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A Brief Investigations of Potentiality of Ethanol as a Fuel for Dedicated Engine and Emission Characteristics of Spark Ignition Engine with Ethanol and Petrol Fuel Blends

Chandrashekar M[1], Syed Juneth[2], Mithun R[3], Pradeep S Ammagol[4], Vilas Rao J D[5]

[1]**Associate professor,** Dept of Mechanical Engineering, Dr Ambedkar Institute of Technology -Bangalore-560056
Dept of Mechanical Engineering, Dr Ambedkar Institute of Technology -Bangalore-560056

ABSTRACT-

This project is about the results and analysis obtained during the test of an IC engine with ethanol before and after modification. As we want to run an IC engine with ethanol, its physical and chemical properties play crucial role. Due to different physical & chemical properties of ethanol than that of gasoline, proper engine parameters should be maintained in gasoline engine to run it with ethanol i.e. the stoichiometric ratio needs to be maintained. An attempt to test gasoline-based IC engine using ethanol initially didn't give promising result in terms of efficiency and mileage. Carburettor of engine was modified so as to maintain proper stoichiometric ratio which improved the brake power of engine but with more fuel consumption; resulting to lesser thermal efficiency at the end. Finally, the optimal utilization of ethanol in the modified gasoline engine was done by changing the compression ratio of the engine. Since, ethanol has higher octane rating, it can sustain higher compression ratio and boost up the engine performance. The gasoline & ethanol (with modified carburettor) test was done in 4 stroke gasoline engine test rig and the results like brake power, specific fuel consumption and brake thermal efficiency was analysed. The loss in efficiency in case of ethanol was brought down by increasing the compression ratio of same engine. Due to some feasibility constraint, variable compression ratio (VCR) engine was used for experiments rather than changing the compression ratio of the engine itself.

Key words- Carburettor, Compression ratio, Ethanol, IC engine, Thermal efficiency, etc.

1. Introduction-

Ethanol, a renewable biofuel derived from plant materials, has garnered significant attention as a potential alternative to traditional gasoline. Its use in internal combustion engines offers several advantages, including reduced greenhouse gas emissions and improved air quality. This study explores the feasibility of using ethanol as a dedicated fuel for internal combustion engines, focusing on its potential to enhance engine performance and efficiency. Additionally, the research examines the emission characteristics of various ethanol-petrol blends, such as E10, E20, and E100, to determine their environmental impact. By analysing the physical and chemical properties of ethanol, as well as the necessary engine modifications, this study aims to provide a comprehensive understanding of ethanol's viability as a sustainable fuel alternative. The findings could pave the way for more widespread adoption of ethanol, contributing to a reduction in fossil fuel dependency and promoting cleaner, greener transportation solutions.

2. Project Statement-

This project aims to investigate the feasibility of modifying a four-stroke petrol engine to run on E10, E20 and E100. analysing its performance, efficiency, and emissions. The study will involve engine modification, performance testing, and emissions analysis, comparing the results with those obtained using gasoline. The project seeks to develop a sustainable alternative fuel solution, reducing dependence on fossil fuels and mitigating environmental impacts.

3. Literature Review-

[1] I. Vimalkannan et al. (2015) conducted an experimental investigation on a four-stroke single-cylinder petrol engine using ethanol-gasoline blends (E75 and E90). The study found that blending 90% ethanol with gasoline improved engine performance, reducing fuel costs while enhancing combustion efficiency. Additionally, ethanol-gasoline blends significantly reduced harmful emissions, including carbon monoxide (CO) and carbon dioxide (CO_2), by 30% and 12%, respectively. Although nitrogen oxide (NO) emissions increased, the use of 90% ethanol was identified as an optimal substitution, balancing enhanced engine performance and reduced emissions.

[2] Poudel and Deb (2017) investigated the feasibility of using ethanol as a fuel in internal combustion (IC) engines. Their study found that ethanol can be used as a substitute for gasoline in existing petrol engines, but with some modifications. The efficiency and output power of the engine were lower with ethanol due to its lower calorific value. However, modifying the carburetor by increasing the jet diameter improved engine performance. Additionally, using ethanol allowed for higher compression ratios, up to 15:1, which increased engine efficiency. The study concluded that with suitable modifications, existing petrol engines can be converted to run on ethanol, reducing reliance on non-renewable energy sources.

[3] Jeuland et al. (2004) examined the effects of ethanol addition to gasoline on engine performance and emissions. The study revealed that ethanol-gasoline blends improved engine power and efficiency, while reducing CO and HC emissions. However, NOx emissions increased with ethanol content up to 30%, then decreased. The results highlight the potential benefits of ethanol-gasoline blends, but also underscore the need for optimal ethanol content based on engine design and operating conditions. The study investigates ethanol- gasoline blends' impact on engine performance and emissions, finding improved power and efficiency, reduced CO and HC emissions, and increased NOx emissions up to 30% ethanol content. Department of Mechanical Engineering Page 15 2024-2025 Potentiality of Ethanol As a Fuel for Dedicated Engine and Study of emission characteristics of ethanol and Petrol fuel blends.

[4] R. Karthikeyan et al. (2021) investigated the effects of ethanol-gasoline blends on engine performance and emissions using a Yamaha RL5 engine. The study found that increasing ethanol levels in the blend decreased brake thermal efficiency due to ethanol's lower calorific value. However, hydrocarbon, carbon monoxide, and nitrogen oxide emissions decreased with increasing ethanol percentages across various engine speeds. The inclusion of oxygen in the fuel blend helped reduce CO emissions, while the high heat of vaporization of ethanol lowered peak temperatures, reducing NOx emissions. Overall, the study suggests that ethanol-gasoline blends can be a viable alternative fuel option for reducing emissions.

[5] Akshay Choudhary and Ashish Suryavanshi (2018) investigated the use of ethanol as a fuel in four-wheeled automobiles. To optimize engine performance, modifications were made, including advancing spark plug timing by 20 degrees to compensate for ethanol's slower burn rate. Additionally, vacuum advancement was set to provide an extra 10 degrees of advance over idle ignition time. To address ethanol's lower energy content, a 14.7:1 stoichiometric air-fuel mixture was recommended, along with increasing jet size by 10-15% for cold starts. Additives and a 350-watt resistance heater were also used to aid cold starts. Furthermore, increasing the compression ratio from 10:1 to 15:1 was suggested to optimize engine performance with ethanol fuel.

[6] Muhammad Usman et al. conducted a comparative study on the performance and emissions characteristics of ethanol (E) and ethanol-methanol (EM) blends with gasoline in a spark ignition (SI) engine. The results showed that E10 and E5M5 blends improved brake power by 5.7% and 4.91%, respectively, and brake thermal efficiency by 2.35% and 1.53%, respectively, compared to pure gasoline. Additionally, hydrocarbon and carbon monoxide emissions decreased significantly, with E10 achieving reductions of 13.2% and 36.2%, respectively. However, carbon dioxide and nitrogen oxide emissions increased, with E10 producing 13.6% more CO2 and 22.7% more NOx than pure gasoline. The study suggests that E10 offers superior performance and lower emissions, while E5M5 produces slightly lower NOx emissions, and highlights the need for future research on post-treatment technologies and additives to support sustainable use of alcoholic fuel blends Department of Mechanical Engineering Page 16 2024-2025 Potentiality of Ethanol As a Fuel for Dedicated Engine and Study of emission characteristics of ethanol and Petrol fuel blends.

[7] Farha Tabassum Ansari, Abhishek Prakash Verma, and Alok Chaube (2013) investigated the effects of ethanol blends (E40, E60, and E100) on engine performance and emissions. The results show that ethanol blends improve combustion efficiency, reduce fuel consumption, and lower emissions (CO and HC). The oxygenated nature of ethanol promotes complete combustion, leading to higher exhaust gas temperatures. Higher compression ratios and ethanol content optimize combustion and reduce emissions. However, proper engine cooling systems are essential to prevent overheating when using ethanol blends. Overall, the findings suggest that ethanol blends can improve engine performance, reduce harmful emissions, and optimize combustion.

[8] V Ganeshan's "Internal Combustion Engines" (4th edition), published by Tata McGraw Hill Education Private Limited, provides a comprehensive overview of IC engines. The book covers essential topics such as engine fundamentals, thermodynamic principles, engine design, performance, and emissions, offering valuable insights for students, researchers, and professionals in the field of automotive engineering.

[9] Alberto Boretti, The paper "Analysis of Design of Pure Ethanol Engines" by Alberto Boretti from the University of Ballarat explores the potential of ethanol as a renewable fuel for engines. Ethanol, unlike petroleum, can be produced from agricultural feedstocks and has a higher-octane number, which may allow for increased power output and better fuel economy. The paper discusses the impact of advanced technologies such as downsizing, turbocharging, liquid charge cooling, high-pressure direct injection, and variable valve actuation on the performance and emissions of pure ethanol engines. The results of simulations provide guidelines for the development of new dedicated engines, highlighting the potential for ethanol to reduce greenhouse gas emissions and improve fuel efficiency.

4. Objectives

- **Analyse the Chemical Properties of Ethanol and its Impact on Engine Performance.** Understand ethanol's chemical composition, energy density, and combustion characteristics to determine its effects on engine efficiency, power output, and emissions.
- **Identify Necessary Engine Modifications for Efficient Ethanol Combustion.** Determine required engine design changes, such as fuel system adjustments, ignition timing modifications, and combustion chamber redesigns, to optimize ethanol fuel utilization.

- **Evaluate the Engine's Performance, Efficiency, and Emissions using Ethanol Fuel.** Assess the modified engine's performance, fuel efficiency, and emissions output using ethanol fuel, comparing results to traditional gasoline-fuelled engines.
- **Optimize Engine Design Parameters for Improved Power Output and Reduced Emissions.** Utilize simulation tools and experimental testing to optimize engine design parameters, ensuring maximum power output, efficiency, and minimized emissions when running on ethanol fuel.

- **Investigate Engine Durability**: Study the long-term effects of using ethanol as a fuel on engine components, including wear and tear, corrosion, and overall engine lifespan.
- **Economic Analysis**: Conduct a cost-benefit analysis of using ethanol as a fuel, considering factors such as fuel production costs, engine modification expenses, and potential savings from reduced emissions and improved efficiency.
- **Environmental Impact Assessment**: Evaluate the overall environmental impact of using ethanol as a fuel, including the life cycle analysis of ethanol production, distribution, and consumption.

5. Description of the Project

This study investigates the potential of ethanol as a dedicated fuel for internal combustion engines, focusing on its performance, efficiency, and emission characteristics. By modifying a four-stroke petrol engine to run on ethanol and various ethanol-petrol blends (E10, E20, E100), the research aims to optimize engine parameters such as the carburettor and compression ratio to enhance ethanol utilization. Initial tests showed suboptimal results with ethanol, but modifications improved brake power and reduced thermal efficiency losses. The study also analyses the emission profiles of these blends, highlighting the environmental benefits and challenges of using ethanol as a sustainable fuel alternative. The findings contribute to the development of cleaner, more efficient transportation solutions, reducing reliance on fossil fuels and mitigating environmental impacts.

History- Ethanol as a fuel for internal combustion engines is not a new concept. Indeed, the first internal combustion engines and vehicles (N. Otto in 1877, H. Ford in 1880, in 1892 in France) were drawn to run with pure alcohol (methanol or ethanol). In the United States and also in many countries such as France or United Kingdom, many studies were achieved in the 1920's and 1930's with this fuel, before the wide diffusion of leaded gasoline induced a decrease in the interest in ethanol for years. During the last decades, a renewed interest for ethanol has grown, linked with the more and more stringent emission limits. Moreover, some economical aspects, such as agricultural development have also favoured to the use of ethanol. Finally, the Kyoto Protocol and the growing concern for greenhouse gas emissions will lead in the next coming years to an increase in biofuel productions, among which ethanol has an important role to play.

Use Of Ethanol in The World- Brazil is the largest user of ethanol as a fuel. It is the only country that uses ethanol blends at concentrations higher than 10%, with the exception of the use of E85 in Flexible Fuelled Vehicles (FFV). Around 20% of the Brazilian cars currently operate on 100% ethanol. The remaining cars are optimized to run on 22% blends (to meet the range of 20-24% blends). Brazil consumption of ethanol is around 15 Gl/y.

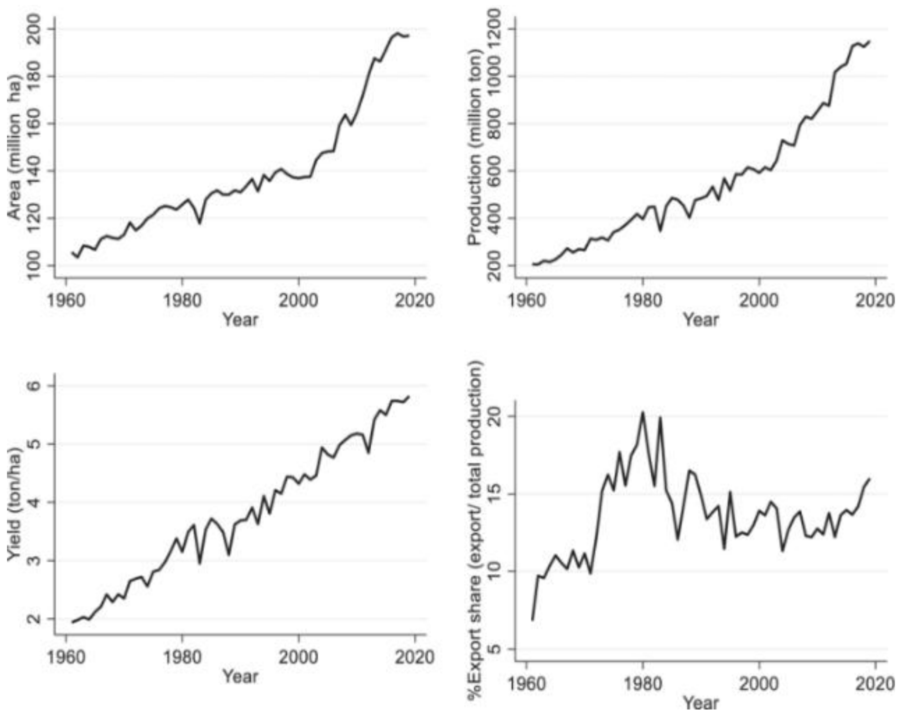
In the United States, the US EPA regulates the use of 10% ethanol blends via the "Substantially Similar Rule" to ensure that the use of oxygenates does not contribute to emission control system failure. The regulation prohibits the introduction, or increase in concentration of a fuel or fuel additive which is not "substantially similar to any fuel or fuel additive already utilized". The Substantially Similar Rule recognizes that the use of certain types of oxygenates have no adverse effect below a specified oxygen content.

The US EPA regulations also create a process by which a waiver can be granted for an oxygenated "recipe" that is demonstrated not to cause or contribute to the failure of any emission control device or system. Under this regulation, the US EPA has granted waivers for concentrations of ethanol in petrol up to 10%. The finished product has to pass gasoline specifications as defined by ASTM D 4814-88 and US original equipment manufacturer (OEM) vehicle warranties specify that petrol must contain no more than 10% ethanol. The use of blends higher than 10% in OEM vehicles could result in the void of vehicle warranties.

The US Department of Energy (under its Clean Cities Program) and the National Corn Growers Association are cooperating to promote the development of refuelling infrastructure for E85 and to encourage fleet operators to choose ethanol to meet the alternatively fuelled vehicles requirements of the Energy Policy Act. As previously stated, E85 blends require FFV. The potential phase-out of MTBE (methyl tert-butyl ether) and an increasing emphasis on domestic energy supplies and energy security are likely to favour in the United States the increased use of ethanol as a fuel. In Europe, the ethanol content in gasoline is limited to 5%vol.

ETHANOL PRODUCTION PATHWAYS

Ethanol production for fuel is a combination of biological and physical processes. The main production process is the fermentation of sugars with yeast. Ethanol is then concentrated to fuel grade by distillation. The raw materials can be obtained from various types of crops, such as corn, wheat, sugar beet, etc. Besides, some new ethanol production pathways appeared in the last years, producing ethanol from unconventional feedstock.



Graph 1: Time vs Area, production, Yield, Export

Formation & Combustion of Ethanol

i) Photosynthesis: (formation of glucose)

$6CO_2 + 6H_2O + light \rightarrow C_6H_{12}O_6 + 6O_2$

264gm 108gm 180gm 192gm

ii) Fermentation: (conversion into alcohol)

$C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2 + heat$

180gm 92gm 88gm

iii) Combustion of Alcohol:

$2C_2H_5OH + 6O_2 \rightarrow 4CO_2 + 6H_2O + heat$

92gm 192gm 176gm 108gm

In the reaction mentioned in reaction, 1 kg of fuel gives 29.7 MJ of energy and literally no Carbon dioxide. It is because the amount of carbon dioxide used to make certain amount of glucose during photosynthesis is same as the amount of carbon dioxide released during fermentation and combustion of alcohol. In overall phenomenon this process keeps the carbon dioxide amount in the atmosphere balanced.

Combustion of octane (a major component of gasoline)

2C8H18 + 25O2 → 16CO2 + 18 H2O + heat

228gm 800gm 704gm 324gm

In the above reaction, 1 kg of fuel gives 44.4 MJ energy and 1.42 kg CO2. From this we can say that, the energy released during combustion of ethanol fuel is approximately 30% lower than that during the combustion of gasoline. However, the gasoline produces significantly great amount of carbon dioxide gas and releases to the open atmosphere which leads to global warming and other hazards to the environment.

Ethanol production process- Ethanol production involves several steps, starting with the fermentation of sugars by yeast. The primary raw materials used are crops like corn, sugarcane, and other biomass. These materials are first ground into a fine powder and mixed with water to create a mash. Enzymes are then added to convert the starches into fermentable sugars. Yeast is introduced to the mash, which ferments the sugars into ethanol and carbon dioxide. The resulting mixture is then distilled to separate the ethanol from the water and other by-products. Finally, the ethanol is dehydrated to achieve the desired purity level, making it suitable for use as a biofuel or in various industrial applications. This process is both efficient and sustainable, contributing to the production of renewable energy sources. After the initial fermentation, the ethanol concentration in the mixture is relatively low, typically around 10-15%. To increase the concentration, the mixture undergoes a distillation process.

Distillation involves heating the mixture to separate the ethanol from water and other components based on their boiling points. Ethanol has a lower boiling point than water, so it evaporates first and is collected as a vapor. This vapor is then condensed back into liquid form, resulting in a higher concentration of ethanol.

However, the ethanol produced through distillation still contains some water. To achieve fuel-grade ethanol, which is at least 99% pure, a dehydration process is necessary. This is often done using molecular sieves or other advanced techniques that remove the remaining water molecules.The final product is anhydrous ethanol, which can be used as a biofuel, either on its own or blended with gasoline to create ethanol-blended fuels like E10 (10% ethanol, 90% gasoline) or E85 (85% ethanol, 15% gasoline).

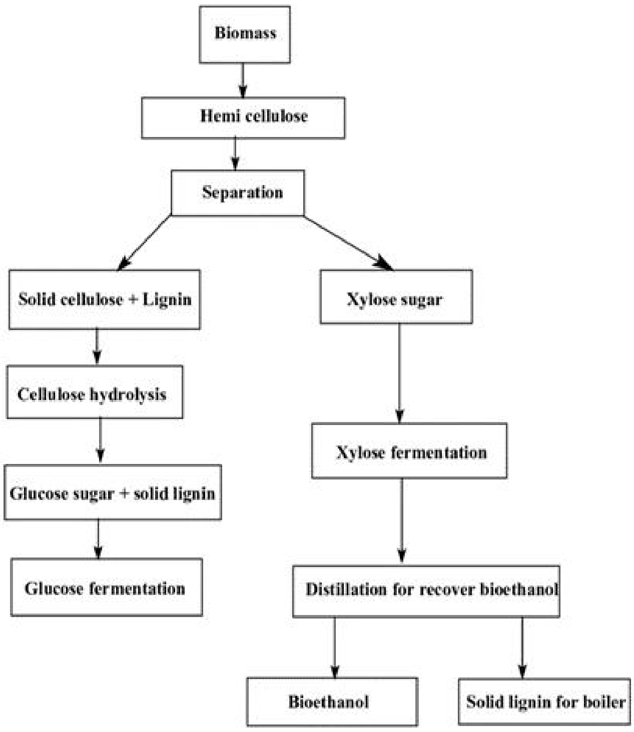


Figure 1: Ethanol production process

BENEFITS OF ETHANOL

Energy and Greenhouse Gas Balance- The development of biofuels, and especially ethanol, is strongly linked to their environmental performances in terms of greenhouse gas (GHG) emissions and energy saving. To evaluate their efficiency, many studies focused on the “Analysis of Life Cycle” of each path (LCA). The calculations show highly variable results, whose apparent discrepancies can be easily explained.

- As ethanol is produced from biomass, its energetic efficiency is strongly related to the raw material considered (corn, cellulose, etc.)
- Even when considering a single raw material type, the global efficiency is still strongly linked to the development of the production process (yield, agricultural techniques, use of fertilizers, etc.)
- Finally, the conversion rate of the raw material into ethanol can vary a lot.

The example of Indian corn ethanol is very symptomatic of these difficulties: before 1990, some studies showed a negative energy balance for corn ethanol. Never the less, the increase in yields, shown in Figure 2, turned the energy balance to positive.

	Beet			
Growing region	North France		EU	*Average*
	Aver.	Best		
Ref./case	[6]	[6]	[8]	
Ethanol yield t/ha	5.3	6.2	3.8	*4.5*
Energy balance	0.9	0.62	0.96	*0.9*
GHG balance	0.7	0.49	0.75	*0.7*

Figure 2: Growing region per Beet

The GHG balance is defined as the ratio of the net GHG production, expressed as CO2 equivalents, emitted when producing the biofuel to the amount of CO2 equivalents emitted when producing and burning an amount of fossil fuel representing the same end-use energy. A value above one denotes a net reduction in GHG emissions.

Considering the French case, the most recently published data (*ADEME*, data from *IFP*) indicate an energy balance of 0.49 for wheat ethanol and beet ethanol, and some more prospective scenarios foresee balances down to 0.28 for wheat and 0.3 for beet. The calculated energy needs for ethanol production have been shown to be highly variable, according to the raw material, the agricultural techniques and the calculation method. Nevertheless, all these calculations show a positive impact of ethanol in terms of greenhouse gas emissions, due to the fact that ethanol, as far as it is produced from biomass, should have (if ideal) a null CO2 balance (the CO2 emitted during the combustion should be counterbalanced by the CO2 captured by the crop during its growth). In fact, this theoretical and ideal case is never reached, due to energy needs for the agricultural process, the fertilizer uses (nitrogen fertilizers are linked with N2O emissions, which have a strong impact on greenhouse effect) and the transformation processes.

KEY PARAMETERS FOR THE MODIFICATION OF A DEDICATED ENGINE

The potential of ethanol in terms of greenhouse gas emissions, when produced from biomass, has been outlined above. Moreover, ethanol has some very interesting physical and chemical properties that can be turned into benefits with a dedicated engine, provided some technical difficulties are overcome. The following section describes these advantages and disadvantages of ethanol and gives an example of a preliminary development with a small displacement dedicated engine.

ETHANOL PROPERTIES

Physical Properties

1. ***Density:***

- E10: 0.75-0.78 g/ml (similar to gasoline)
- E20: 0.76-0.80 g/ml (slightly higher than E10)
- E100: 0.789-0.792 g/ml (higher than E10 and E20)

Density affects the fuel's energy density and engine performance.

2. ***Boiling Point:***

- E10: 38-204°C (similar to gasoline)
- E20: (slightly lower than E10)
- E100: 78.3°C (lower than E10 and E20)

Boiling point affects the fuel's volatility and engine performance.

3. ***Viscosity:***

- E10: 0.5-0.7 mm²/s (similar to gasoline)
- E20: 0.5-0.7 mm²/s (similar to E10)
- E100: 1.2-1.4 mm²/s (higher than E10 and E20)

Viscosity affects the fuel's flow and engine performance.

Performance Properties

1. ***Energy Density:***

- E10: 33.6 MJ/kg (similar to gasoline)
- E20: 32.5 MJ/kg (slightly lower than E10)
- E100: 26.7 MJ/kg (lower than E10 and E20)

Energy density affects the fuel's energy content and engine performance.

2. ***Engine Compatibility:***

- E10: Most gasoline engines
- E20: Most modern gasoline engines
- E100: Specialized engines or modifications required

Engine compatibility affects the fuel's usability in different engines.

3. ***Fuel Efficiency:***

- E10: Similar to gasoline
- E20: Slightly lower than E10
- E100: Lower than E10 and E20

Fuel efficiency affects the fuel's energy content and engine performance.

Environmental Properties

1. ***Greenhouse Gas Emissions:***

- E10: 2-3% reduction (compared to gasoline)
- E20: 4-6% reduction (compared to gasoline)
- E100: Up to 90% reduction (compared to gasoline)

Greenhouse gas emissions affect the fuel's environmental impact.

2. ***Air Quality:***

- E10: Reduced emissions of some pollutants (compared to gasoline)
- E20: Further reduced emissions of some pollutants (compared to E10)
- E100: Significant reduction in emissions of most pollutants (compared to others)

Air quality affects the fuel's environmental impact and human health.

Handling and Storage Properties

1. ***Storage Stability:***

- E10: Similar to gasoline
- E20: More prone to phase separation (than E10)
- E100: Most prone to phase separation (among the three)

Storage stability affects the fuel's usability and engine performance.

2. ***Handling Precautions:***

- E10: Similar to gasoline
- E20: Specialized handling equipment recommended
- E100: Specialized handling equipment required

Handling precautions affect the fuel's safety and usability.

3 ***Compatibility with Materials:***

- E10: Similar to gasoline
- E20: May not be compatible with some materials
- E100: Ethanol suitable materials are used to build a engine

OCTANE NUMBER

- E10 (10% Ethanol, 90% Gasoline): 87-91
- E20 (20% Ethanol, 80% Gasoline): 90-93
- E100 (100% Ethanol): 108-110

Note: The exact octane number may vary depending on the specific fuel blend and the region in which it is produced.

Why Octane Number

Matters The octane number is a measure of a fuel's resistance to engine knocking or pinging, which can damage the engine over time. Higher-octane fuels are more resistant to engine knocking and are typically required for high-performance or high-compression engines.

OXYGEN CONTENT

- E10 (10% Ethanol, 90% Gasoline): 3.7% by weight
- E20 (20% Ethanol, 80% Gasoline): 6.7% by weight
- E100 (100% Ethanol): 34.7% by weight

Why Oxygen Content Matters

Oxygen content affects the fuel's combustion characteristics, emissions, and engine performance.

Higher oxygen content can lead to:

- Improved combustion efficiency
- Reduced greenhouse gas emissions
- Increased engine performance

However, higher oxygen content can also lead to:

- Increased corrosion risk
- Potential engine damage if not designed for oxygenated fuels.

VOLATILITY

- E10 (10% Ethanol, 90% Gasoline): 550-650 mmHg (Reid Vapor Pressure)
- E20 (20% Ethanol, 80% Gasoline): 450-550 mmHg (Reid Vapor Pressure)
- E100 (100% Ethanol): 180-200 mmHg (Reid Vapor Pressure)

Why Volatility Matters

Volatility affects the fuel's:

- Evaporation rate
- Engine performance
- Emissions
- Safety and handling.

Higher volatility fuels:

- Evaporate more quickly
- May cause vapor lock or engine problems
- Can increase emissions and ozone formation

Lower volatility fuels:

- Evaporate more slowly
- May cause engine problems in cold weather
- Can reduce emissions and ozone formation

Effective solution is to blend ethanol with higher volatility fuels, such as gasoline, to improve its overall volatility. Additionally, using fuel additives designed to enhance volatility can help. Another approach is to preheat the ethanol fuel before it enters the combustion chamber, which can be achieved through heated fuel lines or fuel injectors. This preheating helps to vaporize the ethanol more effectively, ensuring better combustion. Implementing advanced fuel injection systems that can precisely control the fuel-air mixture can also improve the volatility and combustion efficiency of ethanol in engines.

WATER TOLERANCE

- E10 (10% Ethanol, 90% Gasoline): 0.5% v/v (volume/volume)
- E20 (20% Ethanol, 80% Gasoline): 0.3% v/v (volume/volume)
- E100 (100% Ethanol): 0.1-0.2% v/v (volume/volume)

Why Water Tolerance Matters

Water tolerance affects the fuel's:

- Stability and phase separation
- Corrosion risk
- Engine performance and emissions
- Safety and handling

Higher water tolerance fuels:

- Can absorb more water without phase separation
- May reduce corrosion risk
- Can improve engine performance and reduce emissions

Lower water tolerance fuels:

- May phase separate more easily
- Can increase corrosion risk
- May cause engine problems and increase emissions

Improving water tolerance in ethanol engines is crucial to prevent phase separation and corrosion. One effective solution is to use co-solvents like iso-propanol or ETBE (ethyl tert-butyl ether). These co-solvents enhance the solubility of ethanol and water in gasoline, reducing the risk of phase separation. Additionally, using materials resistant to ethanol-induced corrosion, such as stainless steel or PTFE (Teflon), in the fuel system can help mitigate the adverse effects of water contamination.

COLD START

Cold Start Characteristics

1. E10 (10% Ethanol, 90% Gasoline)

- Cold start temperature: around -20°C to -15°C (-4°F to 5°F)
- Starting ease: similar to gasoline

2. E20 (20% Ethanol, 80% Gasoline)

- Cold start temperature: around -10°C to -5°C (14°F to 23°F)
- Starting ease: slightly more difficult than E10

3. E100 (100% Ethanol)

- Cold start temperature: around 0°C to 5°C (32°F to 41°F)

- Starting ease: more difficult than E10 and E20, may require additional starting aids

Why Cold Start Matter

Cold start characteristics affect:

- Engine performance and emissions
- Starting ease and reliability
- Fuel efficiency and range
- Engine durability and lifespan

Factors Influencing Cold Start

- Fuel volatility and vapor pressure
- Engine design and compression ratio
- Ignition system and spark plug design
- Ambient temperature and humidity

Overcoming Cold Start Challenges

- Using fuel additives or cold start aids
- Implementing advanced ignition systems
- Optimizing engine design and compression ratio
- Utilizing alternative starting methods (e.g., glow plugs).

To improve cold start performance, several solutions can be implemented. Installing a heated fuel system can help vaporize ethanol more effectively at low temperatures. Using glow plugs can preheat the combustion chamber, making it easier to ignite the ethanol-air mixture. Adjusting the ignition timing to be more advanced can improve combustion efficiency and power output during cold starts. Pre-cranking the engine without fuel injection can help warm up the combustion chamber before the actual start. Additionally, some systems use a small secondary fuel tank with gasoline or a gasoline-ethanol blend to assist with cold starts. Once the engine is warm, it switches back to ethanol. These methods can be used individually or in combination to improve the cold start performance of ethanol-based engines.

EXPERIMENTAL WORK

1) PERFORMANCE TESTING OF EXISTING PETROL ENGINE

Figure 3: Existing petrol engine test

The performance testing of the existing petrol engine involved evaluating its power output, torque, brake specific fuel consumption (BSFC), and brake thermal efficiency (BTE) using petrol and ethanol- gasoline blends (E0,E10 and E20) as test fuels. The engine's performance was evaluated at different loads and speeds, and its exhaust emissions were measured using a gas analyzer. The results provided valuable insights into the engine's performance characteristics and emissions profile, which were used to assess the feasibility of converting the engine to run on ethanol-gasoline blends

ENGINE SPECIFICATIONS	
Type	Four stroke Single cylinder
Make	Major Aluminum alloy
Rating (output)	2 HP
Speed	3000 RPM constant , governor based
Fuel	Petrol
Bore diameter	56 mm
Stroke length	60.7 mm
Starting	Rope pulling
Compression Ratio	9.80 +/- 0.3 : 1

Table 1: Engine specifications

MECHANICAL DYNAMOMETER	
Type	Rope Brake
Rating	2 HP
Speed	3000 RPM (can any speed)
Cooling	Water cooling
Mounting	Bearing Mounting
Coupling	Shaft with Flywheel
Break drum	Machined and balanced
Spring balance	0-25 Kg and dead weights
Hand wheel	With bolt to load
Rope	19 mm dia , manila rope
Scoop	To remove hot water from break drum

Table 2: Specifications of mechanical dynamometer

A dynamometer is a device used to measure the force, torque, or power output of an engine or motor. It operates by applying a controllable load to the engine and measuring its rotational speed and torque. This data is used to calculate performance metrics such as horsepower and efficiency. Dynamometers are essential tools in automotive, aerospace, and manufacturing industries for engine testing and optimization.

2) **REQUIRED MODIFICATIONS**

1. Modification of Carburettor
2. Modification of Fuel lines
3. Modifications to increase compression ratio

1. Modification of Carburettor

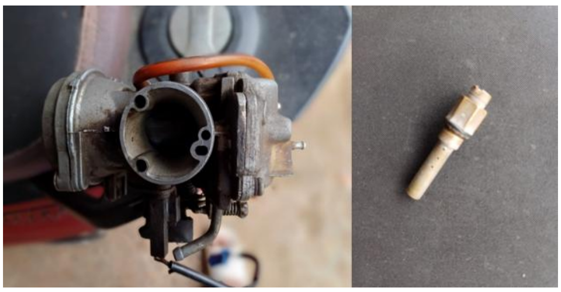


Figure 4: Carburettor and Jet

According to USDA report (2002) , we can use the following formula to get the exact required diameter of jet in carburettor for use in ethanol powered IC engine:

$$D = 3.75\sqrt{\frac{D^2}{14.7 - 5.7g}}$$

Where,

Do = initial diameter of jet (as in given engine carburettor)

ε = fraction of ethanol in ethanol-gasoline blend

D = final required diameter of jet in carburettor

Hence, by using above equation, we can find the required diameter of jet and we can perform drilling in that jet to achieve required dimension. After the jet diameter is altered, again test of engine is with ethanol is performed and similar parameters are analysed. The output power of engine is supposed to be increased by this modification. However, by increasing the jet size of carburetor we are letting more fuel to come out and mix with air so at the end fuel consumption is going to increase as compensation. This leads to one step further innovation in ethanol fuel which is derived by studying the chemical property of ethanol fuel.

2. Modification of Fuel lines

Ethanol can have a number of effects on fuel lines, depending on the concentration of ethanol in the fuel and the materials used in the fuel lines.

Some of the potential effects include:

● ***Degradation:*** Ethanol can cause some types of rubber and plastic fuel lines to degrade, becoming soft, brittle, or cracked. This can lead to fuel leaks, which can be a fire hazard

● ***Swelling***: Ethanol can cause some types of fuel lines to swell, which can restrict fuel flow and cause engine performance problems.

● ***Corrosion:*** Ethanol can corrode some types of metal fuel lines, particularly those made of aluminum or zinc.

To avoid these problems, it is important to use fuel lines that are compatible withethanol blended fuels.

Some suitable materials include:

● ***Nylon:*** Nylon is a type of plastic that is resistant to the effects of ethanol.

Figure 5: Nylon tube

● ***PTFE: Polytetra fluro ethylene (Teflon):*** PTFE is a type of fluoropolymer that is also resistant to the effects of ethanol.

Figure 6: PTFE tube

● ***Stainless steel:*** Stainless steel is a type of metal that is resistant to corrosion from ethanol.

In addition to using compatible materials, there are a few other things you can do to minimize the effects of ethanol on your fuel system:

● ***Use a fuel stabilizer:*** A fuel stabilizer can help to prevent ethanol from degrading your fuel lines and other components.

● ***Keep your fuel tank full:*** A full fuel tank will help to reduce the amount of air in the tank,which can help to prevent ethanol from evaporating and causing problems.

● ***Fuel system inspected:*** A mechanic can inspect your fuel system for signs of damage or corrosion caused by ethanol.

By following these tips, you can help to ensure that your fuel system is not damaged by ethanol-blended fuels.

3. Modifications to increase compression ratio:

Ethanol has a higher-octane rating compared to gasoline, which allows for higher compression ratios without the risk of knocking. Increasing the compression ratio can improve the thermal efficiency and power output of the engine. Typically, ethanol engines can operate with compression ratios ranging from 12:1 to 15:1, compared to the 8:1 to 10:1 range for gasoline engines. This modification involves adjusting the engine's cylinder head, piston design, and combustion chamber to accommodate the higher compression ratio. Additionally, advanced ignition timing and fuel injection systems are necessary to ensure proper combustion and prevent pre-ignition. Overall, modifying the compression ratio for ethanol engines enhances their performance, fuel efficiency, and reduces emissions.

1. Piston Modifications:

Dome or Dish: The shape of the piston crown plays a crucial role. A domed piston increases the compression ratio, while a dished piston decreases it.

Compression Height: The distance between the piston crown and the connecting rod at top dead center (TDC) affects the compression ratio. A shorter compression height increases the ratio.

2. Cylinder Head Modifications:

Combustion Chamber Volume: The volume of the space in the cylinder head above the piston at TDC directly impacts the compression ratio. Milling the head (removing material) or using a thinner head gasket can increase the ratio.

Valve Size and Location: Larger valves or valves positioned differently can affect the combustion chamber volume and thus the compression ratio.

3 Other Modifications

Head Gasket Thickness: A thinner head gasket reduces the distance between the head and the block, increasing the compression ratio.

Stroker Kit: Increasing the stroke of the crankshaft can increase the compression ratio, but it often requires other modifications to the engine.

Important Considerations:

Fuel Requirements: Higher compression ratios generally require higher-octane fuel to prevent engine knock (premature ignition).

Engine Strength: Increasing the compression ratio can put more stress on engine components, requiring careful consideration of material strength and cooling.

Tuning: Modifying the compression ratio often requires adjustments to other engine parameters, such as ignition timing and fuel delivery, to optimize performance and efficiency.

3) TESTING OF ETHANOL FUEL

1. Cleveland open apparatus (Flash point and Fire point)

Figure 8: Cleveland open cup apparatus

The Cleveland Open-Cup Tester is a laboratory device used to measure the flash point of a liquid. It consists of a heated cup or container, a thermometer, and an ignition source, such as a pilot flame. The test procedure involves filling the cup with the test liquid, heating it at a controlled rate, and observing the temperature at which the liquid ignites when the ignition source is applied. This device is commonly used in various industries, including petroleum and chemical processing, paints and coatings, pharmaceuticals, and aerospace. The Cleveland Open-Cup Tester offers several advantages, including a simple and easy-to-use design, fast and accurate results, and compliance with various international standards, such as ASTM D92. However, it also has some limitations, including a limited temperature range, requiring a skilled operator, and may not be suitable for certain types of liquids, such as those with high viscosity.

Table 3: Technical specification of open cup

Technical Specification	
Type	Cleveland open cup apparatus
Application range	up to 250 °C (°C/°F selectable)
Heating	Electric coil heating
Detection of fire and flash point	Manual stick firing
Sample temperature	Mercury in glass thermometer
Cup material	Brass
Safety	Overheat protection, manual shut-off
Power supply	115 V/230 V, 50 Hz/60 Hz, 600 W
Dimensions	150 mm x 150 mm x 200 (WxDxH)
Weight	5
Resolution	0.1w

2. **Red Wood Viscometer**

Figure 9: Redwood Viscometer

The Redwood Viscometer consists of a cylindrical oil cup furnished with a gauge point, a metallic orifice jet at the bottom having a conical depression from inside to facilitate a ball with a stiff wire to act as a valve to start or stop oil flow. The outer side of the orifice jet is convex, so that the oil under test does not escape over the lower edge of the oil cup. The oil cup is surrounded by a water bath with a circular electrical immersion heater and a stirring device. Two thermometers are provided to measure the water bath temperature and oil temperature under test. A round, flat-bottomed flask with a 50ml marking measures 50ml of oil flow against time. The water bath with oil cup is supported on a tripod stand with levelling screws.

Table 4: Technical specification of redwood viscometer

Technical Specification	
Type	Redwood viscometer
Model	IP 70
Oil cup	Silver plate Brass
Heating	Electric heating
Temperature measurement	Mercury in glass thermometer
Supplements	Silver plated ball valve , spirit level and cover , thermometer clip and receiver
Safety	Overheat protection , Manual shut-off
Power supply	230 V, 50 Hz Single phase , AC
Certified	NPL certified

Formulae

- $\rho = \frac{m1-m2}{50000} * 10^6 \text{ kg/m}^3$
- $\gamma = 0.22R - \frac{180}{R} * \frac{10^{-6}m^2}{sec}$

- $\mu = \gamma * \rho \ \ N - \frac{s}{m^2}$

4) Performance test of engine on pure Ethanol and Ethanol Blends (Modified engine)

Figure 10: Cleveland open cup apparatus

Comparing the performance and efficiency of modified engines using ethanol gasoline blends E10, E20, and E100 reveals interesting dynamics. E10, which consists of 10% ethanol and 90% gasoline, shows a slight decrease in engine power due to ethanol's lower energy content. However, it compensates with improved fuel consumption and thermal efficiency, resulting in lower carbon monoxide (CO) and unburned hydrocarbons (HC) emissions. Moving to E20, with 20% ethanol, there is a more noticeable reduction in engine power, but this blend significantly enhances fuel efficiency and thermal performance, leading to even lower emissions. Finally, E100, or pure ethanol, produces the lowest engine power and requires more fuel for the same output. Nevertheless, E100 excels in reducing CO and HC emissions, although it may ncrease aldehyde emissions. Despite the trade-off in engine power, increasing the ethanol content in fuel blends positively influences efficiency and emissions, making ethanol a compelling option for reducing environmental impact.

5) EMISSION TEST

CO_2 *EMISSIONS COMPARISON*

- E0 (0% Ethanol, 100% Gasoline): This serves as the baseline for comparison, with the highest CO2 emissions.
- E10 (10% Ethanol, 90% Gasoline): CO2 emissions are typically around 2-5% lower compared to E0.
- E20 (20% Ethanol, 80% Gasoline): CO2 emissions are typically around 5-10% lower compared to E0.
- E100 (100% Ethanol): CO2 emissions are typically around 60-70% lower compared to E0, due to the high renewable energy content of ethanol.

Key Observations

- CO2 emissions decrease as the ethanol content increases.
- E100 exhibits the largest reduction in CO2 emissions, making it an attractive option for reducing greenhouse gas emissions.
- However, it's essential to consider the overall well-to-wheel emissions, including production and transportation emissions, to accurately assess the environmental benefits of ethanol blends.
- Additionally, engine compatibility and fueling infrastructure must be considered when using high-ethanol blends like E100.Pollutant Emissions

CARBON MONOXIDE EMISSIONS COMPARISON

E10 (10% ethanol) typically reduces CO emissions by 10-20% compared to pure gasoline (E0). This reduction is due to ethanol's oxygen content, which helps fuel burn more completely. Moving to E20 (20% ethanol) can further enhance this effect, potentially lowering CO emissions by an additional few percentage points. In some cases, particularly with older vehicles, E20 might not provide significant additional benefits over E10.

E100 (pure ethanol) offers the most substantial CO reduction, often in the range of 30-50% compared to gasoline. This significant decrease stems from ethanol's clean burning properties and high oxygen content. However, it's crucial to remember that E100 is not compatible with all vehicles and may necessitate engine modifications.

It's important to note that these are approximate ranges, and the actual CO reduction can vary based on factors like engine technology, driving conditions, and fuel quality.

NOX EMISSIONS COMPARISONS

- E10 (10% ethanol): NOx emissions with E10 can be slightly higher, similar, or even slightly lower than E0 (pure gasoline). This depends heavily on factors like engine technology, combustion conditions, and the specific gasoline used in the blend.
- E20 (20% ethanol): Similar to E10, NOx emissions with E20 can vary. Some studies show slight increases in NOx, while others indicate reductions, particularly in modern, optimized engines.
- E100 (100% ethanol): Pure ethanol generally produces lower NOx emissions compared to gasoline. This is because ethanol burns at a lower temperature, reducing the conditions that favor NOx formation.

(HYDROCARBONS)EMISSIONS COMPARISONS

- E10 (10% ethanol): Generally, E10 leads to a noticeable reduction in hydrocarbon emissions compared to pure gasoline (E0). This reduction can range from 10-20%, depending on the engine and driving conditions.
- E20 (20% ethanol): The trend continues with E20, where HC emissions are typically lower than E10 and significantly lower than E0. The reduction with E20 can be in the range of 15-25% compared to gasoline.
- E100 (100% ethanol): Pure ethanol has a different chemical composition than gasoline, and its combustion process results in significantly lower HC emissions. Reductions of 50% or more compared to gasoline are common.

Key Observations

- Ethanol blends tend to reduce CO and HC emissions, but may increase NOx emissions.
- E100 exhibits the largest reduction in CO_2 emissions, making it an attractive option for reducing greenhouse gas emissions.
- PM emissions tend to be lower for E100, but similar or slightly lower for E10 and E20 compared to gasoline.
- The impact of ethanol blends on pollutant emissions can vary depending on engine technology, fuel formulation, and operating conditions.

MODIFIED ENGINE GOT SEIZED WHILE USING E100 AFTER SOME DAYS. WHY?

An engine can seize when using E100 due to a combination of factors. Firstly, ethanol is more corrosive than gasoline, potentially damaging fuel system components like lines, seals, and even metal parts in older engines not designed for it. Secondly, E100 can cause certain materials to swell or degrade, leading to leaks and blockages in the fuel system. Thirdly, ethanol has lower lubricity than gasoline, increasing friction and wear on engine parts, especially in older engines. This can be exacerbated by ethanol contamination of engine oil, reducing its effectiveness. Finally, E100's different fuel delivery requirements and higher octane rating can cause issues in engines not calibrated for it, potentially leading to improper combustion and engine damage. Essentially, using E100 in an incompatible engine can cause a cascade of problems, from corrosion and fuel delivery issues to increased wear and lubrication problems, ultimately resulting in engine seizure.

Solution for it

To build an engine that thrives on E100, you need materials that can withstand ethanol's corrosive nature and unique combustion properties. For the fuel system, opt for durable materials like PTFE (Teflon) or stainless steel for fuel lines, and ensure your fuel pump and injectors have ethanol-compatible seals and components. Within the engine itself, cast iron or specially coated aluminum alloys are suitable for the block and head, while pistons and rings should be coated or made from durable steel alloys to resist wear. Hardened steel alloys or ceramic coatings are crucial for valves and valve seats to handle the increased heat and corrosive effects of ethanol. Remember to use ethanol compatible gaskets and seals throughout, and protect sensors and electronics from exposure. By using these robust materials and incorporating design modifications, you can create an engine optimized for E100, contributing to a greener future for transportation

INVESTIGATION ON SUITABLE MATERIALS USED TO BUILD ETHANOL ENGINE

Building an engine specifically for pure ethanol (E100) requires careful material selection to ensure compatibility and longevity. Here's why:

Cylinder Head: Aluminum alloy is often preferred for its light weight and excellent heat dissipation, crucial for an efficient engine. However, the valve seats require hardened steel or stellite inserts to withstand the increased wear from ethanol's lower lubricity compared to gasoline. Durable valves, typically made of stainless steel, are essential for reliable operation in the high-temperature environment.

Cylinder Block: Cast iron provides robust strength and durability, especially for high-performance applications. Aluminum alloy offers a lighter alternative but may require cylinder liners for added wear resistance.

Pistons: Aluminum alloy pistons are lightweight and offer good heat transfer, contributing to efficient combustion. However, specialized piston rings with enhanced wear resistance are crucial to maintain a proper seal with ethanol.

Connecting Rods and Crankshaft: Forged steel is the go-to material for these critical components due to its exceptional strength and ability to withstand high stresses. Durable bearings ensure smooth operation and longevity.

Camshaft and Valve Train: The camshaft, often made of cast iron or steel, operates the valves, which are typically made of stainless steel for durability. Strong valve springs and rocker arms ensure precise valve control and long-term reliability.

Fuel System: Ethanol's corrosive nature necessitates a fuel system built with compatible materials. A stainless-steel fuel pump resists corrosion, while ethanol resistant fuel lines and a specially coated fuel tank prevent leaks and degradation.

Throughout the engine, ethanol-compatible gaskets and seals are vital to prevent leaks and maintain proper function.

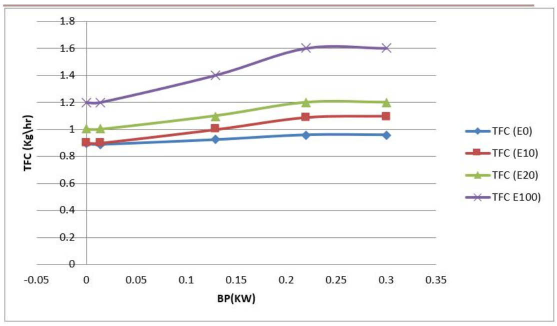
FURTHER OPTIMIZATION

These results show the true benefits brought by ethanol with only a little optimization of the engine: the increased compression ratio induces an important benefit in terms of engine efficiency and CO2 emissions. Still, some points have to be further studied to get a fully optimized engine:

- The tested engine was a PFI engine. To get full benefits from ethanol high latent heat of vaporization via the “cooling effect” (increase in filling efficiency due to the intake air cooling when ethanol is vaporized), a direct injection engine should be used.
- No change was done on the supercharging system. The optimization of this part of the engine could lead to an increased low-end torque.
- Some critical points, such as cold start management or lubricant compatibility, have to be further studied to obtain a fully useable engine.
- Aldehyde emissions have to be considered. As we have worked on engine-out emissions and as even aldehydes have been measured, it is not realistic to conclude on these pollutants without exhaust gas after-treatment.
- The catalyst adaptation has to be checked. Indeed, the low exhaust temperature found with ethanol can induce catalyst light-off difficulties.

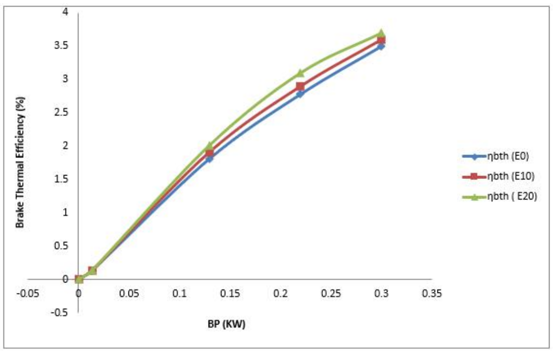
RESULTS AND DISSCUTION

PERFORMANCE TEST ON FOUR STROKE PETROL ENGINE BY USING E0,E10,E20.



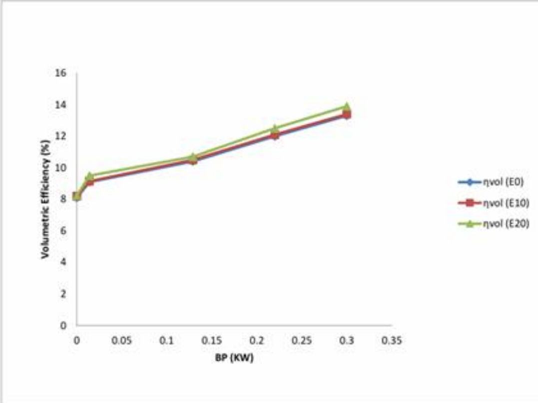
Graph 1: TFC vs BP

- TFC increases with increasing BP for all ethanol blends, indicating higher fuel consumption at higher engine loads.
- E100 exhibits the highest TFC across the entire BP range, followed by E20 and then E10.
- The rate of TFC increase with BP is more pronounced for E100 and E20 compared to E10



Graph 2: BTE vs BP

- The Brake Power (BP) versus Brake Thermal Efficiency (BTE) graph for ethanol blends E10, E20, and E100 shows how the engine's thermal efficiency changes with varying brake power for different ethanol-gasoline blends.
- Increasing the ethanol content in the fuel blend tends to improve the engine's thermal efficiency at higher power outputs, making ethanol a compelling option for enhancing engine performance and reducing environmental impact

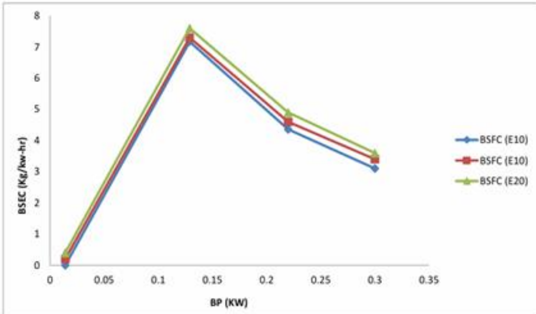


Graph 3: VE vs BP

Volumetric efficiency and brake power are both parameters that are affected by the amount of ethanol in a fuel blend. As the amount of ethanol increases, both volumetric efficiency and brake power increase.

Explanation

Volumetric efficiency: The efficiency of an engine at taking in and burning fuel. Ethanol's lower vapor pressure and higher flame speed increase volumetric efficiency. Brake power: The power produced by an engine.



Graph 4: BSFC vs BP

- BSFC decreases with increasing BP for all ethanol blends, indicating improved engine efficiency at higher loads.
- The Brake Specific Fuel Consumption (BSFC) versus Brake Power (BP) graph for ethanol blends E10, E20, illustrates how the fuel consumption efficiency of the engine changes with varying brake power for different ethanol-gasoline blends.

CONCLUSION

The study investigated the performance and exhaust emissions of a four-stroke single-cylinder petrol engine using Ethanol, in its various blends such as E10, E20, and E100, shows significant potential as an alternative fuel for dedicated engines. E10 and E20 blends offer a balance between improved combustion efficiency and reduced emissions, making them suitable for use in most modern gasoline engines with minimal modifications. E100, while requiring specialized engines or significant modifications, provides the highest reduction in greenhouse gas emissions and pollutants, making it an attractive option for reducing environmental impact. The study highlights that ethanol's higher-octane rating and oxygen content contribute to better engine performance and cleaner combustion. However, challenges such as cold start issues, material compatibility, and fuel system modifications need to be addressed to fully realize the benefits of ethanol as a sustainable fuel alternative. Overall, ethanol blends, particularly E100, present a promising solution for reducing reliance on fossil fuels and mitigating environmental impacts.

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REFERENCES

1. Vimalkannan,A.Pradeep, K.S.Babulal, P.Muthukumar, International Journal of Applied Engineering Research, ISSN 0973-4562 Vol. 10 No.56 (2015)
2. Poudel, S., & Deb, D. (2017). International Journal of Engineering and Applied Sciences (IJEAS) ISSN: 2394-3661, Volume-4, Issue-8, August 2017.
3. N. Jeuland, X. Montagne and X. Gautrot, Oil & Gas Science and Technology – Rev. IFP, Vol. 59 (2004), No. 6, pp. 559-570 Copyright © 2004
4. 4R.Karthikeyan , P.Pavan , T.Sankaramoorthy , S.Nagendharan, International Journal of Engineering Applied Sciences and Technology, 2021 Vol. 6, Issue 5, ISSN No. 2455-2143, Pages 379-382
5. Akshay Choudhary, Ashish Suryavanshi, International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056 Volume: 05 Issue: 06 | June -2018 www.irjet.net p-ISSN: 2395-0072.
6. Muhammad Usman, Muhammad Ali Ijaz Malik , Tariq Nawaz Chaudhary , Fahid Riaz , Sohaib Raza, Muhammad Abubakar, Farrukh Ahmad Malik, Hafiz Muhammad Comparative Assessment of Ethanol and Methanol–Ethanol Blends with Gasoline in SI Engine for Sustainable Development
7. Farha Tabassum Ansari , Abhishek Prakash Verma , Alok Chaube, International Journal of Engineering Research & Technology (IJERT) Vol. 2 Issue 12, December – 2013.
8. V Ganeshan, Published by the Tata McGraw Hill Education Private Limited, 7 West Patel Nagar, New Delhi 110 008.
9. Alberto Boretti,University of Ballarat, Ballarat, Victoria, Australia, Analysis of design of pure ethanol engines, 2010 SAE International.