42.21 **An uninsulated $14in$ round duct painted with nonmetallic white paint has an average surface temperature of $150°F$. The duct passes through a $20ft$ room which has an air temperature of $75°F$ and walls which have a surface temperature of $66°F$. Considering both convection and radiation, what is the total combined heat transfer? Refer to the table below for properties of air.**

T (°F)	ρ (lbm/ft^3)	c_p (Btu/lbm-°F)	μ (lbm/ft-sec)	ν (ft^2/sec)	k (Btu/hr-ft-°F)	Pr	β (1/°F)	$\frac{g\beta\rho^2}{\mu^2}$ (1/ft^3-°F)
0	0.086	0.239	1.110×10^{-5}	0.130×10^{-3}	0.0133	0.73	2.18×10^{-3}	4.2×10^6
32	0.081	0.240	1.165×10^{-5}	0.145×10^{-3}	0.0140	0.72	2.03×10^{-3}	3.16×10^6
100	0.071	0.240	1.285×10^{-5}	0.180×10^{-3}	0.0154	0.72	1.79×10^{-3}	1.76×10^6
200	0.060	0.241	1.440×10^{-5}	0.239×10^{-3}	0.0174	0.72	1.52×10^{-3}	0.850×10^6
300	0.052	0.243	1.610×10^{-5}	0.306×10^{-3}	0.0193	0.71	1.32×10^{-3}	0.444×10^6
400	0.046	0.245	1.75×10^{-5}	0.378×10^{-3}	0.0212	0.689	1.16×10^{-3}	0.258×10^6
500	0.0412	0.247	1.890×10^{-5}	0.455×10^{-3}	0.0231	0.683	1.04×10^{-3}	0.159×10^6
600	0.0373	0.250	2.000×10^{-5}	0.540×10^{-3}	0.0250	0.685	0.943×10^{-3}	0.106×10^6
700	0.0341	0.253	2.14×10^{-5}	0.625×10^{-3}	0.0268	0.690	0.862×10^{-3}	70.4×10^3
800	0.0314	0.256	2.25×10^{-5}	0.717×10^{-3}	0.0286	0.697	0.794×10^{-3}	49.8×10^3
900	0.0291	0.259	2.36×10^{-5}	0.815×10^{-3}	0.0303	0.705	0.735×10^{-3}	36.0×10^3
1000	0.0271	0.262	2.47×10^{-5}	0.917×10^{-3}	0.0319	0.713	0.685×10^{-3}	26.5×10^3
1500	0.0202	0.276	3.00×10^{-5}	1.47×10^{-3}	0.0400	0.739	0.510×10^{-3}	7.45×10^3
2000	0.0161	0.286	3.54×10^{-5}	2.14×10^{-3}	0.0471	0.753	0.406×10^{-3}	2.84×10^3
2500	0.0133	0.292	3.69×10^{-5}	2.80×10^{-3}	0.051	0.763	0.338×10^{-3}	1.41×10^3
3000	0.0114	0.297	3.85×10^{-5}	3.39×10^{-3}	0.054	0.765	0.289×10^{-3}	0.815×10^3

A. $2000 \frac{Btu}{hr}$

B. $5000 \frac{Btu}{hr}$

C. $7000 \frac{Btu}{hr}$

D. $12,000 \frac{Btu}{hr}$

The combined heat transfer is the sum of the convection and radiation.

To find the convection for 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 table given to select the values for properties of atmospheric air at the film temperature and calculate Ra.

$$T_{film} = \frac{T_s + T_\infty}{2} = \frac{150°F + 75°F}{2} = 112.5°F$$

$$Ra_D = \frac{\left(32.2\frac{ft}{s^2}\right)\left(1.75\times10^{-3}\frac{1}{^\circ F}\right)\left(150^\circ F - 75^\circ F\right)\left(\frac{14}{12}ft\right)^3(.72)}{\left(.19\times10^{-3}\frac{ft^2}{s}\right)^2} = 1.34\times10^8$$

Based on the range of Ra, constants C and n may be specified:

$$10^7 < Ra < 10^{12}$$

$$C = .125$$

$$n = .333$$

Calculate the convection heat transfer coefficient:

$$h = (.125)\left(\frac{.0157\frac{Btu}{hr\cdot ft\cdot^\circ F}}{\frac{14}{12}ft}\right)\left(1.34\times10^8\right)^{.333} = .855\frac{Btu}{hr\cdot ft^2\cdot^\circ F}$$

Determine the heat transfer by convection:

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

$$\dot{Q}_c = \left(.855\frac{Btu}{hr\cdot ft^2\cdot^\circ F}\right)\left(\pi\left(\frac{14}{12}ft\right)(20ft)\right)\left(150^\circ F - 75^\circ F\right) = 4700\frac{Btu}{hr}$$

To find the heat transfer by radiation i.e. Net Energy Exchange by Radiation Between Two Bodies, use equation:

$$\dot{Q}_r = \varepsilon\sigma A\left(T_1^4 - T_2^4\right)$$

where ε is the emissivity, σ is the Stefan-Boltzmann constant, A is surface area, and the temperatures are the surface temperature of the duct and the surroundings i.e. walls. Note the temperatures must be in absolute terms i.e. degrees Rankine.

Look up the average emissivity for nonmetallic paints:

$$\varepsilon = .9$$

As previous, the surface area of the duct is:

$$A = \pi DL = \pi\left(\frac{14}{12}ft\right)(20ft) = 73.3ft^2$$

Change the temperatures to Rankine:

$$T_1 = T_{duct} = 150^\circ F + 460^\circ = 610^\circ R$$

$$T_2 = T_{walls} = 66^\circ F + 460^\circ = 526^\circ R$$

Calculate the heat transfer by radiation: