Effect of Alcohol-Gasoline Blends and Compression Ratio on Performance of SI (Spark Ignition) Engines: A Review

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Abstract— Alternative fuels become important as the increasing price and demand of the limited reserves of the petroleum products, and these conventional fuels are responsible for environmental pollution and global warming. Alcohols like ethanol and methanol are good alternative fuels, ethanol and methanol has high octane no and ethanol has anti-knocking properties. This review discusses the effect of alcoholic blended fuels on the performance and exhaust emission of spark ignition engines. Ethanol and methanol reduces the CO and unburned HC in the exhaust emissions. This review also discusses effect of compression ratios on the performance and exhaust of the spark ignition engine with different blended fuel. Break thermal efficiency (BTE) and volumetric efficiency of SI engine increases as the compression ratio of ethanol and methanol blended fuel increases.

Key words: Ethanol, Methanol, Gasoline, SI Engine, Compression Ratio

I. INTRODUCTION

In the recent years the demand of the fossil fuels has dramatically increased due to more need of transportation. The reserves of these fossil fuels are limited and going to be depleted in the next coming decades. The vehicles running on petroleum products like gasoline and diesel emits (CO) carbon monoxide, (HC) unburned hydrocarbon, (CO_2) carbon dioxide and (NO_X) nitrogen oxides after the combustion of diesel and petrol. These gases are polluting environment and dangers for us. They are responsible for global warming and depletion of ozone layer that absorbs harmful radiations coming from the sun, because of this pollution issue and limited reserves of the fossil fuels researchers focused towards the alternatives of these fuel. Many researches has been done on performance and emission characteristics of SI engines with alternative fuels like ethanol, methanol, methyl tertiary butyl ether and diethyl carbonate etc. some of them are discussed in this review article.

Specially ethanol and methanol are good candidates for alternative fuel to the SI engines as they shows good physical and combustion characteristics similar to the gasoline. Methanol and ethanol can be use as blends with petroleum based engine fuels. The smaller the alcohol addition, the easier the typical blending problems like phase separation, corrosion, changed vapor pressure, changed air requirement etc. can be solved. Alcohol has high value of octane no and hence addition alcohol to the gasoline increases the octane no of fuels, therefore it reduces the knocking problem [1]. The combustion characteristics, auto-ignition temperature and flash point of alcohol is higher than that of those gasoline, hence transportation and storage of alcohols is safe. The latent heat of vaporization of alcohol is 3-5 times higher than gasoline, it increases volumetric efficiency. Heating value of alcohol is lower than gasoline hence fuel consumption is 1.5-1.8 times higher than gasoline. Ethanol can be used in SI engines by blending or pure, blended fuel of ethanol-gasoline can used without any modification in the engine but pure ethanol needed some modification [2,3]. The addition of ethanol to gasoline reduces the heating value of blended fuel while increases the octane number and slightly increases the torque and specific fuel consumption [4]. Improvements on engine performance can be obtained by several means such as increasing compression ratio, high compression ratio increases fuel-air mixture density and flow turbulence in the combustion chamber, resulting in high cylinder pressure and fast burning speed. The compression ratio of flexible fuel engine is limited by gasoline knock resistance, and it is the lower optimum value for ethanol operation [5]. Ethanol and methanol have higher octane number, oxygen ratio, flammability limit, low carbon to hydrogen ratio, and is considered to be a renewable fuel. Ethanol and methanol also have high heat of vaporization rate, which cools the air entering to engine and increases volumetric efficiency and power output. The effects of pure methanol usage on engine performance and exhaust emission have investigated on an engine having low efficiency, single cylinder and variable compression ratio. Engine power and emission of CO (carbon mono-oxide), CO_2 (carbon-dioxide), NO_x (nitrogen oxide) had decreased, BTE (break thermal efficiency) and HC (unburned hydrocarbon) increased. In both types of fuel, a significant increase in compression ratio (CR), engine torque and exhaust gas temperature, break thermal efficiency and engine power but volumetric efficiency decreased. The BSFC (break specific fuel consumption) decreased with the increase of compression ratio [6]. Ethanol has potential to be valuable substitute for gasoline fuel, since Ethanol possesses characteristic, properties that have positive influence on engine performance as well as exhaust emissions. The engine shows better performance with reduction in hydrocarbons and carbon monoxide with use of ethanol with gasoline, although there are some drawbacks with use of pure ethanol such as phase stability is main concern when hydrous ethanol is used with petrol, the heating value of ethanol is lower than that of gasoline [7]. Investigated the effect of ethanol-gasoline blends (E5, E10) and methanol-gasoline blends (M5, M10) on the engine performance and combustion characteristics of SI engine. They showed using ethanol lead to an increase in BSFC and octane number, this results is expected because heating values of alcohol 37-54% lower than gasoline. Investigated the effect of methanol addition to gasoline on engine performance and reported that maximum break mean effective pressure (BMEP) was obtained from M5 (5% Methanol aided to the gasoline) [8,9].

II. PROPERTIES OF ALCOHOLS

Alcohols such as ethanol and methanol have high octane number, because of high octane number they can be used at higher compression ratios. As a result higher thermal efficiency can be obtained at the same time alcohols have lean burn properties and good combustion characteristics. Alcohols have higher latent heat of vaporization which leads to denser fuel-air charged. Methanol and ethanol have same anti-knock effect. However, increasing alcohol content in the blends increases fuel consumption because of lower energy contents in the alcohols [12]. Blending of bio-ethanol with the gasoline reported some of advantages increase Torque, Break power and Thermal efficiency. It has a higher octane number (108), a higher enthalpy (higher heat of vaporization) and broader ignition foundries, implying several advantages over the gasoline. However bio-ethanol has some drawbacks such as lower energy density, its corrosiveness on engine and combustion parts, low flame luminosity and lower vapor pressure which makes cold start, engine efficiency and engine durability more challenging as compared to the gasoline. Blending with gasoline reduces these effects and anti-corrosive compound are also applied to reduce the corrosiveness [10]. It was reported that although vapor pressure of pure ethanol is low, Reid vapor pressure (RVP) of ethanol-gasoline blend rises and it is dependent on the ethanol proportion in the blend [3].

III. EFFECT OF ALCOHOL GASOLINE BLENDS ON ENGINE PERFORMANCE

Many researchers have been studied and effects of alcohol-gasoline blends on engine performance are discussed below.

A. *Exhausts Emission:*

CO and unburned HC emissions in the exhaust are important because they represent lost chemical energy that is not fully utilized in the engine. . As expected, when alcohol is aided to the gasoline, it provides more oxygen for the combustion process and decreases exhaust emission levels. The most significant reduction in CO and unburned HC was obtained with the use of alcohol gasoline blends at the vehicle speed of 40km/h and 60 km/h respectively. At these vehicle speeds, on average, CO and unburned HC emission decreases by 11% and 33% with the use of alcohol gasoline blends emission compared to those of pure gasoline respectively. But when mean value at all the vehicle speeds tested, it showed that unburned HC decreases 8%, 16%, 14% and 10% at E5 (5% ethanol), M5 (5% methanol), E10 (10 % ethanol) and M10 (10% methanol). While the CO emission with the use of E5 and E10 decreases 3.4% and 2.6% respectively. In this study, CO_2 emission with the use of E5 and M5 decreases by 0.6% and 6.5%, while CO_2 emission with the use of E10 and M10 increased by 0.1% and 0.8% respectively. In this study CO_2 emission decreases with the use of E5 and M5 by 0.6% and 6.5%, while CO_2 decreases with the use of E10 and M10 by 0.1% and 0.8% respectively. NO_x emission with the use of M5 and E10 is decreased by 1.8% and 1.3%, while increased by 1% and 2.3% with the use of E5 and M10 [1]. Using the ethanol-gasoline blends in the SI engine dramatically reduces the CO concentrations. However NO concentration adversely affected due rising cylinder temperature with increasing ethanol proportion in the blends. It found that the reduction of CO emission grows as the ethanol contents increases. This indicates that the addition of ethanol can reduce the CO concentration efficiently. The emission of CO can be reduced up to 90% depending upon the operating conditions. It is obvious that concentration of CO_2 increases as the ethanol contents increases in the blends. However, the emission of CO_2 is not as obvious as those of CO emission. The increase of CO_2 emission grows from 5% to 25% depending on the operating condition and ethanol contents. It shown that increasing the ethanol contents, the concentration of HC decreases from 20% to 80% in comparison of pure gasoline [2,3]. The concentration of HC and CO decreased as the volume percentage of ethanol increased. This is due to the carbon atoms concentration in the blended fuel and the high molecules diffusivity and high flammability limits which improves mixing process and hence combustion efficiency [7].

B. *Break Power and Break Thermal Efficiency:*

Mean indicated work and mean indicated pressure increase because of the increases in the cylinder pressures. Therefore, engine power and thermal efficiency increases with the increase in ethanol content in the blended fuel, although heating values of blended fuel is lower than gasoline. The wheel power with the use of alcohol- gasoline blend slightly decreased at 40 km/h and 100 km/h vehicle speed, but it increased at 60 km/h and 80 km/h as compared to gasoline. On average the wheel power increased by 2.2%, 2.9% and 1.1% at E5, M5 and E10 relatively, while the wheel power reduced by 0.3% at M10 as compared to gasoline [1,3]. The addition of ethanol shows that the higher break thermal efficiency (BTE) than gasoline. Because of improved combustion efficiency BTE is higher for various additives. BTE gradually increases as the additives increases in the blends. It is observed that BTE is low at low values of break power and increasing with increase of break power for all additives [7]. When the ethanol content in the blended fuel increased, the engine break power decreased for all engine speed. The heating value of ethanol is lower than gasoline and heating value of blended fuel decreases as increasing the ethanol content. As a result, lower power output is obtained. When the methanol (M5 and M10) content in the blended fuel is increased, engine break power slightly increased. This is because of the fact that Oxygenated fuel has better combustion efficiency. When the methanol content (M30 and M50) in the blended fuel increased, the engine break power decreased for all engine speed [9].

C. *Specific Fuel Consumption:*

At all vehicle speed, the fuel consumption rate is increased with the use of alcohol-gasoline blends as compared to the pure gasoline. The fuel consumption for E5, M5, E10 and M10 is increased by 5.2%, 3.4%, 5.5%, and 5.5% as compared to the gasoline. According to these average rates, it can be said that low energy contents of the alcohols affected the fuel consumption rate negatively. In case of using alcohol-gasoline blends, more fuel is needed to achieve same wheel power so that it increases the fuel consumption [1]. The break specific fuel consumption (BSFC) remains constant at low speed when throttle opening is higher than 20% and at high speed with high throttle valve opening greater than 40%. The theoretical AFR of gasoline is 1.6 times more than ethanol; therefore the BSFC should be increases as the ethanol contents in the blend [2]. Addition of ethanol in the gasoline reduces the heating value of blend hence more fuel is needed to obtained same power instead of gasoline. Ethanol addition to gasoline improve combustion efficiency and hence performance. Specific fuel consumptions measured at compression ratio 7.75 and 8.25 is lower than those of gasoline fueled engine. The reduction of specific fuel consumption is 5.59 and 4.94% at the compression ratio 7.75 and 8.25 when fuel is blended with 7.5% of ethanol. However, theoretical study shows that special fuel consumption has increased slightly as increases the ethanol concentration in the blend [3]. Break specific fuel consumption (BSFC) for pure gasoline is 384 g/kwh at the compression ratio 13 and it is increased when the 10% of ethanol aided to the gasoline. It is continuous up to the 60% of ethanol aided to the gasoline, and at this blending ratio BSFC is highest as compared to the other blending ratios. In this study the effect of air fuel ratio on BSFC is also discussed and results shows that the BSFC reduces as the air fuel ratio increase, it is lowest for air fuel ratio 1.2. BSFC initially increases slightly than reduces up to the air fuel ratio 1.2 [4]. Ethanol has lower heating value than gasoline hence blended has lower heating value than pure gasoline due to this lower heating value fuel consumption is increased [7]. The break specific consumption increases as the ethanol content increases because of the reason having lower heating value of blended fuel. Highest specific fuel consumption is obtained at E50 and M50 blended fuel. A slightly difference in BSFC is shown when gasoline and gasoline-ethanol (ethanol, methanol) blended fuel is used without any modification in engine [9].

D. *Exhaust Gas Temperature:*

The exhaust gas temperature increases as vehicle speed for all test fuel. The maximum exhaust gas temperature noticed for blends E5, M5, E10, M10 and gasoline is 834^0C, 833^0C, 825^0C, 776^0C and 833^0C at the speed of 100 km/h respectively. Methanol has higher latent heat of vaporization than ethanol and gasoline, hence vaporization of M10 blend produces large temperature drop inside the engine cylinder [1]. The exhaust gas temperature is the function of combustion temperature and combustion temperature is the function of heating value of fuel and ethanol has low heating value as compared to the gasoline due low heating value of ethanol addition of ethanol into the gasoline reduces the heating value of blend. Low heating value of fuel means low combustion temperature and hence low exhaust gas temperature [7]. The effect of exhaust gas temperature on various gases such as CO (carbon mono-oxide), CO_2 (carbon dioxide), HC (hydro-carbons) and NO (nitrogen oxide) have been studied. Carbon monoxide form when there is not enough oxygen to produce carbon dioxide. In presence of oxygen carbon mono oxide burns and converts into the carbon dioxide. It is obvious that when engine speed increases exhaust gas temperature increases and combustion duration increases, hence CO emission will increased. When ethanol or other oxygen appears, due to rapid evaporation and better mixing of air and fuel and consequently excellent combustion carbon dioxide intensity (CO_2), like other emission decreases. It confirms that by increasing exhaust temperature CO_2 emission increases significantly. When the engine speed is increased, air/fuel ratio decreased, so oxygen in mixture increases and consequently hydro carbons (HC) decrease by increase in exhaust temperature [8].

E. *Thermal Efficiency:*

Maximum thermal efficiency is produced by hydrous ethanol (E100) as compared to the E22 fuel at the compression ratio 12:1 and speed of 4000 rpm [5]. When alcoholic blends prepared and use for test it increases thermal efficiency as compared to the gasoline. Thermal efficiency for gasoline first increase rapidly and after maximum value it reduces, abrupt changes in the thermal efficiency of alcoholic fuels is not seen and increases slowly as the compression ratio increases [6].

IV. EFFECT OF COMPRESSION RATIO ON ENGINE PERFORMANCE

The effects of compression ratio on various performance parameters like break thermal efficiency, break specific fuel consumption, exhaust gas temperature and exhaust emission discussing here after analyzing some of the researches on compression ratio.

A. *Exhausts Emission:*

Alcohols having higher oxygen content than gasoline and hence, unburned hydrocarbons (UHC) and carbon mono oxide decreases due to better formation of combustion. However, at the compression ratio 9.5:1 UHC and CO level increases due to the rise of flame extinction because of increasing surface to volume ratio. It was observed that the minimum UHC emission obtained from the gasoline, ethanol and methanol were 162 ppm, 115 ppm and 97 ppm respectively, and were achieved at a 8.5:1 compression ratio. At the entire compression ratio the UHC emission decreases for ethanol and methanol by 22.79% and 28.22% on average as compared to the gasoline On the other hand CO emission also diminished to about 14.49% and 29.37%. Ethanol and methanol have higher heat of vaporization and lower adiabatic flame temperature and this caused to decreasing the peak temperature inside the cylinder, so that the heat loses and NO_x emission are lower. When the CO_2 emission was obtained from all fuel, it was seen that emission value are same at all compression ratio. For all fuels with increasing compression ratio, the CO_2 and NO_x emission increase to the compression ratio 9.5:1, and then went down repeatedly. Moreover, NO_x emission fairly decreased with the increasing alcohol fuel in the SI engine compared to the gasoline [6]. Thermal efficiency improves at higher compression ratio and decreases CO_2 emission which causes to the global warming. By increasing the compression ratio thermal efficiency of engine with HCNG (hydrogen compressed natural gas) improved by 6.5% and NO_x emission by75% as compared to the conventional CNG (compressed natural gas) [14]. Variation of HC and CO depending on the compression ratio, considerable decrease was observed when the higher ethanol content fuel like E40 and E60 is used. The most significant decrease of CO was observed at E40 and E60, the reduction ratio was 11% and 10.8% at 2000 rpm of engine speed. In HC emission highest decrement was observed at the E40 and E60 at the 5000 rpm of engine speed, the decrement was observed 9.9% and

16.5% for E40 and E60 fuel respectively. Decrement in emission of HC is higher than CO [11]. CO_2 emission with the fuel E50 at the compression ratio 10:1 is lower than fuel E0 at the compression ratio 6:1. CO and CO_2 have complementary relation that is with increasing CO emission CO_2 emission decreases. HC emission obtained with E50 fuel is 26% lower than E0 fuel at the same compression ratio. HC emission increases by 19% with increasing the compression ratio from 6:1 to 10:1. NO_x emission obtained with fuel E50 is 33% lower than the E0 fuel at the same compression ratio 6:1. For fuel E50, NO_x emission is increased by 22% with increasing compression ratio 6:1 to 10:1. As the compression ratio increases, the ratio of combustion chamber surface to volume increases and this increases HC. When engine running with the fuel E50 at the high compression ratio (10:1), emission of HC decreased by about 12% with the fuel E0 at the compression ratio 6:1 [15].

B. Break power and break thermal efficiency:

Ethanol addition to the gasoline enhances the power output of the engine. Measured and predicted power output increases by 2.34 and 2.70% at the compression ratio 7.75. Improvement in power is more evident at higher compression ratio owning to increasing knock resistance of blended fuel with the increasing ethanol content in the blended fuel. Increased measured and predicted power by 4.37 and 2.86% respectively at the compression ratio (8.25) [3]. At the compression ratio 12:1 higher engine power is achieved for both the fuels E100 (0% ethanol) and E22 (22% ethanol) but at the compression ratio 11:1 and 12:1 same engine power output is achieved. When compared with the E22 fuel, hydrous ethanol produced a peek output power 3.1% higher, at the speed of 6000 rpm [5]. The higher the compression ratio increases the cylinder pressure and work done by the piston and there after increases the BTE. However, at the higher compression ratio BTE and BMEP decreased slightly due to increasing surface to volume ratio and poor combustion. At the higher compression ratio both friction and pumping losses were greater. It was observed that slow down in the increase of BMEP and BTE being obtained from ethanol and methanol, and was lower that gasoline. The maximum values of BTE are about 29.73%, 30.22% and 30.47% for gasoline, ethanol and methanol fuels. The highest BTE was obtained by unleaded gasoline at the compression ratio 9:1, while the compression ratio of 9.5:1 was produced by ethanol and methanol which were the highest BMEP values in the investigation [6]. The engine torque increased with increasing compression ratio up to 11:1, the increasing ratio is about 8% compared to the compression ratio 8:1. However, when increasing compression ratio 11:1 to 13:1 increments are about 0.95% with E0. The highest engine torque was obtained at compression ratio 13:1 with E40 and E60 fuels; increment is about 14% when compared to compression ratio 8:1 [11].

C. Specific fuel consumption:

The consumption of fuel is 5.2%, 3.4%, 5.5% and 5.5% higher for blends E5, M5, E10 and M10 as compared to the pure gasoline. It shows that the lower energy content of the alcoholic fuel affects the fuel consumption negatively. More amount of fuel is needed to develop same power, it causes for higher fuel consumption at all blends [1]. Fuel consumption at CR 7.75 increases up to 6.5% of ethanol gasoline blends and then decreases slightly up to 12% of ethanol addition. Fuel consumption at CR 8.25 increases up to 7.5% of ethanol blended fuel and further increment in the ethanol addition to the gasoline slightly decreases specific fuel consumption. Specific Fuel consumption at 7.75 CR is higher than at CR 8.25 for all blended fuel up to 12% of ethanol addition to the gasoline [3]. Specific fuel consumption decreases as the increasing compression ratio from CR 8 to CR 13, it had been founded that specific fuel consumption increases as the proportion of the ethanol increases in the blend [4]. Specific fuel consumption for both fuels hydrous ethanol (E100) and E22 decreases as the increasing compression ratio from 10:1 to 12:1. The highest fuel consumption is achieved at the compression ratio 10:1 and lowest specific fuel consumption achieved at the compression ratio 12:1. Specific fuel consumption for hydrous ethanol (E100) is much higher than the E22 at all compression ratios [5]. BSFC for pure gasoline (E0) increased by 10.4% and 13.6% at 3500 rpm and 5000 rpm respectively at compression ratio 13:1 as compared to the compression ratio 8:1. The break specific fuel consumption for fuel E60 is increased by 14.7% and 17% at the speed of 3500 rpm and 5000 rpm respectively as compared to E0 fuel [11]. Minimum specific fuel consumption is obtained with fuel E0 (pure gasoline) at compression ratio 6:1 and speed 2500 rpm, at the same speed and compression ratio fuel consumption is increased by 19% with the E50 fuel. When E50 fuel is used at the compression ratio 10:1 and 2500 rpm speed, specific fuel consumption decreased by 3%. The maximum value of specific fuel consumption is obtained with fuel E50 at the compression ratio 10:1 and 4000 rpm.

D. Exhaust Gas Temperature:

Exhaust gas temperature obtained at compression ratio 10:1 is Minimum for M10 at all speed of vehicle and maximum for E10 at speed 40 km/hr [1]. Catalytic converter is used to measure the influence of compression ratio on the exhaust gas temperature. Exhaust gas temperature increases as increasing the speed for all blends and compression ratio. Maximum gas temperature is obtained for E20 fuel at all compression ratios as compared to the hydrous ethanol [5]. Exhaust gas temperature varies with varying compression ratio at the all engine speed, exhaust gas temperature generally decreases as the increasing compression ratio. Minimum exhaust gas temperature is obtained for E60 fuel at all speed and compression ratios. At the speed of 5000 rpm minimum exhaust gas temperature obtained for E60 fuel is 790^0C, 730^0C at speed of 3500 rpm and 620^0C rpm at 2000 rpm [11].

E. Cylinder Gas Pressure:

Maximum cylinder gas pressure is obtained for blend of 17% of ethanol at both compression ratios 7.75 and 8.25, generally cylinder gas pressure increases as increasing the ethanol proportion in the blended fuel. This increment in the cylinder increases maximum cylinder temperature about 2%, while studied at constant speed of 1500 rpm. Maximum cylinder gas temperature is obtained at compression ratio 8.25 as compared to the compression ratio 7.75 [3]. Earlier there is no effect of alcoholic blends on cylinder gas pressure at all the compression ratios, generally maximum cylinder gas pressure is obtained for alcoholic blends at 0-

30^0 of crank angle for all compression ratio. At compression ratio 8:1, 8.5:1 and 9:1 maximum cylinder gas pressure is obtained for methanol blended fuel, but at compression ratio 9.5:1 maximum cylinder gas pressure is obtained almost equal for ethanol and methanol blended fuel. As increasing the compression ratio maximum cylinder gas pressure increases from compression ratio 8:1 to 9:1 and maximum cylinder gas pressure slightly decreases further increment in compression ratio [6].

F. Thermal efficiency:

As the increasing compression ratio thermal efficiency increases for both E22 and E100 fuels, at compression ratio 12:1 produces much higher thermal efficiency with hydrous ethanol as compared to the other testing conditions. Hydrous ethanol produces higher volumetric efficiency at 4500 rpm engine speeds and compression ratio 12:1 [5]. Increasing the compression ratio increases the cylinder pressure inside the engine that increases work done, thus increases the thermal efficiency of the testing ring. As increasing the compression ratio for gasoline fuel, it increases the thermal efficiency dramatically up to compression ratio 8.7:1 and then decreases. Maximum thermal efficiency produces by ethanol and methanol fuel is about 30% at the compression ratio 9.5:1 [6].

V. Conclusion

This paper reviews the influences of the alcohols (ethanol and methanol) blending and compression ratio on the performance and exhaust emission of testing engine/vehicle. Alcohols have higher octane number than gasoline it improves combustion of fuel inside the cylinder and it allows engine to operate at the high compression ratio, Alcoholic blends with gasoline reduces the exhaust emission (CO, HC) effectively, CO_2 emission increases due to better combustion. The blending of alcohols increases fuel consumption due more oxygen content in the alcohols. The latent heat of vaporization of ethanol is high because of high latent heat mission of nitrogen oxides (NO_x) not reduced. Overall blending of alcohols and compression ratio improves the performance and exhaust emission of internal combustion engine.

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