CHAPTER 1

INTRODUCTION

1.1 Background

Tubular heat exchangers are very common types of heat exchanger, generally used for liquid-to-liquid and liquid-to-phase change (condensing or evaporating) heat transfer in many engineering applications, including the power plant, food industry, chemical industry, environmental engineering, waste heat recovery, refrigeration and air conditioning. These heat exchangers may be further classified as double-tube and shell-tube heat exchangers. Many attempts have been made to enhance the hydrothermal characteristics in tubular heat exchangers by design optimization or the use of external forces. There are numerous enhancement methods for improving the thermal performance of tubular heat exchangers, namely active and passive methods. In the active method, it requires external power to enhance the heat transfer rate, such as surface vibrations, electrostatic fields, impinging jets, etc. Passive methods do not need any additional energy and have some advantages, such as easy fabrication and low-cost implementation. Therefore, the passive method has become a promising method. There are some passive methods, which have been implied and integrated into the heat exchanger, including wire coil inserts, louvered strip inserts, conical ring inserts, delta wing vortex generators and twisted tape inserts with different modifications. The enhancers act as a passive method, are widely used in both experimental and numerical studies to investigate the performance of the heat exchanger. However, many investigators examined the performance of tubular heat exchangers using enhancers (twisted tape and wire coil inserts). Both the enhancers are usually more active in the laminar flow regime than turbulent flow. Twisted tape insertion is beneficial than wire coil insert without considering pressure drop penalty; though, when the pressure drop penalty is considered, the wire coil inserts show better performance than the twisted tape inserts. Twisted tape inserts and wire coil inserts as turbulators are some of the best passive techniques that form a swirl flow inside the pipe and diminishes the boundary layer thickness and thus increasing the turbulent flow intensity. The heat transfer rate in a heat exchanger can also be improved by modifying the properties of working fluids. As nanofluids have shown significant enhancement of heat transfer properties (mostly due to significant enhancement in thermal conductivity, slip mechanisms and nanofin effect), it can be effectively used in tubular heat exchangers to improve the energy performance **(Huminic and Huminic, 2012)**. The passive method has been recommended as the most effective, simple and economical technique in the open literature. Hence, in view of the increasing demand for energy density, the use of both enhancer (insert) and nanofluids can be a good combination to improve the heat transfer characteristics of the tubular heat exchanger.

1.2 Mono/hybrid nanofluid

Nanofluids are engineered by dispersing nanoparticles, having average sizes below 100 nm, in conventional heat transfer fluids. Proper and stable dispersion of even a negligible fraction of particles in nanofluids can offer significant enhancement in the heat transfer properties. Various types of nanoparticles like metals, metal oxides, alloys, allotropes of carbon, ceramics, phase change materials and metal carbides are being used for preparing nanofluids. In addition to nanofluids, the hybrid nanofluids have also gained attention recently due to significant improvement of heat transfer characteristics and stability may be caused by the synergistic effect of hybridization. For preparing mono or hybrid nanofluids, the two-step method is generally used where firstly, different nanoparticles or nanocomposites are prepared. Then they are mixed in the base fluid through magnetic or mechanical stirring. After that, the solution is sonicated and then characterized using different techniques to assure the proper (homogeneous) mixing and stability of the hybrid nanofluids. Both mono and hybrid nanofluids are thus prepared to provide improved heat transfer characteristics due to an increase in thermal conductivity, Brownian motion, proper dispersion, agglomeration, solid/liquid interface layering, thermophoresis, the improved thermal network between the solid nanoparticle and fluid molecules, nanofin and nanoporous effects at the heat transfer surface. The reason behind this improvement can be summarized as **(Pinto and Fiorelli, 2016)**: (i) More heat transfer surface between nanoparticles and fluid, (ii) Collision between the nanoparticles, (iii) Increment in the thermal conductivity due to the interactive effect of different nanoparticles, and (iv) Proper dispersion of the nanoparticles in the base fluid, creating micro turbulences. Moreover, the phase change material (PCM) suspension as heat transfer fluids have gained a special interest in the heat transfer application. Although the PCMs have low thermal conductivity, water-based PCM suspension exhibits significant enhancement in the convective heat transfer because of the latent heat of phase change. In addition, the hybrid nanofluids provide combined thermal, physical and chemical properties of different materials, whereas a single nanoparticle does not fulfill all the requirements. Therefore, in hybrid nanofluids, both nanoparticles compromise their properties and provide better thermo-physical, chemical and rheological properties within the low cost that makes it preferable over nanofluids for different applications. The nanofluids may be broadly categorized into three groups based on the nanoparticle composition, namely: (i) mono-nanofluids (made from one type of nanoparticles), (ii) hybrid nanofluids containing different nanoparticles, and (iii) hybrid nanofluids consisting of composite nanoparticles (made of one solid or PCM covered by a layer of another solid). It is supposed that hybrid nanofluid has better thermophysical properties over mono nanofluid, which has motivated to implement hybrid nanofluids also in the tubular heat exchanger.

1.3 Contributions

The tubular heat exchanger is used for many engineering applications due to the various advantages discussed above and the use of both insert and nanofluids can be a good combination to improve the heat exchanger performance leading to a reduction of volume and cost, which has motivated to undertake this research work. However, based on the literature review, few experimental studies have been conducted till the date on tubular heat exchanger augmented with mono/hybrid nanofluid as well as an enhancer (modified twisted tape and modified wire coil). As far as the authors know, none of the studies available with the comparison of V-cut twisted tape and tapered wire coil insertion using mono/hybrid nanofluids as a coolant as well as hot fluids. Moreover, no study is available on a tubular heat exchanger with an enhancer for PCM dispersed mono/hybrid nanofluids. The studies on the shell and tube heat exchanger using hybrid nanofluid are very limited. Also, no economic study has not been performed on the existing industrial heat exchanger with hybrid nanofluids to check the replacement feasibility. Various enhancer insertions and various water-based mono/hybrid nanofluids as working fluids can be used to enhance the performance of the tubular heat exchanger. To quantify enhanced performance characteristics, the theoretical and experimental investigations have been planned to study the hydrothermal characteristics of mono/hybrid nanofluids in the tubular heat exchanger using various enhancers.

This study is an original work because the experimental and numerical investigations have been performed on tubular heat exchanger using ***enhancers*** and various ***mono and hybrid nanofluids***. ***Novel modified coil inserts (convergent, divergent and convergent-divergent types)*** have been introduced. Different water-based mono nanofluids (***Al_2O_3, PCM and CNT***) and hybrid nanofluids (***Al_2O_3+PCM, Al_2O_3+CNT, Al_2O_3+TiO_2 and Al_2O_3+MgO***) at different volume concentrations have been investigated. The simulation model has been executed using ***EES*** *(Engineering Equation Solver)*. As unique case studies, ***the energy, exergy and economic feasibility study of existing power plant shell and tube condenser*** using hybrid nanofluids have been done as well.

1.4 Thesis structure

The present study is distributed in seven chapters. In **Chapter 1** and **Chapter 2**, introduction and literature survey on preparation and thermophysical properties of mono/hybrid nanofluids, experimental and numerical investigations on the double pipe heat exchanger and shell and tube heat exchanger with mono/hybrid nanofluids are performed. **Chapter 3** contains the preparation, characterization and measurement of thermophysical properties of various mono/hybrid nanofluids. **Chapter 4** contains the experimentation on double pipe heat exchanger with modified twisted tape and modified tapered coil inserts using different mono/hybrid nanofluids for different concentrations, flow rates and operating temperatures of the mono/hybrid nanofluids. The effect of different twisted ratio, depth ratio and width ratio and different configurations of the tapered wire coil has been studied in the present investigation. The effects on one energy-based parameter and one exergy-based parameter are discussed as well. In **Chapter 5**, the experimental study on shell and tube heat exchanger using different mono/hybrid nanofluids for different flow rates of the hybrid nanofluids flowing in the tube side under the laminar flow condition is presented. **Chapter 6** contains a numerical simulation for the performance of shell and tube condenser of an existing power plant using hybrid nanofluids (case study). In this chapter, the energy, exergy and economic assessments of existing shell and tube type condenser have been investigated numerically by using various hybrid nanofluids as a coolant. Effects of nanoparticle volume concentration on overall heat transfer coefficient, coolant flow rate reduction, pumping power reduction, irreversibility, exergetic efficiency and annual cost have been investigated. Also, the payback period has been determined to measure the duration in which the use of hybrid nanofluids would be profitable. Finally, **Chapter 7** concludes the findings on the present investigation and possibilities for future work.