Journal of Mines, Metals and Fuels, *72(10): 1139-1147; 2024. DOI: 10.18311/jmmf/2024/45419*

Print ISSN : 0022-2755

Journal of Mines, Metals and Fuels

Contents available at: *www.informaticsjournals.com/index.php/jmmf*

A Review on Performance and Emissions Measurements of Ethanol Blends for Gasoline Engines

Ravindra S. Deshpande[1], Nitin Kardekar[2], Prashant Ingle[3], Prakash Kadam[4], Ankush Biradar[5], Prashant Patil[6] and S. S. Thipse[7]

[1]Department of Mechanical Engineering, Sinhgad College of Engineering (SCOE), Vadgaon (Bk), Pune - 411041, Maharashtra India; ravindra.deshpande8888@gmail.com
[2]JSPM Narhe Technical Campus, Pune - 411041, Maharashtra, India
[3]Saraswati College of Engineering, Kharghar, Navi Mumbai - 410210, Maharashtra, India
[4]Jayavantrao Sawant College of Engineering, Pune - 411028, Maharashtra, India
[5]Thakur College of Engineering and Technology, Mumbai - 400067, Maharashtra, India
[6]Abhinav Education Society's College of Engineering and Technology, Pune - 411046, Maharashtra, India
[7]Department of Powertrain Engineering, ARAI, Pune - 411038, Maharashtra, India

Abstract

Vehicles have been running on alcohol since the 19th century. Ethanol is considered the most environmentally friendly, biological, and sustainable fuel in SI engines among all alcoholic beverages. This paper addresses Gasoline-Ethanol (GE) blends' performance as a biofuel in a typical SI engine. This article covers and evaluates the physical characteristics of Ethanol (E), its production process, as well as the performance effects of different ethanol-based gasoline blends. The article focuses on the engine BT, BSFC, volumetric efficiency, and thermal efficiency related to exhaust emissions, including CO_2, CO, NO_x, and HC, which are currently major issues. The benefits and drawbacks of utilizing Ethanol (E) fuel for SI engines were also studied. The overall BTHE, HRR, volumetric efficiency, and cylinder gas pressure of a blend with a higher percentage of ethanol fuel improved. The amount of Ethanol (E) in the mixture has an impact on the Compression Ratio (CR) required for ignition.

Keywords: *Biofuel, Emission, Gasoline, Heat Release Rate, Thermal Efficiency, Volumetric Effi-ciency*

1.0 Introduction

The global demand for and price of crude oil is rising daily, requiring a search for alternative fuels. Because of its many benefits, including oxygenation, renewable energy, and minimal pollution, biofuel is becoming a prominent alternative. It may be blended with other fuels up to 10% in various industries[1]. A major Greenhouse Gas (GHG) directly related to climate change and global warming, CO_2, is emitted yearly by anthropogenic activities at a rate of about 25 billion tonnes. For the most part, air pollution and greenhouse gas emissions are directly related to the burning of fossil fuels. Given these, significant research has focused on enhancing the usage of renewables including biofuels, Geothermal Energy (GE), and solar energy to fulfill the world's rising energy needs by achieving ecological development goals and reducing Greenhouse Gas emissions (GHG)[2]. One of the most important alternative fuels that could eventually replace fossil fuels is ethanol since it is liquid and possesses chemical properties with regular fuels. Ethanol is used in engines to enhance the antiknock phenomena since compared

**Author for correspondence*

to gasoline, it has a higher Octane Number (ON). There is no need to modify the engine while using an ethanol and gasoline combination as fuel; however, by using pure ethanol fuel, some engine changes are required[3]. For the SI engine, ethanol fuel performs best and can be blended with petrol to improve the engine's octane rate and emissions quality. It goes under the name ethyl alcohol as well. One molecule of oxygen found in Ethanol (E) can be regarded as a fully oxidized hydrocarbon. A blend of gasoline plus ethanol (gasohol) is produced by adding less ethanol to the gasoline. Blends of 20% or more ethanol by volume that is safe for use in SI engines as fuel[4]. Since they are renewable and easy to combine with conventional fuels, alcohol-based fuels and additives like ethanol are recommended. Since ethanol is a fuel that can be made from renewable as well as natural resources, there is a possibility that it will help to decrease the amount of fossil fuels used in transportation. Additionally, it is predicted that ethanol will improve combustion and increase thermal efficiency because its flame speed is faster than that of regular gasoline[5]. Presently, using fossil fuels that damage the environment is subject to more stringent rules worldwide. As a result, there is an increasing demand to seek an alternative to petroleum fuels. Using alternative fuels instead of traditional fuels derived from petroleum has been one of the many methods to minimize air pollution that have been presented over the years[6].

2.0 Ethanol is Used as a Fuel for SI Engines

Petrol produces lot of harmful exhaust gases and has a lower Octane Number (ON) than alcohol. Furthermore, environmental deterioration has gained significant attention in recent years. Ethanol is becoming a more widely accepted alternative fuel in worldwide[7]. Ethanol-fueled engines have a higher self-ignition temperature than gasoline-fueled engines with the same compression ratio, which makes them less likely to spark. This allows SI engines to have a higher detonation-free compression ratio, resulting in increased economy and output. Because ethanol fuel vaporizes at a high temperature and burns cleaner than regular gasoline, it increases power and decreases the engine's peak temperature. Gasoline is generally less reactive than ethanol or bioethanol[8]. Bioethanol is typically used as an alternative fuel in petrol blends including E95 (95% E + 5% G) and E85 (85% E + 15% G). These fuel combinations run light-duty vehicles. Additionally, ethanol is added to gasoline as a component (10% ethanol). However, there are barriers put up by the European Union to the use of bioethanol as fuel[9].

2.1 Ethanol Fuel Production

To produce ethanol, any resource that can be transformed into synthesis gas or molasses a CO_2 and hydrogen mixture may be utilized. Moreover, it can also be made by fermenting glucose, bio-converting synthesis gas, using biomass and agricultural products such as grains and sugarcane as well as agricultural solid waste and cellulosic materials. The method of producing ethanol involves these five phases which include dehydration, fermentation, distillation, grinding, and cooking[10]. Furthermore, the synthesis gas that is produced when coal is gasified can also be fermented to produce ethanol. About 96% of the ethanol produced during fermentation is pure by volume. Costly distillation methods are needed to further purify the ethanol or eliminate all of the water in the alcohol. Ethanol fuel costs are increased even more by these processes. Therefore, while it is advantageous to produce ethanol from renewable sources, it is a disadvantage since it is more costly than gasoline[11].

2.2 Ethanol Fuel Properties

Some of ethanol's beneficial fuel properties improve engine performance as fuel economy. To optimize engine output power and utilize ethanol's better knock resistance, for instance, the Ignition Time (IT) might be changed to allow for its higher octane rating. Table 1 discusses the fuel properties of both gasoline and ethanol fuel. The percentage ratio of ethanol fuel in gasoline must be measured or estimated to optimize engine control or make more fundamental adjustments, including adjusting the amount of fuel injection during a cold start[12]. The physical as well as chemical properties of gasoline determine its quality for combustion in an engine. They have an impact on engine performance, emissions, and combustion quality Table 1. compares some properties related to the combustion of ethanol and gasoline[13]. Due

Table 1. Fuel properties[14].

Properties	Gasoline	Ethanol
Oxygen (% Wt.)	----	34.73
RON/MON	95/85	108.6/89.7
Auto-ignition temperature (^{0}C)	228-470	363
Boiling point (^{0}C)	27-225	78.3
Heat of vaporization (kJ/kg)	349	923
Chemical formula	----	C_2H_5OH
Density (g/cm^3 at 20 ^{0}C)	0.72-0.76	0.790
LHV (kJ/kg)	44,300	26,900
Stoichiometric AFR	14.6	9.0
Adiabatic flame temperature (^{0}C)	2002	1920
Molar C/H ratio	0.44-0.50	0.33
Flammable limits (%volume)	1.4-7.6	3.5-15
Stoichiometric flame speed (m/s)	0.34	0.41

to the same Latent Heat (LH), ethanol has a better self-ignition temperature than regular gasoline (CR in the range 6-12), allowing for significantly higher CR (i.e., in the range of 11-14). Because ethanol has 2 carbon atoms compared to 7 in petrol, it emits less CO_2. Despite having a Lower Calorific Value (LCV) than gasoline, ethanol (E) performs better in terms of Brake Thermal Efficiency (BTHE). Because of the chemical and physical properties of ethanol, attention must be taken when using it as fuel in an SI engine. Ethanol (E) has certain properties that

Table 2. Advantages of ethanol over gasoline

Ethanol is less harmful than gasoline.
Gasoline fuel contains ethanol that is easily miscible.
Gasoline contains a significant amount of ethanol as an oxygenated element.
Burning ethanol significantly reduces greenhouse gas emissions.
To prevent knocking, gasoline engines with indirect injection use ethanol.
The volumetric efficiency of ethanol is increased by its higher latent heat.
Thermal efficiency increases with ethanol.
Engine torque output is increased by ethanol.
Bioethanol has the potential to increase feedstock demand and raise agricultural prices as well as farmers' income.

Table 3. Disadvantages of ethanol over gasoline fuel[15]

Decreased ethanol vapor pressure can cause uncontrolled contaminants like aldehydes to grow.
Ethanol has a lower energy content.
The use of ethanol may cause metallic parts, including fuel tanks, to corrode more quickly.
The triatomic molecule ethanol reduces the temperature of the Combustion Gas (CG) while increasing its heat capacity.

make it a viable substitute fuel for SI engines, especially when combined with pure Gasoline. (G). The gasoline-pure ethanol mixtures (E20 and E85) are stable[13.]

3.0 Effects on Engine Performance

3.1 Brake Power

BP indicates the useful power at the output shaft for an engine. Parasitic loads as well as mechanical friction (for example, an oil pump or an air conditioner compressor) always result in a lower BP than indicated. Increasing the ethanol fuel concentration in blended fuel resulted in a slight rise in BP at all speeds. The indicated mean effective pressure increased as a result for blends with higher ethanol content. Due to increased evaporation heat, which also boosts charge density and fuel-air cooling, improved power output is obtained when compared to gasoline. A higher amount of ethanol leads to increased engine volumetric efficiency and mixture density, both of which enhance brake power[15]. Figure 1 presents a comparison of both E0 (0 % ethanol and 100% gasoline) and E50 (50% ethanol and 50% gasoline) fuels with various CRs for the BP. Despite having an identical CR, E50 produces more power by almost 6% than E0 with increasing engine speed. Operating the engine on E50 fuel at a CR of 10/1 reduced engine knocking and resulted in a 29% increase in power over E0 fuel at a ratio of 6/1[16].

3.2 Brake Specific Fuel Consumption

Figure 2. presents a comparison of E0 and E50 fuels at different CRs on BSFC. The lowest specific fuel consumption value for E0 gasoline is 411 g/kWh at a CR 6/1 near about 2500 rpm. The SFC rises by almost 19% when the engine runs on E50 fuel at the same CR. The

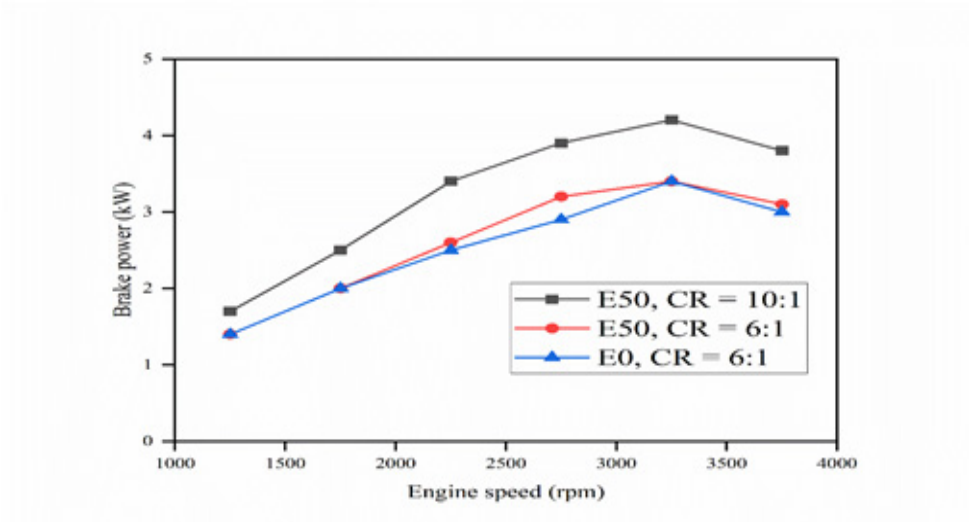


Figure 1. BP for both E0 and E50 fuels with varying CRs[17].

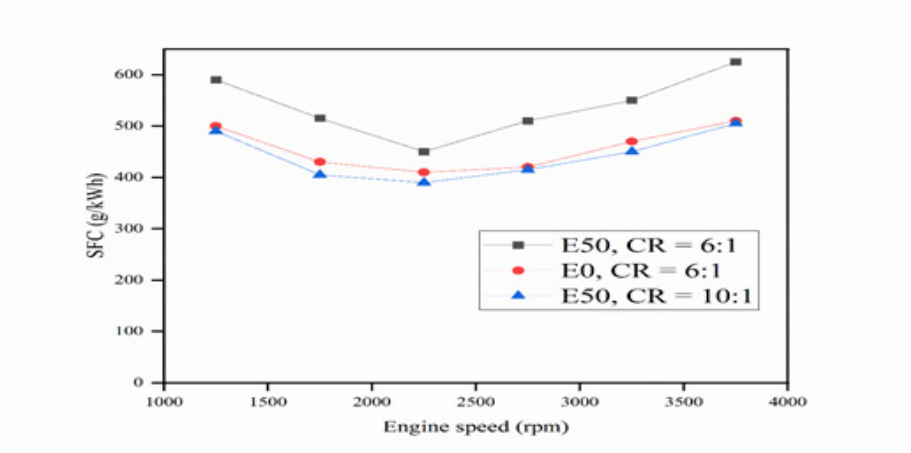


Figure 2. BSFC for E0 and E50 fuels with varying CRs[19].

Heating Value (HV) of ethanol is less as compared to regular gasoline, which leads to enhanced BSFC. About 3% less SFC is obtained when an engine operates on E50 fuel at a CR (10:1). As compared to regular gasoline, ethanol fuel has a lower heating value. Certain increases in fuel usage for E50 fuel were reduced by increasing the CR from 6/1 to 10/1. Additionally, there was a 3% drop in BSFC[18].

3.3 Brake Torque (BT)

The engine torque rose as the compression ratio changed between 8:1 and 11:1. Rise in the ratio was around 8%. However, improvements are about 0.95% with E0 in the range of CR 1:1 and 13:1. With E40 and E60 fuels, the engine torque increasing ratio reached its maximum at 13:1, an increase of almost 14% over the 8:1 compression ratio. Using the tested ethanol proportion in the blends resulted in enhanced engine torque output. It is expected to boost the engine's brake torque. Studies show that when the compression ratio and engine speed rise, it also increases the engine torque[20-21].

3.4 Brake Thermal Efficiency

Blends significantly raised the efficiency of the petrol engine. For speeds, BTE rose but BP improved when E5 (5% ethanol and 95% gasoline) and E10 (10% ethanol and 90% gasoline) blends were used. A decrease in BSFC is one of the main reasons for this. E5 and E10 have 1.9% and 2.5% higher thermal efficiency at 100 km/h than unleaded gasoline. Likewise, from an 80 km/h speed, E10 shows a 0.4% increase in thermal efficiency over E5. E5 has a 0.8% lower thermal efficiency than unleaded gasoline. Since E10 blends burn more efficiently and have a higher oxygen rate than E5 blends. As a result, thermal efficiency increases. As a result of reviews showing that blend usage improves fuel's octane rating, it is stated that using blends more frequently has raised the engine's overall BTE. Engines using E5 and E10 blends have higher BTE than gasoline-powered engines. Higher Octane Numbers (ON) in blended gasoline lead to higher CRs and improved brake thermal efficiency in SI engines[22].

3.5 Volumetric Efficiency (Vol. Eff)

As the fuel blend's E% rises from 0% to 20%, it is evident that the volumetric efficiency rises as well because of the rise in Tv and drop in ΔT. On the other hand, as T rises and ΔT falls, the volumetric efficiency falls as the E% moves from 20% to 25%. Although there are many other ways to increase volumetric efficiency (Vol. Eff), squeezing the Inductive Charge (IC), and forcefully phasing the cams in naturally developed engines as done in racing are the two most effective techniques. The tendency of an IC engine to transport charge into and out of the cylinders efficiently is referred to as volumetric efficiency. When compared to Gasoline (G), blended fuel is considered to have a higher volumetric efficiency. The same can be related to the increase produced by the piston as blends burn in it, resulting in higher and cleaner combustion inside the cylinder and enhanced taking-in capability of an engine.

It is noted that the volumetric efficiency is five to ten percent higher than that of gasoline. The improvement in evaporative cooling of the blends is important due to the better Volumetric Efficiency (Vol. Eff). Reduced emissions of CO and UHC are considered to be a result of the increased volumetric efficiency. More combustion efficiency and a lower Fuel to Air (F/A) ratio are reflected in the improved volumetric efficiency (Vol. Eff)[7,15,19].

3.6 Heat Release Rate

Proper fuel combustion is made possible by the HRR (Heat Release Rate) measurement. HRR calculations attempt to obtain data about an engine's combustion process. By comparing the rates of heat release during combustion, ethanol blends, and gasoline can be used to assess their combustion characteristics. The heat release pattern indicates the additional heat generated when ethanol is mixed with gasoline fuel. It is most noticeable as the piston reaches TDC. The mixtures produce a lot of heat due to their high enthalpy. At both vehicle speeds, gasoline fuel releases heat faster than alcohol-gasoline blends. Moreover, the peak positions of HRR in ethanol-gasoline blends are larger than in regular Gasoline (G). Because ethanol contains oxygen, it burns more readily, which causes a large amount of fuel to burn close to the top dead center. Blends produce better and higher heat release rates in engines. Blends are still being tested, though, for their potential applications[23].

3.7 Cylinder Gas Pressure (CGP)

For engine speeds, the data shows that the cylinder gas pressure of conventional Gasoline (G) is raised earlier compared to that of fuel blends. Petrol has a higher cylinder gas pressure at 10 kW power than ethanol-gasoline fuel mixtures, indicating that the engine runs more effectively. This could be related to the prolonged burning time of Gasoline (G). As power rose, the cylinder gas pressure also increased. Fuel injection into the cylinder at an increasing percentage ratio of fuel and volumetric efficiency is the reason for this. In SI engines, the enthalpy of combustible fuel improves as Cylinder Gas Pressure (CGP) rises. Fuel energy is enhanced by enthalpy. By using the cylinder gas pressure, the ethanol blends' combustion properties can be compared to those of gasoline. An engine may be subjected to a higher compression ratio without producing engine knocking when the octane rating is higher. Consequently, an engine's power output can be significantly raised while using the same amount of gasoline fuel. Taking into account the low engine efficiency of today's petrol engines, this is a fairly beneficial characteristic[24].

3.8 Compression Ratio

Better thermal efficiency allows engines with a high CR to extract more energy from a given amount of A/F mixture. With less fuel, an equal ignition temperature can be reached with longer expansion cycles made possible by higher CRs. When a high CR engine runs on a lower-Octane Number (ON) the detonation increases. Enhanced knock tolerance and a higher compression ratio are provided by the significant octane number. Additionally, a high CR was shown to improve the efficiency of Ethanol (E) blends, which in turn lowered fuel economy loss related to E85's minimized energy level by almost 20%. The amount of NOx emissions is enhanced as the CR rises, particularly at high engine loads. When CR increases at significant engine loads, the overall rich mixture combustion's comparatively rapid burning rate combined with an excess temperature environment leads to a rise in oxides of nitrogen emissions[25].

4.0 Exhaust Emissions Analysis

Engine emissions including CO, HC, and NOx are decreased when ethanol fuel is used. Since blends' pollutants are reported to be significantly cleaner than those of conventional fuels, they also have minimized levels of toxicity. A detailed literature review demonstrates the influence of ethanol blends on the main emission components[26].

4.1 Carbon Dioxide Emissions (CO_2)

The trend of rising CO_2 emissions is attributed to the addition of ethanol to gasoline according to reports. This is due to the fuel's carbon having completely oxidized. Another cause for this unwarranted decline is increased volumetric efficiency. Because ethanol fuel has a higher latent heat of vaporization the CO_2 levels have increased[27]. However, the above-mentioned CO_2 increase issue can also be reduced by raising the ethanol level but only at

slower engine speeds[21,22]. The previous graphs show that adding ethanol or fuel with more oxygen reduces CO_2 emissions and other pollutants. Longer combustion, improved A/F mixing, and rapid evaporation of the fuel may be the reason for this. Minimal speeds and heavy loads lead to less CO_2 pollutants from the engine than other conditions. Furthermore, a 5% increase in the fuel's ethanol concentration results in a 6.3% decrease in carbon dioxide[23].

4.2 Carbon Monoxide Emissions (CO)

The influence of blended fuels on reducing Carbon monoxide emissions. The quantity of CO emissions decreases as ethanol content rises. This indicates that adding ethanol can effectively lower the amount of CO emissions. CO emission levels can be reduced by up to 90%, depending on the engine's operating conditions[24]. At a 10:1 compression ratio, the CO emissions from three fuels (E0, E50, and E85) were less than 1% by volume across the full speed range. When the A/F mixture is not given enough air or time in the cycle for combustion to complete, incomplete combustion takes place. The performance of the engine and the air-fuel ratio have significant effects on the quantity of carbon pollutants. Pollutant levels are significantly affected by changes in the AFR during the experiments. Since CO separates at lower combustion temperatures, it is still present in exhaust even in a lean mixture[25]. CO pollutants can be decreased by using more of the blends in an engine. In the future, this promotes the usage of mixtures as a sustainable way of minimizing harmful emissions.

4.3 Nitrogen Oxides Emissions (NO_x)

Ethanol reduces NOx emissions when added to gasoline fuel. Although the water content in fuel has more effect on lowering these exhaust emissions than the actual alcohol level, it also causes the engine's torque to decrease. We can minimize the engine's operating temperature and significantly raise the compression ratio without increasing NOx by using blends. Based on reports, the generation of NOx, or the interaction of nitrogen and engine fuel along with the formation of harmful greenhouse gases as a result of oxidation, cannot be ignored in low-temperature fuel-rich situations that persist during different phases of the combustion process[17,18,26]. Various blends generate NO_x emissions at different speeds as well as exhaust temperatures, giving valuable insights. In comparison to the data shown preceding, adding upto15% ethanol reduces NOx pollutants by approximately 83%. Although the quantity of gases generated by normal gasoline fuel is fairly substantial at specific rpm. NOx emissions are decreased by fuel with a higher ethanol content, particularly at high exhaust temperatures. When evaluating engine emissions, this is a significant aspect to take into account. NO_x emissions increase as engine speed rises[23].

4.4 Hydrocarbon Emissions

A portion of the F/A mixture "hides" for the flame in diesel engines by filling the gap created by the piston ring grooves. Furthermore, a very faint flame as well as low combustion temperature may occur in some areas of the combustion chamber. There is a reported drop in Unburned Hydrocarbon when the blend's ethanol content rises. Improved chain reaction, or the fuel's hydrocarbons inflaming continuously and unabatedly, also lowers the fuel's hydrocarbon emissions[27]. The significant impact of ethanol blends on HC pollutants. Unburned hydrocarbons are the primary reason for concern when it comes to engine emissions. The low efficiency of the engine is directly related to the rise in pollutants. Significant fuel waste occurred, and pollutant levels rose as well. Blends exhibit better combustion, which results in less unburned fuel being trapped in some particular parts of the engine. Ethanol usage lowers the level of hydrocarbons for every 5% of ethanol, the percentage of hydrocarbons dropped by about 6%[23,27]. The studies revealed that as the engine speed was raised for constant load, HC concentration decreased because of prolonged overlap of valve periods at low speeds, with a more substantial reduction at higher speeds[3].

5.0 Conclusions

The present paper reviews the influence of Ethanol (E) for the performance of SI engines. The addition of ethanol to petrol usually results in faster combustion, better combustion rates, as well as increased engine performance. The following is a list of conclusions from the previous studies:

1. The influence of operating temperatures on all studied SI engine parameters was not taken into account. Ambient temperature variations in India have a significant impact on engine heat transfer rates, requiring further research.

2. The usage of ethanol as a fuel only serves to highlight the dominance of oil-rich nations in international forums and the increasing control over the price of crude oil. The global currency exchange is mostly driven by oil imports, therefore independent ethanol usage is a viable option.

3. Blends of ethanol and gasoline have been shown to improve volumetric efficiency. The percentage of ethanol reduces NO_x concentrations in engine exhaust emissions.

4. A 15% ethanol blend was shown to reduce pollutants by 71% overall. However, it improves the overall efficiency as well as the output power of the engine.

5. It is observed that each 5% rise in ethanol reduces unburnt hydrocarbon emissions by approximately 6%.

6. Ethanol increases the amount of carbon dioxide in the exhaust, which reduces CO_2 emissions when added to gasoline.

7. The efficiency of gasoline engines is better affected by ethanol fuel with higher octane ratings.

8. It shows that raising the CR and engine speed both increase Brake Torque (BT).

9. Ethanol fuel has a Lower Heating Value (LHV) as compared to pure gasoline, which causes the BSFC to rise.

10. It reveals that ethanol addition can significantly reduce CO emissions. Carbon monoxide pollutant levels can be decreased by up to 90% depending on engine operation conditions.

6.0 References

1. Deshmukh M, Pendse DS, Pande A. Effects of blending bioethanol with gasoline on spark-ignition engine-A review. J Integr Sci Technol. 2022; 10(2):87-99.
2. Iodice P, Amoresano A, Langella G. A review on the effects of ethanol/gasoline fuel blends on NO_X emissions in spark-ignition engines. Biofuel Res J. 2021; 8(4):1465–80. https://doi.org/10.18331/BRJ2021.8.4.2
3. Mohammed MK, Balla HH, Al-Dulaimi ZMH, Kareem ZS, Al-Zuhairy MS. Effect of ethanol-gasoline blends on SI engine performance and emissions. Case Stud Therm Eng. 2021; 25. https://doi.org/10.1016/j.csite.2021.100891
4. Verma A, Dugala NS, Singh S. Experimental investigations on the performance of SI engine with Ethanol-Premium gasoline blends. In: Mater Today: Proceedings; 2021. p. 1224–31. https://doi.org/10.1016/j.matpr.2021.08.255
5. Köten H, Karagöz Y, Balcı Ö. Effect of different levels of ethanol addition on performance, emission, and combustion characteristics of a gasoline engine. Adv Mech Eng. 2020; 12(7). https://doi.org/10.1177/1687814020943356
6. Geo VE, Godwin DJ, Thiyagarajan S, Saravanan CG, Aloui F. Effect of higher and lower order alcohol blending with gasoline on performance, emission and combustion characteristics of SI engine. Fuel. 2019; 256.https://doi.org/10.1016/j.fuel.2019.115806
7. Chansauria P, Mandloi RK. Effects of ethanol blends on performance of spark ignition engine- A review. In: Mater Today: Proceedings; 2018. p. 4066–77. https://doi.org/10.1016/j.matpr.2017.11.668
8. Thakur AK, Kaviti AK, Mehra R, Mer KKS. Progress in performance analysis of ethanol-gasoline blends on SI engine. Renew Sustain Energy Rev. 2017; 69:324–40. http://dx.doi.org/10.1016/j.rser.2016.11.056
9. Kowalewicz A, Wojtyniak M. Alternative fuels and their application to combustion engines. In: Proc Inst Mech Eng D: J Automob Eng. 2005; 103–25. https://doi.org/10.1243/095440705X6399
10. Bayraktar H. Experimental and theoretical investigation of using gasoline-ethanol blends in spark-ignition engines. Renew Energy. 2005; 30(11):1733–47. http://dx.doi.org/10.1016/j.renene.2005.01.006
11. Taha AA, Abdel-Salam T, Vellakal M. Hydrogen, biodiesel and ethanol for internal combustion engines: A review paper. In: ASME 2015 Internal Combustion Engine Division Fall Technical Conference, ICEF 2015. American Society of Mechanical Engineers; 2015. https://doi.org/10.1115/ICEF2015-1011
12. Masum BM, Masjuki HH, Kalam MA, Fattah RIM, Palash MS, Abedin MJ. Effect of ethanol-gasoline blend on NOx emission in SI engine. Renew Sustain Energy Rev. 2013; 24:209–22. http://dx.doi.org/10.1016/j.rser.2013.03.046
13. Pana C, Negurescu N, Cernat AL, Soare D. Aspects of the use of ethanol in spark ignition engine. SAE Technical Paper; 2007. https://doi.org/10.4271/2007-01-2040
14. Balki MK, Sayin C. The effect of compression ratio on the performance, emissions, and combustion

of an SI (Spark Ignition) engine fueled with pure ethanol, methanol, and unleaded gasoline. Energy. 2014; 71:194–201. http://dx.doi.org/10.1016/j.energy.2014.04.074

15. Thakur AK, Kaviti AK, Mehra R, Mer KK. Performance analysis of ethanol-gasoline blends on a spark ignition engine: A review. Biofuels. 2017; 8(1):91-112.http://dx.doi.org/10.1080/17597269.2016.1204586
16. Celik MB. Experimental determination of suitable ethanol–gasoline blend rate at high compression ratio for a gasoline engine. Appl Therm Eng. 2008; 28(5-6):396-404. http://dx.doi.org/10.1016/j.applthermaleng.2007.10.028
17. Yücesu HS, Topgül T, Cinar C, Okur M. Effect of ethanol-gasoline blends on engine performance and exhaust emissions in different compression ratios. Appl Therm Eng. 2006; 26(17-18):2272-8. http://dx.doi.org/10.1016/j.applthermaleng.2006.03.006
18. Eyidogan M, Ozsezen AN, Canakci M, Turkcan A. Impact of alcohol–gasoline fuel blends on the performance and combustion characteristics of an SI engine. Fuel. 2010; 89(10):2713-20. https://doi.org/10.1016/j.fuel.2010.01.032
19. Al-Hasan M. Effect of ethanol–unleaded gasoline blends on engine performance and exhaust emission. Energy conversion and management. 2003 Jun 1;44(9):1547-61. https://doi.org/10.1016/S0196-8904(02)00166-8
20. Pikonas A, Pukalskas S, Grabys J. Influence of the composition of gasoline-ethanol blends on parameters of internal combustion engines. J KONES. 2003; 10(1-2):205-11.
21. Elfasakhany A. Investigations on the effects of ethanol–methanol–gasoline blends in a spark-ignition engine: Performance and emissions analysis. Eng Sci Technol Int J. 2015; 18(4):713–9. http://dx.doi.org/10.1016/j.jestch.2015.05.003
22. García CA, Manzini F, Islas J. Air emissions scenarios from ethanol as a gasoline oxygenate in Mexico City Metropolitan Area. Renew Sustain Energy Rev. 2010; 14. http://dx.doi.org/10.1016/j.rser.2010.07.011
23. Ghazikhani M, Hatami M, Safari B, Ganji DD. Experimental investigation of performance improvement and emissions reduction in a two-stroke SI engine by using ethanol additives. Propuls Power Res. 2013; 2(4):276–83.http://dx.doi.org/10.1016/j.jppr.2013.10.002
24. Hsieh WD, Chen RH, Wu TL, Lin TH. Engine performance and pollutant emission of an SI engine using ethanol-gasoline blended fuels. Atmos Environ. 2002; 36(3):403-10. http://dx.doi.org/10.1016/S1352-2310(01)00508-8
25. Koç M, Sekmen Y, Topgül T, Yücesu HS. The effects of ethanol–unleaded gasoline blends on engine performance and exhaust emissions in a spark-ignition engine. Renew Energy. 2009; 34(10):2101-6. http://dx.doi.org/10.1016/j.renene.2009.01.018
26. Suarez-Bertoa R, Zardini AA, Keuken H, Astorga C. Impact of ethanol containing gasoline blends on emissions from a flex-fuel vehicle tested over the Worldwide Harmonized Light duty Test Cycle (WLTC). Fuel. 2015; 143:173-82. http://dx.doi.org/10.1016/j.fuel.2014.10.076
27. Wang X, Chen Z, Ni J, Liu S, Zhou H. The effects of hydrous ethanol gasoline on combustion and emission characteristics of a port injection gasoline engine. Case Stud Therm Eng. 2015; 6:147-54. http://dx.doi.org/10.1016/j.csite.2015.09.007