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Investigation on Natural Circulation Loop with Nanofluid

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ABSTRACT
Natural circulation loops transport heat from a heat source to a heat sink by natural convection process and without the aid of pumps to circulate loop fluid to transport the heat. A vertically placed circular pipe loop is equipped with two heat exchangers placed at its lower end and top end for heating and cooling of the loop fluid respectively forms the Natural circulation loop. The fluid circulation is the result of buoyancy forces, which in turn is the result of the density differences induced by the temperature differences existing in the heat source and sink.
Investigation is carried out with loop fluid as distilled water alone and also with 0.25% concentration of CuO nanofluids as loop fluid at various temperatures of heat source. It is observed that natural circulation flow rates are enhanced with the use of nanofluid than with distilled water alone and also with increasing temperature of hot fluid entering into the heat source.
Key words:- Natural circulation loop, nanofluid, hot end heat exchanger, cold end heat exchanger.

I. INTRODUCTION

The primary function of a natural circulation loop is to transport heat from a heat source to a heat sink. The advantage of the natural circulation system is that the heat transport function is achieved without the aid of any pump. The absence of rotating parts/mechanical parts to generate fluid circulation makes it less prone to failures; thereby the maintenance and operating costs are reduced.

A heat source, a heat sink and the connecting pipes form the natural circulation loop. In the natural circulation loops, the heat sink is located above the heat source to promote natural circulation. The pipes are connected to the source and sink in such a way that it forms a continuous circulation path. When the working fluid is filled in to the loop and by supplying heat in to the heat source the NCL is activated. With both the heat source and heat sink conditions maintained constant, a steady loop fluid circulation takes place.

Natural circulation is a phenomenon which occurs in a fluid in the presence of temperature and density gradients in a fluid field. The motive force for the fluid circulation is generated within the loop simply because of the presence of a heat source and a heat sink maintained at different temperatures. Due to this natural circulation loops find several engineering applications such as solar water heaters, transformer cooling, geothermal heat extraction, natural circulation boilers, electronic device cooling and heat extraction from nuclear reactor cores etc.

Nanofluids are fluids in which nanoparticles are thoroughly dispersed in base fluids. The base fluids may be water, ethylene glycol, lubricating oil etc., and nanoparticles are carbon nanotubes, metal oxides, metal nanoparticles, etc. Nanofluids are having unique properties hence they find many engineering applications. Nanofluids are used for several industrial and research applications because of their improved properties in thermal, electrical, chemical and optical fields. Higher surface-to-volume ratio of nanoparticles enhances their chemical and thermal properties. The thermal conductivity is high at nanolevel compared to bulk material form. Hence, this feature can be used in thermal systems to enhance heat exchange process. When nanoparticles are mixed with base fluid and properly sonicated, the dispersed nanoparticles will float without settlement for months together, will become a good thermal fluid for increased heat transfer capability and the thermal systems can be made compact by reducing the size for the same heat loads.

The performance of natural circulation loop can be improved with the use of nanofluids. Increase in thermal conductivity is the key idea to improve the heat transfer characteristics of the fluids in NCL. Extensive research is going on across research community on the usage of nanofluids to enhance heat transfer in natural circulation loops and in the heat exchange devices, so that lower driving force, higher heat transfer can be achieved for the same heat load, and thereby the size of the heat exchange devices can be reduced.

The working of Natural circulation loops, functions and their advantages to transport heat from a heat source to a heat sink is described by Vijayan et al [1]. In this study, authors explained the natural circulation phenomenon and application of the principle in systems like natural circulation loops, transformer cooling, solar water heaters, cooling of engines and gas turbine blades, and nuclear reactor cores. Authors also described that Nuclear power plants use natural circulation as a means to remove core power during normal operation.

Misale [2] addressed the issues like the problem of the stability of the loops, which is of interest in many industrial applications. The review concentrated on the experimental aspects that could be interesting in the study of the natural circulation systems. In particular, the aspects related to natural circulation loop were discussed viz., applications of natural circulation loops, models, influence of loop size and thermo-hydraulic behaviour. Author suggested for single-phase NCLs, the instrumentation should be able to measure the velocity and the temperature of the fluid without causing disturbance to the fluid movement. The suggested measuring devices are Magnetic flow meter, Ultrasound Pulsed Doppler Velocimetry etc. Author also explained that the thermo-hydraulic behaviour of a single-phase natural circulation loop depends on interaction between the fluid properties, material utilised to construct the loop, heaters and coolers displacement and numbers, horizontal parallel channels used new nuclear reactors, loop inclination and the properties of loop fluid.

Experimental investigation is carried out on a rectangular single-phase natural circulation mini-loop by Misale, et al [3]. The preliminary results show a stable flow rate with a steady temperature difference across the heat sinks. It has been confirmed that the fluid velocity in the mini loop is very small (order of millimetres per second). The effect of power transferred to the fluid and loop inclination has been systematically investigated.

The process of natural circulation mechanism which occurs due to density gradients inside a fluid is investigated by Misale et al. [4]. They conducted experiments on the thermal performance of a mini-loop. They used two working fluids during the tests: distilled water and alumina nanofluid characterized by two different concentrations. They analyzed mini-loop inclination, power transferred to the fluid, and temperature at the cooler.

Natural circulation loop with the use of nanofluids is experimentally investigated by Nayak et al. [5] in which the loop was heated with electric heating coil wire which was wrapped around uniformly on the outer surface of the glass tube in the bottom horizontal leg. They found that not only the flow instabilities are suppressed but also the natural circulation flow rate is increased. The increase in steady natural circulation flow rate due to addition of nanoparticles is found to be a function of its concentration in base fluid. The flow instabilities are found to occur with water alone only during a sudden power addition from cold state condition, step increase in power addition and step decrease in power. With addition of small concentration of nanoparcticles in the working fluid, these instabilities in the flow are found to be suppressed significantly.

The influence of pressure drops on the behavior of a single phase natural circulation loop is investigated by Misale et al. [6]. Two experimental loops were constructed with different diameters but same length/diameter ratio is maintained. The natural circulation loop showed unstable behavior. In order to stabilize the loop, two orifices of different diameters were placed in the vertical legs. Stabilising effect of pressure drops on the overall behavior of the loop is observed. But it may lead to reduction in flow rate.

Experimental work on single-phase natural circulation loop is conducted by Misale et al. [7] and the effect of loop inclination and tube wall thermal conductivity were investigated. The experiments were conducted analysing the interaction between the pipe material and properties of liquid as well as the inclination of the loop.

In this paper, the performance of NCL is presented. The NCL is designed with hot water supply into the bottom hot end heat exchanger i.e. heat source of the natural circulation loop and loop fluid is taken as distilled water alone and CuO nanofluid .

II. METHODOLOGY

In the present investigation, nanofluid was prepared by dispersing CuO nanoparticles of 0.25% by weight which was used as loop fluid in NCL. The nanofluid of CuO was prepared for the above stated percentage using probe sonication process. The schematic diagram of Natural circulation loop is shown in figure 1. For the performance evaluation of natural circulation loop, the flow rate of loop fluid, total flow and temperatures in the loop at various locations etc., were recorded in the experiments. These parameters were used in determining the heat gained by loop fluid, heat rejected by loop fluid in heat sink and also to find the efficiency of the loop.

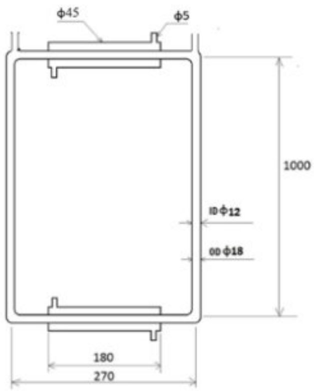

FIGURE 1. Schematic diagram of Natural circulation loop

FIGURE 2. Probe sonicator used for preparation of CuO nanofluid

Experimental investigation was carried out on the natural circulation loop using nanofluids (CuO) and also distilled water alone as loop fluid. During conduction of the experiments, devices viz., Probe sonicator, Ultrasonic flow meter, Data logger, PT100 sensors and Purge rotameters were used.

Nanofluid is prepared using probe sonication process in which the probe of sonicator is directly immersed into the nano-particle loaded fluid. The probe transfers energy in the form of ultrasonic pulses/waves to the fluid thereby particles are dispersed. The sonication process is shown in figure 2. With this energy the nanoparicle agglomerations bursts, particles are dispersed and the fluid is thoroughly mixed and homogenised. In the preparation of nanofluid, probe sonicator is used whose specifications are 20Khz and an Ultrasonic Power 500 Watts. CuO nanoparticles of average particle size of 40nm are used in preparation of nanofluid.

An ultrasonic flow meter is used to measure the flow rates of loop fluid flow. The sensors of the Ultrasonic flow meter are connected at a specified distance on the outer periphery of the pipe through which the loop fluid is flowing. The sensors do not interfere the flowing fluid hence flow is not disturbed. The sensors connected to the riser of NCL are shown in figure 3.The other ends of the sensors are connected to the ultrasonic flow meter. The flow rates can be directly read on the digital display screen of the flow meter. Through RS232 port, the instrument is connected to a computer for recording the data continuously.

FIGURE 3. Data logger and Ultrasonic flow meter

FIGURE 4. Experimental setup

During conduction of experiments at a particular temperature of heat source, a constant temperature water supply is required which is supplied by a constant temperature water bath. The bath is insulated and the piping is also properly insulated to prevent heat losses and to maintain a constant temperature water supply into the NCL. The experimental setup is shown in figure 4.

III. RESULTS

Experiments were carried out first with distilled water as loop fluid and later, CuO nanofluid of 0.25% by weight concentration was placed as loop fluid. The heat source at the bottom of the NCL was supplied with hot water from constant temperature water bath at desired temperatures (50°C, 60°C, 70°C, 80°C and 90°C) during the tests, so that the required temperature was maintained in the heat source. The heat will be transported by loop fluid from the heat source at the bottom of the NCL to the heat sink at the top of the loop. For various heat source temperatures, performance of the NCL was investigated for various loop fluids.

3.1 Experimentation with distilled water as loop fluid

In the first part of experimental investigation on the effect of varying the temperature of heat source of NCL using distilled water as loop fluid was carried out. The heat source temperatures considered were 50^0C, 60^0C, 70^0C, 80^0C and 90^0C. The parameters such as flow rate, velocity, total flow, temperatures at various locations of NCL are recorded and these observations are used to calculate heat given up by heat source, heat extracted by loop fluid from the heat source, heat rejected by loop fluid in the CEHE, the heat gained by circulating water in the heat sink (CEHE) and finally, the efficiency of natural circulation loop.

The plots for temperature variation and for loop fluid flow in the loop were prepared for different heat source temperatures. Typical plots are presented when heat source temperature was kept constant at 70^0 C is shown in figure 5 and figure 6. Similar plots are obtained for other temperatures.

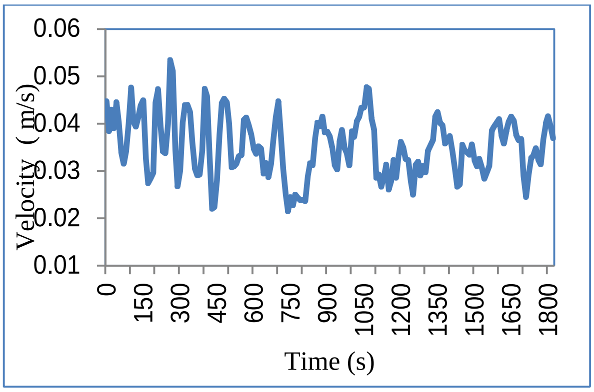

FIGURE 5. Variation of velocity of loop fluid (distilled water) with Temperature of heat source kept at 70^0C.

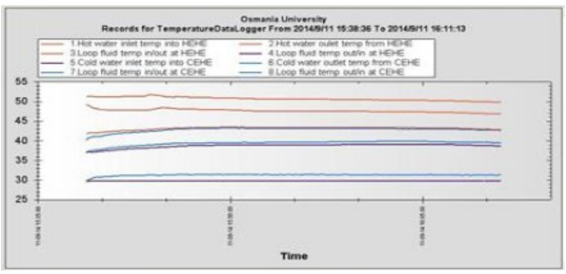

FIGURE 6. Temperature variation at various locations of NCL with time for loop fluid as distilled water while heat source temperature kept at 70^0C

From the experiments, it is observed that the efficiency of the NCL for distilled water as loop fluid is reached to a maximum value at 80^0C and further increase in temperature of hot water supply into the heat source, the efficiency is found to be slowly decreasing. This is due to the change in properties of loop fluid at higher temperatures and increased heat losses.

3.2 Experimentation with Cuo Nanofluid as loop fluid

With varying the temperature of hot water supplied into the hot end heat exchanger i.e. heat source of the NCL, the parameters such as flow rate, velocity, total flow, loop fluid temperatures at various locations of NCL are observed and recorded for CuO nanofluid of 0.25% concentration as loop fluid. These observations are used to calculate heat given up by heat source, heat extracted by loop fluid from the heat source, heat rejected by loop fluid in the cold end heat exchanger, heat gained by circulating water in the cold end heat exchanger and finally, the efficiency of natural circulation loop.

The variation of loop fluid flow rate and temperature of NCL at various locations for CuO nanofluid as loop fluid are shown in the figure 7 through figure 8 for heat source temperature kept constant at 70^0C. similar plots are obtained for other temperatures.

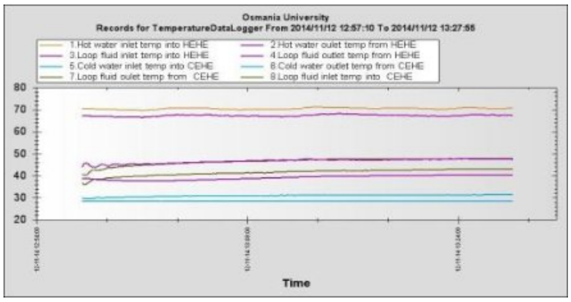

FIGURE 7. Variation of temperatures of NCL with Time for 0.25% CuO Nanofluid with Temperature of heat source at 70^0C

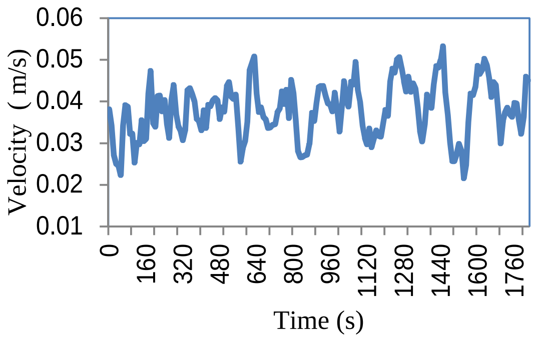

FIGURE 8. Variation of loop fluid velocity with time for 0.25 % CuO nanofluid with Temperature of heat source at 70^0C

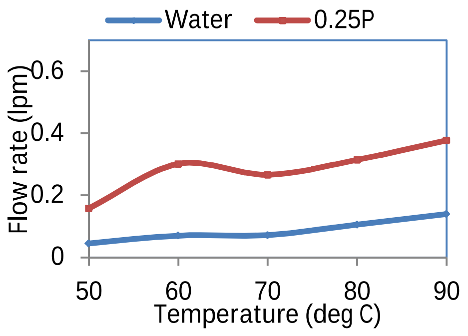

FIGURE 9. Variation of Flow rate with temperature of heat source for water and CuO Nanofluid

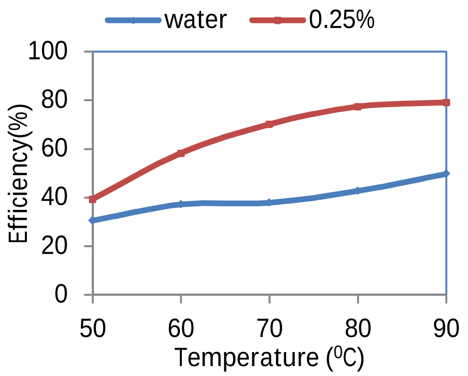

FIGURE 10. Variation of Efficiency with temperature of heat source for water and CuO Nanofluid

Variation of loop fluid flow at different heat source temperatures is shown in figure 9. The performance of NCL was investigated at various temperatures of hot water supplied into the hot end heat exchanger i.e. heat source and for distilled water alone and with 0.25% wt concentration of CuO nanofluid as loop fluid. Variation of Efficiencies with temperature of heat source for water and CuO Nanofluid is shown in figure 10. From the experiments, it is observed that the efficiency of the NCL is reached to a maximum value at 80^0C and further increase in temperature of hot water supply into the heat source, the efficiency is found to be slowly decreasing. This is due to the change in properties of loop fluid at higher temperatures and heat losses at higher temperatures.

IV. CONCLUSIONS

In the present investigation, the performance of Natural Circulation Loop with loop fluid as water alone and also with CuO nanofluid with concentrations of 0.25% by weight has been investigated for various temperatures (50^0C, 60^0C, 70^0C, 80^0C and 90^0C) of heat source of the NCL. From the experimental investigation, the following conclusions are drawn.

- Stabilization of loop fluid circulation is achieved with the introduction of Nanofluid in the loop. The fluctuations in the circulation of loop fluid are of decreasing order with the addition of nanofluid. The enhancement of flow rate in the loop is encountered with the increase of temperature of heat source.
- With the increase in temperature of hot water supply into the hot end heat exchanger i.e. heat source temperature, the efficiency of loop is observed to increase for both distilled water as well as Nanofluid as loop fluid but the rate of increase in efficiency is higher with Nanofluids as loop fluid when compared to distilled water.
- When temperature of HEHE is increased beyond 80^0C it is observed that the efficiency of the loop is slowly decreased due to high temperature effect on properties of nanofluid.

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