*International Journal of Emerging Technology and Advanced Engineering*
*Volume 3, Special Issue3: ICERTSD 2013, Feb 2013, pages 96-100*
An ISO 9001:2008 certified Int. Journal, ISSN 2250-2459, available online at www.ijetae.com

# PERFORMANCE CHARACTERISTICS OF SPARK IGNITION ENGINE USING ETHANOL AS FUEL AT DIFFERENT OPERATING CONDITIONS

Achinta Sarkar[1+], Ambarish Datta[2], Bijan Kumar Mandal[3]

[1, 2]*PhD Scholar, Department of Mechanical Engineering, Bengal Engineering and Science University, Shibpur, Howrah- 711103, West Bengal, India*

[3]*Professor, Department of Mechanical Engineering, Bengal Engineering and Science University, Shibpur, Howrah- 711103, West Bengal, India*

[+]Corresponding author email:achinta.sarkar1@gmail.com

## ABSTRACT

The present study converses the usability of ethanol as a clean and green renewable alternative fuel for spark ignition engine. The study emphasizes not only on the inherent properties of ethanol as a fuel but also elaborately reviews about the performance characteristics of the engine considering the effects of different important parameters like cyclic variability, ignition timing, internal cylinder pressure. The study reveals the physical understanding of the engine performance characteristics under different operating conditions. In this paper, the performance analysis carried out by different researchers from their experimental and theoretical results has been presented in brief. The review of the investigation reports found in the literature reveals that the cyclic variability, ignition timing, internal cylinder pressure have a great role on engine performance with ethanol as a blended fuel with gasoline.

**Keywords:** Ethanol, cyclic variability, ignition timing, temperature, performance.

## 1. INTRODUCTION

Bio-ethanol is a clean, green, biodegradable, environment friendly, renewable alternative fuel for spark-ignition (SI) engines as it can be produced from agricultural products and scrapped resources [1]. It is demonstrated by the researchers that ethanol can be used as a blended fuel with gasoline without any engine modification. Ethanol has many inherent properties as a fuel for SI engines. Ethanol is oxygen enriched chemical compound, containing 35% oxygen by weight. It, therefore, can be treated as a partially oxidized fuel [2]. During combustion of ethanol-gasoline blends, ethanol provides more oxygen and it leads to the so-called “leaning effect” and this leaning effect help the combustion process to complete efficiently. These enhance the efficiency of engine and improve exhaust emissions from the engine. The lower heating value (LHV) of ethanol is 26.8 MJ/kg which is less than that of gasoline. On the other hand, its latent of vaporization (923 kJ/kg), density and octane number are higher than those of pure gasoline. The combined effect of the above said factors is to enhance the engine volumetric efficiency and allow the engine to run at comparatively higher compression ratios. In addition, the storage and transportation of ethanol is safer than gasoline due to its high flash point (more than 56°C comparing with gasoline). Although higher latent heat of vaporization of ethanol may reduce the vaporization of the fuel mixture at the intake manifold, the problem can be avoided by heating intake manifold. He et al. [3] and Thring [4] reported that pure ethanol has lower vapor pressure but Reid vapour pressure (RVP) of gasoline-ethanol blends rises depending on the ethanol percentage in the blend. The addition of comparatively high volatile additives to the fuel blend can overcome this problem [4]. Low RVP can cause cold starting problems; therefore, volatile additive should be used when pure ethanol is used [5]. Also, vapor lock may occur in the warm weather [5, 6]. Because of the cooling effect on the intake charge and leaner operation as it is a oxygenated fuel, significant reductions in CO and $NO_x$ emissions may be expected [3, 4, 7]. Different properties of ethanol related to fuel suitability are compiled from the previous works of Yuksel and Yuksel [8] and Koc et al. [9] and presented in table 1 for comparison with gasoline.

Several studies on the performance and emission of spark ignition engines, fuelled with pure gasoline and blended with ethanol have been performed and are reported in the literature. The present study emphasize on the discussion of the different essential parameters like cyclic variability, ignition timing, internal cylinder pressure which have the direct or indirect influence on the engine performance.

## 2. ANALYSIS OF ENGINE PERFORMANCE

In the literature it was found that different researchers had worked on the use of ethanol-gasoline blends to run the SI engine. But the analysis were made by them did not cover the effects of the most significant parameters like cyclic variability, ignition timing, internal cylinder pressure, cylinder peak temperature and exhaust gas temperature. In this section all these parameters and their significance on engine performance will be discussed based on the experimental results of the different research works available in the literature.

**Table 1:** Properties of ethanol and gasoline [8, 9]

| Fuel property | Ethanol | Gasoline |
|---|---|---|
| Formula | $C_2H_5OH$ | $C_4$ to $C_{12}$ |
| Molecular Weight | 46.07 | 100-105 |
| Specific gravity | 0.79 | 0.69-0.79 |
| Freezing point, °C | -114 | -40 |
| Boiling point, °C | 78 | 27-225 |
| Vapour pressure, kPa at 38°C | 15.9 | 48-103 |
| Specific heat, kJ/kg-K | 2.4 | 2.0 |
| Viscosity, mPa s at 20°C | 1.19 | 0.37-0.44 |
| Flash point, °C | 13 | -43 |
| Auto-ignition temperature, °C | 423 | 257 |
| Latent heat of vaporization, (kJ/kg) | 923 | 380-500 |
| Lower heating value, (MJ/kg) | 26.8 | 42.7 |
| Flammability limit (vol%) | 4.3-19.0 | 1.4-7.6 |
| Stoichiometric air-fuel ratio, weight | 9.0 | 14.7 |
| Octane number | | |
| Research (R) | 108.6 | 88-100 |
| Motor (M) | 89.7 | 80-90 |
| Antiknock index | | |
| (R+M)/2 | 99.1 | 84-95 |

### 2.1 Effect of Cyclic Variability on Performance

In the combustion chamber of an SI engine, variations of pressure exist between the consecutive cycles. In the design and control of spark-ignited engines cyclic variability is considered as an important factor among many factors. It is customary to take care to minimize the cyclic variation in the engine. With respect to combustion phenomena it can be said that rate of pressure variation is the function of mode of combustion process. Faster combustion induces instability in the combustion phenomenon itself [10] and pressure developed in the cylinder becomes very high and pressure variation is also noted. This leads to the well known phenomenon called knocking in spark ignition engine. On the contrary, in case of slower combustion rate, incomplete combustion takes place and pressure develop inside the cylinder is also lower. So, optimum variation of pressure can be obtained between high and low rate of combustion. From the discussion it is cleared that high variation is undesirable and the problem arises when the engine is run with lean fuel-air mixture. Also cyclic variability is lower when the engine is in warm up condition [11]. This is the physical reason behind the cyclic variations. The cyclic variation also takes place due to chemical interactions. In that case, the variation in the residual gas fraction, the fuel-air ratio, the fuel composition and the motion of the unburned gases in the combustion chamber can be taken into consideration [12]. According to Young [13], 10% increase in power output for the same fuel consumption and reduction in pollutant emission from the engine can be achieved if cyclic variability could have been eliminated. One important measure of cyclic variability, derived from pressure data, is the coefficient of variation for the indicated mean effective pressure (IMEP) [14]. It is the standard deviation in IMEP divided by the mean IMEP, and it is usually expressed in terms of percentage as:

$$COV_{imep} = \frac{\sigma_{imep}}{imep} \times 100$$

where $\sigma_{imep}$ is the standard deviation in IMEP.

When $COV_{imep}$ percentage exceeds more than 5%, then problem starts in running the engine. Park et al. [15] investigated the performance and exhaust emission characteristics of a spark ignition engine using ethanol and ethanol-reformed gas. They found that at high concentration of ethanol in the blend $COV_{imep}$ was only 3.1% i.e. the engine was running at stable condition. And the study revealed that in the presence of ethanol thermal efficiency of the engine will be improved even for lean limit operation. Yoon and Lee [16] concentrated on the engine stabilization using anhydrous ethanol and unleaded gasoline as fuels. Both the fuels used separately in the experiment met the ASTM standard. The analysis emphasized on the effect of different intake manifold temperature. They also made comparative study of using ethanol and gasoline as fuels on cyclic variability at peak combustion temperature ($COV_{pmax}$) and wide open throttle condition. Their results have been presented in Fig. 1 to show the variation of engine stability ($COV_{pmax}$) with engine speed. The figure clearly shows that with the increase of intake temperature and engine speed, $COV_{pmax}$ decreases at a certain rate. It is also can be seen in the figure that at every temperature, $COV_{pmax}$ of ethanol is lesser than that of gasoline. According to their reported results, the values of $COV_{pmax}$ for gasoline are 6.65 (10°C), 5.54 (30°C) and 4.92 (50°C) and the corresponding values for ethanol are 5.71 (10°C), 4.34 (30°C) and 3.99 (50°C) at 2500 rpm.. Increasing intake temperature and engine speed helps the fuel for easy evaporation and premixing before the ignition inside the combustion chamber improves cycle to cycle variation. The probable reason for lower $COV_{pmax}$ for ethanol is its higher octane number and contains excess oxygen content.

## 2.2 Effect of Ignition Timing

Ignition timing plays crucial role on the performance of the spark ignition (SI) engines. Spark occurring too early or too late in the engine may stimulate engine vibrations and knocking and the engine may be damaged.

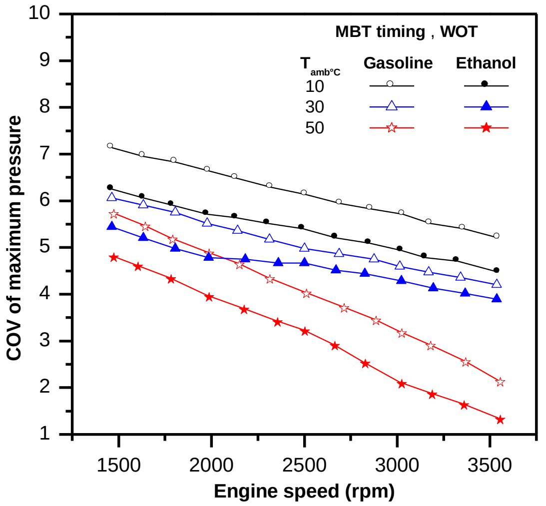


Fig. 1. Coefficient of variation of maximum pressure with intake air temperature. Source: Yoon and Lee [16]

So, depending upon the different variables likes timing of the intake valve, type of ignition system, selected fuel and impurities, type and condition of spark plug, fuel temperature and pressure, engine speed and load etc., ignition timing is normally set. Depending on the time of beginning of ignition of the fuel element and the angle of orientation of the crank, ignition timing is referred as ignition advance and ignition retard. The physical meaning of ignition advance is that the ignition timing is set in such a way so that ignition can take place before top dead centre (BTDC). On the other hand, the ignition retard is referred to a reference timing (specified by manufacturer) after which ignition of the fuel element just begins. For most SI (spark ignition) engine, the typical burn angle is about 25° BTDC. The combustion will be completed at 15° after top dead centre (ATDC) if ignition takes place at about 20° BTDC. Actual ignition timing is typically anywhere from 10° to 30° BTDC, depending on the fuel used, engine geometry, and engine speed. Too early ignition of the fuel will enhances the engine pressure to undesirable level before TDC when the piston moves towards TDC and for that work will be wasted [17]. The fuels which give the provision to ignite at a desirable ignition advances so that all the fuel elements can be burned completely are preferable. Topgul et al. [18] studied the effect of ignition timing on engine performance and exhaust emissions using ethanol-unleaded gasoline blends as fuel at various compression ratios. They found that ignition timing and ethanol as a blended fuel with gasoline have the significant role on engine performance. The results from the experimental work of [18] have been presented in Fig. 2 and Fig. 3. Figure 2 shows the variation of engine torque and brake specific fuel consumption (BSFC) with ignition timing at the compression ratio of 8:1. The figure clearly shows that the engine BSFC decreases with the advancing of the ignition timing. But the maximum torque for pure gasoline (E0) and 60% ethanol (E60) are at 26° and 24° CA (crank angle) advanced ignition timing have been seen and indicated in Fig. 2.

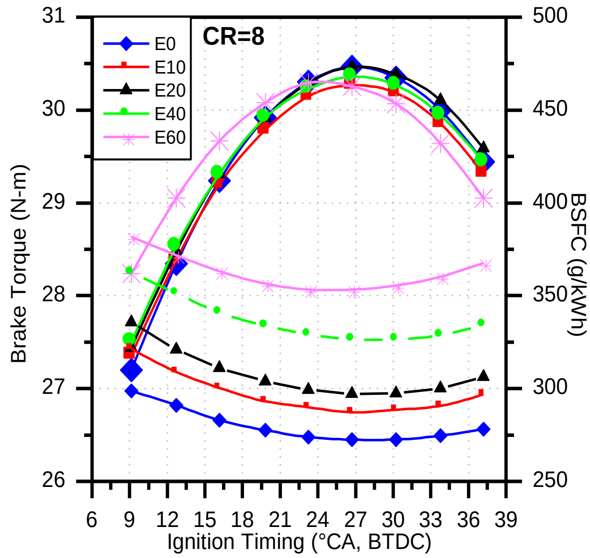


Fig. 2. Variation of engine torque and BSFC with ignition timing at CR=8:1.

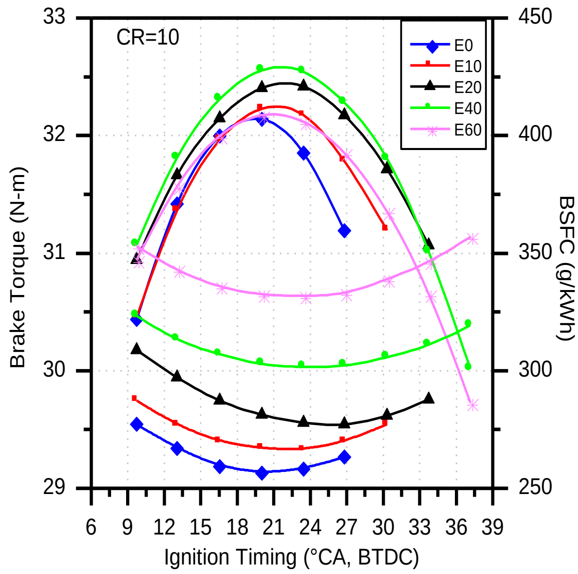


Fig. 3. Variation of engine torque and BSFC with ignition timing at CR=10:1. Source: Topgul et al. [18]

On the other hand, they observed that at 24° CA advancing of ignition timing knock occurrence was found for E0 fuel but the authors did not see any trace of knocking for 40% ethanol (E40) and E60 fuels at 36° CA advancing of the ignition timing. Figure 3 shows the same variation at the compression ratio of 10:1. In this case maximum brake torque was found for E40 fuel.

ISSN 2250-2459, *Volume 3, Special Issue 3: ICERTSD 2013, Feb 2013, pages 96-100*

Possibly, higher octane number, high oxygen content in the ethanol blended fuel has improved the engine performance.

### 2.3 Effect on In-Cylinder Pressure

Growth of in-cylinder pressure after complete combustion and release of pressure in a proper way (depending on piston position with respect to TDC) as per the engine requirement has the vital role on engine power development. Bayraktar [19] investigated the flame propagation process using ethanol-gasoline blends as fuel. He found that ethanol up to 25% by volume with gasoline definitely affects the geometry of the flame propagation and enhance the mass burning rate. This phenomenon enhances in the cylinder pressure and for that reason, the engine power and the thermal efficiency are also increased. Celik [20] studied experimentally to determine the suitable ethanol-gasoline blend rate for gasoline engine. The experiment was performed at the compression ratios of 6:1 and 10:1 respectively using pure gasoline and E50 (50% ethanol + 50% gasoline) as fuels. He observed that engine cylinder pressure to be maximum for both the compression ratios with E50 fuel. He also observed that engine power and cylinder pressure increase in similar way. Melo et al. [21] made tests on a Flex-Fuel engine using hydrous ethanol gasoline blends and investigates the combustion and emissions characteristics of the engine. Figure 4 and figure 5 show the variation of in-cylinder pressure with crank angle for two different torques of 60 Nm and 105 Nm at constant rpm of 3875 as presented by Melo et al. [21].

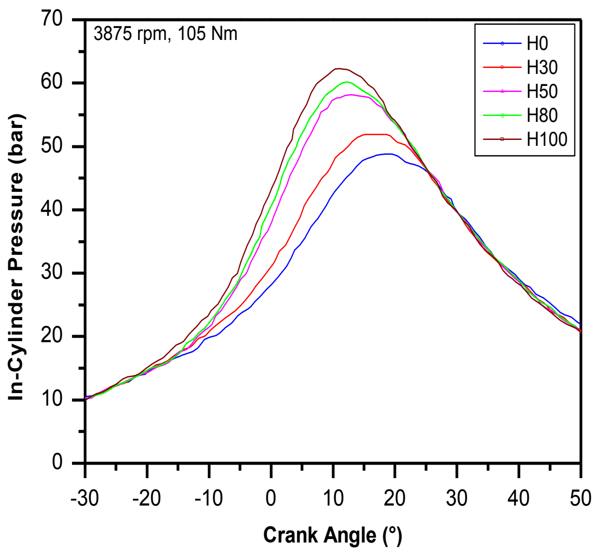


Fig. 4. In-cylinder pressure versus crank angle for 105 N m at 3875 rpm. Source: Melo et al. [21]

Both the figures show the variation of in-cylinder pressure with crank angle at different hydrous ethanol-gasoline blends. Figures show that ethanol addition affects the pressure variation and also it enhances the maximum pressure for each fuel for different crank angles. In the figures, H50 denotes a fuel with 50% hydrous ethanol and 50% gasoline by volume. At higher engine torque the pressure development is also higher for all blends.

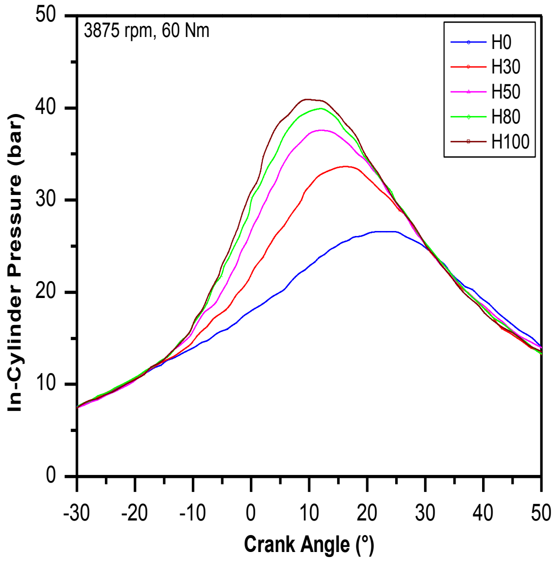


Fig. 5. In-cylinder pressure versus crank angle for 60 Nm at 3875 rpm. Source: Melo et al. [21]

### 3. CONCLUSIONS

The following conclusions can be drawn from the above study. Firstly, the properties of ethanol show that it is a clean and green alternative fuel for SI engines. The engine parameters affect the engine performance differently when ethanol is added to gasoline. The study reveals that the performance characteristics due to cyclic variation change due to both the physical and chemical reason. In case of SI engine, when COV (coefficient of variation) is less than 5% then the engine is in stable condition, but when it is higher than this then the engine cannot run smoothly. Ethanol as a blended fuel with gasoline decreases the COV. Proper setting of the ignition timing has the crucial role on engine performance. High percentage of hydrous ethanol by volume in the blend increases the in-cylinder pressure. Both the pressure and the engine power increases in the similar fashion for different blended fuels.

### REFERENCES

1. Francisco A. M., Ahmad R. G., 2006, "Performance and exhaust emissions of a single-cylinder utility engine using ethanol fuel", SAE technical paper; 2006 [2006-32-0078].
2. Norton T. S., 1990, "The combustion chemistry of simple alcohol fuels", PhD Thesis, Princeton University.
3. He, B. Q., Wang, J. X., Hao, J. M., Yan, X. G., Xiao, J. H., 2003, "A study on emission characteristics of an EFI engine with ethanol blended gasoline fuels", Atmospheric Environment, 37, 949-957.

ISSN 2250-2459, *Volume 3, Special Issue 3: ICERTSD 2013, Feb 2013, pages 96-100*

4. Thring, R. H., 1983, "Alternative fuels for spark-ignition engines", SAE, Paper no. 831685, 4715-25.
5. Furey, L. R., Perry, L. K., 1990, "Volatility Characteristics of Blends of Gasoline with Ethyl Tertiary-Butyl Ether (ETBE)", SAE, Paper no. 901114, 416-29.
6. Wagner T. O., Gray D. S., Zarah B. Y., Kozinski A. A., 1979, "Practicality of alcohols as motor fuel", SAE Paper no. 790429: 1591–1607.
7. Hsieh, W. D., Chen, R. H., Wu, T. L., Lin, T. H., 2002, "Engine performance and pollutant emission of an SI engine using ethanol-gasoline blended fuels", Atmospheric Environment, 36, 403-410.
8. Yuksel F. and Yuksel B., 2004, "The use of ethanol-gasoline blends as a fuel in an SI engine", Renewable Energy, 29, 1181-1191.
9. Koc M., Sekmen Y., Topgül T., Yücesu S. H., 2009, "The effects of ethanol–unleaded gasoline blends on engine performance and exhaust emissions in a spark-ignition engine", Renewable Energy, 34, 2101-2106.
10. Ceviz M. A., Yuksel F, 2005, "Effects of ethanol-unleaded gasoline blends on cyclic variability and emissions in an SI engine", Applied thermal Engineering, 25, 917-925.
11. Chen L., Stone R., Richardson D., 2012, "A study of mixture preparation and PM emissions using fuelled with stoichiometric gasoline/ethanol blends", fuel, 96, 120-130.
12. Jensen T. K., Schramm J., 200, "A three-zone heat release model for combustion analysis in a natural gas SI engine. Effects of crevices and cyclic variations on UHC emissions", SAE paper No: 2000-01-2802, Presentation at the society of Automotive Engineers, Int. Fall Fuels and Lubricants Meeting and Exposition, Baltimore, Maryland, October 16-19, 2000.
13. Young M. B., 1981, "Cyclic Dispersion in the Homogeneous-Charge Spark-ignition Engine A literature Survey", SAE Paper No: 810020, 1981.
14. Heywood J. B., 1988, "Internal combustion engine fundamentals", McGraw-Hill; New York.
15. Park C., Choi Y., Kim C., Oh S., Lim G., Moriyoshi Y., 2010, "Performance and exhaust emission characteristics of a spark ignition engine using ethanol and ethanol-reformed gas", fuel, 89, 2118-2125.
16. Yoon S. H., Lee C. S., 2012., "Effect of undiluted bioethanol on combustion and emissions reduction in a SI engine at various charge air conditions", Fuel, 97, 887–890.
17. Pulkrabek W. W., 2004, "Engineering Fundamentals of the Internal Combustion Engine", International Edition, 2/E, University of Wisconsin – Platteville, Published 19 Aug 2004.
18. Topgul T., Yucesu H. S., Can Cinar, Koca A., 2006, "The effects of ethanol–unleaded gasoline blends and ignition timing on engine performance and exhaust emissions", Renewable Energy, 31, 2534-2542.
19. Bayraktar H., 2007, "Theoretical investigation of flame propagation process in an SI engine running on gasoline-ethanol blends", Renewable Energy, 32, 758-771.
20. Celik M. B., (2008), "Experimental determination of suitable ethanol-gasoline blend rate at high compression ratio for gasoline engine", Applied Thermal Engineering, 28, 396-404.
21. Melo de T. C. C., Machado G. B., Belchior C. R. P., Colaco M. J., Barros J. E. M., Oliveira de E. J., Oliveira de D. G., 2012, "Hydrous ethanol–gasoline blends – Combustion and emission investigations on a Flex-Fuel engine", Fuel, 97, 796–804.

## AUTHOR BIOGRAPHY

**Achinta Sarkar** got B.Tech degree from Kalyani Government Engineering College, India in 2009 and M.E. degree from Bengal Engineering and Science University, Shibpur, India in 2011. Presently he is a PhD scholar in Bengal Engineering and Science University, Shibpur, India.

**Ambarish Datta** obtained his bachelor degree in Automobile Engineering on 2008 and Master of Automobile Engineering from Jadavpur University, on 2010. Presently he is a Ph.D scholar in the Department of Mechanical Engineering, BESU Shibpur, India.

**Bijan Kumar Mandal** got his B.Tech (Hons.) and M. Tech. degrees in Mechanical Engineering from the IIT, Kharagpur and Ph.D. from Jadavpur University. Currently, he is a Professor in the Department of Mechanical Engineering at Bengal Engineering and Science University, Shibpur. His areas of interest include alternative fuels and combustion.