Solution 1

Given : volume of ice cream pack $(V) = 0.2 \times 0.1 \times 0.07 \ m^3$

$= 1.4 \times 10^{-3} \ m^3$

Initial temperature of ice cream $(T_0) = -10^\circ C$

Time $(t) =$ 20 minutes

$=$ 1200 seconds

Ice cream properties →

$K = 2.2 \ W/m^\circ C$

$C = 1800 \ J/kg^\circ C$

$\rho = 900 \ kg/m^3$

$h = 10 \ W/m^2 \, {}^\circ C$

Assumptions

i) Internal energy and the temperature of the ice-cream decreases as a result of transient heat conduction.

ii) Assuming atmospheric temperature (T_∞) as $25^\circ C$

Analysis

The Biot number (Bi) is determined from

$$Bi = \frac{h L_c}{K}$$

Here L_c = charachteristic length of the ice cream pack

$$= \frac{\text{Volume}}{\text{Surface area}}$$

$$= \frac{1.4 \times 10^{-3}}{2[(0.2)(0.1) + (0.1)(0.07) + (0.07)(0.2)]}$$

$\Rightarrow \ L_c = 0.017 m$

$$\Rightarrow Bi = \frac{h L_c}{K} = \frac{10 \times 0.017}{2.2}$$

$$= 0.077$$

Since Biot number is less than 0.1

therefore, lumped analysis is valid

⇒ we can assume the whole ice-cream pack at uniform temperature and write the following relation using energy conservation equation

i.e. $$\frac{T - T_\infty}{T_i - T_\infty} = e^{-\left(\frac{h A_s}{\rho V C_p}\right) t}$$

Here, T_i = initial temperature of ice-cream pack $= -10°C$

T = final temperature of ice-cream pack

T_∞ = surrounding temperature $= 25°C$

A_s = surface area of ice cream pack

$\frac{V}{A_s} = L_c$ = characteristic length $= 0.017\,m$

C_p = Heat capacity of ice cream =

Putting given values in above relation →

$$\frac{T - 25}{-10 - 25} = e^{-\left(\frac{10 \times 1200}{900 \times 0.017 \times 1800}\right)}$$

$$\Rightarrow \frac{T - 25}{-35} = e^{-0.435}$$

$$\Rightarrow T - 25 = (-35)(0.647) = -22.6°C$$

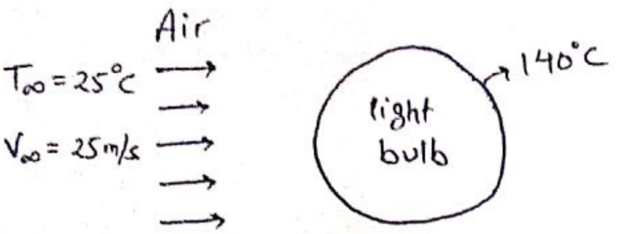
$$\Rightarrow \boxed{T = 2.36°C}$$

Since, the final temperature of the ice cream (i.e. 2.36°c)

is above 0°c, it will melt.

And the kids $\boxed{\text{will not eat}}$ the ice-cream

Solution 2



Diameter = 50mm
= 0.05 m

Fig: schematic of the problem

Assumptions

i) steady operating conditions exist

ii) Radiation effects are negligible

iii) Air behaves like an ideal gas

iv) The outer surface temperature of the light bulb is uniform at all times.

v) The surface temperature of the light bulb is kept constant.

Properties

The dynamic viscosity of air at the surface temperature is

$\mu_s = \mu_{@140°c} = 2.345 \times 10^{-5}$ Kg/m-s.

The properties of air at the free stream temperature of 25°C and atmospheric pressure are obtained from (table A-15)

$K = 0.02551$ W/m°c

$\nu = 1.562 \times 10^{-5}$ m²/s

$\mu = 1.849 \times 10^{-5}$ Kg/m.s

$Pr = 0.7296$

Scanned with CamScanner

Reynolds number is determined from

$$Re = \frac{VD}{\nu}$$

$$= \frac{(25\,m/s)(0.05\,m)}{1.562 \times 10^{-5}\,m^2/s}$$

$$= \underline{\underline{8 \times 10^{4}}}$$

The Nusselt number is determined from Whitaker correlation for flow over a sphere $\rightarrow$

$$Nu = \frac{hD}{K} = 2 + \left[0.4\,Re^{1/2} + 0.06\,Re^{2/3}\right] Pr^{0.4} \left(\frac{\mu_\infty}{\mu_s}\right)^{1/4}$$

$$= 2 + \left[0.4\,(8 \times 10^{4})^{1/2} + 0.06\,(8 \times 10^{4})^{2/3}\right] (0.7296)^{0.4} \times \left(\frac{1.849 \times 10^{-5}}{2.345 \times 10^{-5}}\right)^{1/4}$$

$$= 2 + \left[113.155 + 111.422\right](0.881)(0.893)$$

$$= \underline{\underline{178.64}}$$

$\Rightarrow$ the average convection heat transfer coefficient becomes

$$h = \frac{K}{D} Nu$$

$$= \frac{0.02551\,W/m^\circ C}{0.05\,m} \times 178.64$$

$$= \underline{\underline{91.145\,W/m^2\,^\circ C}}$$

$\Rightarrow$ Heat transfer rate from the light bulb to the surrounding is given by $\rightarrow$

$$\dot{Q} = h A_s (T_s - T_\infty)$$

Here A_s = surface area = $4\pi r^2$

T_s = surface temperature of light bulb = 140°C

T_∞ = surrounding air temperature = 25°C

$$\Rightarrow \dot{Q} = (91.145 \ W/m^2 \, ^\circ C)\left(4\pi\left(\frac{0.05}{2}\right)^2\right)m^2 \, (140-25)\, ^\circ C$$

$$= (91.145)(7.857 \times 10^{-3})(115) \ W$$

$$= \boxed{82.35 \ W}$$

Solution 3

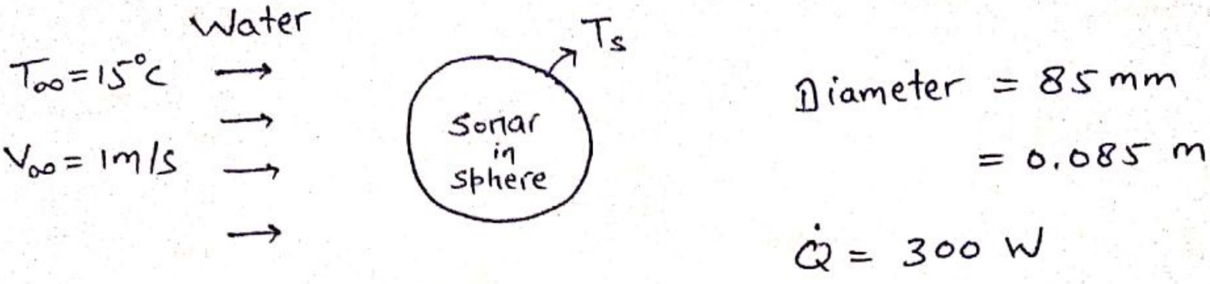


Fig: schematic of the problem

Assumptions

i) steady operating conditions exist

ii) Radiation effects are negligible

iii) Air behaves like an ideal gas

iv) The outer surface of the sphere has uniform temperature.

Properties of water

The dynamic viscosity of water at the surface temperature is $\mu_s = \mu_{@T_s}$

The properties of water at the free stream temperature of 15°c are as follows

$K = 0.588$ W/mK

$\nu = 1.15 \times 10^{-6} \, m^2/s$

$\mu = 1.15 \times 10^{-3} \, Ns/m^2$

$Pr = 8.23$

Reynolds number is given by

$$Re = \frac{VD}{\nu}$$

$$= \frac{(1\,m/s)(0.085\,m)}{1.15\times10^{-6}\,m^2/s}$$

$$= 73913$$

Nusselt number is given by

$$Nu = \frac{hD}{K} = 2 + \left[0.4\,Re^{1/2} + 0.06\,Re^{2/3}\right]\left[Pr^{0.4}\right]\left(\frac{\mu_\infty}{\mu_s}\right)^{1/4}$$

$$= 2 + \left[0.4\,(73913)^{1/2} + (0.06)(73913)^{2/3}\right](8.23)^{0.4}\left(\frac{\mu_\infty}{\mu_s}\right)^{1/4}$$

$$= 2 + (108.74 + 105.67)(2.32)\left(\frac{\mu_\infty}{\mu_s}\right)^{1/4}$$

$$= 2 + 498.22\left(\frac{\mu_\infty}{\mu_s}\right)^{1/4} \quad (1)$$

Now, Dynamic viscosity of water at various temperatures →

$$\mu_\infty = \mu_{15°c} = 1.15\times10^{-3}$$

$$\mu_{20°c} = 1.002\times10^{-3}$$

⇒ by interpolation

$$\mu_T = (1.612 - 0.0305\,T)\times10^{-3}$$

⇒ Putting in equation (1)

$$Nu = 2 + 498.22\left(\frac{1.15\times10^{-3}}{(1.612 - 0.0305\,T_s)\times10^{-3}}\right)^{1/4}$$

$$\Rightarrow Nu = 2 + 498.22 \times \left(\frac{1.15}{1.612 - 0.0305\,T_s}\right)^{1/4}$$

$\Rightarrow$ averege convection heat trons fer coefficient is given by $\rightarrow$

$$h = \frac{K}{D} Nu$$

$$= \left(\frac{0.588}{0.085}\right)\left[2 + 498.22 \times \left(\frac{1.15}{1.612 - 0.0305\,T_s}\right)^{1/4}\right]$$

$$= 13.835 + 3446.51 \times \left(\frac{1.15}{1.612 - 0.0305\,T_s}\right)^{1/4}$$

given Heat trons fer rate $\dot{Q} = 300W$

$$\Rightarrow \dot{Q} = 300W = h A_s (T_s - T_\infty)$$

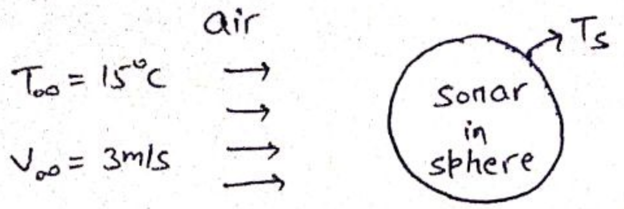
$$\Rightarrow \quad 300 = \left[13.835 + 3446.51 \times \left(\frac{1.15}{1.612 - 0.0305\,T_s}\right)^{1/4}\right]\left(4\pi\left(\frac{0.085}{2}\right)^2\right) \times (T_s - 15)$$

$$\Rightarrow 2 \times 6605.85 = (T_s - 15)\left[13.835 + 3446.51 \times \left(\frac{1.15}{1.612 - 0.0305\,T_s}\right)^{1/4}\right]$$

By solving above equation, we get

$\boxed{T_s = 18.89°C}$ sonar surface temperature

Now, when the sonar was put into air →



Properties of air at free stream temperature of 15°C →

$k = 0.02476 \ W/mK$

$\nu = 1.470 \times 10^{-5} \ m^2/s$

$Pr = 0.7323$

$\mu = 1.8 \times 10^{-5} \ Ns/m^2$

Reynolds number is given by →

$$Re = \frac{VD}{\nu}$$

$$= \frac{(3 m/s)(0.085 m)}{1.470 \times 10^{-5} \ m^2/s}$$

$$= \underline{\underline{17347}}$$

Nusselt number is given by

$$Nu = \frac{hD}{K} = 2 + \left[0.4 Re^{1/2} + 0.06 Re^{2/3}\right](Pr^{0.4})\left(\frac{\mu_\infty}{\mu_s}\right)^{1/4}$$

$$= 2 + \left[0.4(17347)^{1/2} + 0.06(17347)^{2/3}\right](0.7323)^{0.4}\left(\frac{\mu_\infty}{\mu_s}\right)^{1/4}$$

$$= 2 + 82\left(\frac{\mu_\infty}{\mu_s}\right)^{1/4} \quad (2)$$

Now, dynamic viscosity of air at various temperatures $\rightarrow$

$$\mu_\infty = \mu_{15^\circ c} = 1.8 \times 10^{-5}$$

$$\mu_{20^\circ c} = 1.825 \times 10^{-5}$$

$\Rightarrow$ by interpolation

$$\mu_T = (1.731 + 0.0047\,T) \times 10^{-5}$$

Putting in equation (2)

$$Nu = \frac{hD}{K} = 2 + 82 \times \left(\frac{1.8}{1.731 + 0.0047T}\right)^{1/4}$$

$$\Rightarrow h = \frac{K}{D} Nu = \frac{0.02476}{0.085} \times \left[2 + 82 \times \left(\frac{1.8}{1.731 + 0.0047T}\right)^{1/4}\right]$$

$$= 0.582 + 23.89 \left(\frac{1.8}{1.731 + 0.0047T}\right)^{1/4}$$

given, Heat transfer rate $\dot{Q} = 300W$

$$\Rightarrow \dot{Q} = 300W = h A_s (T_s - T_\infty)$$

$$\Rightarrow 300 = \left[0.582 + 23.89\left(\frac{1.8}{1.731 + 0.0047\,T_s}\right)^{1/4}\right]\left(4\pi\left(\frac{0.085}{2}\right)^2\right)(T_s - 15)$$

$$\Rightarrow 13211.7 = (T_s - 15)\left[0.582 + 23.89\left(\frac{1.8}{1.731 + 0.0047\,T_s}\right)^{1/4}\right]$$

By solving above equation, we get

$\boxed{T_s = 709.34^\circ C}$ sonar surface temperature

Since, the surface temperature of sphere (i.e. 709.34°C) in air is very high, this is a reason of concern. It may result in temperature stress on sphere material.

Solution 4

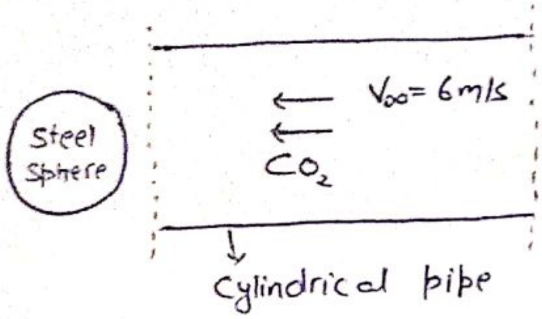


Fig: schematic of the problem

given, diameter of sphere = d = 5cm

diameter of pipe = D = 10cm

Pipe temperature at entrance = 350K

Pipe temperature at exit = 550K

$\Rightarrow$ Average temperature of pipe = $\frac{350K + 550K}{2}$

= 450K

gas temperature at entrance = 300 K

gas temperature at exit = 340 K

$\Rightarrow$ Average temperature of gas = $\frac{300K + 340K}{2}$

= 320K

Assumptions

i) Steady operating conditions exist

ii) Radiation effects are negligible

iii) CO_2 behaves like an ideal gas

Properties of CO_2 at average temperature (i.e. at 320 K) →

$K = 0.0396$ W/m K $\qquad C_p = 1070$ J/kg K

$\mu = 2.758 \times 10^{-5}$ kg/m.s

$\nu = 3.061 \times 10^{-5}$ m²/s

$P_r = 0.7452$

$\rho = 0.9636$ kg/m³

Reynolds number for the flow of CO_2 in the pipe

is given by →

$$Re = \frac{VD}{\nu}$$

$$= \frac{(6\ m/s)(0.1m)}{3.061 \times 10^{-5}\ m^2/s}$$

$$= 19601$$

Nusselt number for flow through cylindrical pipe is

given by →

$$Nu = \frac{hD}{K} = 0.193\ Re^{0.618}\ P_r^{1/3} \quad [\text{for } 4{,}000 < Re < 40{,}000]$$

$$= (0.193)(19601)^{0.618}(0.7452)^{1/3}$$

$$= (0.193)(449.4)(0.9066)$$

$$= 78.63$$

⇒ convective heat transfer coefficient of the gas moving

in the pipe $(h) = \frac{K}{D} Nu$

$$= \frac{0.0396}{0.1} \times 78.63 = \boxed{31.14\ W/m^2K}$$

Now, let the length of the pipe = L

then, by principle of energy conservation →

Energy gained by the gas = Energy supplied by the pipe via convection

$$\Rightarrow \dot{m} C_p \Delta T_{gas} = h A_s \Delta T_{avg}$$

Here $\dot{m}$ = mass flow rate of the gas

$= \rho A_{c/s} V_\infty$

$= (0.9636)\left(\frac{\pi D^2}{4}\right)(6)$

$$\Rightarrow (0.9636)\left(\frac{\pi D^2}{4}\right)(6)(1070)\,\Delta T_{gas} = h(\pi D L)\,\Delta T_{avg}$$

$$\Rightarrow 154.66\,\Delta T_{gas} = h L\,\Delta T_{avg}$$

ΔT_{gas} = increase in temperature of gas

$= 340\,K - 300\,K$

$= 40K$

ΔT_{avg} = average temperature difference between the pipe and the gas

$= 450\,K - 320\,K$

$= 130\,K$

$$\Rightarrow 154.66\,\Delta T_{gas} = h L\,\Delta T_{avg}$$

$$\Rightarrow 154.66 \times 40 = (31.14)(L)(130)$$

$\Rightarrow \boxed{L = 1.53\ m}$ Length of pipe

Now, heat transfer rate at the pipe is given by

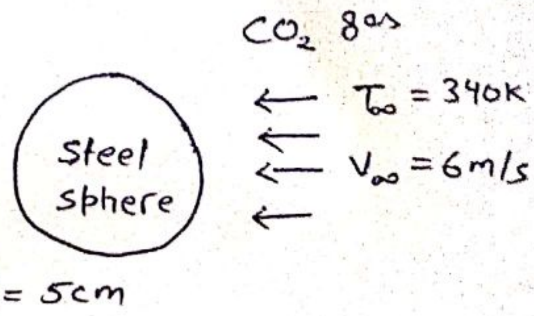
$$\dot{Q} = h A_s (\Delta T)_{avg}$$

$$= h(\pi D L)\,\Delta T_{avg}$$

$$= (31.14\ W/m^2K)(\pi \times 0.1 \times 1.53\ m^2)(130K)$$

$$= \boxed{1944.3\ W}$$

Now, interaction between gas and sphere



$$Re = \frac{V d}{\nu}$$

$$= \frac{(6m/s)(0.05)}{3.2564 \times 10^{-5}}$$

$$= 9213$$

Properties of gas at 340K

$k = 0.0411\ W/mK$

$\mu = 2.833 \times 10^{-5}$

$\nu = 3.2564 \times 10^{-5}$

$Pr = 0.7453$

Nusselt number is given by Whitacker correlation

i.e. $$Nu = \frac{hd}{k} = 2 + \left[0.4 Re^{1/2} + 0.06 Re^{2/3}\right](Pr^{0.4})\left(\frac{\mu_\infty}{\mu_s}\right)^{1/4}$$

$$= 2 + \left[0.4(9213)^{1/2} + 0.06(9213)^{2/3}\right](0.7453)^{0.4}\left(\frac{\mu_\infty}{\mu_s}\right)^{1/4}$$

$$= 2 + 57.58\left(\frac{\mu_\infty}{\mu_s}\right)^{1/4}$$

$$\Rightarrow h = \frac{K}{d} Nu$$

$$= \frac{0.0411}{0.05} \times \left[2 + 57.58 \left(\frac{\mu_\infty}{\mu_s}\right)^{1/4}\right]$$

$$= 1.644 + 47.33 \left(\frac{\mu_\infty}{\mu_s}\right)^{1/4}$$

Now, Heat transfer rate between sphere and gas is given as $\dot{Q} = 7\,W$

$$\Rightarrow \dot{Q} = 7W = h A_s (T_s - T_\infty)$$

T_s = surface temperature of steel sphere

$$\Rightarrow 7 = h (4\pi r^2)(T_s - T_\infty)$$

$$\Rightarrow 7 = h \left(4\pi \left(\frac{0.05}{2}\right)^2\right)(T_s - T_\infty)$$

$$\Rightarrow 890.9 = h(T_s - T_\infty)$$

$$\Rightarrow 890.9 = \left[1.644 + 47.33 \left(\frac{\mu_\infty}{\mu_s}\right)^{1/4}\right](T_s - 340) \quad ①$$

Now, dynamic viscosities of gas at different temperatures are given by

$\mu_\infty = \mu_{340K} = 2.833 \times 10^{-5}$

$\mu_s = \mu_{@T_s}$

$\mu_{320K} = 2.758 \times 10^{-5}$

$\Rightarrow$ By interpolation $\longrightarrow$

$\mu_T = (1.545 - 0.0038\,T) \times 10^{-5}$

Putting in equation ① $\longrightarrow$

$$890.9 = \left[1.644 + 47.33 \times \left(\frac{2.833}{1.545 - 0.0038\,T_s}\right)^{1/4}\right](T_s - 340)$$

By solving above equation, we get

$\boxed{T_s = 349.7\ K}$ surface temperature of sphere