SEP 06 2017

Mark Scored:

KATHMANDU UNIVERSITY

End Semester Examination

August/September, 2017

Level : B. Tech.

Year : III

Course : MEEG 306

Semester : II

SEP 0 6 2017

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Exam Roll No. :

Time: 30 min

F. M. : 20

Registration No.:

Date SEP 0 6 2017

SECTION "A"
[20 Q × 1 = 20 marks]

Cross [×] mark the most appropriate answer.

1. A slab 50 cm thick is made of firebrick with k = 1.5 W/mK. For the same heat transfer and same temperature drop, the wall thickness of material having k = 0.75 W/m$^2$ is ____________
[ ] 0.05 m  [ ] 0.1 m  [ ] 0.2 m  [ ] 0.25 m

2. Heat is considered as a fluid like substance that is massless, colorless, odorless, tasteless and can be poured from one body into another according to ________________ theory.
[ ] Kinetic  [ ] Joules  [ ] Caloric  [ ] Wien's

3. The value of thermal contact resistance does not depend on ________________
[ ] material density  [ ] surface toughness
[ ] material roughness  [ ] type of fluid trapped at the interface

4. Effectiveness of a fin is not a direct function of ____________________________
[ ] thermal conductivity  [ ] surface or cross-sectional area
[ ] temperature difference  [ ] convective heat transfer coefficient

5. The SI unit of dynamic viscosity is ___________
[ ] N.s/m  [ ] Stokes  [ ] kg/m.s  [ ] Pa/s

6. For vertical plates, the critical Grashof number is ___________
[ ] $10^3$  [ ] $10^6$  [ ] $10^9$  [ ] $10^{12}$

7. The value of ________________ constant is $6.626069 \times 10^{-34}$ J.s.
[ ] Boltzmann's  [ ] Planck's  [ ] Wien's  [ ] Kirchhoff's

8. The statement "the emissivity and the absorptivity of a surface at a given temperature and wavelength are equal" is given by ____________________
[ ] Kirchhoff's law  [ ] Wien's displacement law
[ ] Planck distribution theory  [ ] Stefan statement

9. The relationship between the conduction shape factor and the thermal resistance is given by______________
[ ] $S = (k \times R)$  [ ] $S = 1/(k \times R)$  [ ] $S = (k \times R)^{1/2}$  [ ] $S = 1/2(k \times R)$

10. The thickness of thermal boundary layer at any location along the surface at temperature $T_s$ and initial temperature $T_\infty$ is the distance from the surface at which the temperature difference equals ______________

[ ] $0.99 (T_s - T_\infty)$ [ ] $0.99 (T_\infty - T_s)$ [ ] $0.99 T_\infty$ [ ] zero

11. The quantity that describes the magnitude of radiation emitted in a specified direction in space is ______________

[ ] solid angle [ ] radiosity
[ ] radiation intensity [ ] emissivity

12. Sensible heat is the heat required to _________________

[ ] change vapor into liquid [ ] change liquid into vapor
[ ] increase the temperature of liquid or vapor [ ] convert saturated steam into dry steam

13. Fin length that cause efficiency to drop below ______ percent usually cannot be justified economically.

[ ] 50 [ ] 60 [ ] 70 [ ] 80

14. Studies show that error involved in 1 D fin analysis is negligible when $h\delta/k$ is________.

[ ] 0 [ ] < 0.1 [ ] < 0.2 [ ] < 0.3

15. The area density for a compact heat exchanger is at least ___________

[ ] 600 $m^2/m$ [ ] 600 $m^2/m^3$ [ ] 700 $m^2/m$ [ ] 700 $m^2/m^3$

16. __________ is not helpful in enhancing the nucleate boiling heat transfer and maximum heat flux.

[ ] mechanical agitation [ ] surface vibration [ ] surface polishing [ ] finned surface

17. The normal automotive radiator is a ___________ type heat exchange.

[ ] direct contact [ ] parallel flow [ ] counter flow [ ] cross flow

18. In a typical laboratory base shell and tube heat exchanger the flow parameters are measured by _____________

[ ] pressure Gauge [ ] Venturi meter [ ] Rotameter [ ] Orifice meter

19. Milk spills over when it is boiled in an open vessel. The boiling of milk in this instant is referred to as _______________

[ ] interface evaporation [ ] sub-cooled boiling
[ ] Rotameter [ ] Orifice meter

20. The hydrodynamic and thermal boundary layer are identical at Prandtl number equal to _________________

[ ] 0.5 [ ] 1 [ ] 10 [ ] 50

KATHMANDU UNIVERSITY
End Semester Examination
August/September, 2017



Level : B. Tech.
Year : III
Time : 2 hrs. 30 mins.

Course : MEEG 306
Semester : II
F. M. : 55

SECTION "B"
[5Q × 11 = 55 marks]

Attempt *ALL* questions. Formula sheet is attached with the question paper; any extra data sheet is not allowed. Assume suitable data if necessary.

**1.**

a. Two large parallel planes with emissivity 0.6 are at 900 K & 300 K. A radiation shield with one side polished, having emissivity of 0.05, while the emissivity of other side is 0.4 is proposed to be used. Which side of the shield to face the hotter plane, if the temperature of shield is kept minimum? [5]

b. Explain Wien's Displacement Law with proper figure and representative equations. [3]

c. Determine the value of Stefan Boltzmann's constant using Max Planck's distribution law. [3]

**2.**

a. A counter flow heat exchanger operates under the following conditions:
Fluid A, inlet and outlet temperatures 80 $^0$C and 40 $^0$C.
Fluid B, inlet and outlet temperatures 20 $^0$C and 40 $^0$C.
The exchanger is cleaned, causing an increase in overall heat transfer coefficient by 10 % and the inlet temperature of fluid B is changed to 30 $^0$C, what would be the new outlet temperatures of fluid A and B? Assume heat transfer coefficient and capacity rates are unchanged by temperature changes. [4]

b. Draw a typical labeled flow-boiling curve. [4]

c. An industrial freezer is designed to operate with an internal air temperature of -20 $^0$C when the external air temperature is 25 $^0$C and the internal and external heat transfer coefficients are 12 W/m$^2$ K and 8 W/m$^2$ K, respectively. The walls of the freezer are composite construction, comprising of an inner layer of plastic (k = 1 W/m K, and thickness of 3 mm), and an outer layer of stainless steel (k = 16 W/m K, and thickness of 1 mm). Sandwiched between these two layers is a layer of insulation material with k = 0.07 W/M K. Find the width of the insulation that is required to reduce the convective heat loss to 15 W/m$^2$. [3]

**3.**

a. An aluminum heat sink (Figure 1) for electronics components has a base of length 50 mm and width 70 mm. The eight aluminum (k = 180 W/m. K) fins are attached in such a way that their width is 70 mm. The fins are 12 mm long and 3 mm thick. The fins cooled by air at 25 $^0$C with a convective heat transfer coefficient of h = 10 W/m$^2$K. Assuming that the same value of heat transfer coefficient acts on the tip of the fins as along the rest of the external surface, determine: [5]

i. The heat flow through the heat sink for a base temperature of 50 $^0$C,
ii. The fin effectiveness, and efficiency,
iii. The length of the fin such that the heat flow is 95 % of the heat flow for an infinite long fin,
iv. The percentage increase in heat transfer with fins.

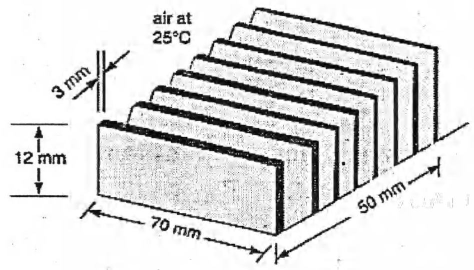


*Figure 1*

b. A turbine blade 5 cm long, 4.5 $cm^2$ cross-sectional area and 10 cm perimeter is made of stainless steel of thermal conductivity 100 kJ/m.hr.$^0$C. The temperature at the root of blade is 500 $^0$C and it is exposed to products of combustion passing through the turbine at 850 $^0$C. Determine the temperature at the middle of blade and the rate of heat flow from it. The film coefficient between the blade and the combustion gas is 1100 kJ/$m^2$.hr.$^0$C. The blade may be treated as a fin losing heat at the tip. [6]

**4.**

a. The temperature profile at a particular location on the surface of plate is prescribed by the identities:

i. $\frac{t_s - t}{t_s - t_\infty} = \sin\frac{\pi y}{0.015}$

ii. $\frac{t_s - t}{t_s - t_\infty} = \frac{1}{2}\left(\frac{y}{0.0075}\right)^3 + \frac{3}{2}\left(\frac{y}{0.0075}\right)$

If thermal conductivity of air is stated to be 0.03 W/m $^0$C, determine the value of convective heat transfer coefficient in each case. [5]

b. A nuclear reactor with its core constructed of parallel vertical plates 2.25 m high and 1.5 m wide has been designed on free convection heating of liquid bismuth (The properties of bismuth at any film temperature is listed as: $\rho = 10^4$ kg/$m^3$, $\mu = 3.12$ kg/m.hr, $K_f = 13.02$ W/m.$^0$C, & $C_p = 150.7$ J/kg.$^0$C). Metallurgical considerations limit the maximum surface temperature of the plate to 975 $^0$C and the lowest allowable temperature of bismuth is 325 $^0$C. Estimate the maximum possible heat dissipation from both sides of each plate and the film temperature. The appropriate correlation for the convection coefficient is $Nu = 0.13\ (Gr.\ Pr)^{1/3}$ where the different parameters are evaluated as the mean film temperature. [6]

**5.**

a. A plate 0.3 m long and 0.1 m wide with a thickness of 12 mm is made from stainless steel (k = 16 W/m K), the top surface is exposed to an airstream of temperature of 20 $^0$C. In an experiment, the plate is heated by an electrical heater (also 0.3 m by 0.1 m) positioned on the underside of the plate and the temperature of the plate adjacent to the heater is maintained at 100 $^0$C. A voltmeter and ammeter are connected to the heater and these read 200 V and 0.25 A, respectively. Assuming that the plate is perfectly insulated on all sides except the top surface, what is the convective heat transfer coefficient? (Consider heat loss by radiation as well). [5]

b. The insulation boards for air conditioning purposes comprise three layers. A 12 cm thick layer of grass (k = 0.022 W/m.K) is sandwiched between 3 cm thick layer of plywood (k = 0.15 W/m.K) on each side. The bonding is achieved with glue, which does not offer any resistance to heat flow. If the side surfaces of the board are maintained at 40 $^0$C and 20 $^0$C temperatures, determine the heat flux. How would the heat flux be affected if instead of glue, the three pieces are fastened by four steel bolts (k = 40 W/m.K) of 1.2 cm diameter at the corners? Draw the resistive circuit diagram for the same. [6]

Table - MEEG-306



| | |
|---|---|
| $Q = mc_p \Delta T = mc_p (T_2 - T_1)$ | $\dot{q} = \dfrac{\dot{Q}}{A_s} \left[\dfrac{\text{W}}{\text{m}^2}\right]$ |
| $\dot{Q}_{\text{cond}} = -k A_s \dfrac{dT}{dx}$ [W] | $\dot{Q}_{\text{conv}} = hA_s (T_s - T_\infty)$ [W] |
| $\dot{Q}_{\text{rad}} = \varepsilon \sigma A_s (T_s^4 - T_{\text{surr}}^4)$ [W] | $R_{\text{total}} = \dfrac{\Delta T}{\dot{Q}} \left[\dfrac{\text{K}}{\text{W}}\right]$ |
| $R_{\text{wall}} = \dfrac{L}{kA_s} \left[\dfrac{\text{K}}{\text{W}}\right]$ | $R_{\text{cyl}} = \dfrac{\ln(r_2/r_1)}{2\pi Lk} \left[\dfrac{\text{K}}{\text{W}}\right]$ |
| $R_{\text{sph}} = \dfrac{r_2 - r_1}{4\pi r_1 r_2 k} \left[\dfrac{\text{K}}{\text{W}}\right]$ | $R_{\text{rad}} = \dfrac{1}{h_{\text{rad}} A_s} \left[\dfrac{\text{K}}{\text{W}}\right]$ |
| $R_{\text{conv}} = \dfrac{1}{h\,A_s} \left[\dfrac{\text{K}}{\text{W}}\right]$ | $h_{\text{rad}} = \dfrac{\dot{Q}_{\text{rad}}}{A_s (T_s - T_\infty)} = \varepsilon \sigma (T_s^2 + T_\infty^2)(T_s + T_\infty) \left[\dfrac{\text{W}}{\text{m}^2\,\text{K}}\right]$ |
| $r_{\text{cr, cyl}} = \dfrac{k_{\text{ins}}}{h}$ [m] | $r_{\text{cr, sph}} = \dfrac{2k_{\text{ins}}}{h}$ [m] |
| $\dfrac{\partial}{\partial x}\left\{\dfrac{\partial T}{\partial x}\right\} + \dfrac{g}{k} = \dfrac{1}{\alpha}\dfrac{\partial T}{\partial t}$ | $\dfrac{1}{r}\dfrac{\partial}{\partial r}\left(r\dfrac{\partial T}{\partial r}\right) + \dfrac{g_0}{k} = \dfrac{1}{\alpha}\dfrac{\partial T}{\partial t} = \dfrac{\rho C}{k}\dfrac{\partial T}{\partial t}$ |
| $Q = \dfrac{T_{\infty_1} - T_{\infty_2}}{\Sigma R_{th}}$ ; | $Q_{\text{infinite fin}} = \sqrt{hPkA_c}\,(T_0 - T_\infty)$ |
| $m = \sqrt{\dfrac{hP}{kA_c}}$ | $\dfrac{T(x) - T_\infty}{T_0 - T_\infty} = e^{-mx}$ |
| $\dfrac{T_L - T_\infty}{T_0 - T_\infty} = \dfrac{1}{\cosh mL}$ | $\dfrac{T - T_\infty}{T_0 - T_\infty} = \dfrac{\cosh m(L-x) + \frac{h}{mk}\sinh m(L-x)}{\cosh mL + \frac{h}{mk}\sinh mL}$ |
| $Q_{\text{fin}} = \sqrt{hPkA_c}\,(T_0 - T_\infty) \times \dfrac{\sinh mL + \frac{h}{mk}\cosh mL}{\cosh mL + \frac{h}{mk}\sinh mL}$ | $\eta_{\text{fin}} = \dfrac{\tanh mL}{mL}$ |
| $\dot{Q}_{\text{adi. tip}} = \sqrt{hpkA_c}\,(T_b - T_\infty)\tanh mL$ | $Q_{\text{unfin}} = hA_{\text{unfin}}(T_0 - T_\infty)$ |
| $L_c = L + \dfrac{d}{4}$ **; for cylindrical fins** | $L_c = L + \dfrac{t}{2}$ **; For longitudinal Straight fins** |
| $A_c = w \times t$ | $A_{\text{unfin}} = w\,(H - N_{\text{fin}} t)$ |
| $\delta = \dfrac{5x}{\sqrt{\text{Re}_x}}$ | $h = \dfrac{1}{x}\int_0^x h_x\,dx$ |
| $\text{Nu}_x = \dfrac{h_x x}{k_f}$ | $\text{Re}_x = \dfrac{\rho u_\infty x}{\mu}$ |
| $\text{Pr} = \dfrac{\mu C_p}{k}$ | $\tau_s = \mu \left.\dfrac{\partial u}{\partial y}\right\|_{y=0}$ |
| $\tau_s = \dfrac{C_{fx}}{2}\rho u_\infty^2$ | $C_{fx} = \dfrac{2\mu}{\rho u_\infty^2}\left.\dfrac{\partial u}{\partial y}\right\|_{y=0}$ |

| | |
|---|---|
| $\varepsilon_{\text{fin}} = \frac{\dot{Q}_{\text{fin}}}{\dot{Q}_{\text{no fin}}} = \frac{\eta_{\text{fin}} h A_{\text{fin}} (T_b - T_\infty)}{h A_b (T_b - T_\infty)} = \eta_{\text{fin}} \frac{A_{\text{fin}}}{A_b}$ | $\text{Gr}_L = \frac{g \beta (T_s - T_\infty) L_c^3}{\nu^2}$ ; $\frac{g \rho^2 \beta \Delta T L_c^3}{\mu^2}$ |
| $\text{Ra}_L = \text{Gr}_L \Pr = \frac{g\beta(T_s - T_\infty) L_c^3}{\nu^2} \Pr$ | $F_f = \frac{1}{2} C_f A_s \rho V^2$ |
| $F_D = \frac{1}{2} C_D A_N \rho V^2$ | $\delta_x = \frac{4.91x}{\text{Re}_x^{1/2}}$ |
| $\tau_x = \frac{C_{fx}}{2} \rho u_\infty^2$ | $\delta_{th} = \frac{\delta}{1.026} \Pr^{-1/3}$ |
| $\tau_s = 2\, \tau_x$ , **Average shear stresss** | $h = 2h_x$ , **Average heat transfer coefficient** |
| $C_{f,x} = \frac{0.664}{\text{Re}_x^{1/2}}$ | $\text{Nu}_x = \frac{h_x x}{k} = 0.332 \text{Re}_x^{1/2} \Pr^{1/3}$ $\Pr > 0.6$ |
| $\text{Nu} = \frac{hL}{k} = 0.664 \text{Re}_L^{1/2} \Pr^{1/3}$ | $C_f = \frac{1.33}{\text{Re}_L^{1/2}}$ |
| $C_f = \frac{0.074}{\text{Re}_L^{1/5}} - \frac{1742}{\text{Re}_L}$<br>$5 \times 10^5 \leq \text{Re}_L \leq 10^7$ | $\text{Nu} = \frac{hL}{k} = (0.037 \text{Re}_L^{4/5} - 871) \Pr^{1/3}$<br>$0.6 \leq \Pr \leq 60$ $5 \times 10^5 \leq \text{Re}_L \leq 10^7$ |
| $\text{Nu}_{cyl} = \frac{hD}{k} = 0.3 + \frac{0.62 \text{Re}^{1/2} \Pr^{1/3}}{\left[\left(1 + (0.4/\Pr)^{2/3}\right)\right]^{1/4}} \left[1 + \left(\frac{\text{Re}}{282{,}000}\right)^{5/8}\right]^{4/5}$ | $\text{Nu}_{sph} = \frac{hD}{k} = 2 + \left[0.4 \text{Re}^{1/2} + 0.06 \text{Re}^{2/3}\right] \Pr^{2/5} \left(\frac{\mu_\infty}{\mu_s}\right)^{1/4}$ |
| $T_f = \frac{T_s + T_\infty}{2}$ | $\dot{q}_{\text{nucleate}} = \mu_l h_{fg} \left[\frac{g(\rho_l - \rho_v)}{\sigma}\right]^{1/2} \left[\frac{c_{pl}(T_s - T_{\text{sat}})}{C_{sf} h_{fg} \Pr_l^n}\right]^3$ |
| $q_{\max} = 0.149\, \rho_v^{1/2} h_{fg} [\sigma g(\rho - \rho_v)]^{1/4}$ | $Q = \dot{m}_e h_{fg}$ |
| $\dot{q}_{\max} = C_{cr} h_{fg} [\sigma g \rho_v^2 (\rho_l - \rho_v)]^{1/4}$ | $\dot{q}_{\min} = 0.09 \rho_v h_{fg} \left[\frac{\sigma g(\rho_l - \rho_v)}{(\rho_l + \rho_v)^2}\right]^{1/4}$ |
| $\dot{q}_{\text{rad}} = \varepsilon\sigma (T_s^4 - T_{\text{sat}}^4)$ | $\dot{q}_{\text{film}} = C_{\text{film}} \left[\frac{g k_v^3 \rho_v (\rho_l - \rho_v)[h_{fg} + 0.4 c_{pv} (T_s - T_{\text{sat}})]}{\mu_v D (T_s - T_{\text{sat}})}\right]^{1/4} (T_s - T_{\text{sat}})$ |
| $\dot{q}_{\text{total}} = \dot{q}_{\text{film}} + \frac{3}{4} \dot{q}_{\text{rad}}$ | $\text{Re} = \frac{D_h \rho_l V_l}{\mu_l} = \frac{4 A_c \rho_l V_l}{p \mu_l} = \frac{4 \rho_l V_l \delta}{\mu_l} = \frac{4\dot{m}}{p \mu_l}$ |
| $h_{fg}^* = h_{fg} + 0.68 c_{pl} (T_{\text{sat}} - T_s)$ | $h_{fg}^* = h_{fg} + 0.68 c_{pl} (T_{\text{sat}} - T_s) + c_{pv} (T_v - T_{\text{sat}})$ |
| $\dot{Q}_{\text{conden}} = h A_s (T_{\text{sat}} - T_s) = \dot{m} h_{fg}^*$ | $\text{Re} = \frac{4\dot{Q}_{\text{conden}}}{p \mu_l h_{fg}^*} = \frac{4 A_s h (T_{\text{sat}} - T_s)}{p \mu_l h_{fg}^*}$ |

| | |
|---|---|
| $h_{vert} = 0.943\left[\frac{g\rho_l(\rho_l-\rho_v)h^*_{fg}k_l^3}{\mu_l(T_{sat}-T_s)L}\right]^{1/4}$ | $Re \cong \frac{4g\rho_l(\rho_l-\rho_v)\delta^3}{3\mu_l^2} = \frac{4g\rho_l^2}{3\mu_l^2}\left(\frac{k_l}{h_{x=L}}\right)^3 = \frac{4g}{3\nu_l^2}\left(\frac{k_l}{3h_{vert}/4}\right)^3$ |
| $h_{vert} \cong 1.47k_l Re^{-1/3}\left(\frac{g}{\nu_l^2}\right)^{1/3}$ | $h_{vert, wavy} = \frac{Re\, k_l}{1.08\, Re^{1.22} - 5.2}\left(\frac{g}{\nu_l^2}\right)^{1/3}$ |
| $h_{vert, wavy} = 0.8\, Re^{0.11}\, h_{vert\,(smooth)}$ | $Re_{vert, wavy} = \left[4.81 + \frac{3.70\, Lk_l(T_{sat}-T_s)}{\mu_l h^*_{fg}}\left(\frac{g}{\nu_l^2}\right)^{1/3}\right]^{0.820}$, $\rho_v \ll \rho_l$ |
| $h_{inclined} = h_{vert}(\cos\theta)^{1/4}$ (laminar) | $h_{vert} = 0.943\left[\frac{g\rho_l(\rho_l-\rho_v)h^*_{fg}k_l^3}{\mu_l(T_{sat}-T_s)L}\right]^{1/4}$ |
| $\frac{h_{vert}}{h_{horiz}} = 1.29\left(\frac{D}{L}\right)^{1/4}$ | $h_{dropwise} = \begin{cases}51{,}104 + 2044T_{sat}, \\ 255{,}310\end{cases}$ |
| $h = 0.725\left[\frac{\rho(\rho-\rho_v)\,g\,h_{fg}\,k_f^3}{\mu\, D\,(T_{sat}-T_s)}\right]^{1/4}$ **Horizontal tube** | $h = 1.13\left\{\frac{g\,\rho\,(\rho-\rho_v)\,h_{fg}\,k_f^3}{\mu\, L\,(T_{sat}-T_s)}\right\}^{1/4}$ **Vertical tube** |
| $\varepsilon_{parallel\ flow} = \frac{1-\exp\left[-\frac{UA_s}{C_{min}}\left(1+\frac{C_{min}}{C_{max}}\right)\right]}{1+\frac{C_{min}}{C_{max}}}$ | $\varepsilon_{parallel\ flow} = \frac{1-\exp\left[-\frac{UA_s}{C_{min}}\left(1+\frac{C_{min}}{C_{max}}\right)\right]}{1+\frac{C_{min}}{C_{max}}}$ |
| $NTU = \frac{UA_s}{C_{min}} = \frac{UA_s}{(\dot{m}c_p)_{min}}$ | $\Delta T_{lm} = \frac{\Delta T_1 - \Delta T_2}{\ln(\Delta T_1/\Delta T_2)}$ |
| $q = \mu\, h_{fg}\left[\frac{g(\rho-\rho_v)}{\sigma}\right]^{1/2}\times\left[\frac{C_p\Delta T_e}{C_{sf}\, h_{fg}\, Pr^n}\right]^3$ | $c = \frac{C_{min}}{C_{max}}$ |
| $\varepsilon = \frac{1-\exp[-NTU(1+C)]}{1+C}$ | $\Sigma R_{th} = \frac{1}{h_i A_i} + \frac{R_{f,i}}{A_i} + \frac{\ln(d_o/d_i)}{2\pi L k} + \frac{R_{f,o}}{A_o} + \frac{1}{h_o A_o}$ |
| $\varepsilon_{counter} = \frac{T_{h,i} - T_{h,o}}{T_{h,i} - T_{c,i}}$ | $\tau = \frac{\int_{\lambda_1}^{\lambda_2}\tau_\lambda E_{b\lambda}\, d\lambda}{\sigma T^4}$ |
| $J = \varepsilon E_b + \rho G$ | $G = \frac{J - \varepsilon E_b}{1-\varepsilon}$ |
| $Q_{net} = \frac{A\varepsilon(E_b - J)}{1-\varepsilon}$ | $Q_{net} = A(J - G)$ |
| **Rate of Energy Absorbed = αAG** | $\lambda = \frac{c}{\nu}$ |
| $e = h\nu = \frac{hc}{\lambda}$ | $E_b(T) = \sigma T^4$ (W/m²) |
| $E_{b\lambda}(\lambda, T) = \frac{C_1}{\lambda^5[\exp(C_2/\lambda T) - 1]}$ (W/m² · μm) | $C_1 = 2\pi hc_0^2 = 3.74177\times10^8\ W\cdot\mu m^4/m^2$<br>$C_2 = hc_0/k = 1.43878\times10^4\ \mu m\cdot K$ |

Table – MEEG-306

| | |
|---|---|
| $E_b(T) = \int_0^\infty E_{b\lambda}(\lambda, T)\, d\lambda = \sigma T^4$ (W/m²) | $E_{b,\,0\text{–}\lambda}(T) = \int_0^\lambda E_{b\lambda}(\lambda, T)\, d\lambda$ (W/m²) |
| $f_\lambda(T) = \dfrac{\int_0^\lambda E_{b\lambda}(\lambda, T)\, d\lambda}{\sigma T^4}$ | $f_{\lambda_1\text{–}\lambda_2}(T) = f_{\lambda_2}(T) - f_{\lambda_1}(T)$ |
| $G_{\text{abs}} = \alpha G = \alpha\sigma T^4$ | $f_{\lambda_1-\lambda_2}(T) = \dfrac{\int_0^{\lambda_2} E_{b\lambda}(\lambda, T) d\lambda - \int_0^{\lambda_1} E_{b\lambda}(\lambda, T) d\lambda}{\sigma T^4} = f_{\lambda_2}(T) - f_{\lambda_1}(T)$ |
| $G_{\text{sky}} = \sigma T_{\text{sky}}^4$ (W/m²) | $F_{j\to i} = F_{i\to j}$ when $A_i = A_j$<br>$F_{j\to i} \neq F_{i\to j}$ when $A_i \neq A_j$ |
| $A_i F_{i\to j} = A_j F_{j\to i}$ | $\sum_{j=1}^{N} F_{i\to j} = 1$ |
| $F_{1\to(2,3)} = F_{1\to 2} + F_{1\to 3}$ | $J_i = E_{bi} = \sigma T_i^4$ (blackbody) |
| $\dot{Q}_{12,\text{ no shield}} = \dfrac{A\sigma(T_1^4 - T_2^4)}{\dfrac{1}{\varepsilon_1} + \dfrac{1}{\varepsilon_2} - 1}$ | $\dot{Q}_{12,\text{ one shield}} = \dfrac{E_{b1} - E_{b2}}{\dfrac{1-\varepsilon_1}{A_1\varepsilon_1} + \dfrac{1}{A_1F_{13}} + \dfrac{1-\varepsilon_{3,1}}{A_3\varepsilon_{3,1}} + \dfrac{1-\varepsilon_{3,2}}{A_3\varepsilon_{3,2}} + \dfrac{1}{A_3F_{32}} + \dfrac{1-\varepsilon_2}{A_2\varepsilon_2}}$ |
| $\dot{Q}_{12,\,N\text{ shields}} = \dfrac{A\sigma(T_1^4 - T_2^4)}{(N+1)\left(\dfrac{1}{\varepsilon} + \dfrac{1}{\varepsilon} - 1\right)} = \dfrac{1}{N+1}\dot{Q}_{12,\text{ no shield}}$ | $\dot{q}_{\text{conv, to sensor}} = \dot{q}_{\text{rad, from sensor}}$<br>$h(T_f - T_{\text{th}}) = \varepsilon\sigma(T_{\text{th}}^4 - T_w^4)$ |