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Insulation of a material: Effects on temperature gradient and temperature difference

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Abstract: - The effects of insulation on temperature gradient and temperature difference in a material were inquired in this study. Four 0.25m-diameter plain cylindrical rods with different thickness of insulation between 10mm and 40mm and one 0.25m-diameter plain cylindrical rod were considered. The heat transfer rate was varied between 660W and 3300W. The plain rod has a highest temperature of 448K at x = 0, but the rod with 40mm insulation thickness has the lowest temperature of 340K at x = 0.35m. A highest temperature difference of 65K was obtained with the rod with 40mm insulation thickness at x = 0.35m.and the highest temperature gradient of 544.45Km^{-1} was obtained with the rod with 40mm insulation thickness at x = 0.07m. A maximum value of 207.35 Km^{-1} of temperature gradient was obtained in the rod of 40mm insulation thickness at 3300W, whereas a minimum value of 105.71Km^{-1} of temperature gradient was obtained in the plain rod at 660W.

Keywords: - *Temperature gradient, thickness, temperature, heat transfer rate, insulation*

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I. INTRODUCTION

The degree of hotness or coldness of a body or a system is generally referred to as temperature. Heat energy is transferred from one part of a body or a system to another part as a result of temperature difference between the two parts. Temperature difference per unit distance through which the heat is transferred is known as temperature gradient [1, 2]. Heat energy has found applications in areas such as heat pipes, aerospace, automobiles, solar water heaters, electronics systems, medicines, and refrigeration plants [3]. In all these applications, both temperature and temperature gradient are determinants of the heat energy. The effects of insulations on temperature difference and temperature gradient in a material at various heat transfer rate were determined experimentally in this research.

Consider a steady-state heat transfer through a distance Δx = L in a material, as shown in Fig. 1. The

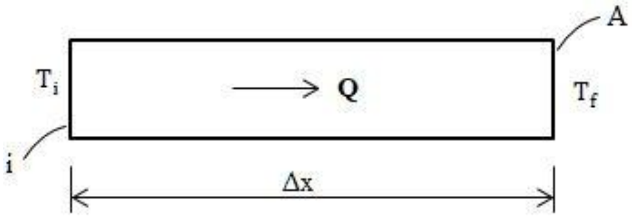

Fig. 1. Steady-state heat transfer through a distance

temperature difference at a point (x) across the material is $\Delta T = T_x - T_i$, where T_i (K) and T_x (K) are the initial temperature and temperature at point x, respectively, of the material. In the submission of Fourier, as presented by Cengel [4] and Incropera et al. [1], the rate of the heat transfer through the material is directly proportional to the temperature difference (ΔT) across the material and the heat transfer area (A) normal to the direction of heat transfer, but is inversely proportional to the distance (Δx) through which the heat is transferred. Mathematically, this statement can be expressed as:

$$Q = kA\frac{T_i - T_x}{\Delta x} = -kA\frac{T_x - T_i}{\Delta x} = -kA\frac{\Delta T}{\Delta x} \tag{1}$$

where the constant k (W/m.K) is known as the thermal conductivity of the material, which is a measure of the ability of the material to conduct heat.

II. PROCEDURE OF THE EXPERIMENTS

In carrying out the investigation, five different samples were used. The first sample was a plain (that is, uninsulated) cylindrical rod of diameter d = 0.25m and length L = 0.35m, as shown in Fig. 2. The plain cylindrical sample is made of steel of thermal conductivity 15.1 W/m.K [4]. The other four samples, depicted in Fig. 3, were insulated cylindrical rod of length 0.35m. The four insulated cylindrical rods were plain cylindrical rods covered individually with cement mortal insulator of thermal conductivity 0.72 W/m.K [1] and various thickness (t) with $10\text{mm} \leq t \leq 40\text{mm}$. The 0.25m uninsulated cylindrical rod serves as the inner diameter (d) for the insulated cylindrical rods of thickness, t, as presented in Fig. 3. The outer diameter (d_o) for the insulated rods was determined by Eq. (2) and presented in Table 1.

$$d_o = d + 2t \tag{2}$$

Table 1. Outer diameter (d_o) of insulated cylindrical rods

Insulation thickness, t (m)	0.01	0.02	0.03	0.04
Outer diameter, d_o (m) of insulated rods	0.045	0.065	0.085	0.105

An electric heater, which was connected to electrical mains, was attached to each of the end, at x = 0, of the plain and insulated samples, as shown schematically in Fig. 2 and Fig. 3. The voltage of the electric heater was 220V and its current was varied between 3 and 15A, thus providing different values of electrical power consumed by the heater and converted to heat generated in the heater as a result of resistance heating. Table 2 shows the different values of the electrical power.

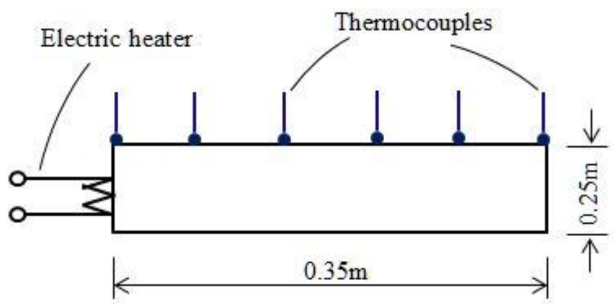

Fig. 2. Schematic setup for plain cylindrical rod

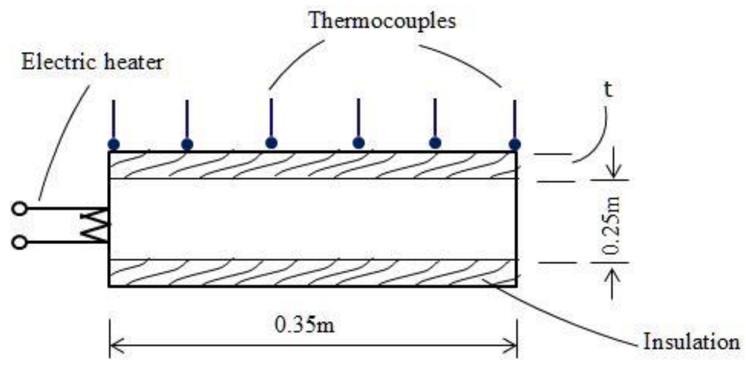

Fig. 3. Schematic setup for insulated cylindrical rods

Table 2. Different values of electrical power

Current, I (A)	3	5	7	11	13	15
Heat transfer rate, Q (W)	660	1100	1540	2420	2860	3300

The surface temperature at the beginning (i.e., at x= 0) of the cylindrical sample rose as a result of the heat generated in the heater. Consequently, heat was transferred through the entire length $\Delta x = L$ of the rods. Six thermocouples were placed at six different positions (x = 0, 0.07, 0.14, 0.21, 0.28, and 0.35m) on the surface of each of the plain and insulated rods to measure the surface temperature under steady operating conditions.

In Table 3 were recorded the calculated temperature (T_x) along each of the rods, which have been read by the thermocouples, for heat transfer rate of 660W. For each of the rods, the temperature difference ($\Delta T_x = T_x - T_i$) between a point x along the rod and the beginning of the rod (i.e. at x = 0), as well as the temperature gradient ($\Delta T/x$) for heat transfer rate of 660W were calculated and recorded in Table 4 and Table 5, respectively. In Table 6, Table 7, Table 8, and Table 9 were recorded the calculated temperature at the beginning of each of the rods (T_i), the temperature at the end of each of the rods (T_f), the temperature difference at the end of each of the rods ($T_i - T_f$), and the temperature gradient at the end of each of the rods ($(T_i - T_f) / L$), respectively, against the changes in the heat transfer rate.

Table 3. Temperature along the cylindrical rods at Q = 660W for various insulation

			T_x (K)		
x (m)	Plain rod	10mm ins. rod	20mm ins. rod	30mm ins. rod	40mm ins. rod
0	448	441	428	416	405
0.07	430	419	401	382	367
0.14	424	415	396	376	360
0.21	421	409	388	367	350
0.28	417	407	387	366	349
0.35	411	402	380	358	340

Table 4. Temperature difference along the cylindrical rods at Q = 660W for various insulation

			ΔT (K)		
x (m)	Plain rod	10mm ins. rod	20mm ins. rod	30mm ins. rod	40mm ins. rod
0	0	0	0	0	0
0.07	18	22	27	34	38
0.14	24	26	32	40	45
0.21	27	32	40	49	55
0.28	31	34	41	50	56
0.35	37	39	48	58	65

Table 5. Temperature gradient along the cylindrical rods at Q = 660W for various insulation

			$\Delta T/x$ (K/m)		
x (m)	Plain rod	10mm ins. rod	20mm ins. rod	30mm ins. rod	40mm ins. rod
0	0	0	0	0	0
0.07	257.14	314.86	392.11	481.97	544.45
0.14	171.43	186.43	230.86	282.74	318.16
0.21	128.57	154.67	190.36	232.24	260.23
0.28	110.71	120.14	147.74	180.15	201.73
0.35	105.71	111.43	136.57	166.17	185.65

Table 6. Inlet temperature against heat transfer rate along the cylindrical rod for various insulation

I (A)	Q (W)	T_i (K) Plain rod	10mm ins. rod	20mm ins. rod	30mm ins. rod	40mm ins. rod
3	660	448	441	428	416	405
5	1100	459	452	439	426	415
7	1540	466	458	445	433	421
11	2420	478	470	457	444	432
13	2860	484	477	463	450	438
15	3300	493	486	472	458	446

Table 7. Outlet temperature against heat transfer rate along the cylindrical rod for various insulation

I (A)	Q (W)	T_o (K) Plain rod	10mm ins. rod	20mm ins. rod	30mm ins. rod	40mm ins. rod
3	660	411	402	380	358	340
5	1100	421	412	390	367	349
7	1540	427	418	396	372	354
11	2420	439	429	406	383	364
13	2860	445	435	412	388	369
15	3300	453	443	419	395	376

Table 8. Temperature difference against heat transfer rate along the cylindrical rod for various insulation

I (A)	Q (W)	ΔT (K) Plain rod	10mm ins. rod	20mm ins. rod	30mm ins. rod	40mm ins. rod
3	660	37	39	48	58	65
5	1100	40	42	51	61	68
7	1540	40	42	51	62	69
11	2420	44	46	55	66	74
13	2860	45	47	56	67	75
15	3300	45	48	57	68	76

Table 9. Temperature gradient against heat transfer rate along the cylindrical rod for various insulation

I (A)	Q (W)	$\Delta T/x$ (K/m) Plain rod	10mm ins. rod	20mm ins. rod	30mm ins. rod	40mm ins. rod
3	660	105.71	111.43	136.57	166.17	185.65
5	1100	109.83	115.66	141.30	171.49	191.36
7	1540	111.41	117.33	143.35	173.99	194.14

11	2420	116.53	122.56	149.08	180.31	200.86
13	2860	118.11	124.23	151.13	182.80	203.64
15	3300	120.23	126.46	153.86	186.13	207.35

III. DISCUSSION OF RESULTS OF THE FINDINGS

This section discusses the results of the findings from investigations conducted in this research. Fig. 4 shows that the temperature along each of the rods decreased from inlet towards their upstream, and that the rod with largest insulation thickness had the least temperature. For the case considered, the plain rod has the highest temperature of 448K at x = 0, but the rod with 40mm insulation thickness has the least temperature of 340K at x = 0.35m. A highest temperature difference of 65K was obtained with the rod with 40mm insulation thickness at x = 0.35m (Fig. 5) and, as shown in Fig.6, a highest temperature gradient of 544.45Km^{-1} was obtained with the rod with 40mm insulation thickness at x = 0.07m.

As can be seen in Fig. 7, the temperature at the beginning of the rods increased with the increase of heat transfer rate, but decreased with the increase of insulation thickness. The results for temperature at the end of the rods follow this same pattern of results as evidenced in Fig. 8. A minimum temperature of 405K at the beginning of the rods was obtained at 660W in the rod with 40mm insulation thickness but a maximum of 493K was obtained at 330W in the uninsulated sample.

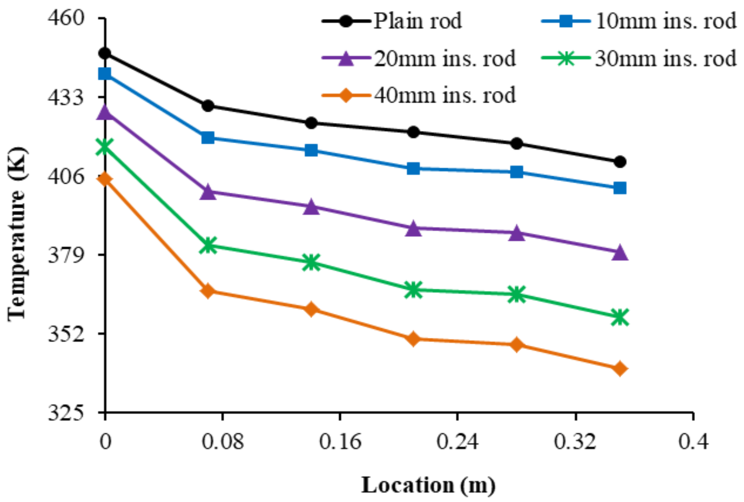

Fig. 4. Temperature along the cylindrical rods at Q = 660W for various insulation

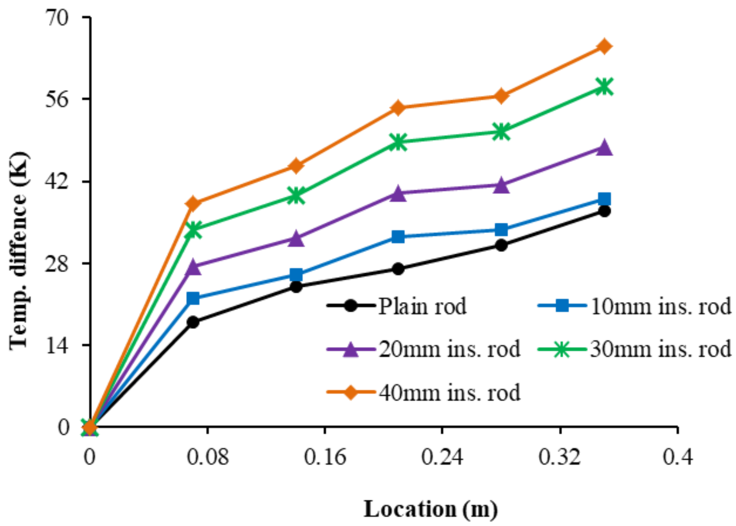

Fig. 5. Temperature difference along the cylindrical rods at Q = 660W for various insulation

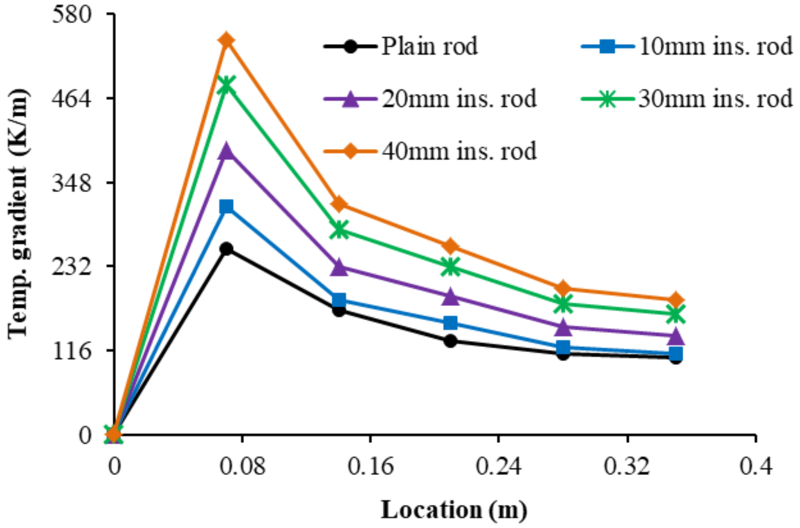

Fig. 6. Temperature gradient along the cylindrical rods at Q = 660W for various insulation

The temperature difference and temperature gradient at the end of the rods for various insulation thicknesses and various heat transfer rate follow the same pattern of results, as evident in Figs 9 and 10. At the end of the rod, a minimum temperature difference of 37K was obtained in the plain rod at 660W while a maximum of 76K was obtained in the rod of 40mm insulation thickness at 3300W. For the temperature gradient (Fig. 9), a maximum of 207.35 Km^{-1} was obtained in the rod of 40mm insulation thickness at 3300W, but in the uninsulated rod at 660W, a minimum temperature gradient of 105.71Km^{-1} was obtained.

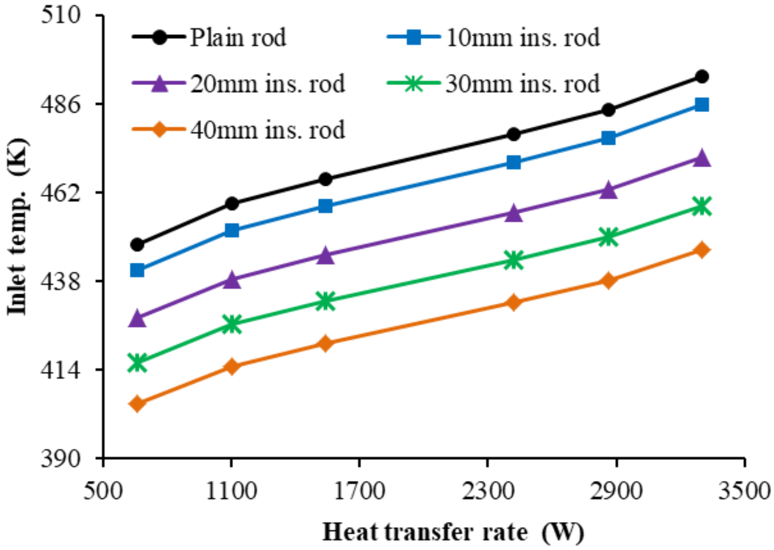

Fig. 7. Inlet temperature against heat transfer rate along the cylindrical rod for various insulation

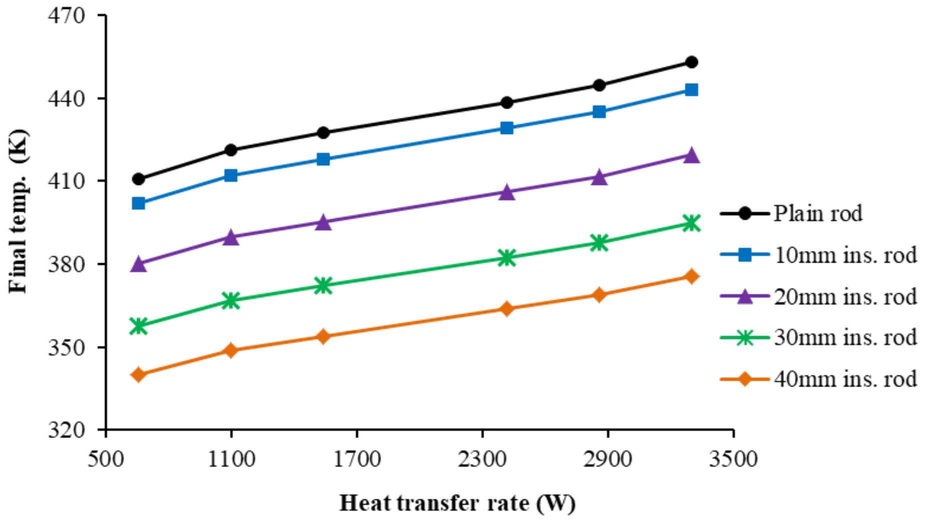

Fig. 8. Outlet temperature against heat transfer rate along the cylindrical rod for various insulation

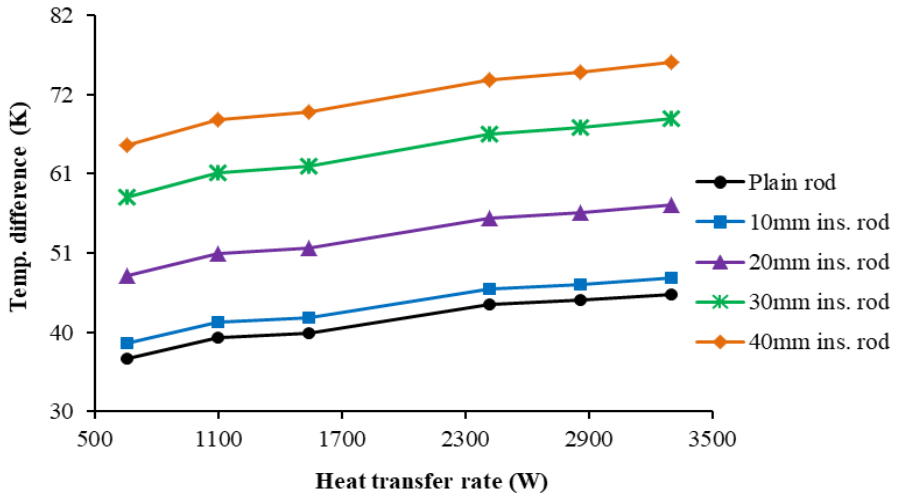

Fig. 9. Temperature difference against heat transfer rate along the cylindrical rod for various insulation

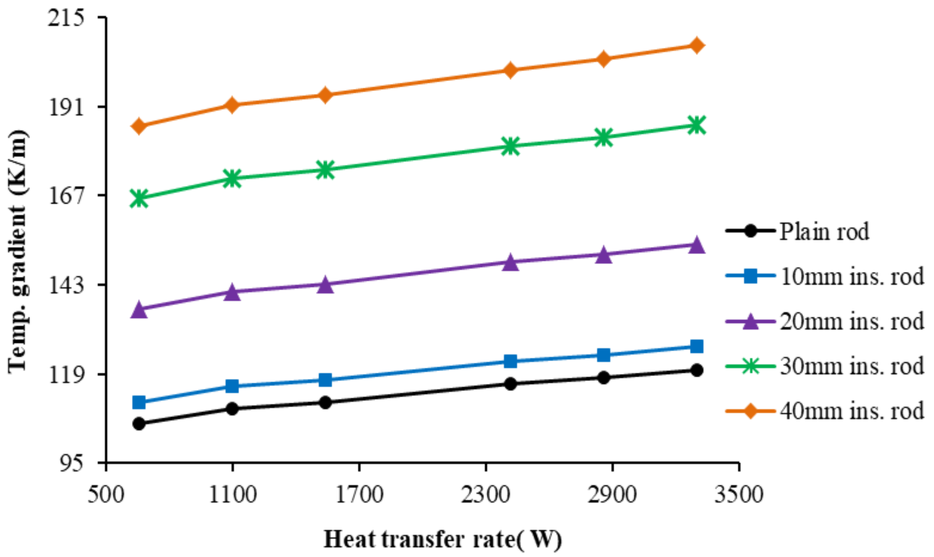

Fig. 10. Temperature gradient against heat transfer rate along the cylindrical rod for various insulation

IV. CONCLUSION

Experiments were carried out to probe the effects of insulation on temperature gradient and temperature difference in a material. It was discovered, through this study, that a material with highest insulation thickness has the least temperature and that increasing the heat transfer rate will result in an increase of the temperature difference and temperature gradient of the material. Thus, the study has revealed how insulation and heat transfer rate impact the temperature gradient, temperature, and temperature difference of a material.

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