Chapter 1

Introduction

1.1 Background and Motivation

Energy consumption is an important indicator of a country's socioeconomic development. As people's living standards grow, so does their energy need. Due to the fast increase of power-generating devices, a large amount of heat must be evacuated from the device to avoid sudden shutdown and risks. Thermal management is not an option; it is a must to guarantee that the systems operate at peak efficiency during their planned duty cycles. In recent years, the automobile industry has experienced a boom. The International Organization of Motor Vehicle Manufacturers (OICA) (**Websource : https://www.oica.net/category/production-statistics**) reported that worldwide vehicle manufacturing reached 1092158316 units in the recent decade. In terms of energy distribution, vehicles convert only around 25 to 35% of total fuel energy into mechanical work, which is then used to propel the vehicle. The coolant in the engine cooling system, on the other hand, absorbs 25-35% of the entire energy intake, while exhaust gases absorb thermal energy in the range of 20 to 40% of the fuel energy releases to the environment presented in the Fig.1.1 (**Copeland et al., 2014**).

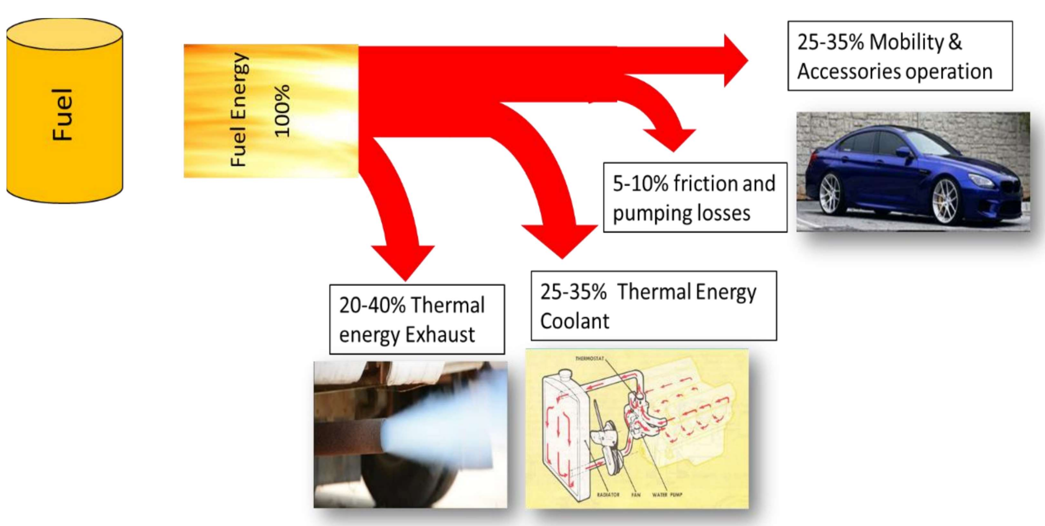

Fig. 1.1. An Internal combustion engine fuel energy typical distribution.

The fuel combustion process inside the chamber generates a tremendous amount of heat, reaching temperatures of up to 2000 degrees Celsius, potentially melting the piston, cylinder, cylinder rings, and lubricants. As a result, a compact fin and tube heat exchanger as a radiator is placed as a cooling system to keep the engine safe from overheating and to make it possible to operate the engine under various working circumstances. In light of the rising need for energy density, coolants with improved thermophysical qualities may be a viable option for dissipating more heat. Heat transfer performance may be increased by utilizing a suitable fluid with enhanced attributes in liquid cooled systems by using a working fluid with high thermal conductivity and specific heat. Within the last two decades, the use of nanofluids (fluids with improved thermophysical and transport capabilities) has been a popular approach. Because a single material does not possess all of the two desirable features necessary for a certain application, hybrid materials are used. Hybrid nanofluids have recently gained popularity because of their improved heat transfer behavior due to hybridization, which has prompted the use of hybrid nanofluids in FTHX. The hydrothermal properties of hybrid nanofluids as a coolant in the FTHX are presented in this thesis, which includes experimental and numerical research. Furthermore, passive device inserts like turbulator inserts mechanism have been utilized for heat transfer improvement. Passive device inserts are mechanical components that uplift the thermal performance of the FTHX, and are suitable to use in a heat exchanger at the cost of power input and provide better fluid mixing, and strength to the component. Also, the coolant from the engine, comprise of low grade energy of coolant, has been utilized for the preheating and its effects on the energy distribution parameters.

1.2 Fin and tube heat exchanger

Fin and tube heat exchanger (FTHX) is employed as a radiator to transfer spare heat to the environment through the use of coolant and air. Air having a lower heat transfer coefficient generally passes to the extended surfaces and hot fluid like coolant passes to the tube side. As the surface density of these heat exchangers is greater than $700 m^2/m^3$, therefore also termed compact heat exchangers (**Zohuri, 2015**). The fin and tube heat exchanger comprises of unmixed cross-flow heat exchanger with air as an external medium to take away the heat of the coolant passes through the fin gap while coolant as an internal hot fluid passes through inside of the tube presented in Fig 1.2. As a result of the increasing thermal loads in a compact heat exchanger due to modified technologies, heat transfer enhancement strategies are focusing on thermos-fluid research to build an energy-efficient heat exchanger (HX) that avoids thermal failure. Heat transfer enhancement techniques are generally divided into two categories: active and passive. The active approach requires an external power source such as a magnetic field or vibration, whereas the passive technique does not and just use flow energy for heat transfer enhancement. Combined active and passive is compound augmentation which can increase the heat transfer performance of FTHX. The active technique requires external energy, whereas the passive method involves introducing flow disruption by surface alteration, swirl, and improved fluid characteristics. A compound or hybrid approach is a combination of active and passive procedures that has a constraint owing to its sophisticated design.

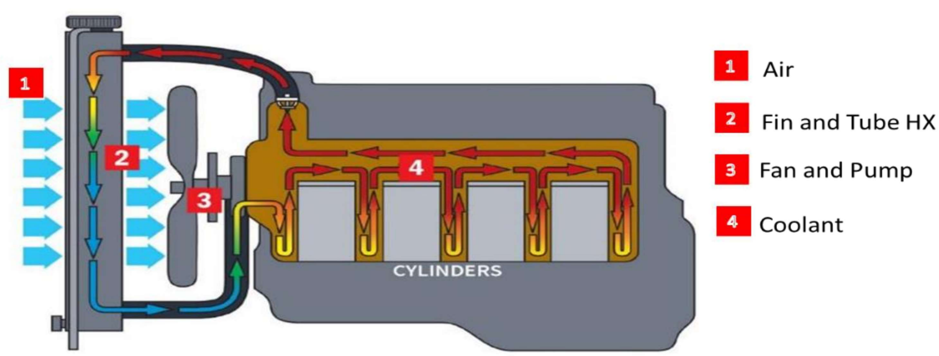

Fig. 1.2. Engine cooling system.

According to the literature, the passive approach is the most successful, easy, and cost-efficient methodology. FTHX has extensive application mainly due to low weight, compactness, better thermo-hydraulic performance, and high heat-removing capacity. Because of its compactness, low weight, great performance, and heat removal capabilities, FTHX has a wide range of applications. FTHX has shown important potential in many engineering applications, including car radiators, crude oil heat exchangers, intercoolers, petroleum refining, petrochemical, gas processing, hydraulic and lubricating systems, refrigeration, fertilizer, water treatment, and many industrial applications.

1.3 Hybrid Nanofluids

Choi, in 1995 employed nanofluids for the first time at the Argonne National Laboratory. A colloidal combination of a nanoparticle suspension in a base fluid is known as a nanofluid. Nanofluid comprises nanoparticles with an average solid particle size of less than 100nm suspended in a base fluid such as water, ethylene glycol, lubricant, engine oil, refrigerant, etc. The thermal conductivities of solid particle materials are much greater than those of base fluids such as ethylene glycol, water, and light oils, according to the research. Different nanoparticles, base fluid, and several additives for nanofluid formation are depicted in Fig 1.3. Various metal oxides, metals (copper, aluminum, titanium, zinc, etc.), metal alloys, carbon allotropes (carbon nanotube, graphene, etc.), carbides, nitrides, and ceramics are used as nanoparticles. However, due to limits in a particular nanoparticle quality that make it inappropriate for some uses, it may have good thermal or rheological capabilities. In some cases, a trade-off between distinct features is essential. Hybrid nanofluids play a role in these situations because their hybridization improves thermal conductivity and heat transfer properties (**Sarkar et al., 2015**). These technologies now have a new dimension, namely composite or hybrid nanofluid, which combines two or more nanoparticles in a base fluid. It is a combination in which the qualities of solid nanoparticles and the primary base fluid combine to improve the base fluid's thermal and transport properties. The thermal conductivity is increased when a very little amount of high thermal conductivity solid nanoparticles is added to the base fluid, boosting the heat transfer capacity. The presence of solid nanoparticles and their random mobility within the base fluid causes a decrease in the thermal boundary layer thickness, which may have a substantial contribution to heat transfer improvement. The heat transmission rate increases as the amount of solid nanoparticles concentration increases, since the collision and contact of nanoparticles, are substantially increased under such conditions. Also, the fast increase in heat transfer from the interface surface to the nanofluid is attributable to the diffusion of solid

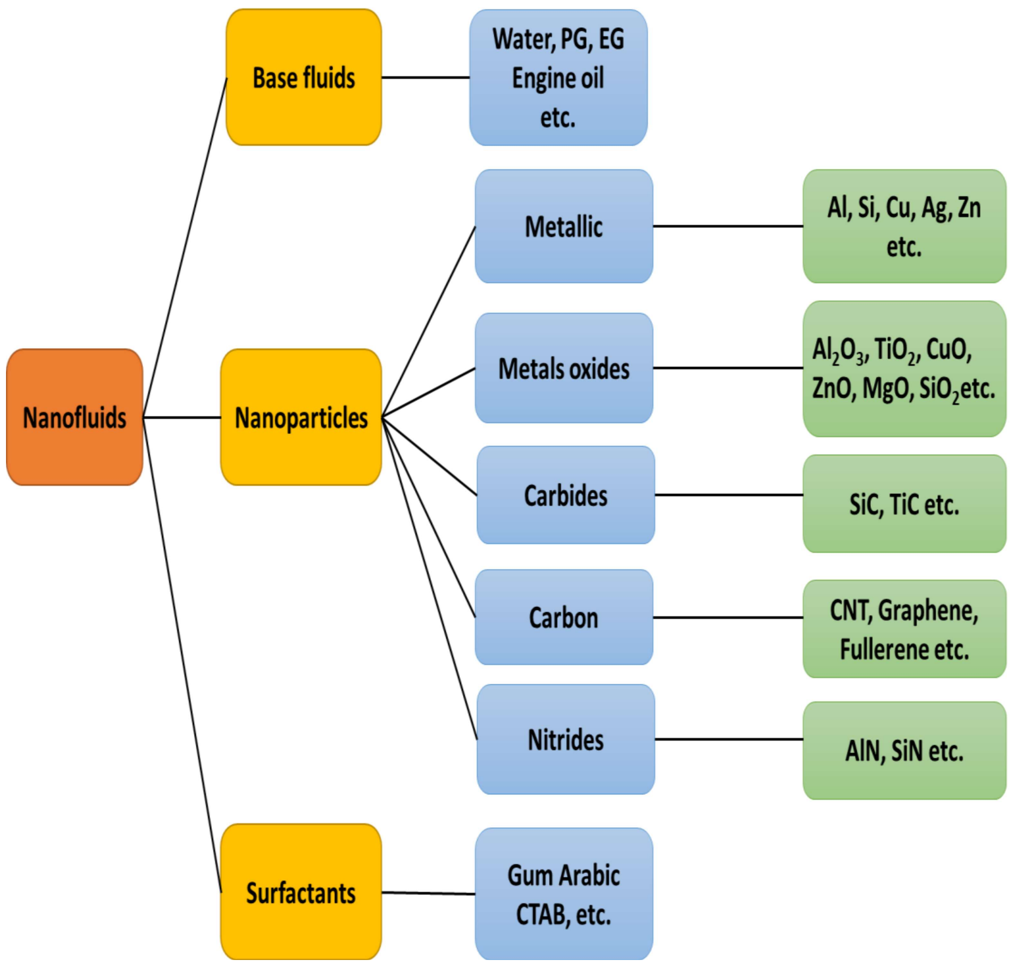

Fig. 1.3. Different nanoparticles, additives, and base fluids for the nanofluid formation.

nanoparticles as well as their relative mobility along the wall. Even at low concentrations, nano fluids improve thermal performance significantly. Due to improved thermal conductivity, it is a current generation of heat transfer fluids that have become a high-potential fluid in heat transfer applications. Brownian agitation triumphs over any settling motion caused by gravity. For a stable nanofluid, the solid particle must remain as tiny as possible (normally below 100nm). Hybrid nanofluid is produced from one step method and two-step method. In one step method, both nanoparticle production and nanofluid preparation are carried out concurrently. Due to the economical mass production limitation, the two-step method is preferred. In two-step method, nanoparticle production and nanofluid preparation are carried out separately. This method is economical in mass production and the homogeneous distribution with a better stable hybrid nanofluid could be achieved by dispersing devices like ultrasonic baths, magnetic stirrers, etc. The hybrid nanofluid can be used for several applications stated as below,

- Car cooling system
- Electronic circuits cooling
- Bio- and pharmaceutical
- Nuclear system cooling
- Solar water heating
- Drilling and lubrication

Hybrid nanofluids can improve the heat transfer and a water-based hybrid nanofluid may be used as the working fluid as a coolant inside the FTHX to improve thermo-hydraulic enhancement.

1.4 Turbulator Inserts

For heat transfer improvement in the heat exchanger, the most commonly used mechanical devices are passive inserts. Passive inserts improve the thermal performance of the HX at the cost of pumping power. Different passive inserts like twisted turbulator inserts, dimpled twisted turbulator inserts, baffle inserts, vortex generators, etc. have been used as a heat transfer improvement technique. Generally, due to the presence of these inserts, better fluid mixing, prolonged fluid flow, swirling and secondary induced flow occur which betters the utilization of fluid energy. The most common inserts used in the tube side are turbulator inserts and it also uplifts the mechanical strength of the heat exchanger. Heat transfer enhancement in the HX with turbulator inserts depends upon the twisted pitch, tape thickness, perforated pitch, perforated diameter, etc. Moreover, the high heat transfer in the HX using turbulator inserts achieves the power requirement to operate the heat exchanger. In presence of inserts, the secondary fluid flow, better intermixing of fluid, and radial fluid flow are some of the reasons for both higher heat transfer and pressure drop. Also, the lower pitch of turbulator inserts increases the number of twists for the given length of the HX and further improvement occurs due to the aforementioned reasons. So, the practical application of turbulator inserts as a heat transfer improvement technique in the heat exchanger is enormous. Therefore, turbulator inserts in HX can improve thermo-hydraulic performance with different water-based hybrid nanofluids.

1.5 Objectives

The compact wavy fin and tube heat exchanger (FTHX) device can be employed for the thermal management of car cooling systems due to the many advantages. The performance of an FTHX can be improved by using turbulator inserts and unusual fluids (hybrid nanofluids). The hydrothermal behavior of hybrid nanofluids as a coolant and the turbulator inserts in the FTHX was studied and utilization of the coolant energy to assess the improved engine performance features.

Present research objectives are summarised as:

- **Preparation of the homogeneous hybrid nanofluids.**
- **Characterization of dispersed nanoparticles using SEM and EDX as well as stability of the prepared hybrid nanofluid with pH and spectrophotometer test.**
- **Determination of thermophysical properties of the hybrid nanofluid.**
- **Detailed design, parametric investigation, and optimization of wavy fin and tube in the air side.**
- **Energy, exergy investigation of tube side heat exchanger using different passive inserts under various hybrid nanofluid.**
- **Numerical thermo-economic, design optimization investigation of tube inserts.**

- **Application of low grade energy of coolant for preheating effects of blended biodiesel and diesel on engine parameters experimentally.**

The aim and novelty of the present work is to design and fabricate an improved compact wavy fin and tube heat exchanger with both the air side and the tube side. Also, the effect of oxides-based hybrid nanofluid on the heat exchanger performance is studied. Energy, exergy, and economic investigation of the fin and tube heat exchanger with various hybrid nanofluids and inserts for performance improvement. The effect of several variables as fluid flow rate, hybrid nanofluids, and tube inserts on the output parameters have been investigated. Output parameter low grade energy of the coolant by a means is a waste to the environment has been utilized for the preheating of the blended biodiesel, diesel and its effect on the engine parameters and energy distribution have also been investigated as a real-life based application.

1.6 Thesis structure and methodology

The present investigation is discussed in eight chapters. The first chapter commences with a detailed background of the current energy scenario of engine, utilization, fin and tube heat exchanger, with passive improvement techniques and basics of hybrid nanofluids suitable to use as radiator coolants. In the consecutive next chapter literature survey details mainly focuses on the preparation and measurement of thermophysical properties of hybrid nanofluid with a detailed experimental and numerical study on utilization of nanofluid in fin and tube heat exchangers along with passive device inserts for thermal enhancement. Also, energy utilization for preheating blended biodiesel using external and waste sources of energy and the effect on engine performance are studied. The third chapter deals with the preparation, characterization, and stability analysis of the hybrid nanofluid. Also, the thermal and physical properties determination of the prepared hybrid nanofluids using different measurement devices are studied for practical application in the heat exchanger. The fourth chapter investigates the parametric study and design optimization of wavy fin and tube air heat exchanger using the Taguchi Grey technique. The consecutive fifth chapter deals with the Energy, exergy, and enviro-economic investigation of air heat exchangers equipped with various turbulator inserts using hybrid nanofluids (THNF): An experimental study. The sixth chapter deals with Computational fluid dynamics (CFD) and TGM (Taguchi grey method) design optimization, thermo-hydraulic and enviro-economic analysis of twisted perforated tape insert-based heat exchanger with nanofluid. The seventh chapter deals with the application part of low-grade energy of the coolant utilized for preheating of prepared blended biodiesel and its effect on engine performance and energy utilization is studied. Finally concluding remark and future scope are presented in the eighth chapter.

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