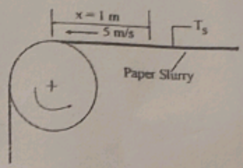
Transport Phenomena (CH30012)
Class Test **12.04.2024**

1. In a paper mill drying process, a sheet of paper slurry (water-fibre mixture) has a linear velocity of 5 m/s as it is rolled. Radiant heaters maintain a sheet temperature of $T_s = 330$ K, as evaporation occurs to dry, ambient air at 300 K, above and below the sheet. What is the evaporative flux at a distance of x = 1 m from the leading edge of the roll? What is the corresponding value of radiation flux (irradiation, G) that must be supplied to the sheet to maintain the temperature at 330 k? The sheet has an absorptivity of 1. Properties: Air (T_f= 315 K, 1 atm): $\gamma = 17.4\times10^{-6}$ m²/s, k = 0.0274 W/m.K, Pr = 0.705, Water vapor - Air (T_f= 315 K): $D_{AB} = 0.28 \times 10^{-4}$ m²/s, Sc = 0.616, Sat. water vapor (T_s = 330 K): $\rho_{A,\,sat} = 0.1134$ kg/m³, h_{fg} = 2366 kJ/kg

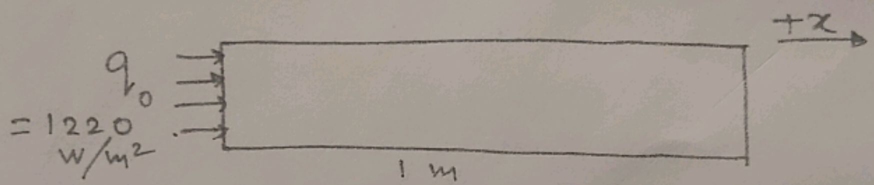


$Sh_x = 0.332 Re_x^{1/2}\ Sc^{1/3}$ $\overline{Sh} = 0.664 Re_x^{1/2}\ Sc^{1/3}$

Reynold's Analogy $St = \frac{C_{fx}}{2}$, $St = Nu/(Re.Pr)$: Chilton Coulburn Analogy $\frac{C_f}{2} = St.Pr^{\frac{2}{3}} = St_m.Sc^{\frac{2}{3}}$ **Marks 10**

2. Consider a wooden block (initial temperature = 25°C) of length 1m (as shown in figure below), whose one surface is exposed to constant solar flux of 1220 W/m². Determine the temperature of exposed surface after 20min. Consider only 1D heat transfer in +x direction. Properties of wood: thermal conductivity = 0.16 W/(m.K), thermal diffusivity = 1.8×10^{-7} m2/s. (You can skip the derivation, partial marking will be provided only for right approach). **Marks 10**

$h'_{A,x}$



Relations/Equations:

$Sc = \frac{\mu}{\rho D_{AB}}$ $Sh = \frac{h_m l}{D_{AB}}$ $St = \frac{Nu}{Re*Pr}$ $Fo = \frac{\alpha t}{l^2}$ $Bi = hl/k_s$ $Le = \frac{\alpha}{D_{AB}}$ $C_f = \frac{\tau_w}{\frac{1}{2}\rho v^2}$ $C_D = \frac{F_D/A_P}{\frac{1}{2}\rho v^2}$

Flow over flat plate

Laminar flow ($0.6 \le Pr \le 60$, $Re \le 5\times10^5$) $\delta = \frac{5x}{\sqrt{Rex}}$ $C_{fx} = \frac{0.664}{\sqrt{Rex}}$ $C_{fL} = \frac{1.328}{\sqrt{Rex}}$ $Nu_x = 0.332 Re_x^{1/2}\ Pr^{1/3}$ $\overline{Nu} = 0.664 Re_x^{1/2}\ Pr^{1/3}$

Turbulent flow $\delta = \frac{0.37x}{Rex^{1/5}}$ $\frac{\overline{V_z}}{U} = \left(\frac{y}{R}\right)^{\frac{1}{7}}$ $C_{fx} = \frac{0.0577}{Rex^{1/5}}$ ($Re \ge 5\times10^5$)

$C_D = \frac{0.455}{\log(Re_l)^{2.88}}$ ($Re \ge 5\times10^9$)

$Nu_x = 0.0296 Re_x^{4/5}\ Pr^{1/3}$ $\overline{Nu_l} = 0.037 Re_l^{4/5}\ Pr^{1/3}$

Mixed flow

$C_f = \frac{0.072}{Re_l^{1/5}} - \frac{1740}{Re_l}$ $Re \le 10^7$ $C_D = \frac{0.455}{\log(Re_l)^{2.88}} - \frac{1610}{Re_l}$ $Re \ge 10^7$ $\overline{Nu_l} = \left(0.037 Re_l^{\frac{4}{5}} - 871\right) Pr^{\frac{1}{3}}$ $5\times10^5 \le Re \le 10^7$

Reynold's Analogy $St = \frac{C_{fx}}{2}$, $St = Nu/(Re.Pr)$; Chilton Coulburn Analogy

$$St \times Pr^{2/3} = \frac{C_{fx}}{2} \quad 0.5 \le Pr \le 50$$

error function: $erf(z) = \left(2/\sqrt{\pi}\right)\int_0^z \exp(-t^2)dt$, gamma function : $\Gamma(z) = \int_0^\infty t^{z-1} e^{-t}\, dt$, and $\Gamma(1/2) = \sqrt{\pi}$

complementary error function, erfc(y) = 1-erf(y), erf(0)=0, erf(∞)=1 .

$$\int erfc(ay)dy = y\left(erfc(ay)\right) - \left(1/a\sqrt{\pi}\right)\exp\left(-a^2y^2\right), \qquad \frac{d(erf(y))}{dy} = \frac{2}{\sqrt{\pi}}\exp(-y^2)$$