

## **Experimental Simulation of Critical Thickness of Insulation For A Hollow Copper Cylinder**

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### **Abstract**

The thickness of insulation corresponding to the critical radius of insulation is known as critical insulation thickness. The critical radius effect is a remarkable incident of heat transfer in insulated hollow cylinders. In cylinders and spheres, the additional insulation increases the conduction resistance of insulation and decreases the convection resistance of the surface. If the radius of a cylinder or sphere is lesser than the critical radius, adding insulation actually increases the heat loss. In the present paper a copper cylinder is heated by means of a heater with a capacity of 350W. Asbestos insulation is provided surrounding the copper cylinder and the effect of critical radius on heat transfer is analyzed experimentally and numerically.

**Keywords:** Critical thickness, insulation, heat transfer, total resistance

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### **Introduction**

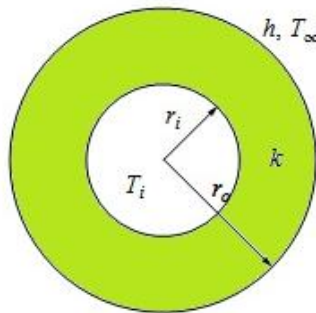
The study of thermodynamics deals with the phenomenon of energy transfer and energy transformation within the system chosen for analysis. The first and second law deal with energy that is transferred from one system to another in the outline of heat. This transfer of energy must be correlated to the energy that is stored in each system called the internal energy. The internal energy of a system is associated with the microscopic motion of the molecules that make up that system. The founding fathers of thermodynamics, nevertheless, did not have this form to build upon, and so classical thermodynamics is primarily a study of the changes in the (large-scale, observable) macroscopic property of a system, with internal energy being one of these macroscopic quantities.

The addition of more insulation to a wall always reduces heat transfer. The thinner the insulation, the higher the heat transfer rate. Since the heat transfer area is

constant, adding insulation always increases the surface conductance resistance of the wall without affecting the convective resistance and thereby minimizes the heat loss. But in case of cylinders, the addition of insulation depends on conductive as well as convective resistances. The additional insulation increases the conduction resistance of the insulation layer, but decreases the convective resistance of the surface because of the increase in the outer surface area for convection.

### Experimental Procedure

Consider a cylindrical pipe of outer radius  $r_i$  which is heated and whose outer surface temperature  $T_i$  is maintained constant as shown in Figure 1. The pipe is now insulated with a material whose thermal conductivity is  $k$  and outer radius is  $r_o$ . Heat is lost from the pipe to the surrounding medium by combined effect of convection and conduction. The heat transfer rate from the insulated pipe to the surrounding air is measured by using temperature sensors like thermocouple. The value of  $r_o$  at which heat transfer rate reaches maximum is found. By the differentiation and simply solving for  $r_o$  yields the critical radius of insulation for a circular body. The insulation of critical radius is given by the following equation  $= (k/h)$ . Above this critical radius, the heat flux decreases and below it, increases the heat flux.



**Figure 1:** Hollow cylinder with insulation

The experimental set-up consists of Frame, Thermocouple, Resistive Heater, Voltmeter, Copper Rod, Temperature Indicator, Ammeter, Electric Conductor Wire, Main Switch, Fiberglass Insulation. Frame of mild steel by length =600mm, Height=600mm, Width=300mm, is manufactured. Frame is used to support other equipment/Control Panels (Thermocouple, Main Switch Voltmeter, Ammeter, Copper Rod, Temperature Indicator, Resistive Heater.)

Supporting Frame is placed on the mainframe to the support of Insulating Copper Rod as well as Resistive Heater is placed inside of copper Rod as shown in Figure. 2. Resistive heater is used for heating of copper rod. The heater is direct connecting to the Dimmer stat.

Dimmer stat is used to increase or decrease Voltage, or regulate the voltage what is essential for the steady state condition. If the voltage increases, then more time

consumes for a coming steady state condition or its decreases, then it will come yearly in a steady state condition.

No. of thermocouples is placed on a surface of Copper Rod, because thermocouples sense the surface temperature of copper rod. Asbestos insulation is wounded outside surface of copper rod. The thermocouples are placed outside surface of the insulation. K type thermocouples are used to measure temperature because frequency of k type thermocouples is more high.

Temperature Indicator is used to indicate the temperature at every position of the thermocouple. Selection Of Material-Copper [K=385W/mK],Asbestos [K=0.04W/mK]

**Thermo-Physical Properties**

L=0.2m for each section.  $r_i=0.015m$ .

$T_\infty =27.5^\circ C$ .

(Properties of air at 1atm pressure  $T_\infty =27.5^\circ C$ ).  $\rho=1.164kg/m^3$ .

$C_p =1007Jkg^{-1}K^{-1}$ .  $K_f=0.02588W/m^{-1}K^{-1}$ .

$\mu=1.872*10^{-5}kgm^{-1}s^{-1}$ .

$\nu=1.608*10^{-5}m^2s^{-1}$ .  $Pr=0.7282$ ).

$r_o=r_i+t$  (t=thickness of insulation).

**Calculation of Total Resistance And Heat Transfer Rate**

Total resistance=conductive resistance +convective resistance =  $[\ln(r_o/r_i)/2\pi k_i L]+1/2\pi r_o hL$

Sample calculation for 18 mm outer radius, Hence  $r_i=15mm$

$r_o=18mm$

Hence total resistance (R)=  $[\ln(18/15)/(2\pi(0.15*0.2))] +1/(2\pi(.018*6*0.2))$

= 8.336 K/W

Heat transfer rate Q = $\Delta T/R$

=  $(50-28)/8.336$

= 2.639 W

22 mm outer radius for Sample calculation

$r_i=15mm$

$r_o=22mm$

Hence total resistance (R)=  $[\ln(22/15)/(2\pi(0.15*0.2))] +1/(2\pi(.022*6*0.2))$

= 8.0616 K/W

Heat transfer rate Q = $\Delta T/R$

=  $(50-28)/8.0616$

= 2.729 W

Sample calculation for 26 mm outer radius

$r_i=15mm$

$r_o=26mm$

Hence total resistance (R)=  $[\ln(26/15)/(2\pi(0.15*0.2))] +1/(2\pi(.026*6*0.2))$

= 8.0204 K/W

Heat transfer rate Q = $\Delta T/R$

$$= (50-28)/8.0204$$

$$= 2.743 \text{ W}$$

Sample calculation for 28 mm outer radius

$$r_i=15\text{mm}$$

$$r_o=28\text{mm}$$

$$\text{Hence total resistance (R)}= [\ln (28/15)/ (2\pi (0.15*0.2))] +1/ (2\pi (.028*6*0.2))$$

$$= 8.0482 \text{ K/W}$$

$$\text{Heat transfer rate } Q = \Delta T/R$$

$$= (50-28)/8.0482$$

$$= 2.7335 \text{ W}$$

Sample calculation for 30 mm outer radius

$$r_i=15\text{mm}$$

$$r_o=30\text{mm}$$

$$\text{Hence total resistance (R)}= [\ln (30/15)/ (2\pi (0.15*0.2))] +1/ (2\pi (.03*6*0.2))$$

$$= 8.098 \text{ K/W}$$

$$\text{Heat transfer rate } Q = \Delta T/R$$

$$= (50-28)/8.098$$

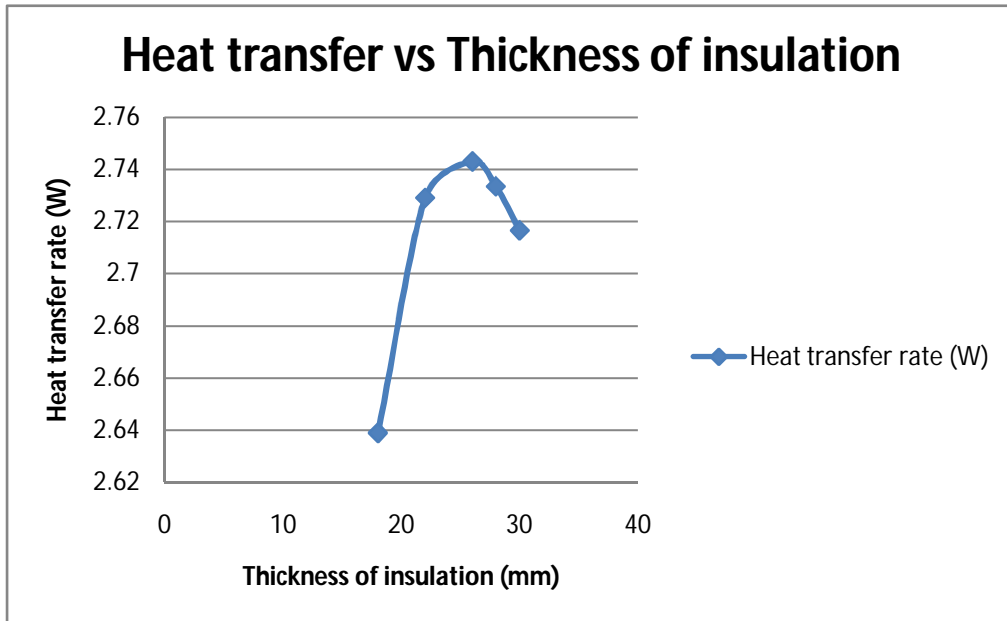
$$= 2.7166 \text{ W}$$

**Table 1:** Heat transfer rate (W) with Radius (mm)

Radius of insulation (mm)	Heat transfer rate (W)
18	2.639
22	2.729
26	2.743
28	2.7335
30	2.7166

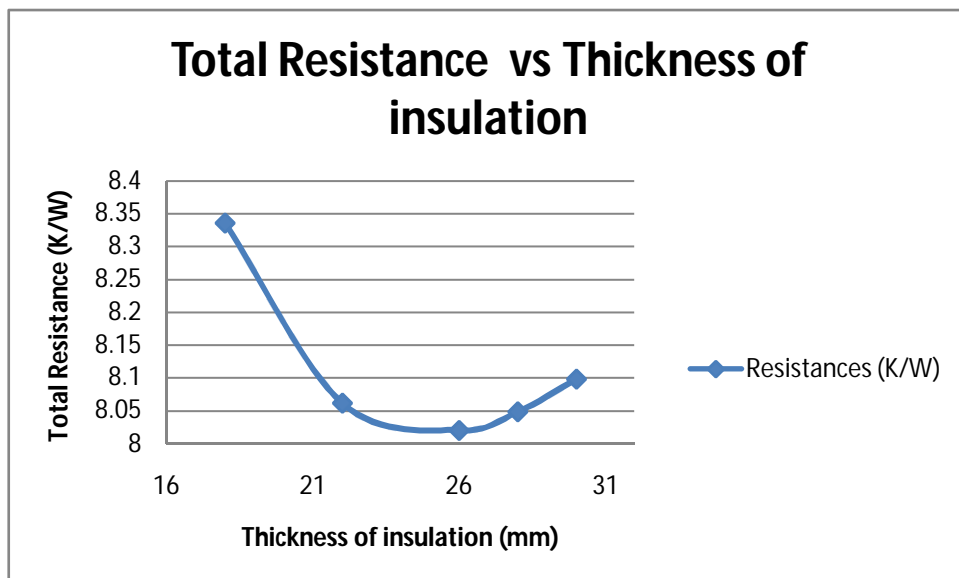
## Result and Discussion

The radius of insulation of the copper cylinder with above specifications and thermo physical properties were found out and the results are plotted.



**Figure 2:** Variation of heat transfer rate with thickness of insulation

Figure 2 shows the variation of heat transfer rate with the thickness of insulation. The heat transfer rate increases for the thickness of insulation of 18 mm, 22 mm and 26 mm. It then decreases gradually for the thickness of insulation of 28 mm and 30 mm. The heat transfer rate corresponding to the thickness of insulation of 26 mm is found to be maximum which is the critical heat flux.



**Figure 3:** Variation of total resistance with thickness of insulation

Figure 3 shows the variation of total resistance with the thickness of insulation. The total resistance decreases for the thickness of insulation of 18 mm, 22 mm and 26 mm. It then increases gradually for the thickness of insulation of 28 mm and 30 mm.

## Conclusion

The critical thickness of insulation of asbestos covered over the hollow copper cylinder was found out using the experimental set up. It can be used effectively for finding the insulation thickness of any insulating material. The salient features are geometries other than cylinder, like spheres, the thickness of insulation can also be calculated, noise free operation. It is found from the results that the critical thickness of insulation obtained from this experiment was 26 mm corresponding to maximum heat transfer rate of 2.743 W.

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