Effect of nanofluids in the performance of a miniature plate heat exchanger with modulated surface

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The development of plate heat exchangers (*PHE*) with modulated surfaces has been mainly driven by the need for compact, high performance, yet small in size and light weight equipment. The type of flow inside *PHE* channels augments heat transfer, due to flow separation and reattachment, while the complexity induced by the modulations significantly increases the friction losses (Kanaris et al., 2006). Since the flow passages in such *PHEs* are complex in geometry and of small dimensions, it is very difficult to conduct accurate measurements of the operation parameters (e.g. temperature, pressure and velocity fields). Thus, *CFD* simulation, which is considered an effective and reliable tool, can be used to estimate momentum and heat transfer rates in this type of process equipment (Kanaris et al., 2006).

During the last decade and in order to enhance the thermal conductivity of the working fluids in heat transfer equipment, nanometer-sized solid-particle suspensions in common fluids (e.g. water, ethylene glycol), called *nanofluids*, have been employed. These suspensions exhibit a significant increase in the thermal conductivity compared to the base fluid (e.g. Assael et al., 2004), while problems of sedimentation can be encountered. Experimental work in the convective heat transfer of nanofluids is still quite scarce, so further investigation is needed (Das et al., 2006).

Various nanofluids containing mainly oxide nanoparticles (i.e., Al_2O_3, TiO_2 and CuO) and their thermophysical properties have been studied in our Laboratory (Pantzali, 2008). The viscosity was measured using a rheometer (Haake RheoStress RS600). Thermal conductivity measurements were carried out using the transient hot-wire technique (Assael et al., 2004). A differential scanning calorimeter (Setaram C80D) and a surface tension meter employing the "pendant drop" method (KSV® CAM 200) were used for the measurement of the nanofluid specific heat and surface tension, respectively. It was confirmed that both the stability of the suspensions and their thermophysical properties strongly depend on the volume fraction, the size, shape and type of the nanoparticles, as well as the physical properties of both the nanoparticles and the base fluid. The general observations made during these measurements are that the addition of nanoparticles in the base fluid invokes an increase in thermal conductivity, viscosity and density and a decrease in heat capacity. The surface tension is not affected, unless some surfactants are used for the suspension stabilization. A nanofluid (CuO in water, 4% v/v) (***Table 1***) was selected in order to study its performance both experimentally and numerically in a *PHE* and compare it to that of a conventional cooling fluid (i.e., water).

Table 1: Thermophysical properties of the 4% CuO nanofluid and water at 25°C.

	Thermal conductivity (k_n, W/mK)	**Heat capacity** ($c_{p,n}$, $J/kg\ K$)	**Viscosity** (μ_n, $mPa\cdot s$)	**Density** (ρ_n, kg/m^3)	**Surface tension** (σ_n, mN/m)
CuO nanofluid	0.670	3280	2.0	1250	51
water	0.607	4180	1.0	1000	72

A commercial miniature *PHE* with modulated surface is employed and its performance is also compared to a respective notional heat exchanger with a flat surface. The *PHE* (***Figure 1***) is comprised of a small copper plate, with corrugations and rods on one side, covered with a plastic case that creates the flow path for the cooling liquid. The other side of the copper plate is flat and is placed in contact with a cell, also made of copper, where hot water flows. The setup is thermally insulated to eliminate heat losses. Temperature data are acquired using high accuracy thermocouples and pressure drop is measured between two taps located at the entrance and the exit of the conduit.

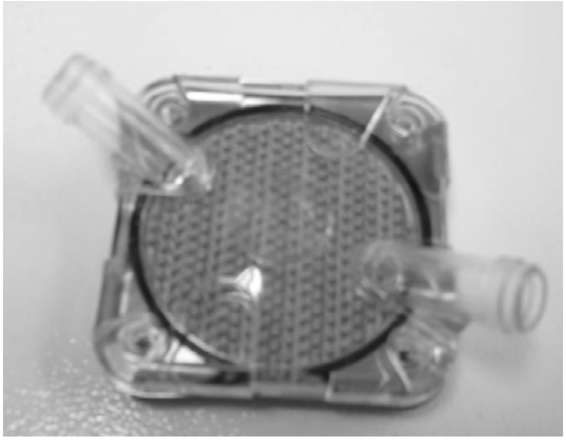

Figure 1: Photo of the miniature *PHE*.

A *CFD* code (i.e., *CFX® 10.0*) is also employed, and its results were found to be in very good agreement with the experimental data in terms of temperatures and pressure drop. ***Figure 2*** presents a typical calculated temperature distribution inside the *PHE*. Thus, the use of the *CFD* code seems suitable for the design of this type of equipment. Typical results for the effect of surface modulation on *PHE* performance shows that for the case of water, as expected (Kanaris et al., 2006), the heat transfer rate increases up to 60% compared to that of the flat plate *PHE*. However, this heat transfer enhancement is accompanied by a significant increase (up to 2.5 times) of the corresponding friction losses.

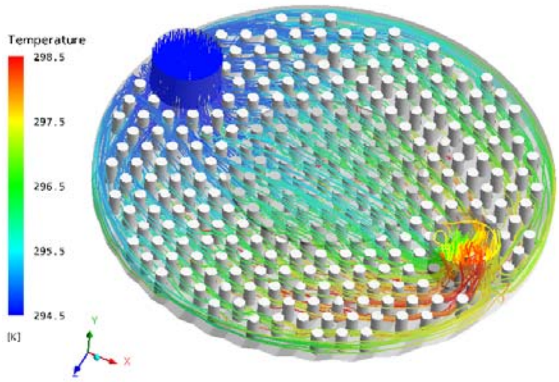

Figure 2: Typical temperature distribution inside the *PHE* calculated by the *CFD* code.

The application of the nanofluid in the *PHE* has shown that the heat transfer rates are significantly enhanced compared to the respective values measured for water. The augmentation is higher for the lower cooling liquid flow rates tested, while at higher flow rates, where convection is the main heat transport mechanism, the nanoparticles contribution to heat transfer is relevantly lower. The results also suggest that a given heat duty can be abducted by a much lower nanofluid flow rate compared to water, and therefore the pressure drop developed is also lower, indicating that in this case less pumping power is necessary.

References

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