HEFAT2014
10th International Conference on Heat Transfer, Fluid Mechanics and Thermodynamics
14 – 26 July 2014
Orlando, Florida

HEAT TRANSFER MEASUREMENT IN ALUMINIUM OXIDE NANOFLUID USING RECTANGULAR THERMOSYPHON LOOP

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ABSTRACT
Nanofluids are generally found to exhibit better thermophysical properties and heat transfer capabilities than the corresponding base fluids. Experimental and theoretical investigations on the forced and free convection behavior have reported superior heat transfer capability of nanofluids, except in a few cases. Studies on natural/free convective heat transfer in nanofluids have shown negative impacts when investigations were performed on a vertical column of the fluid. The absence of a pumping system makes natural circulation loops silent and also saves the energy for pumping the fluid. Since the thermosyphon loop resembles a forced circulation loop except for the absence of a pump, a nanofluid can be expected to yield enhanced heat transfer, compared to the base fluid. The present work captures the heat transfer performance of oxide nanofluids in a rectangular thermosyphon loop. The density gradient created by the temperature gradient between the heating and cooling sections, assisted by gravity, constitute the driving force in the loop. The temperature of the fluid at the inlet and exit of the heating sections and, on the pipe surface along the heating section is measured. The effect of the external heat input, concentration of nanofluids and average temperature of the cooling section on the heat transfer are investigated. The results have shown that the Al_2O_3 nanofluids have enhanced heat transfer characteristics as compared to water in rectangular thermosyphon loops.

NOMENCLATURE

Grm	[-]	Modified Grashoff's number
D	[m]	Loop diameter
L	[m]	Length of the loop
Stm	[-]	Modified Stanton number
Lt	[m]	Total Loop length

INTRODUCTION
Thermosyphon cooling systems find wide applications in automobiles, nuclear power plants, electronic circuits, and other similar equipment. Compared to forced circulation systems, thermosyphon systems do not require a pump to aid in circulation, resulting in lesser power consumption and silent operation. As far as cooling fluids are considered, water is one of the most widely used, owing to its superior heat capacity. A number of investigations have been undertaken in the past, on the heat transfer behavior of suspensions of particulate solids in liquids, which are expected to be cooling fluids of enhanced capabilities, due to the much higher thermal conductivities of the suspended solid particles, compared to the base liquids. However, most of the early studies were focused on suspensions of millimeter or micron sized particles, which, although showed some enhancement in the cooling performance, also exhibited problems such as sedimentation and clogging. The gravity of these problems has been more significant in systems using passages of small dimensions. The suspension of nanometer sized particles in fluids have offset a lot of sedimentation and clogging issues.
It was Choi [1] who first introduced the term nanofluids for the suspensions of nanoparticles in fluids. Investigations on various nanofluids [2][3][4][5] have shown that their thermal conductivities are superior to that of base fluids like water and HE-200 oil. A number of investigations have been reported on the heat transfer performance of different types of nanofluids, under various flow regimes and different configurations of the heat transfer equipment. Convective heat transfer studies have been carried out in the developing region [8, 14] as well as under fully developed conditions [6]. Studies have been reported pertaining to laminar [6, 7, 9, 10, 11], transition [12, 15] and turbulent [10, 13] regimes of flow.

Investigations on the influence of filling ratio, operating temperatures, inclination and dimensions on two phase thermosyphons containing different nanofluids have shown both enhancement and deterioration in performance. Xue et al. [16] showed that carbon nanotube-water nanofluid deteriorates the heat transfer in the thermosyphon as compared with water. Investigations by Khandekar et al. [17,18] on the overall thermal resistance of a closed two-phase thermosyphon using water-based Al_2O_3, CuO and laponite clay disk nanofluids have shown that nanofluids are inferior to water. The heat transfer performance of TiO_2 -water and TiO_2-alcohol nanofluids in a thermosyphon is found to be 10.6% superior to that of water, as reported by Naphon et al. [19]. Naphon et al. [20] also reported that thermosyphon efficiency can be enhanced by 40% by the use of TiO_2-R11 nanofluid. Experiments by Liu et al. [21,22] in a heat pipe using CuO and CNT nanofluids showed that heat transfer performance of the evaporation section and the maximum heat flux (MHF) could be enhanced. Noie et al. [23] reported that Al2O3-water nanofluid in a thermosyphon enhances the heat pipe efficiency by 14.7%, and that the thermosyphon shows a more uniformly distributed temperature. The use of Ag-water nanofluid in a thermosyphon by Paramatthanuwat et al. [24] has hown that the heat transfer capacity can be enhanced by 70%. Teng et al. [25] reported that Al_2O_3-water nanofluid with a mass concentration of 1.0% results in 16.8% enhancement of thermosyphon efficiency.

Investigations into the steady state and transient behavior of single phase thermosyphon loops with water as the base fluid has been carried out by many researchers. Vijayan et al. [26] investigated the influence of loop diameter on the stability of the loop at a wide range of heater power and cooling water flow rate. It was found that stable steady state is obtained for 6 mm and 11 mm loops for the entire single-phase region, while for a 23.2 mm diameter loop, instability was observed for certain range of operating conditions. Instability was identified from the flow reversals and the fluid temperature oscillations. It has been recognized that generally acceptable non-loop specific scaling laws are a necessity for understanding and comparing the behaviour of natural circulation in loops. Vijayan et al. [27] has proposed that for rectangular natural circulation loops under steady state conditions, the Reynold's number is a function of $\left(Gr_m \frac{D}{L}\right)$. This shows that $Gr_m(D/L)$ is the appropriate scaling parameter for the steady state behaviour. Though the power-to-volume scaling principles correctly simulate the steady state behaviour of loops, they fail to do so as far as the transient and stability behaviour are concerned, owing to the influence of loop diameter and modified Stanton number (St_m). Misale et al. [28] analysed the influence of thermal boundary conditions on the flow regimes inside the pipes and on the stability of a natural circulation system containing distilled water. It was found that varying the heat sink temperature between -20 ^oC and +30 ^oC resulted in crossing the stability threshold. The fluid circulation rates were also found to increase with an increase in the sink temperature. Vijayan et al.[29] analysed steady state and stability characteristics of single phase rectangular natural circulation loops with different cooler and heater orientations, namely, Horizontal Heater Horizontal Cooler (HHHC), Horizontal Heater Vertical Cooler (HHVC), Vertical Heater Horizontal Cooler (VHHC) and Vertical Heater Vertical Cooler (VHVC). The HHHC cooler orientation was found to give the maximum flow rate but was also the least stable, while the VHVC orientation was the most stable. Cammarata et al. [30] presented a stability analysis considering the effect of the variation of the modified Grashof number, Grm, for a wide range of loop geometrical configurations, assuming various aspect ratios (ratio of the vertical to the horizontal length of the tube) and inner tube diameters. It was found that loops with lower aspect ratios are more stable and less sensitive to variations of Gr_m. The effect of pressure drop on the stability of single phase natural circulation loops was analyzed by Misale et al. [31]. The insertion of orifices in the vertical legs of the loop increased the pressure drop resulting in stabilizing the loop. Vijayan et al [32] reported the effect of loop diameter in the performance of single and two phase natural circulation loops. In the stability map (Gr_m v/s St_m) the unstable zone is found to shift up with reduction in loop diameter. In other words, increasing the loop diameter destabilizes single-phase natural circulation loop. It was also revealed that the L_t/D ratio (where L_t is the total loop length) is an important parameter affecting instability; higher the Lt/D ratio better will be the stability.

In the present work the steady state performance of a rectangular loop with VHVC orientation was experimentally analysed using water as well as Al_2O_3-water nanofluid as the working fluid.

EXPERIMENTAL SETUP

The experimental setup consists of a natural circulation loop fabricated using copper tube of 10mm diameter. The aspect ratio (height to width) of the loop was maintained as 1, as loops with aspect ratio greater than unity are reported to be less stable [30]. The orientation of the heater and cooler were also chosen as vertical as they are reported to be most stable [29]. The loop was fabricated with a height and width of 150 cm. The heating section was fabricated by wrapping a band heater (Brisk Heat Inc., USA) tightly over the copper tube to provide a constant heat flux, which was then thermally insulated. The heating section was isolated from the other parts of the loop using Teflon sleeves to prevent axial conduction of heat along the tube. The cooling section consisted of a counter-flow heat exchanger which was supplied with cooling water from a refrigerated constant temperature water bath at the required temperature. The parts of the tube other than the heater and cooler sections were also thermally insulated from the ambient. The fluid and heater surface temperatures were measured using calibrated T-type thermocouples. The loop fluid temperatures were measured at the inlet and exit of the heater and the cooler. The temperature of the cooling water was also measured at the inlet and exit of the cooler. The temperatures on the tube surface along the heater region were measured with the help of six T-type thermocouples which were braced on to the copper surface. The thermocouples were connected to a Agilent Benchlink datalogger interfaced to a computer. thus recording the data online at intervals of one second. The heater was connected to the mains through a variable transformer, which helps in varying the heater power input. A schematic diagram of the experimental setup is shown in Fig:1.

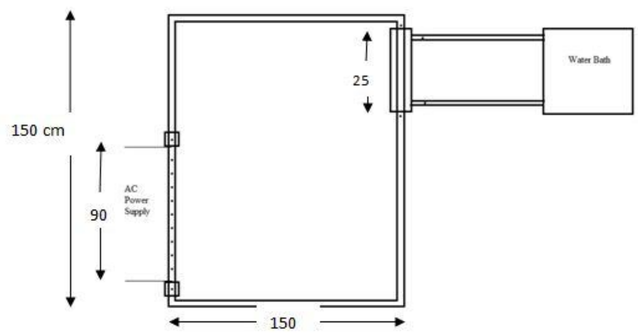

Figure 1 Natural Circulation Loop

The working fluids used in the experimental study consisted of both distilled water and Al_2O_3-water nanofluids. The distilled water was supplied by a Millipore water purification system. The Al_2O_3 nanoparticles were of an average diameter of 30 nm which was supplied by Sigma Aldrich, USA. The nanofluids were prepared by the two step method. The stability of the nanofluids were improved with the addition of Sodium Dodecyl Benzene Sulfonate (SDBS) as surfactant and by sonicating using a probe sonicator (Sonics, USA) for 2 hrs. It was found that the stability of Al_2O_3-water nanofluids are maximum when the amount of SDBS is equal to 25% of the mass of the Al_2O_3 nanoparticle. The required quantity of surfactant is first measured using an electronic balance of 0.1 mg accuracy and is added to the distilled water. The required quantity of nanoparticle is then measured and transferred to a container to which the distilled water containing surfactant is added and then subjected to sonication for proper dispersion of the nanoparticles in the fluid giving them long term stability. The quality of the dispersion is ascertained using a Malvern Zetasizer which measures the zeta potential of the fluid. The SEM image of Al_2O_3-water nanofluid is shown in Figure 2. Figure 3 shows the zetapotential value of 0.01% by volume of aqueous alumina nanofluid containing 25% by mass of SDBS surfactant.

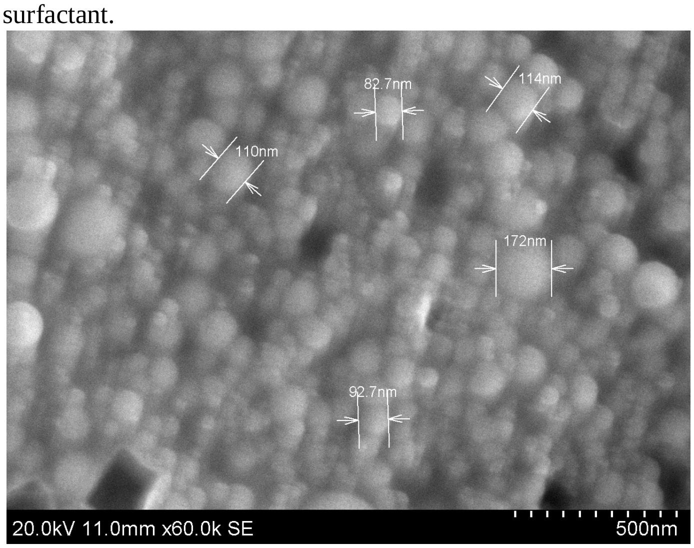

Figure 2 SEM image of Al_2O_3-water nanofluid of 0.01% by volume concentration

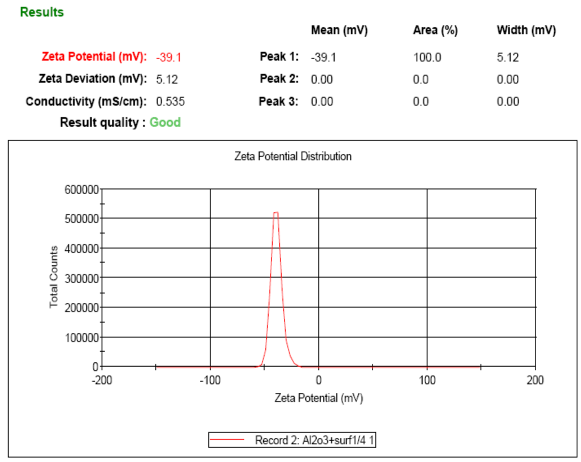

Figure 3 Zeta potential value of 0.01% by volume aqueous alumina nanofluid containing 25% by mass of SDBS surfactant

The experiments were conducted initially using water as the working fluid in the loop at various heat inputs and cooling water temperatures. The experiments were then repeated at the same conditions using nanofluids of particle concentrations 0.01%, 0.025%, 0.05%, 0.075% and 0.1% by volume.

TRANSIENT ANALYSIS

A transient analysis of the thermosyphon loop was performed by monitoring the time varying temperatures of the heater surface and the fluid at various locations in the loop carrying distilled water and nanofluids. The loop temperature gradient is one of the main parameters that indicates the transient characteristic of the loop.

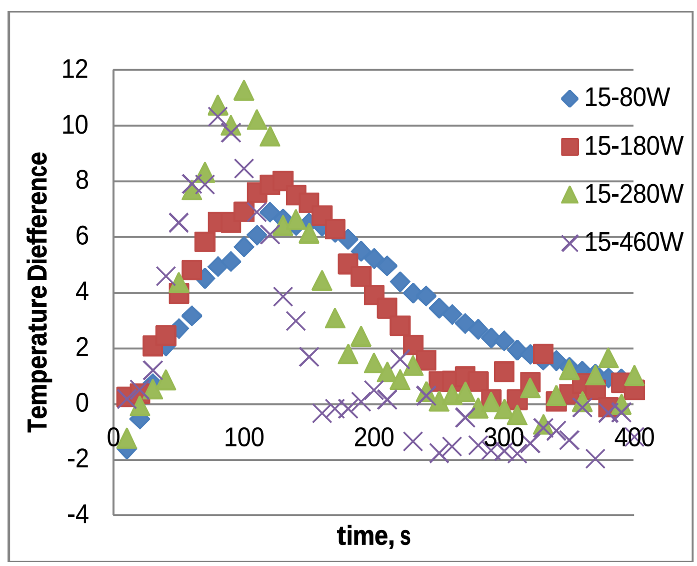

Figure 4 Loop temepraturе gradient for water at 15 deg Celsius for different heat input values

Figure 4 shows the transient variation of the loop temperature gradient (difference between average heater temperature and average cooler temperature) at different heat inputs. for water. Figure 5 shows the transient variation of loop temperature gradient at different heat inputs for 0.05% concentration nanofluid. In both cases the maximum temperature difference reaches earlier at higher heat inputs, as expected. Also all transient profiles show a unidirectional temperature gradient, stating that the flow is unidirectional and the loop is stable at all conditions.

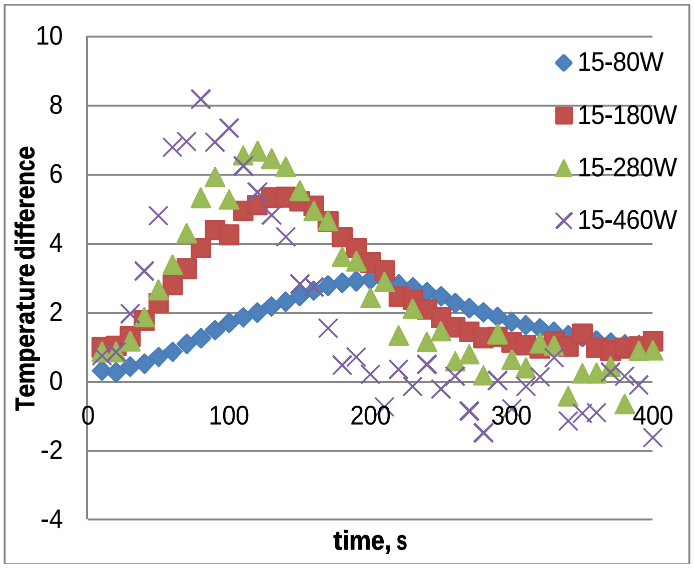

Figure 5 Loop temperature gradient for water- Al_2O_3 0.05% at 15 deg Celsius for different heat input values

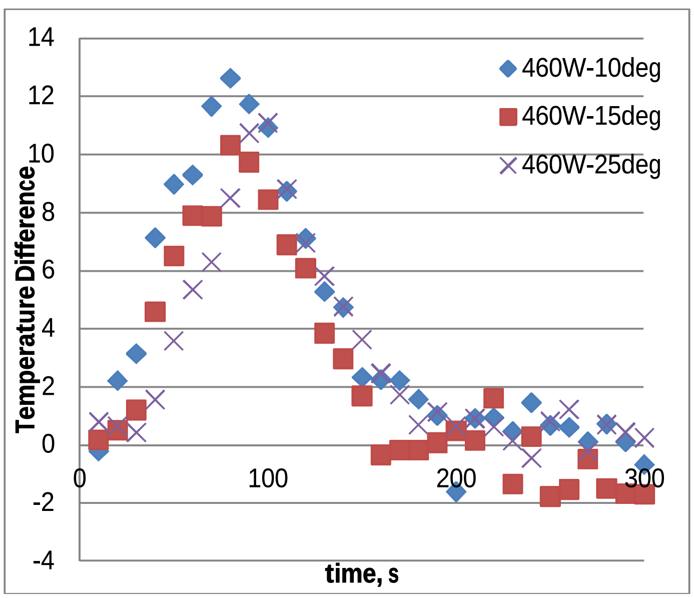

Figure 6 Loop temperature gradient for water at 460W for different cooling water temperatures

Figures 6 and 7 show the transient variation of loop temperature gradient with sink temperature for water and 0.1% concentration nanofluid. In both cases, the maximum loop temperature gradient was obtained for a sink temperature of 10°C. The loop temperature gradient is an important parameter in thermosyphon systems as it propels the flow inside.

Figure 8 shows a comparison of the transient loop temperature gradient between water and different concentrations of nanofluids. Eventhough the maximum loop temperature was reached for water, by the time the system reaches steady state the temperature gradient was higher for nanofluids, showing that the loop containing nanofluids have achieved higher fluid flow rates.

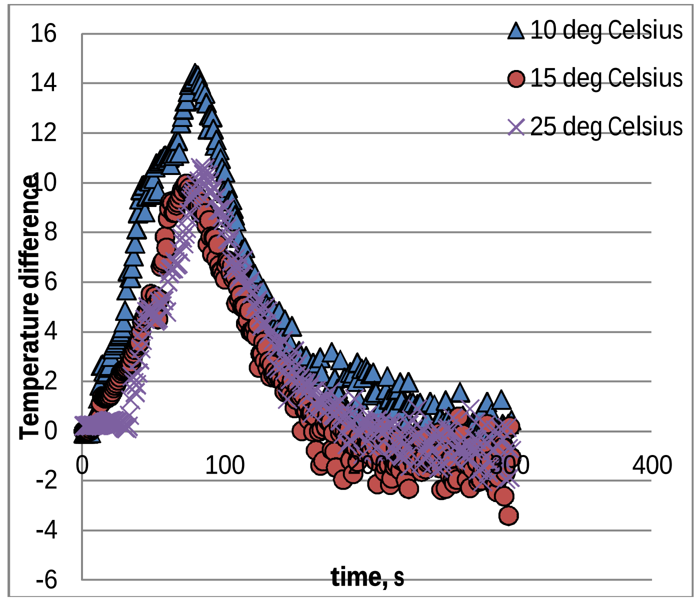

Figure 7 Loop temperature gradient for water- Al_2O_3 0.1% at 460W for different cooling water temperatures

Figure 9 shows the transient variation of average surface temperature for water and different concentrations of nanofluids. For all concentrations of nanofluids, the average heater surface temperature is found to be lower than that for water.

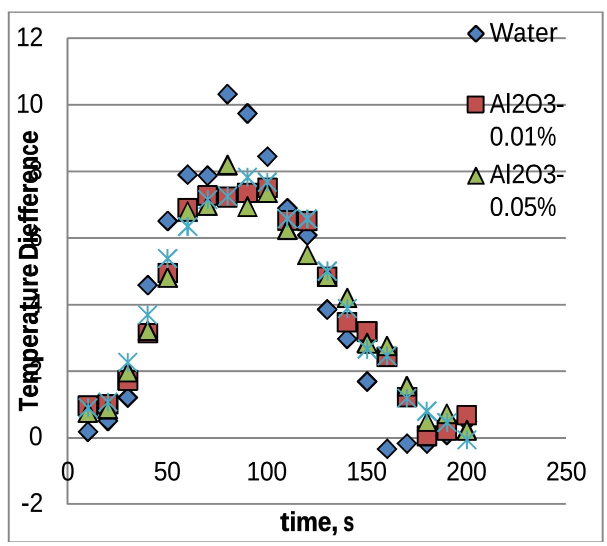

Figure 8 Loop temperature gradient at 460W, 15 deg Celsius cooling water temperature, for water and nanofluids

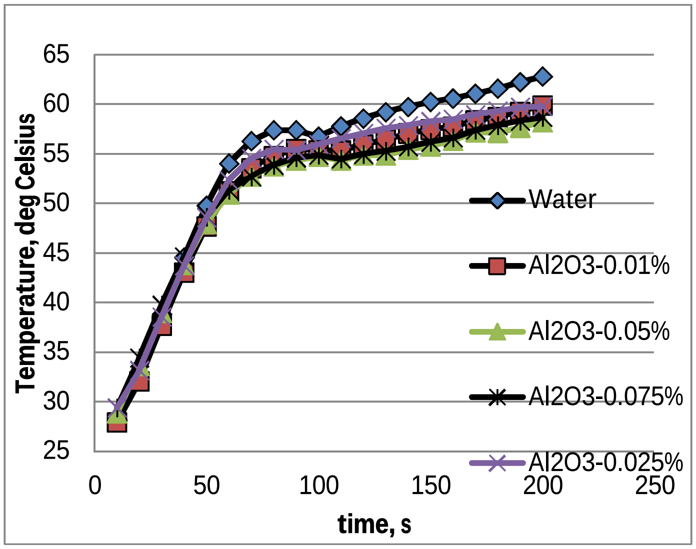

Figure 9 Average heater surface temperature at 460W for water and nanofluids

STEADY STATE ANALYSIS

A steady state analysis was performed based on the temperatures at various points on the heater surfaces and the fluid after they have reached the steady state. The heat capacities of the fluids were arrived at from the energy balance across the heat exchanger acting as the sink. The heat transfer coefficient was obtained from the heat input, heat capacity of the fluid and the steady state fluid temperatures at the inlet and the exit of the fluid and heater surface. Figure 10 shows the variation of the local heat transfer coefficient along the heater section for water and different concentrations of nanofluids. The nanofluids were found to be better heat transfer fluids in a thermosyphon loop as compared to water. This is due to the increased flow rates created by the higher loop temperature gradients in the case of nanofluids, compared to the base fluid.

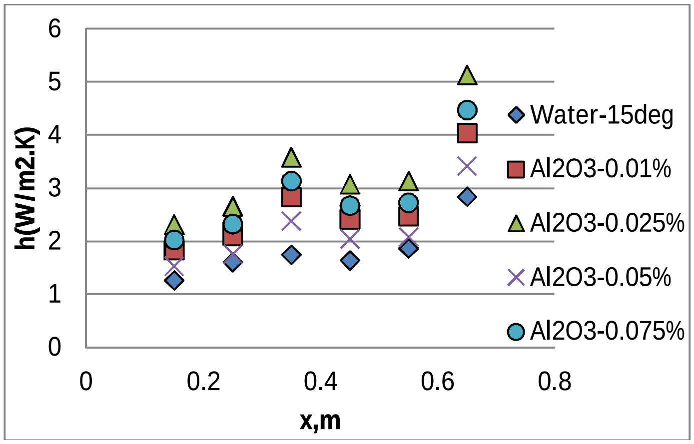

Figure 10 Local heat transfer coefficient at 460W and 15 deg Celsius for water and nanofluids

CONCLUSION

Experimental investigations were performed on a rectangular thermosyphon loop to evaluate its steady state perfromance and stability characteristics. Transient analysis shows that the nanofluids are stable at different combinations of heat inputs and sink temperatures. The loop temperature gradients were found to be higher in the case of nanofluids, compared to water. This is found to result in higher flow rates and is reflected in the higher heat removal capability of nanofluids. As a result of this, the average heater surface temperature is also found to be lower in the case of Al_2O_3-water nanofluids, compared to the base fluid.

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