Fall 2019 Qualifying Exam – Conduction Heat Transfer (Q1) – Closed Book

Transient Temperature Distribution in a Thin Slab

A very large (in *Y* and *Z* directions) thin slab is used inside the wall of a building. It is made of a porous material and has a thickness of 2 cm (in the *X* direction). It is initially at 40 ^{0}C on a hot day. Suddenly, the temperatures of both the large surfaces are reduced to 30 ^{0}C for all *t*>0 where *t* is the time in seconds. Develop an analytical expression for the transient temperature distribution *T*(*x*,*t*) in the porous slab. Assume the effective density of the slab is 850 kg/m^3 and the effective specific heat is 1900 J/kg·K.

Equations

$$\frac{\partial}{\partial x}\left(k\frac{\partial T}{\partial x}\right)+\frac{\partial}{\partial y}\left(k\frac{\partial T}{\partial y}\right)+\frac{\partial}{\partial z}\left(k\frac{\partial T}{\partial z}\right)+\dot{q}=\rho\cdot c_p\frac{\partial T}{\partial t}$$

$$\frac{\partial^2 X}{\partial x^2}+\lambda^2 X=0\ ;\ \text{Solution: } X(x)=A\cos(\lambda x)+B\sin(\lambda x)$$

$$\frac{\partial^2 X}{\partial x^2}-\lambda^2 X=0\ ;\ \text{Solution: } X(x)=Ae^{-\lambda x}+Be^{\lambda x}$$

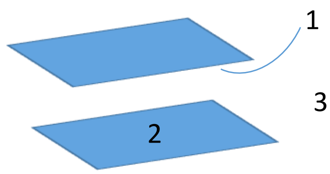
$$\frac{\partial X}{\partial t}+c\lambda^2 X=0\ ;\ \text{Solution: } X(t)=De^{-c\lambda^2 t}$$

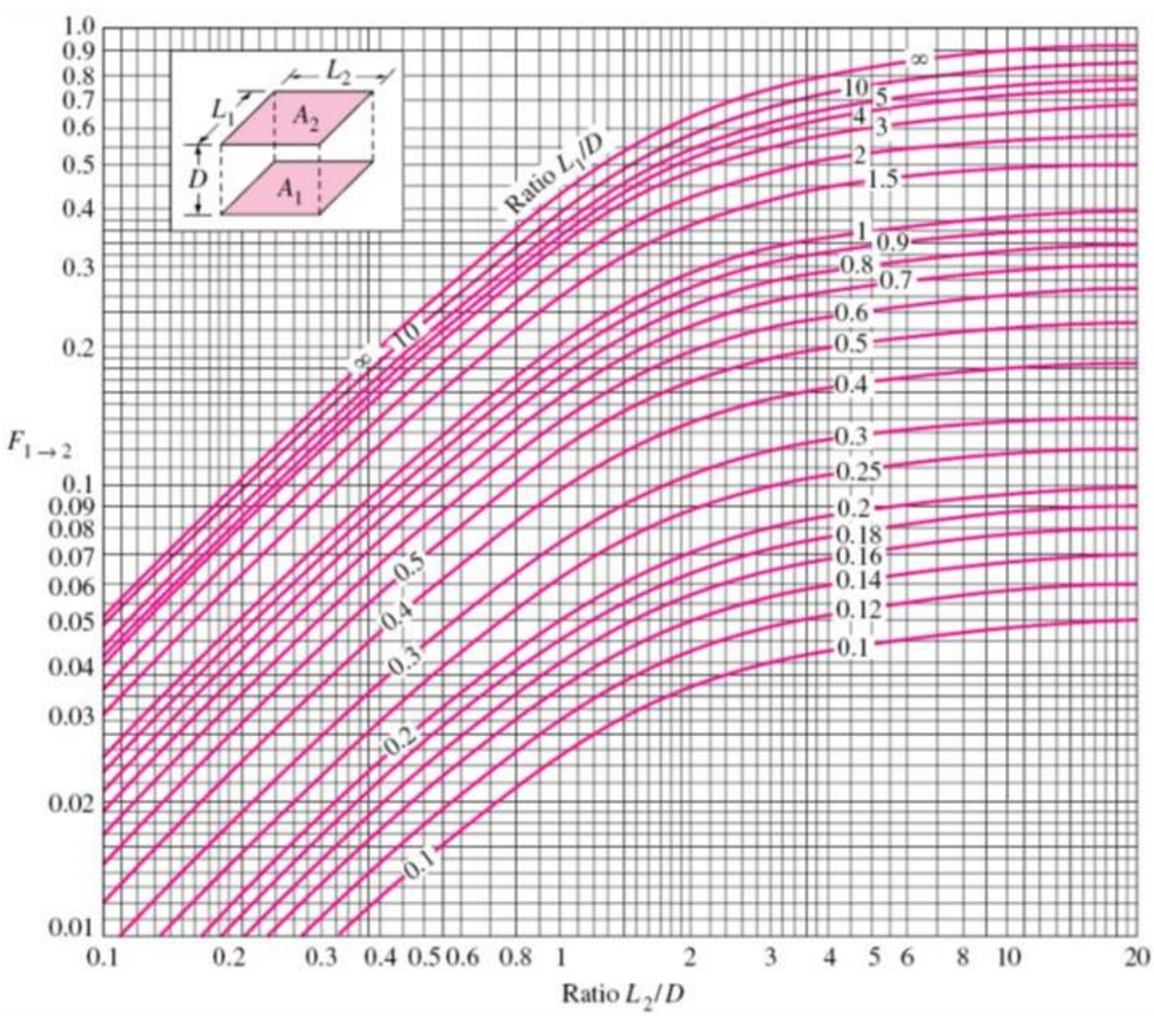
$$\sin^2(x)=\frac{1-\cos(2x)}{2}$$

Fall 2019 Qualifying Exam – Radiation Heat Transfer (Q2) – Closed Book

Real Body Radiation

Two parallel plates 0.5 m X 1 m are spaced 0.5 m apart. One plate is maintained at 1000 ^oC and the other at 500 ^oC. The plates have emissivities of 0.2 and 0.5 respectively and are located in a very large room whose walls are at 27 ^oC. The surfaces of the plates that are facing each other (surfaces 1 and 2) are exchanging heat between them and the room (surface 3). The backsides of the plates are thoroughly insulated. Find the net heat transfer rate to each plate and to the room.





Fall 2019 Qualifying Exam – Thermodynamics (Q3) – Closed Book

Gas Mixtures

(a) A mixture of 60% N_2, 30% Ar and 10% O_2 on a mass basis is in a cylinder at 250 kPa, 310 K and volume 0.5 m^3. Find the mole and the mass fractions and the mass of argon.

(b) A slightly oxygenated air mixture is 69% N_2, 1% Ar and 30% O_2 on a mole basis. Assume a total pressure of 101 kPa and find the mass fraction of oxygen and its partial pressure.

$$\mathrm{mf}_i = \frac{m_i}{m_m} \quad \text{and} \quad y_i = \frac{N_i}{N_m} \qquad M_m = \frac{m_m}{N_m} = \sum_{i=1}^{k} y_i M_i \quad \text{and} \quad R_m = \frac{R_u}{M_m}$$

$$m_m = \sum_{i=1}^{k} m_i \quad \text{and} \quad N_m = \sum_{i=1}^{k} N_i \qquad \mathrm{mf}_i = y_i \frac{M_i}{M_m} \quad \text{and} \quad M_m = \frac{1}{\sum_{i=1}^{k} \frac{\mathrm{mf}_i}{M_i}}$$

$$\frac{P_i}{P_m} = \frac{V_i}{V_m} = \frac{N_i}{N_m} = y_i$$

$R_m = \Sigma\, c_i \cdot R_i$ $\qquad$ *Pv = RT* $\qquad$ R_u = 8.31447 kJ/kmol·K

Molar mass, gas constant, and critical-point properties

Substance	Formula	Molar mass, *M* kg/kmol	Gas constant, *R* kJ/kg · K*
Air	—	28.97	0.2870
Ammonia	NH_3	17.03	0.4882
Argon	Ar	39.948	0.2081
Benzene	C_6H_6	78.115	0.1064
Bromine	Br_2	159.808	0.0520
n-Butane	C_4H_{10}	58.124	0.1430
Carbon dioxide	CO_2	44.01	0.1889
Carbon monoxide	CO	28.011	0.2968
Carbon tetrachloride	CCl_4	153.82	0.05405
Chlorine	Cl_2	70.906	0.1173
Chloroform	$CHCl_3$	119.38	0.06964
Dichlorodifluoromethane (R-12)	CCl_2F_2	120.91	0.06876
Dichlorofluoromethane (R-21)	$CHCl_2F$	102.92	0.08078
Ethane	C_2H_6	30.070	0.2765
Ethyl alcohol	C_2H_5OH	46.07	0.1805
Ethylene	C_2H_4	28.054	0.2964
Helium	He	4.003	2.0769
n-Hexane	C_6H_{14}	86.179	0.09647
Hydrogen (normal)	H_2	2.016	4.1240
Krypton	Kr	83.80	0.09921
Methane	CH_4	16.043	0.5182
Methyl alcohol	CH_3OH	32.042	0.2595
Methyl chloride	CH_3Cl	50.488	0.1647
Neon	Ne	20.183	0.4119
Nitrogen	N_2	28.013	0.2968
Nitrous oxide	N_2O	44.013	0.1889
Oxygen	O_2	31.999	0.2598
Propane	C_3H_8	44.097	0.1885
Propylene	C_3H_6	42.081	0.1976
Sulfur dioxide	SO_2	64.063	0.1298
Tetrafluoroethane (R-134a)	CF_3CH_2F	102.03	0.08149
Trichlorofluoromethane (R-11)	CCl_3F	137.37	0.06052
Water	H_2O	18.015	0.4615
Xenon	Xe	131.30	0.06332

Fall 2019 Qualifying Exam – Convection Heat Transfer (Q4) – Closed Book

Laminar Flow through a Pipe

"Slug" flow in a pipe may be described as that flow in which the velocity is constant across the entire flow area of the tube, i.e., $u = u_0$ (constant). Obtain an expression for the heat-transfer coefficient and the Nusselt number in this type of flow with a constant-heat-flux condition maintained at the wall.

Equations

$$\alpha \cdot \frac{1}{r} \cdot \frac{\partial}{\partial r}\left(r \cdot \frac{\partial T}{\partial r}\right) = u \cdot \frac{\partial T}{\partial z}$$

T_m : Bulk Mean Temperature
or
Mixing Cup Temperature

$$T_m = \frac{\oint \rho \cdot c_p \cdot u \cdot T \cdot dA}{\oint \rho \cdot c_p \cdot u \cdot dA}$$

$$h = \frac{-k \cdot (\partial T / \partial r)_{r=R}}{T_W - T_m}$$

$$\overline{Nu_D} = \frac{\bar{h} \cdot D}{k}$$