42.14 An uninsulated hot water pipe runs horizontally through a room. The water entering the pipe is $130°F$. Where the pipe leaves the room, the water temperature is $110°F$. The room temperature is $70°F$. What is the film temperature?

A. $90°F$

B. $95°F$

C. $100°F$

D. $120°F$

The film temperature of a tube is the average of the bulk temperature of the ambient space, T_∞, and the average surface temperature, T_s. Note this represents the mean boundary layer condition i.e. film condition, for which the coefficient of heat transfer may be specified, if needed.

In this case only the film temperature needs to be calculated. Since the pipe is uninsulated, assume the surface temperature is the same as the hot water temperature, which is the average of the entering and leaving hot water temperature:

$$T_s = \frac{T_e + T_l}{2} = \frac{130°F + 110°F}{2} = 120°F$$

Calculate the film temperature:

$$T_f = \frac{T_s + T_\infty}{2} = \frac{120°F + 70°F}{2} = 95°F$$

Answer B

42.15 How much heat does a $3in$ horizontal hot water pipe lose to the ambient space per unit length by natural convection if the surrounding room has an average temperature of $70°F$, the surface temperature of the pipe is $100°F$, and the coefficient of thermal expansion for air is $1.79 \times 10^{-3}\,per\,°F$.

A. $19\frac{Btu}{hr \cdot ft}$

B. $29\frac{Btu}{hr \cdot ft}$

C. $45\frac{Btu}{hr \cdot ft}$

D. $72\frac{Btu}{hr \cdot ft}$

For convection problems in general, a reasonable starting point is always Newton's Law of Cooling:

$$\dot{Q} = hA\Delta T$$

where h is the convection heat transfer coefficient.

In this case we are not finding the rate of heat transfer in $\frac{Btu}{hr}$ but rather the heat transfer per unit length in $\frac{Btu}{hr \cdot ft}$. Since the surface area of the pipe can be expressed as $A = \pi DL$, where D is the diameter, and L is the length, divide by L on both sides to write an expression for $\frac{\dot{Q}}{L}$:

$$\frac{\dot{Q}}{L} = \pi D h \Delta T$$

For Natural (Free) Convection involving a Long Horizontal Cylinder in Large Body of Stationary Fluid, the convection heat transfer coefficient is:

$$\bar{h} = C\left(\frac{k}{D}\right) Ra_D^n$$

where C and n are constants, k is the thermal conductivity, D is the diameter, and Ra_D is the Rayleigh Number, which can be calculated using:

$$Ra_D = \frac{g\beta\left(T_s - T_\infty\right)D^3}{\nu^2} Pr$$

where g is acceleration due to gravity, β is the coefficient of thermal expansion for air, T_s is the average surface temperature, T_∞ is the bulk (ambient) temperature, D is the diameter, ν is the kinematic viscosity, and Pr is the Prandtl number. Use the tables Properties of Air at Atmospheric Pressure and Properties of Air at Low Pressure to obtain Pr and ν, then calculate Ra_D.

$$Ra_D = \frac{\left(32.2\frac{ft}{s^2}\right)\left(\frac{1.79\times10^{-3}}{^\circ F}\right)\left(100^\circ F - 70^\circ F\right)\left[\left(3in\right)\left(\frac{1ft}{12in}\right)\right]^3 (0.71)}{\left(18\times10^{-5}\frac{ft^2}{s}\right)^2} \approx 592,000$$

Use the table under Long Horizontal Cylinder in Large Body of Stationary Fluid to look up the values for constants C and n.

$$C = 0.48$$

$$n = 0.25$$

Use the Properties of Air at Low Pressure table to obtain the thermal conductivity for air at the approximate film temperature. Calculate $\bar{h}$:

$$\bar{h} = (0.48)\frac{\left(0.0155\frac{Btu}{hr\cdot ft\cdot ^\circ F}\right)}{(3in)\left(\frac{1ft}{12in}\right)}(592,000)^{0.25} = 0.825\frac{Btu}{hr\cdot ft^2\cdot ^\circ F}$$

Solve for $\frac{\dot{Q}}{L}$:

$$\frac{\dot{Q}}{L} = \pi D h \Delta T$$

$$\frac{\dot{Q}}{L} = \pi\left(3in\right)\left(\frac{1ft}{12in}\right)\left(0.825\frac{Btu}{hr\cdot ft^2\cdot ^\circ F}\right)\left(100^\circ F - 70^\circ F\right) = 19.4\frac{Btu}{hr\cdot ft}$$

Answer C