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HEAT TRANSFER PROCESSES IN THERMOSYPHON EMPLOYING NANOFLUID

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Abstract:

Thermosyphons and heat pipes are one of the most effective heat transfer devices known nowadays. Decades of research essentially exhausted possibilities of further improvement based on pure liquids or mixtures. Common heat transfer fluids, such as water or glycols seem to reached their operational limits. One of the most promising solutions for overcoming underlying heat and mass transfer limitations is the introduction of nanofluids.

Nanofluids are defined as suspensions of nanoparticles with at least one dimension smaller than 100 nm. The primary reason of creating suspensions with nanoparticles was to improve thermal conductivity of the base fluid. Since the introduction of nanofluid concept by Choi and Eastman in 1995, the interest in nanofluids is continuously increasing. They are attractive due to improved thermal properties, increased surface to volume ratio, reduced erosion, and great potential in numerous and intensively investigated fields, such as microelectronics, heat transfer systems, or medical applications.

In thermal sciences, the most investigated property of nanofluids is their thermal conductivity. Although literature reports exceptionally high values, it does not simply translate to enhanced thermal capacity of heat transfer devices. During phase change conditions other properties of both working fluid and heater surface affect heat transfer. Limited information in the available literature hinted the need for shifting research to real applications which involve multiple processes at the same time.

This dissertation summarizes the work conducted on nanofluids and surfactant solution used as working fluids in a two-phase closed thermosyphon with focus on the boiling process. Set of working fluids was carefully chosen for experimental investigation to address above mentioned research concerns:

- carbon-based nanofluids, including nanofluid based on single wall carbon nanohorns stabilized with sodium dodecyl sulfate (SDS), and graphene oxide nanofluid with and without SDS,
- two gold nanofluids with the same nanoparticles but different stabilizers - PVP polymer (polyvinylpyrrolidone), and potassium hydroxide (KOH),
- silica nanofluid stabilized with potassium hydroxide (KOH),
- water solution of sodium dodecyl sulfate (SDS),
- distilled water.

Conducted literature review underlined that there is a lack of studies comparing such variety of working fluids under comparable operating conditions in a thermosyphon. Among carbon-based nanofluids, no studies on graphene oxide or nanohorns were conducted. Only one paper analyzed the silica nanofluid in thermosyphon and it focused mostly on the functionalization effect. No investigations of sodium dodecyl sulfate or any other surfactant on thermosyphon efficiency were available. Some hints could be find in the literature discussing pure boiling processes or determining single thermophysical properties. Still, further research was required in all these fields to fully understand mechanisms behind nanofluids behavior. The mentioned lacks in knowledge determined the scope of this dissertation.

Boiling process of a given working fluid in a thermosyphon depends on many factors and thermophysical properties. Characterization of chosen nanofluids were conducted to improve understanding of their behavior. The main emphasis was put on graphene oxide flakes as this is the most innovative material that is still not well investigated. Size and shape of nanoparticles, thermal conductivity, viscosity, specific heat, surface tension, and contact angle were determined.

Analysis of transport of thermal energy in dependence on working fluid was conducted using 1800 mm long copper thermosyphon with inner diameter of 20 mm. For each of investigated working

fluids two experimental series with inlet temperature of cooling water (15°C and 25°C) were conducted. Inlet temperatures of heating water varied in the range of 25-85°C (with 5 K steps). Based on obtained results, the performance of the device was compared. Usage of appropriately selected working fluid (nanofluid) reduced the thermal resistance of the device for small thermal loads.

Under some specific conditions, thermosyphon operates under *geyser boiling* regime. Literature review showed the lack of studies considering the impact of nanofluids and surfactant solution on geyser boiling. Usage of highly precise pressure transmitters located along the device with high frequency of data gathering allowed for observation and analysis of time-dependent behavior. Data reduction methodology was implemented in Python with purpose of statistical analysis. Calculated frequencies and amplitudes of geyser events proved a previously unknown inhibitory effect of surfactant on geyser boiling. Effect on geyser boiling seems to be negligible small on the averaged thermal performance of the device. However, it causes high mechanical loads and may be dangerous for thermosyphons usually installed in systems that are respected to work for long periods of time.

The condition of internal surface of the thermosyphon was analyzed using endoscopy camera after conducting all measurement series with a given working fluid. Fresh graphene oxide flakes and agglomerates remained in working fluid after all experiments were analyzed using scanning electron microscope. The deposition of nanoparticles in the upper part of the evaporator section changed the working fluid behavior during boiling process.

The obtained results showed the possibility of regulation of thermosyphon parameters in the studied range of thermal loads by using nanofluids and surfactant solution. It confirms the scientific thesis that is the basis of the presented dissertation.

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