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# Experimental study on performance, combustion, and emission behaviour of diisopropyl ether blends in MPFI SI engine

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## HIGHLIGHTS

- Effect of adding diisopropyl ether oxygenate with gasoline in four-cylinder MPFI engine was performed.
- Addition of diisopropyl ether decreased 27.67% hydrocarbon and 25% carbon monoxide emissions.
- Oxygenate improved thermal efficiency by 3.56%.
- Change in ignition timing from 14 °bTDC to 12 °bTDC decreased NOx value from 5319 ppm to 4512 ppm.
- DIPE-gasoline blend produced higher in-cylinder pressure and heat release rate.

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## ABSTRACT

In this study, the effects of diisopropyl ether (DIPE)-gasoline (D10, D20, and D30) fuel blends on the performance, combustion, and emission characteristics of a spark ignition engine were investigated. In the study a four-stroke, four-cylinder multi-point fuel injection system (MPFI) engine with an eddy current dynamometer was used. The tests were performed at speeds between 1400 rpm and 2800 rpm under the load conditions of 20 N m and 25 N m. The results obtained from the DIPE-gasoline blends were compared with gasoline fuel. The DIPE-gasoline blends produced higher brake thermal efficiency, in-cylinder pressure, and heat release rates as compared to gasoline fuel. From emission point of view hydrocarbon (HC) and carbon monoxide (CO) emissions were found lesser, whereas carbon dioxide ($CO_2$) and nitrogen oxide (NOx) emissions were observed higher in case if DIPE-gasoline blends compared to gasoline. However, retarding the ignition timing resulted in reduced NOx emission in DIPE-gasoline blends.



## 1. Introduction

Usage of clean fuel for transportation and power generation sectors is the worldwide prerequisite from the point of view of environmental protection and sustainable growth. A large part of the energy consumed worldwide is utilized by the automotive sector; road transportation depends mainly on fossil fuels, resulting in economic and environmental consequences [1]. The transport sector is the single largest consumer of petroleum products [2]. Engine emissions are the main contributors to air pollution problems in both developed and developing countries. Vehicles contribute about 50% of the total emissions worldwide [3]. In India vehicles in major metropolitan cities are estimated to account for 70% of CO, 50% of HC, 30–40% of NOx, 30% of solid particulate matter (SPM), and 10% of sulphur dioxide ($SO_2$) of the total pollution load of these cities, of which approximately 67% is contributed by two wheelers alone [4].

Currently, research attention is focused on reducing exhaust emissions from spark ignition (SI) engines because of their higher popularity in automotive sectors owing to high acceleration capabilities, better comfort, quieter operation, and relatively cheaper initial purchase cost [5]. Combustion fluctuations in a spark ignition engine influence the emission of HC, CO, $CO_2$, NOx, and PM and contributing the greenhouse effect [6]. The formation of CO, HC, and NOx are varying with air–fuel equivalence ratio relative to unity and the combustion temperature. While CO and HC arise as products of incomplete combustion in a rich mixture, NOx formation is most rapid at high temperatures with sufficient levels of oxygen. With a lean mixture, the combustion temperature drops so that NOx emissions fall off and HC emissions increase [7].

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Exhaust treatment control devices have been used to reduce pollution, but have resulted in a reduction of about 15% in vehicle mileage. Therefore, suitable 'clean-burning' fuels must be chosen in spark ignition (SI) engines to reduce the emissions and increase the performance [8]. In the transport sector, biofuels can be good substitutes for fossil fuels, because they can be directly used without modifying the engine and fuelling processes [9].

More-efficient engine technology options require higher octane ratings in line with the goals of reducing greenhouse gas (GHG) emissions and fuel consumption. These important changes in the fuel/vehicle landscape warrant a re-evaluation of gasoline octane ratings [10]. SI engine fuel (Gasoline) is indexed mainly with respect to octane numbers; research and motor octane numbers (RON, MON), which indicate the quality characteristics of gasoline with respect to anti-knocking behaviour. The higher the octane number, the better the gasoline resists detonation and smoother the engine runs. The octane rating is one of the important parameter for determining the fuel quality and this influence the engine performance and emissions [11,12]. Oxygenates are used by refiners not so much as crude oil supplements but rather as an important and much needed sources of octane. The elimination of lead as an anti-knock compounds from gasoline, due to legislations, compelled to find out an alternate option for octane enrichment [13]. The addition of oxygenate to gasoline is considered as an effective method for fuel octane enhancement and reduction of engine carbon monoxide (CO) and hydrocarbon (HC) emissions.

The advantages of adding oxygenates to gasoline are that the fuel burns more cleanly and leaves fewer deposits, opportunity to operate the engine with high compression ratio (CR) without knocking, and increase the engine horsepower due to increased octane number [14–16]. Positive effects of higher RON have been realized in engines with higher CR and with turbocharged intakes. A study on a high CR (13.0:1) spark ignition direct injection (SIDI) engine showed that a high RON fuel with high aromatics content resulted in significant torque improvement under high loads. Higher CR engine produced 13% higher torque and 21% higher efficiency as compared to the original engine with CR of 9.8:1 [17]. Palmer [18] studied the effect of ethanol addition to unleaded gasoline. The results show that addition of ethanol to unleaded gasoline increases research octane number by 5 units for each 10% ethanol addition. The study also shows that 10% ethanol addition in gasoline as a fuel additive improves the engine power by 5%. Shenghua et al. [19] conducted experiments in a three-cylinder engine with gasoline and methanol–gasoline blends. Methanol was blended in proportions of 10%, 15%, 20%, 25%, and 30% with gasoline. The results show that increasing the methanol ratio in the gasoline decreased the engine torque and power, but brake thermal efficiency (BTE) was increased. The study also revealed decreasing trend in HC, CO, and NOx emissions with methanol–gasoline blends. Farkade and Pathre [20] studied the effect of methanol, ethanol and butanol addition to gasoline on blending percentage and oxygen percentage in the blend. The results show that presence of oxygen gives more desirable combustion resulting into lower CO, HC emissions and higher emissions of $CO_2$ as a result of complete combustion.

Gravalos et al. [21] studied the effect of addition of alcohol blends (1.9% methanol, 3.5% propanol, 1.5% butanol, 1.1% pentanol, and various concentrations of ethanol) with gasoline in a single-cylinder SI engine. A total of 30% alcohol was blended into the gasoline. The study observed that alcohol–gasoline blend emits less CO and HC but more NOx and $CO_2$ compared to pure gasoline. Georgios Karavalakis et al. [22] examined the effects of different ethanol and iso-butanol blends on the gaseous and particulate emissions from two passenger cars equipped with spark ignition direct injection engines and with one spray-guided and one wall-guided configuration. The results show that emissions of THC (total hydrocarbons), NMHC (non-methane hydrocarbons), and CO (carbon monoxide) reduced with increasing oxygen content in the blend for some of the vehicle/fuel combinations, whereas NOx (nitrogen oxide) emissions did not show strong fuel effects. The higher ethanol and butanol blends showed reductions in PM (particulate matter) number, and soot mass emissions. He et al. [23] compared the combustion characteristics of n-butanol and ethanol with gasoline in a single-cylinder port-fuel-injection gasoline engine with a fixed intake/exhaust valve. At 1500 rpm with the same inlet-valve-open (IVO) timings and alcohol volume fraction, earlier auto-ignition was observed for n-butanol–gasoline blends compared to ethanol–gasoline blends. The combustion durations of n-butanol–gasoline blends were shorter than that of ethanol–gasoline blends. Qian Yejian et al. [24] investigated the effect of ethanol–gasoline blends in the MPFI engine and reported decrease in HC, NOx, and CO emissions of 45.3%, 58.1%, and 18.8%, respectively compared to plain gasoline. Jing Yang et al. [25] studied the effect of butanol on single cylinder high speed SI engine by 30% and 35% blends in volume basis under full load and partial load conditions at two different speeds of 6500 and 8500 rpm. Good results were observed in terms of higher engine performance and lower emissions with 35% blend. Varol et al. [26] compared the effect of adding methanol, ethanol, and n-butanol in gasoline with pure gasoline in terms of exhaust emissions and performance in a four stroke four-cylinder SI engine. The study found that blends with different alcohols produced lower carbon monoxide and hydrocarbon emissions. The higher fuel consumption rates and $CO_2$ emissions were also observed. Gravalos et al. [27] compared the effect of adding lower and higher molecular mass alcohol with gasoline in a non-road spark ignition engine. Methanol blends resulted in good combustion efficiency with low CO and HC but high $CO_2$ emissions; ethanol blends did not produce extreme emissions values and their level of NOx emissions was much lower than that of methanol–gasoline blends; propanol blends produced similar results to that of ethanol blends. Butanol blends in several cases produced lower emissions compared to ethanol and propanol blends. The emissions obtained from pentanol–gasoline blends were similar with neat gasoline.

From this literature review, it is concluded that the use of oxygenates enhances the combustion process, increases the performance of the engine and gradually reduces CO and HC emissions as a result of complete combustion of the fuel. Diisopropyl ether (DIPE) is one of the best oxygenate additives from the ether family with a potential to blend with gasoline due to its favourable properties. DIPE ($C_6H_{14}O$) provides higher octane number compared to gasoline. The higher octane number in the DIPE provides an opportunity to operate the engine with high compression ratio and improves its performance. Less number of experimental works in the area of combustion and emissions of DIPE-gasoline blends in the MPFI engines are available in the literature. In this regard the present study aims to find out the effect of adding oxygenate, DIPE, with gasoline on the performance, emission and combustion characteristics of multi cylinder MPFI engine.

## 2. Experimental method and apparatus

### 2.1. Experimental setup

The tests were performed in a four-stroke, four-cylinder water cooled MPFI engine. The specifications of the test engine are given in Table 1. The engine has a 72 mm bore and 61 mm stroke with a compression ratio of 9.4:1. The engine with other components and it's inter connections are schematically shown in Fig. 1.

An eddy current dynamometer with a maximum loading capacity of 45 N m was used to load the engine. Fuel flow was measured gravimetrically using an electronic balance (strain gauge measure-