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Computational Fluid Dynamics Simulation of a Nanofluid-Based Annular Solar Collector with Different Metallic Nano-Particles

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Abstract : Motivation- Solar energy constitutes the most promising renewable energy source on earth. Nanofluids are a very successful family of engineered fluids, which contain well-dispersed nanoparticles suspended in a stable base fluid. The presence of metallic nanoparticles (e.g. gold, silver, copper, aluminum etc) significantly improves the thermo-physical properties of the host fluid and generally results in a considerable boost in thermal conductivity, density, and viscosity of nanofluid compared with the original base (host) fluid. This modification in fundamental thermal properties has profound implications in influencing the convective heat transfer process in solar collectors. The potential for improving solar collector direct absorber efficiency is immense and to gain a deeper insight into the impact of different metallic nanoparticles on efficiency and temperature enhancement, in the present work, we describe recent computational fluid dynamics simulations of an annular solar collector system. The present work studies several different metallic nano-particles and compares their performance. Methodologies- A numerical study of convective heat transfer in an annular pipe solar collector system is conducted. The inner tube contains pure water and the annular region contains nanofluid. Three-dimensional steady-state incompressible laminar flow comprising water- (and other) based nanofluid containing a variety of metallic nanoparticles (copper oxide, aluminum oxide, and titanium oxide nanoparticles) is examined. The Tiwari-Das model is deployed for which thermal conductivity, specific heat capacity and viscosity of the nanofluid suspensions is evaluated as a function of solid nano-particle volume fraction. Radiative heat transfer is also incorporated using the ANSYS solar flux and Rosseland radiative models. The ANSYS FLUENT finite volume code (version 18.1) is employed to simulate the thermo-fluid characteristics via the SIMPLE algorithm. Mesh-independence tests are conducted. Validation of the simulations is also performed with a computational Harlow-Welch MAC (Marker and Cell) finite difference method and excellent correlation achieved. The influence of volume fraction on temperature, velocity, pressure contours is computed and visualized. Main findings- The best overall performance is achieved with copper oxide nanoparticles. Thermal enhancement is generally maximized when water is utilized as the base fluid, although in certain cases ethylene glycol also performs very efficiently. Increasing nanoparticle solid volume fraction elevates temperatures although the effects are less prominent in aluminum and titanium oxide nanofluids. Significant improvement in temperature distributions is achieved with copper oxide nanofluid and this is attributed to the superior thermal conductivity of copper compared to other metallic nano-particles studied. Important fluid dynamic characteristics are also visualized including circulation and temperature shoots near the upper region of the annulus. Radiative flux is observed to enhance temperatures significantly via energization of the nanofluid although again the best elevation in performance is attained consistently with copper oxide. Conclusions-The current study generalizes previous investigations by considering multiple metallic nano-particles and furthermore provides a good benchmark against which to calibrate experimental tests on a new solar collector configuration currently being designed at Salford University. Important insights into the thermal conductivity and viscosity with metallic nano-particles is also provided in detail. The analysis is also extendable to other metallic nano-particles including gold and zinc.

Keywords : heat transfer, annular nanofluid solar collector, ANSYS FLUENT, metallic nanoparticles
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