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Performance and emission of turbocharger engine using gasoline and ethanol blends

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Abstract. In this decade, alternative fuels such as ethanol were extensively studied as an additive or substitute for increasing engine performance and decreasing the release of harmful gases into the environment. The objective of the study is to assess engine performance and exhaust emission using Gasoline and Ethanol blends in a turbocharged spark-ignition engine. Gasoline was used as a reference fuel, and ethanol was blended into gasoline at 10%, 20% and 30% named as E10, E20, and E30, respectively. The turbocharger spark ignition (SI) engine has been coupled to eddy current 100 kW dynamometer to measure the engine efficiency. The engine test was carried out at an engine speed of 3000 rpm and 40% wide open throttle (WOT). As results, the performance parameters such as volumetric efficiency (VE), rate of heat release (ROHR), brake mean effective pressure (BMEP), brake specific fuel consumption (BSFC) of the engine increased with gasoline-ethanol blends compared to gasoline. Also, the complete combustion contributed to the reduction of the hydrocarbon (HC), carbon dioxide (CO_2) and nitrogen oxide (NOx) emissions. From the study, it can be concluded that ethanol is highly suited for turbocharged SI engines to reduce emissions and increase performance.

1. Introduction

With the rapid economic development, the problem of increase in pollution has become limitless [1]. Currently, the use of ethanol in gasoline has become a priority in the automotive industry due to the lack of fossil fuel reserves and environmental pollution issues. It is used in an internal combustion engine (ICE) to reduce the environmental effects of harmful emissions. Based on EU reports, CO_2 reduction targets are set between 20% and 30% for year 2020 and increase to 50% by the year 2050 [2] to endeavour sustainable growth. Some scientist predicts that if no action taken to reduce the emissions at present, greenhouse gas (GHG) concentration in the environment may double its range as early as 2035 [3] which may worsen the world's problems.

Biofuel such as ethanol are capable to reduce or control CO_2 emissions because they are renewable fuel. The use of ethanol in gasoline fuel is inevitable. Additionally, the use of ethanol in the combustion engine is cleaner than fossil fuels, thereby reducing environmental pollution and greenhouse emissions [4]. Ethanol has advantages as an alternative fuel because it is derived from renewable energy sources such as waste biomass, corn, soybeans, cassava, sweet potatoes, and so on. They have higher octane value, thus resulting in better anti-knock and allowing engine run under higher compression ratio [5].

Also, ethanol has low sulfur content, biodegradable and obtained from plant biomass [6]. Biofuels can reduce 80% greenhouse gas emission by replacing fossil diesel use in the internal combustion engines [7]. Hsieh et al. [8] concluded that the use of alcohol increases the volumetric efficiency (VE) due to the lower intake temperature. Zhuang & Hong [9] described that among various factor, charge cooling intake manifold with injecting ethanol into the cylinder significantly contributes to the increase in BMEP. The ethanol has a higher latent heat of vaporisation, which contributes to higher combustion velocity and higher energy content. Koç et al. [10] mentioned that to get the same energy output; the mass of alcohol fuel should be increased by 1.5-1.8 times compared to gasoline to increase the BSFC.

The formation of nitrogen oxide (NOx) is closely related to cylinder pressure. The NOx emission ideally takes place due to the Zeldovich mechanism reaction when the flame temperature is above 1850 K during the combustion. Three mechanisms are influencing the formation NOx: enrichment of oxygen, the reaction time of Nitrogen dioxide (NO) and higher cylinder temperature [11]. Carbon dioxide (CO_2) is one of the basic GHG, which is formed by the complete combustion of hydrocarbon fuel. The CO_2 formation is affected by the carbon-hydrogen (C/H) ratio in the fuel. Hydrocarbon is a product of incomplete combustion in the engine. It occurs in three condition: (1) absorption of fuel vapour into oil layer in cylinder block; (2) flame quenching due to incomplete combustion and (3) filling crevice volumes with the unburned mixture [12].

From the literature above, increasing alcohol fuel into the gasoline induces to vary suggestion in engine performance and emission. Furthermore, it is well known in the literature that using alcohol fuel as blends in gasoline contributes further substitution for gasoline feedstock. However, the effect of engine efficiency on different fuel blends in a turbocharged is not clear and less report. Considering this fact, this paper aims to investigate the engine efficiency and emissions characteristics of ethanol-gasoline blends in the turbocharged spark-ignition engine without any modification. In this study, the gasoline was utilized as a reference fuel. The ethanol was blended at concentrations of 10%, 20% and 30% with gasoline are named as E10, E20 and E30 respectively. These percentage of blended ethanol to gasoline fuel implemented in this study is a platform of knowledge and reduce dependency on fossil fuel. The experiments have been conducted at 40% wide open throttle (WOT) and 3000 rpm engine speed on the turbocharged SI engine.

2. Experimental methodology

The experiment was conducted on a turbocharged (1.8 Litre), spark ignition (SI), four-stroke, and a four-cylinder engine. The technical parameters of the engine are shown in table 1. The engine test rig, coupled with a 100 kW dynamometer (Dynalec Controls, India) is shown in figure 1.

Table 1. Specifications of the engine (Mitsubishi Motors Corporation, 1998).

Type	SOHC 16 V MPI
Number of cylinders	4
Type of chamber	Pent-roof Type
Displacement	1.8 Litre
Bore	8.1 cm
Stroke	8.9 cm
Compression ratio	9.5:1
Spark Timing	10° -35° BTDC
Injection Timing	715° BTDC
Power Maximum	118 kW
Torque Maximum	220 Nm

Ethanol is mixed with gasoline at 10%, 20%, and 30% ratios and labelled as E10, E20, and E30 respectively. A magnetic stirrer is used to blend ethanol and gasoline for about 10 minutes before testing the properties. The properties of the Fuel blends are assessed from the UMP Central laboratory. Table 2 shows the properties of gasoline, ethanol and ethanol blends used in the experiment. A gas analyzer from

Kane Auto-plus 5-2 is used to evaluate the engine emission, e.g. CO_2, HC, NOx and air-fuel ratio. The emission sensor is mounted at the exhaust tailpipe to obtain emission data.

Table 2. Properties of gasoline, ethanol and ethanol blends [11, 14, 15].

Properties	G	E	E10	E20	E30	Test standard
Chemical Formula	$C_{5-10}H_{12-22}$	C_2H_5OH	-	-	-	-
Density, (kg/m^3)	737	785	761	765	768	ASTM D4052
Boiling Temperature, °C	27-225	78.25	-	-	-	-
Octane Number	95	108.6	98.1	100.7	102.4	ASTM D2699
Motor Octane Number	82-92	92	99.9	101.6	-	ASTM D2700
Heat of Vaporization, kJ/kg	349-500	904-923	-	-	-	-
Lower Heating Value, MJ/Kg	44	26.9	41	39.4	37.8	ASTM D240
Flash Point, °C	45	12-20	-	-	-	-
Auto Ignition Temperature,°C	257	425	-	-	-	-
Water content (%)	0	7-11%	5.4	10.2	14.4	-
Air-fuel ratio	14.6	9	13.5	12.6	11.7	-

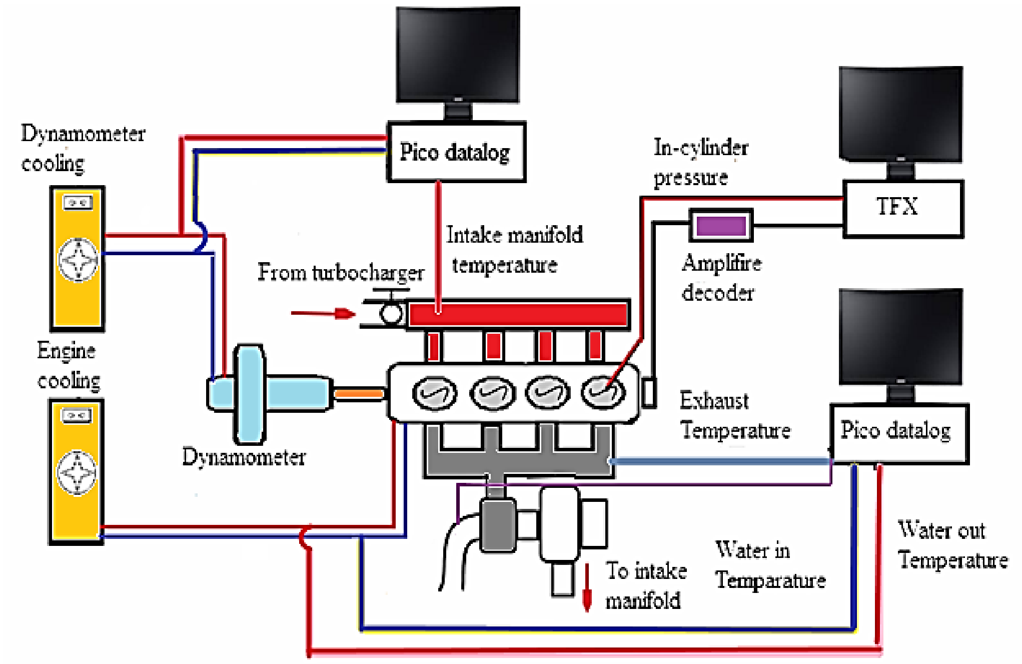

Figure 1. Schematic layout engine test rig.

The cylinder pressure sensor range between 0-200 bar with a sensitivity of 1.12 mV-Psi connected to the TFX Data Acquisition System (DAQ) used to record the in-cylinder pressure. Sensor-based optical-fibres and magnetic encoders are set up to detect crank angles and the combustion pressure in this study. An anemometer with a resolution 0.001 m/s (CENTER 330 model) is used to measure the air-flow rate into the intake manifold. The K-type thermocouple sensor with a data logger (TC-08 Picolog) was installed to measure coolant water, engine oil, air delivery in the manifold, manifold temperature and outlet exhaust gas temperature. The cooling tank circulates cold water to reduce the engine temperature. An electric fan is used to cool down the intercooler air temperature before entering the engine cylinder.

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3. Results and discussion

The study was conducted to evaluate engine performance and exhaust emission on turbocharged SI engine at 3000 rpm for 40% WOT. The study was explored by comparing the test results of gasoline and gasoline-ethanol blends up to 30%. The testing was repeated three times to collect the data, and the average values are reported.

3.1. Volumetric efficiency

Figure 2 shows the trend of volumetric efficiency (VE) for stated fuel blends at 3000 rpm and 40% engine load. It shows averagely 6.5% increasing trend when using E10, E20 and E30 compared to G. The VE for G, E10, E20 and E30 was recorded at 52%, 54%, 58% and 64% respectively. The increasing of VE is due to the charge cooling of the intake manifold while using ethanol-gasoline blends. Also, the water content in ethanol correlates to the octane number in fuel. As the octane number increases, the VE also increases. Similar results were observed by Alahmer & Aladayleh [15] for various ethanol blends in engines. Lie et al. [16] described that the higher latent heat of alcohol fuels caused lower intake manifold temperature and induced to increase VE. They added that reduced combustion by using alcohol fuel was beneficial for improving thermal efficiency. In addition, Simsek & Ozdalyan [17] declared that alcohol fuels may have a cooling effect on the drawn fresh mixture due to their heating value below than gasoline and higher enthalpy of vaporization. This phenomena introduces to increase VE of the engine. Due to higher VE, engine operations may have higher torque and horsepower. On the other hand, with fresh charge cooling temperature engine operation, it will be operating with poorer mixtures, there may be significant decline in CO and NOx emission.

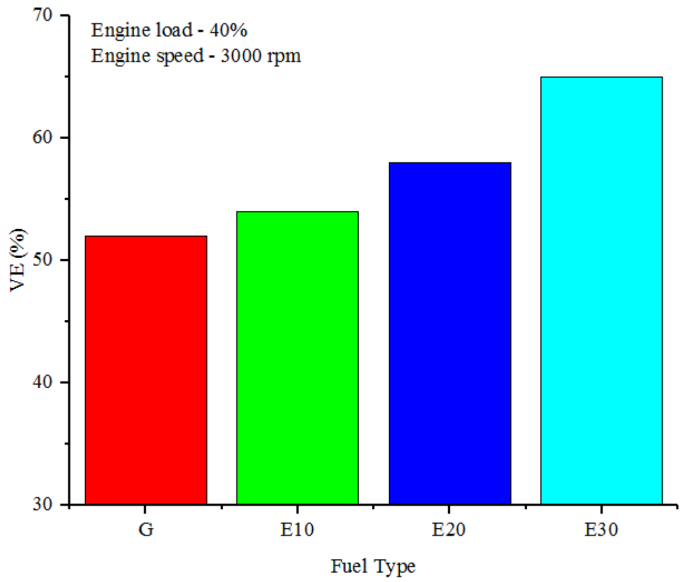

Figure 2. Volumetric efficiency (VE) for various fuel blends at 40% WOT at 3000 rpm.

3.2. Rate of heat release

The Rate of Heat Release (ROHR) is defined as the rate of chemical energy of the fuel released by combustion. The ROHR is calculated based on first law thermodynamic during the closed valve period from the average pressure. The cylinder pressure and ROHR profile were measured with crank angle (CA) for various blends gasoline-ethanol are shown in figure 3. The maximum cylinder pressure shows the range at 55-60 bar was obtained for all test fuels. The E30 shows higher pressure than others. When using ethanol blends, the ROHR was increased compared to gasoline. The corresponding ROHR for G, E10, E20 and E30 shows range at 60-70 J/degree. As a consequence, the use of ethanol blends in gasoline slightly increases and larger quantity of CA of cylinder pressure and ROHR. Thangavelu et al. [18] have similar result with this study. They described that the velocity of combustion by ethanol blend is faster, and higher peak heat release when using higher engine speed. In addition, ethanol blends show the higher laminar flow burning which promotes by formation of hydroxyl radical in combustion [19, 20].

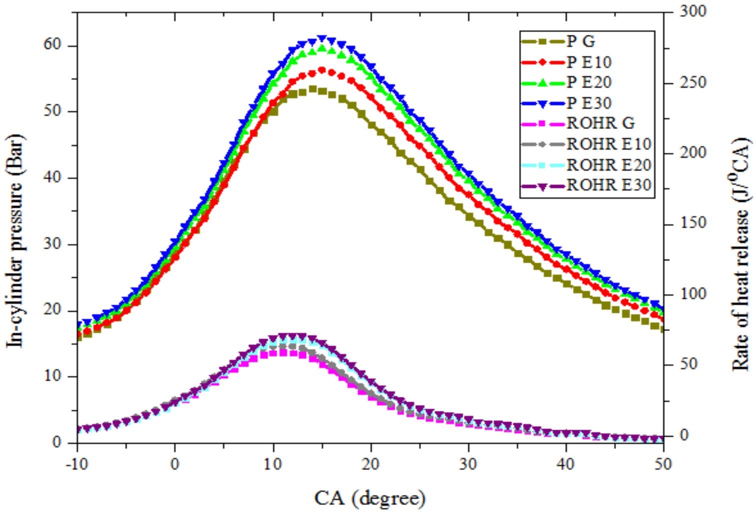

Figure 3. In-cylinder pressure and heat release rate for various fuel blends at 40% WOT at 3000 rpm.

3.3. Break mean effective pressure

Brake mean effective pressure (BMEP) is a parameter that reflects engine power. Figure 4 shows the comparison of the BMEP at 3000 rpm and 40% WOT for various ethanol-gasoline fuel blends. It was observed that ethanol fuel blends showed increases BMEP compared to gasoline. The latent heat of vaporization ethanol is higher than gasoline. Due to blends with gasoline, the latent heat of vaporization of ethanol-gasoline blends become higher compared to gasoline [21]. It offers an additional benefit of improved charge cooling and reduces the temperature of the intake manifold. With more air during suction stroke enter to the engine cylinders, fuel can be burnt properly to obtain high power output. In addition, effect of charge air cooling leads to higher volumetric efficiency and introduces higher BMEP. Furthermore, ethanol, as an oxygenated fuel introduces hydroxyl radical (-OH), enhances the efficiency of combustion in an engine which promotes complete combustion [18]. The finding also concordant with [5] that blends ethanol-gasoline increases the BMEP.

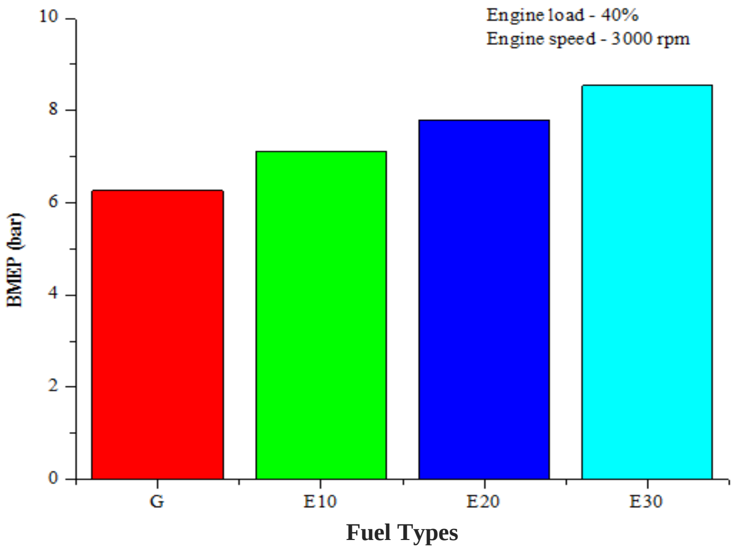

Figure 4. BMEP for various fuel blends at engine speed 3000 rpm and 40% WOT.

3.4. Brake specific fuel consumption
Brake specific fuel consumption (BSFC) defined as the amount of fuel consumed for each unit of brake power developed per power [18]. Figure 5 shows the BSFC with various blends of fuel at 3000 rpm and 40% WOT. From observation, BSFC increased with the increase percentage proportion blends. In these cases, the engine runs without any modification. The increase in BSFC is significantly related to the fuel properties such as lower heating value, high kinematic viscosity, density and the air-fuel ratio [22]. Najafi et al. [22] concluded that the increase of BSFC is due to higher density and octane number of ethanol-gasoline blends. Hassan et al. [23] described that due to lower heating value of ethanol, it should be 15% increased more than that of gasoline to achieve same power with gasoline. As consequently, the BSFC increases compared to gasoline.

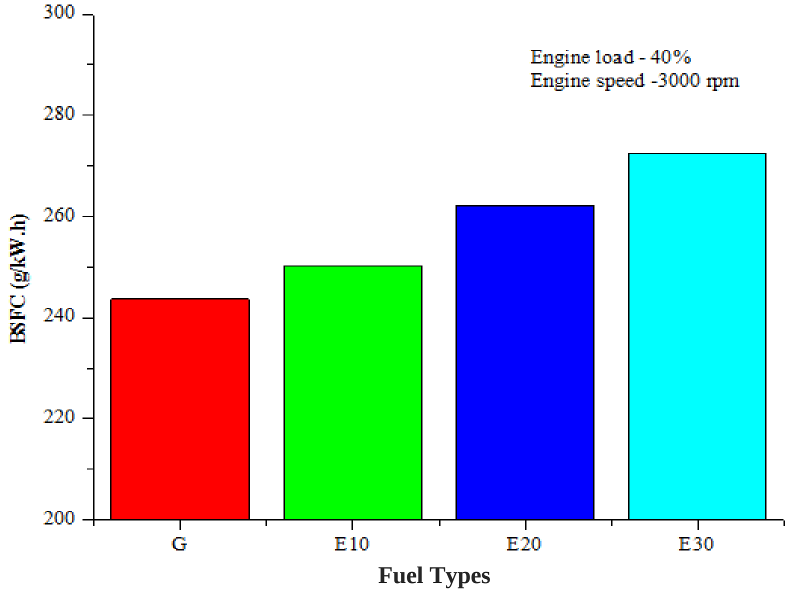

Figure 5. BSFC for various fuel blends at 40% WOT and 3000 rpm.

3.5. Nitrogen oxide emission
Nitrogen oxide (NOx) is harmful gaseous emission and generalized for NO and NO_2. Figure 6 shows the emission of NOx for various fuel blends at 3000 rpm and 40% WOT. From the figure, it is observed that the effect of using ethanol-gasoline blends shows decreasing trend of NOx emission compared to gasoline. The formation of NOx emission depends on the cylinder temperature, oxygen concentration and residence time for the reaction of gas temperature [24]. Increased cylinder pressure introduces to increase cylinder temperature [25]. With the ethanol-gasoline blends, the temperature of combustion is greatly reduced due to the high latent heat of vaporisation, lower heating value and oxygen content in alcohol, and these leads to the reduction in NOx emissions [11]. Some researchers identified that the reaction time of each engine cycle was reduced. The gas residence temperature within the cylinder was shortened [21, 23, 24]. This condition also led to lower NOx emissions [22].

3.6. Hydrocarbon emission
The Hydrocarbon (HC) emission for various fuel blends for at 40% WOT and 3000 rpm is shown in figure 7. Gasoline shows higher of HC compared to other fuel blends. Normally, HC emission presences when occurring incomplete combustion. HC emission shows decrease trend when engine uses ethanol-gasoline blends. Averagely, the HC reduced at 6.6% when proportion of percentage ethanol increase compared to gasoline. Park et al [27] mentioned that introducing ethanol in gasoline can reduce the HC emission because non-polar molecules cannot easily absorb the water molecules in the lubricating oil layer. Therefore, the probability of producing HC emission can be reduced. The reduction of HC is due

to lean combustion and the presences of water content (about 7%) in the gasoline-ethanol blends which promotes complete combustion [5].

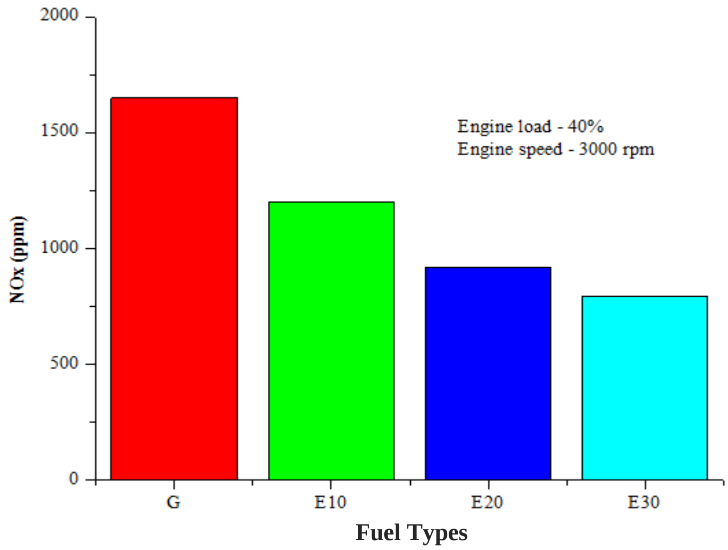

Figure 6. NOx emission for various fuel blends at 3000 rpm for 40% WOT.

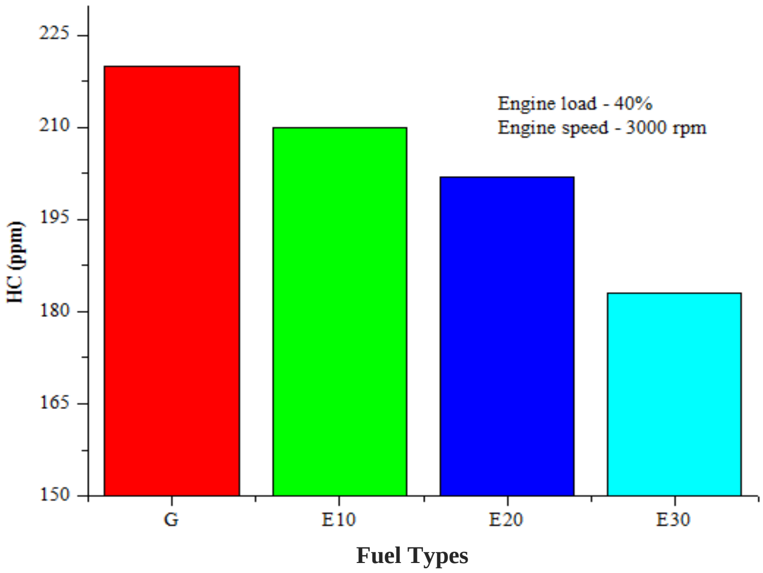

Figure 7. Hydrocarbon for various fuel blends at 40% WOT and 3000 rpm.

3.7. Carbon dioxide emission

Carbon dioxide (CO_2) is produced by the complete combustion of hydrocarbon fuel. Figure 8 shows the CO_2 emission for various fuel blends at 40% WOT and 3000 rpm. It showed that with the use of E30, the CO_2 emission decreased by 33% compared to gasoline. The CO_2 emission decreased with the increase in the proportion of ethanol. The engine has been running at lean condition when uses the ethanol-gasoline blends. The reduction in CO_2 is due to the hydroxyl radical (-OH) in ethanol, which encourages complete combustion in the engine cylinder. Also, the lower carbon content in ethanol compared to the gasoline lead to the reduction of CO_2 [11]. A similar result was obtained by [28], they mentioned CO_2 reduce extensively due to rapid evaporation and better mixing of air and fuel blends. The extra oxygen in gasoline fuel blends resulted excellent combustion. Due to the complete combustion of bioethanol in fuel, CO was transformed into CO_2 [22].

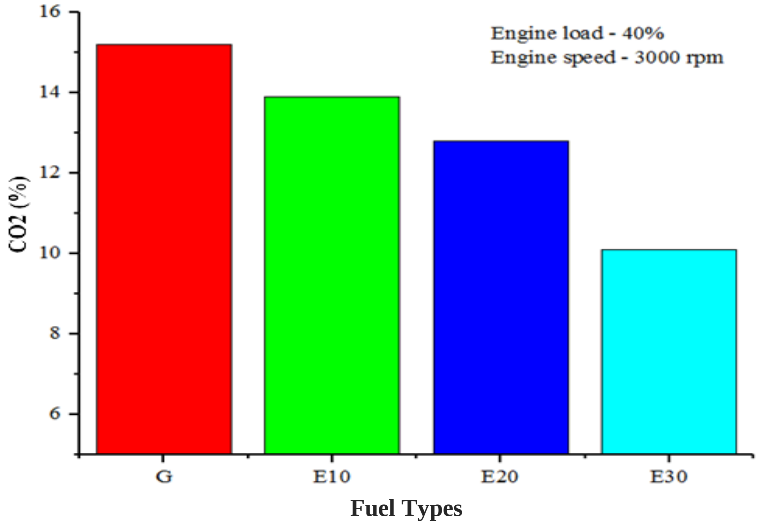

Figure 8. CO_2 emission for various fuel blends at 40% WOT and 3000 rpm.

4. Conclusion

The engine performance and emission characteristics of the 1.8L turbocharger engine fuelled with gasoline and ethanol blends was investigated at 3000 rpm and 40% WOT. The following conclusions are obtained from the study:

i) The use of ethanol up to 30% blends improves the performance of turbocharger engine due to high octane number and latent heat vaporization.
ii) The lower energy content and higher density of ethanol–gasoline blends increased the BSFC of the engine.
iii) The charge cooling effect the intake manifold introduces to increase the VE and also contributed to the lean combustion.
iv) The exhaust emission such as NOx, HC, and CO_2 showed a significant reduction due to the presence of oxygen in ethanol and combustion enhancement.
iv) Ethanol-gasoline blends show advances combustion leading to a higher in-cylinder pressure compared to gasoline. Also, the engine knock tendency is greatly reduced due to advance combustions.

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