Performance and emissions of SI engine with additives

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Abstract. In the current economy with rising fuel prices and higher concerns being raised for the safety of the environment, it creates an opportunity to test additives available in the market to achieve lower emissions with an increase in performance. Fuels today provide either higher performance or lower emissions, this study aims in achieving both by combining two additives, namely ethanol and toluene. Ethanol is an additive which helps reduce emissions from a vehicle but reduces the overall performance of the vehicle. While toluene improves the performance of a vehicle tremendously, it has higher emissions when compared to ethanol. Hence, two samples were created to be tested against pure petrol and pure ethanol by combining these two additives with gasoline. Four samples were tested, which were pure petrol, 10\% ethanol, 10\% ethanol with 5\% toluene and 20\% ethanol with 5\% toluene and were labelled sample A, B, C and D respectively. These four samples were tested against two performance parameters and four emission parameters. Results obtained in this study showed that sample C had the lowest emission and sample D had the highest performance.

1. Introduction

Since the initiation of cars in the world, spark ignition engines have been the most produced in the automotive industry and have been fit for changing chemical energy into valuable mechanical energy. Because of which it became, the most widely used type of engine on the planet. The principle issue emerging from the spark ignition engine being the emissions discharged from the cars establishes in the ascent of global warming. Another issue being, to give an improved performance in the engine without adjusting its parts, is to utilize additives. Additives are utilized to increase the octane rating of the fuel. These liquids counteract knocking by utilizing anti-knock additives.

1.1. Gasoline

A petroleum derived liquid which is used as fuel in spark ignited engines.

| Table 1. Properties of Gasoline. |
|-------------------------------|
| Octane Number | Density (kg/m\(^3\)) | Heating Value (MJ/kg) | Enthalpy of Vaporization (kJ/mol) |
|----------------|----------------------|----------------------|----------------------------------|
| 95-98          | 765                  | 44                   | 33.97                            |
1.2. Toluene

Toluene is a clear liquid being water insoluble having the smell of paint thinners. It has a chemical formula of C7H8 and is a mono-substituted benzene derivative.

| Table 2. Properties of Toluene. |
|---------------------------------|
| Octane Number | Density (kg/m³) | Heating Value (MJ/kg) | Enthalpy of Vaporization (kJ/mol) |
|----------------|-----------------|-----------------------|----------------------------------|
| 112            | 867             | 40.528                | 38.1                             |

1.3. Ethanol

Ethanol being a renewable energy source and having good anti-knock characteristics compared to gasoline makes a suitable choice for a test additive. Moreover, it is favoured because of its lower evaporative losses since it makes it less demanding to transport and store it. It is a clear and colourless liquid with a chemical formula of C2H5OH.

| Table 3. Properties of Ethanol. |
|---------------------------------|
| Octane Number | Density (kg/m³) | Heating Value (MJ/kg) | Enthalpy of Vaporization (kJ/mol) |
|----------------|-----------------|-----------------------|----------------------------------|
| 106-110        | 785             | 26.9                  | 40.65                            |

2. Literature Review

The purpose behind picking toluene over the customary additives is on the grounds that it demonstrates generous increment in brake specific fuel consumption, brake power and brake thermal efficiency and created the highest amount of air-fuel ratio as per Amit R P et al. [1] and had additionally specified that the sensitivity rating of toluene was 12. Demirbas A et al. [2] picked toluene because of its low sensitivity rating and also stated that it is more preferred for heavily loaded engines. Alcohols as a rule always have a sensitivity rating anywhere between 20 to 30.

Demirbas A et al. [2], also conveyed that the density of toluene is higher than that of gasoline and the energy per unit volume produced is also much higher when compared to gasoline. Due to this, combustion of toluene prompts more energy being discharged and more power being made. This is in opposition to oxygenated additives like Methyl Tertiary Butyl Ether (MTBE) or ethanol, where the energy per unit volume produced is less compared to gasoline.

Khan M Y et al. [3] expressed the availability of a sustainable energy source which we know as ethanol and since it can be processed from sugarcane, corn, grain, and from numerous different materials. Due to the presence of an oxygen atom within ethanol, it is considered being a partially oxidized hydrocarbon. Therefore, ethanol has a lower heating value when compared to gasoline and the density of ethanol is seen to be marginally higher than gasoline. Ethanol produces a higher octane number when contrasted with petroleum because of which compression ratios of a higher extent can be reached.

Amit R P et al. [1] and Khan M Y et al. [3] expressed that toluene is a superior additive when contrasted with ethanol, and it gives a considerable change in torque and brake thermal efficiency. It is also capable of bringing down the value of brake specific fuel consumption to a small value in comparison to ethanol and gasoline. However, where it is lacking is in terms of emissions since it...
escalates carbon monoxide (CO) and carbon dioxide (CO₂) emissions and specifically reduces hydrocarbon (HC) and NOₓ emissions. As said by Amit R P et al. [1], ethanol escalates NOₓ and hydrocarbon (HC) emissions and decreases carbon monoxide (CO) and carbon dioxide (CO₂) emissions.

It was expressed by Yusaf T et al. [4] that carbon monoxide (CO) emission declines as the percentage of ethanol rises and this was because of ethanol having less carbon compared to gasoline and due to the presence of additional oxygenates inside the cylinder. Due to this occurrence, carbon monoxide (CO) emissions are reduced. It was additionally expressed that higher in-cylinder pressure and higher indicated mean pressure could be reached by increasing ethanol percentage in the mixes. It would likewise result in a higher measure of density of the charge being available and more fuel-air charge being created in the cylinder.

As expressed by Yusaf T et al. [4] and Adebayo A et al. [5], the increase in NOₓ emissions is caused by incrementing ethanol percentage. Be that as it may, toluene diminishes NOₓ emissions. The creation of NOₓ emissions is due to the exposure to high temperatures. It is achieved via combustion within the cylinder and when sufficient heat is present, NOₓ is formed due to the combination of oxygen and nitrogen as expressed by Adebayo A et al. [5]. Machado G et al. [6] said, we can comprehend that toluene, iso-octane and n-heptane have a higher octane rating than ethanol due to which they have a much higher performance yield.

Poitras M et al. [7] had made a comparison between isobutanol and ethanol in terms of emissions and had discovered that utilizing an ethanol-gasoline mix had acquired a reduction NOₓ, hydrocarbon (HC) and carbon monoxide (CO) emissions. However, it brought about a slight increment in carbon dioxide (CO₂) emissions when contrasted with isobutanol-gasoline mix. The reduction noted in emissions was in any event over 8% for each situation.

Kushwaha G et al. [8] had performed tests for obtaining unburnt hydrocarbon (HC) emissions and had prepared five distinct fuels, in order to obtain the required results. The results which they obtained showed them that lesser hydrocarbon (HC) emissions were observed for gaseous fuels while liquid fuels discharged higher hydrocarbon (HC) emissions. This occurrence was due to oil layer adsorption/desorption.

Singh P et al. [9] utilized E20 to test against combustion, performance and emissions of an engine while comparing the same with gasoline. They found that E20 had decreased hydrocarbon (HC) emission by 38% and carbon monoxide (CO) emission by 65% while causing NOₓ emissions to double. It was discovered that this causes the combustion duration to increase while utilizing E20 and it likewise had slight improvement in the performance of the engine.

Ramos M et al. [10] had expressed that particulate emissions from vehicles are injurious to health because of the release of ultrafine particles. It was additionally said that the inconstancy in these particles rises with the change in the composition of the mixes. At the point when toluene was added to gasoline, it affirmed the theory and caused an increase in particle number concentration. A similar observation was made when ethanol was added to gasoline as well.

Leach F et al. [11] had also stated that there are ways to reduce particulate emissions from an engine by increasing the inlet air temperature and fuel injection pressure, but likewise it is said to increase particulate emissions for increasing engine loads.

3. Methodology
In order, to obtain results for this study, four samples were made to be tested and these were pure
petrol, 10% ethanol, 10% ethanol with 5% toluene and 20% ethanol with 5% toluene. These four samples were labelled as sample A, B, C and D respectively and were put through standard emission and performance tests.

Sample A had 3 litres of petrol which was used to set the baseline result. Sample B had 30ml of ethanol added to it. Sample C had 30ml of ethanol, 15ml of toluene and 7.5ml of stabilizer added to it. Sample D had 45ml of ethanol, 15ml of toluene and 7.5ml of stabilizer added to it.

During sample preparation, sample B didn’t require any stabilizers since ethanol was miscible with petrol but for sample C and D, a stabilizer was added to make toluene miscible with petrol. The stabilizer added was an automatic transmission fluid (ATF). 2.5% of ATF was added in sample C and D.

The performance tests were carried out under a consistent speed of 1500 RPM with changing loads of 10kg, 20kg and 30kg. Emissions tests were led utilizing an AVL DiTEST MDS 215 exhaust or fumes gas analyzer to get varied discharges or emissions from the exhaust fumes and to quantify the fumes gas constituents from the engine utilizing a probe. The readings from the exhaust gas analyser were recorded on its proprietary application on a smartphone.

The setup comprises of a four stroke, four-cylinder, Ambassador 1800 ISZ carburetted SI Engine coupled to an Eddy current dynamometer. It comprises of a panel board setup which shows the RPM of the engine. A throttle valve is present to alter the RPM of the engine and also consists of a fuel input estimation system which comprises of a 10-litre fuel tank mounted onto a stand and a burette which is used to estimate the fuel utilization for a certain time period.

4. Results and Discussion
The outcomes were acquired from the setup which was kept running consistently at 1500 RPM.
All the four mixes or samples were tested and the accompanying outcomes were procured from the tests conducted.

4.1. Variation of Specific Fuel Consumption

![Figure 1. SFC trend for samples A, B, C & D](image)

The proportion of the measure of fuel burnt in one hour to create 1 kilowatt of energy is called Specific Fuel Consumption or SFC. From figure 1 it can be noticed that the pattern determines that SFC diminishes with an increment in BP. It can be seen that sample A has the most elevated SFC taken after
by sample B and sample C and lastly it can be observed that sample D has the least specific fuel consumption. SFC decreases for a rise in brake power, since brake power rises more quickly than the fuel utilization. Due to the presence of higher toluene and ethanol content within the mixture, it causes an increase in indicated mean pressure and the in-cylinder pressure which results in the rise or gain of brake power.

4.2. Variation of Brake Thermal Efficiency

![Brake Thermal Efficiency trend for samples A, B, C & D](image)

We can surmise from figure 2 that the pattern demonstrates that with the rise in brake power, brake thermal efficiency increases. It can likewise be observed that sample A has the most reduced brake thermal efficiency, trailed by sample B, sample C and sample D. Sample D produces the most astounding brake thermal efficiency when contrasted with the other samples as observed from figure 2. We can derive from table 2 that it has the highest density of 867 kg/m$^3$ trailed by ethanol, from table 3 having a density of 785 kg/m$^3$ and lastly by gasoline, from table 1 having a density of 765 kg/m$^3$. Because of the higher density of toluene and ethanol, it delivers the significant increment in power which prompts in the ascent of brake thermal efficiency.

4.3. Variation of Carbon Monoxide (CO) Emission

![Carbon Monoxide (CO) Emission](image)
Figure 3. Carbon Monoxide (CO) trend for samples A, B, C & D

It can be gathered from figure 3 that there are three patterns visible, the first pattern can be noticed while making a comparison between sample A and sample B, it can be seen that there is a huge decrease in carbon monoxide (CO) emission. The second pattern is seen when a comparison is made between sample C and sample D, it can be seen that carbon monoxide (CO) emissions for sample D at first sight increments to an extent, however it begins to diminish at higher loads. Additionally, a third pattern can be seen when contrasting sample C and sample D between sample A, it can be noticed that there is an ascent in carbon monoxide (CO) emissions.

The primary or the first pattern occurs in light of the fact that ethanol has lesser carbon when contrasted with gasoline and also more oxygenates are available in the cylinder. Because of this, oxygen and carbon join to form carbon dioxide (CO₂), which demonstrates that total or complete burning is happening inside the cylinder.

For the second pattern, it can be seen that carbon monoxide (CO) emissions first increments but at higher loads carbon monoxide (CO) emission diminishes. The initial rise is because of the presence of toluene inside sample C and sample D. Since toluene is available inside the blend, the carbon content inside the blend is more in comparison to gasoline, and because of which there are more carbon atoms in comparison to oxygen atoms. The decline in the pattern is on the grounds that the fuel blend moves towards a leaner mixture for increasing loads and increasing blends, because of which more oxygen is available inside the cylinder.

For the third pattern, since toluene is available inside the blends of sample C and sample D, it causes a rise in carbon monoxide (CO) emissions because of the presence of surplus carbon content in the blend.

4.4. Variation of Carbon Dioxide (CO₂) Emission

Figure 4. Carbon Dioxide (CO₂) emission trend for samples A, B, C & D

It can be induced from figure 4 that there is a rising or increasing pattern. When a comparison between sample B and sample A is made, it very well may be seen that at first sample B has higher carbon dioxide (CO₂) emissions in comparison with sample A, however at higher loads sample B shows a decline in carbon dioxide (CO₂) emissions while comparing with sample A.

Additionally, it can be seen that sample C has a comparative pattern when compared with sample A. Sample C when contrasted with sample B has a general higher carbon dioxide (CO₂) emission discharge.
While contrasting sample D with the rest of the samples, it may be seen that it has the most excessive carbon dioxide (CO₂) emission discharge.

As indicated by Yusaf T et al. [4], carbon dioxide (CO₂) emission diminishes with the increment in carbon monoxide (CO) emission discharge. From figure 4, it can be seen that the pattern acquired is unique. Since, sample D has the most elevated discharge of carbon dioxide (CO₂) and due to which it may be said that total or complete combustion happens when sample D is contrasted with the other samples.

4.5. Variation of Hydrocarbon (HC) Emission

![Figure 5. Hydrocarbon (HC) emission trend for samples A, B, C & D](image)

Hydrocarbon emissions are discharged because of incomplete combustion or because of discharging unburnt fuel into the air. From, figure 5 it can be surmised that there are two patterns present. The first pattern being the correlation of hydrocarbon (HC) emission between sample A and sample B. The second pattern being making a comparison of hydrocarbon (HC) emissions between sample D and the rest of the samples.

For the primary or first pattern, it can be seen that sample B has higher hydrocarbon (HC) emissions than sample A. This is due to the fact that ethanol has lesser carbon when contrasted with gasoline.

For the second pattern, it can be seen that sample D has the least hydrocarbon (HC) emissions when contrasted with the rest of the samples. This is due to the fact that sample D has a higher carbon content in the blend because of the presence of ethanol and toluene, due to which more oxygenates are available inside the cylinder.

4.6. Variation of NOₓ Emission
Figure 6. NO\textsubscript{X} emission trend for samples A, B, C & D

NO\textsubscript{X} emission occurs because of the combination of oxygen and nitrogen under high temperatures, which occurs over 1370\textdegree{}C. It can be surmised from figure 6 that three patterns can be noticed. The first pattern being a comparison between sample B and the rest of the samples. The second pattern being making a comparison between sample C and sample D. The third pattern being making the comparison between sample C and the rest of the samples.

From the first pattern, it can be seen that sample B has the most excessive NO\textsubscript{X} emissions. The reason as to sample B having the most excessive NO\textsubscript{X} emissions is because of the presence of ethanol, due to which more oxygenates are available inside the cylinder which makes NO\textsubscript{X} emission increment.

From the second pattern, it can be seen that sample D has a higher NO\textsubscript{X} emission when contrasted with sample C. This is because of the presence of more ethanol in sample D, as said prior, it contains more oxygenates, henceforth would give a rise in NO\textsubscript{X} emissions.

From the third pattern, it can be seen that sample C has the least NO\textsubscript{X} emissions when contrasted with the rest of the samples. This is because, sample C has less time to reach over 1370\textdegree{}C and because of the presence of toluene, more carbon content is present and it joins with oxygen to create carbon dioxide (CO\textsubscript{2}) and carbon monoxide (CO) emissions at lower temperatures, thus lesser oxygen is present at higher temperatures for the development of NO\textsubscript{X}.

5. Conclusion
The impact of utilizing toluene-ethanol-gasoline mixtures or blends in an SI Engine has been studied and researched upon. This study comprises contrasting the toluene-ethanol-gasoline mixture with gasoline and gasoline-ethanol mixtures utilizing the emissions and performance parameters and figuring out which has the best emissions and performance attributes.

Figure 1 demonstrated that sample D had the least specific fuel consumption and figure 2 demonstrated that sample D had the highest brake thermal efficiency. With regards to emissions, figures 3 and 4 individually demonstrated that sample D and sample C have higher carbon monoxide (CO) and carbon dioxide (CO\textsubscript{2}) emissions when contrasted with sample B.

In any case, sample D and sample C indicate a much lower hydrocarbon (HC) and NO\textsubscript{X} emissions when contrasted with sample B in figures 5 and 6 respectively, which is less harmful towards our environment. Complete combustion happens when the toluene-ethanol-gasoline mixture is utilized
because of its high carbon dioxide (CO₂) discharge and furthermore because of its reduction in carbon monoxide (CO) emission as seen in figure 3 for sample D.

From the results obtained via this study it can be said that sample D demonstrates the best performance and sample C shows the best emission attributes when contrasted with conventional gasoline and gasoline-ethanol mixture. Further testing with these mixtures can be done, keeping in mind that the end goal is to locate the ideal blending proportion for toluene and ethanol so as to accomplish better emissions without a reduction in performance.

6. References
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