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Investigations of Super Premium Octane Rating Ketone-gasoline Blends Fuelled Spark Ignition Engine Characteristics

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ABSTRACT

The present investigation is focused on investigating the engine characteristics of ketone-gasoline blends (super premium octane rating) in spark ignition engine. Ketones are oxygenated chemicals, which have higher octane ratings. Ketone-gasoline blends were formulated to match the research octane number of commercially available super premium gasoline. 2-Butanone-gasoline blend, and 4-Methyl-2-pentanone-gasoline blend were formulated for spark ignition engine investigations on a volume basis. The results of formulated fuels were compared with the commercially available gasoline. Engine experiments were conducted with selected ketone-gasoline blends in spark ignition engine at varying engine speed i.e. 1500 rpm, 2500 rpm, and 3500 rpm. At 2500 rpm engine speed condition, the brake thermal efficiency was higher and brake-specific fuel consumption was comparatively lesser than 1500 rpm and 3500 rpm engine speed conditions for all tested fuels. At 2500 engine speed condition, the brake thermal efficiency of 2-Butanone-gasoline blend and 4-Methyl-2-pentanone-gasoline blend blends were comparable with the brake thermal efficiency of super premium gasoline (30%).Carbon monoxide and nitrogen oxides emissions for2-Butanone-gasoline and 4-Methyl-2-pentanone blends were found lower than gasoline.

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Abbreviations

4M2P-G	:	4-Methyl-2-pentanone gasoline blend
B-G	:	2-Butanone-gasoline blend
BSFC	:	Brake specific fuel consumption
BTE	:	Brake thermal efficiency
CO	:	Carbon monoxide
LHV	:	Lower heating value
NHR	:	Net heat release
NO_x	:	Nitrogen oxides
RON	:	Research octane number
rpm	:	Revolution per minute
SI	:	Spark ignition

1. Introduction

Internal combustion engines are commonly used in automotive, power-generation, agricultural , and construction sectors [1]. In a county like India, vehicle growth has increased significantly due to the rapid increment in the population [2]. Energy plays an essential role in the development of economic growth for countries [3]. The fossil fuel reserves are depleting at a faster rate [4]. Economic sectors like transportation, industry, agriculture, and power generation are dependent on fossil fuels [5]. The combustion of these fuels increases environmental pollution. The transportation sector primarily using fossil fuels and is among one of the major contributors to air pollution [6,7]. Biomass-derived biofuels can be promising solutions due to their renewable nature and low carbon footprint [8]. The use of biofuels for transportation sector helps in decreasing the dependency on fossil fuels and reduces greenhouse emissions [9][10]. Ketones are potential substitute for gasoline due to their higher knock resistance, higher RON and other comparable properties as gasoline [11][12]. High anti-knock quality of fuel is attractive to reduce knocking in modern SI engines [13]. Ketone can widely reduce the gasoline use from transportation systems (automobiles, motorcycles, agricultural equipment, boats, forestry aircraft, etc.) and other chemical fields (paint, grease, synthetic rubber, etc.) [14]. McCormick et al. [15] measured and presented the RON number of bio-derived ketone chemicals. The authors reported the RON number of 2-Butanone and 4-Methyl-2-pentanone as 111 and 105.7 respectively. Pentanone is one of the biofuels, which can be produced from cellulosic biomass [16]. 2-Butanone (also known as methyl ethyl ketone) can be produced from biomass through hybrid biological or chemical pathways [17] and also produced through dehydration of 2,3-butanediol [18]. Due to its favorable properties as a fuel for SI engines, 2-Butanone is the future promising biofuel to be used with the blending in SI engines [19]. Hoppe et al. [19] reported improved combustion characteristics for 2-butanone than ethanol and gasoline. Butanone is one of the competitive chemicals to ethanol [20]. Lemaire et

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al. [21] formulated gasoline blends with ethanol, 1-butanol, butanone, butanal, and methyl propionate blends in volume percentages of 10%, 20%, and 40%. These formulated blends were tested in the direct-injection SI engine with 2000 rpm speed and 3.5 bar brake mean effective pressure. They reported oxygenated fuel-gasoline blends increased specific fuel consumption due to lower heating value of oxygenated fuels. The emissions such as nitrogen oxides (NOx) and particulate matter decreased with the increase in oxygen quantity in tested blends [21]. Hoppe et al. [22] reported higher knock resistance characteristics for 2-Butanone and 2-methyl furan than commercially available 95 RON gasoline in SI engine. The high octane rating of 2-butanone helps in higher efficiency gain.

The aim of the present investigation is to investigate the performance, combustion, and emission characteristics of super premium level (RON-100) ketone-gasoline blends (B-G and 4M2P-G) and super premium commercially available gasoline in a three-cylinder four-stroke variable speed SI engine. The formulated ketone-gasoline blends target RON is 100. The SI engine experiments were conducted with varying engine speed (1500 rpm, 2500 rpm, and 3500 rpm). The engine characteristics (performance, emission, and combustion) of ketone-gasoline blends were compared with engine characteristics of super premium gasoline. The present study is essential to predict the optimum blend or fuel (among tested super premium level blends/fuel) in terms of better performance and lower emissions by varying engine speed.

2. Experimental Setup and Methodology

A water-cooled eddy current dynamometer, flue gas analyzer (Testo-350), and Engine-soft LV data acquisition software were connected with a multi-point fuel injection SI engine, and this fixed bed SI engine tests set-up was used for experimental investigations (refer Fig. 1). The SI engine specifications are provided in Table 1. Eddy current dynamometer and load cell were used for engine loading. The load was monitored by a digital load indicator. For cooling purposes, a constant water supply was maintained to the water jacket of the engine and dynamometer through water pump. The water supply to the engine and dynamometer was checked by using water rotameters. The engine set-up consists of a piezo-sensor, data acquisition device, crank angle sensor, temperature sensor, fuel-flow transmitter, air-flow transmitter, temperature transmitter, rotameter, etc. These sensors are interfaced with Engine-soft LV software and this software was used for performance and emissions characteristics data acquisition.

Kline and Mc Clintock approach was used for evaluating the uncertainties in experimentation [23]. The evaluated SI engine test set-up error is 1.5%. Testo-350 flue gas analyzer was used for the exhaust emissions measurement. The properties of tested blends and fuel are provided in Table 2. The engine experiments were conducted with varying engine speeds (1500, 2500, and 3500 rpm). The performance characteristics (BTE and BSFC), emission characteristics (CO and NO_x), and combustion characteristics (cylinder pressure with crank angle position, and net heat release rate with crank angle position) of ketone-gasoline blends were compared with super premium gasoline engine characteristics.

Table 1. SI Engine specifications

Engine part	Specifications
Fuel injection	Multi-point fuel injection
Engine cylinders and stokes	Three cylinders and four strokes
Engine cylinder diameter	66.5 mm
Stroke length	72 mm
Connecting rod length	114 mm
Compression ratio	9.2:1
Dynamometer arm length	210 mm

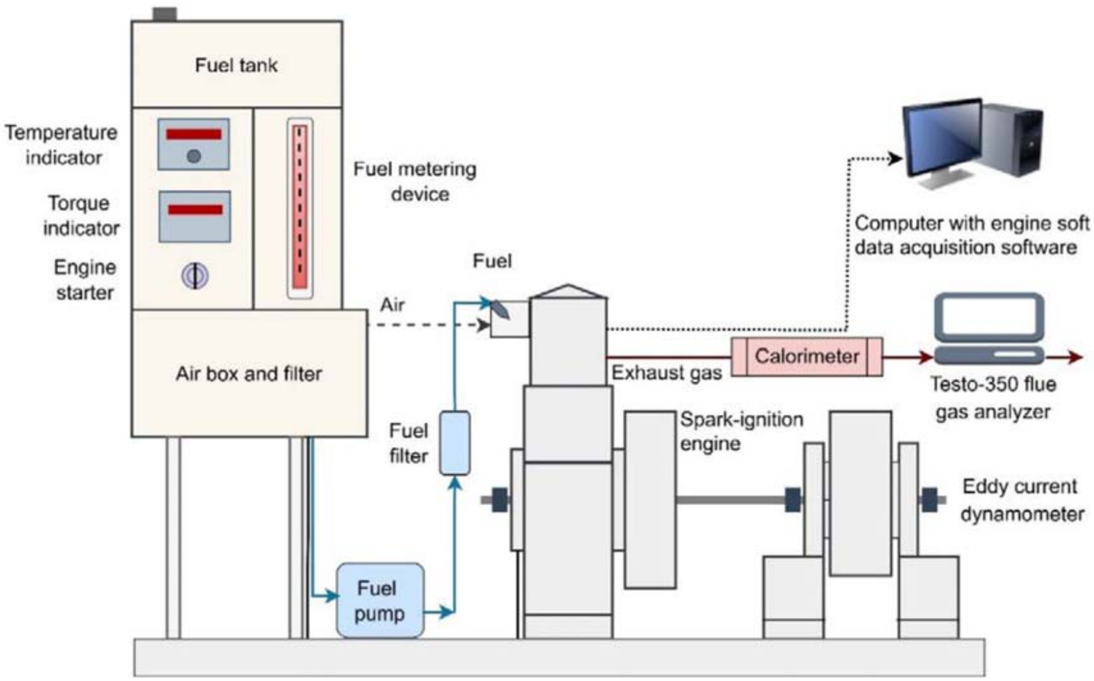

Fig. 1. Fixed bed SI engine experimental test set-up

Table 2. Properties of tested blends and fuel

Fuel/Blend	Composition	Lower heating value	Density	RON
2-Butanone-premium gasoline blend	31.25% 2-Butanone + 68.75% premium gasoline	39370	767	100
4-Methyl-2-pentanone-premium gasoline blend	46.73% 4-Methyl-2-pentanone + 53.27% premium gasoline	38900	773	100
Super premium gasoline	-	43000	752	100

3. Results and Discussion

3.1 Performance characteristics of SI engine

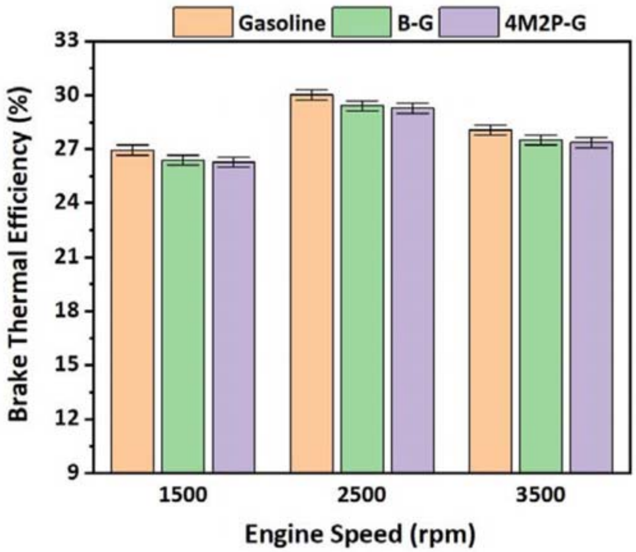

Fig. 2. Variation of BTE with engine speed

Figure 2 shows the BTE for tested ketone-gasoline blends and gasoline at variable engine speed conditions. BTE is defined as the ratio of generated brake power to fuel energy [24]. Fuel consumption and brake power generated by the ketone-gasoline blends and gasoline increase with the increase in engine speed from 1500 rpm to 3500 rpm. BTE of tested ketone-gasoline blends increase with the increase in engine speed from 1500 rpm to 2500 rpm, as the lesser effect of heat transfer from the engine combustion chamber and relatively higher motion of the air-fuel mixture are the dominant factor up to 2500 rpm speed [25]. The BTE of ketone-gasoline blends and gasoline decrease from 2500 rpm to 3500 rpm engine speed condition due to inadequate air-fuel mixing as the time available for air-fuel mixture formation was shorter [25]. At 2500 engine speed condition, the BTE of B-G (29.43%) and 4M2P-G (29.28%) blends, were comparable with the BTE of super premium gasoline (30%).

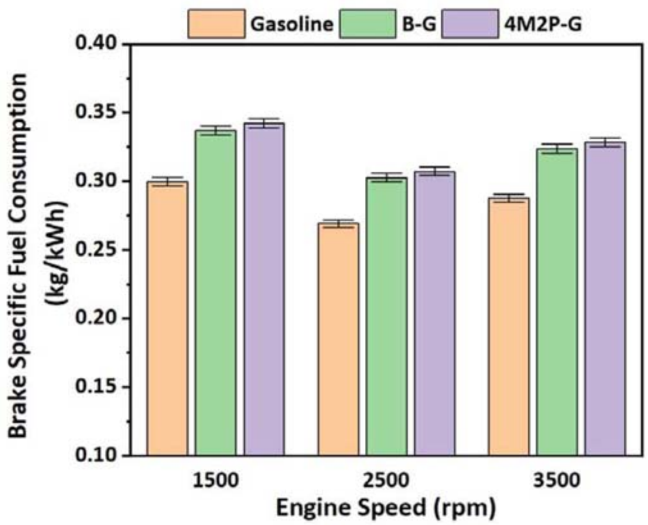

Fig. 3. Variation of BSFC with engine speed

The variation of BSFC with engine speed for ketone-gasoline blends and gasoline is shown in Fig. 3. BSFC is the ratio of consumed fuel mass flow rate and brake power. BSFC values for ketone-gasoline blends and gasoline were lower at 2500 rpm engine speed condition than 1500 rpm and 3500 rpm engine speed condition. At 2500 rpm engine speed condition, BSFC of tested ketone-gasoline blends (B-G: 0.303 kg/kWh and 4M2P-G: 0.307 kg/kWh) were higher than BSFC of gasoline (0.2696 kg/kWh) due to higher fuel mass flow rate of ketone-gasoline blends than gasoline and equal brake power were generated for ketone-gasoline blends and gasoline.

3.2 Emission characteristics of SI engine

CO emission is one of the harmful emissions, and generated in higher amount during fuel combustion in the engines due to engines being operated with a rich air-fuel mixture [26]. The formation of CO emissions is one of the indications of incomplete combustion. The variation of CO emissions with engine speed condition is shown in Fig. 4. For ketone-gasoline blends and gasoline, CO emissions were slightly lower at 2500 rpm engine speed condition than at 1500 rpm and 3500 rpm engine speed conditions. At 2500 rpm engine speed condition, CO emissions of ketone-gasoline blends (B-G: 15.4 g/kWh and 4M2P-G: 14.7 g/kWh) were lower than CO emissions of gasoline fuel (17.1 g/kWh).The presence of oxygen content in ketone-gasoline blends may help in reduction of CO emissions.

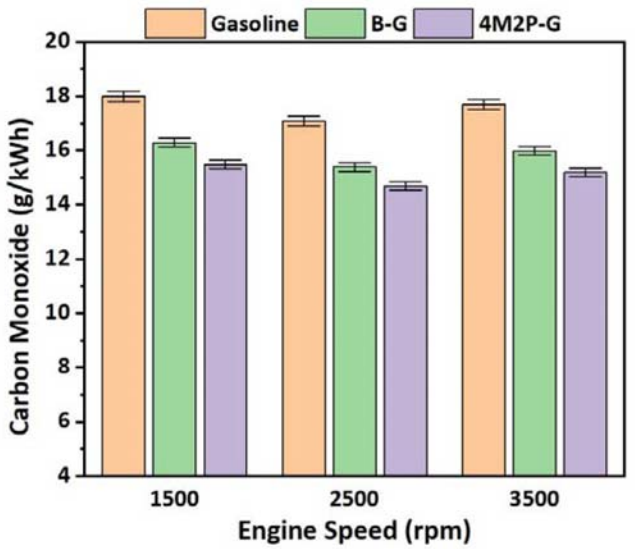

Fig. 4. Variation of CO emissions with engine speed

NO_x emissions variation with engine speed is plotted (see Fig. 5). NO_x emissions for ketone-gasoline blends and gasoline increase with the increase in engine speed from 1500 rpm to 3500 rpm. NO_x generation is related to the engine inside cylinder combustion temperature [27]. The intake air diatomic nitrogen (N_2) was dissociated in monoatomic nitrogen in the engine cylinder at a higher temperature, and NO_x emissions formation happens with the reaction of monoatomic nitrogen with available oxygen during the combustion process [28]. At 3500 rpm engine speed condition, NO_x emissions were lower for tested ketone-gasoline blends than NO_x emissions for gasoline fuel.

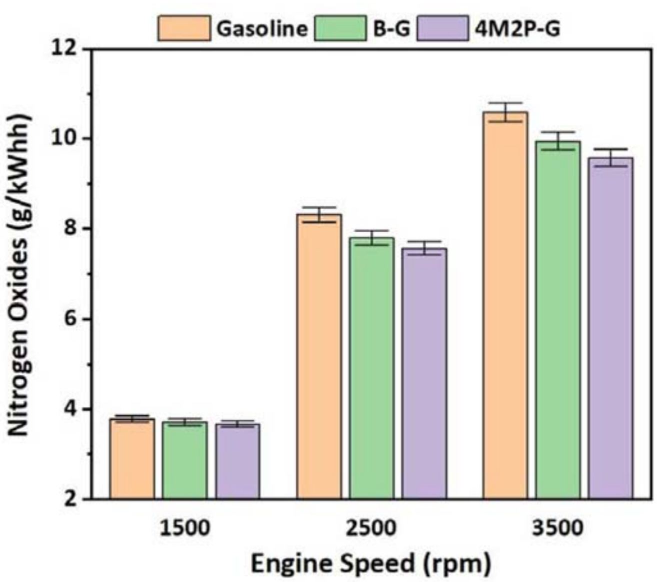

Fig. 5. Variation of NO_x emissions with engine speed

3.3 Combustion characteristics of SI engine

As per the performance characteristics and emission characteristics of ketone-gasoline blends and gasoline at 2500 rpm engine speed condition seems to be more promising than 1500 rpm and 3500 rpm engine conditions, hence combustion characteristics such as cylinder pressure with crank angle position and net heat release rate (NHR) with crank angle position are discussed for 2500 rpm engine speed condition for ketone-gasoline blends and gasoline.

Figure 6 shows the comparison of inside cylinder pressure for tested ketone-gasoline blends and gasoline at 2500 rpm engine speed condition.. For tested ketone-gasoline blends and gasoline fuel, inside engine cylinder pressure increases immediately after the start of the combustion until peak cylinder pressure. The peak cylinder pressure value for gasoline (46.95 bar) is higher than the peak cylinder pressure value for ketone-gasoline blends (B-G: 43.5 bar and 4M2P-G: 43.06 bar) Ketone-gasoline blends have a higher oxygen content and latent heat of vaporization compared to gasoline, resulting in a greater charge cooling effect in an engine fueled with ketone-gasoline blends as opposed to a gasoline engine. Moreover, the LHV for ketone-gasoline blends is lower than the gasoline (see Table 2). After the peak cylinder stage inside cylinder pressure decrease in the afterburning phase (peak cylinder pressure to end of combustion stage).

The NHR with crank angle position for tested ketone-gasoline blends and gasoline is shown in Fig. 7. The peak NHR value of gasoline (51.39 J/deg) is slightly higher than the NHR of ketone-gasoline blends (B-G: 47.6 J/deg and 4M2P: 47.13 J/deg) due to the higher LHV value of gasoline than the ketone-gasoline blends. Heat release occurred during power or expansion stroke. The heat release rate in the engine cylinder is responsible for higher frequency combustion noise arising from the engine[29].

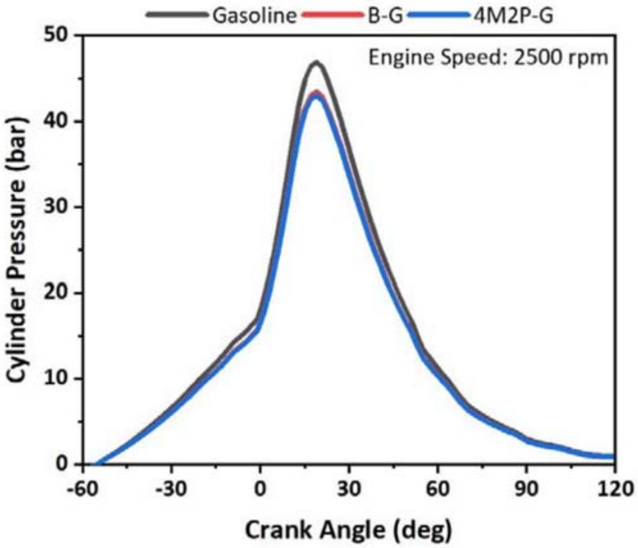

Fig. 6. Cylinder pressure with crank angle position

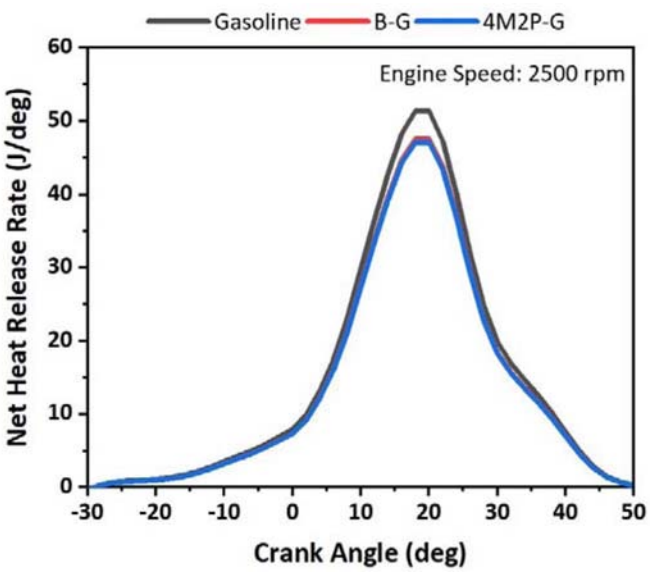

Fig. 7. Net heat release rate with crack angle position

4. Conclusions

Super premium octane ketone-gasoline blends fueled SI engine characteristics were studied with varying engine speed. BTE of B-G (29.43%) and 4M2P-G (29.28%) blends, were comparable with the BTE of super premium gasoline (30%), but the BSFC of selected blends were higher than BSFC of super premium gasoline due to lesser lower heating value. At 2500 engine condition, CO emissions of B-G (14.7 g/kWh) and 4M2P-G (15.4 g/kWh) blends were lower than super premium gasoline (17.1 g/kWh). Oxygen content in tested ketone-gasoline blends helps in the reduction of CO emissions. NO_x emissions were increased with an increase in engine speed. NO_x emissions of ketone-gasoline blends were lower gasoline due to lesser combustion temperature. Combustion characteristics such as cylinder pressure and NHR rate of gasoline are found promising for tested ketone-gasoline blends. It can be concluded that the ketones are effective in reducing harmful emissions without compromising the engine performance. Hence, ketones blends have capability to use in place of super premium gasoline. The tested ketone-gasoline blends and gasoline both have a research octane number of 100. Consequently, the tested ketone-gasoline blends are also compatible with higher compression ratio SI engines. Based on the present investigations, it is recommended that the tested ketone-gasoline blends show promise as an alternative fuel to gasoline in sustainable transportation applications.

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