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NUCLEATE POOL BOILING HEAT TRANSFER IN DIFFERENT METALS OF HEATING SURFACES WITH DIFFERENT LIQUIDS

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ABSTRACT
The experiments are performed to understand the effect of some important parameters like heat transfer coefficient and heat flux on nucleate pool boiling by using different heating surfaces like aluminium rod, brass rod, copper rod, aluminium rod heating surface covered with 2mm brass sheet and aluminium rod heating surface covered with 2mm copper sheet at atmospheric pressure for different liquids like distilled water and methanol. The brass sheet and copper sheet are tightened on the surface of the aluminium rod to prevent heat losses. The experimental data for boiling of liquids on horizontal plain heating tube obey the well-established $h = C_1 q^n$ i.e. heat transfer coefficient varies with heat flux raised to the power of 0.7. The experiment results are used to calculate heat flux and heat transfer coefficient and graphs are drawn between heat flux and heat transfer coefficient. The values of exponent 'n' and constant 'C' are obtained for all the system and the range of values are 0.65 to 0.7 and 0.9 to 1.2 for 'n' and 'C' respectively.

Keywords: Nucleate pool boiling, heat flux, heat transfer coefficient

INTRODUCTION
The enhancement of nucleate pool boiling heat transfer coefficient of boiling liquids has received significance attention in recent years [1-5]. Heat transfer to boiling liquids with phase change is of great practical significant in a large number of processes. The importance of vaporization in common systems such as fractional distillation and low temperature refrigeration is well known in industrial processes [6-8]. The nucleate pool boiling of liquids plays a predominant role in the design and operation of such heat exchange equipment. The heat transfer rate depends on number of factors such as modes of heat transfer, type of heating tube used, and surface area of the heating tube. By changing one and all the above factors the heat transfer rate can be enhanced. But the best results are obtained when we change the heating tube characteristics. The heating tube characteristics depend on the material used and type of machining done on the heating tube. The heat transfer rate can be augmented by providing knurled surface, reentrant cavities and many other methods by which the surface area of the heating tube is increased. In this study aluminium rod, brass rod, copper rod, aluminium rod covered with brass sheet and aluminium rod covered with copper sheet with water and methanol have been taken to obtain additional information on increasing the heat flux from nucleate pool boiling.

EXPERIMENTAL SET-UP
The details of the experimental set-up, employed in the present investigation have been shown in fig(1). It mainly consists of test vessel, electrical heater, heating tube, knockout condenser, bubbler, vacuum pump and measuring instruments. The vessel had a top flange cover and a dished bottom with a drainpipe. Two diametrically opposite view ports helped in the visual observation of dynamics of vapor bubbles on and around the heating tube. Water-cooled knockout condensed vapor generated in vessel. The condenser thus formed the liquid by gravity. Four holes of 2mm dia, equi-spaced on a pitch circle dia of 25mm in the thickness of the tube was made and copper constantan thermocouples, thermocouples with insulation piping were fitted into these holes, surface temperature were calculated from measured thermocouple readings by extrapolation. The whole heating section was confined in the pool of liquid boiling in the test vessel. The aluminium rod was chosen for construction of heating surface and 2mm thickness of copper and brass sheet tightly covered over the aluminium surface.

DATA PROCESSING
For calculation of outer wall temperature (t_{wo}) at the top, the sides and the bottom positions of a heating tube,

the following heat conduction equations were employed.

$$(t_{wo})_t = (t_w)_t - (q\, d_o/2k) \ln (d_o/d_h) \quad (1)$$

$$(t_{wo})_s = (t_w)_s - (q\, d_o/2k) \ln (d_o/d_h) \quad (2)$$

$$(t_{wo})_b = (t_w)_b - (q\, d_o/2k) \ln (d_o/d_h) \quad (3)$$

Average outer wall temperature have been calculated as arithmetic average the values at the top-the sides – and bottom positions. Mathematically it is represented as follows

$$T_{wo} = [\, (t_{wo})_t + 2\, (t_{wo})_s + (t_{wo})_b \,] / 4 \quad (4)$$

Based on argument similar to average wall temperature as above average liquid bulk temperature t_l is calculated as follows

$$T_l = [\, (t_l)_t + 2\, (t_l)_s + (t_l)_b \,] / 4 \quad (5)$$

For calculation of average boiling heat transfer coefficient the following equation was used

$$h = q / [\, a\, (t_{wo} - t_l) \,] \quad (6)$$

Where q, represents energy input and a, the outer wall surface area of heating tube ($\Pi\, d_o\, l$.). For plain tube d_o represents outer diameter of the heating tube l is the effective length of the tube and $d_h = (d_i + d_o) / 2$.

RESULTS AND DISCUSSIONS

The experimental data of present investigations for aluminium rod, brass rod and copper rod with distilled water are shown in Figure 2 which is drawn to log-log scale. It is observed from the Figure 2 that the heat transfer coefficient for aluminium rod is lower than that of brass rod and copper rod. The general trend of variation of heat transfer coefficient with heat flux for all metal rods with distilled water is common. That is the boiling heat transfer coefficient increases with heat flux consistently. This behavior is attributed to the fact that with the rise in the heat flux the value of wall super heat increases, thereby the minimum value of radius required for activation of nucleation site gets reduced. This in turn leads to (a) activation of more nucleation sites on heating tube as compared to those lower heat flux (b) increase in bubble emission frequency. These two factors combine together raise the induced turbulence in the liquid pool, which ultimately makes boiling heat transfer coefficient increase, more and more with heat flux.

The slope (n) for all the parallel lines is nearly equal for all plain aluminium, brass and copper rods. The constant value of 'C' (intercept) is slightly lower for aluminium rod than that of brass and copper rods.

The variation of heat transfer coefficient, h, with heat flux, q, for aluminium rod and aluminium rod covered with brass sheet in distilled water is shown in Figure 3 which is also drawn to log-log scale. It is closely observed that the heat transfer coefficient for aluminium rod covered with brass sheet is slightly more than that of aluminium rod. The similar behavior is observed for aluminum rod covered with copper sheet in Figure 4.

The similar results and trend for all metal rods and aluminium rod covered with brass sheet and copper sheet in methanol are observed and are shown in Figure 5, 6 and 7. The all 'n' and 'C' values are shown in Table 1.

The value for 'n' is the same for all metal rods and for aluminum rod covered with brass sheet and copper sheet because the value of 'n' is the same for all plain surfaces irrespective of metal rods and irrespective of boiling liquids. The value of 'C' is different for different boiling liquids. The 'C' accounts for surface characteristics of a heating tube and physico-thermal properties of a boiling liquid in its contact.

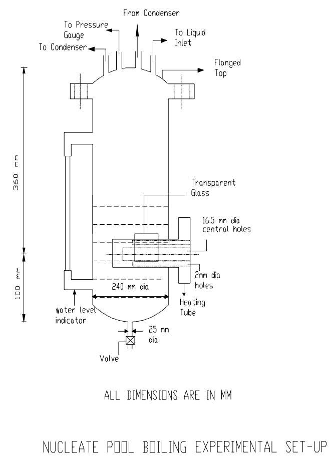

Fig. 1(a). Nucleate Pool Boiling Experimental Setup

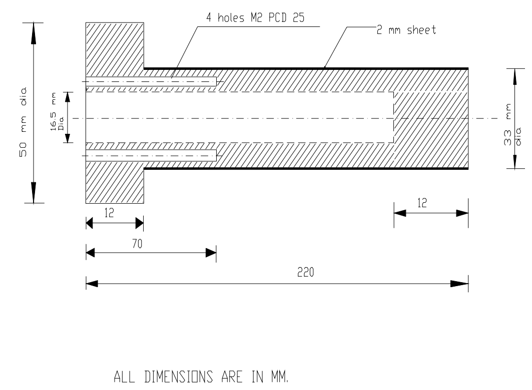

Fig. 1(b). Heating Tube

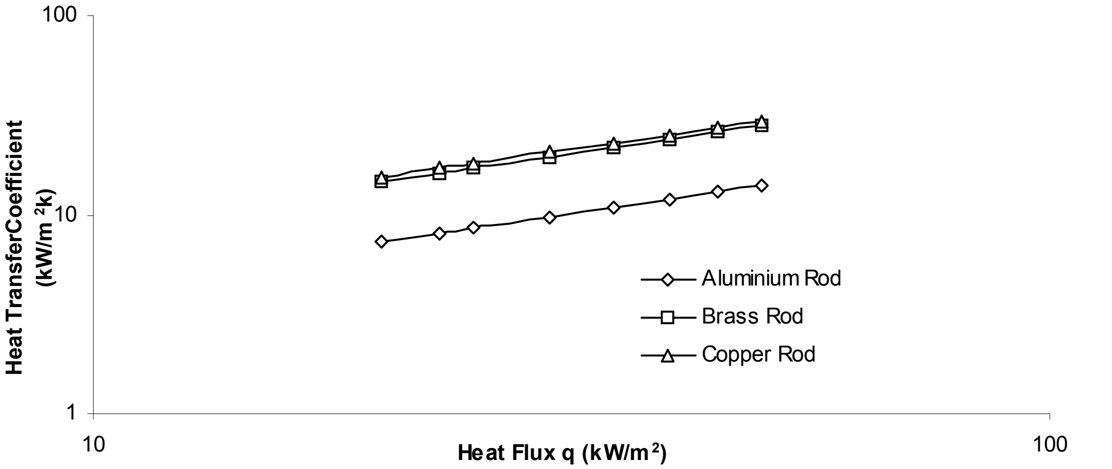

Figure 2. Variation of h with q for Aluminium rod, Brass rod and Copper rod in distilled water

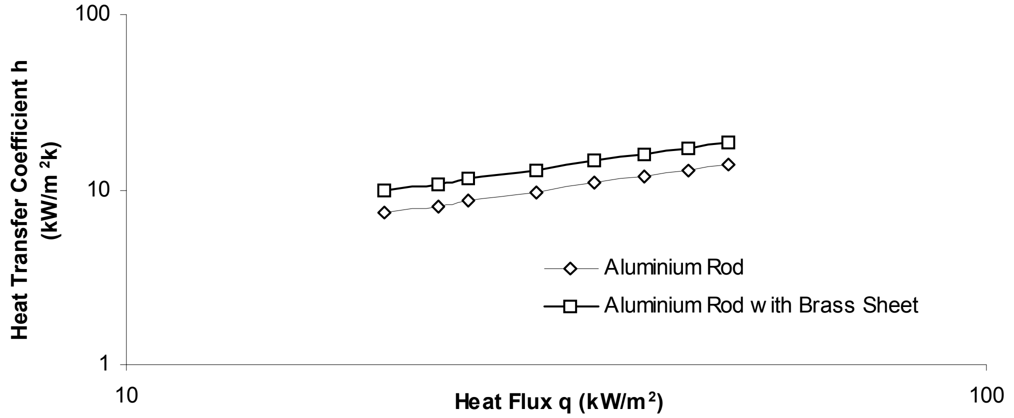

Figure 3. Variation of h with q for Aluminium rod and Aluminium rod covered with Brass sheet in distilled water

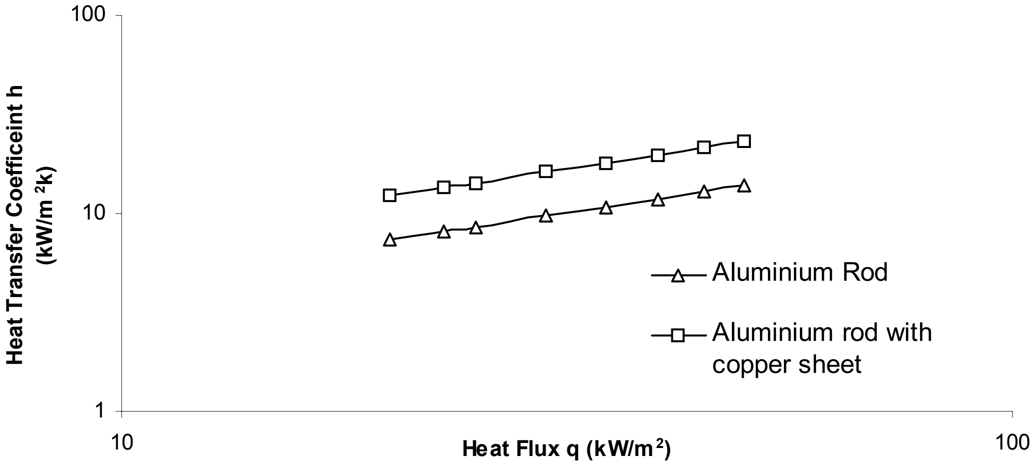

Figure 4. Variation of h with q for Aluminium rod and Aluminium rod covered with copper sheet in distilled water

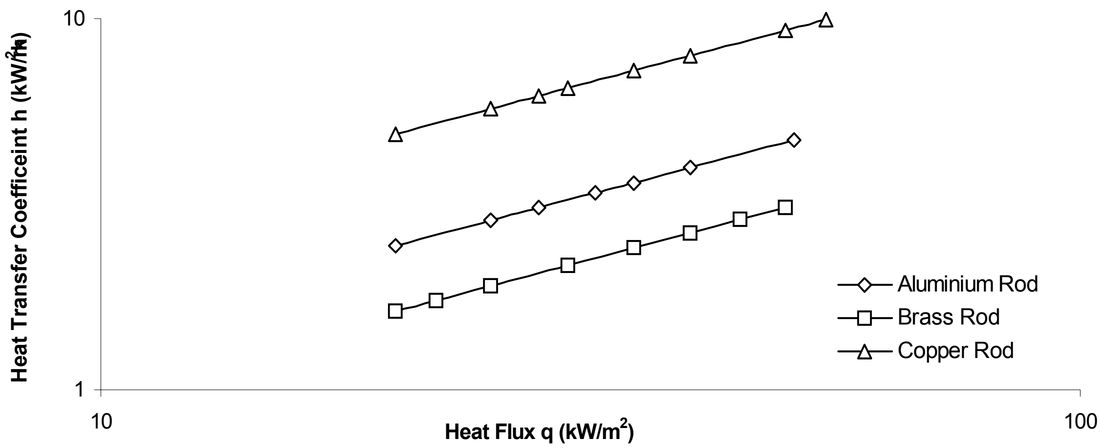

Figure 5. Variation of h with q for Aluminium rod, Brass rod and Copper rod in Methanol

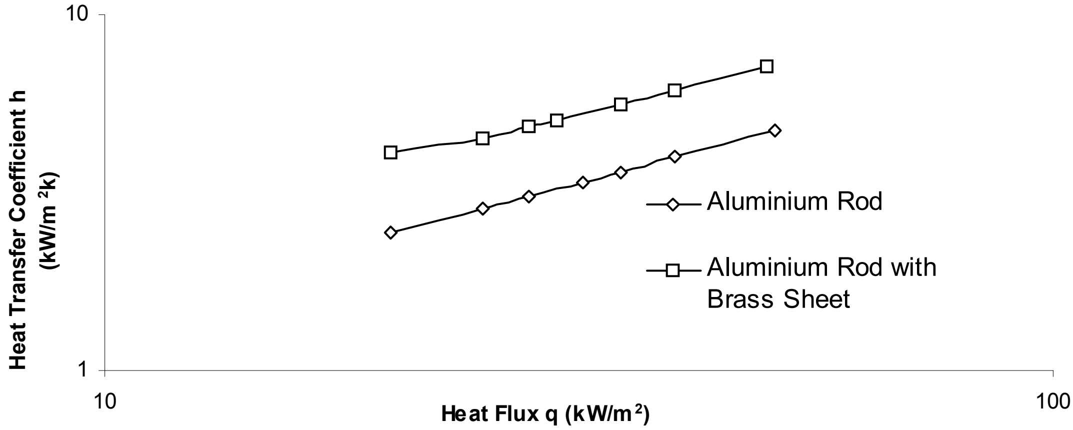

Figure 6. Variation of h with q for Aluminium rod and Aluminium rod covered with Brass sheet in Methanol

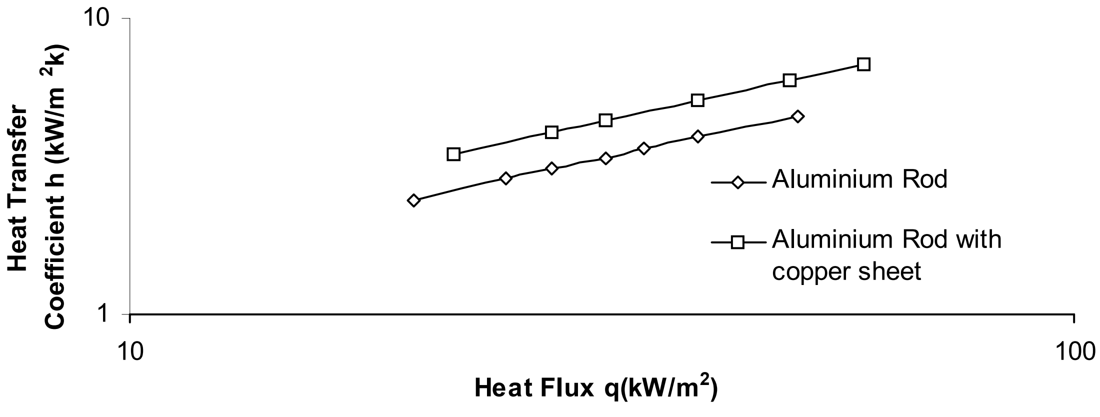

Figure 7. Variation of h with q for Aluminium rod and Aluminium rod covered with Copper sheet in Methanol

Table 1.

S No	Name of the liquid	Name of the Metal rod	n	C
1	Distilled Water	Aluminium Rod	0.699	0.900
2		Brass Rod	0.699	1.801
3		Copper Rod	0.700	1.899
4		Aluminium rod covered with Brass Sheet	0.700	1.199
5		Aluminium rod covered with copper sheet	0.699	1.500
6	Methanol	Aluminium Rod	0.699	0.300
7		Brass Rod	0.700	0.200
8		Copper Rod	0.699	0.600
9		Aluminium rod covered with Brass Sheet	0.633	0.594
10		Aluminium rod covered with copper sheet	0.700	0.399

NOMENCLATURE

Symbol	Meaning	Unit
l	Length of heating tube	mm
d_i	Inner diameter of the heating tube	mm
d_o	Outer diameter of the heating tube	mm
a	Surface area of the heating tube	m^2
Q	Heat flow	w
q	Heat flux	w/m^2
K	Thermal conductivity	w/mk
Two	Outer wall temperature	k
T_l	Average Liquid temperature	k
h	Convection heat transfer coefficient	w/m^2k
V	Voltage	v

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