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ENHANCING TWO-PHASE CLOSED THERMOSIPHON PERFORMANCE THROUGH GRAPHENE OXIDE NANOFLUID INTEGRATION: A CFD STUDY

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Abstract

The high power electronic systems development has seen a rapid change in which generation of heat has raised and is thus an urgent requirement to find a way of managing the heat efficiently through efficient thermal management techniques. Two-Phase Closed Thermosiphon (TPCT) or passive cooling tools also, have received a significant interest since they are highly capable of heat transfer, reliable, and they are simple to build. Their performance is however constrained by the thermophysical properties of conventional working fluids. This paper examines the improvement of the TPCT performance with the help of Graphene Oxide (GO) nanofluids with the help of the Computational Fluid Dynamics (CFD) analysis. The nanofluid concentration (0.01% and 0.02% and 60 and 40% filling ratio) are investigated. Conclusions have shown that the thermal resistance of the GO nanofluids is greatly lowered and the heat transfer performance of deionized water is enhanced. The best situation is achieved at 0.02% concentration and 60% loading volume. The results can give information on the development of sophisticated passive cooling systems.

Keywords

Two-Phase Closed Thermosiphon, Graphene Oxide, Nanofluids, CFD, Thermal Resistance, Heat Transfer Enhancement

1. Introduction

The growing need of small and highly functional electronic systems has produced a massive increase in the amount of heat flux, which requires effective thermal management products. Traditional cooling techniques can hardly manage large amounts of heat. Passive heat transfer equipment like heat pipes and thermal siphons also provide a viable alternative since it can be used to transfer high amounts of heat with low temperature gradient and no need of external power.

A capillary wick structure was the earliest definition of heat pipes that was introduced by Grover et al. (1964) to move the working fluid [1]. The Two-Phase Closed Thermosiphon (TPCT) in contrast does not use any wick, and uses the gravitational force to return the liquid to the tower, so it is less complex and cheaper to implement on land. The TPCT works on the principle of transfer of heat by phase change as the heat transfer is performed by evaporation and condensation processes in order to transfer thermal energy effectively.

In spite of these strengths, TPCT cannot be used with a high boiling heat transfer coefficient because of hydrodynamic limitations, including flooding. Water-based traditional fluids are known to be limited in their thermal conductivity to provide performance gains. In order to eliminate these shortcomings, nanofluids have been proposed as an advanced media of heat transfer. The idea of the nanofluids was firstly put forward by Choi (1995) who emphasized that it is far superior to the thermal performance [8].

A promising candidate that has been generated through the Graphene Oxide (GO) is carbon based nanomaterial, which is known to be have outstanding thermal conductivity and surface properties. It has been found that GO nanofluids can improve the boiling heat transfer and provide greater critical heat flux [13]. Nonetheless, the effect of comprehensive CFD analysis of their effect in TPCT systems has not been well studied yet.

2. Heat Pipe Fundamentals

The TPCT is a continuum of thermodynamic process which is used in evaporation, vapor transport, condensation, and liquid return. The working fluid is vaporized by heat input into the evaporator. Pressure difference drives the vapor upwards and condensation happens in the cooler condenser section giving out latent heat. The evaporator receives the liquid back through gravity.

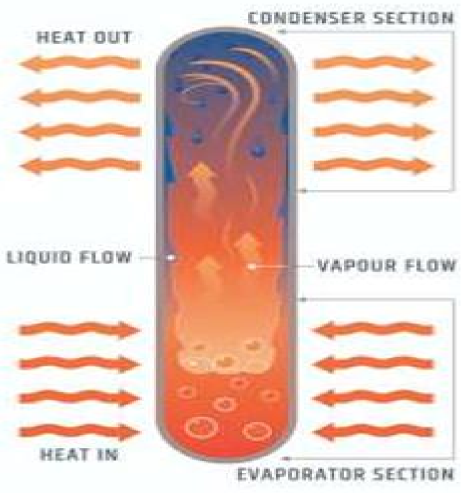


Figure 1: Schematic of Heat and Fluid Flow in a Two-Phase Closed Thermosiphon (TPCT)

The performance of TPCT is evaluated using thermal resistance, defined as:

$$R_{th} = \frac{T_e - T_c}{Q}$$

where T_e and T_c are evaporator and condenser temperatures, respectively.

Performance can be greatly influenced by such limits as flooding and boiling which are operational. Flooding is the situation where the flow of the vapour does not allow the liquid to return, whereas boiling limit provides circumstances of dry-out [2].

3. Literature Review

Nanofluids have been fully observed in the improvement of heat transfer. Eastman et al. (2001) found that nanofluids demonstrated higher thermal conductivity as opposed to base fluids [7]. Do et al. (2010) found that the thermal resistance to heat pipes in Al_2O_3 nanofluids was lower [5].

Huminic and Huminic (2015) showed improved performance of thermosyphons with the use of Fe_3O_4 nanofluids, where improved performance was attributed to the increased nucleation sites [4]. According to Sarafraz et al. (2018), the filling ratio and hydrodynamic limits played a crucial role in the performance of TPCT [3].

Nanofluids made of graphene have been quite promising. Baby and Ramaprabhu (2011) had found increased boiling heat transfer because of the graphene nanoparticles [14], and Kole and Dey (2012) had found lower thermal resistance with the help of GO nanofluids [16].

Although this has been done, research on the effects of combined parameters with this type of study is lacking and this study meets this gap.

4. Methodology

A CFD model of a vertical TPCT is created in order to model two-phase heat transfer. The bottom houses the evaporator with the top positioned condenser. Working fluids used are deionized water and GO nanofluids.

Two filling ratios (40% and 60%) and two concentrations (0.01% and 0.02%) are taken into consideration. A thermal flux is sustained at the evaporator and the assumption is the steady-state.

Table 1: Simulation Parameters

Parameter	Value
Working Fluids	Water, GO Nanofluid
Concentration	0.01%, 0.02%

Parameter	**Value**
Filling Ratio	40%, 60%
Orientation	Vertical
Heat Input	Variable
Model Type	CFD Multiphase

5. Results and Discussion

The findings demonstrate that GO nanofluids have a considerable impact on the increase of TPCT performance. When heat input is high, the thermal resistance will be reduced because the boiling heat transfer will be better.

A stronger concentration (0.02) has stronger performance as it has increased thermal conductivity and nucleation. However, heavy concentration can result in an increased viscosity.

This has a filling ratio of 60% that offers optimal performance, which guarantees the availability of liquid enough, but still leaves enough vapor space.

Table 2: Performance Comparison

Fluid Type	**Filling Ratio**	**Thermal Resistance**	**Performance**
Water	40%	High	Poor
Water	60%	Medium	Moderate
GO (0.01%)	40%	Medium	Good
GO (0.02%)	60%	Low	Best

Figure 2: CFD Temperature Contour – 0.02 GO Nanofluid at 60% Filling Ratio (80 W) – Optimal Case

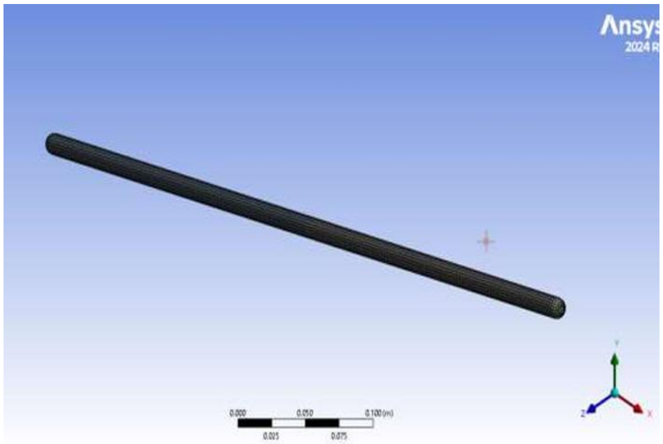
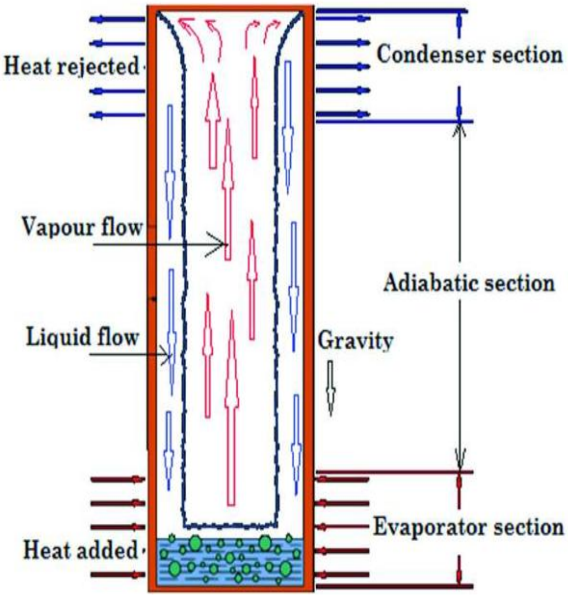


Figure 3: Working of gravity-assisted/wickless heat pipe



the working principle of a gravity-assisted wickless heat pipe, or Two-Phase Closed Thermosiphon (TPCT) as shown in Figure 1. The diagram is explicit in that the three main parts have been presented namely the evaporator, adiabatic region and condenser. Heat supplies at evaporator vaporize the working fluid to produce the vapor that moves upwards because of pressure differences. Once in the condenser section the vapor will drop off its latent heat and condense once again into liquid form. The condensed liquid is then pumped into the evaporator again through influencing gravity which completes the thermodynamic process. The efficiency of overheated heat transfer and lack of external pumping mechanism are a result of this repeated process of phase change that is ideal in the heat transfer process, which underscores the simplicity and operability of TPCT systems in passive thermal management systems.

Figure 4: Evaporator Temperature vs. Working Fluid (40% and 60% Filling Ratios)

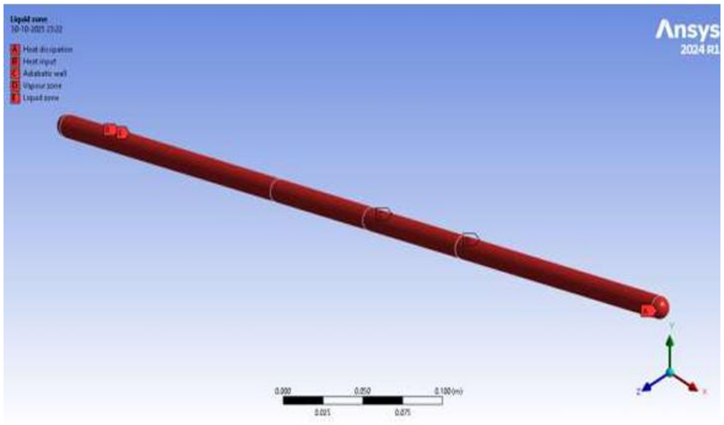
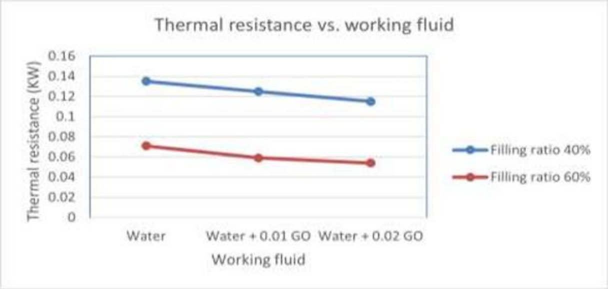
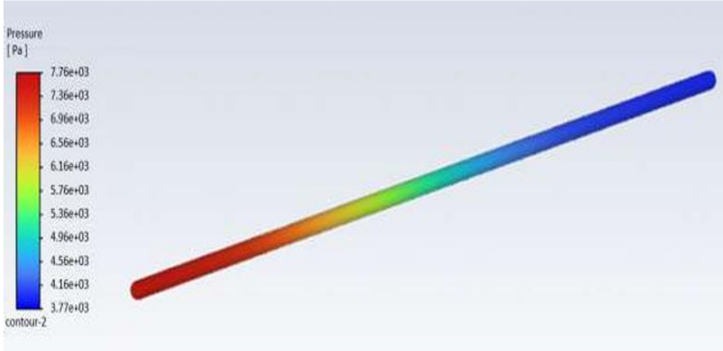


Figure 5: Thermal Resistance vs. Working Fluid



The variation of thermal resistance with respect to the various working fluids and working conditions is represented in Figure 2. It is noted that the thermal resistance of the Graphene Oxide (GO) nanofluids is considerably low relative to the conventional water. The nanofluid that was tested under highest concentration and filling ratio of 0.02 per cent and a filling ratio of 60 per cent is the least thermal resistant and therefore, has excellent heat transfer capability. This is mainly due to high thermobabicity as well as the greater number of nucleation points which the nanoparticles offer and subsequently facilitate efficient boiling and condensation. This figure shows clearly that GO nanofluids are effective in enhancing the TPCT performance and would therefore make them to be a good alternative to use in promoting its application in enhanced cooling.

Figure 6: Thermal Resistance vs. Filling Ratio for Water and GO Nanofluids



6. Conclusion

This research paper is confirming that the Graphene Oxide nanofluids are pivotal in enhancing thermal performance of Two-Phase Closed Thermosiphon (TPCT) system. Addition of GO nanoparticles contributes to the effective thermal conductivity of the working fluid and facilitates an increased rate of heat transfer by the augmented phase change processes. The most desirable system is chosen out of the studied conditions to be at a nanofluid concentration of 0.02% alongside a filling ratio of 60, in which the system is observed to have the least thermal resistance and most stable operation. The above improvement can be mainly credited to the presence of better boiling heat transfer features such as the higher concentration of nucleation sites as well as better uniformity and concentration of bubbles at the evaporator surface. Also, nanoparticles may occur, and they lead to the effects of surface modification, thus facilitating the effective heat transfer through the change in wettability and the evaporation of thin layers.

Moreover, the thermal conductivity of GO nanofluids is also enhanced, which allows faster energy transfer of the fluid, decreases the temperature differences between the evaporator and condenser part. The optimum filling ratio guarantees that the liquid phase exists with a perfect coexistence of the vapor phase without getting too dry and at the same time leaving the vapor space ample with great ease of transportation. This balance is important in reducing hydrodynamic instabilities like flooding and entrainment which are major drawbacks in TPCT systems.

All in all, incorporation of Graphene Oxide nanofluids has a great potential in enhancing passive thermal management systems, especially when high-heat flux is required as in the case of electronic cooling systems, renewable energy systems, and small-scale heat exchangers. The conclusions of this research are not only justified effectiveness of the nanofluid-based enhancement, but also are the basis of the further optimization of this work with the help of the advanced numerical and experimental studies. Future directions can be identified as the analysis of long-term stability, effects of dispersion of nanoparticles, and scaled to application to the industry in order to achieve the full benefits of the practical application of the GO-based thermosiphon systems.

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