

Design and Analysis of a Fuel Preheating Device for Evaluation of Ethanol Based Biofuel Blends in a Diesel Engine Application

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ABSTRACT

With the alarming increase in vehicular population, there is depletion of fossil fuel availability. Hence to overcome the difficulties, alternative fuels are tested and used in parts of the world. One of the difficulties with usage of alternate fuels is their high viscosity in comparison to fossil fuels. To overcome this, preheating of biofuel is a good option as it makes the fuel less viscous. In our research, we have used a helical coil heat exchanger to preheat the inlet fuel using the engine's exhaust gas, making the system more sustainable since no external energy is used. In order to evaluate the effectiveness of preheating device a simulation study has been carried for the ethanol based biofuels. For simulation work, a set of boundary conditions has been arrived based on the experimental analysis. The results from the experiment such as velocity of air and fuel inlet were utilized as input for simulation work. The simulation study was carried out using Fluent solver, to compare the effectiveness of proposed preheating device for the ethanol blends (E20 and E30). The simulations results are obtained for various temperature and pressure profiles for air outlet, fuel outlet & outer wall of preheating device. These were analyzed and a comparative study between ethanol blends. The result shows that the temperature profile of E30 is slightly higher than E20, this is solely due to viscosity of E20 being higher than E30. With the preheating device the fuel's viscosity reduces which helps in better fuel flow and improved atomization. Also the preheating of ethanol leads to improve vaporization characteristic and hence the improved combustion can be accomplished. Hence preheating is a viable solution for in biofuels. The focus of the research is to validate the effectiveness of preheating device.

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INTRODUCTION

Today, an alarming increase in vehicle population has resulted in excess pollution and ways to combat it are being looked at in all fronts. At this point of time, the conventional fossil fuels like petrol, diesel, etc cannot be relied upon not only because of high content of pollutants but also because of high rate of depletion. Under such a scenario, new ways of fuel combustion, hybrid mix of fuels and better equipment are required to increase efficiency thereby reducing emissions. A complete isolation of petrol and diesel from the markets are not possible since most vehicles are already equipped with engines that utilize fossil fuels only. Hence an economical solution will be to make minor modifications to the engine such a way that it uses blends of natural renewable fuels and fossil fuels. Another approach would be to reuse the unnecessary residual products such as exhaust gas to enhance the efficiency of conventional engines that exist [1, 2, 3].

Fuels are any substance that when reacted upon gives energy in the form of heat. Fuels can be classified into two types: renewable and non-renewable. All fossil fuels contain carbon as one key component and they are a product of geological processes on the remains of organic matter over a prolonged period of time. Fossil fuels can be utilized to provide heat when burnt in the presence of air or with

oxygen derived from air. This energy is then either directly used to power vehicles, furnace, etc or is then made to produce steam which generates other forms of energy. Diesel fuel requires highly compressed hot air in order for combustion to occur; hence diesel fuel can only be used in CI engines. There are new forms of diesel that are being developed and are trying to be implemented for usage in the present vehicular setup and in newer hybrid models [4, 5].

Ethanol being an oxygenated renewable bio fuel, it has a lot of advantages over fossil fuels such as the ability to reduce particulate emissions. Having a lower carbon foot-print, on combustion ethanol shows lower CO₂ emissions as well [6, 7]. Ethanol addition to diesel fuel could be an important method to reduce the amount of NO_x in the exhaust gases of diesel engines [8, 9]. Higher thermal efficiency and an increased engine power have been reported when biodiesel is blended with diesel. However, there is a dip in power when neat form of the same is used [10]. Further an ethanol blended diesel is capable of absorbing moisture and hence is very effective in cleaning the fuel system. Ethanol has a higher octane level compared to other fuels; hence by blending it with diesel/gasoline, it replaces other environmentally harmful components present in them [11].

Higher viscosity of any fuel leads to bigger drops formation from the atomization system. Hence preheating the fuel before it enters the injector will reduce its viscosity, promote uniform flow and improve the overall injection process [12, 13, 14, 15]. Ethanol possesses poor auto ignition combustion due to lower cetane number and high quenching effect. According to Dinesh and Mohanan preheating of fuel blend improves the viscosity sharply and also improves the emission and performance of the engine [16].

By preheating the fuel blend, density of the biodiesel decreases and increases the volatility which leads to a desirable effect on fuel atomization and combustion. This will further increase the oxidation of ethanol-diesel blend in the cylinder and decrease the CO emissions arising due to incomplete combustion in the chamber [17, 18, 19]. The experimental analysis done by Shahir et al. shows that 20% ethanol blended diesel gives low emission and higher efficiency since optimum mixing ratio is achieved when compared to 10% and 30% ethanol blended diesel. The 20% blend of ethanol diesel fuel significantly decreased the concentration of smoke, hydrocarbons and carbon monoxide in exhaust gas. Hence we have opted to test our device by using 20% and 30% ethanol blended diesel and comparing the results with diesel fuel [20]

Many authors have done extensive research on preheating devices and the benefits of ethanol blends. As the ethanol fuel has tendency to lose certain amount heat during initial stage of combustion due to its latent heat of vaporization. High vaporization enthalpy poses a difficulty especially at lower loads as compared to higher loads where the loading conditions provide the additional energy required. Because this ignition delay of the ethanol combustion is increase as compare to the diesel. By means of preheating the ethanol the increased temperature of fuel leads to vary the vaporization and ignition delay characteristic. But there is a gap in the literature which has become our motivation for study. Two major gaps have been found; firstly fuel preheating hasn't been performed for ethanol blends and the other gap being a lack of simulation study done. Hence we have coupled fuel preheating with alternate fuels. The alternate fuel used is a blend of ethanol and diesel. The ethanol percentages taken are 20% and 30% which are E20 and E30 respectively. These blends are in particular chosen due to their optimal mixing ratio.

Within this context this work features the CFD simulation of the preheating device for the ethanol blends. The simulation work is done on Fluent model in ANSYS. Based on this simulation work, effect of preheating the ethanol fuel is studied and this ensures to improve the vaporization characteristic of ethanol blends. Simulation is based upon the velocity of air and fuel inlet obtained through experimentation. Three parameters are taken, which are then compared on a fuel as well load basis to provide us with a wide area of study. The parameters are temperature of fuel outlet, pressure drop of fuel and temperature of air coming out after heating the coil.

FUEL PREHEATING DEVICE AND ITS DESIGN SPECIFICATIONS

The preheating device was designed using Solid Works; the design was constructed with keeping the specifications of the Kirloskar TAF1 engine. The designed preheating device is supposed to connect the one into the exhaust gas passage and other is end is open for the exhaust gas flow out after heating the coil passage. The coil has the fuel inlet and outlet passage for the fuel flow. By means of this device the waste heat is recovered and utilized in the fuel heating to improve the combustion characteristic.

Since the whole research study is based upon the experiment done on said engine. Based on the above design specifications, the preheating device is created with specification shown in [Table.1](#) and then drafted. The outer shell which encloses the copper coil is made of galvanized iron, the copper coil in particular is chosen, due to its high thermal conductivity and economic feasibility. Designed preheating device shown in [Figure 1](#) consists of fuel passing coil pipe inside it. The copper coil mesh and outer GI case which hold the coil is shown in [Figure 2](#) and [3](#) respectively.

Table 1. Design Specifications

S.No	Parameter	Specifications
1	Length of device	490.0mm
2	Coil Diameter	11.0mm
3	Diameter of inlet	30.4mm
4	Coil Thickness	2.0mm
5	No of turns in coil	10(turns)
6	Device make	Galvanized Iron
7	Coil make	Copper

Simulation Conditions for the Preheating

Certain boundary conditions are necessary for the simulation work to be done. For this purpose, experimentation is done and through experiment we are able to obtain the needed input values, these are as follows:

- Air inlet temperature
- Air inlet velocity
- Fuel inlet temperature
- Fuel inlet velocity
- Fuel inlet pressure

For the simulation process, we have assumed that the mass flow rate of air doesn't change between entry and exit of the combustion chamber as the mass flow rate of exhaust particles can be considered to be negligible when compared to the exhaust air. We have also assumed that the fuel outlet is open to the atmosphere for the flow to take place. Simulation is done by using fluent solver which is a part of the ANSYS workbench.

The setup for our simulation of our preheating device employs the transient state with 18 time steps, with each step size being 10. The step size is taken so as to match the real world experimental set up. The other major component of the fluent solver is to define which

type of equation is chosen. This is the equation which is used to simulate viscous flow. Mesh details and fuel properties employed in simulation is listed in Table.2 and 3 respectively.

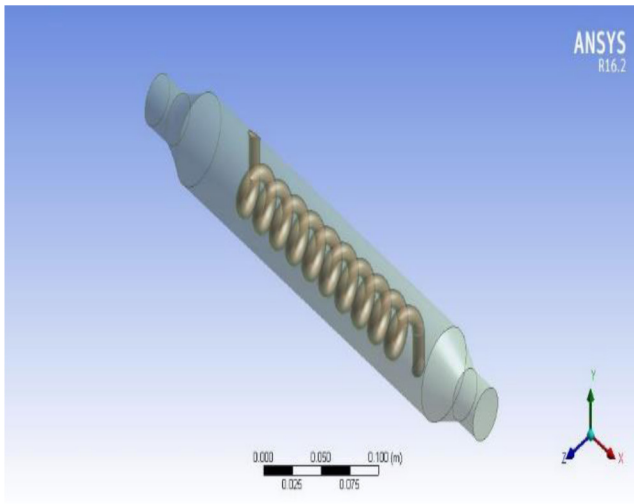


Figure 1. Isometric view of designed preheating device

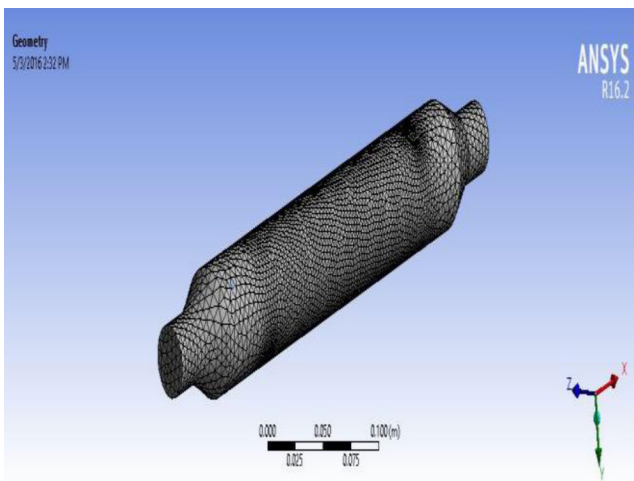


Figure 2. Mesh file of outer GI casing with copper coil inside

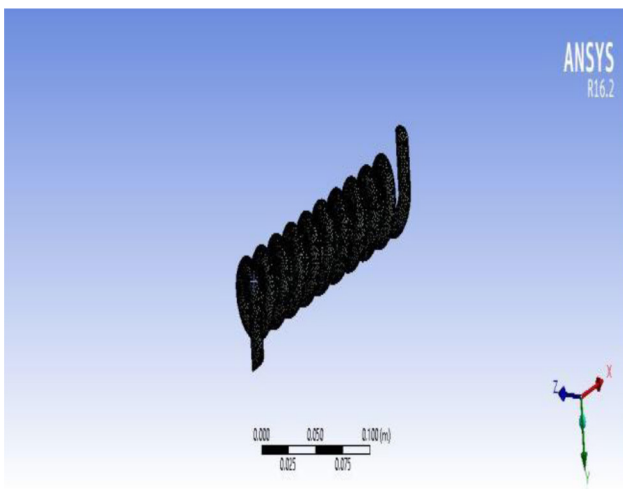


Figure 3. Internal view of designed copper coil mesh model

Table 2. Mesh details of simulation

S.No	Parameters	Specifications
1	Total Nodes	128464
2	Total Elements	473528
3	Mesh Metric	Orthogonal Quality
4	Relevance	Fine
5	Transition	Slow

Table 3. Fuel properties employed in simulation

S.No	Fuel Type	Diesel	E20	E30
1	Density (kg/m ³)	860	835	817
2	Specific heat (J/kg K)	2090	2164	2201
3	Kinematic viscosity (cSt)	2.3	1.9	1.7
4	Thermal Conductivity (W/mK)	0.14948	0.12005	0.1117

SIMULATION RESULTS AND DISCUSSION

The designed preheating device is simulated for the different fuel blends such as E20 (20% of ethanol and 80% diesel) and E30 (30% of ethanol and 70% diesel). The simulation results of temperature and velocity profile is discussed in the following section.

Figure 4 and 5 shows the temperature contour of exhaust gas at the outlet of preheating device for E20 and E30 blends respectively. The temperature of the inlet air being supplied to the device for E30 is greater than E20. From these two figures it's seen that the gas outlet temperature range is higher in the case of E30 when compared to E20. The temperature difference between inlet and outlet air using E30 is 7.54% greater to than when E20 is used as fuel. This 7.54% increase is attributed the fact that the specific heat the specific heat of E30 is greater when compared to E20.

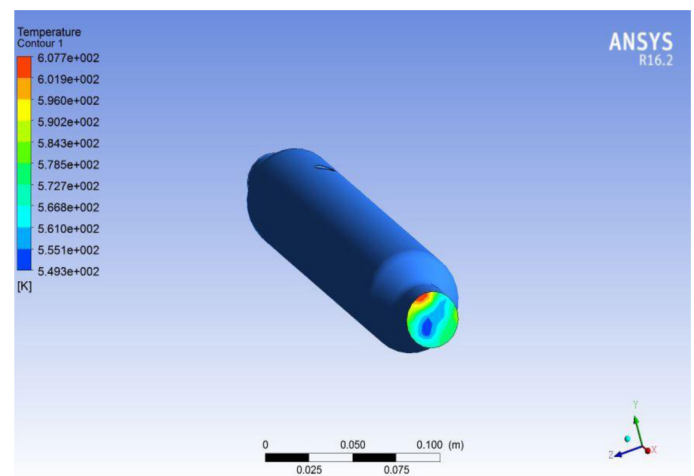


Figure 4. Exhaust gas outlet temperature of E20 from the device