

Abstract

Energy utilization is a crucial parameter for the socio-economic growth of a nation. As living standard improves, the energy demand also rises. Modern science has brought forth cutting-edge innovations, forcing the car sector to create more potent engines. The cooling system of the engines needs to be improved to keep up with the innovation. Emergence in modified technologies requires rapid heat removal methods for better performance of the heat exchangers. To overcome this issue, the heat exchanger is optimized to use for practical applications, and for the betterment of the heat exchanger performance, different working fluids and optimized passive device turbulator inserts are used. Also, for practical application, the waste energy of the coolant is used to preheat the prepared blended biodiesel fuel using an intermediate heat exchanger with its effect on the engine performance and energy utilization. The three different compositions of hybrid nanofluids (0.06-0.12%) (v/v) are prepared for utilization as a coolant in the heat exchanger. The better coolant is used in the engine and the waste energy of coolant is utilized for preheating fuel, concurrently. The prepared ternary hybrid nanofluids are found to be stable and nanoparticles are well dispersed for the lower concentration as claimed by the Ultraviolet-visible spectrophotometer. All the nanoparticles obtained to be the spherical shape of size lower than 100nm, obtained using SEM and EDX analysis. The pH of the solution obtained far away from the isoelectric point ensures the fluid is used for practical application. On nanoparticle addition, thermal conductivity, and viscosity increased but the specific heat of the fluid reduced significantly.

In the present study, based on heat exchanger requirement, parametric study for the air-side is considered with larger heat transfer and lower frictional factor as the target response using the Taguchi method. Also, a statistical concept Grey relational analysis is used for combined optimization considering all target responses at one time. Experimental suitable

correlations are used for the 27 orthogonal runs. Investigation revealed the highest 47.06% fin pitch, 37.24% fin pitch, 25.46% air velocity, and 23.9% fin thickness contribution ratio for the target response of friction factor, TPF, heat transfer coefficient, and Colburn factor respectively. GRG gives an optimum set of design parameters for a wavy fin and tube of fin pitch of 3.5mm, the number of tube row 3, waffle height 2.2mm, fin thickness 0.15mm, air velocity 5m/s, longitudinal tube pitch 19.6mm, and transverse tube pitch of 24.8mm, at which TPF is maximum while the friction factor is minimum. Hence, an improved heat transfer performance design of a wavy fin and tube heat exchanger is achieved using the above techniques.

In the subsequent experimental investigation, for thermal improvement, passive inserts of twisted turbulator/tape inserts (TTI), Perforated twisted turbulator/tape inserts (PTTI) are used. In this work, the optimized dimension of wavy fin and tube heat exchanger is used. The energy, Exergy, and Economic sustainability effect of modified inserts with prepared water-based ternary hybrid nanofluid (THNF) are investigated. The 3E's (Energy, Exergo-economic), are investigated with a control flow parameter. Experimental results revealed that turbulator inserts (TTI, PTTI) with nanofluid enhance the thermal and hydraulic performance of the compact air heat exchanger. The turbulator inserts of PTTI and TTI in plain tubes using 0.12% (v/v) of THNF results in the highest 28% and 19% heat transfer, 80% and 50% friction factor, 49.4% and 34.4% exergy change, 17.8%, and 12.7% entropy, and higher sustainability index at lower Reynolds number, respectively. Meanwhile, the turbulator inserts of PTTI and TTI in the tube core require 2.6 and 2.1 times, 2.07 and 1.8 times higher CO₂ discharge and operating cost compared to plain tube. PTTI with 0.12% (v/v) THNF as working fluid and tube insert should be preferred due to its PEC ranges of 1.075-1.04.

To use the perforated twisted turbulator inserts for the application in heat exchanger the exact dimensional and fluid flow selection are investigated. Also in the present

investigation, the effect of PTTI based heat exchanger utilizing nanofluid as working fluid undercooling, turbulent flow model has been investigated numerically. Parameters perforated pitches (20mm – 40mm), 0.12%(v/v) THNF at different flow conditions (3800-8150), and perforated diameters (2mm - 4mm) variation effects on fluid outlet temperature, Nusselt ratio, Friction ratio, pressure drop, overall thermal performance, CO₂ discharge, and HX_{OC} have been investigated. This work also focuses on design optimization with three different factors and three levels for higher HTC (Heat transfer coefficient) and minimum pressure drop based on the Taguchi-Grey method. CFD output is used as an input value for statistical analysis. According to the results, PTTI in HX successfully achieved overall heat transfer enhancement in the range of 19.2% to 28.5%, but at the cost of pressure penalty of 126% to 163% higher than the plain tube. Critical Reynolds number 6000, above which PTTI in HX is least suitable for heat transfer enhancement as fluid velocity dominates over heat transfer and 1.7 to 2.5 times higher carbon discharge to the environment and higher HX_{OC}. Preference sets of geometrical and fluid parameters are obtained using Grey analysis. Based on statistical analysis, in the considered levels, a group of parameters to attain higher HTC and minimum pressure drop are lower Reynolds number 3800, the perforated pitch of 20mm, and a perforated diameter of 4mm. These suitable optimized dimensions were used for the experimental investigation.

For practical application, the experimental study investigated the utilization of preheated Methyl ester orange blend, MEOB of D-30%OPB biodiesel (30% Methyl ester and 70% diesel) blended biodiesel as a renewable fuel to the diesel engine. The orange peel methyl ester is a sustainable, renewable, toxic less, alternative fuel produced from the transesterification of orange peel oil. Blended biodiesel and diesel are preheated to a temperature ranging from 30 – 43°C using the heat extracted from the coolant waste from a preheating section (PHS). Coolant energy is dependent upon the engine load. Preheated diesel

and blended biodiesel are tested in a diesel engine at different loading conditions at a fixed speed 1500 RPM to evaluate the engine performance (brake thermal efficiency (BTE), brake specific consumptions (BSFC)), exhaust emissions (HC, NO_x, and CO), and fuel energy distribution. Results are obtained with the engine load variation of different part loads. Results revealed that preheating of fuel causes better fuel spray and combustion characteristics which significantly improves the BTE, and reduces BSFC, HC, and CO emissions with increased CO₂ and NO_x emissions. Optimum performance obtains at 5.6kW load conditions. At 5.6kW loading, with preheating (WPH), BTE of D-30%OPB biodiesel increased by 3.3%, and diesel by 3.2% than unheated fuel. BSFC, HC, and CO emissions of preheated D-30%OPB biodiesel and diesel at 43°C, 5.6kW load conditions are reduced by 7.9% and 8.4%, 3.9% and 5.2%, 3.6%, and 4.4% respectively compared to unheated fuel. Energy utilization revealed a maximum of 6.6% and 6.1% waste energy of coolant is utilized to preheat the D-30%OPB biodiesel and diesel at 5.6kW load conditions, respectively. Therefore, an efficient engine is possible if the waste energy of engine coolant is utilized.