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Effects of SI Engine Operating Temperature Fuelled with Gasoline Ethanol Blends on Performance and Emissions Characteristics

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Abstract:** The atmospheric temperature in different regions of India is varying between 0℃ and 50℃, and because of this huge variation, it is not easy for the engine to operate under these adverse conditions. Therefore, it is very important to investigate the most suitable operating temperature for the engine to obtain the better performance and emission results. The purpose of this investigation is to analyze the problem experimentally to find the better engine performance and emissions levels by using three-cylinder four-stroke SI engine computerized test rig used ethanol–gasoline different blends as engine fuel i.e. blended rates 0%, 5%, 10%, 15%, and investigate the engine operating temperature levels at which performance emission level is better with different ethanol gasoline blended fuels. In this analysis, the operational parameters of a three cylinder, four-stroke gasoline engine such as brake power (bp), brake thermal efficiency (η_{th}) and brake specific fuel consumption (bsfc) have been experimentally investigated for different ethanol-gasoline blended fuels also examined emission characteristics such as hydrocarbons (HC) and nitric oxide (NO_x). These characteristics (bsfc) are measured with constant engine speed, different engine operating temperatures i.e., coolant temperatures and constant loads of dynamometer. The results obtained on performance and emissions of engine parameters at 3000 rpm with 12 Kg of dynamometer load, i.e., brake thermal efficiency (η_{th}), brake power (bp) and brake specific fuel consumption hydrocarbons (HC) also nitric oxide (NO_x) have presented graphically with respect to the coolant temperature of the engine. The present study showed that it is suitable to operate the engine at temperature 65°C-75°C for obtaining better performance and emissions indications for gasoline and ethanol gasoline blends.

***Keywords:** SI Engine, Ethanol, Gasoline, Blends, Specific Fuel Consumption & Brake Power, Emissions*

I. INTRODUCTION

In the current scenario, the engine's spark ignition (SI) design used by various manufacturers is not adapted to Indian weather conditions. India is one of the tropical countries where the temperature variations are enormous, from 0℃ to 50℃ in different parts of the country. Having found a variable temperature range, it is not easy to say which temperature is suitable for the operating conditions of an internal combustion engine (I C) and will provide the best emission performance levels. At present, researchers are facing a dual problem in the field of internal combustion engines, on the one hand reduced fuel consumption and on the other, compliance with the latest emission standards. Increasing demand and availability of fuel is a serious problem today. The development of automotive energy technologies contributes to the search for alternative fuels. Energy efficiency and emissions are a major problem for users, designers and manufacturers of internal combustion engines. The increase in air pollution is one of the most important problems in countries with a large number of motor vehicles, such as India. Exhaust emissions from cars play an important role in environmental pollution. There is little room to make engine design changes to comply with the latest emission regulations. It is therefore necessary to continue working with alternative fuel technologies. Alternative fuels such as LPG, CNG and bio-fuels are more useful in reducing exhaust emissions than conventional fuels [13]. It is important to replace environmentally friendly energy sources and this can only be possible from renewable resources that can be used directly without major modifications of the engine components. Ethanol is a pure substance. However, gasoline consists of hydrocarbons C4 to C12 and has many transit properties. Ethanol contains an oxygen atom considered a partially oxidized hydrocarbon [1]. Alcohol is completely mixed with water in all proportions and gasoline and water are not mixed. This could lead to water retention in the mixed fuel as well as corrosion problems in mechanical parts, particularly copper, brass or aluminum parts. Ethanol can cause corrosion problems to mechanical components, especially copper, brass or aluminum components. To reduce the problem with the fuel system, the following materials should be avoided [2]. Ethanol can react with most rubbers and create jam in the fuel pipe. Therefore, it is advised to use fluorocarbon rubber as a replacement [3].

Maintaining a clean environment in an industrial society has become an important issue. Air pollution due to automobiles is one of the important environmental problems that must be addressed. Fuel additives are important these days, as many of these can be added to fuel and increase their efficiency and productivity. Oxygen compounds (organic compounds containing oxygen) are among the most important additives to improve fuel efficiency [4]. Alcohol has been used as fuel for automobiles since the 19th century; however, it is not widely used because of its high price. As a fuel for spark-ignition engines, alcohol (methanol, ethanol) has several advantages over gasoline, such as improved anti-knock characteristics and reduced CO and HC emissions [5]. Despite these advantages, due to limited technology, economic and regional considerations, as well as alcohol-based fuels, still cannot be widely used. Ethanol is considered renewable energy because it can be fermented and distilled from biomass [1]. For environmental reasons, the use of ethanol blended gasoline fuel is better than methanol, because of its renewability and low toxicity. Based on economic and environmental considerations in India, we are interested in studying the effects of engine operating temperature on ethanol–gasoline blended fuel on the engine emissions. Alcohol can react with the most of rubber parts and create a jam in the fuel line. Therefore, it is recommended to use fluorocarbon rubber as replacement of rubber [3].

The heat transfer rate in the engine depends on the temperature of the coolant between the other variables and the size of the engine. There are complex interactions between many operating parameters. For example, as the engine cooling temperature decreases, the coolant increases the heat transfer and reduces the combustion temperature [5]. The properties of ethanol and petrol-based blended fuels according to the usual ASTM methods shows that, if the ethanol content increased, the heating value of the blended fuel decreased and the octane number increased.

Goodger [6] performed an experiment on SI engine at a fixed compression ratio using different hydrocarbon fuels; results showed that there was a 5% improvement in efficiency while using ethanol. Alternatively, the flash point and auto-ignition temperature of ethanol are higher than gasoline. Also, Ethanol has low Reid evaporation pressure which makes it easy and safer for transportation and storage [9, 10], it causes lower evaporative losses [7]. Al-Hasan [4] used various ethanol-gasoline blends from 0% to 25 % in increments of 2.5% to evaluate the performance and exhaust emissions of a 4-cylinder 4-stroke SI engine. The research indicated that the best performance and the lowest exhaust emissions were attributed to a 20% ethanol blend for all parameters measured and all engine speeds. Palmer [8] reported that all oxygen-enriched fuel blends gave the better anti-knock performance when accelerating at low speed compared to hydrocarbon fuels with the same octane range. Bayraktar [11] studied numerically and experimentally the effects of ethanol-gasoline blended fuels on the performance and emissions of a single cylinder, 4-stroke, SI engine. He used various ethanol-gasoline blends from 0% to 12% in increments of 1.5%. Experimental results showed that among different blends, the 7.5% ethanol-gasoline blend was the most adequate for performance of engine and less emission. Abdel et al. [10] performed an experiment using different ethanol-gasoline blended fuels (E10, E20, E30, and E40) on a variable-compression-ratio engine. They found that while increasing the ethanol content, the octane number shows an increasing trend, but reduces the heating value. The addition of 10% ethanol showed the most obvious effect on the octane increase.

Though, the literature review shows that the ethanol-gasoline blends can effectively reduce the emissions without a major modification of the engine design but the effect of engine operating temperature has not been considered to analyze the effect on engine exhaust emissions. Therefore, it has been investigated the effects of operating temperature (coolant temperature) on engine performance and exhaust emissions using different ethanol gasoline blends.

II. EXPERIMENTAL SETUP

A. Engine and Equipment

1) A computerized SI engine carburetor type test rig was used for present experimental work. This investigational test rig consists of three cylinders, four stroke, water cooled spark ignition engine. The engine has a swept volume of 800cm^3, a compression ratio of 9.2:1 and a maximum power of 27.6 kW at 5000 rpm. The engine was coupled to an eddy current dynamometer, which is equipped with an instrument cabinet fitted with a torque gauge and switches for the load control. This test rig also has various sensors and instrumentation integrated with computerized data acquisition system for online measurement of different parameters. Figure 1 (a) shows the photographic image of the experimental setup used in the laboratory to conduct the present investigation and Figure 1 (b) shows the schematic diagram and its instrumentation. Figure 1 (b) shows the photographic image of exhaust gas analyzer.

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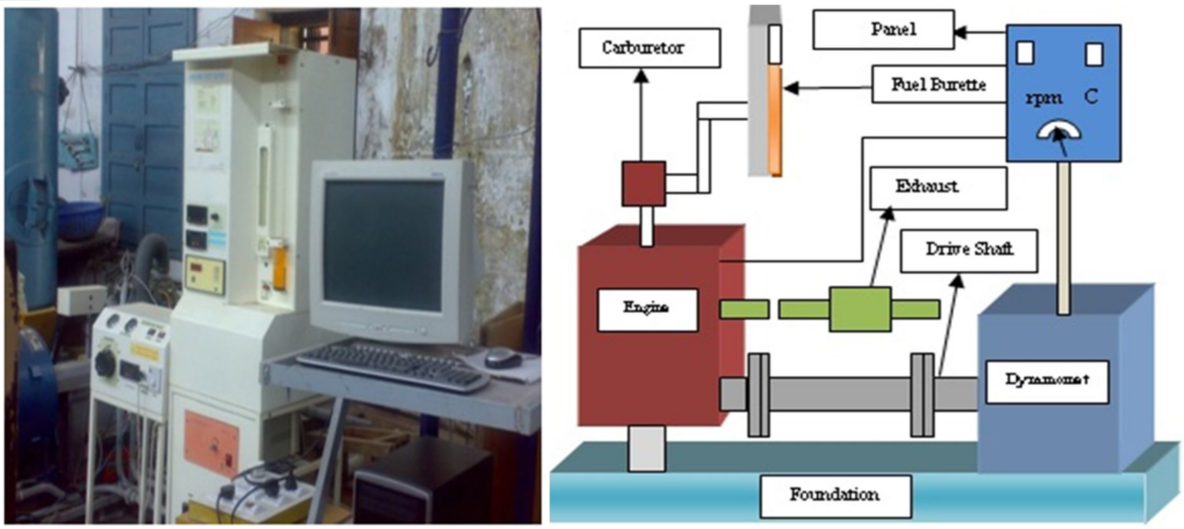

Figure 1. (a) Experimental Set up (b) Schematic diagram of engine set up

Figure 1(c) AVL exhaust gas analyzer

B. AVL Exhaust Gas Analyzer

1) In present research AVL exhaust gas analyzer (AVL Di gas 444- CDS model) is used to measure emissions. The percentage uncertainties, accuracy and measuring range are listed below

S. No.	Instrumentation	Measuring range	Accuracy	Uncertainty %
1.	Nitric oxides (NO_x) emission	0-5000 ppm	± 50 ppm	0.2
2.	Hydrocarbon (HC) emission	0-30000 ppm	± 15 ppm	0.2
3.	Carbon monoxide(CO) emission	0-10% volume	± 0.02% volume	0.2

2) An AVL exhaust gas analyzer (Di gas 444 CDS model) was used to measure CO, NO_x and HC emission from SI engine. It was calibrated by using leak test and HC residue test as per recommended standards and a filter paper was changed after every set of readings.

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C. Fuels

Four different fuel samples were experimentally investigated during this study. Ethanol with a purity of 99% was used for the preparation of the blends.

Table 1.Sample fuel properties

Property		Gasoline	Ethanol
Formula (liquid)		C_8H_{18}	C_2H_5OH
Molecular weight (kg kmol^{-1})		114.15	46.07
Density (kgm^{-3})		765	785
Heat of vaporization (kJ kg^{-1})		305	840
Specific heat (kJ kg^{-1} K^{-1})	Liquid	2.4	1.7
Specific heat (kJ kg^{-1} K^{-1})	Vapor	2.5	1.93
LHV (kJ kg^{-1})		44000	26900
Stoichiometric air–fuel ratio		15.13	9
Enthalpy of formation (MJ kmol^{-1})	Liquid	-259.28	224.1
Enthalpy of formation (MJ kmol^{-1})	Gas	-277	-234.6

The unleaded gasoline was blended with ethanol to get four test blends ranging from 0% to 15% ethanol with an increment of 5%. The fuel blends were prepared before starting the experiment to ensure that the fuel mixture is homogenous and to prevent the reaction of water vapor with ethanol.

III. EXPERIMENTAL RESULTS AND DISCUSSION

The performance parameters considered in the present study are Brake power, Brake specific fuel consumption and emissions (HC and NO_x) responding to coolant temperatures considered as engine operating temperature. Thermal Performance Evaluation is carried out in following two different experimental stages;

A. Gasoline as fuel at different coolant temperatures and loads.
B. Blends of Ethanol and gasoline as fuel at different coolant temperatures and loads.

The blends are prepared by directly mixing both the fuels in required proportions. Mixing is done with the help of a magnetic stirrer. Blends used are as follows;

1) E5: 5% ethanol and 95% gasoline
2) E10: 10% ethanol and 90% gasoline
3) E15: 15% ethanol and 85% gasoline.

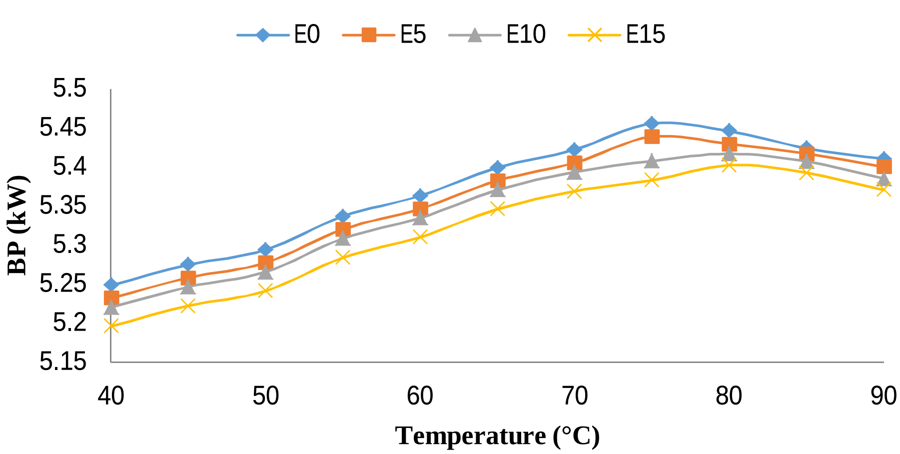

Figure 2. Brake power (BP) of E0, E5, E10, E15 with different coolant temperatures (T) at 12 kg load and 3000 rpm

Figure 2 shows the graph of brake power versus coolant temperature at part load (12kg) with 3000 rpm of engine speed. It has been observed that by incremental increase in engine temperature the brake power increases gradually upto 75°C for fuel E0 and E5 and

80°C for fuel E10 and E15 and then there is slight fall in the brake power (bp) at the engine temperature towards 90°C. The sharp increase in brake power (bp) is seen upto 75°C with respect to all fuels. The maximum brake power is 5.45 kW at 75˚C with gasoline, while with ethanol gasoline blend (E15); the maximum brake power is 5.40 kW at 80˚C. All fuels have minimum break power at 40˚C. It is also observed that blends decreased power in the whole temperature range by increasing the ethanol percentage.

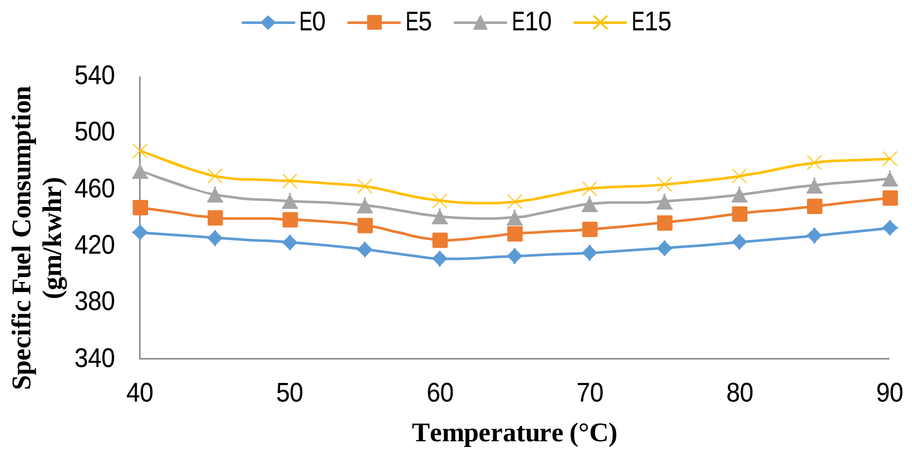

Figure 3. Specific fuel consumption (sfc) of E0, E5, E10, E15 with different coolant temperatures (T) at 12 kg load and 3000 rpm

Figure 3 represents the graph between specific fuel consumption (sfc) and coolant water outlet temperature at 12 kg dynamometer load with engine speed of 2000 rpm on the engine. It is seen from the graph that specific fuel consumption reduces with an increase in coolant temperature upto 60°C. This is attributed to the fact that there is a decrease in air density with increase in operating temperature due to which the bsfc decreases [12]. The decreasing trend is due to higher temperature results in better combustion of fuel. It is also observed that sfc is increased with increase in ethanol content in the blend at a constant temperature. The increment may be due to the calorific value of ethanol which is lower than that of gasoline. It is seen from the figure that SFC is minimum at 60°C, beyond which it shows an increasing trend up to 90°C for all fuels.

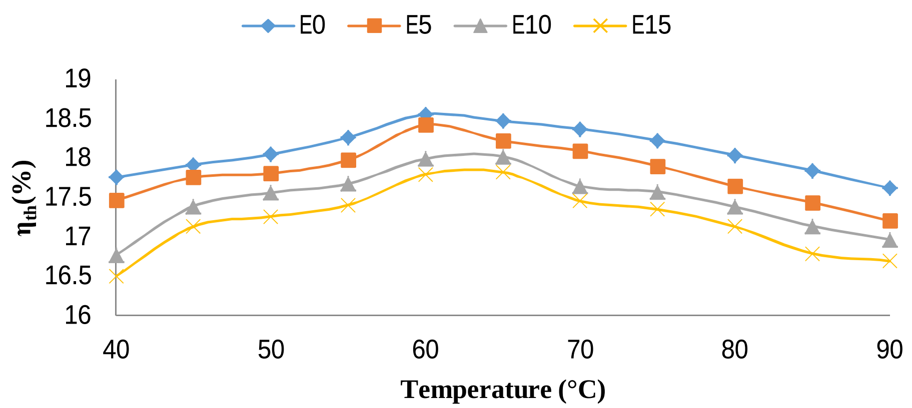

Figure 4. Brake thermal efficiency (ηth) of E0, E5, E10 and E15 with different coolant temperatures (T) at 12 kg load and 2000 rpm

Figure 4 represents the variation of brake thermal efficiency (η_{th}) for ethanol and its blends with gasoline with different operating temperatures at full load on the test engine. It can be observed from the graph, that brake thermal efficiency (η_{th}) for fuels E0 and E5 increases only up to 60°C with an increase in temperature, after 60°C brake thermal efficiency (η_{th}) shows decreasing trend up to 90°C. For fuels E10 and E15, It is observed that η_{th} is increases up to 65°C, after that decreases up to 90°C. It is also observed that brake thermal efficiency (η_{th}) for all fuels, decreased with an increase in ethanol content in the blend at a constant temperature. The decrease may be due to the higher viscosity of ethanol which hinders the fuel evaporation due to poor atomization during the combustion process.

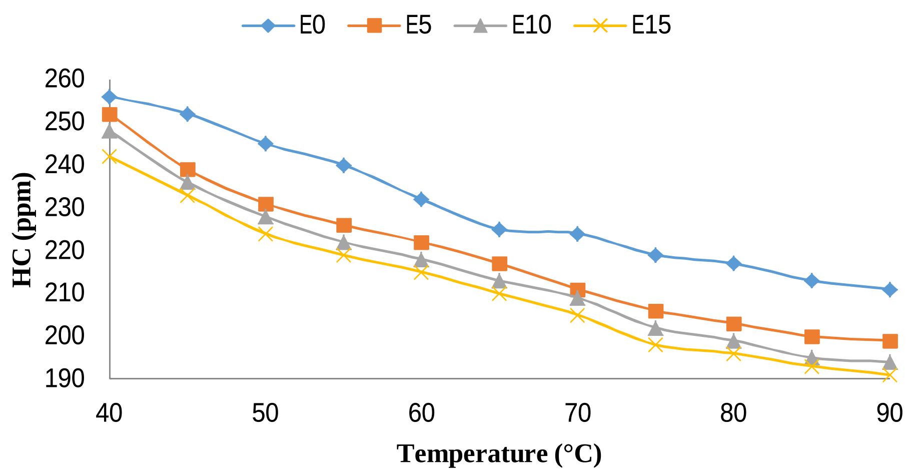

Figure 5. Hydrocarbon (ppm) of E0, E5, E10 and E15 with different coolant temperatures (T) at 9 kg load and 2000 rpm

Figure 5 presents the comparison of variation of HC emissions with engine coolant temperature and different ethanol gasoline blends at 9 kg of dynamometer load and 2000 rpm of engine speed. The unburnt hydrocarbons (HC) are generated in the exhaust as the result of incomplete combustion of fuel. Hydrocarbons cause eye irritation and choking sensations. They are major contributors to the characteristic of exhaust smell and also have a negative environmental effect, being an important component of smog. It can be observed from the figure that HC emissions decrease with increase in temperature for all the fuels tested. The trend observed may be due to complete combustion of fuel at higher temperatures. It is also observed that HC decreases with the increase in blend proportion. The trend may be due to better combustion of ethanol due to its oxygenated nature.

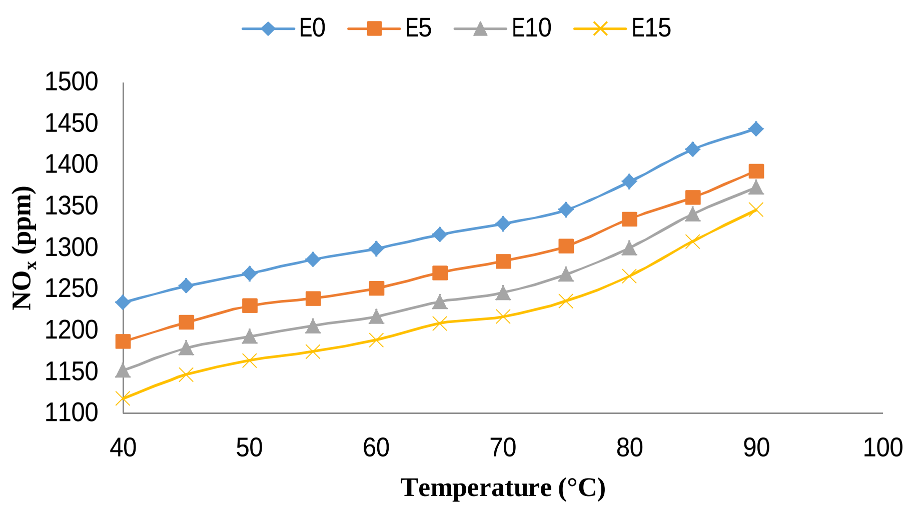

Figure 6. Nitric Oxide NOx (ppm) of E0, E5, E10 and E15 with different coolant temperatures (T) at 12 kg load and 2000 rpm

Figure 6 shows the graph of NO_x versus coolant temperature at full load (9kg) with 2000 rpm of engine speed. It is observed that the Nitric Oxide (NO_x) increases with the increase in temperature. As the temperature increases, Nitric Oxide increases may be due to the leaning effect of the blend. The maximum Nitric Oxide is 90˚C with gasoline, the minimum Nitric Oxide is 40˚C. The maximum Nitric Oxide occurs at temperature 90˚C for all fuels tested. It is also seen from the figure that the increase of ethanol percentage in the blends resulted in a decrease of Nitric Oxide the entire temperature range.
It can be observed from the figure that NO_x emissions increases for gasoline while it decreases for ethanol blends with increase in coolant temperature. The lower NO_x emission for ethanol blended fuels at lower temperature is because less oxygen is available from blends to form NO_x due to less heat. At higher temperature availability of oxygen for ethanol and higher heat increases the formation of NO_x.

IV. CONCLUSIONS

The experimental study is conducted on three cylinders, four-stroke, variable speed, water-cooled, spark ignition engine using ethanol blends with gasoline. The thermal performance was evaluated by running the engine at different combinations of engine loads varying from 12 kg, with various coolant temperatures at the exit from 40˚C to 90˚C.

A. Three cylinders, four-stroke, variable speed, water-cooled, SI engine originally designed to operate on gasoline as fuel can also be operated on ethanol-gasoline blends without any system hardware modifications.
B. Based on the observations pertaining to the effect of coolant temperature on the engine brake, it can be concluded that the brake power of SI engine using fuel E0, tends to increase upto 75℃, followed by decreasing tend till 90℃.
C. It is also seen that the brake power of SI engine operated using different gasoline ethanol blends (E5, E10, and E15) tends to increase upto 80℃ after that brake power decreases.
D. The specific fuel consumption shows minima at operating temperature of 60℃ for fuels E0 and E5. For the fuels E10 and E15, the minima of specific fuel consumption shifted to 65℃.
E. The increase of ethanol percentage in the blends resulted in a decrease of brake power over the entire temperature range attributed to the fact that the higher viscosity and lower heating value of ethanol reduce brake power.
F. A significant reduction in hydrocarbon emissions was observed due to the leaning effect and additional oxygen in the fuel resulting from the addition of ethanol.
G. A reduction in NO_x emissions was achieved with the addition of ethanol because of the high latent heat of evaporation of ethanol.
H. The 15% ethanol fuel blend gave the best results of the engine exhaust emissions.
I. The best emissions results were obtain between 50℃ to 70℃ for all fuel blends hence the engine operating temperature also plays an important role in exhaust emissions.

Based upon the performance characteristics of SI engine under investigation it is inferred that engine should operate between 65℃ and 70℃ of coolant temperature for gasoline and different ethanol gasoline blends. This experimental result shows that there is a requirement to think about modifications in existing engine cooling system design as per India's climatic condition.

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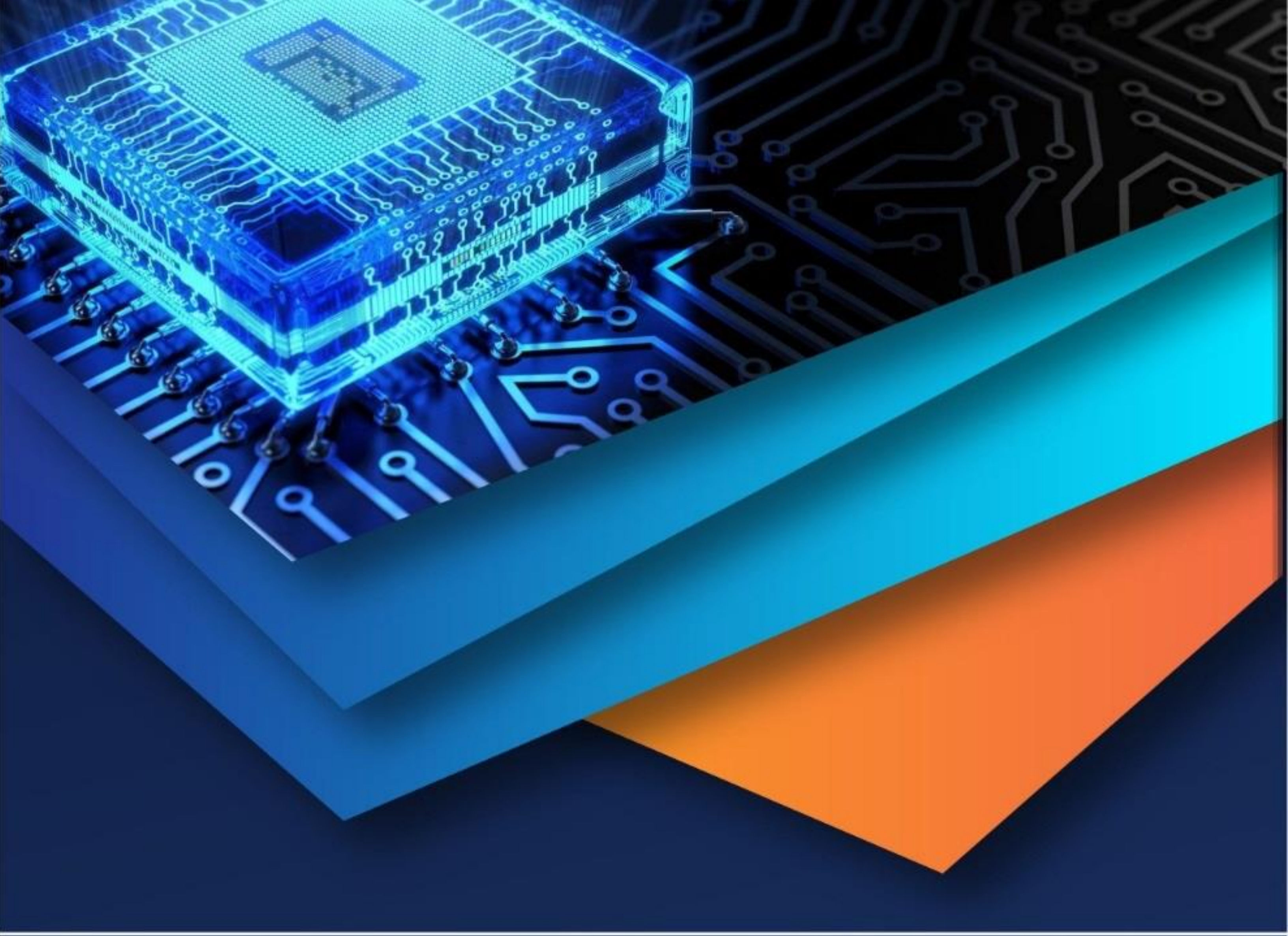

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