

ABSTRACT

Global urbanization and industrialization processes are causing a significant rise in energy usage. The growing energy demand requires a reliable passive device like a natural circulation loop for heat recovery, transfer and use. The selection of a single-phase natural circulation loop is motivated by the independence of any mechanical device or active power source for its simple operation. The difference between buoyancy, generated by the heating and cooling, and pressure-drop leads to the setting up of flow in a natural circulation loop. The safety, reliability, and maintenance cost motivate the use of natural circulation loops for power generation, viz. solar thermal and nuclear, heating and cooling applications, etc., in industries. The literature review revealed the dearth and potential for hybrid nanofluids that are envisaged as a promising working fluid in the futuristic natural circulation loops. Furthermore, many related issues have to be explored, such as the effect of nanoparticle shape and using hybrid nanofluids, the effect of various assumptions for numerical modelling and the effect of oil and nano-oil for medium temperature applications. Considering these issues, the present thesis includes detailed numerical and experimental investigations of a single-phase natural circulation loop with the vertical heater and the vertical cooler arrangement. The objectives are to evaluate the transient and steady-state thermo-hydraulic behaviour, energetic and exergetic performances using water-based binary and ternary hybrid nanofluids for low temperature ($< 100\text{ }^{\circ}\text{C}$) and oils and oil-based mono and hybrid nanofluids for medium temperature ($100\text{ }^{\circ}\text{C}$ to $250\text{ }^{\circ}\text{C}$). Effects of various modelling assumptions and heat flux distribution of heater on steady-state and transient performances are studied as well.

For numerical investigation, the different water-based binary and ternary hybrid nanofluids with $\text{Al}_2\text{O}_3+\text{Ag}$, $\text{Al}_2\text{O}_3+\text{Cu}$, $\text{Al}_2\text{O}_3+\text{TiO}_2$, $\text{Al}_2\text{O}_3+\text{CNT}$, and $\text{Al}_2\text{O}_3+\text{Graphene}$ and ternary hybrid nanofluids with $\text{Al}_2\text{O}_3+\text{Cu}+\text{CNT}$, $\text{Al}_2\text{O}_3+\text{Cu}+\text{Graphene}$,

$\text{Al}_2\text{O}_3+\text{CNT}+\text{Graphene}$, $\text{Cu}+\text{CNT}+\text{Graphene}$, for 1% volume concentration of nanoparticles, are selected. Also, the different thermal oils, viz. Therminol VPI, Paratherm CR, Dowtherm A, and Dowtherm Q are selected as the base fluids for further investigations. The investigations include the effect of the shape of nanoparticles, geometrical parameters like diameter, height, loop aspect ratio (height to width), loop inclination, nanoparticle shapes, and power input on the energetic and exergetic performance, viz. mass flow rate, effectiveness, and total entropy generation rate of a single-phase natural circulation loop. The results reveal that (a) the energetic and exergetic performance for the binary and ternary nanofluid is better than the respective base fluids. Moreover, ternary nanofluid shows better performance than binary nanofluids, (b) Paratherm CR shows a better performance among all thermal oils, (c) the shape of nanoparticles significantly affect the performance by influencing the mass flow rate, (d) the time required to attain a steady state is reduced with nanofluids, which is beneficial for a system, (e) the mass flow rate and the time required to achieve the steady state increase with tube diameter and height, (f) the effectiveness and entropy generation rate increase with decreasing loop diameter and height, (g) for a low input power the flow stabilizes at an early instant, and the steady state mass flow rate increases, (h) effectiveness decreases and entropy generation increases with increasing heater power, and (i) with the increasing loop aspect ratio the steady-state heat transfer effectiveness decreases, and the total entropy generation rate and the mass flow rate increases at an input power. The optimum value of the height to width ratio can be different for different types of fluids.

A detailed numerical investigation on the effect of different assumptions related to Boussinesq approximation, thermophysical properties, bend loss, heat loss, axial conduction of fluid, and wall conduction on the transient and steady-state characteristics has also been carried out. The effect of assumptions on the above-explained performance

parameters for different working fluids, viz. water, brines, and hybrid nanofluids, and the effect of different heat flux distributions, like the uniform, linear, non-linear, sinusoidal, and Gaussian, applied to heater have been explored. The results reveal that using the Boussinesq approximation, the error in the performance parameter is higher for EG and PG brine fluids, which restricts its use for all the fluids. The simulations with non-Boussinesq with temperature-dependent properties, including wall and fluid conduction, bend loss and heat loss, provide the closest agreement with the experiment for steady and transient behavior of a single-phase natural circulation loop.

Finally, experimental investigations are performed to evaluate the transient and steady-state performance of the selected single-phase natural circulation loop using mono and hybrid nanofluids that are based on water, Therminol VP1 and Soyabean oil. The nanoparticles and their combinations, viz. Al_2O_3 , $\text{Al}_2\text{O}_3+\text{CuO}$, $\text{Al}_2\text{O}_3+\text{SiC}$, and $\text{Al}_2\text{O}_3+\text{MWCNT}$ are selected for a volumetric concentration up to 0.1%. Here, the effect of input power, loop inclination (counter-clockwise and clockwise), and coolant inlet temperature on the performance parameters have been investigated. The result reveals (a) Therminol VP1 shows better performance than the Soyabean oil, (b) $\text{Al}_2\text{O}_3+\text{CNT}$ nanoparticles-based hybrid nanofluid shows the best performance among other hybrid nanofluids, (c) the increasing coolant inlet temperature enhances the mass flow rate and total entropy generation rate and reduces the effectiveness, (d) the decreasing loop inclination reduces the mass flow rate, whereas it increases the effectiveness and total entropy generation rate.