

## The Effect of Pine Oil Emulsifier on Gasoline-Alcohol Blends in a Spark Ignition Engine with Multi-Point Fuel Injection

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### Abstract

This paper presents the results of a study conducted to establish the effect of pine oil as an emulsifier on gasoline-alcohol blends in a twin cylinder spark ignition (SI) engine with multi-point fuel injection (MPFI) system. The test fuels were prepared by blending both ethanol and isopropanol with gasoline separately and pine oil was used as an emulsifier to either of the fuel blends. The 3 sets of fuel samples were used in which the concentration of pine oil was kept constant at 20 % by volume, while the concentration of both alcohols namely ethanol and isopropanol was varied from 5 to 15 % and the rest is gasoline. The experiments were conducted at different loads from 0 to 100 % in steps of 20 % at a constant speed of 2500 rpm. The results demonstrate that the use of gasoline-alcohol blends with pine oil in MPFI SI engine improved brake thermal efficiency (BTE) by 7.8 and 11.2 % with the higher proportions of ethanol and isopropanol in gasoline, i.e., E15 and IPA15, respectively when compared to neat gasoline. Carbon monoxide (CO) and hydrocarbon (HC) emissions reduce by 22.5 and 27.5 %, respectively while HC emissions reduce by 21.5 and 28.8 %, respectively with the E15 and IPA15, respectively. However, higher amounts of nitrogen oxides (NO<sub>x</sub>) emissions are the negative impact of the said blends. It was also observed that there is a reduction in brake specific fuel consumption (BSFC).

**Keywords:** Emulsifier, Isopropanol, Multi-point fuel injection (MPFI), Pine oil, SI engine

### Introduction

The present world has two major challenges to deal with, one is fossil fuel depletion, and the other is environmental degradation due to increased emissions by fossil fuel usage. The primary energy and raw material reserves in the world are limited. Due to the enormous increase of population, technological developments, and standards of living in industrial nations, these limited reserves would be depleted at a faster rate. The alternative fuel which is used as a substitute for petroleum-based fuels must be produced from renewable sources. Biofuels are prominent octane boosters in SI engines with the consequent performance improvement of the engine. It has become a widespread practice to add to the gasoline, 5–10% of ethanol, derived from biomass, as an octane booster in several countries. Several alcoholic fuels have emerged as alternative fuels for SI engines due to their comparable properties with gasoline. The usage of blended fuels is crucial now-a-days since many of these blends can improve engine performance and emissions. In general, the oxygenates as additives being introduced into the fuel can potentially improve the engine performance and reduce the emissions such as CO, HC, and NO<sub>x</sub> etc. The oxygenates containing organic oxygen compounds are more promising as fuel additives to improve fuel properties, octane rating and hence combustion quality in SI engines. Oxygenates make more oxygen available in the combustion chamber and hence decrease the exhaust emissions. The notable oxygenates are ethanol, methanol, butanol, propanol, methyl tertiary butyl alcohol (MTBE), and tertiary butyl ether.

The use of light alcohols such as ethanol and methanol as engine fuels dates back to 1907 due primarily to the reason of energy security. The major advantage with alcohol is it can be produced from

variety of feedstocks, from vegetables that contain sugar or starch with the given supply it can be produced at a reducing cost in unlimited quantities [1]. Alcohol as engine fuels offer several benefits. The primary factor which makes alcohol a potential gasoline blend is its miscibility with the gasoline. Both ethanol and methanol blends in SI engine will exhibit similar combustion behavior when they operate under the same air fuel ratios. When compared to gasoline, alcohol has higher auto-ignition temperature and flash point enabling them safer transport and storage. Moreover, the latent heat of evaporation of ethanol is about 3 - 5 times higher than that of gasoline, this lowers the intake manifold temperatures very much thereby increasing the volumetric efficiency of the engine [2]. In SI engines, higher proportions of ethanol, E85 (ethanol 85 %) and methanol, M57 (methanol 57 %) resulted in highest knock limits than gasoline combustion with the consequent improvement in thermal efficiency. If an SI engine can be modified to operate on pure alcohol, it could be possible to achieve the thermal efficiencies even higher than that is achieved by their compression ignition (CI) engine counterparts [3]. Ethanol is a viable choice as an alternative to gasoline due to its high value of octane number and latent heat of vaporization. It also forms less soot during combustion [4]. Ethanol is the commonest alcohol considered for SI engines [5] and its production from biological sources helps it contribute towards the energy security and reduction in greenhouse gas (GHG) emissions that are typically higher in SI engines as opposed to that of CI engine counterpart [6]. Ethanol evaporates and combusts faster due to lower boiling point compared to gasoline. Also, it has higher fuel efficiency due to its lower heating value. Ethanol-gasoline blends do not require a co-solvent unlike ethanol-diesel blends. This makes it possible to store them easily and at a lower cost [7]. However, the lower calorific value of ethanol when compared to that of gasoline necessitates 1.6 times higher ethanol per same energy output. Moreover, higher ethanol blends such as E85 or neat E100 cannot be used in unmodified vehicles. Excessive cooling effect of ethanol, due to its higher latent heat of vaporization, may lead to troubled cold start. Another alcohol-based alternative, n-butanol, is a better candidate due to its straight-chain structure with the OH at the terminal carbon [8], higher energy density and compatibility, lower vapor pressure and corrosion than that of ethanol [9]. Isopropanol, on the other hand, can be used as an additive for the preparation of high-octane gasoline and it has high energy density comparatively [10].

So many researchers have investigated alcohol as an alternative fuel for SI engines. Hassan *et al.* [11] investigated unleaded gasoline-ethanol blends and found that there is an increase in thermal efficiency and brake power and decrease in BSFC, CO and HC emissions. Silva *et al.* [12] studied cold start and drivability characteristics of vehicle fueled with ethanol and methyl-t-butyl ether (MTBE) fuel blend and found satisfactory drivability characteristics. The study also emphasized that the utilization of MTBE decreases the cold starting problems in vehicles. Wei-Dong *et al.* [13] conducted experiments on gasoline-ethanol blends in the percentage range of 0 - 30 of ethanol and found that there is no relationship between NO<sub>x</sub> emissions and ethanol content in the blend. Bang-Quan *et al.* [14] found that 30 % ethanol blending by volume can decrease total hydrocarbons (THC) at operating conditions. Yuksel *et al.* [15] investigated the use of ethanol-gasoline blended fuel and found that hydrocarbon and carbon monoxide emissions reduce by approximately 80 and 50 %, respectively.

Agarwal *et al.* [16] conducted experiments on methanol-gasoline blends that were used for multi cylinder spark ignition engine and found that the combination improves BTE, NO<sub>x</sub> and CO but with a slight increase in hydrocarbon emissions. Methanol produces 21 %, higher brake power than gasoline for the given energy input. It however results in an increase in BSFC by 46 % due to high latent heat of vaporization and high heat required for vaporization [17].

Scifter *et al.* [18] investigated ethanol-gasoline blends in SI engine and revealed that blends up to 10 % have minimal impact in combustion rates while 20 % blend has impacted combustion efficiency positively.

Keskin *et al.* [19] concluded that an increased isopropanol (IPA) in the blends, decreases hydrocarbon, carbon monoxide and carbon dioxide and increases NO<sub>x</sub> emissions. Kisain *et al.* [20] studied the effect of propanol and camphor blended with gasoline and reported that the increase in the blend percentage in gasoline increased the brake power and brake mean effective pressure (BMEP) and reduced the emissions HC and NO<sub>x</sub>. They concluded that the highest percentage of propanol that can be blended with gasoline is 15 % by volume.

Many researchers found that alcohol is also a substitute for diesel [21-24]. According to Elfaskhany *et al.* [25], acetone-gasoline blends are effective in controlling the pollutants such as CO and unburned hydrocarbons (UHC) at higher speeds when compared to lower engine speeds. The fuel conversion efficiency and engine performance were found to be higher in the case of blends with improved power and torque. Topgul *et al.* [26] have identified methyl butyl ester-gasoline blends affected CO emissions positively, while the NO<sub>x</sub> emissions the other way.

Alcohol with high octane number can be more effective compared to ethanol due to their desirable properties. When alcohol is blended with gasoline, there is an increased BSNO<sub>x</sub> (brake specific nitrogen oxides) emission compared to unblended gasoline. Shamim *et al.* [27] used cyclohexylamine and n-butyl alcohol as the blends to gasoline and found that there is a marginal increase in brake thermal efficiency of 1 - 1.5 % and reduction in emissions of HC and CO of 6 - 7 and 11 - 22 %, respectively. However, they reported increased NO<sub>x</sub> emissions in both cases. Increased amount of ethanol in ethanol-gasoline fuel blends resulted in a higher indicated power for a variable compression ratio SI engine. The fuel blend containing 10 % ethanol and 90 % gasoline showed maximum improvement in engine efficiency [28].

For an unmodified gasoline engine, a better option would be the multi alcohol-gasoline blends [29]. The higher amount of oxygen in the blend leads to more desirable combustion process and reduced CO and HC emissions [30]. The blends of isopropanol-n-butanol-ethanol (IBE) and gasoline blend IBE30 (30 % IBE and 70 % gasoline) could improve the BTE by about 4 % and reduce CO, unburned hydrocarbons (UHC) and NO<sub>x</sub> by 4, 20 and 18 %, respectively. The main advantage with IBE is it can be produced from non-edible biomass feedstock without any recovery process and presents environmental benefits [31].

The effect of ethanol-gasoline blends with additive, 4 dioxanon in a multi-cylinder spark ignition engine resulted in improved brake thermal efficiency with reduction of CO, CO<sub>2</sub>, HC and NO<sub>x</sub> [32]. Recently Liu *et al.* [33] investigated 3 oxygenated fuel blends with gasoline in a GDI turbocharged engine. They found that the above fuels can be used at high blending ratios. Though these blends reduced emissions, they resulted in higher fuel consumption. Ramakrishnan *et al.* [34] studied ethanol-gasoline blends and CNG as alternative fuels in a turbo-charged GDI engine at higher compression ratios with intent of reducing the cost of vehicle ownership. They tried to correlate blending percentage and compression ratio with ownership benefit.

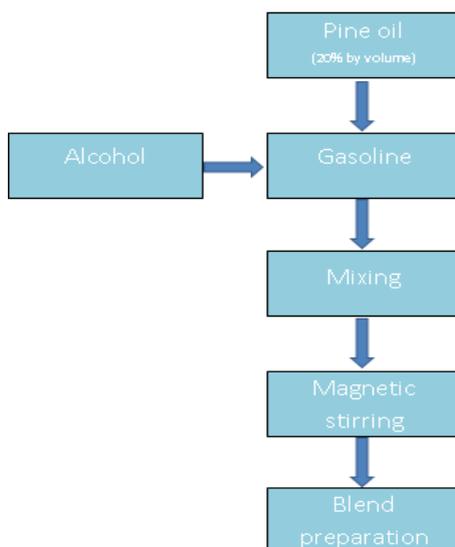
John *et al.* [35] observed that with increasing amount of ethanol blending with gasoline in direct-injection spark ignition (DISI) turbocharged engine the emission quality is improved. The pine oil which is extracted from oleoresins of pine tree by water distillation method is being considered as an emulsifier to gasoline-alcohol blends. Pine trees are being grown for wood, bark, and oil. The pine oil features stability under all conditions of its storage and use and the feedstock used for production originates from forest which is a renewable source and thus poses no problems with agricultural land usage. It is pale yellow in colour and immiscible with alcohols and other mineral oils [36].

Babu *et al.* [37] found that pine oil-gasoline blends resulted in better performance with 20 % pine oil. Pine oil properties are almost close to petroleum diesel and its viscosity is even lower than diesel fuel and hence does not require any esterification of the same to be used in diesel engines. Pure pine oil (100 %) was investigated by Vallinayagam *et al.* [38] in a diesel engine and reported that it could reduce the CO, HC and smoke emissions by 65, 30 and 70 %, respectively when compared to the diesel operation which however are accompanied by increased NO<sub>x</sub> emissions.

Previous literature mostly concentrated on alcoholic blending with gasoline and very less literature is available on the blends of IPA and pine oil. This work focuses on gasoline-ethanol blends and gasoline-IPA blends with pine oil as an emulsifier for either of the blends considered which were not reported earlier to the best of the authors' knowledge.

## Materials and methods

In this investigation, the effect of pine oil as an emulsifier on gasoline-alcohol blends in an MPFI SI engine is studied. The alcohols used in this experiment are ethanol (E) and isopropyl alcohol (IPA). Pine oil which is extracted from pine tree leaves by water distillation process is considered. Ethanol, isopropyl alcohol, and pine oil were purchased from commercial supplier A.H Impex Kondithope, Chennai. The purpose of emulsifier is to improve the combustion characteristics and to reduce emissions. For experimental investigation, 3 sets of fuel blend samples were prepared. The first set consists of gasoline-pine oil, the second set consists of gasoline-ethanol-pine oil while the third set consists of gasoline-isopropanol-pine oil. The concentration of pine oil was kept constant at 20 % by volume, while the concentration of both alcohols namely ethanol and isopropanol was varied from 5 to 15 % in second and third sets of fuel samples and the rest is gasoline. First, 3 of the oil samples were taken into a container and mixed then they are stirred in a magnetic stirrer. **Figure 1** shows the flow chart of blend preparation with the oil samples considered.



**Figure 1** The flow chart showing blend preparation with the oil samples.

**Blends with their specifications**

The specifications of the blends prepared are given below.

- 1) Gasoline-pine oil blends (P20): gasoline 80 % + pine oil 20 %
- 2) Gasoline-ethanol-pine oil blends: i) E5: gasoline 75 % + ethanol 5 % + pine oil 20 % ii) E10: gasoline 70 % + ethanol 10 % + pine oil 20 % iii) E15: gasoline 65 % + ethanol 15 % + pine oil 20 %
- 3) Gasoline-isopropanol-pine oil blends: i) IPA5: gasoline 75 % + isopropanol 5 % + pine oil 20 % ii) IPA10: gasoline 70 % + isopropanol 10 % + pine oil 20 % iii) IPA15: gasoline 65 % + isopropanol 15 % + pine oil 20 %

**Table 1** compares the properties of gasoline, ethanol and isopropanol while **Table 2** compares the properties of gasoline and pine oil.

**Table 1** Properties of gasoline, ethanol and isopropanol.

Properties	Gasoline	Ethanol	Isopropanol
Density, kg/m <sup>3</sup>	736	789	786
Calorific value, kJ/kg	45524	29700	30400
Latent heat of vaporization, kJ/kg	349	904	758
Octane number	90	106	112
Chemical formula	C5-C12	C <sub>2</sub> H <sub>5</sub> OH	C <sub>3</sub> H <sub>7</sub> OH

**Table 2** Properties of gasoline and pine oil.

Properties	Gasoline	P20
Specific gravity	0.71	0.7603
Density, kg/m <sup>3</sup>	736	759
Calorific value (Lower), kJ/kg	45524	44799
Acidity (mg of KOH/gm)	0.023	0.076

**Experimental set-up and methodology**

**Test Apparatus**

The tests were performed on a 2-cylinder 4-stroke multi point fuel injection SI engine at Annamalai University, Tamilnadu. This engine consists of a system which injects the fuel into the intake manifold of each cylinder controlled by electronic control unit (ECU). It results not only in higher output but also quick response in throttling process. The ECU commands the fuel injector to supply the necessary quantity of fuel that mixes with air based on different driving conditions. The engine consists of different sensors which are used to detect the engine conditions such as air, fuel and other requirements. The

engine is connected to an eddy current dynamometer for loading purposes. An AVL di-gas analyser was used for measuring emissions. **Figure 2** shows the test engine used for experimental investigations. **Table 3** shows the test engine specifications.

### Experimental methodology

The experiments were conducted to evaluate the engine performance and emissions at different loads from no load to full load, i.e., 0 to 100 % in steps of 20 % at a constant speed of 2500 rpm. The first set of experiments was conducted with pure gasoline from no load to full load. The same procedure was repeated for other 3 sets of fuel blends, i.e., for gasoline with pine oil 20 %, blends of gasoline-ethanol-pine oil (E5, E10 and E15) and blends of gasoline- isopropanol-pine oil (IPA5, IPA10 and IPA15). The engine was started and allowed to attain the steady state conditions then the test readings were taken at steady state of the engine. The readings for fuel consumption, air consumption etc., were noted down. The exhaust gas composition was measured with AVL di-gas analyser at steady state.



**Figure 2** Experimental setup.

**Table 3** Test engine specifications.

Parameter	Value
Number of cylinders	2
Type	4-stroke, vertical in-line engine with MPFI
Displacement volume	624 cc
Bore	73.5 mm
Stroke	73.5 mm
Compression ratio	9.5:1
Maximum output	25.74 kW @ 5250 rpm
Maximum torque	48 Nm @ 3000 rpm
Speed	2500 rpm
Orifice diameter	20 mm
Number of injectors	2 (1 per cylinder)
Fuel injection pressure	5 bar
Number of holes on the injector	3

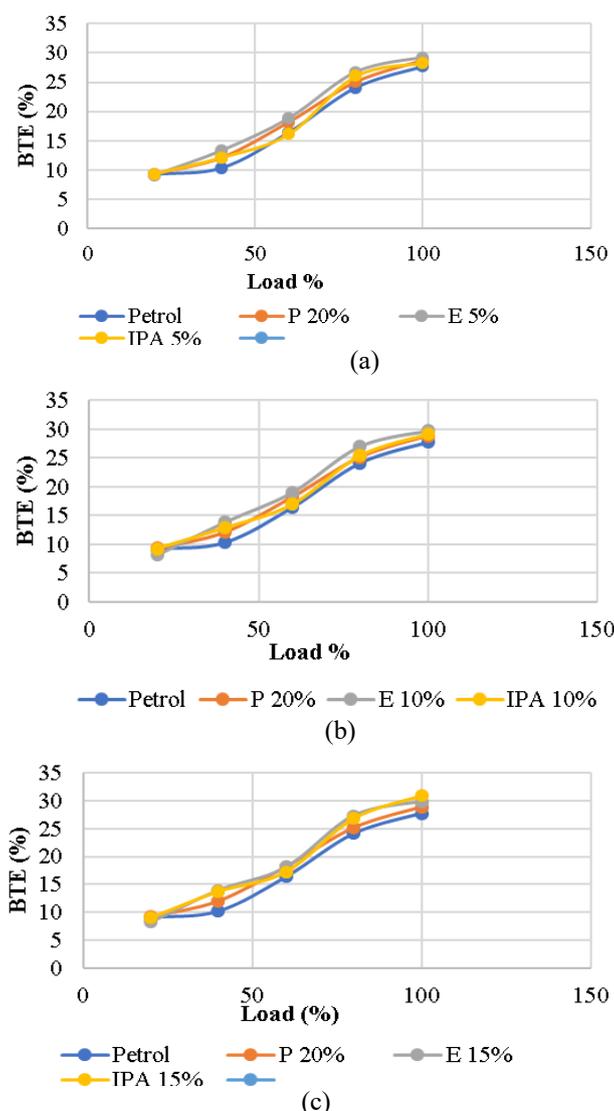
## Results and discussion

This section presents the experimental results on performance and emissions characteristics of multi point fuel injection SI engine with different fuel blends. Performance characteristics considered are BTE and BSFC while emission characteristics are CO, HC and NOx.

### Performance characteristics

#### Brake thermal efficiency

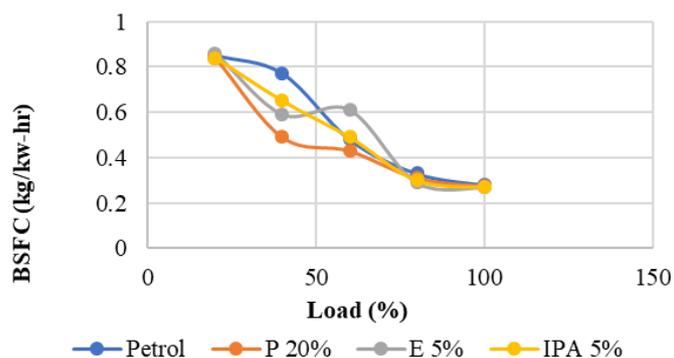
Figures 3(a) - 3(c) show how the BTE varies with load for different fuels considered i.e., gasoline with pine oil 20 %, blends of gasoline-ethanol-pine oil (E5, E10 and E15) and blends of gasoline-isopropanol-pine oil (IPA5, IPA10 and IPA15). The test results show that with a rise in blending percentage and load, BTE gradually increased. The main reasons for this are: 1) alcohols are manufactured completely with biological processes involving zero carbon ii) alcohol's higher content of oxygen which helps in better combustion 2) higher latent heat of alcohols compared to gasoline which enables absorption of more heat from walls and cooling of fresh charge. At 100 % load, the increase in BTE is 5.4, 7.2, 7.8 % for E5, E10 and E15, respectively when compared to gasoline. Similarly, for IPA5, IPA10, IPA15, it is increased by 2.2, 5.8 and 11.20 %, respectively. It is also observed that IPA15 gave higher thermal efficiency than gasoline for full load condition. The improvement in brake thermal efficiency with IPA15 blend is 11.20 % at 100 % load, when compared with that gasoline at same load.



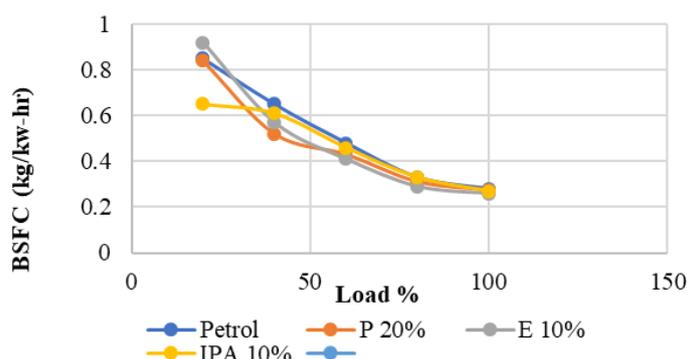
**Figure 3** Variation of BTE with load: (a) BTE variation with load for gasoline, P20, E5 and IPA5, (b) BTE variation with load for gasoline, P20, E10 and IPA10, and (c) BTE variation with load for gasoline, P20, E15 and IPA15.

### Brake specific fuel consumption

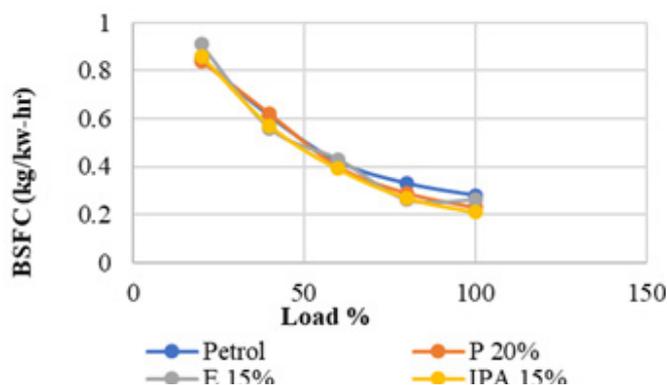
Figures 4(a) - 4(c) show how the BSFC varies with load for different fuels considered i.e., gasoline with pine oil 20 %, blends of gasoline-ethanol-pine oil (E5, E10 and E15) and blends of gasoline-isopropanol-pine oil (IPA5, IPA10 and IPA15). It is observed that BSFC decreases with respect to load in all blends. The reason for this is less fuel is required at higher loads with an increase in brake power due to reduction in heat loss. At 100 % load, BSFC decreased by 3.5, 7.14, and 7.6 % for E5, E10, and E15, respectively when compared to gasoline. A similar trend is observed for IPA5, IPA10, IPA15, with a reduction of 3.5, 12.34, 25 %, respectively when compared to gasoline. It is found that IPA15 gave maximum reduction in BSFC, i.e., up to 25 % as compared to that of gasoline.



(a)



(b)



(c)

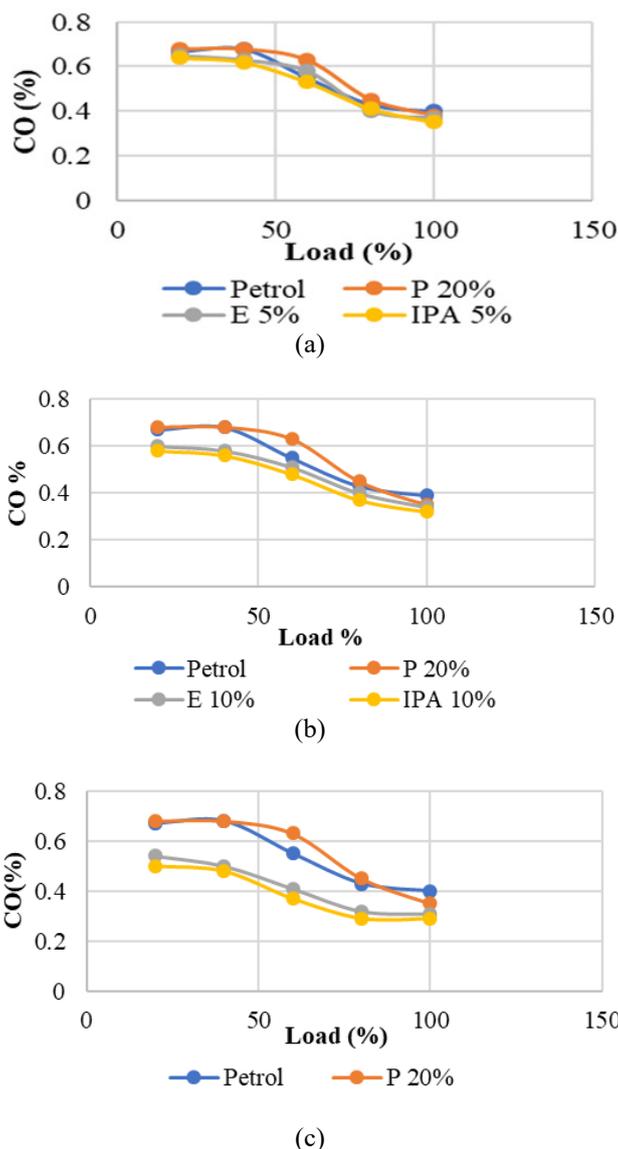
**Figure 4** Variation in BSFC with load: (a) BSFC variation with load for gasoline, P20, E5 and IPA5, (b) BSFC variation with load for gasoline, P20, E10 and IPA10, and (c) BSFC variation with load for gasoline, P20, E15 and IPA15.

**Emission characteristics**

**Carbon monoxide (CO) emissions**

The presence of carbon monoxide in emission indicates incomplete combustion. **Figures 5(a) - 5(c)** show how CO emission varies with load for different fuels considered i.e., gasoline with pine oil 20 %, blends of gasoline-ethanol-pine oil (E5, E10 and E15) and blends of gasoline- isopropanol-pine oil (IPA5, IPA10 and IPA15).

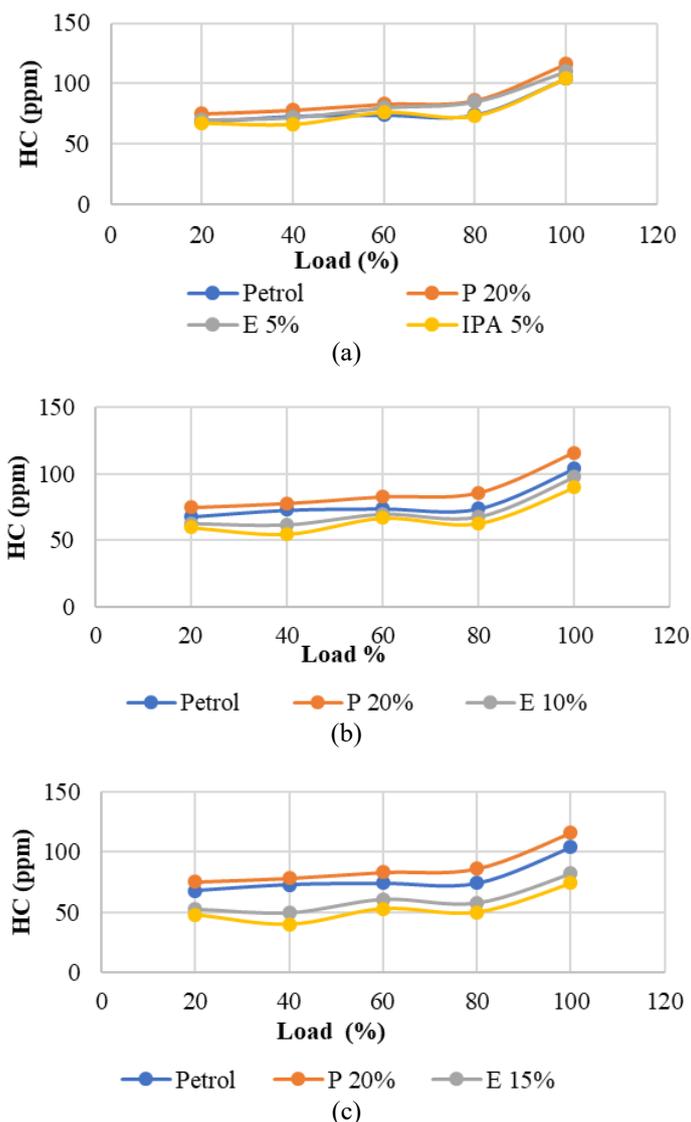
It is observed that CO emissions decrease in case of all blends with respect to load, due to lesser heat of evaporation and higher oxygen content. At 100 % load, CO emissions decreased by 7.5, 12.8 %, and 22.5 % for E5, E10 and E15, respectively when compared to gasoline. Similarly, for IPA5, IPA10, IPA15, it is decreased by 12.5, 17.9 and 27.5 %, respectively when compared to gasoline. It is found that IPA15 presents highest decrease in CO that is 27.5 %, when compared with gasoline.



**Figure 5** Variation in CO emissions with load: (a) CO variation with load for gasoline, P20, E5 and IPA5, (b) CO variation with load for gasoline, P20, E10 and IPA10, and (c) CO variation with load for gasoline, P20, E15 and IPA15.

**Hydrocarbon (HC) emissions**

Incomplete combustion is the main reason for the presence of hydrocarbons in the emissions. **Figures 6(a) - 6(c)** show how HC emission varies with load for different fuels considered i.e., gasoline with pine oil 20 %, blends of gasoline-ethanol-pine oil (E5, E10 and E15) and blends of gasoline-isopropanol-pine oil (IPA5, IPA10 and IPA15). It is observed that when the proportion of oxygen increases in the fuel blend, the emission level of hydrocarbons decreases. At 100 % load, HC emissions decreased by 5.7, 11.66, 21.5 % for E5, E10, E15. Similarly, for IPA5, IPA10, IPA15, they decreased by 7.24, 13.4 and 28.8 %, respectively. It is also found that IPA15 presents higher reduction in HC emissions, i.e., up to 28.8 %, when compared with gasoline.

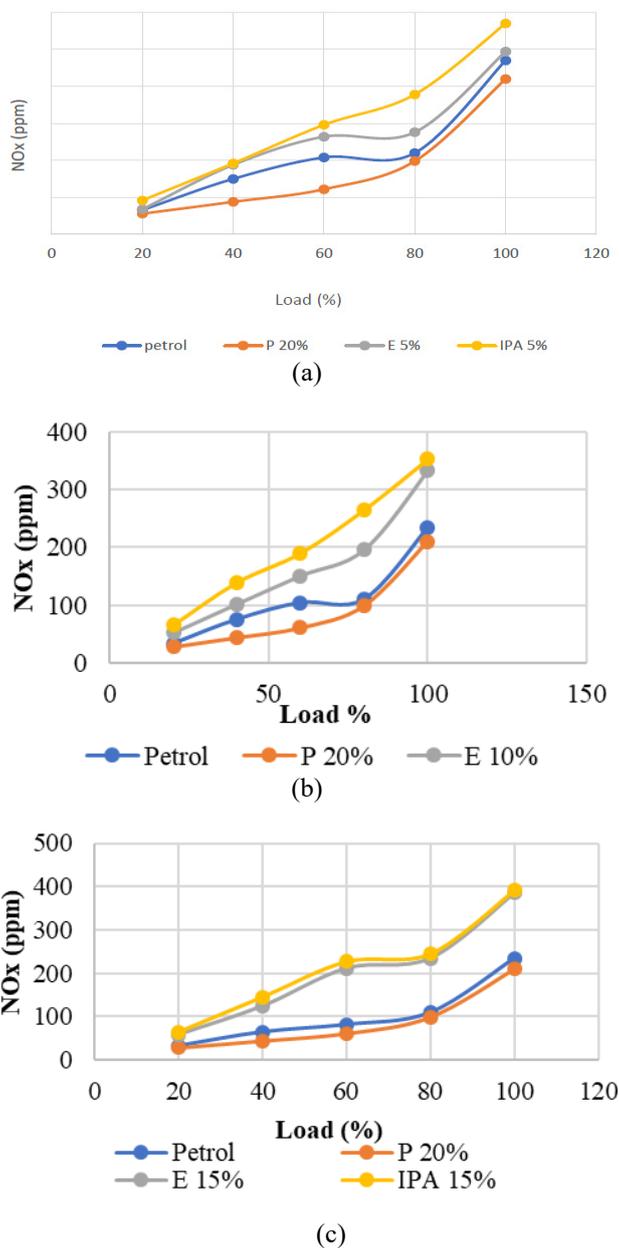


**Figure 6** Variation in HC emissions with load: (a) HC variation with load for gasoline, P20, E5 and IPA5, (b) HC variation with load for gasoline, P20, E10 and IPA10, (c) HC variation with load for gasoline, P20, E15 and IPA15.

**Oxides of nitrogen (NO<sub>x</sub>)**

Major contribution to NO<sub>x</sub> emission includes elevated temperature in combustion chamber and presence of oxygen during combustion. **Figures 7(a) -7(c)** show how NO<sub>x</sub> emission varies with load for different fuels considered i.e., gasoline with pine oil 20%, blends of gasoline-ethanol-pine oil (E5, E10 and E15) and blends of gasoline-isopropanol-pine oil (IPA5, IPA10 and IPA15). It is observed that NO<sub>x</sub>

emissions increase for all the blends. The reason for increased NO<sub>x</sub> emissions with the alcohol-based fuels can be attributable to the in-built oxygen content of the alcohols that reacts with the nitrogen in the air at higher combustion temperatures leading to the increased NO<sub>x</sub> emissions. Another factor which contributes to increased NO<sub>x</sub> emission is higher octane number of alcohol. Moreover, from the chemical formula of pine oil (C<sub>10</sub>H<sub>16</sub>+ C<sub>10</sub>H<sub>18</sub>O), it can be observed that it has oxygen content that can also contribute towards increased NO<sub>x</sub> emissions [38].



**Figure 7** Variation in NO<sub>x</sub> emissions with load: (a) NO<sub>x</sub> variation with load for gasoline, P20, E5 and IPA5, (b) NO<sub>x</sub> variation with load for gasoline, P20, E10 and IPA10, and (c) NO<sub>x</sub> variation with load for gasoline, P20, E15 and IPA15.

## Conclusions

The performance and emissions of ethanol and isopropanol with pine oil as an emulsifier in a twin cylinder multi-point fuel injection (MPFI) SI engine were evaluated in this study. The conclusions from this investigation are as follows:

- 1) The addition of an emulsifier in quantity of 20 % with alcohol-gasoline blends increases the brake thermal efficiency of the engine and reduces the specific fuel consumption.
- 2) Brake thermal efficiency (BTE) by 7.8 and 11.2 % with the higher proportions of ethanol and isopropanol in gasoline, i.e., E15 and IPA15, respectively when compared to neat gasoline.
- 3) CO and HC emissions reduce by 22.5 and 27.5 %, respectively while HC emissions reduce by 21.5 and 28.8 %, respectively with the E15 and IPA15, respectively.
- 4) However, higher amounts of nitrogen oxides (NO<sub>x</sub>) emissions are the negative impact of the said blends.
- 5) Due to higher octane value of alcohol and emulsified fuel, the unburned hydrocarbon (HC) decreases when compared with gasoline.

From the above results, it is concluded that optimum emulsified fuel blend for MPFI engine is gasoline 65 % + pine oil 20 % + alcohols (ethanol or isopropanol) 15 %) which gives a better performance and lower emissions.

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