EFFECT OF ALCOHOLS ON THE PERFORMANCE AND EMISSION CHARACTERISTICS OF SPARK-IGNITED ENGINES

[1]Prasenjit Halder, [2]Indranil Sarkar, [3]Shwetabh Suman
[1,2,3]M.Tech Student
[1]School of Mechanical Engineering (SMEC)
[1]Vellore Institute of Technology, Vellore, India- 632014

Abstract: In recent times, the stringent legislation for upcoming Bharat-Stage 6 makes it very difficult for the auto makers to comply with emission standards. An easy way to meet emission standards is to go electric. But with the current infrastructure India has, it will take another decade or so to have an all-electric fleet with sufficient charging infrastructure. An easy way out while successfully meeting emission standards is to make use of alternate fuels while retaining the same IC engine technology. One good advantage of using alcohol as a fuel is that it has similar combustion and ignition characteristics as that of gasoline. Pure alcohol can also be used as a fuel in an IC engine with some modifications. The objective of this paper is to make a comparative study by testing different percentage by volume blends of ethanol, Iso-propanol, Iso-butanol and n-butanol with petrol.

***IndexTerms*–Alcohol blends, SI engine, Performance and Emission Characteristics**

I. INTRODUCTION

The alcohols as a SI engine fuel predates back to the time, when Nicolas Auto used Ethyl alcoholsinearlyversionofinternalcombustion engines in 1860. During the 1890s alcohol operated engines came into farm use as farm machineries in Europe. In the time of US civil war from 1862 to 1864, a tax was imposed on alcohols to pay for civil war making it costlier. On the other hand, horse less carriages started appearing on the roads of Europe and United States by 1896. As gasoline was so cheap and alcohol was taxed at high, early automobiles in United States were developed for use with gasoline. In the 20thcentury use of additives such as TEL(Tetra Ethyl Lead) allowed the use of gasoline with higher compression ratios without knock, as a result alcohol was no way close to gasoline.However, with the appearance of stringent emission standards, eventually TEL was banned globally. This again lead to race for a harmless safer additive for gasoline. LawerKet.al[7]studiedpropertiesofdifferent alcohols starting with carbon atoms three tosix and came up with the following revelations. Alcohols such as Methanol, Ethanol have Octane rating of the range 90 to 115. Thus, the blending of these alcohols with gasoline provides an overall good Octane rating than neat gasoline. On the other hand, alcohols having carbon atom three or more, then three have Octane rating lower than Methanol and Ethanol. The alcohols having carbon atoms three or more than three have energy densities much higher than both Methanol and Ethanol. As a result of this when the same engine is provided with a blend of gasoline and higher alcohol, rather than gasoline and Ethanol, the range of the car improves significantly in the former case. The boiling point of the alcohol decreases rapidly with the increase in the number of carbon atoms. As a result of this, Methanol has the lowest boiling point among all alcohols. It is observed that neither too lessboiling point nor too high boiling point is good for engine. A too less boiling point may lead to vapour lock whereas, a too high boiling point may lead to severe cold starting problems.

1.1 Octane Phenomenon

At present time higher alcohols (alcohols with carbonnumberthreeormorethanthree)arenot popular as SI engine fuels and very less data is available on blend properties of these alcohols withgasoline.TheOctaneratingofthealcohols can be described as a function of Research OctaneNumber(RON)andMotorOctaneNumber (MON). As the number of carbonatom increases, the Research OctaneNumber decreases. This can be explained due to thefact that higher chain alcohols have higher number of secondary carbon hydrogen bonds which make them more prone to auto-ignition. The RONvalueofthealcoholsrangesfrom105.1to 69.3 and it is observed that Isopropanol has highest RON among all alcohols. Again, for the same no of carbon atoms the RON increases from n-structure to Iso-structure. The MON valuefollowsthesametrendasRONvalueand Isopropanol is having the highest MON value which is at 96.7. The knock sensitivity is defined as the difference between RON and MON values. The higher the value of knock sensitivity,thehigheristheOctanerating.Even though Isopropanol is having the highest RON and MON values, it does not have the highest knock sensitivity because the difference between RON and MON is small for Isopropanol. It is found that Ethanol is having the highest knock sensitivity which is at19.2.

Table 1: Characteristics of liquid fuel

Physical property	Petrol	Ethanol	I- Propanol	I-Butanol	N-Butanol
Molecular Weight	72- 170	46	60	74	74
Density at 200C(g/cm3)	0.700- 0.790	0.794	0.785	0.802	0.810
Boiling at 1 atm (°C)	32- 210	78	62.5	108	118
Energy Density(MJ/KG)	44.5	29.7	33.6	36.1	36.1
Net Heat of Combustion (BTU/gal)	124000	80000	---	95000	93000
Octane Rating	87	112	106	103.5	87
Blend RVP (psi at 1000F)	14.7	18-22	14	5.0	4.3

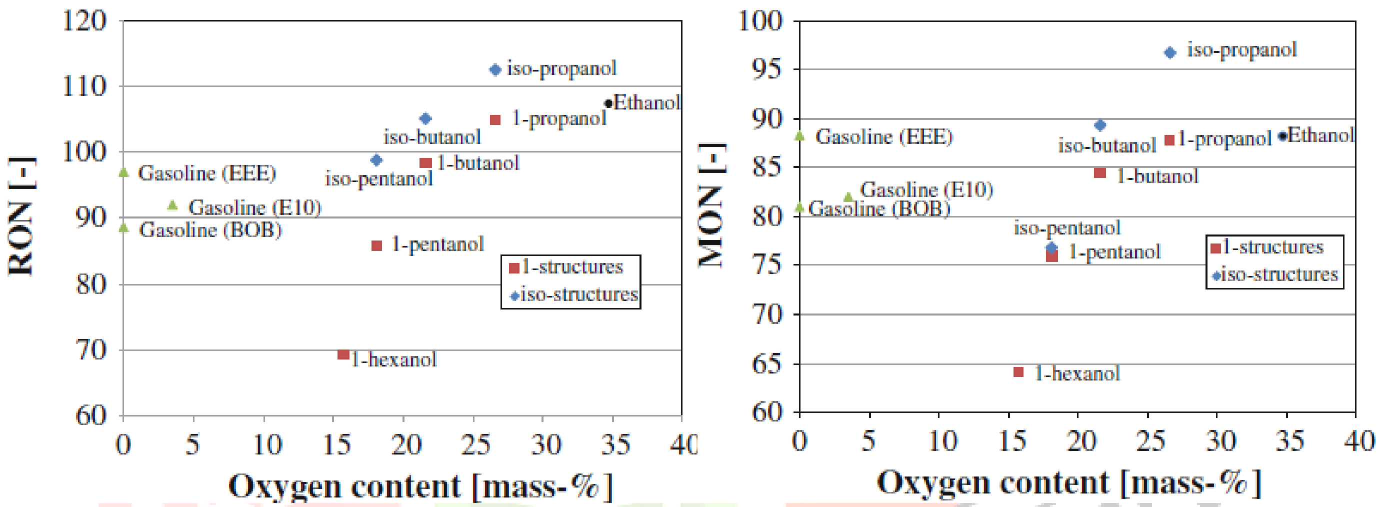


Fig.1 RON and MON of branched andstraight chain alcohols [5]

1.2 Lower HeatingValue

As the number of carbon atoms increases, the energy content or lower heating value increases. Since the number of chemical bonds increases, more energy is obtained forbreaking of the bonds during combustion. Among the alcohols chosen for study later discussed in the paper we see that Iso-butanol is having higher energy density which is at 36.1 MJ/Kg. The presence of less energy density makes the stoichiometric or chemically correct ratioless than 14.7:1 which in turn leads to more fuel consumption for a given quantity of energy in comparison to gasoline.

1.3 Additional Properties

Wallner T et. al [5] performed analytical assessmentofalcoholscontainingcarbonatoms two to five and came up with the following observations. As the number of carbon content increases, the Oxygen content of the alcohol decreases. Since combustion requires the reaction between Oxygen and hydrocarbons present in the fuel, thus it is seen that the presence of additional Oxygen in the form of OH bond improves the overall combustion phenomena.

With increase in number of carbon atoms, the Reid Vapour Pressure (RVP) continuously decreases. The RVP is a function of volatility and boiling point of the fuel. As the carbon number will increase, volatility will decrease and boiling point will increase. Petrol ishaving higher RVP than almost all alcohols. However, study suggests that certain shorter chain alcoholshavehigherRVPthanthatofgasoline. Very high Reid Vapour Pressure can lead to vapour lock. Higher volatility often leads to excess evaporative emission of fuel from the tank and float chamber, causing a decrease in economy of the car and a too low RVP leads to cold start problems and followed by increasein HCemissions.Itisfoundthatifasmallquantity of alcohol is added to gasoline, the volatility of the mixture is greatly affected. Recent study suggests that low level addition ofalcohols such as Ethanol and Methanol actuallyincrease theRVPofthemixture,duetotheformationof Azeotropes. Thelatentheatofvaporizationorboilingpoint increases with increase in number of carbon count. Since alcohols have higher heat of vapourisation, as a result, the intake charge inside the combustion chamber will absorb moreheattoformcombustiblemixture,thereby allowing higher compression ratio which is in the range of 11:1 to 13:1 and controlling the knock phenomenon in SI engines. In SIengine, the brake thermal efficiency is a function of compression ratio (r), thereby increasing the brake thermalefficiency.

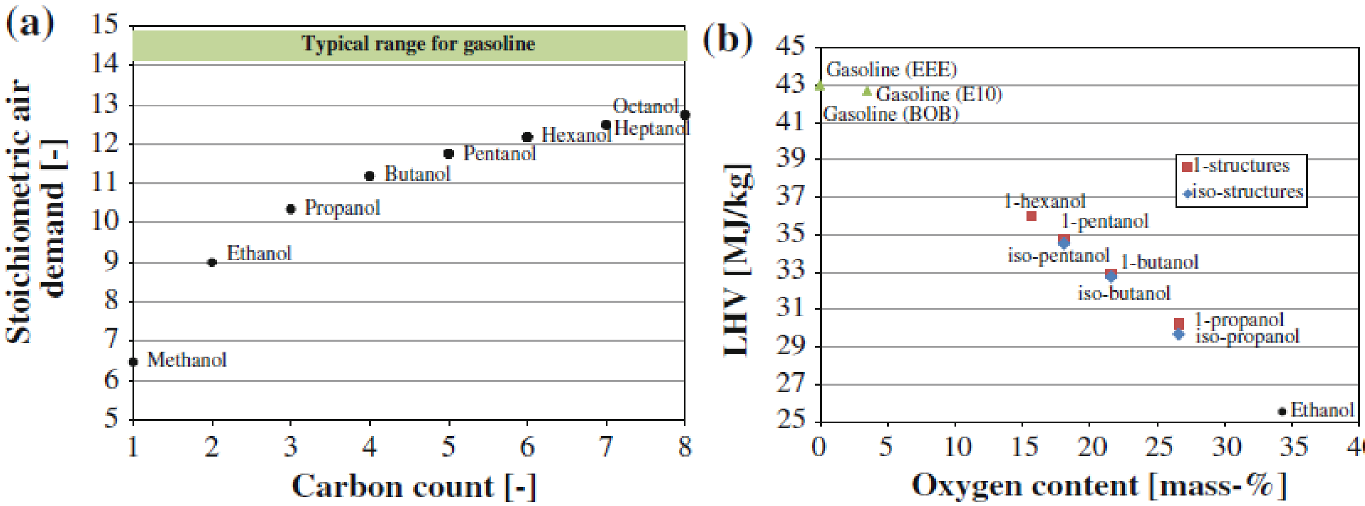


Fig.2 (a) Stoichiometric air demand [5] Fig..2 (b) Lower heating value for alcohols**[5]**

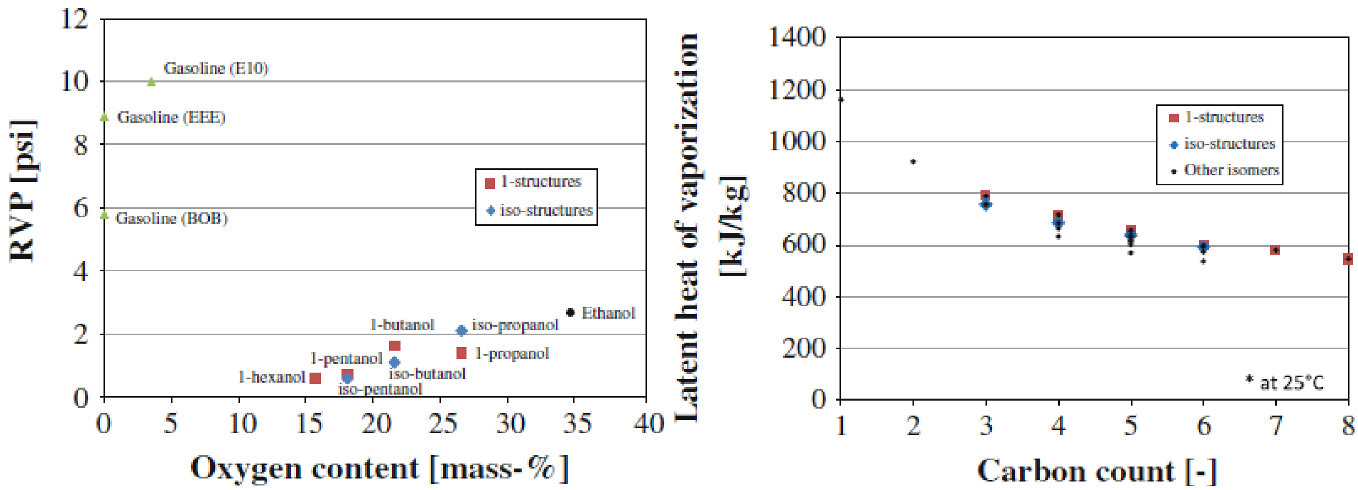


Fig.3 (a) ReidVapor Pressure for various alcohols[5] Fig.3(b) Latent heat of vaporization for Branched and straight chain alcohols [5]

Solubility of alcohols in water decreases with increase in number of carbon atoms. Alcohols having carbon count one to three (C1-C3) are fully miscible in water, carbon count from four to eight (C4-C8) are partially miscible in water and higher alcohols (>C8) are immiscible in water.The shorter chain alcohols follow the same flammabilitylimitsasthatofgasoline.Withthe increase in number of carbon atoms, the upper flammability limit decreases, while the lower flammability limit which is more important remainsame.Studies conducted previously for C1-C4 alcohols suggest that with increase in carbon chain length, the laminar flame speed decreases.

ABBREVIATIONS

RON- RESEARCH OCTANE NUMBER
MON- MOTORABLE OCTANE NUMBER
RVP-REID VAPOUR PRESSURE
HC-HYDROCARBONS
P+20%E- PETROL+20%ETHANOL
P+20%IP-PETROL+20%ISOPROPANOL
P+20%IB- PETROL+20%ISOBUTANOL
P+20%NB- PETROL+20%N-BUTANOL
P+20%(IP+NB)- PETROL+20%ISOPROPANOL+20%N- BUTANOL
P+20%(IP+IB)- PETROL+20%ISOPROPANOL+20%ISOBU TANOL
P+30%IP+10%IB- PETROL+30%ISOPROPANOL+10%ISOBU TANOL
P+10%E+10%IB+20%IP- PETROL+10%ETHANOL+10%ISOBUTAN OL+20%ISOPROPANOL

II. EXPERIMENTAL SETUP

Experiments were performed in a HONDA GX 160 CC air cooled four stroke overhead valve single 250 inclined cylinder gasoline engine coupled to an AC generator or Electric Brake Dynamometer. The peak power output of the engine is 4.86 HP at 3000 rpm. The overall dimension of the engine is 312x362x346 mm^3.The compression ratio of the engine is 9.0:1. Bore and stroke of the engine are specified at 68mm and 45 mm respectively. The swept volume or the displacement volume is fixed at 163 cm^3.

2.1 Exhaust Gas Analyzer

A QROTECH QRO-402 exhaust gas analyzer was employed for measuring CO, CO_2, NOx and HC emission. CO and CO_2 quantities were represented as percentage of total exhaust emissions whereas, NOx and HC emission came in parts per million. CO, CO_2 and HC emissions were performed through NDIR methods and O_2, NOx measurements were performed through Electrochemical method. A probe was designed to be fitted in the exhaust pipe that carried the exhaust gases to the meter through the sampling tube. The measuring range of CO is 0-9.99% of exhaust gas and that of CO_2 is 0-20% of exhaust gas. Lambda varies between the ranges of 0-2. HC varies between the range of 0-20000 ppm and NOx varies between the ranges of 0-5000 ppm.

2.2 Test Fuel

Four different types of fuel were considered for the test, which are Ethanol, Isopropanol, N-butanol and Iso-butanol. Pure Petrol was considered as a reference fuel. Methanol was not considered due to poor energy density. Alcohols having carbon atoms more than four were not considered due to poor volatility and very high boiling point. Thus, the interest of the study was restricted from C2-C4 alcohols.

Table 2: Engine Specifications

Model GX 160	
Engine Type	Air cooled 4-stroke OHV Petrol engine, 25° inclined cylinder, horizontal shaft, cast iron Sleeve
Bore × Stroke	68 × 45 mm
Displacement	163 cm^3
Compression Ratio	9.0: 1
Net Power	3.6 KW (4.8HP) / 3600 rpm
Contd. Rated Power	2.5 KW (3.4HP) / 3000 rpm 2.9 KW (3.9HP) /3600 rpm
Max. Net Torque	10.3Nm / 1.05 kgfm / 2500 rpm
Ignition System	Transistorized
Starting System	Recoil starter
Fuel Tank Capacity	3.1 L

III. RESULT AND DISCUSSIONS

The first set of tests was conducted by blending 20% by volume blend of alcohols with gasoline. The blend percentage was selected after consulting numerous research papers to get an idea of how the blend curve varies with that of pure Petrol.

3.1 For Single Blend (20% by Volume Alcohol + 80% by Volume Petrol)

The Brake Specific Fuel Consumption for pure Petrol and 20% by volume blend of Ethanol goes on par with each other (Fig.4).The BSFC for higher alcohols is more for initial load condition which can be explained due tohigher heat of vapourisation of n-Butanol, Iso-butanol and Isopropanol the amount of combustible mixture formed is insignificant for a fixed volume, as a result more fuel was drawn in to compensate for the losses. However, for end load condition due to attainment of high combustionchambertemperaturetheamountof combustible mixture formed is sufficient for a fixed volume for all alcohols, as a result they overlap with each other.

The thermal efficiency for 20% volume blend of Ethanol surpassed all other alcohol curves and even that of pure Petrol (Fig.5). This tendency can be explained due to higher Octane rating of Ethanol, complete combustion of fuel occursin the combustion chamber; as a result, heat released is more.

For Ethanol blend and for pure Petrol, the volumetric efficiency is found to be maximum for initial load conditions (Fig.6). The reason for this can be stated as due to the higher heat of vaporization of n-Butanol, Iso-butanol and Isopropanol, excess fuel was taken in due to which volumetric efficiency fell down. But for end load condition the volumetric efficiency was same for all curves. This can be stated due to the fact that high combustion chamber temperature prevails which can easily vaporize alcohol and thus no excess fuel was required.

For blend of Ethanol with Petrol, the CO &HC emissions were lowest for 100% loading condition among other loads, while the NOx emission followed opposite trend, it was highestamongall.ForblendofIsopropanol,the curve followed the same trend as that of Ethanol. Although, CO & HC emissions were poor in comparison to Ethanol but, NOx emissions were slightly better thanEthanol.

For single blends of N-Butanol & Iso-butanol the CO & HC emissions were not as good as former and lagged even well behind pure Petrol. However, NOx emissions were better in comparison to single blends of Ethanol and Isopropanol.

From this experimental work it was concluded that as the load increases the CO & HC emissionsgodownandonthecontrarytheNOx emission (for blends of Ethanol, Isopropanol and pure Petrol) increases. The decrease of CO & HC in high loads indicates that the temperature inside the combustion chamber is high enough to cause more oxidation of CO &HCandmoreformationofCO_2isaproofofthe above statement. On the other hand, due to more complete combustion, the heat releasedis high and which in turn leads to more formation of NOx. The alcohol contains Oxygen molecules within them which can contribute more towards the formation of NOx if high temperature prevails. Moreover, due to charge cooling effect of alcohols, higher compression ratio can be supported, as a result, high heat is obtained and so more NOx is formed. So, it is understood that an inverse relationship follows betweenformationofCO,HCandformationof NOx.

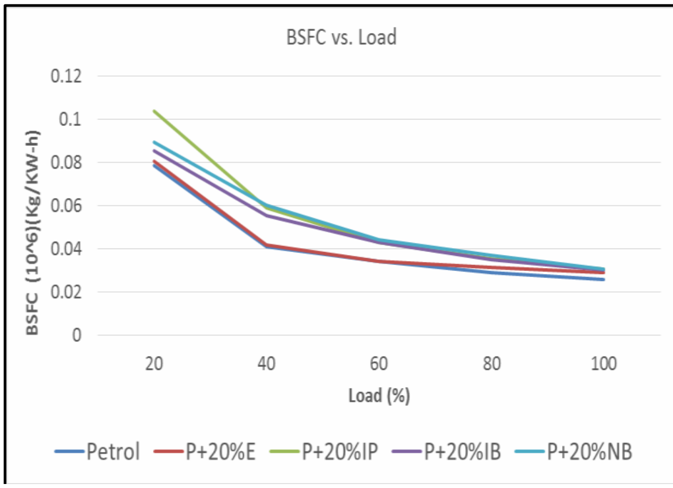


Fig. 4 BSFC vs. Load for 20% mono volume blend

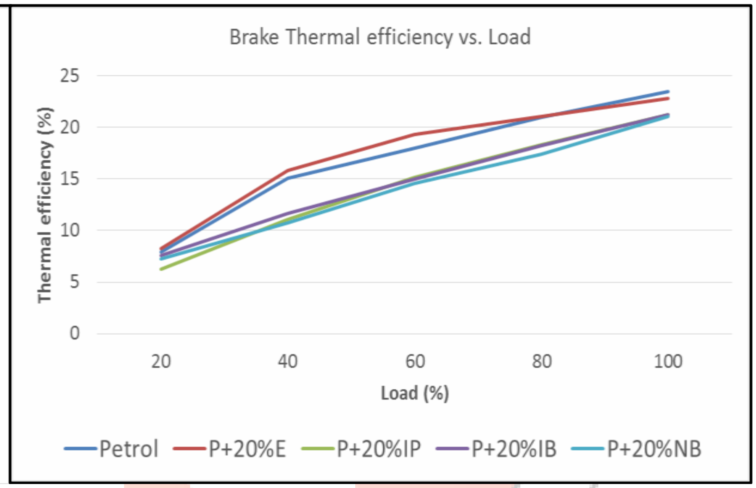


Fig. 5 Brake Thermal Efficiency (BTE) vs. Load for 20% monoblend

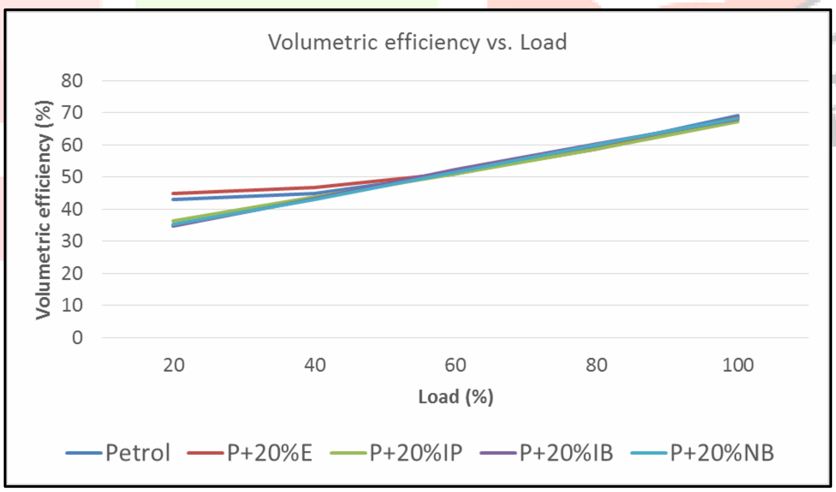


Fig.6 Volumetric Efficiency vs. load for 20% mono volume blend

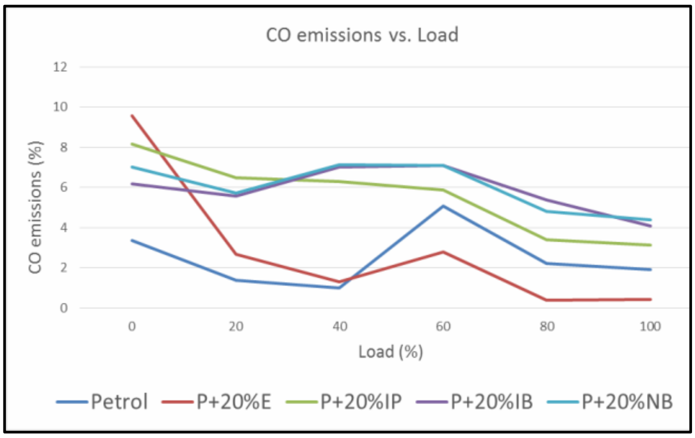


Fig. 7 CO emission vs.loadfor20%monovolume blend

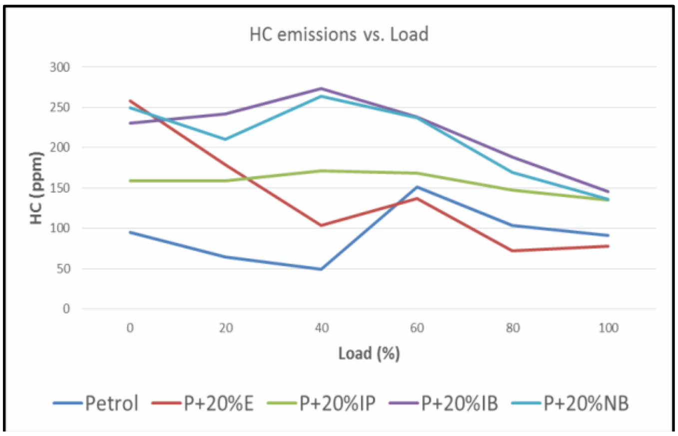
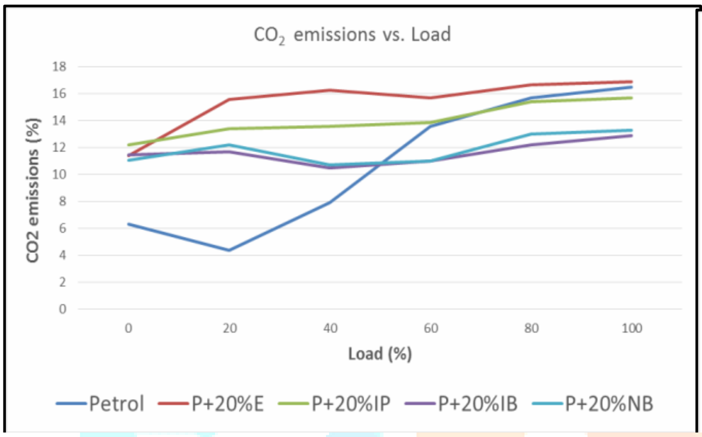


Fig. 8 HC emission vs.loadfor20%monovolume blend



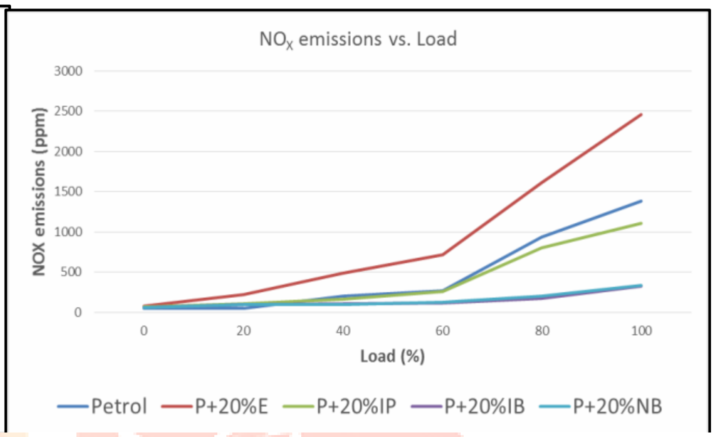


Fig. 9 CO_2 emission vs.loadfor20%monovolume blendFig.10NOx emission vs.loadfor20%monovolume blend

At low loads, the formation of more HC can be described by factors such as quenching of heat on cylinder walls, presence of crevice volume, incomplete combustion etc. (Fig.8).The higher latent heatofvaporizationofalcoholstendtoproduce more HC than pure gasoline duringidling condition. The formation of CO also goes up due to incomplete combustion. The formation of more HC and CO for higher chain alcohol can also be explained due to the fact that the engine is expected to run at MBT timing for Petrol only and not for alcohols.

3.2 For Single Blend (40% by Volume Alcohol + 60% by Volume Petrol)

Nextsetoftestsinvolved40%byvolumeblend of alcohols with petrol. For blend of Ethanol, again the CO & HC emissions were least for full loading condition among other loads, followed by slight increase in NOx emission (Fig.14).The emission values for 40% by volume blend of Ethanol were poor in comparison to 20% by volume blend of Ethanol for HC, CO & for NOx it was slightly better. The emissions obtained from blend of Isopropanol surpassed all alcohol blends tested for all loading conditions. The CO & HC emissions wereleast for 40% by volume blend of all alcohols at highest load, on the other hand NOx emissions were highest among all blend ofalcohols. (Fig.11 and Fig.12)

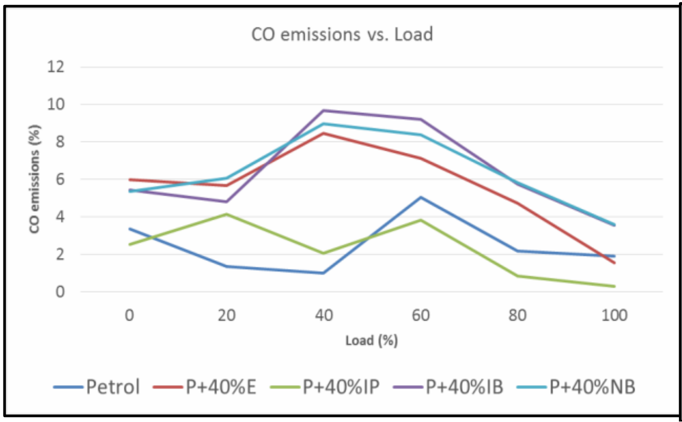


Fig.11CO emission vs. Load for 40% mono volume blend

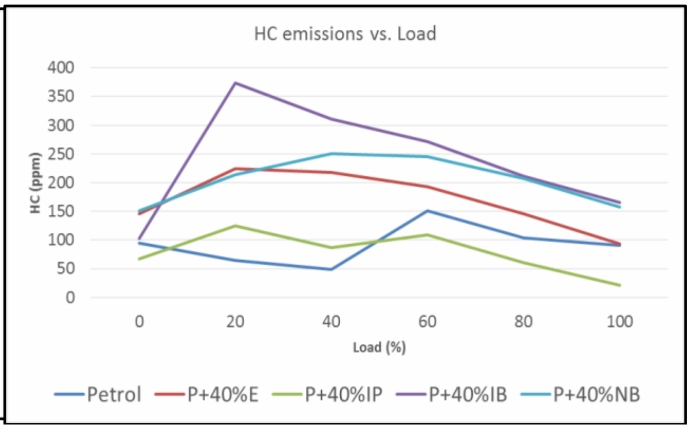
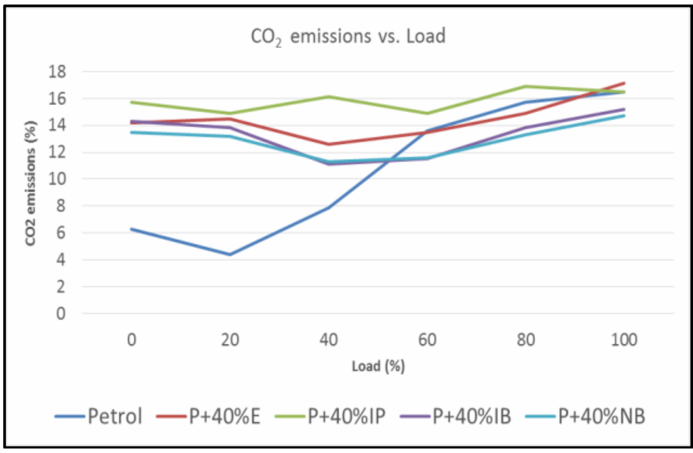


Fig.12 HC emission vs. Load for 40% mono volume blend

For blend of N-butanol and Iso-butanol, the CO & HC emissions were also least in case of full loading condition among other loads. The emission measurements obtained from Iso-butanol and N-butanol blends lagged far behind Isopropanol, Ethanol blends and even thatofpurePetrol.Thesecurvesweresimilarto that of their 20%blends.

The overall performance and emission curves for 40% volume blend was found to be similar to 20% volume blend with one majorexception being that Isopropanol blend was having the least CO, HC emission at full load among all alcohol blends at all loads. This trend also followed with highest emission of NOx at full load among all blends.



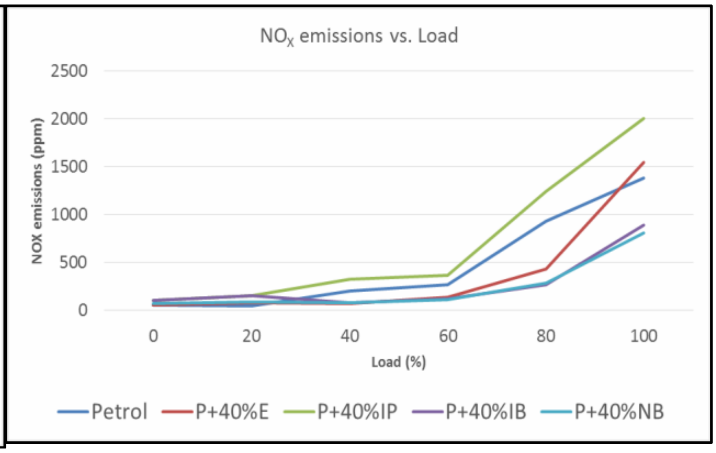


Fig.13 CO_2 emissions vs. load for 40% mono volume blendFig.14 NO_X emissions vs. load for 40% mono volume blend

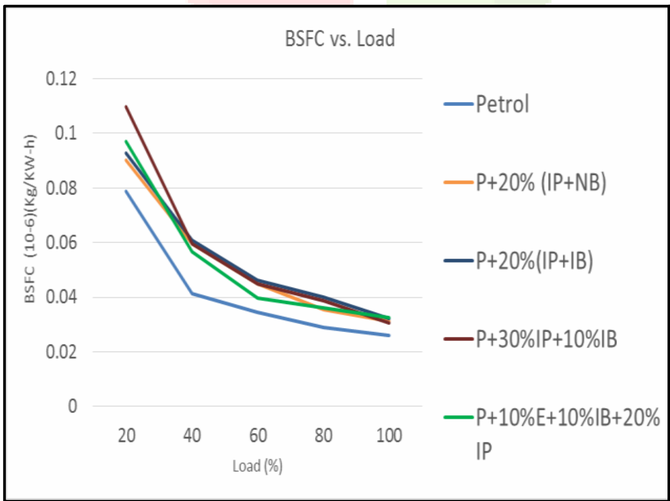
Theinferencethatcanbedrawnfromtheabove tests is that as the CO, HC emissions improve, more complete burning occurs inside the cylinder as a result, more heat is generated and moreCO_2isformed.Onthecontraryastheheat generated is high, more NOx will comeout from the exhaust. So a complete combustion will be accompanied by low CO, HCemissions and high emissions of CO_2, NOx. An incomplete combustion will be followed by high emissions of HC, CO and low emissions of CO_2 and NOx.

Theperformancecurvesforsingle40%volume blend of alcohols were similar to their 20% volume blend counterparts, thus they were not discussed in detail.Since at higher volume percentage of alcohols, the lack of energy content becomes significant, thus higher volume percentages were not desired for the study. Instead a new approach was considered which was mixing different blend of alcohols with gasoline.

3.3 For Multi Blend (40% by Volume Alcohol + 60% by Volume Petrol)

BSFCcurvesforallalcoholblendsweresimilar to each other. Pure petrol was requiring the least BSFC for initial loading condition and multi blend of 30% by volume Isopropanol, 10%byvolumeIsobutanol,and60%byvolume Petrol was requiring the highest BSFC atinitial load (Fig. 15). For end loading condition, due to high temperature of combustion the BSFC for all blends are close to pure gasoline. The brake thermalefficiencyforpurepetrolisfoundtobe highest, while that of multi blend 20% by volume Isopropanol, 20% by volume Iso-butanol, 60 % by volume Petrol is found to belowest.(Fig. 16)

Only at initial loading conditions, petrol is having higher volumetric efficiency because due to higher heat of vapourisation of alcohols, the blended mixtures require more fuel during idlingcondition.Oncethecombustionchamber temperature surges, the volumetric efficiency of all curves overlap with each other. (Fig.17)



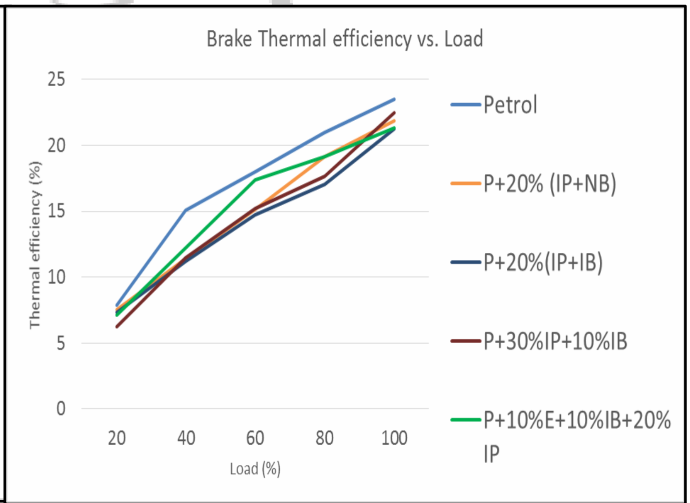
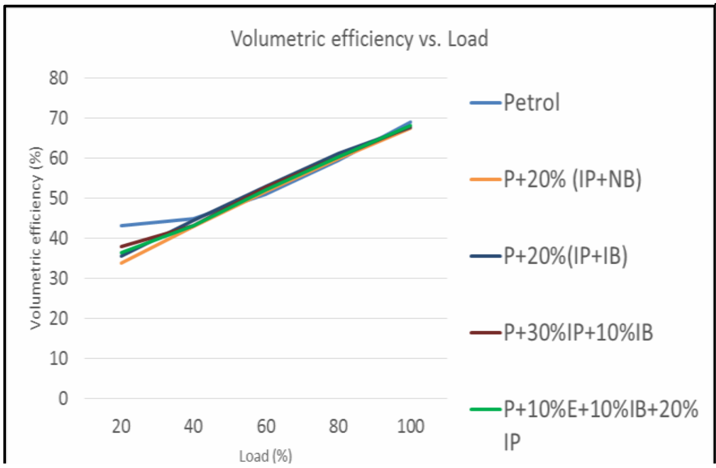


Fig.15 BSFC vs. load for 40% multi blend Fig.16 Brake Thermal Efficiency vs. load for 40% multi blend



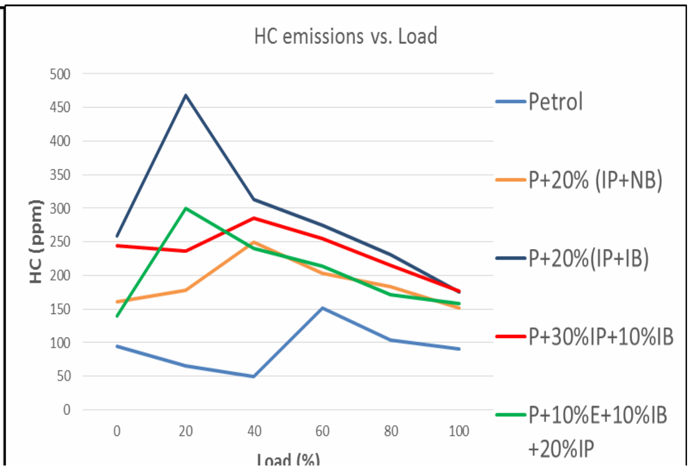
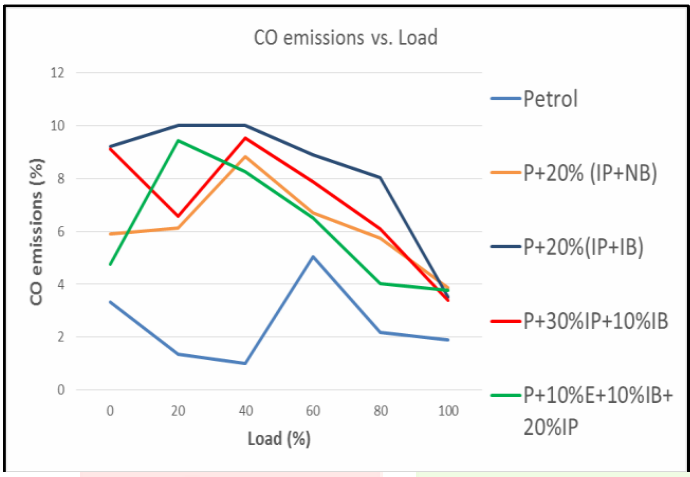


Fig.17 Volumetric Efficiency vs. load for 40% multi blendFig.18 HC emissions vs. load for 40% multi blend



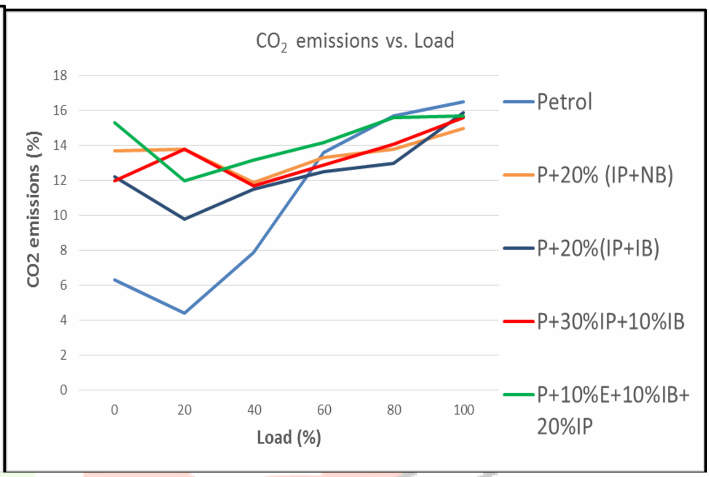


Fig.19 CO emissions vs. load for 40% multi blend Fig.20 CO_2 emissions vs. load for 40% multi blend

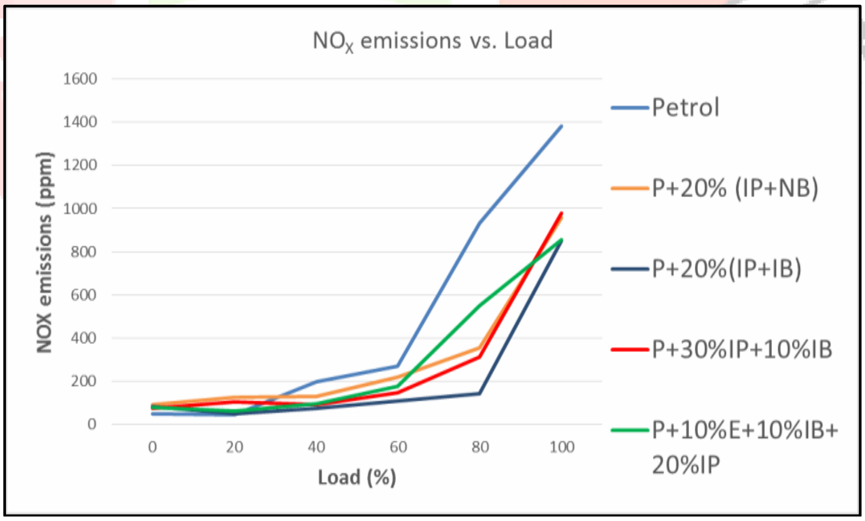


Fig.21 NOx emissions vs. load for 40% multi blend

3.4 60 % by Volume Petrol + 20% by Volume Isopropanol + 20% by Volume Iso-butanol

The CO and HC emissions for this blend were highest among other multi blends at all loads(Fig. 18 and Fig. 19)CO_2 emissions were least for this multi blend almost at all loads(Fig. 20) The increase in CO & HC emissions were compensated by a highest decreaseinNOxemissionatfullloadamongall other multiblends.

3.5 60 % by Volume Petrol + 20% by Volume Isopropanol + 20% by Volume N-Butanol

The CO and HC emissions were much higher than pure gasoline, characterized by a decrease in CO_2 and NOx emissions than pure petrol as depicted from above figures.

3.6 60 % by Volume Petrol + 30% by Volume Isopropanol + 10% by Volume Iso-butanol

This blend was characterized by a moderate increaseinHCandCOemissions.Thedecrease in NOx emission was also significant. (Fig.21)

3.7 60 % by Volume Petrol + 20% by Volume Isopropanol + 10% by Volume Ethanol + 10% by Volume Iso-butanol

One interesting phenomena about this blend wasnotedthatCOandHCemissionswereleast amongallblendsatallloads (Fig.18).TheCO_2emission was almost at par with pure Petrol which is a good characteristic. The largest dip in NOx emission was a huge success for this blend among all.

IV. CONCLUSION

Pure gasoline and different blends of alcohols were tested in a HONDA GX 160 CC single cylinder engine at fixed spark timing. Performance and emission measurements were carried out at different loading conditions. The following conclusions were drawn from the above tests.

- The performance for 20 and 40 percent by volume blend of alcohols comes with slight increase of BSFC. The Brake Thermal Efficiency of certain blends is same as that of neat 100 percent neat petrol. The decrease in power output can be compensated with increase in fuel spray inside the combustion chamber. The volumetric efficiency for the alcohol blends becomes same as neat petrol at high loads.

- TheformationofHC,COandformation of NOx follows inverse relationship.As thecombustionbecomesmorecomplete in nature, the concentration of HC, CO goes down and concentration of CO_2, NOx rises. As the temperature in the combustion chamber surges at highest loading condition the oxidation of HC, CO is highest, as a result CO_2 emission shoots up and is also corroborated by the fact that NOx emission is highest at endloadsirrespectiveofalcoholblends.

- Propanol is found to be the optimum blend fuel for 40% by volume single blend with Petrol. The combustion is characterized by lowest release ofHC, CO at full load and highest release of NOx as a result.

- Among multi blended fuels, themixture of 20% by volume Isopropanol, 10%by volume Ethanol, 10 % by volume Iso-butanol with 60% by volume Petrol tends to produce less CO and HC emission among other multi blended fuels at all loads. There is also ahighest dip in NOx emission among all multi blends at allloads.

REFERENCES

[1]WallnerT,MiersSA,McConnellS. A Comparison of Ethanol and Butanol as Oxygenates using a Direct-Injection, Spark-Ignition Engine. Journal of Engineering for Gas Turbines and Power 2009;131:1-9

[2]Nehare SU, Raizada KS, Kothare CB. A Review On Propanol as an Alternative Fuel in SI Engine. IJARIIE 2015;1:758-3

[3]Khaled D. El, Novas N, GázquezJA et.al.Alcoholsandalcoholsmixturesas liquid biofuels: A review of dielectric properties. Renewable and Sustainable Energy Reviews 2016;66:556-16.

[4]Karpov SA. Aliphatic alcohols as components of fuels for internal combustion engines. Chemistry and Technology of Fuels and Oils 2008; 44:249-6.

[5]Wallner T, Ickes A, Lawyer K. Analytical Assessment of C2–C8 Alcohols as Spark-Ignition Engine Fuels. Proceedings of the FISITA2012; B01-004:15-12.

[6]Gulyamov YM, Gladkikh VA, Shtefan YV, Malykhin VD. Anti-knock rating of alcohol based synthetic motor fuels. Plenum publishing corp. 1991; 184-4.

[7]Lawyer K, Wallner T. Blend ratio optimization of fuels containing gasoline blendstock, Ethanol, and higher alcohols (C3-C6): Part I - Methodology and Scenario definition. SAE International;2013-01-1144.

[8]WangBW,ShiAQ,TuR,ZhangXL et.al.Branched-ChainHigherAlcohols. AdvBiochemEngin/Biotechnol 2012; 128:101-18.

[9]Zhang J, Nithyanandan K, Li Y et. al. Comparative Study of High- Alcohol-Content Gasoline Blends in an SI Engine. SAE International;2015-01- 0891.

[10] Wei Y, Wang K, Wang W. Contribution Ratio Studyof Fuel Alcohol and Gasoline on the Alcohol and HydrocarbonEmissions of a Gasohol Engine. Journal of Energy Resources Technology 2014;136:1-7.

[11] Gautam M, Martin II DW. Emissions characteristics of higher alcohol/gasoline blends:1-39

[12]Fulzele SD, Kothare CB, Raizada KS. Higher alcohol blend with Petrol: Alternative fuel for SI engine aReview. IJARIIE 2015; 1-5: 598-4.

[13] Mamun AL. Studies of Binary Systems of Long Chain Alcohols.Lipid Chemistry Laboratory, G6teborg University, S-431 33 M61ndal, Sweden;234-4.

[14] Wallner T, Frazee R. Study of Regulated and Non-Regulated Emissions from Combustion of Gasoline, Alcohol Fuels andtheir Blends in a DI-SI Engine. SAE International;2010-01-1571.

[15] Stansfield PA, Bisordi A, Oude Nijeweme D. The Performance of a Modern Vehicle on a Variety of Alcohol-Gasoline Fuel Blends. SAE International;2012-01-1272.