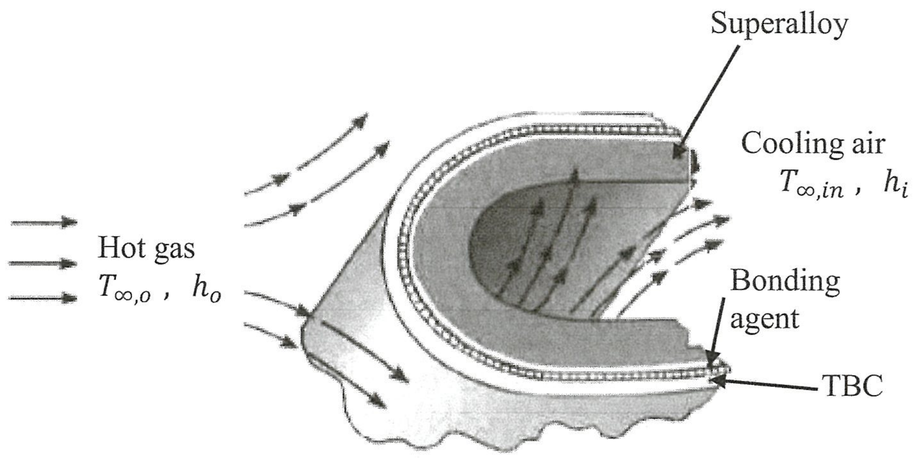

Figure Q2(b)

FINAL EXAMINATION

SEMESTER/SESSION: SEM I/2017/2018
COURSE NAME : HEAT TRANSFER

PROGRAMME CODE: BDD
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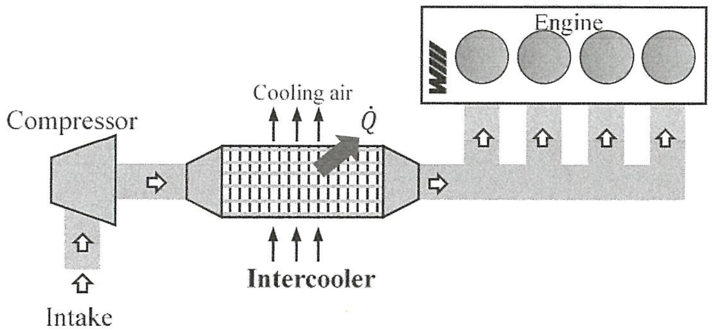


Figure Q5(b)

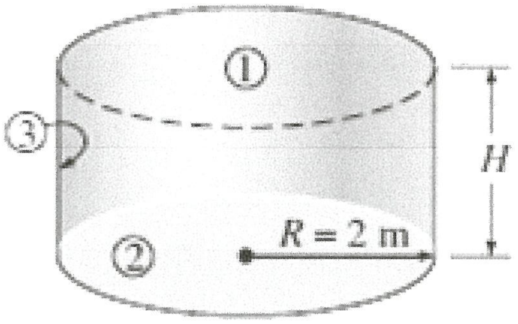


Figure Q6(d)

FINAL EXAMINATION

SEMESTER/SESSION: SEM I/2017/2018 PROGRAMME CODE: BDD
COURSE NAME : HEAT TRANSFER COURSE CODE: BDA30603

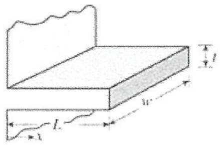
APPENDIX A

Efficiency and surface areas of common fin configurations

Straight rectangular fins

$m = \sqrt{2h/kt}$
$L_c = L + t/2$
$A_{fin} = 2wL_c$

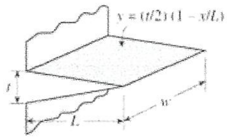
$$\eta_{fin} = \frac{\tanh mL_c}{mL_c}$$



Straight triangular fins

$m = \sqrt{2h/kt}$
$A_{fin} = 2w\sqrt{L^2 + (t/2)^2}$

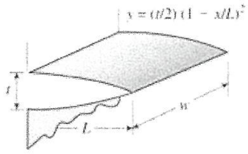
$$\eta_{fin} = \frac{1}{mL}\frac{I_1(2mL)}{I_0(2mL)}$$



Straight parabolic fins

$m = \sqrt{2h/kt}$
$A_{fin} = wL[C_1 + (L/t)\ln(t/L + C_1)]$
$C_1 = \sqrt{1 + (t/L)^2}$

$$\eta_{fin} = \frac{2}{1 + \sqrt{(2mL)^2 + 1}}$$

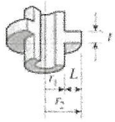


Circular fins of rectangular profile

$m = \sqrt{2h/kt}$
$r_{2c} = r_2 + t/2$
$A_{fin} = 2\pi(r_{2c}^2 - r_1^2)$

$$\eta_{fin} = C_2\frac{K_1(mr_1)I_1(mr_{2c}) - I_1(mr_1)K_1(mr_{2c})}{I_0(mr_1)K_1(mr_{2c}) + K_0(mr_1)I_1(mr_{2c})}$$

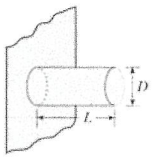
$$C_2 = \frac{2r_1/m}{r_{2c}^2 - r_1^2}$$



Pin fins of rectangular profile

$m = \sqrt{4h/kD}$
$L_c = L + D/4$
$A_{fin} = \pi DL_c$

$$\eta_{fin} = \frac{\tanh mL_c}{mL_c}$$

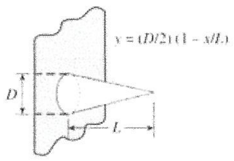


Pin fins of triangular profile

$m = \sqrt{4h/kD}$
$A_{fin} = \frac{\pi D}{2}\sqrt{L^2 + (D/2)^2}$

$$\eta_{fin} = \frac{2}{mL}\frac{I_2(2mL)}{I_1(2mL)}$$

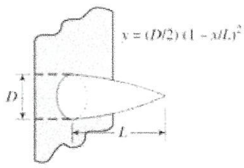
$I_2(x) = I_0(x) - (2/x)I_1(x)$ where $x = 2mL$



Pin fins of parabolic profile

$m = \sqrt{4h/kD}$
$A_{fin} = \frac{\pi L^3}{8D}\left[C_3C_4 - \frac{L}{2D}\ln(2DC_4/L + C_3)\right]$
$C_3 = 1 + 2(D/L)^2$
$C_4 = \sqrt{1 + (D/L)^2}$

$$\eta_{fin} = \frac{2}{1 + \sqrt{(2mL/3)^2 + 1}}$$



Pin fins of parabolic profile (blunt tip)

$m = \sqrt{4h/kD}$
$A_{fin} = \frac{\pi D^4}{96L^2}\left\{[16(L/D)^2 + 1]^{3/2} - 1\right\}$

$$\eta_{fin} = \frac{3}{2mL}\frac{I_1(4mL/3)}{I_0(4mL/3)}$$

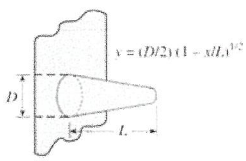


FIGURE A1: Efficiency and Surface Areas of Common Fin Configurations

FINAL EXAMINATION

SEMESTER/SESSION: SEM I/2017/2018 PROGRAMME CODE: BDD
COURSE NAME : HEAT TRANSFER COURSE CODE: BDA30603

APPENDIX A

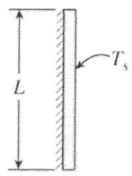
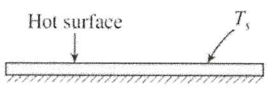
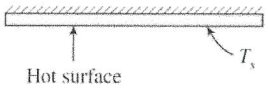
Empirical correlations for the average Nusselt number for natural convection over surfaces			
Geometry	Characteristic length L_c	Range of Ra	Nu
Vertical plate 	L	10^4–10^9 10^{10}–10^{13} Entire range	$Nu = 0.59Ra_L^{1/4}$ $Nu = 0.1Ra_L^{1/3}$ $Nu = \left\{0.825 + \frac{0.387Ra_L^{1/6}}{[1 + (0.492/Pr)^{9/16}]^{8/27}}\right\}^2$ (complex but more accurate)
Horizontal plate (Surface area A and perimeter p) (*a*) Upper surface of a hot plate (or lower surface of a cold plate) 	A_s/p	10^4–10^7 10^7–10^{11}	$Nu = 0.54Ra_L^{1/4}$ $Nu = 0.15Ra_L^{1/3}$
(*b*) Lower surface of a hot plate (or upper surface of a cold plate) 		10^5–10^{11}	$Nu = 0.27Ra_L^{1/4}$

FIGURE A2: Empirical Correlation for Average Nusselt Number for Natural Convection

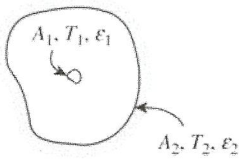
FINAL EXAMINATION

SEMESTER/SESSION: SEM I/2017/2018 PROGRAMME CODE: BDD
COURSE NAME : HEAT TRANSFER COURSE CODE: BDA30603

APPENDIX A

Radiation heat transfer relations for some familiar two-surface arrangments.

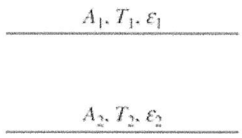
Small object in a large cavity



$$\frac{A_1}{A_2} \approx 0 \qquad F_{12} = 1$$

$$\dot{Q}_{12} = A_1 \sigma \varepsilon_1 (T_1^4 - T_2^4) \qquad (13\text{–}37)$$

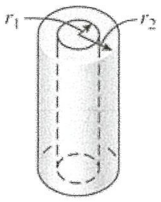
Infinitely large parallel plates



$$A_1 = A_2 = A \qquad F_{12} = 1$$

$$\dot{Q}_{12} = \frac{A\sigma(T_1^4 - T_2^4)}{\dfrac{1}{\varepsilon_1} + \dfrac{1}{\varepsilon_2} - 1} \qquad (13\text{–}38)$$

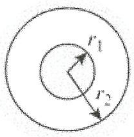
Infinitely long concentric cylinders



$$\frac{A_1}{A_2} = \frac{r_1}{r_2} \qquad F_{12} = 1$$

$$\dot{Q}_{12} = \frac{A_1\sigma(T_1^4 - T_2^4)}{\dfrac{1}{\varepsilon_1} + \dfrac{1-\varepsilon_2}{\varepsilon_2}\left(\dfrac{r_1}{r_2}\right)} \qquad (13\text{–}39)$$

Concentric spheres



$$\frac{A_1}{A_2} = \left(\frac{r_1}{r_2}\right)^2 \qquad F_{12} = 1$$

$$\dot{Q}_{12} = \frac{A_1\sigma(T_1^4 - T_2^4)}{\dfrac{1}{\varepsilon_2} + \dfrac{1-\varepsilon_2}{\varepsilon_2}\left(\dfrac{r_1}{r_2}\right)^2} \qquad (13\text{–}40)$$

FIGURE A3: Radiation Heat Transfer Relations for Some Familiar Two-surface Arrangements