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Effect of fuel temperature on diesel engine performance and emission characteristics for ethanol-diesel blend fuel

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Abstract

The increase of demands to use petroleum products causes rapid depletion of the fuel and becomes very limited and expensive. The two factors to implement alternative fuels in internal combustion (IC) engines are the environmental effects and the energy independence from petroleum-based fuels. High price, limited source of petroleum products, and high level of global warming have directed to searching for renewable fuels. To match the requirements of the demands and to reduce environmental pollutions alternative renewable fuels are very important and attract researchers to study since they are renewable, sustainable, biodegradable, and emit low greenhouse gases. Ethanol is a sustainable power source and is more beneficial than other biofuels since it ensures less pollution to the environment. One of the difficulties with the usage of alternate fuels is their poor fuel properties in comparison to fossil fuels (diesel). To eliminate this, preheating of the ethanol-diesel blend is a good option as it makes the fuel-efficient. The objectives are to explore the effects of fuel temperature on the performance parameters and emission on compression ignition engine run in ethanol-diesel blend fuel at a constant engine speed under varying engine loads. Ethanol-diesel blends were used from 10% of ethanol and 90% diesel (E10) to 40% of ethanol and 60% diesel (E40). Engine performance and emission characteristics were measured and compared with pure diesel fuel mode. Performance improvement and reduction of exhaust emissions were observed using preheated ethanol diesel blend fuel than pure diesel.

Keywords: *Blend, Diesel engine, Emissions, Ethanol, Fuel temperature, Performance, Preheater.*

1. Introduction

The motivation behind internal combustion (IC) engines is the creation of mechanical work from the compound contained in the fuel. Energy is the key for every activity in the current time to simplify working load and to have a better living standard. Due to that, there is a high energy demand [1]. Resources are depleting due to rising energy demand and the cost required to import fuel products are high and always increases [2]. The major limitation of currently used petroleum fuels is that they release air pollutants which cause environmental pollution. Diesel engines are major sources of air pollutants such as carbon monoxide (CO), oxides of nitrogen (NOx), particulate matter (PM), other harmful compounds and create threats for bio-diversity. To reduce the air pollutant problems in using diesel fuel, alternative renewable fuels like ethanol are found more attractive because of their good environment-friendly nature [3].

Literature shows that alcohol can be effectively used as oxygenated fuel in dual engine operation mode. From the alcohol's ethanol is more common and easily produce and prepares from feedstocks. Ethanol fuel is the least expensive and cost-effective energy source than other biofuels and it can be easily prepared by every country. Corn, sugar cane, or grain grows in almost every country which makes the production economical compared to fossil fuel. Diesel and ethanol fuel blends were studied and found to be technically practicable [3,4].

The initial idea of using ethanol in diesel engines was performed in South Africa in the 1970s and continued in Germany and United States during the 1980s. The beginning of oxygenated compounds for example ethanol into diesel fuel is one of the alternative ways to reduce smoke emission [5-7]. Ethanol can be prepared through the processes of distillation and fermentation since it does not occur naturally. While the energy-based use of ethanol fuel is new, it has been few for our lives in a particularly delayed interval. Ethiopia possesses different sugar industries including Finchaa Sugar Factory, Metehara, Wonji Showa, and others. These factories are producing ethanol alcohol [8].

Fuel blending is the process of mixing more than one fuel to get desired chemical output. In contrast to gasoline, diesel fuel isn't easily mixed with ethanol under all conditions. The dissolvability of ethanol and diesel fuel is depending on the hydrocarbon content, wax content, and temperature in which diesel fuel operates. Especially problematic states of low temperature or potentially water contamination. Both can bring fuel to non-homogeneous because of phase separation. If the operating temperature is low emulsifier and co-solvent or solubilizer can be used to remove fuel separation [3-6]. The addition of ethanol in diesel fuel produces the diesel fuel to change chemical-physical properties such as decreases of cetane number, thickness, low heat content, pour point and flashpoint, etc. change the spray attributes, burning performance, and engine exhaust emissions [7,9-11]. The cetane number of ethanol and diesel fuel is a vital fuel property in diesel engine operation. The cetane number is the number that measures the ignition ability of fuel at low temperatures. It is an important fuel property for diesel engines. It affects engine start-ability, peak cylinder pressure, emissions, and combustion noise. A high cetane number confirms good cold starting ability, long engine life, and low noise. The cetane numbers of used blend fuel are based on the percentage of fuel and additive properties used in the blends. Addition of 10% by vol. ethanol to the diesel fuel marks a reduction of about 7.1-unit in the cetane number of the subsequent blend [12]. Having more Cetane number produce better engine performance and fewer emissions but if it becomes less which cause poor engine operation [6].

Ethanol cetane number is less than 15 whereas, diesel fuel is above 40. Lesser cetane number means longer ignition delays, needs more time for fuel to vaporize before combustion starts [3,6]. With the addition of ethanol reduction of viscosity and energy content [3,12], reduction of BTE and increase of BSFC [5,9], and reduction of NOx, CO, particular matter (pm), and smoke [5,9,12] were discussed by researchers.

Besides, the gap observed in using ethanol on diesel fuel is as the amount of ethanol increases phase separation formed and the fuel not mixes totally. As the ethanol percentage increase, it reduces energy content below pure diesel fuel. The low temperature of fuel requires more vaporization time to produce desired power. Due to the addition of ethanol unburned hydrocarbons increase, brake power reduces, and brake-specific fuel consumption increases.

From different perspective blend fuel preheating is the best way to solve the most common problems in using ethanol as fuel. The above reasons lead to raise the idea of preheater device design. In this research work, to achieve better engine performance different ethanol-diesel blends (E10 to E40) at optimum temperature were used. In this research work, ethanol is blended with diesel fuel with volumetric composition from 10% to 40% outside using a high-speed mixer and add to the fuel tank and then the blend flows through the fuel preheater.

The present investigation is to examine diesel engine characteristics (performance and emission parameters) of preheated ethanol-diesel fuel with different blend ratios at a constant speed of 1700rpm under varying engine loads. Table 1 gives fuel properties of pure diesel and ethanol fuel used during testing.

2. Materials and Methods

The experimental test was performed on a 2.2 kW, single-cylinder, and air-cooled compression ignition (CI) engine with an integrated electric starter motor for starting and applying load. The load varies from no loading to 80%. The full specifications of the engine are given in Table 2.

Table 1: Fuel properties of used fuels.

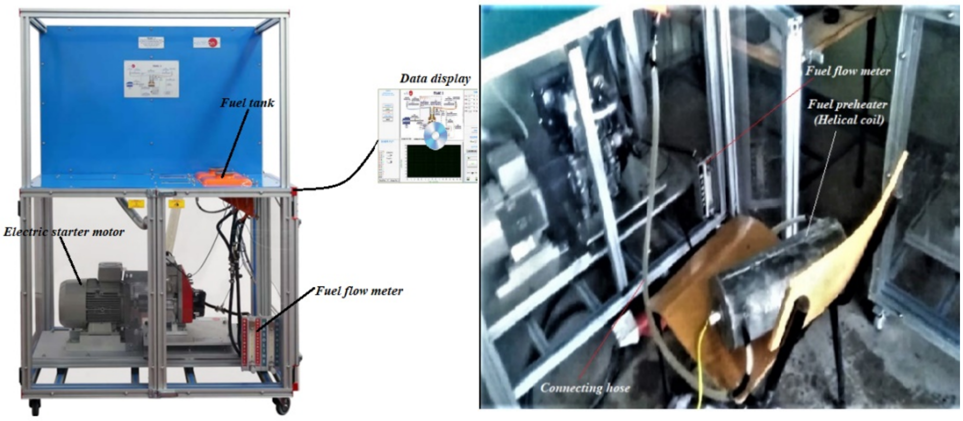
Properties	Diesel ($C_{12}H_{23}$)	Ethanol (C_2H_5OH)
Density kg/m^3	818	772
Cetane number	40-50	8-9
Vapor pressure (Kpa)	0.3	17
Auto-ignition temperature (^{o}C)	254-446	363-365
Kinematic viscosity (mm^2/s @ 40^{o}C)	2-4.1	1.07-1.2
Flash point ^{0}C	38-55	14
Boiling point (^{o}C)	180-360	78-78.5
Flammability limits (^{o}C)	64-150	13-42
Calorific value kJ/kg	36600-42500	21300-26800

Table 2: Engine specifications.

Name of manufacturer	edibon
Type	Single cylinder, 4 stroke CI engine
Stroke and Bore	60mm x 69mm
Engine speed	6000rpm
Rated power	2.2 kW
Displaced volume	224 Cm^3=0.000224m^3
Types of air intake	Naturally aspirated
Cooling system	Air cooling
Compression ratio	21:1

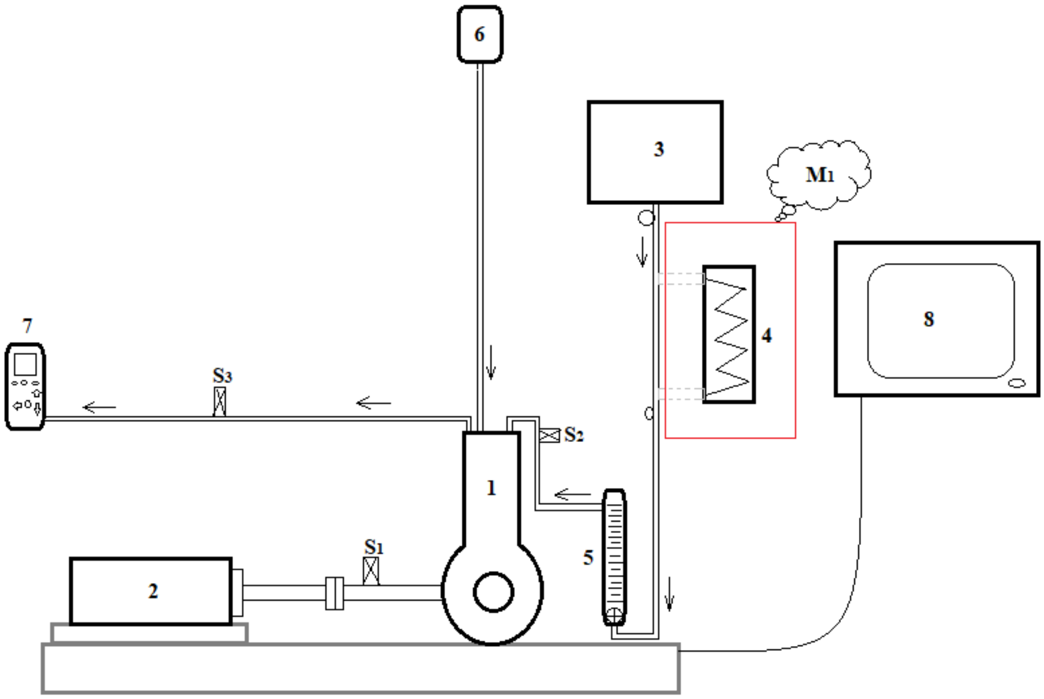
Different integrated sensors and measuring devices are integrated with the engine setup. The conventional engine setup is shown in Figure 1a) and the modified engine setup is given in Figure 1b). The engine performance parameters including brake power (BP), EGT, BSFC, and BTE were recorded and calculated. The detailed schematic diagram of the experimental setup is shown in Figure 2 with all integrated devices. Glass tube fuel flow meter was used to measure the amount of fuel consumed during operation using a stopwatch. Diesel engine performance parameters were calculated by using equations (1)-(3) as stated [8].

The Modified setup consists of a fuel preheater device and its schematic diagram and product are shown in Figure 3 and Figure 4, respectively. The exhaust emissions of the engine were measured by using Kane auto plus exhaust gas analyzer and its photographic view is shown in Figure 5(a). It measures CO, CO_2, HC, and NO_x constituents in the exhaust gas. The exhaust gas temperature sensor measures and show the temperature of the gas on the computer display. Engine BP and EGT are displayed on a computer display as shown in Figure 5(b).



a) b)

Figure 1: Experimental setup arrangement. a) Conventional engine setup. b) Modified (with preheater) engine setup.



1. Test engine	4. Fuel preheater device	7. Exhaust gas analyzer	S_2- Fuel temperature sensor
2. Electric starter motor	5. Fuel flow meter	8. Data display	S_3- Exhaust gas temperature sensor
3. Fuel tank	6. Air filter	S_1- Engine speed sensor	M_1- Ethanol-diesel mode

Figure 2: Schematic diagram of the experimental setup.

The experimental study was performed in two stages. The first effect of varying blend fuel temperature on viscosity was tested and brake-specific fuel consumption (BSFC) results checked to select optimum fuel temperature. And then preheated ethanol diesel blends were used to study emission and performance results.

2.1. Fuel preheater device

Preheating of blend leads to improve vaporization characteristics and hence the improved combustion can be obtained. So, they are a means to improve the usage of ethanol in diesel fuel. In this study, a helical coil type heat exchanger is considered to preheat ethanol-diesel blend fuel to improve the blended fuel properties. Design and manufacturing of helical coil heat exchanger were performed following important design steps and procedures for maximum ethanol percentage (E40) blend fuel. The schematic diagram of the shell and helical coil heat exchanger is shown in Figure 3. In reference to design and simulation results, the required heat exchanger was fabricated in-house as shown in Figure 4. An integrated fuel temperature sensor and glass thermometer have been used to read the fuel temperature. An electric Immersion water heater coil is used which increases the temperature of the primary stationary fluid (water) up desired value. Power on and off switch is used to control fuel temperature. For full specification refer to Appendix A.

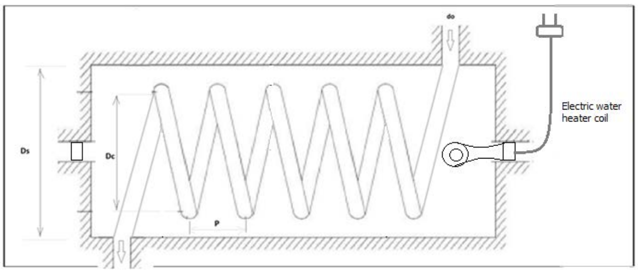


Figure 3: Schematic diagram of shell and helical coil heat exchanger.

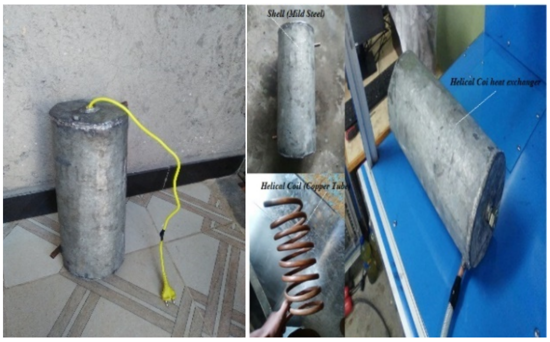


Figure 4: Shell and helical coil assembly.

The heat exchanger aimed to preheat the ethanol-diesel blended fuel (up to 40% ethanol blended with 60% diesel). In the shell helical copper tube coil is placed and through which hot water stayed stationary in the shell. To ensure maximum heat transfer the copper helical coil is fully immersed in the hot water in the shell. The cold ethanol-diesel blended fuel flows through the coil based on the maximum engine fuel consumption flow rate. It is prepared by rough welding of sheet metals and by bending the copper tube to form a helical coil.

Table 3: Kinematic viscosity and density of fuels over temperature.

Fuel preheating temperature (°C)	Kinematic viscosity (mm^2/s)			Density (kg/m^3)		
	Diesel	Ethanol	E40-D60	Diesel	Ethanol	E40-D60
25	3.72	1.35	2.77	830	789	813.8
30	3.3	1.23	2.47	824.8	780.9	807.3
35	3.0	1.15	2.26	821.4	776.7	803.5
40	2.7	1.07	2.05	817.9	772.4	800.1
45	2.48	0.98	1.88	814.4	768.2	795.9
50	2.26	0.91	1.72	810.9	763.9	792.1
55	2.09	0.85	1.59	807.4	759.6	788.3
60	1.92	0.8	1.47	803.9	755.4	784.5

In most current engines the viscosity of used fuels is advisable to be above $2mm^2/s$. Increasing fuel temperature beyond 40^oC reduces the fuel viscosity and density below American society for testing and materials (ASTM) standard. According to ASTM standard, fuel should have a viscosity of more than $2mm^2/s$.

a) 

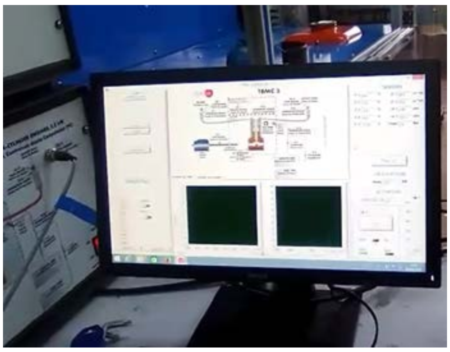
b) 

Figure 5: a) Exhaust gas analyzer and b) Engine performance display and operation adjustment software.

Optimum temperature is selected comparing BSFC and fuel properties for blend fuels. All operating modes, operating conditions, and studying parameters are summarized in Table 4.

Table 4: Experimental test matrix.

Mode of operation	Engine Load (%)	Used fuel	Evaluating Engine Parameters
Diesel fuel	0 – 80% in step of 20%	Pure diesel (D100)	a) Performance parameters: BP, BTE, BSFC, EGT b) Emission Parameters: CO, HC, CO_2, NOx,
1st Effect of fuel temperature (25°C-60°C)	No loading	40% ethanol (E40)	a) BSFC and kinematic viscosity Compared and the optimum preheating temperature is selected
2nd Effect of preheating (40°C) on engine performance	0-80%	E40	b) BP, BTE, and BSFC Compared with and without preheating and identify the best one.
Preheated Ethanol-diesel blend fuel	0 – 80%	E10, E20, E30, E40	a) Performance parameters: BP, BTE, BSFC, EGT b) Emission Parameters: CO, HC, CO_2, NOx Compared the results with a baseline and best blend fuel is identified.

Formulation of Performance Parameter Analysis [8]

$$\dot{V}_f\left(m^3/s\right)=\frac{Volume\ of\ fuel\ consumed}{time\ taken}=0.0036\times\left[\frac{V(ml)}{t(sec)}\right] \quad (1)$$

$$\dot{m}_f\left(kg/hr.\right)=\dot{V}\left(m^3/hr.\right)\times\rho_{fuel}\left(kg/m^3\right)$$

Here, $\dot{V}_f$, $\dot{m}_f$ is volume flow rate and mass flow rate fuel, respectively.

$$BTE_{diesel}\left(\%\right)=\frac{BP}{\dot{m}_{diesel}\times LHV_{diesel}}\times 100 \quad (2)$$

$$BTE_{(ethanol/diesel\,blend)}\left(\%\right)=\frac{BP}{\dot{m}_{ethanol/diesel\,blend}\times LHV_{ethanol/diesel\,blend}}\times 100\%$$

$$BSFC_{diesel}\left(kg/kWhr.\right)=\frac{\dot{m}_{diesel}}{bp} \quad (3)$$

$$BSFC_{ethanol/diesel\,blend}\left(kg/kWhr.\right)=\frac{\dot{m}_{ethanol/diesel\,blend}}{bp}$$

3. Result and discussion

First standard diesel fuel as baseline test was used without preheating. Then the effect of fuel temperature on BSFC is tested and the optimum temperature is selected. Effects of preheated blend ratios were investigated on performance and emission of a compression ignition engine running on ethanol-diesel blend fuels (E10-D90, E20-D80, E30-D70, and E40-D60). The results of diesel engine performance and emissions are compared operating on ethanol-diesel blended with pure diesel fuel mode. The experimental results of performance parameters (brake power, brake thermal efficiency, brake specific fuel consumption, exhaust gas temperature) and emission constitute of CO, CO_2, HC, and NOx emissions were analyzed at various engine loads (0-80%).

3.1. Optimum temperature selection

As the ratio of ethanol increases, phase separation in the blend fuel increase. Besides, the viscosity of blend fuel reduces below neat diesel fuel due to the less viscous property of ethanol fuel. Less energy content of ethanol is one of the limitations to fully use as a fuel. Considering those problems increasing fuel temperature is one means to improve fuel efficiency. Selection of optimum temperature is the primary activity before doing the main test. To select the optimum one, the effect of fuel temperature on BSFC at no loading and fuel viscosity from 25°C to 60°C was tested for E40-D60 blend fuel and the result is shown in Figure 6 and Figure 7, respectively. As shown in Figure 6 results revealed that an increase in fuel preheating temperature caused a gradual decrease of the BSFC for E40-D60 blend fuel in a diesel engine due to the improvements of blend fuel viscosity with increased temperature.

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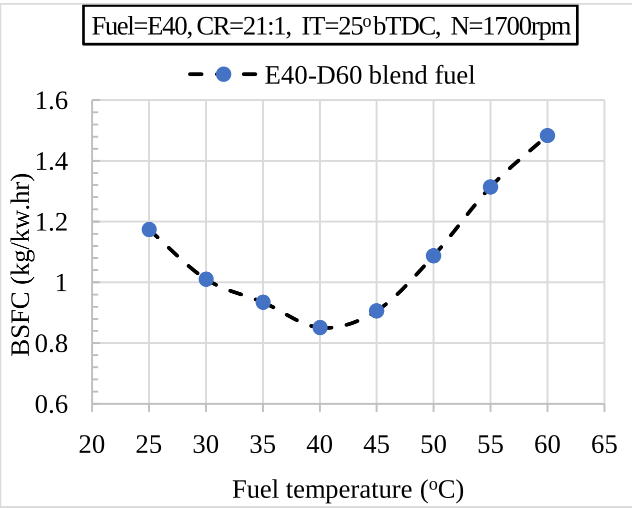

Figure 6: Variation of BSFC with temperature.

However, when the temperature increased further, the viscosity is getting less and less, and this can lead to a more volume fuel sprayed into the combustion chamber with limited ignition timing and causes the lowest ignition delay, which increases brake power. Researchers reported that the lowest possible value of brake-specific fuel consumption is the most desirable [13]. Beyond the limit, the increasing temperature reduces combustion efficiency and power output. So, the BSFC becomes more again.

Also, blend fuel preheating up to 40°C is better to meet the standard lowest viscosity for no. 2 diesel fuel ($2mm^2/s$). Below that it is not advisable to work on conventional diesel engines as it causes burning of fuel at the wrong timing, leakage of fuels, and damage to engine parts [3,5,14]. Viscosity is also strongly related to fuel consumption in the combustion process.

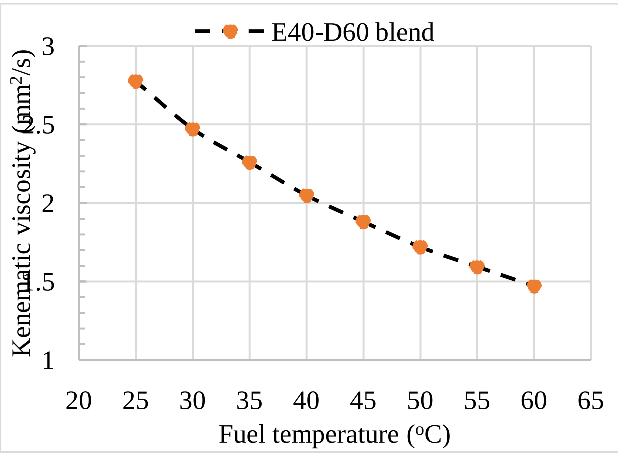

Figure 7:Variation of kinematic viscosity with temperature for blend fuel.

Note: Engine performance is improved at elevated temperature (40°C).

3.2. Comparative performance analysis for E40-D60 blend fuel with and without preheating.

The engine performance parameters of diesel engines are studied using the ethanol-diesel blended fuel (E40-D60) under the preheated condition at an elevated temperature of 40°C by varying engine loads (0-80%) with an increment of 20%. Initially, the experiments were carried out with the blended fuel without preheating at the same engine operating conditions. The test results were compared with each other and graphs have been plotted for various characteristics of the engine.

Brake power is the power measured at the output shaft of the engine. When engine load increases the engine brake power increases, it can be due to better combustion of fuels occurred with increasing load. Figure 8 examines the effect of fuel preheating on output brake power (BP) for E40-D60 blend fuel. The results revealed that preheating slightly improves the brake power of the engine over the given load ranges.

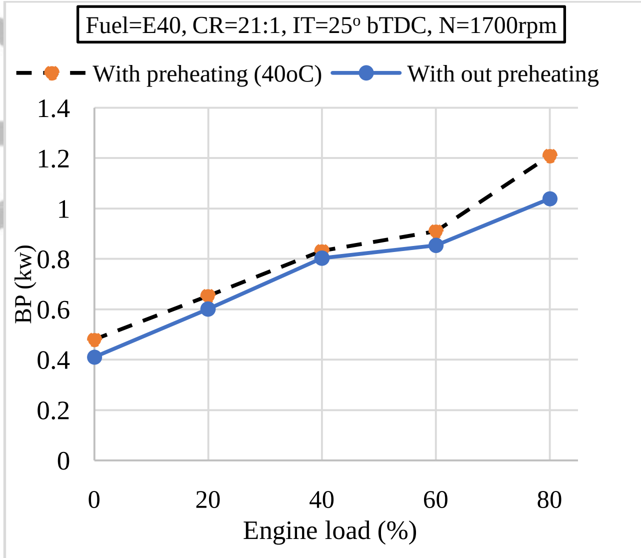

Figure 8: BP versus engine load with and without preheating.

In all loading fuel with preheating gives higher brake power because more volume of fuel is consumed (more energy content) and better fuel penetration as a result of reduction of its viscosity. Fuel heating does not improve fuel consumption but increases BP [15-17]. E40-D60 with preheating gives a maximum increase of 17.03% than without preheating at no loading.

Brake thermal efficiency (BTE) is the ratio of BP to the fuel energy consumed. It depends on the amount of fuel consumed and the brake power produced. Figure 9 presents the effect of fuel preheating on BTE for E40-D60 blend fuel under different engine loading. The result showed that as the load increase BTE increases for both modes of operation. However, the blended fuel (E40) with preheating (40°C) gives relatively higher BTE than without preheating condition. The reason can be preheating improves the fuel properties of blended fuel, due to increased molecular vibration, reactivity, and moment of molecules. Subsequently, this improves combustion efficiency and engine performance within a short period [16,18]. The BTE for E40 with preheating is more with a maximum increase of 48.2% (10.4% BTE) at 60% loading than without preheating.

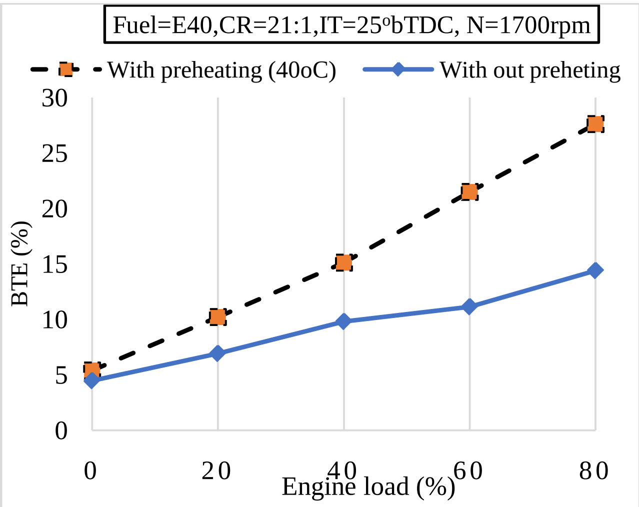

Figure 9: BTE versus engine load with and without preheating.

Brake-specific fuel consumption (BSFC) is the ratio of fuel consumption per power produced. Figure 10 presented the effect of fuel preheating on BSFC with varying engine load (0-80%) at a constant speed (1700rpm). The result reveals that when the engine load increases the BSFC of the engine operated with both modes decreases gradually. Also, the effect of fuel preheating slightly improves the BSFC of a diesel engine over an entire load. Because preheating decreases the viscosity of the blend and increase fuel flow rate but at the same time increases brake power and so BSFC decreases [16]. The blended fuel (E40) with preheating (40°C) produces less BSFC with a maximum reduction of 11.13% at 80% loading.

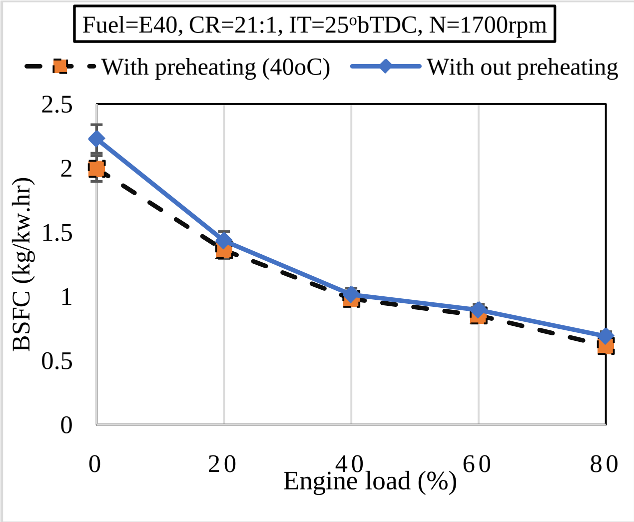

Figure 10: BSFC versus engine load with and without preheater.

3.3. Effect of preheated ethanol-diesel blend fuel on engine performance and exhaust emissions

A. Engine performance parameters

This section presents the effect of the addition of ethanol on diesel engine performance indicators. The engine performance parameters include BTE, BSFC, and EGT. Each result is discussed in detail as follows.

Figure 11 shows the graph of the effect of varying blend ratio on BTE under varying engine load in the step of 20%. The BTE for E10 and E20 mode shows relatively higher as compared with neat diesel in all loading.

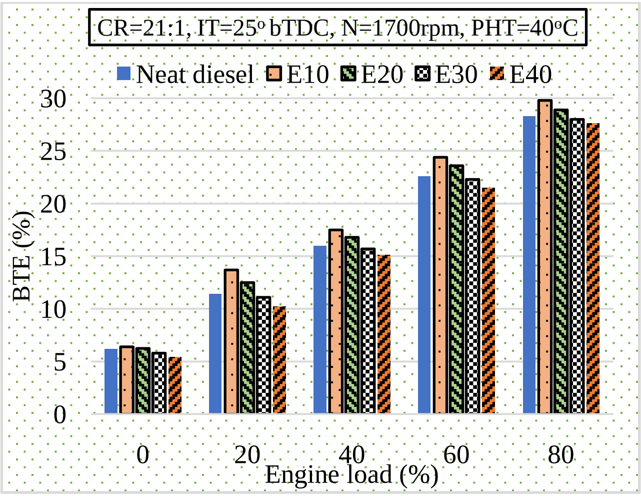

Figure 11: Variation of BTE with engine load.

Adding more ethanol (E30 and E40) reduces BTE because of less energy content of ethanol fuel compared to diesel and so power output of the blends and thermal efficiency of the engine becomes less [5,19]. The maximum BTE was obtained with preheated E10 blend and minimum BTE was observed with preheated E40 blend fuel.

Addition of less ethanol to diesel fuel and preheating results in more BTE than pure diesel fuel mode. When operating with E10 a maximum BTE increment of 20.2% is observed at 20% loading. Maximum BTE reduction of 12.9% is resulted with E40 at no loading.

BSFC is the ratio of fuel consumption to the power produced (brake power). The main reason for an increase in BSFC was incomplete combustion of fuel at low engine loads in comparison to high engine loads. The deviation of BSFC with engine load for pure diesel and ethanol-diesel blend fuel mode is illustrated in Figure 12. As the engine load increase BSFC for different test fuels decrease under the given load operation. This is because at low load the combustion process in the combustion chamber is poor. Increasing the load causes a complete combustion process and resulted in better specific fuel consumption [20,21].

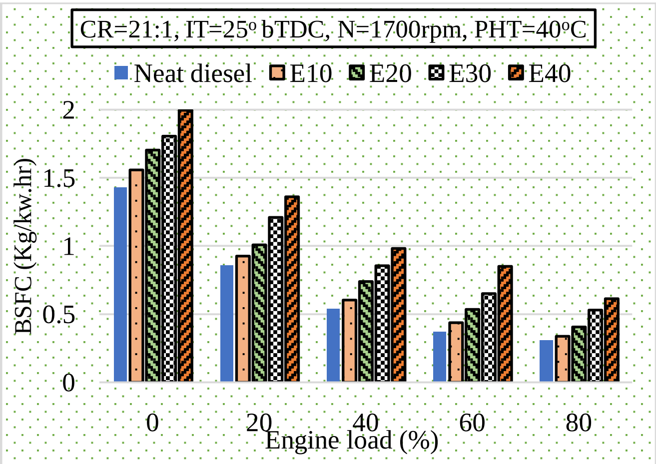

Figure 12: Variation of BSFC with engine load.

At all loading conditions, pure diesel fuel mode has less BSFC than the ethanol-diesel mode. The addition of ethanol to diesel fuel results in higher BSFC than pure diesel mode. Because the viscosity and heating value of blend fuel becomes less than diesel fuel and resulted in more fuel flow rate [3,5]. The lowest BSFC was obtained with pure diesel fuel; however, an increase of 127.63% was measured with preheated E40 fuel at 60% loading conditions.

EGT is an indicator of the combustion efficiency of a diesel engine. Having more EGT indicates better thermal efficiency due to better fuel combustion ability [2,22]. Figure 13 shows the exhaust gas temperature concerning engine load for pure diesel and different preheated ethanol-diesel blends at a constant speed (1700rpm). As the load increase, the values of exhaust gas temperature increase for all test fuels. Since cylinder temperature increases and used fuel property improved at high temperature [2,22]. Preheated E10 and E20 blend fuel resulted in more EGT than neat diesel mode. Preheating the blended fuel improves fuel efficiency and improves combustion. So, the heat release rate becomes more. As the percentage ratio of ethanol in the blend increase, the EGT becomes less compared to pure diesel, due to the lower heating value and high oxygen content of ethanol as compared to diesel fuel. In addition, the flash point (lowest temperature to ignite) of ethanol-diesel blend is less and the blend ignites easily at low temperature and loose its temperature before comes to exhaust manifold. Result shows that the usage of more ethanol with diesel fuel reduces the heat pollution to the environment [5,12,19]. From ethanol-diesel blends, E10 resulted in more EGT with a maximum increment of 13% than pure diesel fuel at 60% engine load. Ethanol-diesel blend fuel (E40) has less EGT with a maximum reduction of 3.9% than pure diesel at no loading.

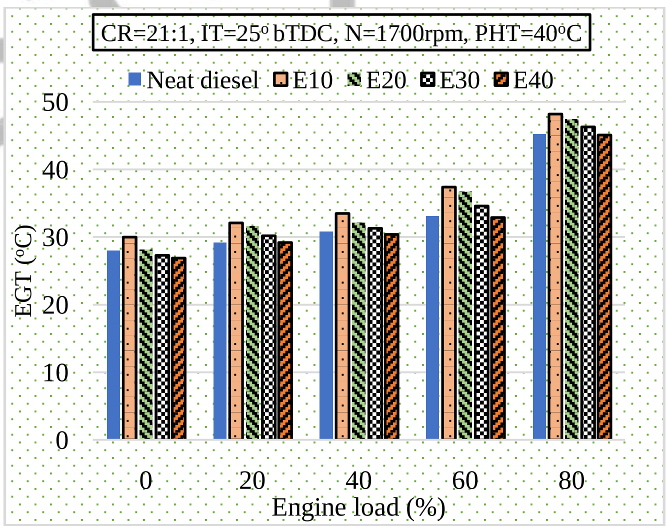

Figure 13: Variation of EGT with engine load.

B. Exhaust emission constituents

When fuels burn with oxygen different gases and particles are emitted from the combustion chamber. Theoretical chemical equation during combustion with air for pure diesel and ethanol fuels are given by:

Diesel, $C_{12}H_{23} + a(O_2+3.76N_2) \longrightarrow bCO_2+cH_2O+dN_2$

Ethanol, $C_2H_5OH+ \longrightarrow a(O_2+3.76N_2)$ $bCO_2+cH_2O+dN_2$

Exhaust gas emissions of CO, CO_2, HC, and NOx are observed in the experimental test for pure diesel and ethanol-diesel blend fuel mode under varying engine load at a constant speed of 1700rpm.

Carbon monoxide (CO) is a highly toxic gas produced when fuels burn incompletely or there is more oxygen occurred in the combustion chamber. Carbon monoxide (CO) depends on the combustion property of the fuel based on the oxygen and energy content of the fuel. Figure 14 depicts the deviation of CO emission concerning engine loads for different test fuels. As engine load increases, CO emission for pure diesel increases but CO decreases for all ethanol-diesel blends. In general, at low loads (up to 40%), pure diesel shows less CO emission, and E40 resulted in higher CO.

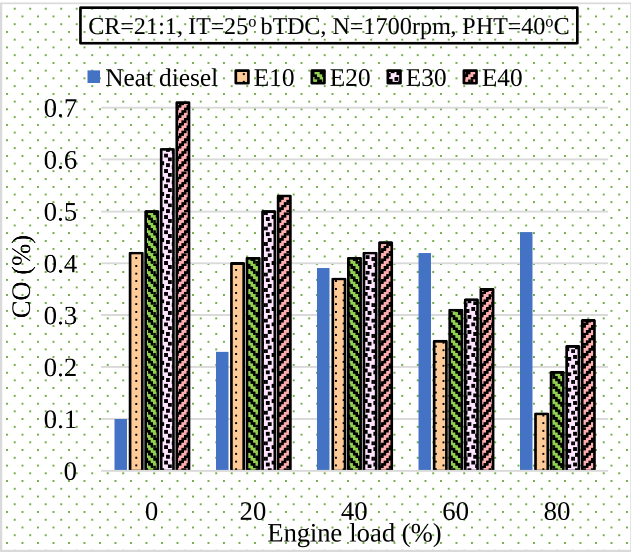

Figure 14: Variation of CO with engine load.

At high engine load (above 40%) pure diesel shows higher CO but E10 shows less CO value at all. The addition of ethanol on diesel fuel produces more CO at initial loads and shows less CO at higher loads. This result is because of the additional oxygen present in the ethanol, which helps in making the combustion more complete at higher loads [11,19,23]. The result of the study shows that E40 gives the highest CO emission at low load with an increase of 610% (0.61% CO) at no loading. From ethanol-diesel blends, E10 resulted in a reduction of CO emission at a higher load with a maximum reduction of 47.83% at high loading (80%). In general, at low load ethanol-diesel generates high CO compared to pure diesel but as the load increase, it results less CO than pure diesel modes. More complete combustion results CO_2 emission and incomplete combustion generates more CO emissions [21,23].

Figure 15 presented the amount of CO_2 emission for different test fuels under varying engine load at a constant speed of 1700rpm. Complete combustion released more CO_2 emissions. It is observed from Figure 15 that as the load increases CO_2 emission increase for all modes of operation. In all loading, ethanol-diesel blend gives less emission [24]. Through all pure diesel shows more CO_2 and E40-D60 shows less emission of CO_2. Since all the ethanol-diesel blends have more oxygen content than pure diesel fuel. A high content of oxygen can have a positive effect on combustion and CO_2 emission. The presence of ethanol resulted in somewhat incomplete combustion and carbon dioxide emission also decreases. The increase in CO_2 is directly proportional to the decrease in the amount of ethanol. Because less amount of preheated ethanol resulted better combustion and less CO emissions [5]. From ethanol-diesel blends, E40 gives less CO_2 emissions than all other modes with a maximum reduction of 24.37% than pure diesel fuel at 20% load and E10 gives high CO_2 emissions than other ethanol-diesel modes with a reduction

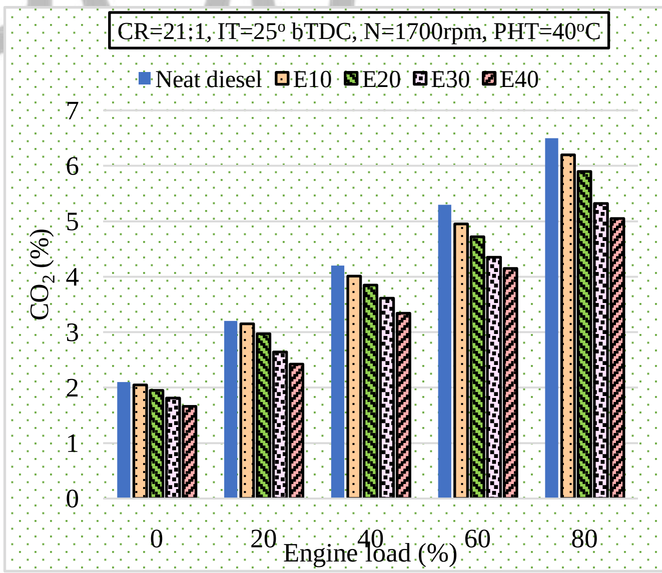

Figure 15: Variation of CO_2 with engine load.

of 6.6% than pure diesel at 60% engine load. During the combustion process, high heat is created near the engine cylinder. This high heat leads to the formation of NOx (NO, NO_2, N_2O_2, etc.). The blended fuel shows lower NOx emission compared to diesel fuel. It can be due to the low energy content of blend fuel and less heat near the engine cylinder [20,23].

Figure 16 investigates oxides of nitrogen for different test fuels under varying engine load at a constant speed of 1700rpm. As the load increase, there was a gradual increase in NOx emission in all modes of operation. Because when the engine loads increase cylinder temperature also increases, this caused high NOx emission in the exhaust manifold. At all loading conditions, the NOx emission of pure diesel fuel is relatively higher than all ethanol-diesel blends [2,11]. The NOx emission of ethanol-diesel blends is always lower than that of pure diesel mode of operation due to its combustion timing and oxygen concentration. Since ethanol has a very low cetane number, the cetane numbers of the blends are lower than that of pure diesel. The temperature in the combustion chamber becomes less and this causes less NO_X emission in the blends. As the amount of ethanol increases, NOx emission reduces [5,19,20,23]. From ethanol-diesel blends, E40 shows less NOx emission with a maximum reduction of 18.18% at 20% engine load compared to pure diesel. Whereas, the NOx emission for E10 is more compared to other ethanol-diesel blends with a maximum reduction of 6.36% at 20% load than pure diesel.

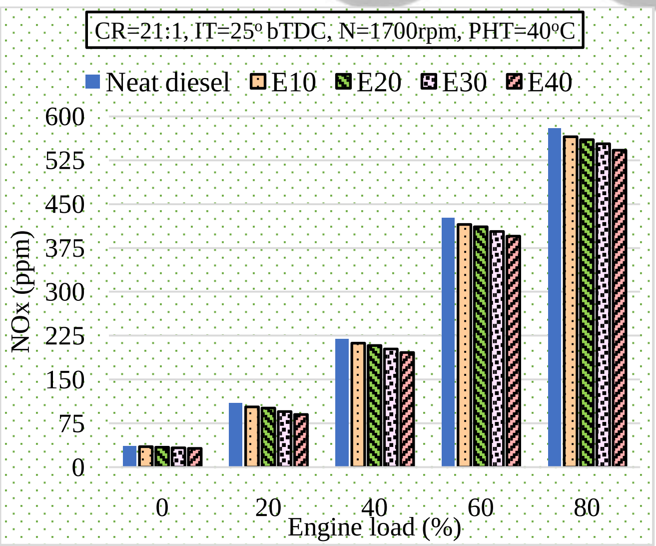

Figure 16: Variation of NOx with engine load.

HC emission is formed due to the incomplete combustion of fuels. The possible reasons is less combustion timing and the release of unburned fuels as a product [23]. Figure 17 presented HC concerning engine load for pure diesel and preheated ethanol-diesel blend fuel modes of operation at a constant speed of 1700rpm. As the load increase, HC increases up to 40% engine load for all modes of operation and then decrease. The available engine setup causes a gradual result change above 40% loading. Preheated Ethanol-diesel blends resulted fewer HC emissions than pure diesel due to better combustion and less unburned fuel in the exhaust. The reduction of HC emissions is due to better combustion at higher loads. Since at higher load the oxygen reactivity is increased due to the higher temperature of the combustion chamber [20]. The addition of ethanol to diesel fuel resulted in fewer HC emissions than pure diesel at all loading conditions. In all loading, E40 shows less HC emission in contrast to the pure diesel fuel mode.

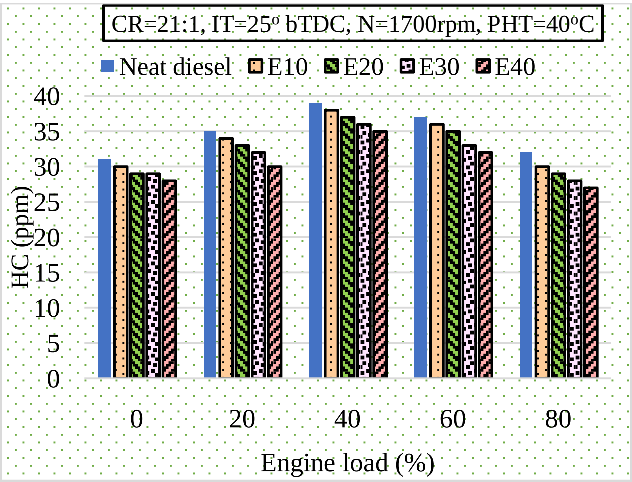

Figure 17: Variation of HC with engine load.

From Figure 17, ethanol-diesel blend resulted fewer HC emissions than pure diesel mode. An increasing amount of ethanol decreases HC emission. Because most fuels are burned and no remaining fuels in the exhaust [12,23]. The result depicted that E40 shows less HC emission with a maximum reduction of 15.6% than pure diesel at 80% loading. From ethanol-diesel blend, E10 gives more HC emission with a reduction of 6.25% than pure diesel at 80% loading.

4. Conclusion

An experimental investigation of combustion performance and emission characteristics of pure diesel and preheated ethanol-diesel blend fuel on diesel engine have been performed at a constant speed with varying engine load and results are summarized as follows:

- It can be concluded that the ethanol-diesel blend can be used in diesel engines with a preheater device.
- The usage of ethanol highly reduces diesel fuel consumption because of the replacement of some amount of diesel fuel with ethanol.
- Increasing fuel temperature improved fuel property and performance output.
- Usage of preheated E10 and E20 blend fuels resulted in better BTE than neat diesel.
- The addition of ethanol resulted in more BTE and EGT (for E10 and E20), BSFC, and CO (up to medium loading) but less NOx, CO_2, and HC than pure diesel. From ethanol-diesel blends, E10 shows better performance, and E40 resulted less exhaust emission than others.
- Adding more amount of ethanol reduces air pollutant emissions but at the same time, it reduces the performance parameters because of the low energy content of the ethanol fuel.
- Usage of purified alternative fuel is advisable to approach diesel fuel properties and better performance results.
- Comparing all the results preheated E10 and E20 shows better average performance and exhaust emission results than pure diesel mode.

Nomenclature

BP: Brake power
BSFC: Brake specific fuel consumption
BTE: Brake thermal efficiency
CI: Compression ignition
CO: Carbon monoxide
CO_2: Carbon dioxide
CR: Compression ratio
EGT: Exhaust gas temperature
E10: 10% vol ethanol fuel mix with 90% vol diesel fuel
E40: 40% vol ethanol fuel mix with 60% vol diesel fuel
HC: Unburned hydrocarbon
IC: Internal combustion
IT: Injection timing
N: Engine speed
NOx: Oxides of nitrogen
PHT: Preheating temperature
PM: Particular matter

Conflict of Interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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Appendices

Appendix A

Table A1: Dimensional parameters of fuel preheater (helical coil heat exchanger).

Parameters	Values
Shell length	$0.47m$
Shell inner diameter	$0.15m$
Shell wall thickness	$1.5mm$
Coil tube outer diameter, d_o	$12.7mm$
Coil tube wall thickness, t	$1.245mm$
Length of coil tube, $\mathrm{L_c}$	$2.541m$
Number of turns in coil, N_t	$8\,(\text{turns})$
Coil pitch, P	$19.05mm$
Curvature ratio, δ	0.1021
Helix angle, α	20^o