The current research on boiling in heat transfer applications has been increased due to the effective heat dissipation rate in solar applications, cooling of new generation electronic chips with the goal of improving performance by controlling physical factors. Thermosyphons are one among the phase change medium which has the higher critical heat flux to accelerate the heat transfer. Current work in Thermosyphon focuses on the design, fabrication and performance analysis of dimpled Thermosyphon with certain variables like surface area of heat exchange, composition of working fluid and setup angle. Due to the impact of nanotechnology, the investigation is carried out by using Al₂O₃ Nano fluid as working fluid. The experiments are conducted initially with plain Thermosyphon, later with surface modifications (dimple) by changing the orientation of the Thermosyphon. The performance results of the plain Thermosyphon filled with water, plain Thermosyphon filled with Nano fluid is compared with dimpled Thermosyphon with Nano fluid at different angles such as 0°, 45° and 90°. Evaporator side dimple and condenser side dimple also designed and investigated. It is observed that thermal resistance for dimple Thermosyphon-Nano fluid is very low in the range of 0.06°C/W-0.20°C/W when compared with Plain Thermosyphon-water varies from 0.1°C/W-0.45°C/W, for Plain Thermosyphon-Nano fluid is 0.1°C/W-0.31°C/W. It is also observed that the efficiency of dimpled tube Thermosyphon with Nano fluid is estimated as 50.66%, 69.7% and 74.23% at 0°, 45° and 90° respectively which is the maximum value when compared with plain Thermosyphon with water and Nano fluid.

Keywords: Dimpled Thermosyphon, Al₂O₃ Nano fluid, Characterization, Performance

1. Introduction:

In recent days, the combination of nanoscience and heat transfer researches are engraving their footprints on the major applications such ascooling of electronic systems, electric vehicle systems, solar applications and semiconductor areas. In cooling of thermal systems, thermo syphon is the major
device which connects both research areas. A thermosyphon is one of the passive type cooling system with hot and cold interface ends where the prepared working fluids will take the phase change. At the evaporator side hot interface end, a liquid which is in contact with the hot surface turns into vapor by receiving the heat from the wall surface. This vapor formed travels axially to the cold interface and condenses, where the latent heat is released. Then, condensate will return to the hot end by capillary action, centrifugal force or gravity and the cycle repeats. The thermal conductivity (k) of the copper Thermosyphon is almost 90 times higher than that of a normal bar made of copper with the same configuration [1]. Several studies concluded that the thermosyphons are good choice for the thermal management of all computer accessories [2-4] Electronic circuits cooling [5, 6] battery cooling of Electric vehicles [8-11] and solar applications [12-13]. So, the current study has been chosen. The Thermosyphons with different geometry due to higher demand in better cooling, need of the larger ability in transferring heat in low thermal gradient and low weight applications. The wick structure’s capillary pressure limits the heat transport characteristics of applications at moderate temperatures [14]. The wick material’s porosity and permeability, as well as the mass flow rate of the working fluid that is utilized, all have an impact on the evaporator's heat resistance [15]. For the purpose of improving heat transfer process, the evaporation properties of various wick microstructures were the subject of experimental research [16]. The experiments were conducted on different geometries such as flat heat pipes without fins [18], with array of fins, with internal grooved heat pipes, mesh type of internal wicked heat pipes [19], sintered metal evil intensity heat pipes [20] and ultra-thin flat heat pipes [21] were previously reported. In recent researches, liquids with nanoparticles (more modest than 100 nm) have an extraordinary potential in heat transfer enhancement using the heat pipes. Inclusion of nanoparticles in fluids will drastically alter the thermo physical properties conventional fluids. [17] A study reported that, the performance of TPCT (Two phase closed thermo syphon) with aqueous Al2O3 nanoparticles of volume concentration of 1–3%. The experimental results indicated that the TPCT’s efficiency increased by up to 14.7% for various input powers [22]. In a similar vein, the effectiveness of various Nano fluids in a heat pipe evacuated tube solar collector was the subject of numerous experimental studies. A review noticed the issue of settling down of nanoparticles with a somewhat huge load of Al2O3 Nano fluid. At the same testing conditions, the Nano fluids performed better than acetone. It was higher at a volumetric concentration of 0.5%, which was higher than the 0.25 percent concentration [23]. A similar experiment with WO3/Water Nano fluid at three different volume fractions of WO3 nanoparticles (0.014%, 0.028%, and 0.042%) were examined at several mass flow rates per unit arealike 13 g/s.m², 15 g/s.m² and 17 g/s.m². The efficiency of this evacuated tube solar collector is about 72.8%, which is 19.3% higher than water. This complete literature on Thermosyphons indicates the usage of Thermosyphons in different applications with different geometrics and fluid medium. It is well understood that, the usage of dimpled surface Thermosyphon is very limited and not provided results in various aspects. Hence, the present work identified a new geometric Thermosyphon called dimpled surface for any kind of Thermosyphon applications. Especially, this work believes that, the dimpled surface Thermosyphon may be a right choice for the solar thermal collectors due to high heat transport characteristics. Also in electronic systems and supercomputers developed by companies like IBM heat generation is as much as 300 W to 800 W. In such scenarios, Thermosyphons are preferred solution due to their compact design and impressive thermal conductivity.

2. Thermosyphon and Nano fluid preparation Methods

2.1. Characterization of Nanoparticles
Aluminium oxide Nanoparticles are produced using sol gel method. Initially, 18.76 g of aluminum nitrate was taken by measuring in a digital weighing scale. It has been dissolved with citric acid in the distilled water. The solution was well- stirred at 60°C, for certain period of time until it becomes yellowish meta-stable solution. Further, the solution was maintained at 80°C temperature with constant stirring which turns into the transparent gel after some time. The transparent gel was gradually dried at 100°C in an oven for 12hours. The dried gel was taken out and sintered at 600°C to prepare Aluminium oxide nanoparticles and considered for characterization process. The phases of the prepared nanoparticles are examined using the X-ray diffraction (XRD) model Shimadzu XRD-6000 at room temperature and SEM image was taken 2000x and 4000x magnification range. The micrograph showed the irregular shape and sponge like structure of nanoparticles.

2.3. Nanofluid preparation and Characterization

The present work has thought about the spherical aluminum oxide (Al₂O₃) as nanoparticles (50 nm, acceptable diameter, mass per unit volume 3.88 g/cc) and deionized water as the base liquid to set up the Nano fluid. Catalytic chemical vapor deposition was used to make Al₂O₃ nanoparticles. The number of nanoparticles required to produce a solution with a volume concentration of 3% is calculated. The nanoparticles were dispersed in Deionized water using an ultrasonic homogenizer, and the solution was vibrated for 90 minutes to create a uniformly dispersed mixture as shown in Figure 1. Every one of the finished samples must be statically put for 45 days and it is seen that even after 45 days the fluid was stable and didn’t have much suspension. Thermal conductivity is determined by using KD2 Pro Thermal properties Analyzer and was 0.625W/m-K and Dynamic Viscosity is found by using Brook field digital Viscometer and was around 1.05 centipoise. Surface Tension was 1.05 MN/m which was found using SITA Tension meter.

![Day 1 and Day 45 of Nano fluid](image)

**Fig.1, Preparation and stability testing of Al₂O₃ – DI water Nano fluid.**

2.4. Design and fabrication of Thermosyphon

Copper was selected as the material for the Thermosyphon because of its higher thermal conductivity and compatibility with selected working medium. In this study, the Thermosyphon has a total length of 380 mm, Length of the condenser section is 180 mm, Length of the evaporator section is 120 mm, an outer diameter of 19 millimeters, and a thickness of 1 millimeter, Dimple projection was created on the surface of the Thermosyphon using a die with 3 mm diameter. The process was carried out in a drilling machine with high precision and pressure. The die is fixed inside the chuck of vertical drilling machine and is allowed to make punch on the surface of Thermosyphon. A uniform pressure is maintained to create uniform dimple formation. Dimple diameter is 3 mm, Centre to Centre distance between Dimples is 12 mm. Nano fluids and DI water are filled in the Thermosyphon. To extract more heat
from the Thermosyphon than air cooling, the condenser section is cooled by liquid water while the evaporator side is enclosed by a surface electric heater. A variable angle holder is used to adjust the Thermosyphon’s inclination angle from its horizontal axis to 0°, 45°, and 90°.

2.4.1 3D Model of the Thermosyphon

The design of Thermosyphon is carried by using solid works software in three stages like, plain Thermosyphon, Thermosyphon with dimple on evaporator and Thermosyphon with dimple on condenser. Figure 2a & 2b shows the 3D model of Thermosyphon with dimple, where the condenser length is assumed higher than evaporator section.

Fig. 2, (a) Dimpled condenser surface (b) Dimpled evaporator surface.

Fig 3, (a) Protrusion inside the pipe (b) Prediction of dimple size.

Fig3 (a) shows that, how the protrusion developed inside the Thermosyphon due to the external dimpling. Fig 3 (b) shows the analysis of dimple size. The dimple formation has followed the zigzag pattern. From the figure it is understood that, a uniform transverse pitch of 12mm is maintained. Each dimple is created with 3 mm diameter and 1.5mm depth approximately.

2.5. Experimental setup:

The current experimental apparatus is depicted in Fig4a. A preferred test section, a cooling water circuit, and a data acquisition system make up the test circuit. A storage tank with volume of 0.125 m³ serves as the source of supply for cold water. A temperature controller controls the flow of cold water before it is pumped out of storage tank. A flow meter is used to set temperature of cooling water at 20±0.5 °C and keeping an eye on the fixed flow rate. The thermosyphon of study is a long copper material tube with an outer diameter of 19millimeter and a length of 380 millimeter and 1 millimeter thick. The condenser segment of Thermosyphon was embedded upward into the cooling chamber. The coolant moved through the cooling chamber, where it was forced to condense heat from the condenser section into a bath of constant temperature. Fig 4b depicts the dimpled tube during the experiment.
Fig. 4, (a) Experimental set up. (b) Dimpled Thermosyphon during experiment.

Fig. 5, Schematic layout of Thermosyphon with thermocouple location.

Fig. 5 depicts the schematic layout of Thermosyphon with thermocouples located at a distance of 20mm, 60mm, 100mm, 140mm, 180mm, 220mm, 260mm, 300mm & 340mm from the evaporator end which indicates the measurement of vapor temperature and surface temperature at all locations. The observations are made for Plain Thermosyphon-Water, Plain Thermosyphon-Nano fluid, Dimple Thermosyphon-Nanofluid combinations. In each orientation, 4 set of trails (8 readings) has been done.

3. Results and Discussion

The performance of dimpled Thermosyphon is influenced by the certain parameters such as evaporator and condenser length, resistance offered by the flow medium, heat supplied and heat transfer rate. These factors are considered for discussion based on the obtained and calculated results.

3.1. Effect of Evaporator length and condenser length

The evaporator’s length is comparatively lesser than the condenser. The investigation is carried out at three orientations such as 0°, 45° and 90°. The values obtained at 90° only presented here for discussion. When heat is supplied, the fluid inside the evaporator will absorb the heat energy from heat source and gets saturated. This flows axially to the adiabatic section, then condenser. Figure 6&7 shows the temperature distribution with respect to the distance along flow direction in evaporator and condenser. It is initially showing an incremental temperature distribution measured along the length of condenser and Evaporator section in Thermosyphons, later it has been reduced gradually for heat inputs 40W, 80W, 120W, 160W, 200W, 240W and 280 W which clearly infers that there is an increase in heat transfer.
Fig. 6, Evaporator temperature (a) Plain pipe-Water (b) Plain pipe-Nano fluid (c) Dimple pipe.

Fig. 7, Condenser temperature (a) Plain pipe-Water (b) Plain pipe-Nano fluid (c) Dimple pipe.

This indicates the tendency of Nano fluid to accelerate the heat transfer than normal water. Also, the inside protrusion due to external dimple will interrupt the heat flow and generates the more heat flux which caused the temperature hike up to certain distance, than it reduced towards the condenser as shown in figure 6& 7. Similar results have been obtained for 0° and 45° tilt angle. At all inclinations at lowest heat loads the local temperature variation is around 5°C to 7°C in both condenser and evaporator and for highest heat loads local temperature variation is around 8°C to 10°C in both condenser and evaporator side.

3.2. Effect of heat input on Temperature

Figure 8 indicates the variation of temperature for various heat input with respect to the tilt angle. When the orientation has changed, the free flow of heat is being restricted and evaporator needs to generate more vapor mixture to push up the heat flow. It is found that, the amount of heat required for Thermosyphon at tilt angle 45° and 90° is high compared with 0°. At these angles, the initial temperatures are high at evaporator as shown in figure 8 (a), (b) & (c). At 90° tilt angle the heat flux is high which increases the amount of heat transfer than other two orientations of 0° and 45° tilt angle.

Fig. 8, Effect of heat input on Temperature distribution (a) at 0° (b) at 45° (c) at 90°.
3.3. Effect of heat input on Thermal resistance

The thermal resistance is a kind of factor which resists the heat flow from the evaporator to the condenser and it influence the heat transfer capacity of the plain or dimpled Thermosyphon. It ensures the efficiency of both condenser and the evaporator. This can be estimated by

\[ R = \frac{T_{\text{evaporator}} - T_{\text{condenser}}}{Q_{\text{input}}} \]

Fig. 9, Thermal resistance(a) at 0° (b) at 45° (c) at 90°.

Figure 9 (a), (b) & (c) shows the thermal resistance value estimated at different angles. From these figures, it is evident that, Thermosyphon with dimple surface are showing very less thermal resistance value compared to plain Thermosyphon with water and Nano fluid which is more important for heat transfer enhancement. At 90° orientation, dimpled Thermosyphon and nanofluid combination has shown better results.

3.4. Effect of heat input on Nusselt number

The Nusselt number is often used to quantify how effective is the heat transfer enhancement due to convection. From the results obtained the Nusselt number value is calculated and it is evident that the value of Nusselt number values of dimpled tube thermosyphon at 90° inclination with 3% concentration of Aluminium oxide Nano fluid is found higher when compared to others and the same is indicated in Figure 10.

Fig. 10, Nusselt Number at 90° inclination Thermosyphon.
3.5. Effect of pipe inclination

The thermal efficiency of Thermosyphon is calculated by ratio of cooling capacity rate of condenser and the input power at the evaporator section. Figure 11 shows the thermal efficiency difference of Thermosyphon based on the variation in tilt angles and it is noted that thermal performance increases with the increase in the angle of inclination. It is due to increase in temperature of working medium and hence there is a possibility of more amount of heat being removed in the condenser section. Here, gravitational force also a cause on the flow of working fluid from the evaporator section to the condenser section.

![PERCENTAGE EFFICIENCY AT DIFFERENT TILT ANGLE](image1)

**Fig. 11, Efficiency at different angle.**

But at 90°, the efficiency is slightly maximum. Due to increased rate of formation of liquid film inside the condenser, the value of the thermal resistance is increased. So, the heat transfer efficiency of the test Thermosyphon increases with Nano fluid as compared to that of the base working fluid. Also the dimpled Thermosyphon comparatively has obtained higher efficiency than plain Thermosyphon.

4. Conclusion

This experimental research has reported the performance of Thermosyphon and dimpled Thermosyphon with water and \( \text{Al}_2\text{O}_3 \) Nano fluid and results have concluded the outcomes below.

1. For given heat inputs, the estimated efficiency for plain Thermosyphon-water is 41.1%, 62.4%, and 65.5%, for plain Thermosyphon- \( \text{Al}_2\text{O}_3 \) Nano fluid is 45.36%, 63.41% and 67.34%, for dimpled Thermosyphon-Nano fluid is 50.66%, 69.7% and 74.23% at 0°, 45° and 90° respectively. Here, the Thermosyphon with 90° tilt angle provided the optimal performance as it exhibits maximum efficiency value in all Thermosyphons and also Dimpled tube Thermosyphon exhibits high efficiency than plain pipe.

2. The thermal resistance for Plain Thermosyphon-water varies from 0.19°C/W to 0.55°C/W, for Plain Thermosyphon-Nano fluid is 0.1°C/W to 0.39°C/W, for dimpled Thermosyphon-Nano fluid is between 0.089°C/W to 0.34°C/W. The thermal resistance value is minimum in dimple Thermosyphon-Nano fluid which implies more heat will be transferred using dimple.

3. The average heat input required for a cycle is estimated for 0°, 45° and 90° as 160.75 W, 160.05W and 160.28 W respectively. This indicates there is no much difference in heat input, but orientation of 0° consumes more than the other two angles of orientation.

4. With increase in heat input the Nusselt number value is found to be increasing and it is found to be high in dimpled Thermosyphon than the plain Thermosyphon with Nano fluid and water.
5. The performance of Thermosyphon at 90° provides the higher efficiency than other two angles of 0° & 45°. In addition to that Thermosyphon with dimpled surface has provided the highest efficiency amongst all the three samples. So, the experimental results are supporting the dimple Thermosyphon’s performance for heat transfer applications.

References


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