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Proposal for an Experimental Study of the Thermal-Hydraulic Performance of Nanofluids MWCNT/Water as Coolant in Light Water Nuclear Reactors (LWR)

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Abstract: The development of nanofluids is extremely important for improving the thermal conductivity of the base fluids. One of the ways to improve the safety of nuclear power plants is related to improving their heat transfer capacity. The study of new fluids that improve the rate of removal of heat is fundamental to obtain greater efficiency of energy systems. Among the several factors that compromise the efficiency of energy systems, it is possible to highlight the thermophysical limitations of conventional fluids. These limitations inhibit, quite significantly, some industrial applications. This paper presents a work proposal to be carried out in the Thermo-Hydraulic Laboratory of the CDTN, whose objective is the study of the improvement of the heat transfer characteristics of the refrigerant, used in the primary circuit of nuclear reactors, through the addition of nanoparticles. Carbon nanotubes will be used mainly in light water, which is the most commonly used cooling fluid for nuclear reactors. As support to the work, an experimental workbench will be designed, assembled and calibrated in order to study the thermo-hydraulic behavior of these components.

Key words: nanofluidos, thermal efficiency, thermo-hydraulics, nuclear reactors, LWR

1. Introduction

Nanofluids are known to present the possibility of higher heat transfer and are therefore investigated for engineering applications [1-3]. The study of new fluids that improve the rate of heat removal is fundamental to obtain greater efficiency of energy systems. Among the several factors that compromise the efficiency of the energy systems, it is possible to highlight the thermophysical limitations of the conventional fluids, inhibiting in a very significant way some industrial applications. In this work, we intend to study the heat transfer characteristics of fluids commonly used, through the addition of nanoparticles, made of carbon nanotubes, in light water. Water is the most commonly used fluid in the cooling of nuclear reactors.

The improvement of the thermal properties is limited by the thermal conductivity of the working fluid. In order to overcome these limitations, several studies of fluids with solid particles in suspensions have been carried out since Maxwell's first publication at the end of the 19th century [4]. According to [5], however, such studies are limited to the use of micro scale particles, which present some disadvantages such as:

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• Sedimentation — the particles, after some time, sediment, creating a layer next to the surfaces reducing the thermal capacity.

• Wear — Sedimentation can be reduced by increasing the flow velocity of the fluid, but with increased wear of equipment and piping, etc.

• Obstruction — Due to particle size the channels tend to become clogged, particularly in the narrow cooling channels.

• Load losses — increase significantly.

• Thermal conductivity — is proportional to the concentration of particles, but potentiating previous problems.

2. Nanofluids

Nanofluids are composed of colloidal dispersions with a traditional refrigerant as a base, in which the nanoparticles are suspended. In 1995, Choi [6] was the first to use the term “nanofluids”, and published the results of his theoretical research. Subsequent developments in nanofluid engineering have contributed to the rapid growth of nanotechnology and surface technologies over the last decade [7].

The colloidal suspensions were found to be substantially intriguing from the point of view of thermal performance, on four points [6]:

1) Increase in thermal conductivity (approx. 150%);
2) Single-phase increase of the heat transfer coefficient (approx. 60%);
3) Increased critical heat flow with extended nucleated boiling regime (approx. 200%);
4) Increased cooling efficiency.

They have been found to exhibit improved thermal properties, for example, when acting as a coolant, elevate the critical heat flow point and wettability of the surface in small concentrations, which is a useful feature in nuclear reactors.

In recent work [8], they evaluated experimentally nanofluids of multi-walled carbon nanotubes (MWCNTs) based on water, with volume concentrations of $0 < \varphi < 0.24\%$, for mass flow rates of 20 g/s to 90 g/s. The heat supplied by the wall of the tube through the resistance in the test section ranged from 500 W to 900 W. The evaluation of the thermohydraulic performance of the three samples of nanofluids tested was performed by specifying the relative coefficient of heat transfer by convection as a function of the relative pumping power obtained at the pumping powers in the test section. The three samples showed an increase in thermal conductivity, on average, of 6.3%, 8.8% and 17% higher than the base fluid (distilled water). Demonstrating the effect of concentration on increasing this property. However, the three samples also showed an increase in viscosity on average of 8.8%, 17.8% and 11.6%.

Much has been studied regarding the performance of heat transfer in various flow types using nanofluids, consisting of nanoparticles of different materials and various base fluids, as shown in Table 1.

Although many of the reported studies show that there was an increase in heat transfer by forced convection using nanofluids, flowing in laminar and turbulent regimes, other studies show inconsistencies in the presented results, that is, under certain conditions, they report an increase in the coefficient of heat transfer. There are situations where there is neither addition nor decrease in the heat transfer coefficient by convection when nanoparticles are added to the base fluids. However, in some cases the reduction of the value of the heat transfer coefficient by convection is noted. Therefore, further studies are needed to validate and verify the thermal-hydraulic performance of these new cooling fluids [8].

Table 1 Comparison of the work carried out that analyzed convective heat transfer in nanofluids [6].

Author	Flow range	Nanofluid type	Convective coefficient increase h (%)
[13]	Turbulent	Al_2O_3 em água	+45
[20]	Laminar	Al2O3 em água	+47
[21]	Turbulent	SiC em água	-7 to 3.5 vol% mesma velocity
[5]	Turbulent	TiO_2 em água	+26 to 1 vol% -14 to 2 vol%

[16]	Turbulent	TiO_2 em água	+22
[7]	Turbulent	TiO_2 e Al_2O_3 em água	+15%, same number of Reynolds. -10%, same pumping power.

A study was conducted on the use of nanofluids for emergency core cooling systems, which is a safety feature of nuclear power plants [3]. These studies showed that there was an increase in critical heat flux through the injection of nanofluid in case of loss of cooling by accident.

Inhibition curves (temperature versus time) were obtained in small metal (~ 1 cm) spheres exposed to pure water and water based nanofluids with alumina, silica and diamond nanoparticles at low concentrations (≤ 0.1% Vol) [16]. The beads used were made of stainless steel and zircaloy, and were cooled from an initial temperature of approximately 1000°C. The results show that the quenching behavior in nanofluids is almost identical to that of pure water. However, it has been found that some nanoparticles accumulate on the surface of the sphere, which results in the destabilization of the vapor film in subsequent tests with the same sphere, thus greatly accelerating the cooling process.

Nanofluids consisting of dilute dispersions of alumina, zirconia, and silica nanoparticles in water were used. Several parameters that affect heat transfer (boiling point, viscosity, thermal conductivity, and boiling surface tension) were measured and consistent with other nanofluid studies [17], it was found to be similar to pure water. However for pool boiling experiments showed significant improvements of critical heat flux in nanofluids (up to 200%).

3. Metodology

The main objective of this research is the study and improvement of thermal conductivity in nanofluid systems with addition of carbon nanotubes. For this, there are several methods, which are intended to be used for the measurement of the thermal conductivity, namely: temperature oscillations, steady-state parallel plates and the transient hot wire technique, being the latter the most used [18].

The hot wire technique works by measuring the temperature/time response of the was to an abrupt electrical pulse. In this technique, the wire acts as a heater and thermometer, the thermal conductivity being calculated through a derivation of the Fourier Law.

Systems with suspension of carbon nanotubes have presented the highest values for thermal conductivity. A study carried out by [19] on nanofluids composed of multiple wall nanotubes added to the oil, aiming to measure the effective thermal conductivity. The experimental results were noted because they were much higher than those indicated by the theoretical predictions.

In recent work [9], studied water-based nanofluids of Al_2O_3 and ZrO_2 were characterized for their promising use in heat transfer applications. Three different concentrations of dispersed solutions of nanofluids cited (0.01 vol%, 0.05 vol%, and 0.1 vol%) of commercial nanofluids were prepared. Experimental measurements were performed at different temperatures. Thermal conductivity, viscosity and density of nanofluids were measured. It was concluded that the concentration in volume, particle size/shape and temperature are important variables.

4. Results and Conclusions

This research began in March of this year (2016). At the moment the bibliographic review is under way, including research of the most suitable nanofluids to be acquired for tests in the experimental bench.

Due to the potential of the use of nanofluids in cooling systems of nuclear reactors, even with the research still in progress, the viability of this application was verified. In addition, it is possible to improve the heat transfer characteristics of fluids commonly used as refrigerants by adding nanoparticles made up of carbon nanotubes. And acting as primary coolant in safety systems, contributing to the mitigation of serious accidents.

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