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# The effects of research octane number and fuel systems on the performance and emissions of a spark ignition engine: A study on Saudi Arabian RON91 and RON95 with port injection and direct injection systems

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ABSTRACT

This research aims to experimentally analyze the performance and emissions of a single cylinder, four-stroke spark ignition (SI) engine fuelled by two grades of gasoline used in Saudi Arabia, RON91 and RON95 while operating with two fuel delivery systems; port injection (PI) and direct injection (DI). The experiments were conducted on a single cylinder research engine with pent-roof type cylinder head that can be interchangeably operated with either port injection or direct injection. Brake power, brake specific fuel consumption (BSFC) and exhaust emissions were measured at different engine speeds, loads and fixed compression ratio of 10:1. Cylinder pressure, mass burnt fraction and rate of heat release were analyzed. The experimental results showed that the brake power of the engine is higher with RON91 which is mainly due to higher heating value. The BSFC decreases with increasing in engine load and it increases with increasing engine speed. However, there are no noticeable differences between two tested gasoline fuels in the BSFC except at high speed and load, where BSFC of RON91 is higher than RON95. Combustion analysis showed a mixed response to different RON and fuel systems. Generally, combustion of RON95 is faster than RON91 in both PI and DI systems. In DI system, RON95 showed longer combustion duration at low speed and load. The concentrations of nitrogen oxides ($NO_X$), carbon monoxide (CO) and total hydrocarbon (THC) emissions in the exhaust system were measured. It is observed that $NO_X$ emissions of RON91 are higher than RON95 in most cases except at high engine speed with DI system. It is also detected that CO emissions of RON91 are higher than RON95 in both injection systems at higher load. It is also noticed that RON91 system has higher THC emissions.



## 1. Introduction

The internal combustion engine, powering 90% of world vehicles, is the main driver in the transportation sector from which 20% of total world energy is consumed. The engine performance, thermal efficiency and pollutant emissions have a significant impact extending to the environment. Local and global environmental concerns include increased emitted concentrations of carbon dioxide ($CO_2$), carbon monoxide (CO), hydrocarbons (HC), and nitrogen oxides ($NO_X$) that are threats to air quality and contribute to climatic warming.

Emissions from the transportation sector are considered a cause of Green House Gases (GHG's) and account for more than 30% of global $CO_2$ emissions while consuming 63% of petroleum products [1]. In Saudi Arabia, a study estimated the annual emission of $NO_X$ per fuel type and their relative contribution to total emissions in the kingdom is shown in Table 1. In comparison to emissions levels reported by several countries in the developed world, the Saudi

*Abbreviations:* AFR, air-fuel ratio; ATDC, after top dead center; BTDC, before top dead center; BSFC, brake specific fuel consumption ; CO, carbon monoxide; EVO, exhaust valve open; EVC, exhaust valve closed; DI, direct injection; HCCI, homogeneous charge compression ignition; IC, internal combustion; IVO, intake valve open; IVC, intake valve closed; MBF, mass burnt fraction; MBT, maximum brake torque; MON, Motor octane number; $NO_X$, nitrogen oxides; PI, port injection ; RON, Research octane number; ROHR, rate of heat release; SI, spark ignition; SCRE, single cylinder research engine; THC, total hydrocarbon emissions.

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**Table 1**
Annual emission of $NO_X$ from different fuels in Saudi Arabia [4].

| Fuel type | $NO_X$ emission (%) |
|---|---|
| Diesel | 47 |
| Natural gas | 25 |
| Gasoline | 12 |

Arabia total annual $NO_X$ emissions are higher [2,3]. A study indicated that the $NO_X$ concentration in Riyadh during 2005 was equal to 0.360 ppm, which exceeds the planned limit of 0.353 ppm [4]. A new European legislation on $CO_2$ emission targets was set for vehicle manufacturers, which are 130 g/km $CO_2$ to be achieved by 2015 and 95 g/km $CO_2$ to be achieved by 2020. These increasingly stringent emissions legislation is forcing vehicles manufacturing to produce vehicles with improved fuel economy and reduced exhaust emissions.

The mixture preparation strategies in the SI engines can be classified as either direct injection or Port injection. Recent development of Homogeneous Charge Compression Ignition (HCCI) is gaining significant interest to improve thermal efficiency in IC engines due to low temperature combustion, but is challenged with difficulties to stabilize the operation due to uncontrolled combustion [5–10]. Direct injection gasoline engines offer better performance and fuel economy than Port injection gasoline engines at the optimal conditions [11]. Direct injection increases the charge heating value as volumetric efficiency is increased, controlling mixture stoichiometry is improved and lean limits have been extended. Direct injection also makes unthrottled operation possible, which can significantly extend the thermal efficiency. In the Port injection engines, the fuel is injected into the intake port and mixed with air prior to entering into the cylinder. One downside of Port injection engines is the port wall wetting that leads to cause an inaccurate amount of injected fuel inside the cylinder [12,13]. The fuel entering into engine cylinder in direct injection engines is much better atomized than that of the Port injection engines particularly under cold operating condition. This is due to the higher operating fuel pressure of the direct injection engines.

Gasoline is considered the main fuel for the SI internal combustion engines. The octane number of the gasoline, which is indicated by the Research and Motor octane numbers (RON and MON), is one of the most important parameters describing the anti-knock quality of fuel that allows higher compression ratio which has a significant impact on the engine efficiency and emissions [14]. The influence of octane number on engine performance has been investigated by several researchers [15–18]. The optimal octane number of an engine is identified according to the engine design and compression ratio. Practically, it is believed that the higher-octane rating makes engine better in performance. A study, by Sayin and Kilicaslan, was reported that octane number plays an important role in exhaust emissions. They tested two different octane gasoline fuels, which are RON91 and RON93; these were conducted in a four-cylinder and four-stroke SI engine. The results confirmed that as the octane number was increased from RON91 to RON93, CO emissions increased nearly 5% [19]. Sayin et al. also tested the influence of two octane gasoline fuels, which are RON91 and RON95, on engine performance using a low compression ratio engine (8.0:1). They noticed that RON91 gasoline produced 4.2–4.8% higher power and 5.6% lower BSFC than RON95 fuel. The results also showed that lower emissions were detected by using RON91 fuel with 5.7% and 3.4% of CO and HC respectively [14]. Chanchaowna studied the effect of gasoline octane number on the engine performance by using three different octane ratings of RON91, RON95 and RON97 in three engine models that all required RON95 [20]. Test runs were conducted at two throttle settings of 50% wide open throttle (WOT) and 100% WOT and with a range of engine speeds. It was noticed that an insignificantly changes of the engine power with an octane number at a given throttle position for all tested engines. A study by Esterhuyse on engine response to lower RON than an engine requirement (RON91 versus RON95) showed that increase in emissions of total unburned hydrocarbon and decrease in CO emissions with higher RON [21].

Knocking in SI engines is an abnormal combustion phenomenon that takes place when the fuel charge self ignites during combustion. This can damage the engine if it is not prevented or controlled. There are various methods can be applied to control or prevent knocking which have been summarized in the following:

- *Ignition timing*: The most practical parameter to deal with knock control is the ignition timing. The end-gas temperature can be reduced by retarding the ignition timing. This process can be monitored by the engine control unit (ECU) [22].
- *Turbo pressure*: Maintaining the pressure in the intake manifold has an effect on the in-cylinder mixture temperature and the knock tendency. This process can be controlled by using the variable geometry turbocharger [22].
- *Fuel quality*: Increase the fuel octane number has an influence on the knock tendency. The higher octane number fuel is the lower knock sensitivity. This can be done by introducing an antiknock additive to fuel.
- *Combustion duration*: Reducing the combustion time has an obvious impact on the knock control and can be approached by either increasing the combustion speed through a higher turbulence intensity, or reducing the flam propagation distance by means of an optimal design of the combustion chamber geometry and an optimal location of the spark plug [23].
- *Injection strategy*: The use of direct injection of a second fuel, in particular, alcohol such as ethanol or methanol is an effective approach for knock control in SI engine [24].

In this paper, two available gasoline grades from the Saudi Arabian market; RON91 and RON95 were evaluated using a single-cylinder research engine that can be operated with Port injection and direct injection systems. This will give a good overview on the effects of local RON grade on engine performance of the current fuel systems. Investigating the effects of RON grade on the resulting combustion behavior and formation of exhaust emission of the Port injection and the direct injection engines will be of obvious importance to further refinement in the formulation of gasoline to match the development of fuel system technology.

## 2. Experimental investigation

### 2.1. Experimental setup

In this investigation, the experiments were performed on a Lotus Single Cylinder Research Engine (SCRE); a four-stroke, water-cooled, naturally aspirated, and spark ignition (SI) gasoline engine. The engine specification is given in Table 2.

Fig. 1 shows the single cylinder research engine (SCRE). A 30 kW Eddy current dynamometer (Froude Hoffman, AG30) was used. The fuel consumption rate was measured in the range of 0.03–20 l/h by a PLU positive displacement meter combining a servo-controlled gear counter with a dynamic piston sensor (AVL KMA 4000). Engine performance, fuel consumption and exhaust gas emissions data were logged using Texcel V10. In-cylinder pressure data were measured by a water cooled piezoelectric sensor. The air fuel ratio (AFR) was calculated using an ECM meter (AFRecorder 2000) with measurement accuracy of 0.01–0.03. The schematic diagram of the experimental setup is shown in Fig. 2.