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Numerical simulation of diesel engines EGR cooler

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ABSTRACT

This article investigates the effect of using three nanofluids as exhaust gas cooling fluid in an EGR cooler. Reducing the exhaust temperature of diesel engines can reduce environmental and thermal pollutants. In a conventional 3-liter engine in all kinds of vehicles, 20 to 40 kW of its 115 kW power is being wasted. The engine shell temperature rises to 600 degrees Celsius. Exhaust gas recirculation can recover a part of it. Exhaust gas recirculation can recover thermal energy by exhaust gas recirculation method by charging a thermal energy storage tank to feed a diesel engine in cold start.Many researchers have simulated natural convection in the nanofluids. The innovation of the current research is the use of 61 tubes inside the small heat exchanger that is cooled by the discussed nanofluids in the exhaust gas recirculation system of the diesel engine that works with the paraffin phase changer and the exhaust gas recirculation rate is 60% to Reduce of environmental pollution and smoother operation of diesel engine. The inlet is steady state turbulent. The thickness of the inner tubes is considered close to zero. The shell is adiabatic. Both of them exit the heat exchanger under pressure. Three nanoparticles of diamond, silicon dioxide, and copper are considered. This numerical simulation has solved the continuity equations, energy, Navier-Stokes, the pressure drop along the pipe, flow, and rotation equation, kinetic energy disturbance, and energy loss rate equation. The results showed a higher pressure drop for the silicon dioxide-ethylene glycol nanofluid. Silicon dioxide-ethylene glycol nanofluid has a higher Nusselt number, slightly different from other nanofluids. Also, Copper ethylene glycol has a lower Velocity among nanofluids.

1. Introduction

Industries that use heavy diesel engines [1-5] use the heat exchanger as a cooling part [6] Reducing the exhaust temperature of diesel engines can reduce environmental and thermal pollutants. [7-10] Many researchers have simulated natural convection in the nanofluids. [11-15] Mathematical modeling of the suggested mass fractions compounds table, proportional to the exhaust gas recirculation rate. [16-17] Neeraj R. Koshta et al worked on dealing with the sonochemical synthesis of finely dispersed reduced graphene oxide–TiO_2 (rGO/TiO_2) nanocomposites with successful immobilization of TiO_2 nanoparticles on rGO.[18]. In an experimental study by Akash, the results reported a maximum of 25% improvement in Al nanofluid. [19-22]. Pantzeli et al. [23-24] showed that the use of nanofluid will be beneficial only when viscosity increases and is not limited to the turbulent flow regime. Peyghambarzadeh et al [25] showed that by adding 1% aluminum oxide to nanofluid, the Nusselt number can be increased by 40%. This result was obtained from an experimental study by increasing the water circulation rate (increasing the water flow rate) inside the car radiator. Five different compounds of 0.1% to 1% copper oxide in combination with water-based fluid were investigated in this research. Fan et al. [26] showed that it is possible to improve the convection heat transfer by

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adding carbon nanofiller to the phase change paraffin. This work was done by reducing the phase change enthalpy in a numerical study with laminar flow. In this type of heat exchanger, Carbon nanotubes are installed with multi-layered walls, and the thermal energy storage tank is made of carbon nanofibers. Johnson [27] showed that in a conventional 3-liter engine in all kinds of vehicles, 20 to 40 kW of its 115 kW power is being wasted. Exhaust gas recirculation can recover a part of it. The engine shell temperature rises to 600 degrees Celsius. Schatz [28-30] has presented the necessary concept to recover thermal energy by exhaust gas recirculation method by charging a thermal energy storage tank to feed a diesel engine in cold start. In this research, it is shown that the heat of the engine before turning off is saved and used for better engine start in cold environments. Not many methods have been proposed to improve the heat exchanger with nanofluid or by optimizing the geometry design. Combine these two areas of work besides cooling and exhaust gas recirculation is the novelty of the current research. The returning system can recycle heat energy. As in Fig 1, heat that the heat exchanger takes exits the oil circuit and takes it to the tank carrying the phase change material. This research uses a flat heat exchanger (plate) and water-copper oxide nanofluid (4% copper oxide) has been done experimentally. A 3.8% improvement in heat transfer rate by only adding 2% nanoparticles copper to ethylene glycol base fluid has been obtained in this research. [31-34] Heidar Sadeghzah, and Marc A Rosen [35] showed that by designing a multi-subject algorithm on important variables in heat exchanger geometry design. It is possible to reach the design of an optimal heat exchanger. Miqdam T Chaichan, and Shaimaa H Kamel, showed that nanoparticles such as aluminum oxide and titanium dioxide with five different volume fractions can be mixed with paraffin to store or dissipate more heat. [36] Sarkar and Tarodia [37] showed that volume dispersion is important in the performance of nanofluid to such an extent that, cooling and second laws efficiency, decreases. Barry and Nisar Hossein [38], showed that 50% of the working load of the engine is always being wasted, and they were 18% of the system's output. In addition, they showed that at a working pressure below 30 atmospheres, parallel arrangement, and higher pressure, sequential arrangement will be beneficial to obtain higher power. Usman Rahman [39-45] showed that for the numerical simulation k-Ɛ model is more suitable for high Reynolds numbers near a wall. This research was carried out by investigating the Ansys Fluent with pure water cooling fluid. Anderson and Nation [46] presented a special design for recovering heat energy that is being lost, which has two separate cooling fluids, in two separate circuits and with different pressure and temperature. A heat exchanger and a molten salt energy storage tank were placed between these two circuits.

2.Mathematical model

Geometry designed in the Ansys design modeler and c omputational meshing made with Ansys meshing are given in Fig 1, 2, and 3.

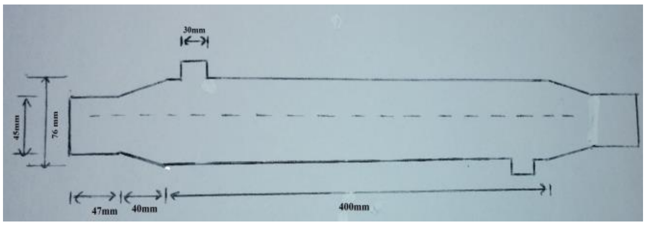

Fig. 1. Dimensions of studied heat exchanger geometry (Property of author(s))

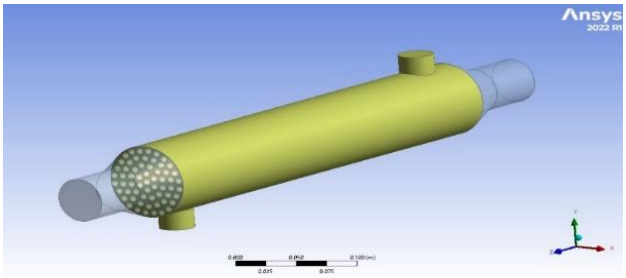

Fig. 2a. Shell side (Property of author(s))

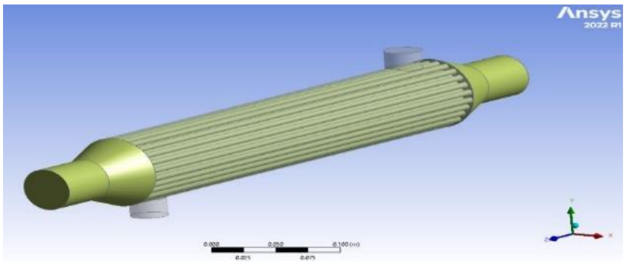

Fig. 2b. Tubes side (Property of author(s))

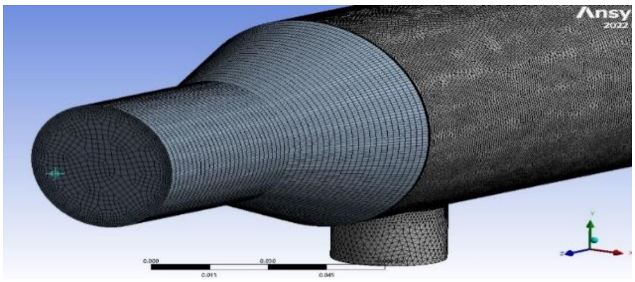

Fig. 3. Mesh network (Property of author(s))

60% R_{EGR} was used for this numerical work. (Highest R_{EGR} rate with considering all exhaust gas constituents) [16]

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Table I. Exhaust gas compositions proportional to the EGR rate [16]

R_{EGR} [%]	Y_{O2}	Y_{CO2}	Y_{H2O}	Y_{N2}
0	0/1839	0/043	0/0164	0/7564
20	0/1718	0/0536	0/0205	0/7539
40	0/1519	0/0711	0/0272	0/7496
60	0/1126	0/1055	0/0403	0/7413
80	0	0/2043	0/0781	0/7175

Equations governing the problem are:

$$\partial\rho\partial t + \boldsymbol{\nabla}\cdot(\rho u) = 0 \qquad [38]\ (1)$$

$$\frac{\partial \rho \mathbf{u_i k}}{\partial \mathbf{x_i}} = \frac{\partial}{\partial \mathbf{x_i}}\left[\left(\mu + \frac{\mu_i}{\boldsymbol{\sigma_k}}\right)\frac{\partial \mathbf{k}}{\partial \mathbf{x_i}}\right] + G_k - \rho\varepsilon \qquad [39]\ (2)$$

$$\frac{\partial \mathbf{u_i} T}{\partial \mathbf{x_i}} = \rho\frac{\partial}{\partial \mathbf{x_i}}\left[\left(\frac{\mathbf{v}}{p_r} + \frac{\mathbf{v_i}}{\mathbf{p_{r_j}}}\right)\frac{\partial T}{\partial \mathbf{x_i}}\right] \qquad [40]\ (3)$$

$$\rho(T) = \frac{P_0}{[(\Sigma_i \frac{y_i}{M_i}) R_g T]} \qquad [16]\ (4)$$

$$\mu(T) = \Sigma_i y_i \cdot \mu_i \qquad [16]\ (5)$$

$$\lambda(T) = \Sigma_i y_i \cdot \lambda_i \qquad [16]\ (6)$$

$$C_P(T) = \Sigma_i y_i \cdot C_{Pi} \qquad [16]\ (7)$$

$$\mu_i = \sum a_{i,j} \cdot T^j \qquad [16]\ (8)$$

$$k_i = \sum\nolimits_j b_{i,j} \cdot T^j \qquad [16]\ (9)$$

$$c_{pi} = R_g \cdot \sum\nolimits_j c_{i,j} \cdot T^j \qquad [16]\ (10)$$

$$Nu = \frac{hL}{k} \qquad [16],\ (11)$$

$$f_{laminar} = \frac{64}{Re} \qquad [42],\ (12)$$

3. Numerical model

The inlet is steady state turbulent. The thickness of the inner tubes is considered close to zero. The shell is adiabatic. Both of them exit the heat exchanger under pressure. The boundary conditions are [16]:

For inlet of exhaust gas:

T_{in}=523/15 k
u=v=w=33 m/s→ -r ≤ x ≤ r, -r ≤ y ≤ r, z=0
For the outlet of exhaust gas:
P_{out} , T_{out} → -r ≤ x ≤ r , -r ≤ y ≤ r , z=L
Wall side of the tubes:
T=T_W
u=v=w= 0 → 0 ≤ z ≤ L, x = ±r, y = ±r

At different flow rates of the pure water coolant, The observed difference is a maximum of 5%, which indicates the validity of the results obtained from the present simulation.

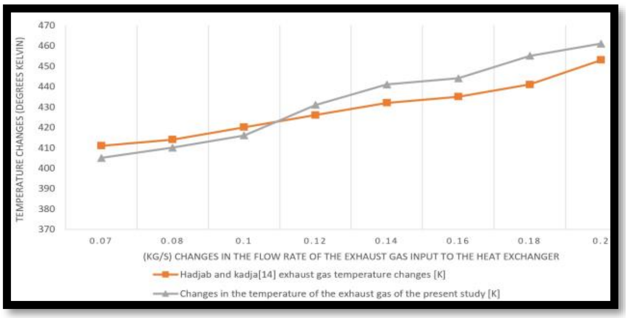

Fig. 4. Validation chart (Property of author(s))

The figure below shows the change in the exhaust gas temperature from the numerical simulation of the current research in different mesh networks. Numerical simulation showed that when the mesh number of the network exceeds 10 million, the same result is obtained in three different mesh sizes, indicating the mesh's independence from the computing network in the numerical simulation of the present study.

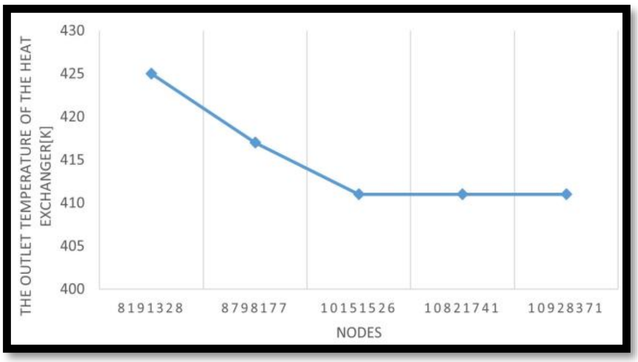

Fig. 5. Diagram of mesh independence of computing network (Property of author(s))

4. Results

Temperature changes are not noticeable. Because the exhaust gas outlet temperature has not changed almost by changing the coolant from pure water to the mentioned nanofluids.

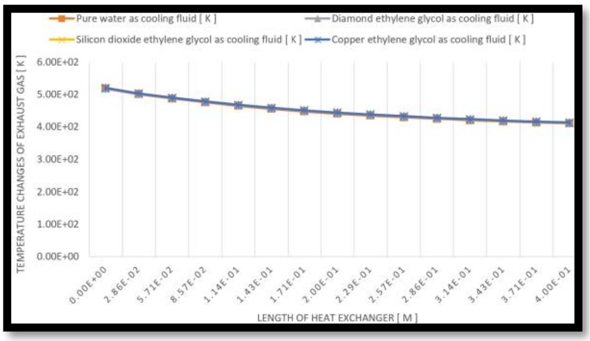

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Fig. 6. Exhaust gas temperature changes according to heat exchanger length changes (Property of author(s))

The comparison of nanofluids shows that the pressure drop of silicone dioxide-ethylene Glycol is higher than copper-ethylene glycol and diamond-ethylene glycol. This result shows the better heat transfer properties of silicon dioxide ethylene glycol nanofluid.

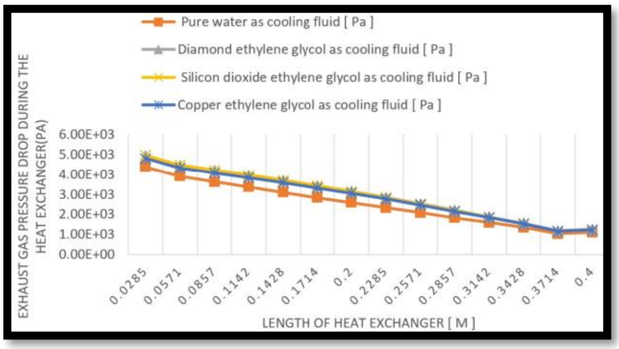

Fig. 7. Changes in exhaust gas pressure (Property of author(s))

Nusselt number (Nu_L) [39, 40] was calculated by extracting changes from Fluent software and calculating the specific heat values (variable with temperature) [16], Then The amount of energy was calculated with a known flow rate and specific heat formula. The convection has been calculated. The conduction coefficient is also obtained [16]. Nusselt number change charts show a higher Nusselt number for SiO_2-EG. This result shows the better heat transfer properties of silicon dioxide ethylene glycol nanofluid.

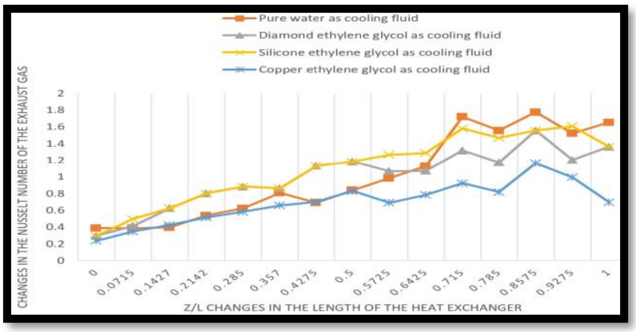

Fig. 8. Changes in the Nusselt number of the exhaust gas (Property of author(s))

In the figure below, calculations of the amount of friction with the help of Excel software and output data from Fluent showed that if pure water is the cooling fluid, it has a lower friction coefficient than the current nanofluids. Therefore, in the case where pure water is used as a coolant, less sedimentation occurs in current nanofluids. It is effective in increasing the life of the heat exchanger in the long run.

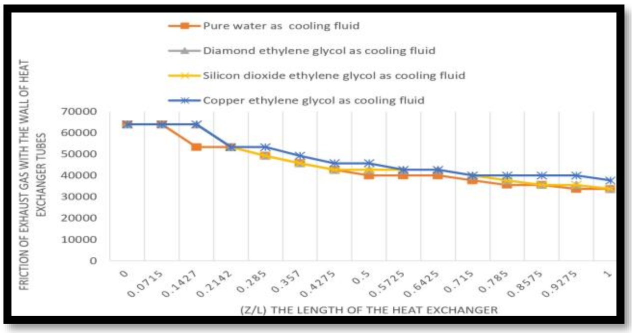

Fig. 9. Friction coefficient changes according to heat exchanger length changes (Property of author(s))

Velocity graphs [38,39,41,42] have shown that the exhaust gas with water as cooling fluid passes with lower velocity. Output data from Fluent showed, that if the exhaust gas is cooled with copper ethylene glycol in the heat exchanger, it passes through the heat exchanger at a lower velocity(Compared to other nanofluids), so it can have more opportunity to cool the exhaust gas.

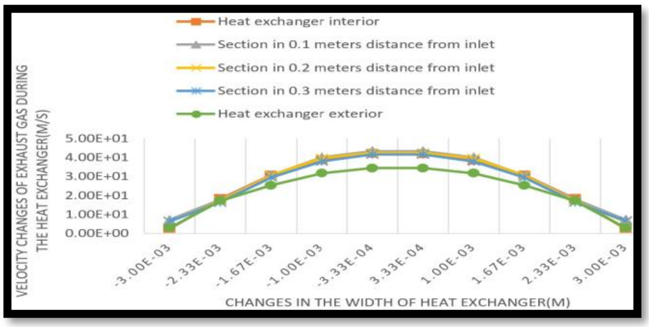

Fig. 10. Velocity profile of gas for pure water (Property of author(s))

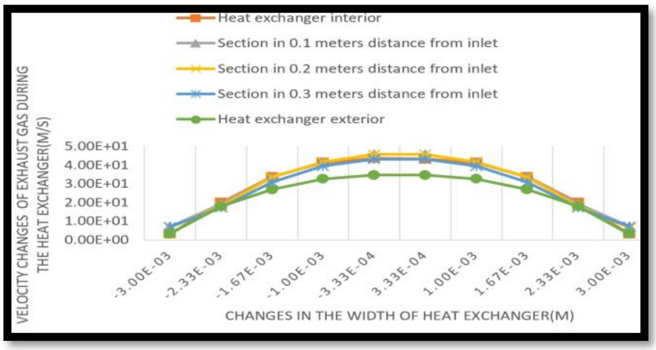

Fig. 11. Velocity profile of gas for di-eg (Property of author(s))

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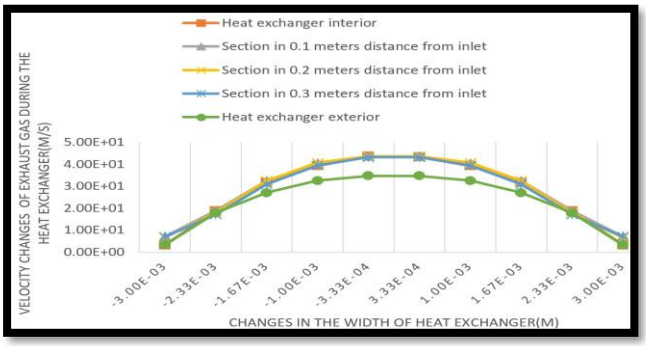

Fig. 12. Velocity profile of gas for si-eg (Property of author(s))

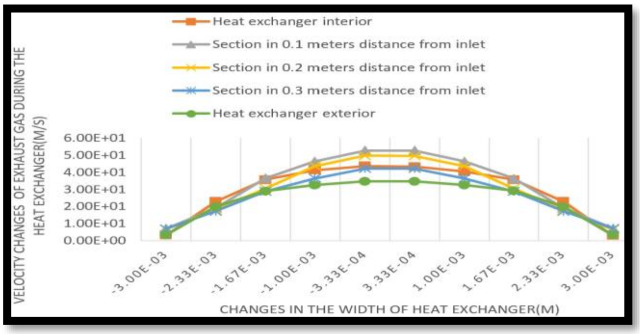

Figure 13. Velocity profile of gas for cu-eg (Property of author(s))

5. Conclusion

1) Examining the contours and pressure profiles for silicon dioxide-ethylene glycol nanofluid shows the better heat transfer properties of silicon dioxide-ethylene glycol nanofluid.
2) In the (Nu_L) diagram, silicon dioxide-ethylene glycol nanofluid is better. The higher the forced convection, the more energy the exhaust gas recirculation system will store in the phase change paraffin tank.
3) Although the amount of friction of the exhaust gas is not very important considering its discharge into the atmosphere. But due to the effect of temperature changes on it, it has been investigated and its diagram shows the lower friction of the gas cooled by pure water.
4) Examining velocity graphs has shown that Copper ethylene glycol has a lower velocity among nanofluids.

List of Symbols

cu-eg	Copper- ethylene glycol
di-eg	Diamond-ethylene glycol
k_i	Conduction function
P_o	Initial pressure [Pa]
R_g	Ideal gas constant
R	Radius [m]
si-eg	Silicon- ethylene glycol
v	Velocity along with j
w	Velocity along with k
Y	Volume fraction [%]

Greek symbols

ϵ	Turbulent dissipation rate *[J/kg.s]*
$\lambda(T)$	Convection function [w/ m^2. k]
$\mu(T)$	Viscosity function
μ	Viscosity [kg/m.s]
$\rho(T)$	Density function
∂	Partial differential
σ_k	Turbulent Prandtl number

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