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Experiments with Al_2O_3 nanofluid in a single-phase natural circulation mini-loop: Preliminary results

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ABSTRACT

Natural circulation (NC) is a heat transfer mechanism which occurs in case of density gradients inside a fluid. Even if the heat transfer coefficients are lower than in case of forced convection, NC guarantees a good reliability and low costs of maintenance as it does not need any mechanical part. Therefore the main industrial applications of NC systems are in the field of nuclear power plants, solar heaters and passive cooling systems of engines, turbines and electronic components. Most researchers focused their attention on large size systems, with particular care to performance optimization and stability analysis, while there are few studies about natural circulation inside small size devices. In this paper an experimental study focused on the macroscopic effects on the thermal performance of a mini-loop is presented. In particular, two working fluids were used during the tests: distilled water and a nanofluid (distilled water and Al_2O_3) characterized by two different concentrations (0.5% and 3.0% by volume). The analised parameters were: power transferred to the fluid, mini-loop inclination and temperature at the cooler. Experimental results of the two fluids were compared to the Vijayan's correlation, developed for large scale natural circulation loop, showing good agreement.

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1. Introduction

Natural circulation is a widely used mode of heat removal due to its passive nature. It is self starting and the driving force necessary for the fluid motion is obtained from the density differential between the heated and cooled sections. Therefore, NC loops have in-built safety feature of being driven by heat input. Different type of NC loops could be considered.

Single-phase NC loops find practical applications in large scale thermal systems [1–3] such as nuclear power plant [4] or solar water heating system. Moreover, NC systems have recently been introduced in electronic circuit cooling as alternative to two-phase systems. For this reason it is also necessary to study the thermo-hydraulic behaviour of mini-NC loops.

Garibaldi and Misale [5] studied the thermal performance of mini-loops, using distilled water and FC-43 as working fluids, varying both power transferred to the fluid and mini-loop inclination. The thermo-hydraulic behaviour was always stable for both fluids and for all combinations analysed. The best thermal performance of the mini-loop was a flux density of about 40 kW/m^2 with distilled water. All the data showed a very good agreement with the Vijayan's correlation [2].

Recently, a new family of fluids called "nanofluids" are intensively studied. Nanofluid is the name conceived by Argonne National Laboratories to describe a fluid in which nanometer-size particles are suspended [6]. Nanofluids enhance the thermal conductivity and convective heat transfer performance of the base liquid [7].

In particular the addition of small amount of nanoparticles (less than of 1% by volume), with typical length scale of 1–100 nm, increases up to twice the thermal conductivity of the nanofluid [8,9]. At the same time, the viscosity of the nanofluid increases as the nanoparticles concentration increases [10,11].

Most papers concerning nanofluids are generally focused either on their rheological behaviour or on characterising their thermophysical properties. Only few papers analyse industrial applications, in particular in the field of transportation [12,13], electronic cooling [14], space [15,16], biomedicine [17], and nuclear reactor safety systems [18].

Concerning single large scale phase NC systems, an interesting study about the use of Al_2O_3 nanofluid was recently presented in Ref. [19]. The presence of the nanoparticles causes both the stabilisation of the thermo-hydraulic behaviour in the loop and the increment of the flow rate in stable cases.

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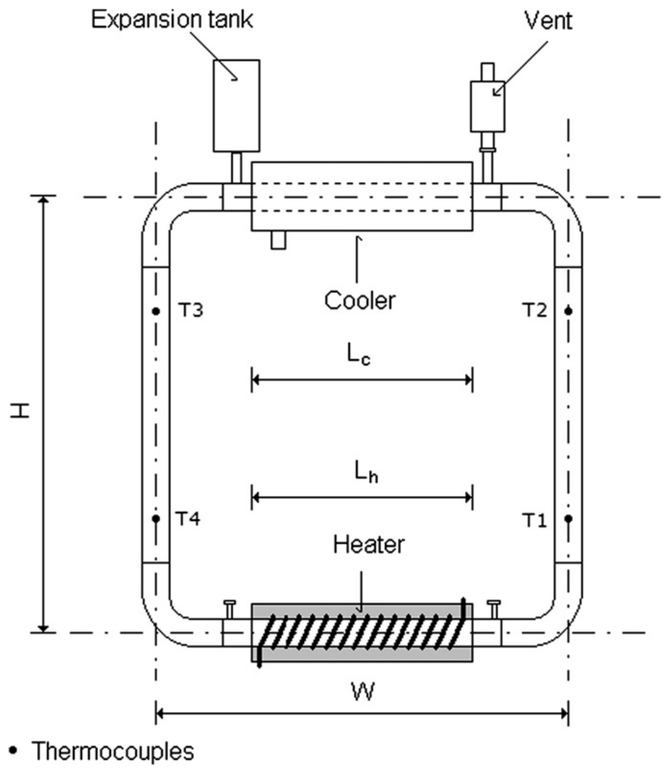

Fig. 1. Scheme of the mini-loop ML2.

In this paper the preliminary experimental results about the thermal performance of a mini-loop filled either with distilled water or Al_2O_3 nanofluid are presented. The following parameters are investigated during the experimental campaigns: mini-loop inclination, power transferred to the fluid, and temperature at the upper heat sink. All data are compared with the Vijayan's correlation, originally developed for large scale NC loop.

2. Experiments

2.1. Experimental apparatus

The experimental set up consists of a rectangular single-phase natural circulation mini-loop called ML2 (Fig. 1). Geometrical dimensions of ML2 are summarized in Table 1.

All the tubes are made of copper (99.9%) and are connected by means of four glass bends.

The heater, placed at the bottom side of the mini-loop, is made by a nichromel wire rolled around the horizontal copper tube, connected to a power supply Electronic Measurements TCR 80S13. The cooler is a coaxial heat exchanger placed at the top of the mini-loop, fed by a cryostat Haake K-F3, which provides a mixture of 50% water and 50% glycol.

Since the flow rate at the cooler is high (0.6 l/min), the temperature throughout the whole heat exchanger can be considered uniform (maximum inlet–outlet temperature difference is 1.2 °C at the heat flux of 50 W).

Table 1
Geometrical dimensions (mm) and characteristics of ML2.

D	4
W	180
H	264
$L_h = L_c$	100
L_{tot}	888
L_{tot}/D	222
H/W	1.47

Heater, cooler and vertical tubes are thoroughly insulated. Heat losses, estimated with classical literature correlations, are lower than 5% of the supplied heat flux. Therefore, the boundary conditions of ML2 are of imposed power at the heater, imposed temperature at the cooler and adiabatic vertical tubes.

An expansion tank allows fluid expansions as consequence of increase of temperature.

The fluid temperatures were measured with four calibrated (±0.1 °C) and shielded K-Type thermocouples, two for each vertical tube, placed at a distance of 40 mm from the horizontal heat exchanger axes (Fig. 1)

The thermocouples, characterized by external diameter of 0.2 mm, are positioned in the middle of the cross section. The reduction of the cross sectional area, due to the presence of the thermocouples, is evaluated as 3.2%, and is considered sufficiently small to neglect the consequent increase in pressure losses [20].

Two additional calibrated (±0.1 °C) and shielded T-Type thermocouples measure the temperature of the cryostat internal bath and of the ambient, respectively.

Data are recorded by means of a high speed data acquisition system by National Instruments (PCI-1200, SCXI-1000, SCXI-1102, SCXI-1303).

The mini-loop is placed on a plate (Figs. 2 and 3) which can rotate from vertical ($\alpha = 0°$) up to close to horizontal ($\alpha = 75°$) position. With inclined mini-loop the buoyancy forces are reduced by a $\cos(\alpha)$ factor. Neglecting the three-dimensional effects inside the flow, the mini-loop inclination could simulate reduced gravity.

2.2. Properties and preparation of nanofluid

As written above, in this study two working fluids are used: distilled water and an Al_2O_3 nanofluid. The thermophysical properties of distilled water are well known [21], whereas several

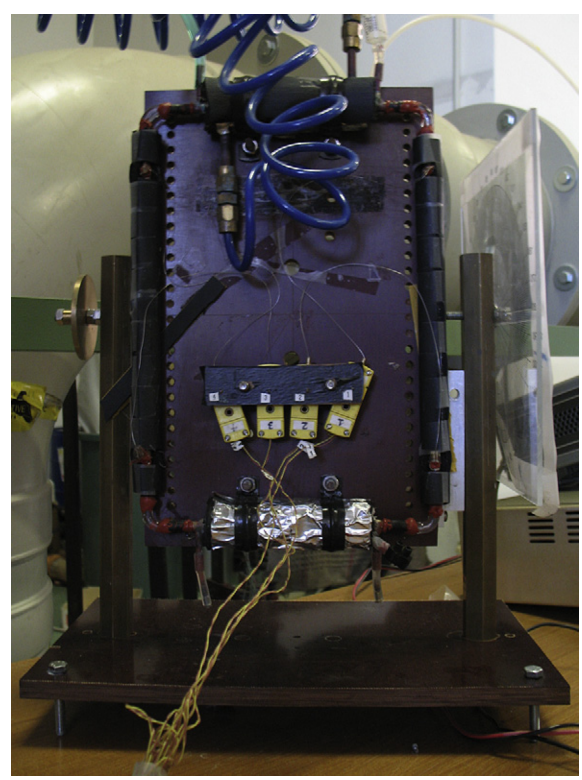

Fig. 2. Picture of the mini-loop.

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