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Parametric Evaluation of Spark Ignition Engine with Ethanol Blended Gasoline Fuel

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Abstract:-The purpose of this study is to see the effect of blending gasoline fuel with ethanol on performance and emission of SI engine through literature review. As, emission norms are stringent across the globe to protect environment and human being from ill effect of pollution and also to preserve fossil fuel for future. Extensive research has been carried out for alternative source as fossil fuel replacement. Ethanol, best known alternative source of energy which is used as fuel blend with gasoline but not solely because of variation in thermo-physical properties effects on performance and emission of an SI engine. The thermo-physical properties of ethanol is examined by ASTM standards. Results reflects that with blending CO, HC emission decreases with CO2 increases. NOx emission still unpredictable as it depends upon the engine operating. Brake specific fuel consumption is also confliction between practically obtain results and theoretical calculation. Volumetric efficiency, torque output, brake thermal efficiency, octane number, density increases considerably with blending. While heating value decreases and RVP increases initially and then decreases
Keyword— Alternative Fuel, Performance and emission of SI engine

1. INTRODUCTION

i. Fossil fuels are the major source of energy and 90-95% of total quantity is consumed by transportation sector. Transport vehicles are rapidly increasing day by day lead to more requirement of fuel. Currently 13.848 MT fossil fuel is required to meet the need where as in 2011-2012 12.85 MT fuel was required and expected demand to be 16.40 MT in India according to Planning commission of India. . As, fossil fuel reserves are limited and requirement of fossil fuel is more, extensive research across the globe is carried out from last many years in search of best alternative source of energy. Another most important factor is harmful emissions that are generated due to complete as well incomplete combustion of fossil fuels. By anthropogenic sources, 25 billion ton of CO2 is generated every year [1] which affects environment and human health very badly. This environmental degradation, forces responsible member of global community to must play a role in exploring and adopting ways to reduce emission without effecting the process of growth and development. The research emphasis was on the development of fossil crude oil, coal, and natural gas based refinery to exploit the cheaply available fossil feedstock to meet the growing demand of population [2].

ii. One of the ways in which this can be achieved is by ethanol and bio-diesel blending them with gasoline and diesel respectively. Fossil fuels still represent 80% of total energy supply whereas biofuel contributes only 1% [3]. Brazil, is the first country which has opted ethanol as a complete replacement of fossil fuel after facing oil crisis in 1971. The government of Brazil have taken steps, formed strategy and now able to reduce petrol consumption by 30%. Ethanol has attracted attention worldwide because of its potential use an alternative fuel [4]. Ethanol is a green fuel because growing sugarcane crops function as a CO2 sink, thereby contributing to the reduction of greenhouse gases (GHG) [6]. Recently, ethanol has been used extensively as a fuel additives or alternate fuel for Spark Ignition Engine (SI) as it is having high octane number [7].

iii. According to [8], using ethanol-gasoline blend fuel in SI engine caused torque than of gasoline fuel. The maximum torque is obtained at 0.9 relative air fuel ratio. The effects of ethanol–gasoline blends (E0, E10, E20, E40 and E60) on engine exhaust emissions and performance has been investigated by [9].]. It was also reported that blends with ethanol allowed the compression ratio to increase without any knock [10]. The specific fuel consumption was reduced by approximately 3% [11, 12].With increasing the ethanol content in gasoline fuel, the heating value of the blended fuels is decreased, while the octane number of the blended fuels increases [13] reported that blending unleaded gasoline with ethanol increases the brake power, torque, volumetric and brake thermal efficiencies and fuel consumption, while it decreases the brake specific fuel consumption [14, 15].) The 20 vol. % ethanol in fuel blend gave the best results for all measured parameters at all engine speeds [13]. Burning of ethanol in SIengines also reduces emissions of carbon monoxide (CO), hydrocarbon (HC), and so on, but there are some inconsistencies in NOx emissions as shown by many researchers.The Environmental Protection Agency (EPA) listed NOx as one of the critical pollutants that can affect the respiratory system. NOx concentration are increased due to rising of the cylinder temperature with increasing ethanol percentage in the blends [16]. The effect of ethanol blended gasoline fuels on emissions was investigated in a spark-ignition engine with an electronic fuel injection (EFI) system [15]. The effects of using ethanol-unleaded gasoline blends on cyclic variability and emissions in a spark-ignited engine have been investigated by [17]. It was reported that using ethanol- un- leaded gasoline blends as a fuel decreased the coefficient of variation in indicated mean effective pressure.The 10 vol. % ethanol in fuel blend gave the best results.

Table.1Properties comparison of Gasoline and Ethanol

Property	Gasoline	Ethanol	Method
Chemical Formula	C5-C12	C2H5OH	
Molecular Weight(kg	114.15	46.07	
Density(kg/l) at 15^{0}C	0.7575-0.765	0.789-0.791	AS Per App15464:20042 'A'
RON(octane number)	95.4	108.6	ASTM D2699
RVP(kPa 37.8^{0}C)	53.7	15.857	ASTM D5191
Higher Heating	47.3	29.7	
Lower Heating Value(MJ/kg)	42.6	26.9	
Specific Heat(kj/kg k)	2.4	1.7	
Specific Heat(kj/kg k)	2.5	1.93	
Boiling Point(^{0}C)	27-225	78	
Flash Point(^{0}C)	-45 to -13	12-20	
Auto Ignition	257	425	
Latent Heat of Vaporization(kj/kg)		900-920	
Conductivity(µS/m Max)	380-400 None	300	AS Per App 'H' 15464:2004
Kinematic Viscosity (mm2/sec)	0.5-0.6	1.2-1.5	
Carbon (wt. %)	86.6	52.2	
Oxygen (wt. %)	0	34.7	
Hydrogen (wt. %)	12.6	13	

VARIATION IN THERMO-PHYSICAL PROPERTIES AND CONSEQUENCES

a) DENSITY

Engine performance is increased by increasing the amount ofenergy available above piston and by converting all chemical energy of fuel into mechanical work. Energy above piston is increased by supplying more amount of fuel mass within a given volume. As density of ethanol is more than gasoline, more mass of fuel per unit volume is available at inlet. Figure1, given below show that as % of ethanol is increasedwhile using as blend with gasoline more mass per unit volume is supplied. E0 represent pure gasoline while E5 stand for 5% ethanol and 95% gasoline.

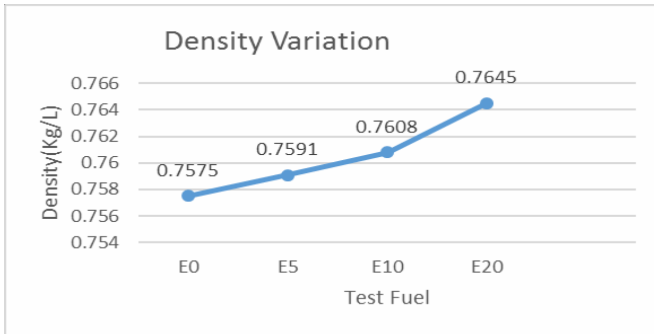

Figure1- Variation of Density is nearly linear

No mathematical expression is availble in the literature to calculte value of density when two fluids having different density is mixed with each other at different perportion. The density test fuel is defines by ASTM D405

b) REID VAPOUR PRESSURE(RVP)

RVP basically measures the volatility of the blended fuel that how easily a fuel burn. When gasoline is blended with ethanol, RVP varies as shown in figure given below. RVP is estimated by test method ASTM-D-5191RVP increases when gasoline is blended with ethanol, but it shows some drastic variation. Initally, RVP increases when % of etahnol is 10% v/v. But after that it decreses, this is due to formation of azeotropes with the hydrocarbons typically comprising gasoline by ethanol. An azeotrope is a mixture of two or more liquids in such a ratio that the composition of the mixture cannot be changed by simple distillation. Azeotrope always deviate from Raoult's law, an equation that describes the vapor pressure of ideal solutions containing two or more liquid components. In the case of ethanol/gasoline blends, this results in a positive deviation from ideal behavior, so that the vapor pressure of the blend will be higher than that of the base gasoline up to about 10% v/v ethanol and then will gradually fall again at higher ethanol levels. Volatility is one of the main characteristics that a fuel must possess to be used in SI engine. Decrement in RVP lead to poor performance of SI engine in winter as well more prone to evaporative emissions. No doubt, evaporative emission control system is implemented but at the same time increasing the cost of an SI engine. These systems are used in such a way that engine is not at all modified which is always preferable.

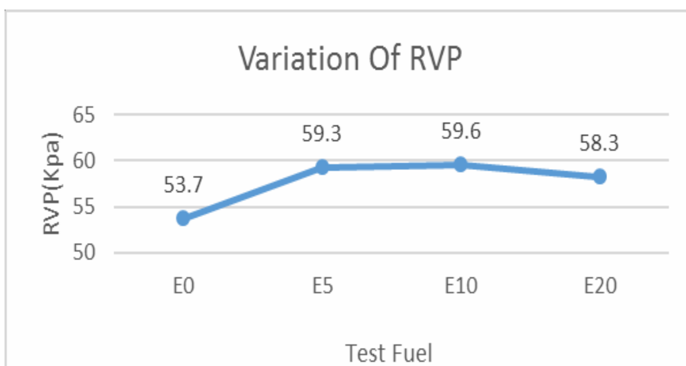

Figure2- Variation in RVP is differ with different rate of blending.

c) RESEARCH OCTANE NUMBER (RON)

Knocking is a major problem that affects the performance ona gasoline engine. Knocking stand for disturbed motion of piston when it approaches to BDC in power stroke from TDC. There are several factors on which knocking tendency depends upon. The factors are volatility of fuel, spark timing, combustion characteristics, engine construction and operating conditions etc. But out of these quality of fuel affects the most. Pure gasoline has octane number 91-100. Fuel with higher octane number is preferred because of better anti- knocking qualities. Present study more emphasizes Research Octane Number. RON is another common and world wise used method for octane rating. Octane rating of test fuel is carried out by comparing it with iso-octane (octane rating 100) and heptane (octane rating 0) in a test engine. Whereas RON of a test fuel is determined in the test engine with variable compression ratio by comparing it with mixture of iso-octane and n-heptane.Another way to increase the octane number of gasoline is to blend it with another fuel is having competitively more octane rating. Ethanol has octane rating as 108.61-110. When ethanol is blended with gasoline, anti-knocking tendency is increased. RON is estimated by ASTM-D-2699.

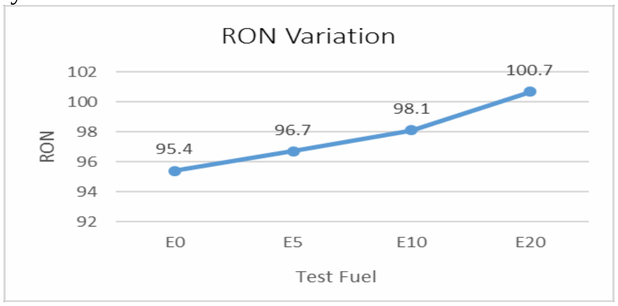

Figure3 - RON varies linearly

d) HEATING VALUE

The heating value is a measure of heat released by combustionof given quantity of fuel. Bomb calorimeter generally used to measure heating value.

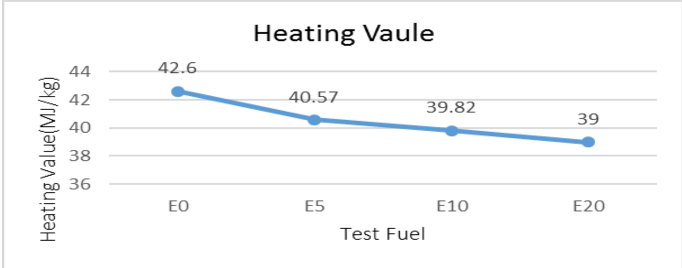

Figure 4- Heating values decreases as blending increases

Higher heating value

Higher heating value is to be determined by assuming that components of water at the end of combustion is in liquid state. HHV is a gross calorific value that measures the amount of heat liberated by specific fuel quantity when combusted initially at room temperature and combustion products returned back to room temperature. It, basically a measure of the latent heat of vaporization of water of combustion products. Lower heating value on the other hand is defined amount of heat produced when given weight of the fuel is completely burnt and water vapor remains with reaction products without being condensed. Lower Heating Value differ from Higher Heating Value in terms of heat of vaporization of water. There are number of definitions suggested by different organization like American Petroleum Institute (API), Gas Processors Suppliers Association (GPSA).

The LHV for gasoline is 42.6 MJ/kg while for pure ethanol is 26.9 MJ/Kg.

Effect on Engine performance due to properties variations

2. VOLUMETRIC EFFICIENCY

Volumetric efficiency predicts the breathing ability of an engine. For the conversion of chemical energy of fuel into mechanical energy combustion of fuel is done with the help of atmospheric air. The performance of inlet system is depends upon volume in flow rate of air and engine configuration but not on the mixture flow rate. Volumetric efficiency is calculate as ratio of mass flow rate of air to the displaced volume of system.

$$\eta v = \dot{m}a / (\dot{\rho}a * Vd)$$

Variables that do influence the volumetric efficiency are quality of fuel, F/A ratio, latent heat of vaporization of fuel, ratio of exhaust to inlet manifold ratio and engine revolution.After combing all these factors resulting equation

$$\eta v = (M/Ma)(Pi/Pao)(Tao/Ti)(1/1+(F/A)$$

Most influencing factor are taken collectively into an equation and theoretical calculation results shows as blending increases volumetric efficiency increases. But practically, when an engine revolutions are higher volumetric efficiency is relatively lowers as shown by [19]. At higher revolution of engine air velocity increases relatively which creates more pressure difference at venturi and let more fuel to be in for a fixed throttle valve opening by decreasing volumetric efficiency.

3. EQUIVALENCE RATIO (Φ)

Air-fuel ratio, a dimensionless quantity is ratio of mass of air to the mass of fuel. The stoichiometric air fuel ratio signifies the minimum amount of air is needed for complete combustion of unit quantity of fuel.

$$\varphi = (A/F)st / (A/F)act$$

(A/F) st- stoichiometric air fuel ratio means exact amount of air needed for complete combustion. (A/F)act- actual amount of air used for complete combustion. Stoichiometric air fuel ration is calculated as

$$C\alpha H\beta O\gamma N\delta + m_a (O2+3.76N2) \text{------} n1CO2+n2H2O+n3N2$$

Where αβγδ- represent the composition of Carbon, Hydrogen, Oxygen and Nitrogen respectively of a fuel. n1, n2, n3 shows compositional amount of CO2, H2O and N2 respectively that are formed after the combustion of fuel.By balancing the equation Value of m_a is calculated.

$$(A/F)st = m_a * 4.76 * 28.97 / \text{molecular weight of tested fuel}$$

The stoichiometric air fuel for pure gasoline is nearly 15. But for ethanol it is less than 15 due to less amount of air is required to burn same quantity of ethanol as compare with gasoline. So, equivalence ratio is decreased for Ethanol fuel. When gasoline is blended with ethanol at different rates, variation of equivalence ratio has been noticed. Theoretically blending of gasoline with ethanol lower the equivalence ratio as decrement in stoichiometric air fuel ratio and increment is actual air fuel ratio. Actual air fuel ratio is increased as with ethanol blending more amount of air enter inside the engine as volumetric efficiency increases. But according to [13] up to 20% of ethanol blending equivalence ratio is decreased and beyond which it increases. Two factors that decides the equivalence ratio are blending rate and r.p.m on SI engine.At higher r.p.m volumetric efficiency decreases, equivalence ratio increases.

3.1 BRAKE THERMAL EFFICIENCY

It is measure of engine output. The term thermal efficiency is used because the mechanical output of the gasoline engine obtained from the thermal energy of fuel which is burnt inside the cylinder. Brake thermal efficiency in actual amount of power available at crank shaft w.r.t power given to the piston. Power is measure as a product of R.P.M and torque obtained at output. Brake thermal efficiency is increased due to complete combustion of fuel. But at the same time heating value of fuel is less so as less power is available at input. But with ethanol complete combustion occur and more power is generated. Same result has been shown by [17] that brake thermal efficiency is 35% when gasoline is blended with 20% of ethanol.

3.2 SPECIFIC FUEL CONSUMPTION

It is another indicator of engine performance. SFC also used to compare different same size engines to predict more efficient one. Specific fuel consumption measured in terms of brake specific fuel consumption (bsfc) and thrust specific fuel consumption (tsfc).bsfc measure the efficiency of engines, generally reciprocating type engine as it is a ratio of fuel consumed per unit for producing power. Units (g/J). While tsfc measure the efficiency engines that are specifically used for propulsion system as it is ratio of fuel consumed per unit time for producing thrust. Units (Kg/hr/KN). Different study shows the variation of bsfc with the rate of blend [13, 17]. Some contradictory results are shown but at last same conclusion is described. According to [17] bsfc is increased with the increase of ethanol contents while [13] says bsfc decrease as ethanol percentage increases up to 20%. Theoretically, air fuel ratio of gasoline is 1.6 times more than ethanol. Practically, with the increase of ethanol bsfc ought to be increased. There are many views over specific fuel consumption. But bsfc decreases due to following reason:

1. Increase in brake thermal efficiency 2. Decrease in equivalence ratio. 3. Leaning effect of ethanol fuel irrespective of richer fuel condition of gasoline engine.

Gasoline engines are operated near to stoichiometric air fuel ratio. But ethanol blending decreases the equivalence ratio as cited above, at the same time increased brake thermal efficiency lowers the bsfc.

3.3 TORQUE OUTPUT

Horsepower sells engines and cars. But torque moves the car. Torque output varied with the throttle valve opening for a fixed engine speed. Higher the throttle valve opening more fuel will be available for burning gives more power output. Torque output is quite insensitive to the variation of blend rate of ethanol-gasoline fuels. However, the torque output of pure gasoline E0 is slightly lower than those of E5-E30, especially for low throttle valve opening or high engine speed [17]. Numbers of researchers have experienced effect of various blend rates at different speeds and different operating conditions [17]. But, the ultimate result comes out that there would not be large variation in the engine torque output. Torque output is clearly depends upon the throttle opening. At same throttle opening (generally low), torque output of engine running with blended fuel is more comparatively due to proper burning of fuel near stoichiometric ratio.

3.4 Effect of Blending on Emissions

Tail pipe emissions contributes a lot to increasing pollution very rapidly. About 80-85% of pollution is generated by the automobiles. This is due to proper burning as well improper burning of fuel both causes toxic and hazardous emission out from exhaust system of automobile. Out of these two, improper burning of fuel does more damage to environment so as to human health. Reasons for improper burning of fuel are

i. Quality of fuel to be used in specified engine, design for specific application is not good.
ii. Bad condition of Engine i.e. engine age, inadequate designing, defective material used, components failure.
iii. If blending is needed, the thermo physical properties of mixed fuel.
iv. Environment conditions like extreme high and low atmospheric temperature.

Combustion products of fossil fuel are Carbon dioxide. Carbon mono oxide, unburnt hydrocarbons, compounds of nitrogen like N_2O, N_2O_3 etc. When fossil fuel like gasoline is blended with alcohol i.e. ethanol more products are formed after combustion. These are formaldehydes, acetones etc. Let's compare the emission generated by gasoline when used in SI with and without blending of ethanol.

1) CARBON MONOXIDE EMISSIONS.

CO emission resulted due to incomplete combustion of fossil fuels. Reasons for incomplete combustion are limited amount of air is available for combustion, poor mixing. This occur when fuel avail for combustion is richer one. As, in SI engine fuel burn slightly richer leads to more CO emission. With blending of ethanol, CO emission reduced as shown by many researchers [13, 17]. Possible reasons are ethanol contains oxygen contents as its constituents and also percentage of carbon in ethanol is comparatively less as shown in table above. As experiment conducted by [18], found at 3000 r.p.m when ethanol blends as E0,E10,E15 and E20 was used, co emission was reduced by 13.7%, 24.31%, 27.93% and 45.42%.But when the r.p.m in increased beyond 3000, CO emission is increased. This is due to lesser time is available for proper combustion of fuel. This difficulty is overcome by some extent with advancing spark timing for SI engine running at higher r.p.m. No mathematical model or formula is available for literature which shows relation between r.p.m and CO emissions. This is determined experimentally.

2) CARBON DIOXIDE EMISSIONS.

Carbon dioxide is another combustion products which liberated due to complete combustion of fuel. CO_2 emission is increased and decreased for same blend rate is depending upon the engine r.p.m. Initially at lower r.p.m CO_2 emission is higher due to more time is available for combustion of fuel so CO emission is decreased. At higher r.p.m CO2 emission is decreased resulting more CO emission because of lesser availability of time. Same results shown by [18] as using E5, E10, E15 and E20 CO_2 emission decreased by 3.87%, 6.06%, 6.76% and 10.14%.

3) HYDROCARBON EMISSION.

Hydrocarbons are the unwanted products formed mainly due to either improper burning of fuel or leakage of fuel from the burning chamber. With proper design of combustion chamber and stroke to bore ratio, evaporative control systems, exhaust gas recycling, catalytic convertor and maintaining temperature of intake air adequate emission caused by leakage is reduced. But, hydrocarbon emissions are strongly depend upon air to fuel ratio. The techniques listed above reduces the leakage which is basically low in percentage as compare to improper burning. For same engine set up using gasoline with or without blending of ethanol shows that as percentage of ethanol increases hydrocarbon emission decreases. Reasons for improper burning are too lean or too rich mixture. As SI engine run on nearly stoichiometric air fuel ratio or near to it, more hydrocarbons emissions are liberated. But blending of ethanol with gasoline increases percentage of air which ultimately burns all the fuel leads to low hydrocarbons emissions. HC emissions checked by [18] found irrespective to r.p.m variation HC found to be decreased with percentage of Ethanol increased.

4) NITROGEN OXIDES.

Oxides of nitrogen are very dangerous and harmful to health causing respiratory problems, lung tissue damage, heart diseases and formation of ozone etc. NOx formation is done as suggested by Zeldovich mechanism are

- $N_2 + O \rightarrow NO + N$
- $N + O_2 \rightarrow NO + O$
- $N + OH \rightarrow NO + H$

Many researchers have found NOx is increased by using ethanol blended gasoline fuel in SI engine but at the same time some researchers have found NOx decreased. The NOx level is decreased while using higher percentage of ethanol as high heat of vaporization of ethanol as compare to gasoline [19]. Using bike engines [20] shows with increasing ethanol percentage causes CO and NOx emission increases due to complete combustion of fuel. Storey et al. [21] found with increase of blending NOx emission decreases as lower energy density of ethanol. So NOx emission is depends upon engine operating conditions, flame temperature and propagation. NOx emission is higher when richer fuel is completely burn inside the engine as compare to leaner fuel.

4. CONCLUSION

The present study shows that blending of gasoline with ethanol increases density, research octane number and volumetric efficiency. Ethanol has less heating value than gasoline so more amount of fuel is needed to obtain same power output. This will also lead to more brake specific fuel consumption, decreased brake thermal efficiency. Exhaust emission co and hc decreases due to complete combustion of blended fuel because fuel present is comparatively leaner for same compression ratio and air fuel mixtures and more oxygenated. Co2 emissions increases again showing complete combustion of fuel present inside. Nox emission slightly depend upon blend rate but majorly depend upon the engine and operating condition of engine. Optimization of process parameters is to be needed so as less emission generated and also better efficiency is achieved.

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