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Indian Institute of Technology, Kharagpur

Date of Examination:	Time: 3Hrs. Full Marks 90
End Semester Exam. 2009	**3th Yr BTech**
Sub No. ME30005	Sub Name: **Heat Transfer**
No. of Students: 120	of the dept. of: **Mech Engg**

Answer all questions. The marks are given on the left margin in the box

[10] 1. A large copper plate of thickness 2 cm is initially at a uniform temperature of $30\,°C$. It suddenly receives a net radiation heat flux of 600 W/m^2 on one side and simultaneously air at a temperature of $30\,°C$ starts flowing on both sides of the plate. If the average convective heat transfer coefficient between air and the plate is 30 $W/m^2.K$, find the time required for the plate to reach steady state and the temperature of the plate at steady state. Properties of copper are: $k = 400$ W/m.K, $C_p = 385$ J/kg.K, $\rho \approx 8900$ kg/m^3.

[10] 2. A large, thick concrete wall initially at a uniformly high temperature is insulated on one side and is cooled by air flowing on the other side. Assuming constant wall properties,

(a) Develop a mathematical model that describes the heat transfer through the wall (but do not solve it) and show how this mathematical model is used to calculate the heat transfer rate from the wall to the air,

(b) Draw the temperature gradients inside the wall at the beginning and towards the end of the cooling process.

[10] 3. Explain briefly with suitable equation(s) the need for solving fluid mass, momentum and energy conservation equations to obtain the theoretical convection heat transfer rates.

Draw the boundary layer velocity and temperature profiles for fluid flow over a uniformly heated, horizontal, flat plate for the following cases:

(a) Flow is laminar and the Prandtl number of the fluid, $Pr << 1$

(b) Flow is laminar and the Prandtl number of the fluid, $Pr >> 1$

(c) Flow is turbulent

State under what assumptions the above profiles are valid.

[10] 4. Atmospheric air at $40\,°C$ with a free stream velocity of 8 m/sec flows along a flat plate of length 3 m and width 3 m. The plate is maintained at a temperature of $100\,°C$. Calculate the average heat transfer coefficient over the entire length of the plate and the heat transfer rate considering a transition Reynolds number of 5×10^5. Use the following properties for air, $k = 0.0295$ W/(m.K), $\nu = 2.0 \times 10^{-5}$ m^2/sec, $Pr = 0.7$. The following correlations for local Nusselt number may be used to obtain the required information:

$$\begin{aligned} \mathrm{Nu}_x &= 0.332\,\mathrm{Re}_x^{1/2}\mathrm{Pr}^{1/3} \quad \text{for } \mathrm{Re}_x \le 5\times10^5, \quad 0.6 \le \mathrm{Pr} \le 60 \\ \mathrm{Nu}_x &= 0.0296\,\mathrm{Re}_x^{4/5}\mathrm{Pr}^{1/3} \quad \text{for } 5\times10^5 \le \mathrm{Re}_x \le 10^8, \quad 0.6 \le \mathrm{Pr} \le 60 \end{aligned}$$

Show that almost the same answer can be obtained by using the following correlation for mixed, average forced convection over a flat plate instead of using separate correlations for laminar and turbulent flows

$$\overline{\mathrm{Nu}_L} = (0.037\,\mathrm{Re}_L^{4/5} - 871)\,\mathrm{Pr}^{1/3} \quad \text{for } \mathrm{Re}_x \le 10^8, \quad 0.6 \le \mathrm{Pr} \le 60$$

Continued...

10 5. An object of irregular shape has a characteristic length $L = 1\,m$ and is maintained at a uniform surface temperature of $T_s = 400\,K$. When placed in an atmospheric air at a temperature of $T_\infty = 300\,K$ and moving with a velocity of $V = 100\,m/s$ the average heat flux from surface to air is $20,000\,W/m^2$. If a second object of the same shape, but with a characteristic length of $L = 5\,m$, is maintained at a surface temperature of $T_s = 400\,K$ and is placed in atmospheric air at $T_\infty = 300\,K$ what will the value of the average convection coefficient be if the air velocity is $V = 20\,m/s$?

10 6. A counterflow double-pipe heat exchanger operates with hot water flowing inside the inner pipe and a polymer fluid flowing in the annular space between the two pipes. The water flow rate is 2.0 kg/s and it enters at $90°C$ and leaves at $60°C$. The polymer enters at a temperature of $10°C$ and leaves at a temperature of $50°C$. Calculate the value of the overall heat transfer coefficient expressed in $W/m^2\,°C$, if the area for heat exchange is $10m^2$. The specific heat of water is $4.18kJ/kg°C$

10 7. Calculate the view factor for the following configurations

(a) Calculate F_{21} and F_{22} if sphere 1 is placed concentrically inside sphere 2.

(b) Find out the view factor F_{12} for the infinitely long plates 1 and 2 if the plate 3 is partially obstructing the view. Use Hottel's crossed-strings method.

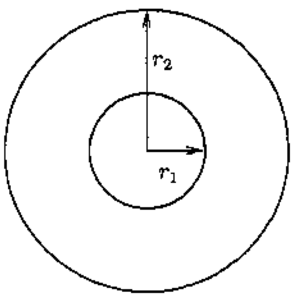

Figure (a)

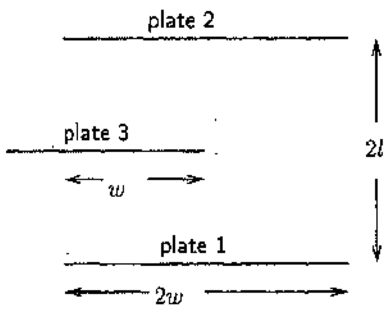

Figure (b)

10 8. A thermocouple junction in the form of a 2mm diameter sphere with a surface emissivity of 0.6 is placed in a moving hot gas stream at temperature of $500°C$ flowing through a large duct. What temperature will be indicated by a thermocouple if the duct surface temperature is $200°C$ and its emissivity $\epsilon = 0.9$. The convection heat transfer coefficient is $100W/m^2K$. The Stefan-Boltzmann constant $\sigma = 5.669 \times 10^{-8}\,W/m^2K^4$

10 9. A certain material at $1000K$ and surrounded by ambient air has the following spectral hemispherical emissivity.

$$\epsilon_\lambda = \begin{cases} 0.75 & \lambda < .8\mu m \\ 0.2 & \lambda > .8\mu m \end{cases}$$

(a) What is the total, hemispherical emissivity of this material with diffuse surface? The fractional blackbody emissive power $f(n\lambda T)$ contained between 0 and $(n\lambda T)$ is given in the attached table.

(b) If sun at $5700K$ irradiates this diffuse surface at a normal angle, what is the relevant total hemispherical absorptivity.

The fractional blackbody emissive power

$n\lambda T$ [μm K]	η/nT [cm^{-1}/K]	$E_{b\lambda}/n^3T^5$ [W/m$^2\mu$m K^5]	$E_{b\eta}/nT^3$ [W/m^{2}cm^{-1}K^3]	$f(n\lambda T)$
1000	10.0000	0.02110×10^{-11}	0.00211×10^{-8}	0.00032
1100	9.0909	0.04846	0.00586	0.00091
1200	8.3333	0.09329	0.01343	0.00213
1300	7.6923	0.15724	0.02657	0.00432
1400	7.1429	0.23932	0.04691	0.00779
1500	6.6667	0.33631	0.07567	0.01285
1600	6.2500	0.44359	0.11356	0.01972
1700	5.8824	0.55603	0.16069	0.02853
1800	5.5556	0.66872	0.21666	0.03934
1900	5.2632	0.77736	0.28063	0.05210

$n\lambda T$ [μm K]	η/nT [cm^{-1}/K]	$E_{b\lambda}/n^3T^5$ [W/m$^2\mu$m K^5]	$E_{b\eta}/nT^3$ [W/m^{2}cm^{-1}K^3]	$f(n\lambda T)$
3000	3.3333	1.28245×10^{-11}	1.15420×10^{-8}	0.27322
3100	3.2258	1.27242	1.22280	0.29576
3200	3.1250	1.25702	1.28719	0.31809
3300	3.0303	1.23711	1.34722	0.34009
3400	2.9412	1.21352	1.40283	0.36172
3500	2.8571	1.18695	1.45402	0.38290
3600	2.7778	1.15806	1.50084	0.40359
3700	2.7027	1.12739	1.54340	0.42375
3800	2.6316	1.09544	1.58181	0.44336
3900	2.5641	1.06261	1.61623	0.46240
4000	2.5000	1.02927	1.64683	0.48085
4100	2.4390	0.99571	1.67380	0.49872
4200	2.3810	0.96220	1.69731	0.51599
4300	2.3256	0.92892	1.71758	0.53267
4400	2.2727	0.89607	1.73478	0.54877
4500	2.2222	0.86376	1.74912	0.56429
4600	2.1739	0.83212	1.76078	0.57925
4700	2.1277	0.80124	1.76994	0.59366
4800	2.0833	0.77117	1.77678	0.60753
4900	2.0408	0.74197	1.78146	0.62088
5000	2.0000	0.71366	1.78416	0.63372
5100	1.9608	0.68628	1.78502	0.64606
5200	1.9231	0.65983	1.78419	0.65794
5300	1.8868	0.63432	1.78181	0.66935
5400	1.8519	0.60974	1.77800	0.68033