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Performance and Emission Characteristics of a Spark Ignition Engine using Gasoline and Alcohol Blends with and without Recirculation of Exhaust Gas–A Review

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Abstract—*To reduce the dependency on petroleum based fossil fuels and to mitigate the problem of air pollution due to the toxic vehicle exhaust, a lot of research and developmental activities are being undertaken on bio-fuels and gasoline blends. Most of the research works reported in literature discuss the performance of internal combustion engines using the first and second generation bio-fuels that is Methanol and Ethanol respectively. Though there was an overall improvement in performance with the first and second generation alcohol gasoline blends, however there were certain shortcomings like phase separation of gasoline and methanol/ethanol., etc. Very recently research work has been focussed on the third generation biofuels that is Butanol which has certain advantages over the previous bio-fuels. In the present work, an extensive review of literature has been conducted to determine the feasibility of using alcohol gasoline blends for use in spark ignition engine from the performance and emission point of view.*

1. INTRODUCTION

The worldwide vehicle population is increasing rapidly due to increase in urbanization and globalization. As on 2010, there were more than one billion motor vehicles in use in the world excluding off-road vehicles [1]. India's vehicle fleet had the second-largest growth rate after China in 2010. India has a fleet of 1.1 million natural gas vehicles as on December 2011 [2]. The increase in vehicle population leads to an increase in demand for petroleum based fuels. As the demand for fuels increase in India, oil imports also increase which ultimately affects the economy of the country.

Another significant aspect of the increasing vehicle population is the increase in exhaust gas emissions. Combustion of fossil fuels emits hazardous pollutant gases such as nitrogen dioxide, carbon monoxide, carbon dioxide and sulphur oxides, which contribute significantly towards the greenhouse effect and global warming [3]. In a study conducted by NASA, it was found that **motor vehicles emerged as the greatest contributor to atmospheric warming now and in the near term.** Globally, about 15 percent of manmade carbon dioxide comes from cars, trucks, aero planes, ships and other vehicles.

In view of all these problems, development of new environmental friendly fuels is the need of the hour to reduce the strain on fossil fuel reserves and reduce exhaust gas emissions thereby reducing air pollution and global warming. One possible renewable fuel is biofuel. It has been shown that biofuels reduce the emission of greenhouse gases by 80% or more below the 1990 levels in the transportation sector and also lower their lifecycle emissions of CO_2[4]. Biofuels have in general the advantage of reducing most of the regulated emissions such as unburned hydrocarbons (UHC) and carbon monoxide (CO) from engines [5].

In first generation biofuels, the source of carbon is sugar, lipid or starch directly extracted from a plant and using them may cause food shortages [6]. Experiments conducted on first generation bio-fuels yielded satisfactory results. The second generation biofuels are derived from cellulose, hemicellulose, lignin or pectin and their use thus reduces the strain on food supply compared to that of the first generation biofuels [7]. One of the second generation biofuels is n-Butanol. Extensive research is being done using various Butanol blends with gasoline in Spark Ignition (S.I.) engines.

Compared to gasoline, corn-based n-Butanol as a transportation fuel can save about 39–56% of fossil fuel, while reducing greenhouse gas emissions by up to 48% on a lifecycle basis [8]. It has several advantages over other biofuels like ethanol and methanol. n-Butanol is easier to ignite in gasoline engines since it has a lower auto-ignition temperature than ethanol and methanol. It is also easier to transport and can be transported like gasoline through pipelines as it has similar physical properties like gasoline. Also, the same has lower tendency to separate from base fuel when contaminated with water. n-Butanol can also be blended with gasoline without phase separation and this makes it more cost effective with the present gasoline infrastructure [9]. The fuel properties of the base fuels are given in Table 1.

Table 1: Properties of Gasoline and n-Butanol [18]

Properties	Gasoline	n-Butanol
Chemical Formula	C_4-C_{12}	C_4H_9O H
Composition (C, H, O) (mass %)	86,14,0	65,13.5,21.5
LHV (MJ/kg)	42.9	33.0
Density (kg/m^3)	736	810
Octane number	97	89
Boiling temperature	25-215	118
Latent heat of vaporization (kJ/kg)	380-500	716
Self-ignition Temperature(˚C)	~300	343
Stoichiometric AF ratio	14.7	11.2

n-Butanol has higher octane number which gives it an advantage over ethanol and methanol as an additive to gasoline fuel. It is much less evaporative and releases more energy per unit mass than ethanol and methanol. It is less corrosive and has higher energy content than ethanol and methanol [10]. The net energy stored in n-Butanol is 6.53 MJ/L compared to 0.40 MJ/L stored in ethanol [11]. n Butanol has hence received increasing attention in recent years and its blend with gasoline has been identified as a feasible alternative to gasoline in internal combustion engines. In addition, n-Butanol closely resembles that of gasoline in the air-fuel ratio which enables us to use a greater percentage of n-Butanol with gasoline in comparison to ethanol and methanol without any significant effect on fuel economy [12].

A popular technique to reduce exhaust gas emissions is exhaust gas recirculation (EGR). It mainly reduces emissions of NO_X. EGR works by re-circulating a portion of the engine's exhaust gases back to the engine cylinders. The impact of EGR on engine efficiency depends on the specific design of the engine and leads to a compromise between engine efficiency and NO_X emissions. Most modern engines use EGR to meet emission standards.

In the present work, an extensive review of literature has been conducted to determine the feasibility of using alcohol gasoline blends for use in spark ignition engine from the performance and emission point of view.

2. REVIEW OF LITERATURE.

Extensive research has been done to investigate the engine performance characteristics and exhaust gas emissions of a S.I. Engine using various gasoline-n-Butanol blends. A review of some important publications related to the aforementioned topic is done below.

Singh *et al.* [3] conducted an experiment to assess the performance of a spark ignition engine with different Butanol-gasoline blends (5, 10, 20, 50, and 75 %) and compared the same when it was operated with gasoline only. They observed that there was very small variation in cylinder pressure rise for Butanol-gasoline blends. It was also found that the heat release for gasoline begins relatively earlier than Butanol-gasoline blend (Figure 1).

When the engine was operated with Butanol-gasoline blend, the brake specific fuel consumption (bsfc) was higher than that operated with gasoline. The brake thermal efficiency (BTE) with blend was also lower than that of gasoline under low loads (Figure 2). As the speed was increased to 3500 and then to 4500 rpm, Butanol 20 and Butanol 50 gave better BTE compared to that of gasoline (Figure 3). Exhaust gas temperature with Butanol-gasoline blends was also found to be lower than that of gasoline for low loads, but under high load Butanol 75 produced higher exhaust temperature.

Feng *et al.* [13] conducted an experimental study on a motorcycle engine (single cylinder four stroke, two valve air cooled engine with a compression ratio of 9.2) operated with Butanol-gasoline blend to assess the combustion, heat release, performance, fuel economy and emission characteristics. Combustion and heat release studies showed that Butanol gasoline blends provides higher knock resistance compared to that of gasoline alone which results in higher ignition advance and better combustion. With increase in the fraction of Butanol blend, anti-knock quality increased and the combustion improved. The emissions of CO, HC, NO_X and CO_2 were also compared when the engine was operated with pure gasoline and with 30% and 35% Butanol gasoline blend. The study revealed that the HC emission decreased by 15.8%, (Figure 4) CO emission decreased by 48.1% (Figure 5) for 35% Butanol gasoline blend compared to that of gasoline and this was achieved using ignition timing optimization. But NO_x and CO_2 emission increased by 165.3% and 12.2%.

Venugopal *et al.* [14] conducted an experiment on a spark ignition engine using Butanol and gasoline blend through dual injection system. They found that the maximum torque of the engine increased as the fuel ratio of n-Butanol was raised. With 100% Butanol, the torque increased by 2% even though the volumetric efficiency reduced by 2.5% compared to that of gasoline (Figure 6).

With increase in the throttle opening, the brake thermal efficiency of Butanol gasoline blends increased. It was also observed that the HC emission reduced by 33%, 27% and 41% with 25%, 35% and 100% throttle opening compared to that of the gasoline (Figure 7).

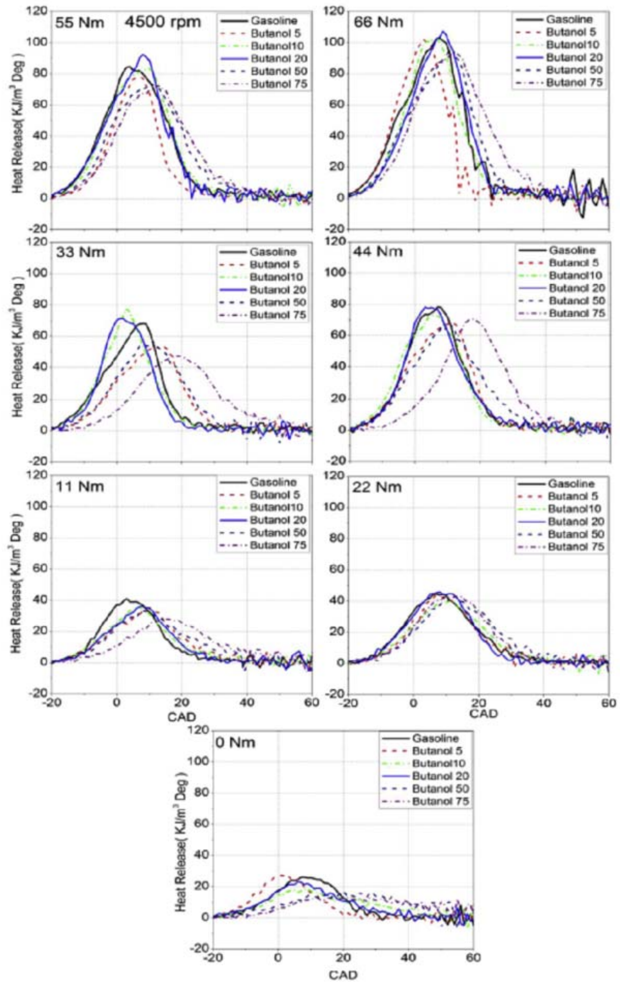

Figure 1: Heat Release rate vs. crank angle for different loads at 4500 rpm [3].

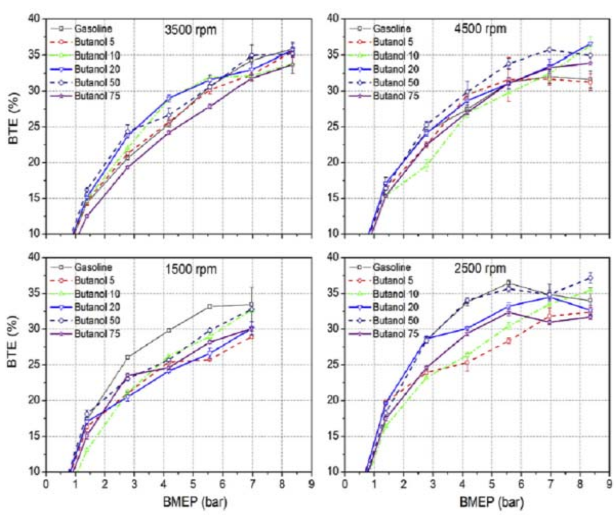

Figure 2: Variation of BTE with BMEP at different engine speeds and loads [3].

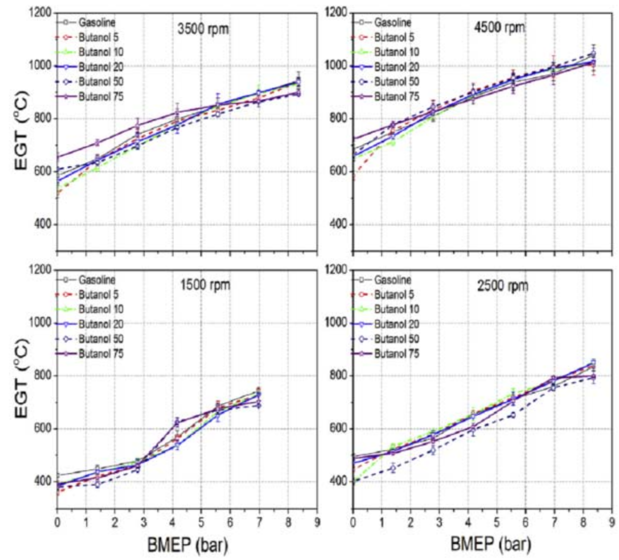

Figure 3. Variation of EGT with BMEP at different engine speeds and loads [3].

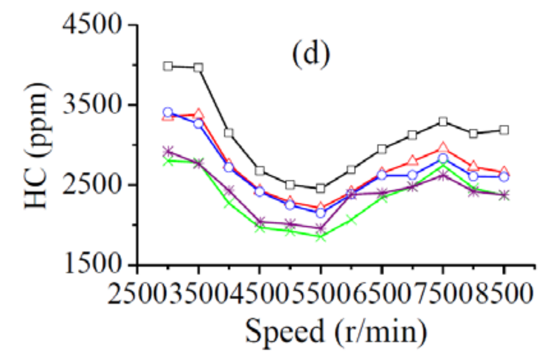

Figure 4: HC Emission comparisons [13]

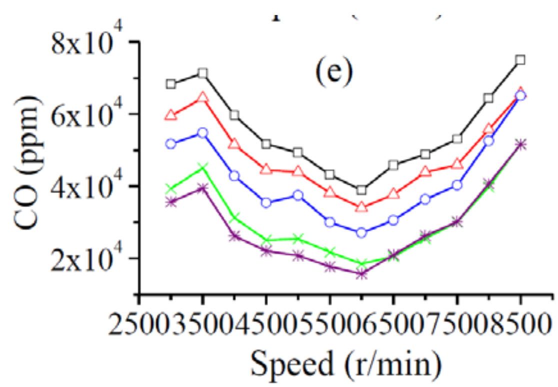

Figure 5: CO emission comparison [13]

Uyumaz [15] conducted an experiment on a homogeneous charged compression ignition engine using n-heptane, iso-propanol and n-Butanol fuel blends for different inlet temperatures. He observed that the thermal efficiency increased by about 28.8% with 20% n-Butanol compared to that of n-heptane for a given inlet temperature (393K). (Figure 8) The CO emissions increased with increase of percentage of n-Butanol in the fuel used (Figure 9). Canakci*et al.* [16] conducted an experiment on a SI engine with multipoint injection system using alcohol-gasoline fuel blends. It was observed that at a speed of 80km/hr., the bsfc increased by 0.2%, 0.5%, 1.6% and 1.1% for E5, E10, M5, M10 respectively (Figure 10). At the same speed CO emission decreased by 18%, 17%, 14% and 11% for E5, E10, M5 and M10 respectively (Figure 11) and CO_2 emission also decreased by 9.5%, 8%, 11.3% and 3% for E5, E10, M5 and M10 respectively (Figure 12).

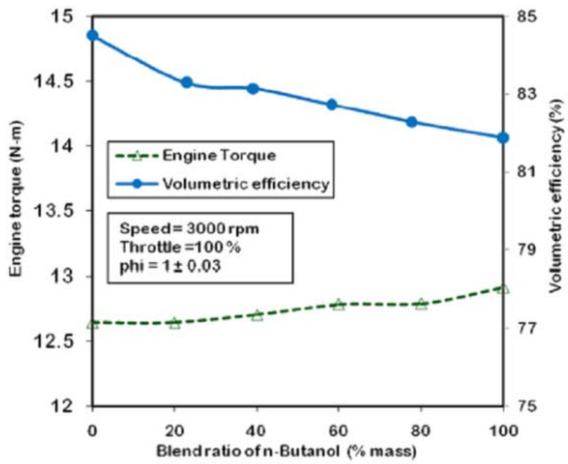

Figure 6. Variation of engine torque and volumetric efficiency with fuel ratios (full throttle) [14].

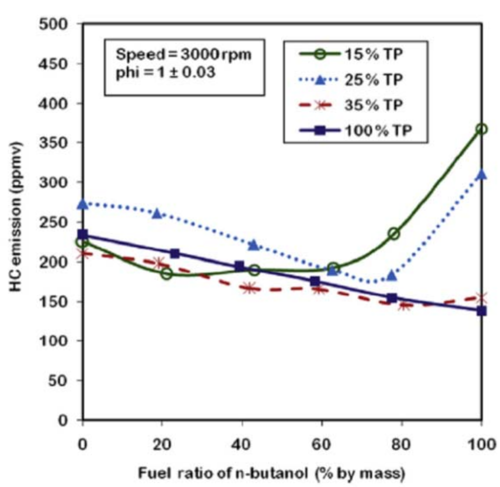

Figure 7. HC emission vs. fuel ratio [14]

Zhang *et al* .[17] experimented with ethanol-gasoline and n-Butanol-gasoline blends with exhaust gas recirculation (EGR) and compared the results with pure gasoline as fuel with EGR in a direct injection spark ignition (DISI) engine. They observed that with same rate of EGR, it was necessary to advance the spark for ethanol/gasoline blends, while for n-Butanol/gasoline blend, the spark needed to be retarded. Gu*et al.*[18] conducted an experiment in a SI engine using n-Butanol –gasoline blends with exhaust gas recirculation. They found that specific HC, CO and NO_x emissions of the engine using gasoline and n-Butanol blends are lower than those using gasoline. Less than 40% Butanol blending can reduce HC emission. 30% Butanol –gasoline blending decreased NO_x emissions by almost 50% compared to pure gasoline engine. With increase of EGR rate, specific emissions of HC and CO increase but specific NO_X emission decreases.

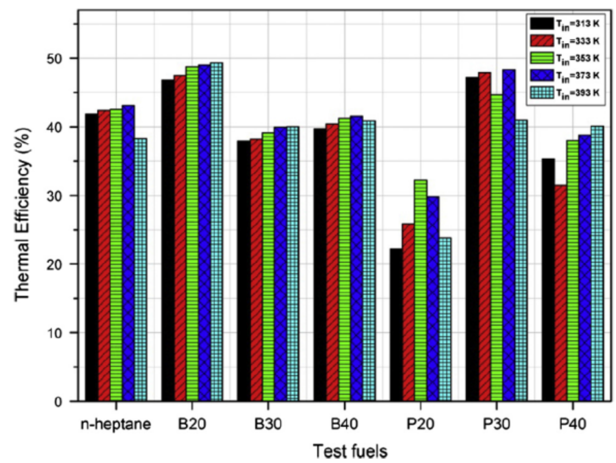

Figure 8: Effects of test fuels and inlet air temperature on Thermal Efficiency [15]

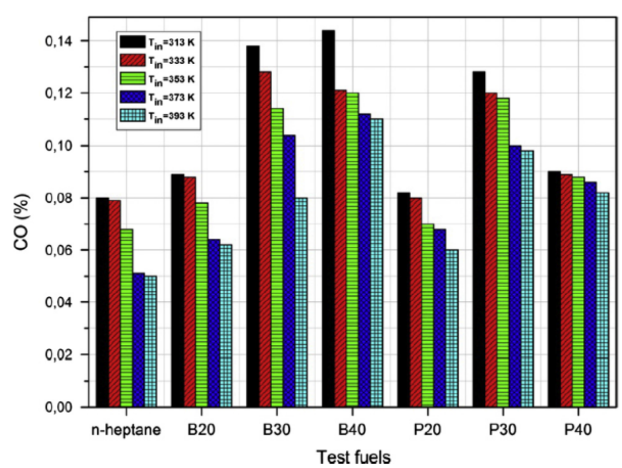

Fig. 9. The variation of CO emissions.

Figure 9: The variation of CO Emission [15]

Fontana *et al.*[19] conducted an experiment on a spark-ignition engine using exhaust gas recycle at Wide Open Throttle (WOT) operation. They observed that the volumetric efficiency and torque decreased by almost 12.5% and 10% respectively, when EGR was used in comparison to the same engine operated without EGR (Figure 14, 15 and 16). They also observed that at wide open throttle position with EGR, the bsfc improved marginally in the range of 2.5% –7%. Also, the exhaust gas recirculation lowered the exhaust gas temperature.

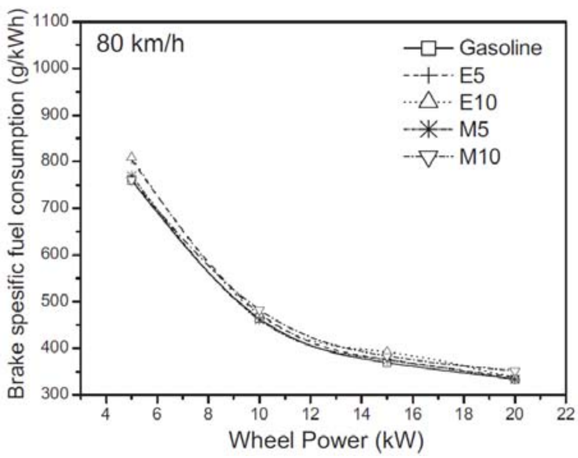

Figure 10. BSFC at engine speed of 80 kmph [16]

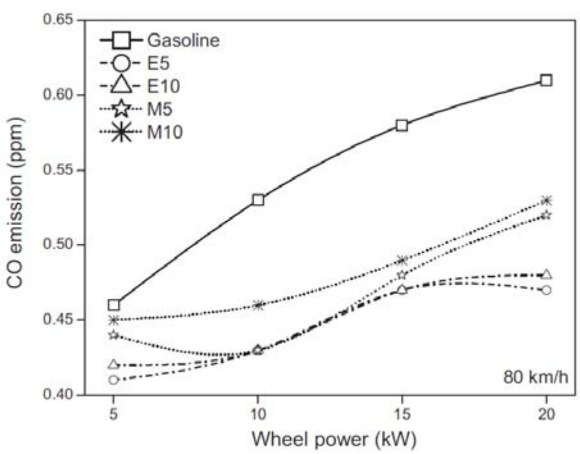

Figure 11. Emission of Carbon Monoxide [16]

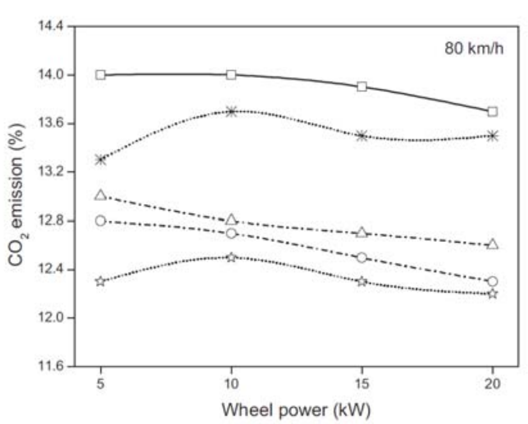

Figure 12. Emission of Carbon Dioxide [16]

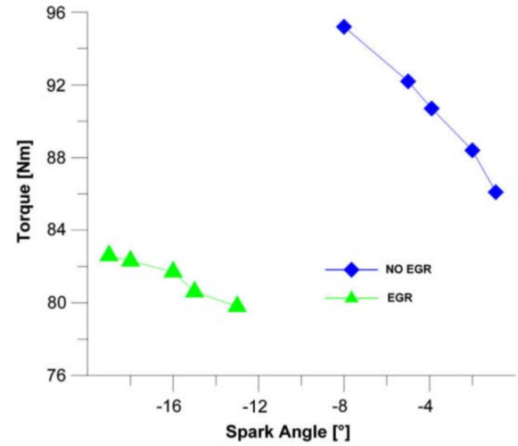

Figure 14. Engine Torque at different spark angle, engine running at 2000 rpm [19]

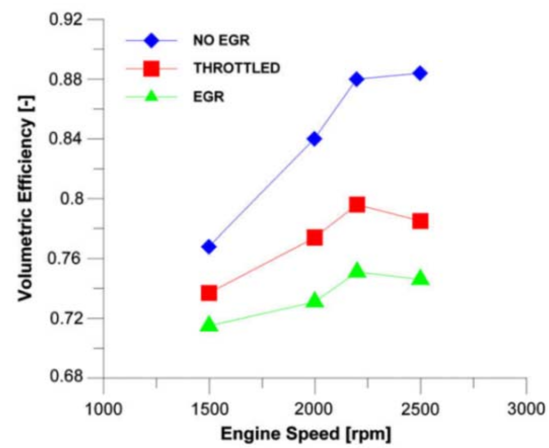

Figure 15. Measured Volumetric Efficiency vs. Engine speed [19]

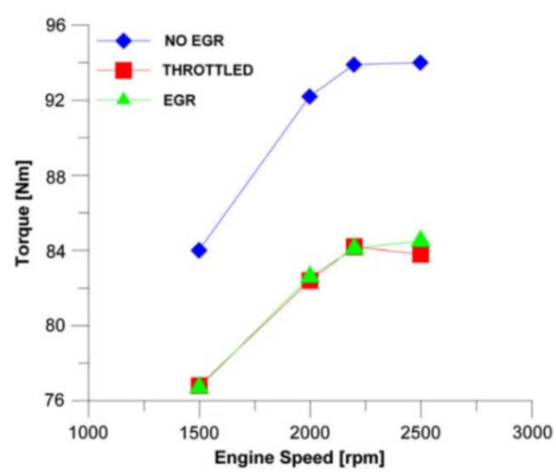

Figure 16. Torque at Knock Limited Conditions [19]

3. CONCLUSION

(i) Gasoline Butanol blends provides slightly higher bsfc than pure gasoline for SI engine. With increase in speed and concentration of butanol, bsfc remains almost the same.

(ii) Gasoline Butanol blends provide lower BTE than pure gasoline at low speeds for SI engine. However, at high speeds BTE is almost same.

(iii) Gasoline Butanol blends yield lower exhaust gas temperatures. Under EGR condition the exhaust gas temperature decreases with increase in EGR rate.

(iv) Emission of UHC for SI engine using gasoline butanol blends is lower than pure gasoline. Under EGR, similar trend is noted.

(v) Emission of CO for Butanol blends is lower than that of gasoline. With increase in concentration of Butanol and engine speed, higher CO emissions were observed.CO emissions increased under EGR condition.

(vi) Gasoline butanol blends produce less NO_x. In EGR condition NO_x emission decreases with increase in percentage of EGR rate.

REFERENCES

[1] Sperling, Daniel, Deborah Gordon, “Two billion cars: driving toward sustainability”, *Oxford University Press, New York*. (2009), pp. 4 and 13. ISBN 978-0-19-537664-7.

[2] John Sousanis (2011-08-15), "World Vehicle Population Tops 1 Billion Units", *Ward Auto World*. Retrieved 2011-08-18.

[3] Suraj Bhan Singh, Atul Dhar, Avinash Kumar Agarwal, “Technical feasibility study of butanol gasoline blends for powering medium-duty transportation spark ignition engine”, *Renewable Energy* **76** (2015), pp.706-716.

[4] Thomas S, “Transportation options in a carbon-constrained world: hybrids, plug-in hybrids, bio fuels, fuel cell electric vehicles, and battery electric vehicles”, *Int J Hydrogen Energy* **34** (2009), pp.9279–96.

[5] Sarathy SM, Thomson MJ, Togbe C, Dagaut P, Halter F, Mounaim-Rousselle C, “An experimental and kinetic modeling study of n-Butanol combustion”, *Combust Flame* **156** (2009), pp.852–64.

[6] Qureshi N, Ezeji TC, “Butanol, a superior biofuel production from agricultural residues (renewable biomass): recent progress in technology”, *Biofuels Bioprod Bioref* **2** (2008), pp.319–30.

[7] Elfasakhany A, Klason T, Bai XS, “Modeling of pulverised wood combustion using a functional group model”, *Combust Theory Model* **12**(2008), pp.883–904.

[8] Wu M, Wang M, Liu J, Huo J, “Assessment of potential life-cycle energy and greenhouse gas emission effects from using corn-based Butanol as a transportation fuel”, *Biotechnol Prog* **24** (2008), pp.1204–14.

[9] Nitesh Mittal, Athony RL, Bansal R, Kumar CR., “Study of performance and emission characteristics of a partially coated LHR SI engine blended with n-Butanol and gasoline.”, *Alexandria Engineering Journal* **52** (2013),pp. 285–293.

[10] Szwaja S, Naber JD, “Combustion of n-Butanol in a spark-ignition IC engine”, *Fuel* **89** (2010), pp.1573–82.

[11] Swana J, Yang Y, Behnam M, Thompson R, “An analysis of net energy production and feedstock availability for bioButanol and bioethanol”, *Bioresour Technol* **102 (**2011), pp.2112–7.

[12] Andersen VF, Anderson JE, Wallington TJ, Mueller SA, Nielsen OJ, “Distillation curves for alcohol–gasoline blends” *Energy Fuel* **24** (2010)24:2683–91.

[13] Renhua Feng, Jianqin Fu, khaldrogo, Jing Yang , Yi Wang , Yangtao Li , Banglin Deng ,Jingping Liu , Daming Zhang, “Combustion and emissions study on motorcycle engine fueled with butanol-gasoline blend”, *Renewable Energy* **81** (2015), pp. 113-122.

[14] T. Venugopal, A. Ramesh., “Effective utilisation of butanol along with gasoline in a spark ignition engine through a dual injection system”, *Applied Thermal Engineering* **59** (2013), pp. 550-558.

[15] AhmetUyumaz, “An experimental investigation into combustion and performance characteristics of an HCCI gasoline engine fueled with n-heptane, isopropanol and n-butanol fuel blends at different inlet air temperatures”, *Energy Conversion and Management* **98** (2015),pp. 199–207.

[16] Mustafa Canakci, AhmetNecatiOzsezen, ErtanAlptekin, MuharremEyidogan, “Impact of alcohole gasoline fuel blends on the exhaust emission of an SI engine”, *Renewable Energy* **52** (2013), pp. 111-117.

[17] Zhijin Zhang, TianyouWanga, Ming Jia, Qun Wei, XiangzanMeng, GequnShu, “Combustion and particle number emissions of a direct injection spark ignition engine operating on ethanol/gasoline and n-butanol/gasoline blends with exhaust gas recirculation”, *Fuel* **130** (2014), pp. 177–188.

[18] XiaoleiGu, Zuohua Huang, JianCai, Jing Gong, Xuesong Wu, Chia-fon Lee, “Emission characteristics of a spark-ignition engine fuelled withgasoline-n-butanol blends in combination with EGR”, *Fuel* **93** (2012), pp. 611–617.

[19] G. Fontana, E. Galloni, “Experimental analysis of a spark-ignition engine using exhaust gas recycle at WOT operation.”, *Applied Energy* **87** (2010), pp. 2187–2193.