Surfactant effect in the thermal performance of a two-phase thermosyphon using Al$_2$O$_3$ nanofluid

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Abstract. An experimental study was carried out to evaluate the effect on the thermal performance of a two-phase closed thermosyphon (TPCT) during operation cycles using nanofluids. Al$_2$O$_3$ (0.1 wt.%) based nanofluids with two concentrations of SDBS (0.032 wt.% and 0.064 wt.%) were prepared via two-step method. Stability after nanofluids preparation was evaluated using visual inspection, UV-spectroscopy and dynamic light scattering (DLS). Nanofluids with and without surfactant were used as working fluid in a glass TPCT. Results show that the TPCT thermal resistance was decreased up to 20% respect to water by the presence of nanoparticles and surfactant. A dried limit with water as working fluid was observed and fluid expansion was identified with surfactant presence. Differences in thermal efficiency and temperature profiles using nanofluids with and without surfactant and only surfactant-water as working fluids in TPCT were not significative. However, in evaporator zone, a slight increase of the thermal resistance was identified when surfactant was added. After TPCT operation with nanofluids, nanoparticles agglomeration and sedimentation were observed and a layer on the evaporator surface was observed.

1. Introduction
Heat pipes are effective passive heat transfer devices and are used when heat transfer with small temperature differences is the primary objective. These devices are commonly used in isothermal applications, temperature control, and in heat transfer recovery from low-grade energy waste [1]. Two-Phase Closed Thermosyphons (TPCT) are a simple type of gravity-assisted wickless heat pipes and have applications in a broad temperature range compared to a conventional heat pipe. In the last years, research works on thermosyphons have intensified noticeably due to their abundant applications in heating and cooling processes and solar energy recovering [2].

Nanofluids are a complex class of working fluid that have been used in closed two-phase thermosyphons with the goal of increase their thermal performance. Nanofluids are colloidal

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suspensions composed by nanomaterials (1-100 nm) dispersed in a fluid. The thermal performance of a thermosyphon using nanofluids has been evaluated experimentally by several researchers. The results found in these investigations shows increases [3–8] or decreases [9–11] in the thermal resistance using different nanofluids. These changes in the thermal resistance of the thermosyphons have been associated with a porous layer deposited on the evaporator surfaces and the effect of this layer in the boiling heat transfer mechanism. This layer is formed due to the agglomeration and deposition of nanoparticles in the heated surfaces on the evaporator. This agglomeration and deposition may perhaps be connected to parameters used when the nanofluid is prepared and complications with the permanence of the nanomaterials disperse with time.

The structure and morphology of this layer is affected by nanoparticle type [5,11], nanoparticles concentration [12] and the chemical additives such as surfactants, used during the nanofluid preparation [13]. Surface active agents or surfactants are commonly used with the goal to improve the nanoparticle dispersion. Paramethanuwat et al. [14] described the effect of oleic acid on the nanofluids performance in a TPCT. Using different concentrations of oleic acid to disperse Ag nanoparticles in water, they found that with a concentration of 1 w/v% of the surface-active agent, the maximum increase in the TPCT performance was attained. However, the effect of this surface-active agent on the dispersion stability and the mechanisms of heat transfer were not described.

Amiri et al. [4], evaluated experimentally the performance of a TPCT using two types of nanomaterials dispersed in water, functionalized graphene nanoplatelets and graphene nanoplatelets (GNP) with SDBS used as a surfactant. They obtained an increase of 33 % in the heat transfer coefficient using functionalized graphene nanoplatelets compared to the nanofluid using 0.1 wt.% of SDBS surfactant.

The surfactant present in nanofluids could generate modifications in the TPCT thermal behavior [15]. These modifications are associated with variations in surface tension, viscosity and thermal conductivity, which can produce modifications in convection and boiling [16]. However, although is evident that the surfactants can modify the TPCT thermal performance, few studies were found in the literature that evaluated the surfactant presence in the nanofluid and their impact on the TPCT thermal performance.

In this work, an experimental evaluation was carried out to evaluate the effect of surfactant addition to improve the nanoparticles dispersion during nanofluids preparation, on the thermal resistance of a TPCT.

2. Methodology

2.1. Materials and methods

Nanoparticles of Al₂O₃ (<50 nm, from Sigma-Aldrich) were dispersed in deionized water (DI) (18 MΩ cm) using an ultrasonic processor (Ultrasonicator, QSONICA 500). The mass concentrations of the nanomaterials in water was 0.1% wt. Sodium dodecylbenzene sulfonate (SDBS) was used as surface-active agent at 0.032 and 0.064 wt%. Nanomaterial was dispersed in water by two-step method, first SDBS was added to DI water and mixed using agitation. After, this solution was added to nanoparticles previously weighed. Nanoparticles were dispersed using an ultrasonication probe tip immersed directly in the mix by 30 minutes. The detailed methodology followed to nanofluids preparation is described in a previous work [17].

Nanofluids stability variation with the time was supervised using visual inspection, UV visible spectroscopy (Spectrofotometer, Agilent 8453) and dynamic light scattering technique DLS (Nanoplus HD3, Micromeritics). After evaluating stability in static mode, nanofluids with the best stability were supervised using visual inspection, UV visible spectroscopy (Spectrofotometer, Agilent 8453) and dynamic light scattering technique DLS (Nanoplus HD3, Micromeritics). After evaluating stability in static mode, nanofluids with the best stability were used in a glass TPCT with a copper surface in the evaporator at 40 W and a filling ratio of 45%.

The TPCT experimental setup is shown in Figure 1. A borosilicate glass thermosyphon was used to observe the fluid behavior through operation and the nanomaterial settled after TPCT operation. The TPCT has a length of 400 nm and, an outer and inner diameter of 26 mm and 30 mm, respectively. In the evaporator section, a thermal resistance enfolded along the evaporator was used to bring the power
to the working fluid. In the lowest part of the evaporator zone, a copper element was located, with the purpose of examine the Al₂O₃ nanoparticles sedimented after the experiment. Cooling water at 9 °C was used in the condenser section, using a bath to control the temperature (Alpha RA 24, LAUDA). A Coriolis flow meter was used to measure the mass flow of cooling water (Siemens, SITRANS 2100 DI). In the start of the experiments, a vacuum pressure of 12.5 in Hg was used.

Each experiment was done by eight hours and the evaluation was carried out for two days without change the working fluid. To measure the temperature along the TPCT, ten K-type thermocouples were used, two along the evaporator zone, three in adiabatic zone and five in condenser zone as is shown in figure 1. Two more were positioned to evaluate the external water temperature in the condenser. After operation, the evaporator surface was inspected, and nanoparticles deposition was evaluated using a Field Emission Scanning Electron Microscopy (FE-SEM, JEOL JSM7100F). Thermal resistance was calculated using Equation 1.

\[ R_{\text{total}} = \frac{T_e - T_c}{\Delta T} \]  

(1)

Where, \( T_e \) and \( T_c \) are averaged temperatures in the evaporation and condenser zone, respectively. \( \dot{m} \) and \( \Delta T \) are mass flow and temperature difference of the water in the condenser section, respectively; \( V \) and \( I \) are the voltage and current values of the thermal resistance used to supply the heat in the evaporator section.

3. Results and discussion

3.1. Stability in static mode

Figure 2a, shows the absorbance variation over time for the different nanofluids evaluated. In all cases, absorbance decreases with time, and sedimentation was evident as can be observed in images obtained by visual inspection (see Figure 2b).
According to absorbance variation, the nanofluid most stable was Al₂O₃ 0.1 wt.% with SDBS 0.064 wt.%. DLS results showed a hydrodynamic average diameter after 24 days of 121 ±1.25 nm and 117.4 ±1.73 nm for Al₂O₃ 0.1 wt.% and Al₂O₃ 0.1 wt.% (SDBS 0.064 wt.%), respectively. Both nanofluids were used in the TPCT experimental tests. Additionally, to see the effect of surfactant presence a fluid composed of DI-Water and SDBS was used too.

![Absorbance vs Day](image)

**Figure 2.** (a) UV-absorbance variation with time (b) Visual inspection of nanofluids

### 3.2. Thermal performance of TPCT

Figure 3, show the thermal resistance (3a) and temperature profiles (3b) of the TPCT, respectively. Results showed decreases up to 20% in the TPCT thermal resistance using Al₂O₃ nanofluids and SDBS-water with respect to deionized water. Water high thermal resistance was caused by a dried zone in evaporator accompanied by an increase in evaporator temperature (see position two in Figure 3b).

Differences in thermal resistance and temperature profiles using nanofluids with and without surfactant and only surfactant-water as working fluids in TPCT were not significative for these experimental conditions. Only a slight increase in evaporator temperatures was observed with the surfactant presence, this can be due to bubbles formation with the decrease in the fluid surface tension. Additionally, when the nanofluid was left in the TPCT without working one day, no changes were identified in the temperature profiles and thermal resistance.

Different phenomena associated with the fluids used in the TPCT can be identified in Figure 4. During the visualization in the operation of the TPCT, an expansion of the fluid and a considerable amount of bubbles were identified with the surface-active agent presence (Figure 5c), this expansion although not affected the thermal performance need to be controlled depending of the experimental parameters used, such as filling ratio, vacuum pressure among others, to avoid problems with the condensed return to the evaporator zone. The effect on heat transfer adding only nanoparticles without surfactant and adding only surfactant to DI water was the same, also, when nanoparticles and surfactant were used simultaneously the effect was not additive and the result was not modified. Additional studies are required to decouple the individual effects.
Effect on heat transfer in TPCT generally have been focused on a nanoparticles layer formation on the evaporator surface, as a result of nanoparticle deposition [8,18–21]. This nanoparticle sedimentation modifies the nucleation sites, and the fluid bubbles generation and surface wettability are altered, affecting the boiling heat transfer phenomena. Moreover, the use of surfactants also contributes to the boiling heat transfer on evaporator zone and this is due to surface tension effect that allow an increase in the nucleation locations and the bubble leaving diameter improving the boiling heat transfer [22–24].

After experiments with nanofluids a high sedimentation of nanoparticles was observed, and a layer of Al₂O₃ nanoparticles was identified on the evaporator surface, even with the presence of surfactant (see evaporator surface and SEM image in Figure 5). However, the evident presence of nanoparticles on the evaporator surface and the changes in the boiling phenomena observed in Figure 4 with and without surfactant, do not caused significative changes in the temperature profiles, compared with only the surfactant addition to DI water. However, more studies are necessary to concluded about the effect of surfactant addition to working fluids used in TPCT and the real advantages of nanoparticles dispersion in the common working fluids.
4. Conclusions
Alumina nanofluids with SDBS addition were prepared and their stability was monitored using UV-vis absorbance, DLS and visual inspection. Al₂O₃ with SDBS (0.064 wt.%) showed the best stability in static mode.

The TPCT thermal resistance was decreased up to 20% using Al₂O₃ nanofluids with SDBS and SDBS-water with respect to deionized water.

Differences in thermal resistance and temperature profiles using nanofluids with and without surfactant and only surfactant-water as working fluids in TPCT were not significative for these experimental conditions

Different phenomena with the diverse fluids in the TPCT were observed. A dried zone with DI-water was identified and this was the cause for the poor thermal performance. When surfactant-water was used as a working fluid, a fluid expansion and a big quantity of bubbles were observed, this produced a slight increase in the temperatures in the evaporator.

After experiments with nanofluids a high sedimentation of nanoparticles was observed, and a layer of Al₂O₃ nanoparticle was identified on the evaporator surface, even with the presence of surfactant.

The surface-active agents have an effect in the heat transfer boiling phenomena and in the TPCTs thermal behavior, their effect in TPCT thermal performance must be decoupled from the effect of the nanoparticles. Surfactant represents an alternative to improve the TPCT performance.

5. References
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