# Effects of ethanol–gasoline blends on performance of SI engines

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*Abstract*— **Ethanol-gasoline blend have been highly researched upon as a fuel by researchers since the oil crisis of 70's, among all the alcohol that can be blended with gasoline, ethanol ($C_2H_5OH$) has been deemed as most suited for spark-ignition engines in terms of performance it can extract from the power unit, and therefore is used in NASCAR© in order to obtain a higher horsepower from statutory mandated capacity of engine, alongside ethanol being renewable and eco-friendly in nature helps achieving emission regulations without compromising on the performance. After reviewing several papers on ethanol gasoline blends and their effect on spark-ignition (SI) engine this literature review discusses the effect of ethanol-gasoline blends as a bio-fuel within the conventional spark-ignition engine. The review highlights the properties of ethanol and the effect of varied ethanol blends on the performance of the engine. The parameters discussed in this study are engine brake torque, brake power, engine volumetric efficiency, thermal efficiency, heat release rate, cylinder gas pressure, brake specific fuel consumption (BSFC), compression ratio. The interdependency of the parameter studied are also explained and their effect on each other in terms of performance is discussed. It's been inferred from the study that with the increasing percentage content of ethanol within the blend; the general thermal efficiency, heat release rate, engine volumetric efficiency and cylinder pressure increases leading to the better performance of the engine with no modification required; the need of the compression ratio for the occurrence of ignition also rises with the proportion of ethanol within the blend affecting the overall performance of the engine.**

## I. Introduction

Increase in pollution leading to global warming is the foremost concern of the nations all over the world. Exhaust emissions from vehicles have a main role as pollutant, it's not sufficient just to tune down the engine in order to deal with the legal regulations, so it is necessary to work on alternative fuel technologies. It is important that the replacement fuel to be used must be produced from renewable resources and it must be used directly without requiring any major changes within the structure of the engine. Among the various alcohols, ethanol is known as the most suited fuel for spark-ignition (SI) engines. the foremost attractive properties of ethanol as an SI engine fuel is that it is often produced from renewable energy sources like sugar, cane, cassava, many sorts of waste biomass materials, corn, and barley. Furthermore, ethanol has some merits over gasoline, like the reduction of carbon monoxide (CO), and unburned hydrocarbon (HC) emissions and better anti-knock characteristics, which allow for the utilization of a higher compression ratio of engines. The reduction of CO emission is seemingly caused by the wide flammability and oxygenated characteristic of ethanol providing an oxidizing environment for the partially oxidized CO. Therefore, improvement in power output, efficiency and fuel economy is observed with implementation of ethanol gasoline blends. On the other hand, the auto-ignition temperature and flash point of ethanol is more than those of gasoline, and therefore the low Reid evaporation pressure which makes it safer for transportation and storage, and causing lower evaporative losses. The latent heat of evaporation of ethanol is 3–5 times more than that of gasoline; this provides lower temperature intake manifold and increases volumetric efficiency. Since ethanol may be a liquid fuel, the storage and dispensing of ethanol is analogous to that of gasoline. Additionally, for most unleaded gasoline, methyl tertiary butyl ether (MTBE) is a problem because it will contaminate groundwater and harm human health. Ethanol are often used to substitute MTBE in the future. Presently, ethanol is employed in spark-ignition engines with gasoline at low concentrations with no modification. Pure ethanol can be utilized in spark-ignition engines but necessitates some modifications to the engine. To avoid modifying engine design, using ethanol–gasoline blended fuel was suggested then, cold start and anti-knock performance are improved. Additionally, the flame of the alcohol is colorless within the natural burning processes and this is another advantage of alcohols. Since the heating value of ethanol is lower than that of gasoline, it is necessary for more ethanol fuel to achieve the same power output or distance. Ethanol contains an oxygen atom so that in can be viewed as partially oxygenated fuel. Ethanol is completely miscible with water in all proportion, while the gasoline and water are immiscible. This may cause the blended fuel to contain water, and further result in the corrosion problems on the mechanical components.

The effects of ethanol–gasoline blended fuels on engine performance and/or exhaust emissions have been investigated by many researchers such as-

**(Check reference section for research paper details*)**

Kelly et al. [1] tested gasoline, E50 and E85 in 21 cars and found that operating with E85 would decrease non-methane HC emissions and CO emission in comparison with pure gasoline. Cowart et al. [2] investigated the effect of M85 and E85 blended fuels on engine performance. When blends are used as fuel, the engine brake torque and brake horse power increased with the both fuels M85 and E85 by 7% and 4%, respectively. Alexandrian et al. [3] found that the CO emission was greatly affected by air–fuel ratio. CO and NOx emissions can be lower than using gasoline in fuel-rich conditions. On the other hand, Rideout et al. [4], concluded that the emission of formaldehyde, acetaldehyde and acetone would increase ethanol addition to gasoline as a fuel in engine. He et al. [5] showed that the fuel containing 30%

ethanol by volume can drastically reduce HC, CO and NOx emissions at idle, however unburned ethanol and acetaldehyde emissions increase. Wu et al. [6] explained that the air–fuel equivalence ratio and ethanol content play an important role in combustion process. Al-Hasan [7] investigated the effect of using unleaded gasoline–ethanol blends with different percentage on SI engine performance and exhaust emission. The results showed that the addition of ethanol to unleaded gasoline increased the brake power, torque, volumetric and brake thermal efficiencies and fuel consumption, while it decreased the brake specific fuel consumption and equivalence air–fuel ratio. The CO and HC emission concentrations decreased, while the carbon-dioxide ($CO_2$) concentration increased. Yucesu et al. [8] and Topgul et al. [9], used unleaded gasoline (E0) and unleaded gasoline–ethanol blends (E10, E20, E40 and E60) in a single cylinder, four-stroke, spark-ignition engine with variable compression ratio. They found that blending unleaded gasoline with ethanol slightly increased the brake torque and decreased CO and HC emissions. It was also found that blending with ethanol allows increasing the compression ratio without knock occurrence.

## II. Properties of Ethanol

From the literature survey, ethanol–gasoline blended fuels can be used effectively in spark-ignition engine with little or no modifications. Ethanol has higher evaporation heat, higher octane number and the low evaporation pressure compared with gasoline, and contains 34.7% oxygen by weight. If the amount of ethanol is increased in blended fuel, the heating value decreases. But on the other hand, increase of ethanol amount in blended fuels enable to decrease of air–fuel ratio, so we can take much more fuel during the intake processes. Ignition timing, excess air ratios, latent heat of vaporization, compression ratio, and flame speed have also influence on engine performance. In this study, the effects of unleaded gasoline (E0) and unleaded gasoline–ethanol blends (E50 and E85, where E represents ethanol and the numerical value, the percentage of ethanol content in the blend) on engine performance and pollutant emissions were investigated in a single cylinder, four-stroke spark-ignition engine with variable compression ratio. Properties of ethanol and gasoline are tabulated below.

| Properties | Ethanol | Gasoline |
|---|---|---|
| Chemical formula (–) | $C_2H_6O$ | C2-C14 |
| Density (kg/m$^3$) | 785.5 [34] | 714.9 [34] |
| Viscosity (kg/m s) | 0.001007 [34] | 0.0004549 [34] |
| Research octane number (–) | 106 [3] | 91 |
| Stoichiometric air/fuel ratio (–) | 9.0:1 [3] | 14.8:1 [3] |
| Lower heating value (MJ/kg) | 26.9 [3] | 42.9 [3] |
| Enthalpy of vaporization (kJ/kg) | 948 [42] | 298 [42] |
| Saturation vapour pressure (kPa) | 8.773 [34] | 28.828 [42] |
| Laminar flame velocity @ $\lambda$ = 1, 100 kPa, 100 °C (m/s) | ~0.62 [43] | ~0.49 [43] |

Figure.1. property of ethanol and gasoline [19].

## III. Effect of Ethanol- Gasoline Blend on Engine Performance

### *A. Brake Thermal Efficiency*

In spark-ignition engines the more the octane number the higher brake thermal efficiency is predicted, i.e., because of the improved compression ratio, for the blended fuel. Here clearly revealed the increased efficiency because of the incorporation of blends within the SI engine. While using E10 and E20 blends, the brake thermal efficiency increased with the increasing brake power. Main reason for this case is that the decrease in brake specific fuel consumption. At the brake power of 10 kW, the increases in thermal efficiencies of E10, E20 are 1.8% and 3.9% respectively, compared to gasoline. At the brake power of 5 kW, the increases in thermal efficiencies for E10 is 1.6%. An increase of 3.4% in the thermal efficiency for E20 is observed in comparison to gasoline, this is because E20 blend contains a more oxygen rate than E10, the combustion becomes better so the thermal efficiency Increases. It's been reviewed that use of blends have a positive influence on octane number of the fuel hence it's quoted that increased use of blends have increased the overall brake thermal efficiency of the engine, the brake thermal efficiency of engine is seen to be more with E10 and E20 blends, than that of gasoline, as will be seen in the graph.

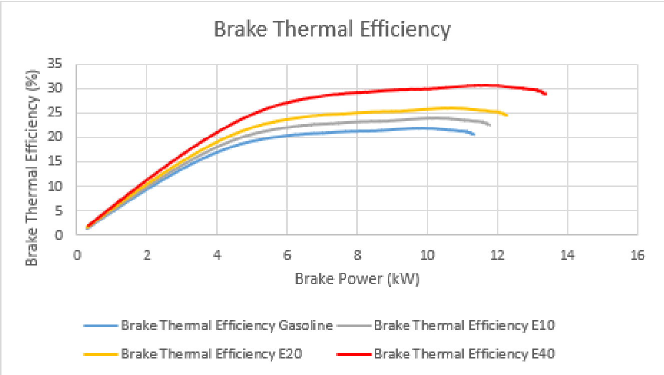
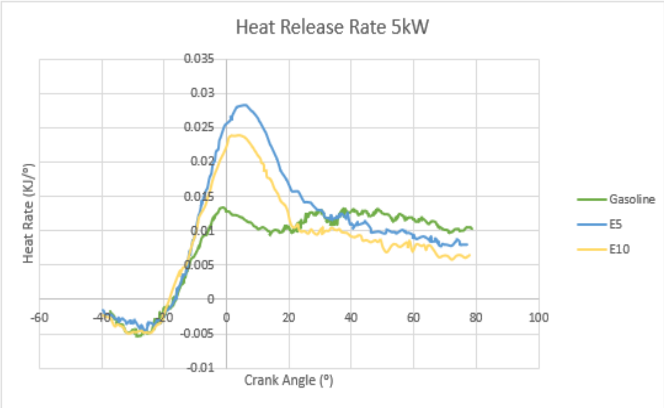



Figure.2. Effect on Brake Thermal Efficiency by using various blends of Ethanol-Gasoline.

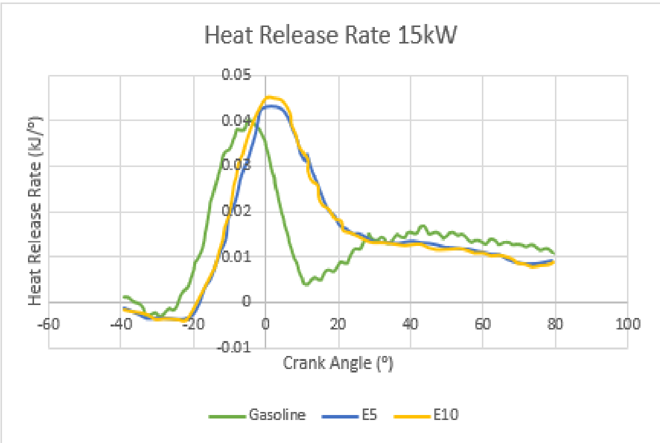
### *B. Heat release rate*

Heat release rate is defined as the rate of heat generation by combustion of the fuel. The data of Heat release rate gives proper information about the nature of combustion. Heat release rate calculations are made to understand about the combustion process in an engine. The combustion characteristics of the ethanol blends are compared with gasoline by comparing their heat release rates during the combustion process in the following graph.

The heat release pattern exhibits the increased heat liberated with the incorporation of ethanol in gasoline. It's particularly observed when the piston is reaching the top dead center. The high amount of heat release is the results of the greater enthalpy on the part of the blends. The heat release rate for gasoline fuel began to rise before than that of alcohol–gasoline fuel blends at both vehicle speeds. Also, the peak locations of the heat release rate of ethanol-gasoline blends are wider than that of pure gasoline. The main reason for this, ethanol which contains oxygen in their structure improves combustion and a large amount of fuel combustion takes place in the area near to the top dead center. As shown in the heat release vs crank angle graph for various fuel blends above, Therefore the greater and better heat release rates are observed during use of the blends in the engine, the use of blends is sort of tentative within the near future.




(a)

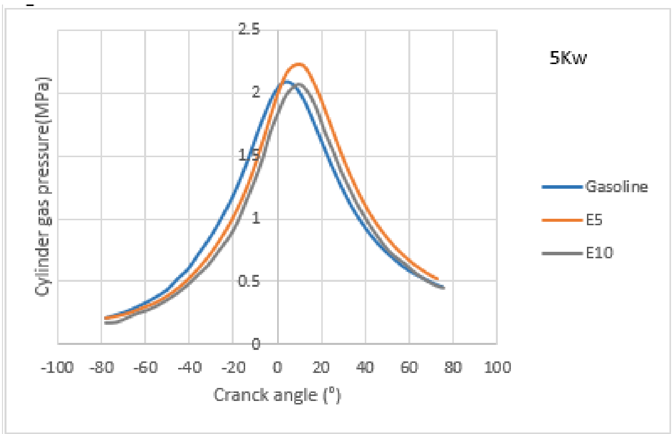



(b)

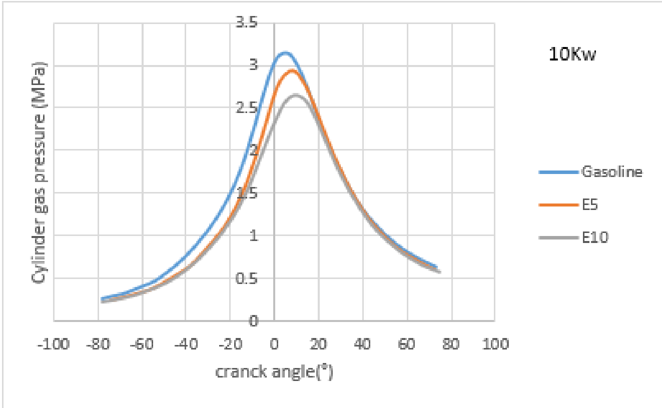
Figure.3. Heat Release Rate of Ethanol-Gasoline blend combustion vs crank angle. (a) Power produced is 5 kW, (b) power produced is 15 kW.

## *C. Cylinder gas pressure*

Work is done on the gases by the piston during compression stroke and the gases produce energy through the combustion process, in the Spark-ignition engine with the increase in cylinder pressure the enthalpy of the charge improves. Because of increase in enthalpy, the energy which can be given out by fuel improves. Here, the combustion characteristics of the ethanol blends is compared with gasoline using the cylinder pressure, The Effects of cylinder gas pressures for the test fuels at the power production of 5 kW and 10 kW, As are often seen in the peak pressure reached in the engine cylinder is significantly faster within the case of gasoline, i.e., because of the lower octane number of the fuel. The higher the octane number, the greater will be the compression ratio to which the engine is subjected without observing the phenomenon of the knock of the engine. Thus, the work output from a given engine are often significantly enhanced for an equivalent quantity of the fuel used. This is often quite positive aspect while we take care of the lack of engine efficiency just in case of the today's gasoline engines.




(a)




(b)

Figure.4. Cylinder Gas Pressure for Ethanol-Gasoline blend combustion vs crank angle. (a) When power produced is 5 kW, (b) when power produced is 10kW.

## *D. Volumetric Efficiency*

The volumetric efficiency is observed to be higher when ethanol-gasoline blend is used as a fuel compared with purely gasoline powered engine. Latent heat of vaporization for ethanol is roughly 2.13 times more than that of gasoline (depending upon the quality of ethanol and gasoline.) like causes the decrease in combustion temperature for a constant compression ratio as more energy will be required to vaporize ethanol as compared to gasoline.

The same can be attributed to the higher combustion temperature generated in the cylinder while the ethanol blends burn to give a higher and clean combustion in the cylinder leading to the increased breathing capacity of the engine. The increased rate of evaporative cooling brought by the blends is the key to the increased volumetric efficiency. The volumetric efficiency is seen to be more by 5% to 10% for ethanol blends, than that of with gasoline, as can be seen in graph below. The increased volumetric efficiency leads to reduction of unburnt hydrocarbon emissions and carbon monoxide as the stratified charge is fully combusted instead of partial combustion due to increase in oxidation capability. The increased volumetric efficiency represents the leaner fuel-air ratio and the better combustion efficiency. It is also a vital factor for the improved engine power and BMEP (Break Mean Effective Pressure) in the cylinder. The increased volumetric efficiency is represented from the volumetric efficiency vs torque chart.

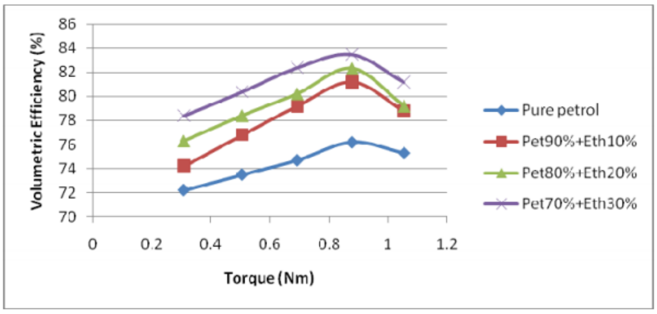



Figure.5. Effect of using Ethanol-Gasoline blend on Volumetric efficiency vs Torque [18].

### *E. Brake Specific Fuel Consumption*

The brake specific fuel consumption is observed to be better for ethanol-gasoline blended fuel, i.e., E5 and E10 compared with gasoline fuel. It indicates the decreased brake specific fuel consumption of the engine with blended fuel. At the brake power of 5 kW, brake specific fuel consumption for E5 and E10 increased by 1.6% and 3.6% respectively as compared to gasoline. At the vehicle speed of 100 km/h, brake specific fuel consumption for E5 and E10 increased by 0.2%, 1.5%, respectively [10]. It has been seen at the vehicle speed of 10 kW, brake specific fuel consumption for gasoline at the brake powers of 5 kW and 10 kW is lower than that of E5 and E10. However, the maximum brake specific fuel consumption was obtained at the starting conditions in the gasoline test. Certainly, these upwards in brake specific fuel consumption with the use of E5 and E10 are normal due to the lower energy content of the alcohols. The increased rpm also significantly increases the brake specific fuel consumption and the graphs below are also indicative to the lower brake Power obtained at the same time.

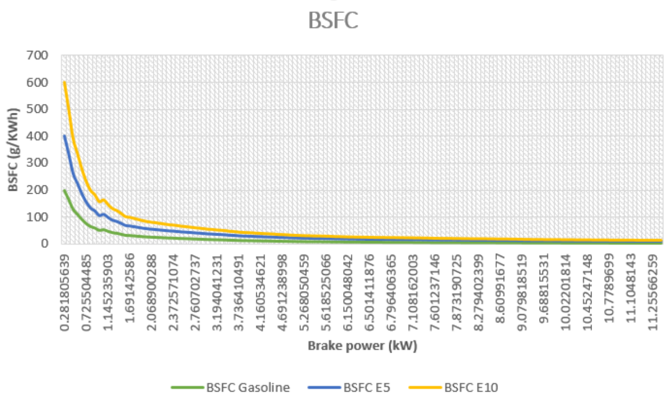



Figure.6. Effect of using Ethanol-Gasoline blend on Specific Fuel Consumption (g/kWh) vs Brake Power (kW). (Stacked).

### *F. Brake Power*

When the ethanol content in the blended fuel is increased, the engine brake power slightly increased for all engine speeds. The gain of the engine power can be due to the increase of the indicated mean effective pressure for higher ethanol content blends. The heat of evaporation of ethanol is higher than that of gasoline, this provides fuel–air charge cooling and increases the density of the charge increasing the volumetric efficiency, and thus higher power output is obtained [6]. With the increase in ethanol percentage, the density of the mixture and the engine volumetric efficiency increases and this causes the increase of power.

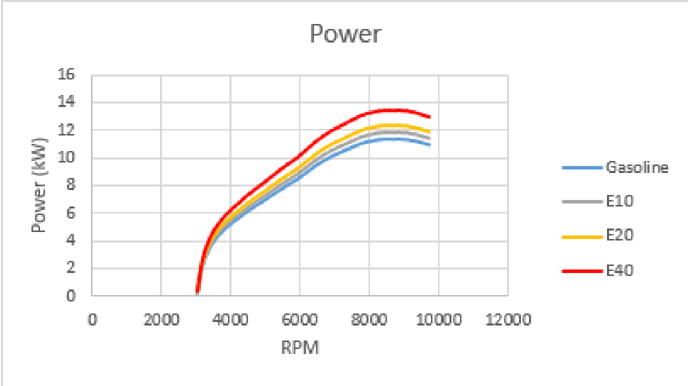



Figure.7. Effect of using Ethanol-Gasoline blend on Power produced vs RPM.

### *G. Brake Torque*

The brake torque directly influences the brake power generated by the engine. The rise in the cylinder pressure is observed, with the increase in the ethanol content in the blend, it expectedly increases the brake torque of the engine leading the increase in brake power as well. While compression ratio and engine speeds increases, the engine torque will raise as can be concluded by the literary review of various research papers. Also, the influence of different ethanol–gasoline blended fuels on engine torque. The increase of ethanol content increases the torque of the engine. Added ethanol produces lean mixtures that increase the relative air–fuel ratio ($\lambda$) to a higher value and makes the burning more efficient. The improved antiknock behavior (due to the addition of ethanol, which raises the octane number) allowed a more advanced timing that results in higher combustion pressure and thus higher torque.

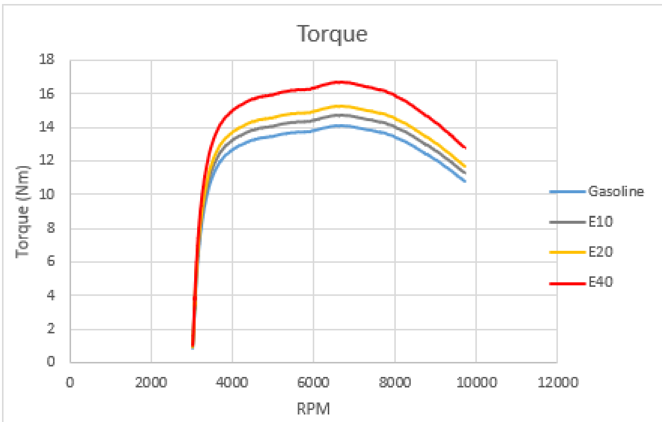



Figure.8. Effect of using Ethanol-Gasoline blend on Torque produced vs RPM.

### *H. Compression Ratio*

The maximum compression ratio that can be achieved in the engine without the excessive knocking is improved by using ethanol blend as a fuel. The high-octane rating of the ethanol increases the overall octane rating of the blend improving the thermal efficiency of the engine, as can be seen from the graph below. Moreover, it has an influence on the engine emissions. It is observed that better thermal efficiency keeps a check on the exhaust emissions. This literary review concludes that the relative ability to increase the compression ratio in an engine is high with that of the ethanol content of the fuel rather than gasoline standalone. The active compression ratios increased by a margin of 1.5 to 2 with up to 30% increase in ethanol content of the fuel.

This investigation also confirmed that the content of ethanol is directly proportional to the applicable compression ratio without detonation within the engine. The specific fuel consumption rate is reported to be decreased with the increase of the compression ratio. As seen from the graph the higher content of ethanol leads to a lower cylinder pressure compared to the lower content ethanol blend, this rise in pressure cause the detonation in the cylinder which leads to knocking.

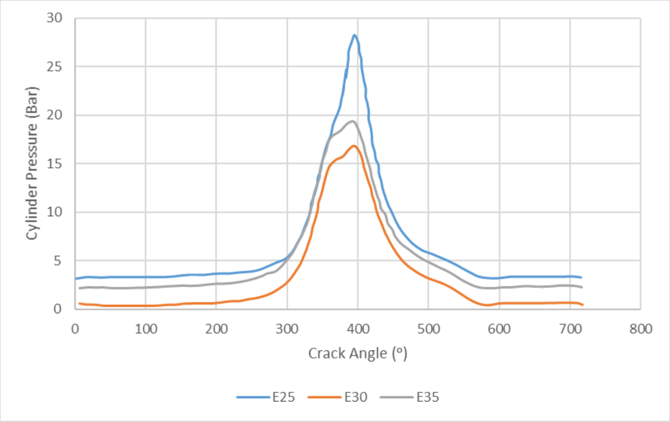



Figure.9. Cylinder pressure v/s crank angle.

## IV. Conclusion

• Torque with blended fuels (E10 and E20) were generally found to be higher than that of base gasoline (E0) in all the speed range due to higher latent heat of evaporation of ethanol addition and oxygenated fuel.

• The lower energy content of ethanol–gasoline fuel caused some increment in brake specific fuel consumption of the engine depending on percentage of ethanol in the blend.

• It was also found that higher content of ethanol in ethanol–gasoline blends allow higher compression ratio operation without knocking due to reduced cylinder pressure.

• Higher octane rating of the fuel has better implication on the efficiency and lower knocks in the gasoline engines, the more the octane rating of the fuel the better in gasoline engines.

• It is analyzed that better volumetric efficiency could be achieved using blends of ethanol and gasoline, the percentage content of ethanol in the blend directly effects the volumetric efficiency as it cools the charge more and makes for a denser charge.

• For all the parameters investigated the operating temperature was not considered, the operating temperature will vary the approach and the outcome of the investigation. The operating temperature was assumed to be 298K. Ethanol percentage content have to be changed as per the operating temperature to obtain the optimal result.

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