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Thermal performance of Anodised Two phase closed Thermosyphon (TPCT) using Aluminium Oxide (Al2O3) as nanofluid

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Abstract: Heat pipes are passive heat transfer devices, it transfers heat by evaporation and condensation of working fluid partially filled in it. Two phased closed thermsyphons are passive heat transfer devices, it transfers heat by evaporation and condensation of working fluid partially filled in it. Thermal performance of an anodized two-phase closed thermosyphon (TPCT) charged with Al_2O_3 nanofluid is studied and compared with that of De Ionised (DI) water as base fluid. An anodization is performed to produce a porous coating on the inner wall of thermosyphon. The anodized TPCTs filled with Al_2O_3nanofuid and DI water is evaluated for the heat supply range of 50–200 W. The effects of inclination angle, heat input and anodized surface on the thermal performance of the thermosyphon (TPCTs) are investigated. Due to the anodization process, heat transfer coefficient improves up to 45% at the inclination angle of 45° for the heat supply of 50-250W. Also, thermal resistance of the anodized TPCT is reduced by 14%, 26% and 23% respectively for horizontal, inclined and vertical positions when compared to the water as base fluid in TPCT. Thermal performance of TPCT increases Al_2O_3 nanofluid compared with based fluid (DI water).

Keywords: Anodization, Thermosyphon, Porous inner coating, Al_2O_3nanofluid, De Ionised Water, Electronic Cooling.

1. Introduction

For effective thermal management, the most vital challenges in many technologies due to constant demand for faster heat removal and miniaturization of device dimensions. In consideration with miniaturization thermosyphons are efficient devices. A thermosyphon performs 20 times better than a metallic conductor (fin), this is due to the fact that convective heat transfer is faster than conductive heat transfer. So thermosyphon finds application in the area of electronics cooling, aerospace applications, thermal energy storage, waste heat recovery, etc. This fact has made two-phase closed thermosyphon a common apparatus in a variety of thermal engineering areas such as electronic device cooling, solar systems, heat recovery, HVAC and aerospace[1, 2] refrigeration systems[3], cooling super conducting bearings[4], boiler application[5] Thermosyphons are hollow metallic tube partly filled with working fluid that evaporates at the hot end and condenses at the relatively cold end. Because of hollow tubes used, heat pipes are light weight compared with equivalent metallic conductors for the same heat removal. When heat is supplied to the hot end, the working fluid evaporates; the vapour formed inside is at higher pressure than that provided through the section for vapour space. So that vapour condenses thereby releasing its latent heat at the relatively colder end.

When using nanofluid as working fluid, a confusing manifold of additional parameters like nanoparticle size, shape, material, base fluid characteristics etc. – Influence heat transfer rate of the heat pipe. The aim is to reduce the thermal resistance of the working fluid, defined as the heat transfer due to the temperature difference between evaporator and condenser section. The working fluid plays a substantial role in the performance of thermosyphons. When choosing the fluid, some characteristics must be taken into consideration such as boiling properties, vapour pressure, thermal conductivity and surface tension. A fluid with improved thermo physical properties could lead to enhance in the thermal performance of a thermosyphon Different methods has been used to prepare the nanofluid: the one-step method [6,7]and the two-step method[8]. The one step method simultaneously makes and disperses nanoparticles into base fluids. The two-step method initially produces the nanoparticles and then mixed the (disperses) nanoparticles with base fluids. The one-step method is not economic because it has complicated fabrication work .Therefore; the two-step method is highly used because of its convenience and economic. Most of the literatures were use the two-step method to calculate the heat transfer characteristics of nanofluids.

Noie et al.[9] the performance of a thermosyphon with Al2O3 nanoparticle suspensions as working fluids. The calculate results showed that for various power inputs, the efficiency of the thermosyphon improves up to 14.7% when Al2O3/water nanofluid was used instead of pure water. Also found that the wall temperature of the thermosyphon with nanofluids is less than that of the one filled with pure .water BangandChang[10] investigated the pool boiling heat transfer of Al2O3-water nanofluid on vertical and horizontal surfaces. Results found that the improvement of CHF can be in the range of 32%–52% for the horizontal surface, and 13% for the vertical surface. Khandekar et al.[11] investigated a thermosyphon (TPCT) with pure water and various water base fluids (Al_2O_3, copper oxide and laponite clay) as the working fluids. Suriyawong and Wongwises [12] found that volumetric concentration and the material of the heating surface are also of importance. Peng et al.[13] used aluminium nanoparticles to water and experimentally calculated the thermal performance of a thermosyphon. It reduces the wall temperature, higher heat transfer co efficient rate (47–96%) and heat flux as the results of using nanofluid. In another experiment by Huminicet al[14], again with FeO_2 nanoparticles, thermal performance of a thermosyphon was investigated in various inclined angles (45° and 90°). Using Copper Oxide (CuO) nanoparticles dispersed with water, thermal performance of a two-phase closed thermosyphon (TPCT) was reported by Alagappan and Ramanathan[15] .Heat transfer performance enhanced up to 50% after using the nanofluid. There are some other studies available on the performance investigation of nanofluids in different heat pipes [16, 19].

The main focus of this work is directed towards the effects caused when nanoparticles are added to the working fluids and tested with anodised two phase closed thermosyphon(TPCT) ,which is compared with DI water as base fluid. Porous structure is created in the TPCT using anodisation process. We have experimentally investigated the performance of TPCT. Al_2O_3 as nanofluid (working fluid) on the cooling performance of a two-phase closed thermosyphon. Concentrations of nanoparticle are 0.060% were prepared and applied for different input powers. The effects of heat input and the inclination angle on the performance of TPCTs are also investigated. Heat transfer performance and thermal resistance Al_2O_3 in TPCT is compared with DI water.

Nomenclature

Doff	**diameter of nanoparticle, nm**		
d_i	inner diameter of heat pipe, mm	US	Ultrasonic vibration
H	Heat Transfer co efficient, W/m2K	V	Voltage (V)
l_e	length of evaporator section, mm	I	Current(A)
l_c	length of condenser section, mm	T_e	Evaporator temperature (°C)
l_{hp}	length of TPCT, mm	T_c	condenser temperature (°C)
R	thermal resistance (°C/W)	T_w	water temperature(°C)
		Q_{in}	Inlet heat (W)
Abbreviation			

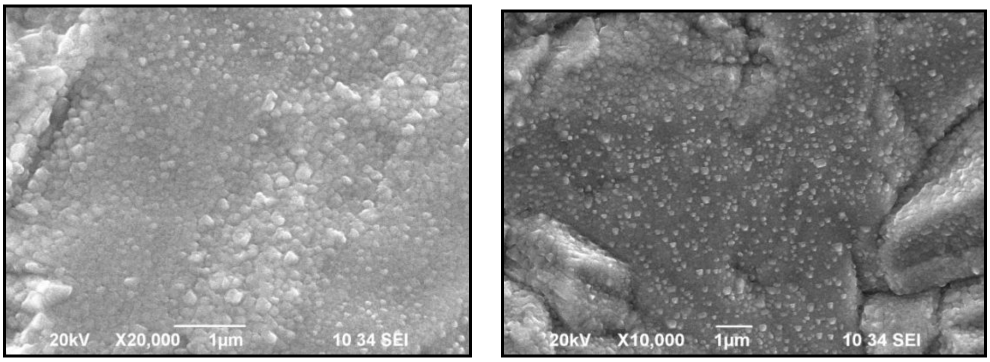
s			
HP	Heat Pipe		
TPCT	Two phase closed Thermosyphon		
Al_2O_3	Aluminium Oxide	Greek symbols	
DI	De-Ionised Water	φ	concentration of nanoparticles, vol,wt %

2 Experimental details

2.1. Preparation of coating

Anodization is performed to make a uniform porous coating at the inside wall of TPCT. Before anodizing process, it is necessary clean the TPCT because it is performed to make a uniform porous coating at the inner wall of TPCT. The test section consisted of a copper tube with an inner diameter (d_i) of 16 mm and length of TPCT (l_{hp}) 350 mm. The copper tube and a copper rod are considered as an anode and cathode respectively. The radius of the cathode is 5 mm. The cathode is placed at the inside of the anode with a distance of 3 mm from the anode. To avoid a surface contact between cathode and anode, Teflon sleeves are used at both ends of the anodizing TPCT. Temperature is maintained at the constant level in cell assembly by circulating cooling water around the entire anodizing cell setup. The anodizing process involves two steps, which are pre-treatment and internal anodic porous making. For the pre-treatment, 50 g/l NaOH solution is circulated in-between the cathode and anode for 2 min followed by De Ionised water is circulated for about 5 min. Then , impurities are removed by circulating 15 vol.% Nitric acid(HNO_3) solution for 2 min. Afterwards that DI water is circulated for 5 min and rinsed.

After completing pre-treatment process, internal anodic porous making is performed by circulating electrolytic solution (H_2SO_4). The uniform porous structure is achieved by using the required anodizing conditions of 10 vol. % concentration, 450 ml/min electrolyte flow rate and 50 min of anodizing time. Initially, the cell voltage is set at 1 V and is raised in steps of1 V until it reaches 15 V, where it is maintained up to 50 min. After this internal anodic porous making the surface is cleaned with DI water and used for further investigation. The anodized surface is analyzed using scanning electron microscope (SEM) and is shown in Fig. 1(a) and (b). In this method, the porous structure with an average thickness of 1µm and an average pore size of 150 nm is achieved.



(a) (b)

Fig 1. SEM image of anodised surface (two resolutions)

2.2 Preparation and characteristics of nanofluid

Nanofluids are engineered colloidal suspensions of nanoparticles in base fluids. In general the size of these nanoparticles varies from 1-100nm in size. Nanofluid is produced by metal oxide nanoparticles suspended in base fluid such as DI water. The nanoparticle suspended in the base fluid should stable for long a long time. For this research Al_20_3 nanofluid is prepared by two step method. Initially Al_2O_3 nanoparticle size is reduced by high energy ball milling method. Average Al_20_3 nanoparticle size (Dnf) is 50nm. At that point the molecule were blended in base liquid utilizing attractive stirrer for 3h and after that ultrasonicated (US)for a few hours to get even and stable suspension of nanoparticle. In this study no dispersant or stabilizer was as they may affect fluid properties. Even after sonication sedimentation of particles was observed, so stirrer was used during the experiment to minimize the sedimentation of Al_20_3 nano particles.

(a) (b)

Fig 2. (a) Magnetic stirrer (b) Al_2O_3 nanofluid

2.3. Test set-up and details

The trial testing setup of the TPCT is appeared in Fig. 3.It consists of a resistance heater (1000 W), variable transformer, Wattmeter and data acquisition system. The total length of the TPCT is assumed as 350 mm. The evaporator (l_e), adiabatic and condenser (l_c) area lengths are 100, 100 and 150 mm separately.Al_2O_3 nanofluid is used as a working fluid. TPCT fenced in area was cleared and kept up at a vacuum weight of 104 mbar for around 6 h. During the vacuum pumping process, temperature of the TPCT is kept up at 400°C so as to evacuate the non condensable gasses. After this process the vacuum line is closed by adjusting a valve and the TPCT enclosure is cooled by ice. Then the required amount of working fluid (22ml) is charged while the vacuum line is closed. After the charging process, instrumentation is made for the execution investigation. After the instrumentation, heating element connected with variable transformer and wattmeter are used to apply a controlled heat input at the evaporator of TPCT. The LXI Data Acquisition/Switching Unit (Agilent-34972A) is used to record the thermocouple signals. After the charging process, instrumentation is made for the execution examination. After the T-sort thermocouples (OMEGA) with a precision of±0.1°C are utilized to record the temperature readings. The delta and outlet temperature of the cooling water are likewise recorded. The whole evaporator and adiabatic segment of the TPCT is protected with 4 cm thick fibre glass material to keep away from warmth misfortune to the environment.

A cooling coat with channel and outlet ports is manufactured utilizing the acrylic funnel. At the condenser, cooling water with a consistent stream rate of 420ml/min is supplied with steady temperature of 15°C.The exactness of thermocouple incorporating the instability in the information logger is ±0.2°C. The instabilities in the estimation of temperature and stream rate are ±0.5% and ±3%respectively.

Fig 3. The experimental testing setup of the TPCT

3. Results and discussions

In this study, the execution of the TPCT is studied by differing the parameters, for example, inclined angle and heat inputs. The charging amount of working fluid is 0.60%(φ volume concentration).The inclination angle is varied between 0°and 90°and the heat input is varied from 50 to 250 W. Heat balance equation is used to calculate the heat transferred (Q_ out) by the TPCT

$Q_{out} = mC_p(T_{out} - T_{in})$

Where m is the mass flow rate of the coolant and cp is the heat capacity of the coolant. Tout and Tin are the temperature of the

Cooling water at the outlet and inlet, respectively.

Heat load was supplied by the resistance heaters with different values of 50 W, 100 W, 150 W, 200Wand 250 W. Power was measured with the guide of a voltmeter and ammeter as portrayed in the figure. This value could be indicated as:

$Q_{in} = VI$
Where V is voltage and I is current
The thermal resistance of the thermosyphon is calculated as
$R = (T_e - T_c) / Qin$
Where Te and Tc are the normal evaporator and condenser temperatures individually

Fig. 4(a–c) demonstrates the wall temperature profiles of anodized TPCT with DI water as base liquid at flat, inclined and vertical positions separately, and Fig. 4(d–f) demonstrates the wall temperature profiles of anodized TPCT with Al_2O_3 nanofluid as base fluid at flat, inclined and vertical positions separately From the Fig. 4(a–f) it is found that the wall temperature increments as the heat input increments for both DI water and Al_2O_3 nanofluid TPCT at all inclined angles. Also it is seen that the evaporator temperatures of the TPCTs are higher than the temperature at the adiabatic and condenser sections. Along the height of the TPCT, the temperature diminishes for water and Al_2O_3 nanofluid all conditions at all inclined points. Further it is seen that the evaporator temperature distribution of the anodized TPCTs with Al_2O_3 nanofluid at horizontal and inclined position (Fig. 4(a) and (b)) is uniform contrasted and anodized TPCT with DI water as base fluid (Fig. 4(d) and (e)). This variation is due to the change in boiling dynamics at the evaporator portion. Fig. 1(a) and (b) shows the inner surface morphology of the anodized surface.

It is clearly seen that the anodized surface consists of numerous nucleation cavities also anodised surface worked efficiently with Al_2O_3 nanofluid compared with DI water. The large number of nucleation cavity promotes a nucleate boiling. Hence, in the anodized surface with nanofluid, the bubbling system is more successful than the in the anodized surface with DI water. Further, it is seen that the evaporator temperature of theTPCT with anodized surface with $Al_2 O_3$ nanofluid is lower than that of anodized TPCT with DI water at all heat inputs for all inclination angles and the difference between wall temperatures of the TPCT Al_2O_3 nanofluid and DI water anodized surfaces increases with increasing heat input. In order to clarify the purpose for the heat transfer enhancement, the anodized surface with Al_2O_3 nanofluid is further dissected. The quantity of microcavities present in the anodized surface with that nanofluid is assessed by counting the number of pores per micrometer range and determining for the entire evaporator. It is found that the total micro-cavities present in the evaporator of the anodized TPCT with Al_2O_3 nanofluid are higher than the anodized surface with DI water. This will drastically reduce the wall temperature of the anodized surface with Al_2O_3 nanofluid and improve the heat transfer. Further the evaporator performance of the anodized TPCT with Al_2O_3 nanofluid is depends on the nucleation site density, bubble diameter, bubble frequency and thermo physical properties of working fluids.

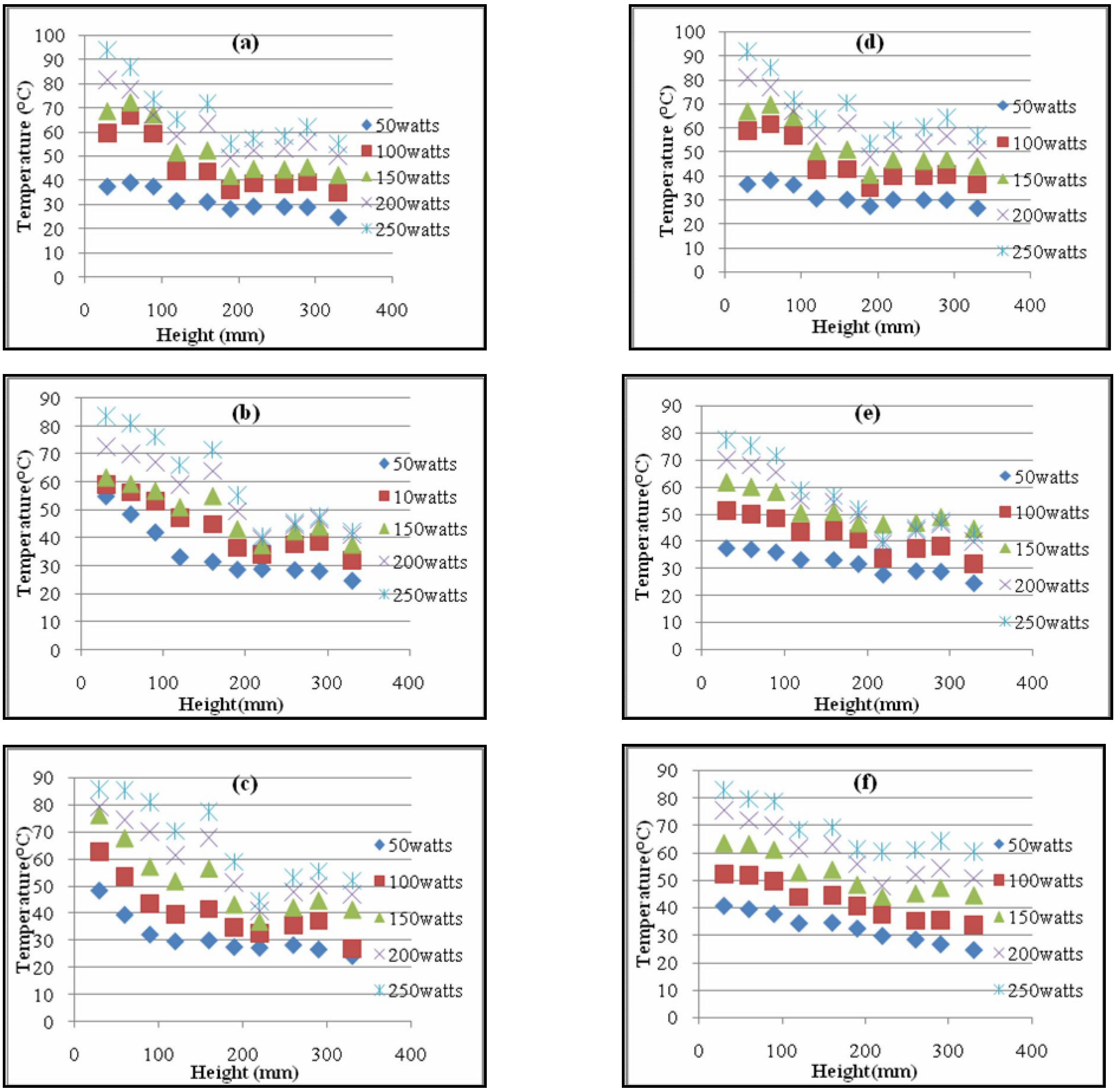


Fig 4. Wall temperature profiles of anodised TPCT with DI water at (a) horizontal (b) inclined and (c) vertical positions, anodised TPCT with Al_2O_3 nanofluid at (d) horizontal (e) inclined (f) vertical position

Further to concentrate on the heat transfer performance of TPCT, the heat transfer coefficients of the TPCT are resolved from Eqs

$h = q/\Delta T$

$q = Q_{in}/dl$

The temperature difference between evaporator and condenser is calculated from below Eqs

$\Delta T = T_e - T_c$

T_e = Average evaporator temperature

T_c = Average condenser temperature

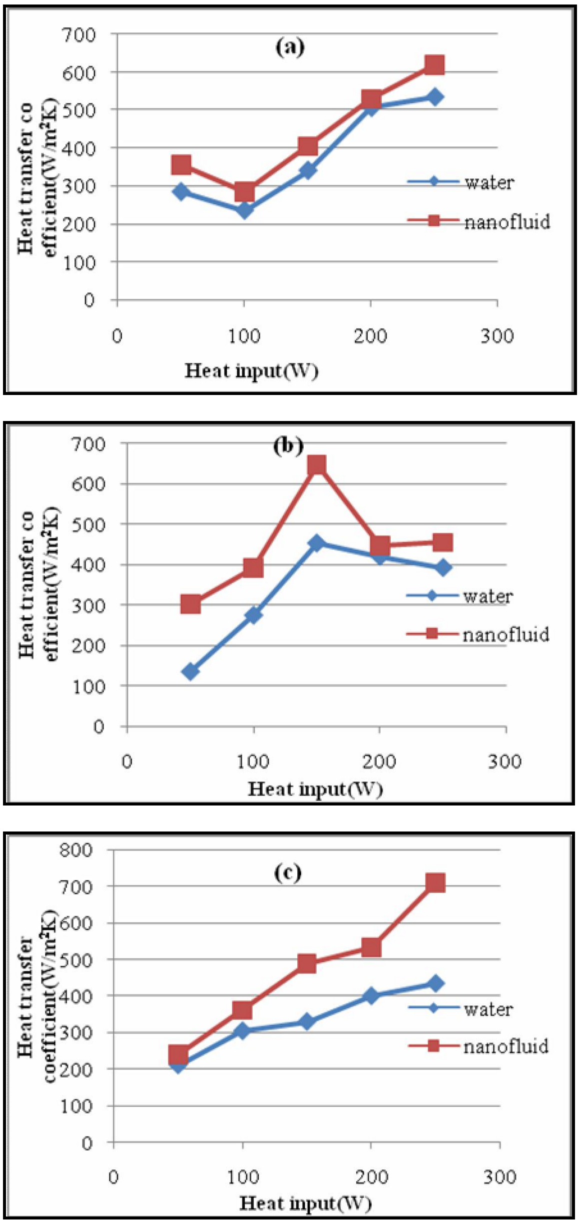


Fig 5.Comparison of Heat transfer co efficient in anodised two phase closed thermosyphon at (a) horizontal (b) inclined (c) vertical

Fig 5 (a-c) shows the heat transfer co efficient of anodised TPCT (water and Al_2O_3nanofluid) at horizontal, inclined, vertical positions. It is seen that the heat transfer co efficient for Al_2O_3 nanofluid is higher than that of DI water as base fluid. Heat transfer co efficient is increasing so as to expand heat information (with the exception of inclined position). A greatest heat transfer co efficient upgrade of 34%, 45%, 17% (Al2O3 nanofluid) contrasted and DI water at the position of vertical, inclined, horizontal separately. It is mainly due to higher thermal performance of Al2O nanofluid in anodization surface compared with DI water. Combination of anodised surface andAl2O3 nanofluid makes higher bubble surface compared with DI water. Higher bubble surface creates higher heat transfer co efficient in nanofluid compared with base fluid.

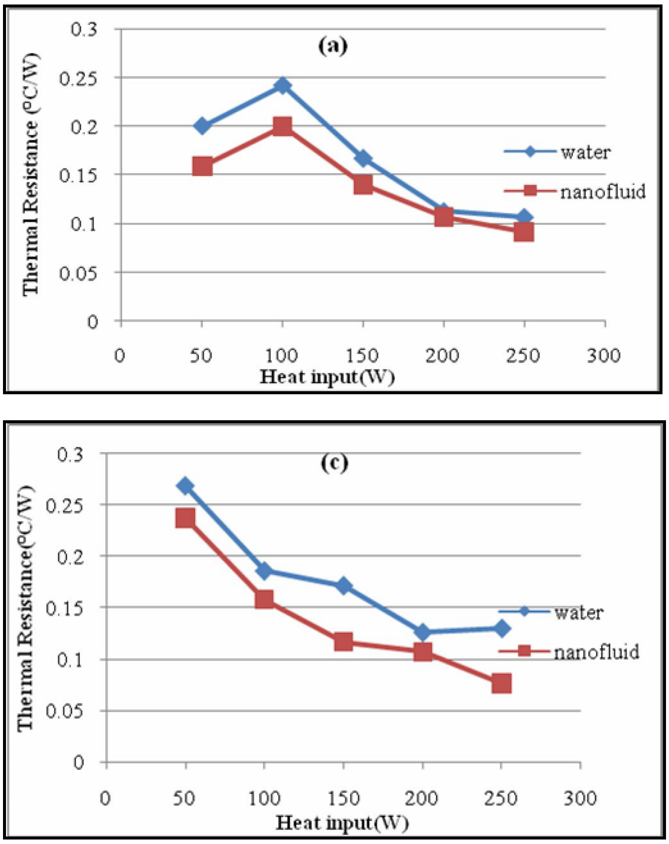


Fig 6. Comparison of Thermal resistance with DI water and Al_2O_3 nanofluid at (a) horizontal (b) inclined (c) vertical positions

The thermal resistance of TPCT at various inclination angles for anodised surface with Al2O3 nanofluid and DI water is shown in fig. It shows that the thermal resistance decreases gradually with increasing heat input at the position of inclined and vertical while compared with DI water. The difference in the thermal resistance between Al2O3 nanofluid and DI water is high at low heat input at the position of horizontal and inclined and it decreasing as the heat input increases. The maximum thermal resistance of 23%, 26%, and 14% are obtained at the position of vertical, inclined, horizontal respectively.

4. Conclusion

In this paper, effect of porous coating on the inside wall of TPCT with DI water and Al_2O_3 nanofluid has been studied. The anodic oxidation is performed at the inside wall of TPCT. Anodization process makes porous structure and enhances heat transfer with Al_2O_3 nanofluid compared with DI water (base fluid). Due to this anodised TPCT, wall temperature, heat transfer co efficient is calculated. Also thermal resistance of anodised TPCT with Al_2O_3 nanofluid decreases compared to anodised TPCT with DI water (base fluid). It is noticed that heat transfer co efficient enhanced up to 34%, 45%, and 17% for Al2O3 nanofluid obtained at the position of vertical, inclined, horizontal respectively compared to that of DI water. Due to this enhancement in the heat transfer co efficient, thermal resistance of the TPCT is reduced up to 23%, 26%, and 14% at vertical, inclined, horizontal position respectively.

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