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Influence of Ethanol-Gasoline Fuel Fractions on Variable Compression Ratio Engine

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Abstract: ***Increase in demand of ethanol as blending fuel with gasoline is increasing. For noting the performance of the engine, experimentations are required to be done on engine, fuelled with various percentages of ethanol in gasoline. In this study, fuel fractions of ethanol and gasoline were taken for observing the performance of spark ignition engine. One-cylinder gasoline engine was used for conducting the experiments and to analyse the effects of ethanol-gasoline fuel fraction on performance of the engine. The engine was tested at Full Open Throttle condition. The load on the engine was changed by changing the load on Eddy Current Dynamometer to vary the engine speed from 1300 to 1700 rpm in the interval of 100 rpm. Gasoline is blended with ethanol to make five fuel fractions from 0 % ethanol (E0) to 40 % ethanol (E40) in gasoline at the interval of 10% by volume. Engine performance was observed at various Compression Ratio (CR) of the engine as 7,8,9 and 10. Calorific Value (CV) of the fuel fractions observed decreasing from E0 to E40 as CV of ethanol is less than base gasoline. Increase in Brake Specific Fuel Consumption was not very significant with rise in ethanol percentage. Power outputs in terms of Brake Power (BP) was increasing with increase in speed of the engine and observed decreasing with increase in ethanol percentage at constant CR. However various engine output parameters like BP, Mechanical Efficiency found decreasing with increase in fuel fractions ratio. Brake Thermal Efficiency (BTE) was observed decreasing with increase in fuel fractions. However, BTE was observed increasing with increase in CR.***

Keywords: ***Ethanol-Gasoline Fuel Fractions, VCR Engine, Experimental Analysis, SI Engine Performance***

I. INTRODUCTION

The reserves of fossil fuel are depleting rapidly due to increasing application of fossil fuel for the generation of energy and automobile use. The need for use of renewable and alternative fuels is increasing due to the rapid need of reducing the emission from fuel [1]. As a renewable and alternative energy options, alcohols are gaining significance. Alcohols presently are being used for fuel blending constituents in gasoline. It improves gasoline octane quality and also increases oxygen content. Ethanol plays a major role as an alternative fuel. In India, most of the ethanol is produced in sugar mills in the process of sugar production. The sugar mill produces molasses, bagasse and sugar. Major part of bagasse is utilised in the sugar mill for production of electricity and steam. Due to recycling internally, in the sugar mill, allocation is not necessary. The fraction of bagasse is utilised for electricity production and is sold to power grid. Molasses is used for the production of ethanol [2]. Around 85% of the petroleum fuel requirement of India is met through imports. Vehicle population in India is steadily going up and so is the need of transportation fuel. Government of India has already mandated 10% ethanol blend in gasoline for reducing the import of oil. Bureau of Indian Standards is deciding to use 20% ethanol-gasoline fuel fraction for motor fuel [3].

Ethanol is largely used as motor fuel in Brazil for more than 45 years. Ethanol is used in both hydrous and anhydrous forms. This is set as the best reference example for other countries for the use of ethanol as promising alternative fuel [4]. Even with certain limitations of ethanol like lower calorific value, high water affinity and problems with cold starting, ethanol is still gaining the importance as blend fuel with gasoline [5], [11]. Ethanol can be produced from various sources like agricultural products like sugar cane and grains, agricultural wastes, cellulosic materials like wood and coal etc. Cost of production of ethanol increases with an increase in purity. To remove water contents in ethanol, additional costly distillation process is required [6], [12].

Recent advancements also enable use of hydrous ethanol in flex-fuel engine with 100 % hydrous ethanol (up to 5% water content) as a substitute of blends of anhydrous ethanol. Use of hydrous ethanol provides better engine performance and reduction in engine emissions like CO & Hydrocarbons (HC). This may be considered as an alternative to blend anhydrous ethanol in gasoline at an affordable cost [7], [8]-[11]. Type of ethanol also makes difference in engine performance and emissions. Sugarcane-based ethanol is effective in terms of emissions produced when compared with corn-based ethanol [9]. Along with Sugarcane and corn as a feedstock for producing ethanol, many other feedstocks are also used like Straws of wheat and rice, bagasse of sweet sorghum, rice hulls, straws of barley and rape straw, Miscanthus(grass), corn stover, shells of hazelnut, top portions of sugarcane and waste created in horticulture [10]. In India Sugarcane is the major source for production of ethanol. Government of India under Ministry of New and Renewable Energy (MNRE) is promoting use of agricultural wastes for ethanol production in India.

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Various researchers attempted to blend ethanol in gasoline and observed the performance of different engines under different operating conditions. The researchers also tried to predict the performance using various prediction models and mathematical tools.

Ambros et.al. in their study, found that cost of ethanol rises due to costly distillation process and proposed to use wet (up to 5% water) ethanol gasoline fuel fraction. The authors proposed a mathematical model for prediction of the engine performance with wet ethanol. The model presented was able to effectively predict the temperature and pressure gradients in the engine cylinder and it presented considerate ability of engine performance prediction, based on the variations of torque, power, efficiency of conversion and Brake Specific Fuel Consumption (BSFC) [11]. Dhaundiyal used dimensional analysis method for finding the relationship of various engine performance parameters [12]. Some researchers also compared performance of the engine by blending ethanol with gasoline and methanol with gasoline. Iliev used 1-D model for performance prediction and found that few engine parameters change on positive side whereas NOx emissions changes do not follow a linear relation [13].

Kamboj et.al. also observed the performance of the engine by conducting engine tests using fuel fractions of ethanol-gasoline and methanol-gasoline. They observed that engine power and Brake Mean Effective Pressure (BMEP) was highest with 5% ethanol blend [14]. Hsieh et.al. showed that the experimental results indicate using ethanol-gasoline fuel fractions, there is a slight increase in output torque and consumption of fuel. HC and CO emissions drops down due to the leaning effect of addition of ethanol and rise in CO2 emission due to enhanced combustion in engine. It was also observed that the emission of NOx depends on operating conditions of the engine and does not depend largely on ethanol content [15].

Yucesu et.al. conducted experimentations on variable compression ratio engine and corelated various engine performance parameters with ethanol blends and operating conditions including the change in compression ratio [16]. With mixing of ethanol in gasoline, the Research Octane Number (RON) of fuel blend increases. This helps in reduction in knocking and smoother running of the engine. Sayin et.al. established relations of RON with engine performance parameters by doing energy and exergy analysis [17]. Elfasakhany experimentally investigated the performance of ethanol-methanol fuel fractions with gasoline. He observed that ethanol blends with gasoline produce higher torque and volumetric efficiency. It is also observed that CO and HC are reduced in ethanol-gasoline fuel fractions, due to the existence of extra oxygen in ethanol [18]. Sezer et. al. presented the mathematical analysis of Spark Ignition (SI) engine in his research. He used first law and second law for analysis of engine performance. Exergy analysis presented by the authors provides a relationship of various parameters with spark timings and engine speed [19]. CFD analysis of engine combustion chamber and Simulink analysis using single-zone zero-dimensional model was done by Chaudhari et.al. The results of simulations were validated with experimental results and found in good agreement with the simulations [20].

Various researchers have taken the efforts to predict the performance of the engine using mathematical tools or various softwares. Many of them have also done experimentation and validated their results. It is also observed that for simplification of the models and to keep the experimentation and results to the minimum possible, the researchers have kept the independent parameters in the range of one to two. It is required to observe the performance of the engine with higher percentage of ethanol in fuel fraction. Some researchers have not observed the engine performance with ethanol-gasoline blend at Full Open Throttle (FOT) condition. The efforts have been made in the present research to overcome the gaps mentioned above. Research done and presented in this paper are based on three major independent variables of Engine Speed, Compression Ratio and Blend Ratio. Effect of compression ratio is considered by using Variable Compression Ratio (VCR) engine. The results are observed while running the VCR engine at FOT condition. This study provides a scope to observe the engine performance with ethanol-gasoline fuel fraction for 40% ethanol in gasoline (E40) and at various compression ratios. This study also provides the overall behavior of the engine at different operating conditions. Key features of this research work are engine operating at FOT for complete experimentation, running the engine for full operating range, blending ethanol to high percentage up to E40 and observing all major output parameters for engine performance analysis.

II. EXPERIMENTATION

Present study is based on experimentation done on single cylinder VCR engine with fuel fractions of ethanol-gasoline tested at FOT condition to observe the engine performance.

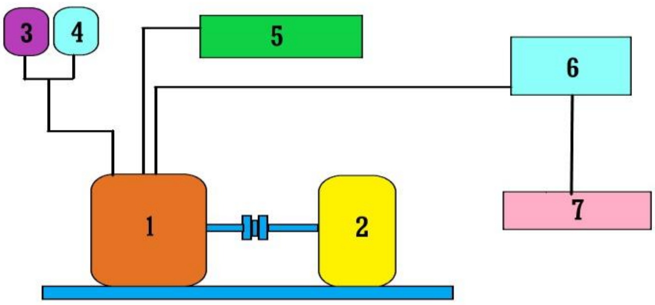

Fig. 1a: Schematic of Experimental Setup

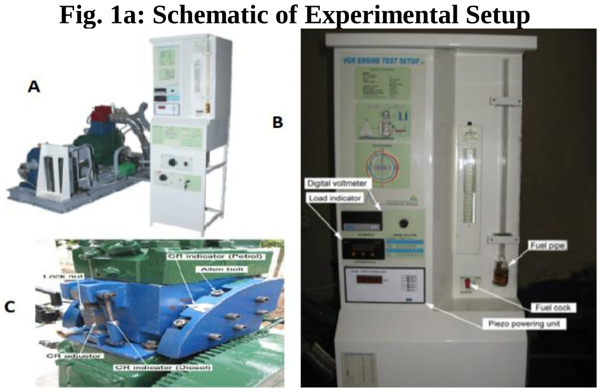

Fig. 1b: Experimental Setup for Engine Testing.

As shown in Fig. 1a, Engine 1 is coupled to Eddy Current Dynamometer 2. The loading of the engine is done through this dynamometer. The setup is provided with two fuel tanks 3 and 4. These fuel tanks are used for feeding two different fuel to the engine. For conducting the engine tests, tank 3 is filled with pure gasoline while tank 4 is filled with blends of ethanol and gasoline. Various engine parameters are sensed, and engine is controlled through control panel 5. This panel displays various engine parameters like engine speed, various temperatures, water flow rate, engine load, air and fuel flow rates etc. Exhaust gases are passed through exhaust gas calorimeter 6, where water is circulated to absorb the heat from gases for calculating the heat loss to exhaust gases. The exhaust gases are tapped in exhaust gas analyser 7 to measure various exhaust gas contents. The tapping of the exhaust gas is done in exhaust gas pipe after exhaust gas calorimeter. Fig 1b shows A: engine setup view, B: control panel and C: arrangement for changing CR.

Table I: Engine Setup Specifications

Engine	Kirloskar Make, one cylinder, four strokes, water cooling, 4.5 kW power, Speed Range: 1200–1800 revolutions per minute, piston travel 110 cm, cylinder diameter 87.5 mm, 661 cc, Compression Ratio 7 to 10, Modified to VCR engine
Dynamometer	Eddy current, water cooled
Calorimeter	Pipe in Pipe
Piezo Sensor	Suitable for 5000 PSI fitted with cable for low electric noise
Sensor for Crank Angle	One degree resolution, speed 5500 rpm with TDC pulse
Data acquisition device	National Instruments, USB 6210, 250 kS/s, 16 bits
Power unit for Piezo	Cuadra made, AX-409
Temperature measuring sensors	RTD, PT 100 and K type Thermocouple
Load Indicator	Digital type, 0-50 Kg. 230 V AC
Load Sensor	Load Cell, strain gauge, 0-50 Kg range
Transmitters of Fuel Flow	DP Transmission, 0-500 mm WC range
Transmitter of Air Flow	Pressure Transmitter, (-) 250 mm WC range
Software	EngineSoft LV, Analysis Software for engine performance
Rotameter	For cooling engine 40 -400 LPH, For calorimeter 25-250 LPH

Engine setup specifications are given in Table I. Engine can be converted from one to other liquid fuel by replacing few mechanical components. Engine CR is changed in engine running condition. This is done by special arrangement of tilting cylinder, as shown in Fig. 1b-C, adjusted through adjusting nut and fixed by lock nut. Spark plug port and injection port are change parts of the setup and can be fitted easily along with cylinder head. Various required sensors are fitted for in-cylinder pressure and measurement of crank rotation angle. The signals generated are utilised for plotting pressure versus crank-angle diagrams. Necessary transducers and sensors are fitted on the setup to measure fuel flow, air flow, engine load and temperatures. The set-up of experimentation has a panel box, as shown in Fig. 1b-B, fitted with air box, fuel tanks for duel fuel test, fuel measuring unit, manometer, transmitters for measurement of air and fuel flow, various indicators of processes and interface for hardware.

For measuring water flow through calorimeter and for cooling of engine, two rotameters are fitted. Engine has a facility of electric start using starter and battery. The engine test-setup is designed for effective measurements of various engine parameters like powers (indicated, brake and frictional), Indicated and Brake Mean Effective Pressures (IMEP & BMEP), Indicated Thermal Efficiency (ITHE), Brake Thermal Efficiency (BTHE), Mechanical Efficiency, Volumetric Efficiency, A/F ratio, BSFC, combustion analysis and heat balance sheet.

EngineSoft, is a LabView based software used for performance analysis of engine. It is provided for data collection, engine control and performance evaluation. Computer can be connected to the control panel using USB port for collection of data from engine in Enginesoft and the software also plots various engine performance curves.

Engine is run for 15 to 20 minutes for allowing the time to bring the engine at steady state and reading are taken after that state. Initially pure gasoline is used for testing the engine. Fuel blends are prepared using various fuel fractions of ethanol and gasoline. 10 % ethanol mixed with 90% gasoline by volume is treated as E10. Similarly, blends are prepared for E20, E30 and E40. Readings are taken at FOT condition. Engine is loaded by applying load through eddy current dynamometer. The speed of the engine at the beginning is matched with its highest rated speed and gradually the speed of the engine is reduced by increasing the load on the engine. Reading are taken from 1700 rpm to 1300 rpm in the interval of 100 rpm. This is the full range of engine speed. For each single fuel fraction, engine compression ratio is also changed from 7 to 10 at the interval of 1. Performance of the engine is observed for each fuel fraction with change in compression ratio and speed of the engine.

III. RESULTS AND DISCUSSIONS

The engine is run with various fuel blends and compression ratio. For a specific fuel blend, a compression ratio is set to minimum value. The engine is started and allowed to run at the FOT condition. The engine speed is changed by changing the load and various such readings are taken at different speed, compression ratio and fuel blends.

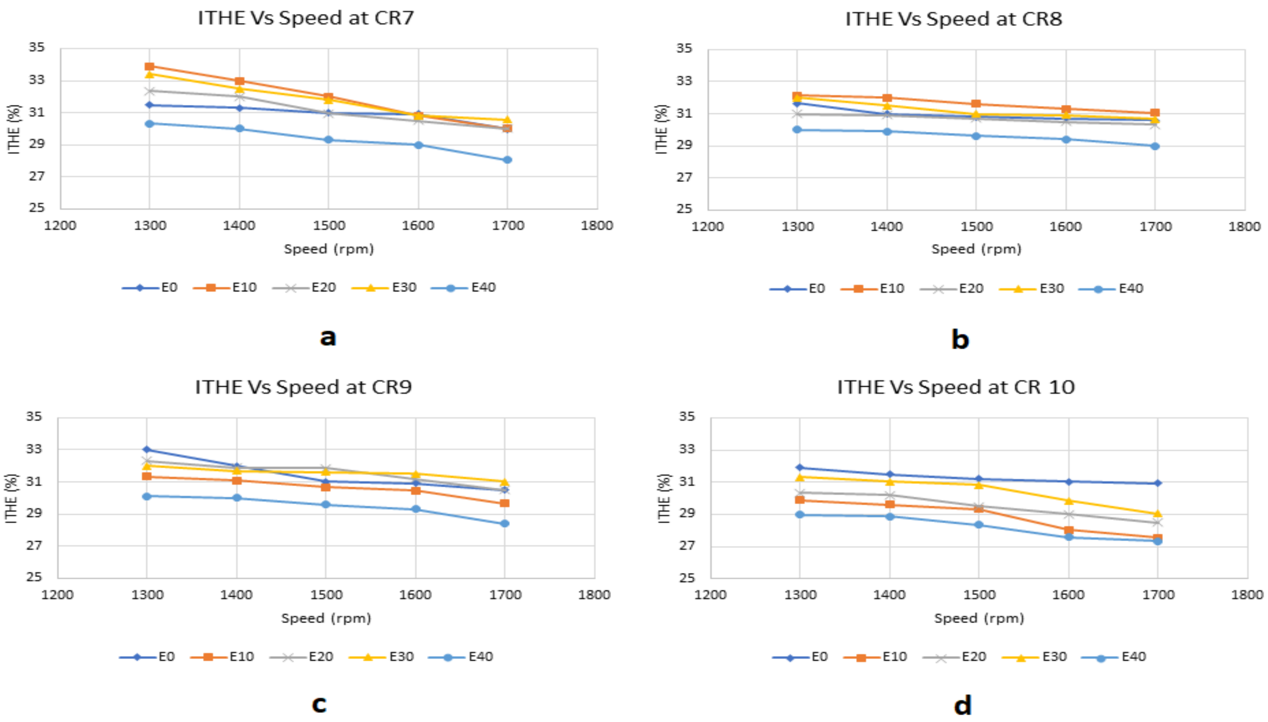

Fig. 2. Indicated Thermal Efficiency Vs Speed a. CR 7 b. CR8 c. CR9 d. CR10

Various output parameters of the engine are observed, and the results are plotted on graphs. The experimental tests are repeated for three times to observe the precision in readings. As shown in Fig. 2, ITHE results are plotted with change in engine speed and at various compression ratios. It is found that ITHE reduces with rise in speed at any compression ratio. With increase in load, Indicated Power (IP) of the engine increases. At the same time, engine requires more fuel to run. As ITHE is a ratio of IP developed with fuel energy consumed, it is important to observe the behavior of change in ITHE with engine speed, fuel blends and compression ratio.

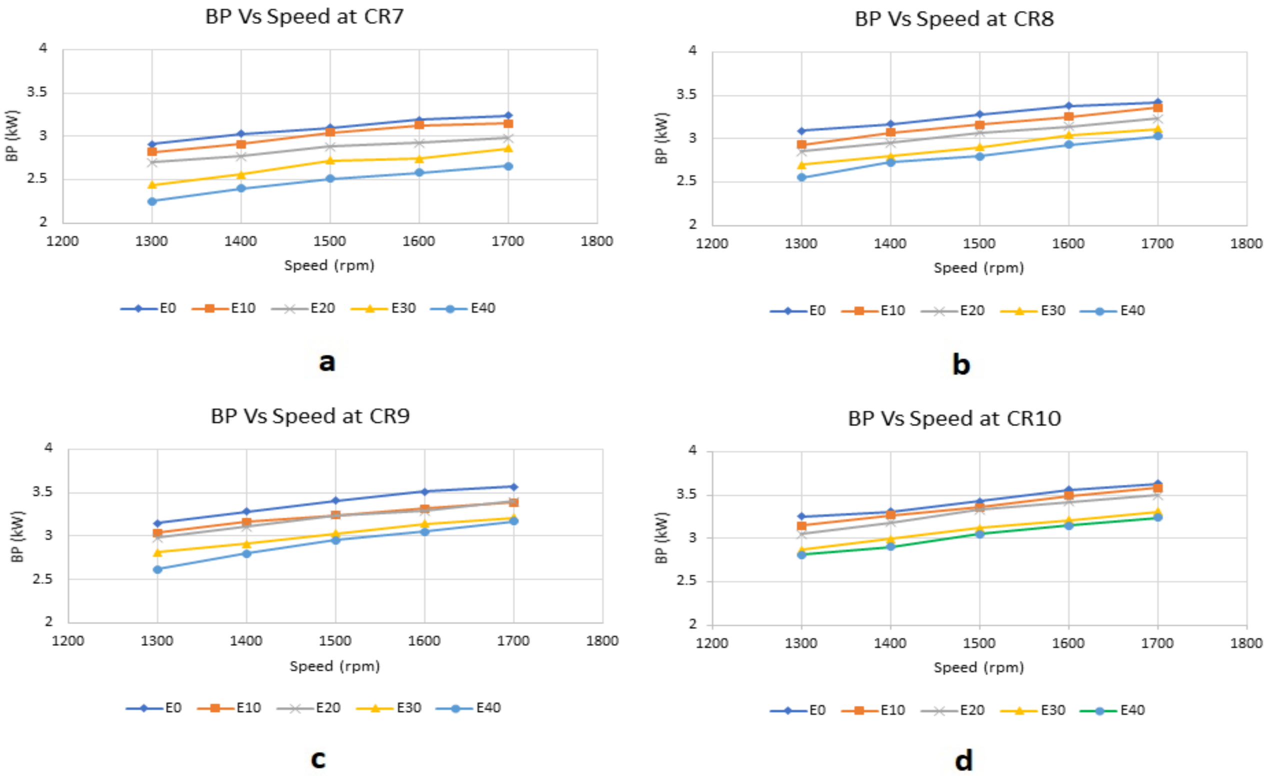

Fig. 3. Brake Power Vs Speed a. CR 7 b. CR8 c. CR9 d. CR10

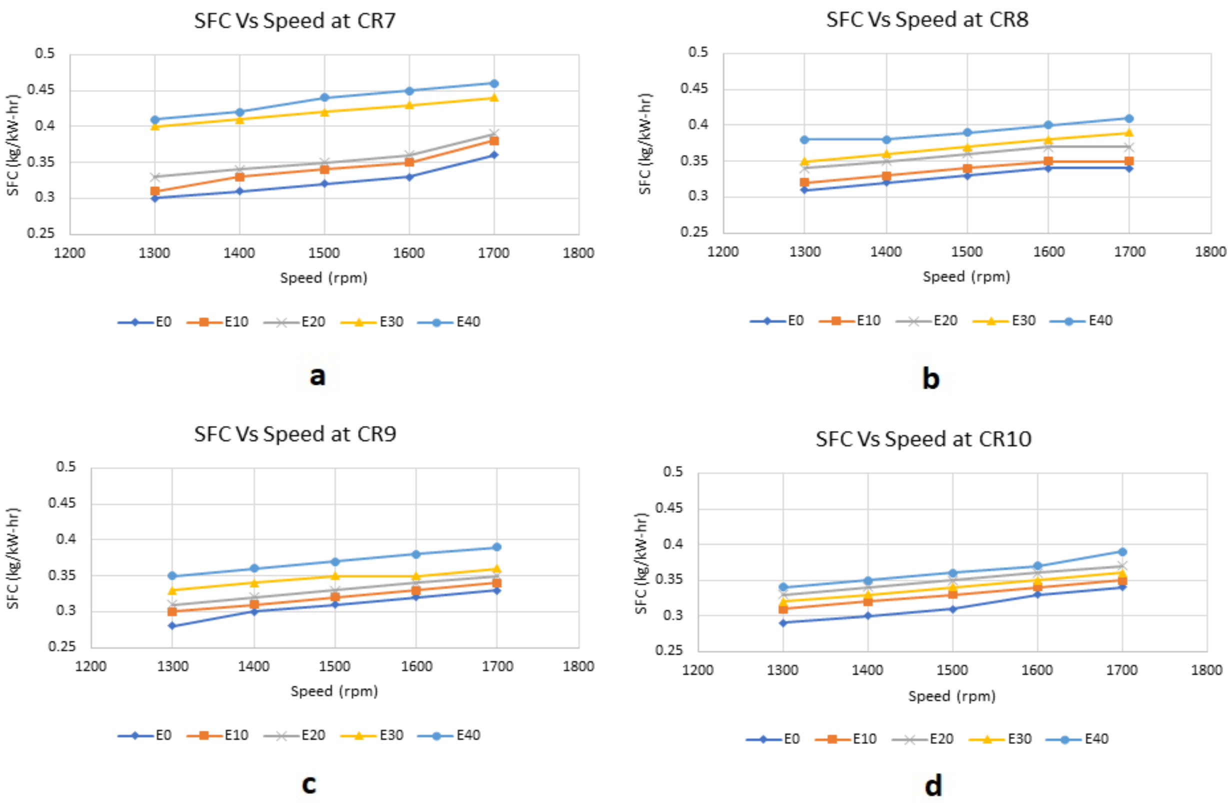

Fig. 4. Specific Fuel Consumption Vs Speed a. CR 7 b. CR8 c. CR9 d. CR10

The variation of ITHE with these parameters is limited to the range of 28% to 34%. Ethanol has lower calorific value, compared with pure gasoline and with increase in ethanol percentage, engine consumes more fuel. Due to this at higher ethanol percentage, ITHE reduces. Lowest ITHE is observed at E40. It is also observed that CR of the engine is not a predominant factor to affect ITHE. The change in ITHE with respect to CR is very small. It is also noted that engine load and subsequent change in engine speed affects ITHE. Behavior of ITHE does not follow a specific pattern with reference to fuel fractions and compression ratio. It depends on IP and CV of fuel. CV of fuel fraction is changing due to difference in calorific values of ethanol and gasoline. Engine IP also depends on various factors, not considered in the study.

Engine BP is calculated by EngineSoft by taking the input of measured load and engine speed. BP is observed directly proportional to speed of engine and load on the engine.

As presented in Fig. 3, it is observed that with increase in the engine speed, BP is proportionally increasing. This variation is observed at all CR values and blend ratios. Engine power is also dependent on type of fuel fraction used. With rise in ethanol percentage in the fuel fraction, engine developed lesser power. It is observed that engine develops least BP at E40, whereas the highest engine power is observed at E0. This is observed due to lesser ethanol calorific value. The behavior of change BP with respect to engine speed is similar in various compression ratio. Highest BP is observed at CR 10 and 1700 rpm. With increase in compression ratio, engine pressure increases, and rise in engine power is observed.

BSFC is calculated for finding the specific fuel consumed with reference to BP developed by the engine. These values of BSFC are calculated by EngineSoft and are plotted versus Speed of the engine at various compression ratios and blend ratios. As shown in Fig. 4, it is noted that with rise in speed, engine requires more fuel. This naturally increases the value of BSFC. The value of BSFC is also observed increasing with increase in blend ratio. With rise in volume of ethanol in fuel fraction, more fuel is required by the engine. This is noted as ethanol has lesser calorific value than gasoline. Increased volume of ethanol in fuel fraction, demands more fuel to be delivered to the engine. In actual practical engine, this higher value of BSFC with rise in ethanol volume in fuel fraction is justified with the ethanol cost. In India ethanol is 40% cheaper than gasoline and ethanol is renewable and can be produced even as a biproduct in sugar industries. Overall variation of BSFC with change in speed and CR is not to a greater extent. The total variation in observed between 0.27 to 0.47.

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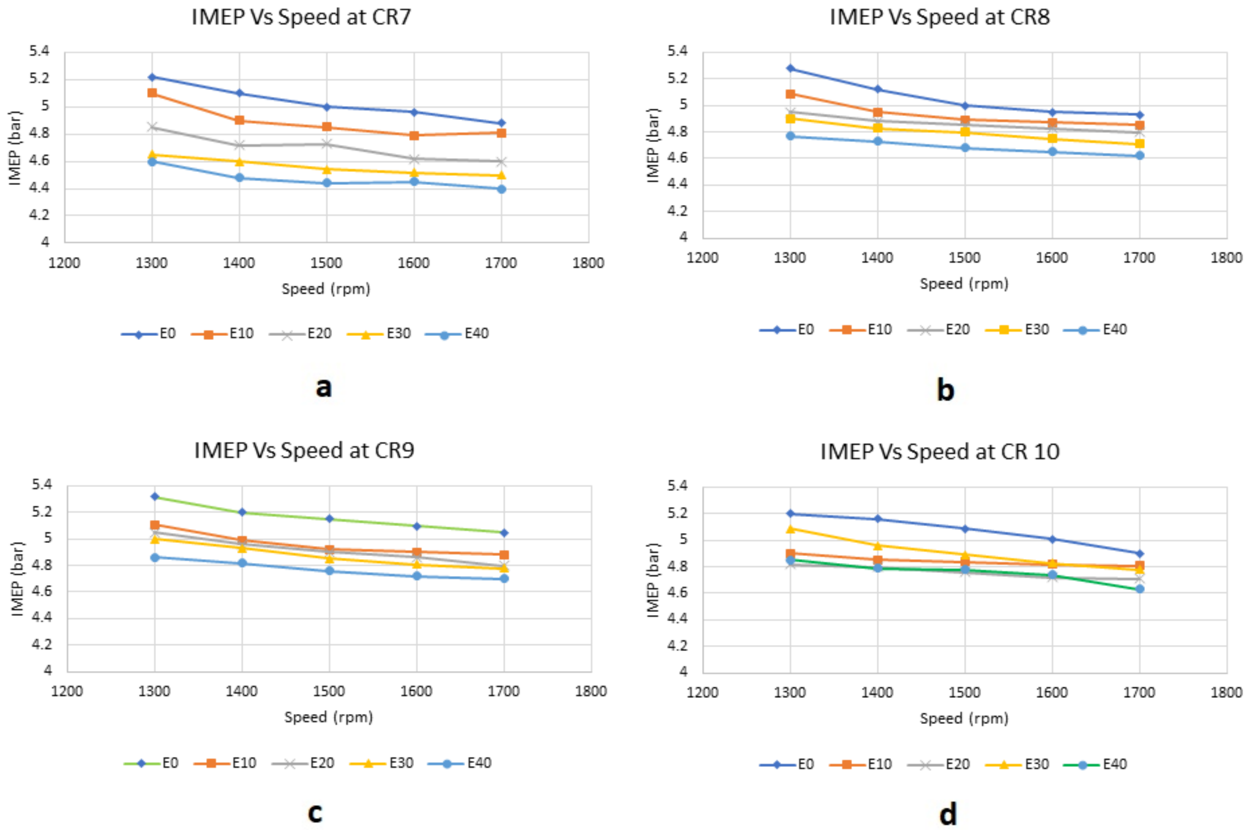

Fig. 5. IMEP Vs Speed a. CR 7 b. CR8 c. CR9 d. CR10

Pressure inside the engine cylinder is measured by pressure sensor. The readings of the same are taken in the EngineSoft and IMEP values are captured in the software. IMEP shows the mean values of effective pressure in engine cylinder. These values are plotted to observe the change in behavior with reference to engine speed. Refer Fig. 5, it is noted that, IMEP is reduced with rise in engine speed. It is also observed that IMEP gets changed due to percentage of ethanol in fuel blend. IMEP is highest for E0 and lowest for E40. This variation of IMEP with reference to ethanol percentage is observed similar for all values of compression ratios. Highest IMEP is observed at compression ratio 9, E0 and at 1300 rpm condition.

Mechanical efficiency is the variation of BP with reference to IP. It is the ratio of BP with IP. Mechanical efficiency is directly proportional to BP but at the same time is changing due to IP. BP changes in direct proportion to engine speed and engine torque. Variations of mechanical efficiency with engine speed, compression ratio and blend ratio are shown in Fig. 6. Mechanical efficiency is observed decreasing with increase in engine speed. With rise in compression ratio, engine torque increases, and BP also increases, being the function of torque. Mechanical efficiency is found increasing with increase in compression ratio. With increase in ethanol volume in fuel fraction, the fuel calorific value drops down. This leads to reduction of BP. For each compression ratio, Mechanical efficiency is highest for E0 and lowest for E40. Overall peak value is observed at E10, CR10 and 1400 rpm.

Changes in volumetric efficiency is presented in Fig. 7. It is noted that volumetric efficiency reduces with rise in engine speed. The variation of volumetric efficiency is similar for any compression ratio. It is also observed that changes in volumetric efficiency is very small with reference to compression ratio. At many points is it observed that volumetric efficiency is more with increase in percentage of ethanol. Ethanol has additional oxygen in it and it gets added for effective combustion of fuel. With rise in engine speed, it takes lesser time for the charge to get inducted in the engine and effectively the volumetric efficiency gets reduced.

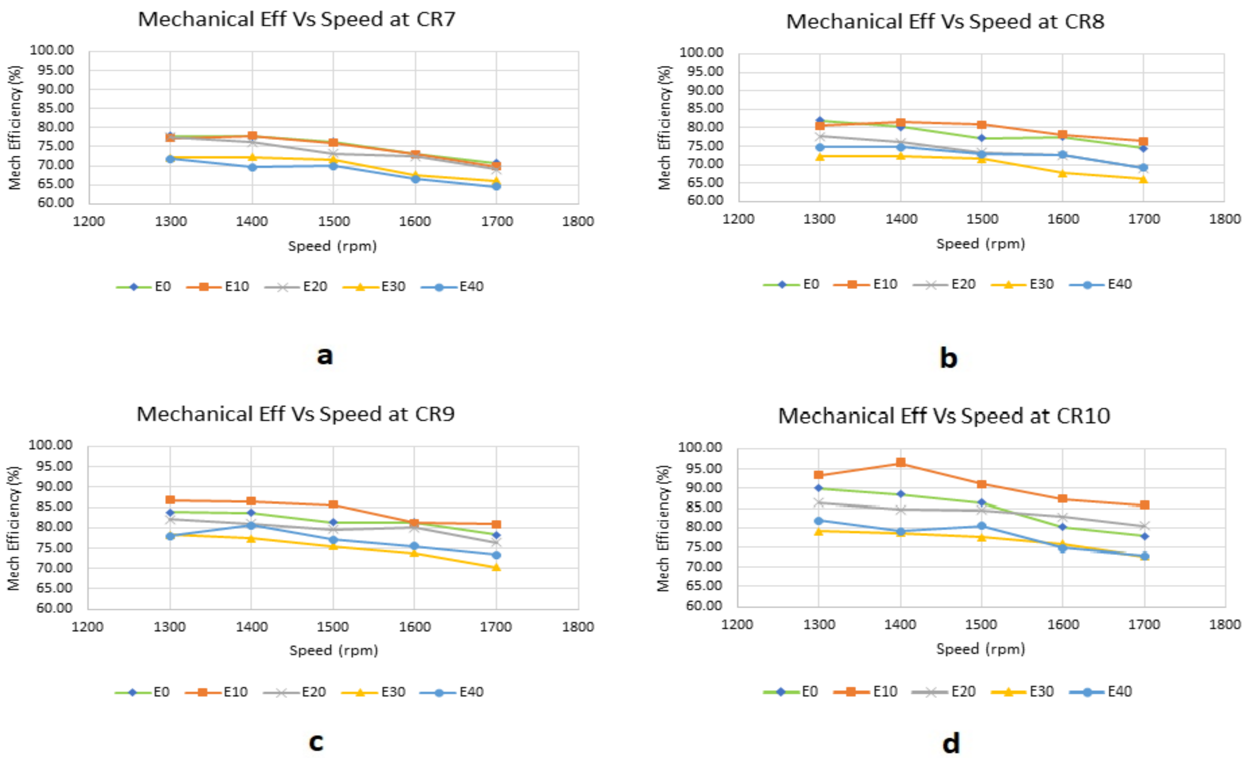

Fig. 6. Mechanical Efficiency Vs Speed a. CR 7 b. CR8 c. CR9 d. CR10

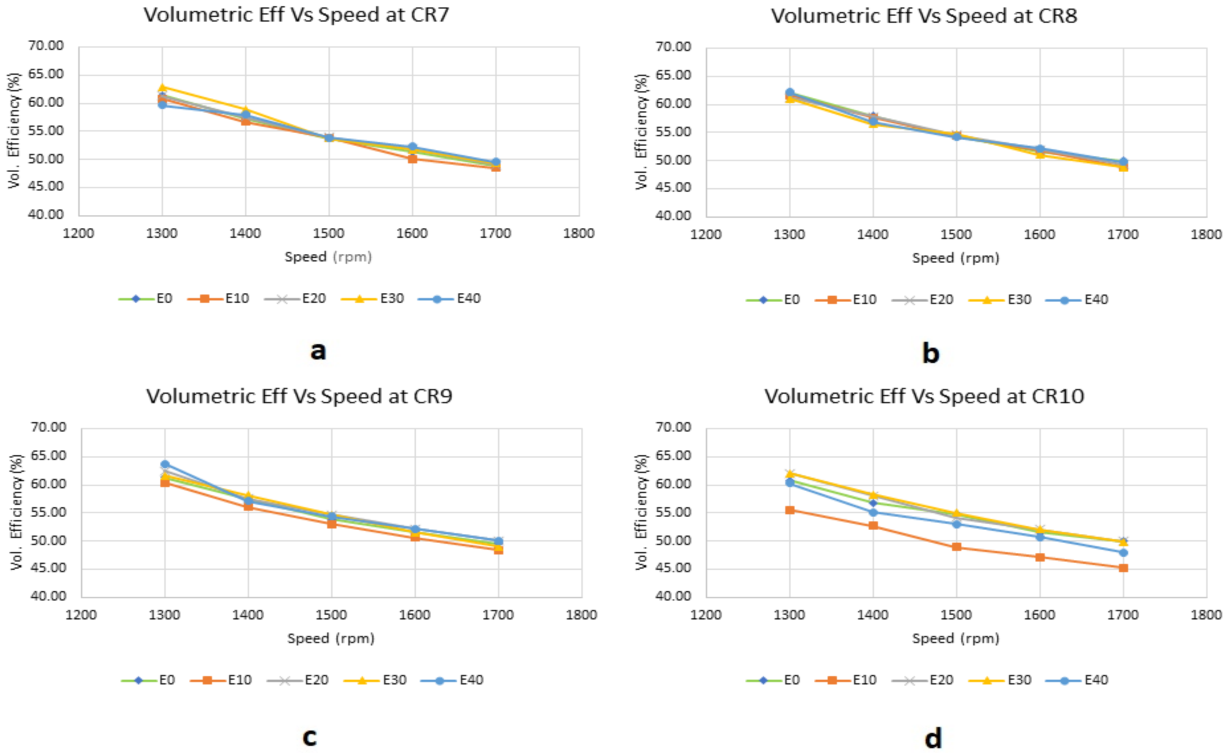

Fig. 7. Volumetric Efficiency Vs Speed a. CR 7 b. CR8 c. CR9 d. CR10

IV. CONCLUSIONS

VCR engine is tested for its performance under different operating conditions with ethanol-gasoline fuel fractions. Experimental results and study show the behavior of various engine parameters with ethanol-gasoline fuel fractions. Following results can be concluded from the engine test observations.

1. It is recommended to run the engine at high speed and high compression ratio. BP is observed more at high compression ratio.
2. Mechanical Efficiency is more at E10, CR 10 and 1400 rpm. Ethanol blend improves this efficiency and it is recommended to use E10 for improved efficiency.

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3. Volumetric efficiency is observed more at E30 for most of the range of engine speed and compression ratio.

4. BSFC rises with increase in engine speed and also with rise in ethanol percentage. The change in BSFC is within a small region. However due to price difference of ethanol and gasoline, it is recommended to use higher percentage of ethanol in blends.

This study provides details of the process carried for effective testing of ethanol-gasoline fuel fractions and provides the information of various engine performance parameters and their behavior for different fuel fractions.

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