Iraqi gasoline performance at low engine speeds

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Abstract. Four grades of gasoline fuel – obtained from Iraqi oil refineries – are used in this research to investigate their performance in spark-ignition (SI) engines. These grades are RON 77, RON 82, RON 87, and RON 93. We used a four-stroke, four-cylinder SI engine laboratory rig to conduct the experiments and calculate the engine performance for each gasoline grade. We compared the experimental results with the predicted numerical simulations carried out using a well-known commercial software called Lotus Engine Simulation (LES). The numerical results obtained using LES show good agreement with experimental findings. A higher gasoline grade shows better engine performance than lower grades owing to its superior quality and purity, better combustion characteristics and performance, and lower amount of gasoline inclusions. Gasoline fuel RON 93 provided the best engine performance in comparison to the remaining grades. The variation between the numerical and experimental results in all tested conditions was below 3%.

1. Introduction

Currently, researchers are working on developing new engine designs that have higher performance, lower gas emissions, and improved fuel consumption [1-13]. Eighty-five per cent of the world’s vehicles are powered by internal-combustion engines, which are fuelled by different octane grades. These vehicles use a very high proportion of the world’s total energy consumption. The pollutant emissions, performance, and thermal efficiency of these engines have a significant impact on the environment, according to worldwide energy statistics.

Over the years, many researchers have studied the influence of the research octane number (RON) on the performance of engines, and reported that increasing the octane number is crucial for improving the engine’s performance [11],[14-17]. The fuel’s auto-ignition resistance is called its octane number; engines powered by gasoline require high octane numbers to avoid knock, whereas engines powered by diesel require auto-ignition, and thus lower octane numbers (higher cetane numbers in the fuel) [15]. The quality of the fuel’s antiknock capability is usually calculated using either the motor octane number (MON) or the RON. The benefits of using gasoline with a high octane number include engine durability, enhanced cold starting, reduced engine noise, and lower exhaust emissions.
This research aims to study four-cylinder spark-ignition (SI) engine performance using a laboratory rig, through experimentation and numerical simulations. The engine’s performance is diagnosed by several parameters, which are volume efficiency, BFSC, brake power, and brake thermal efficiency. Different grades of gasoline with different octane numbers (RON 77, RON 82, RON 87, and RON 93), obtained from Iraqi oil refineries, will be tested at low engine speeds. The results will also be compared and discussed.

2. Experimental

2.1 Engine Rig

A laboratory-scale 2000cc engine rig was used to perform the experiments using four types of Iraqi gasoline grades. The specifications of the SI engine rig are shown in table 1. A schematic of the engine rig employed in this study is shown in figure 1.

A tachometer was used to check the rotational speed of the engine (in rpm). A hydraulic dynamometer was coupled with the engine to calculate the brake torque and other engine characteristics. A glass tube and a stopwatch were adopted to measure the fuel consumption. The air consumption was calculated using an induction-air system that included a manometer, airbox, and an orifice. The experiments were conducted on gasoline samples with four different octane numbers, for engine speeds between 1300 and 2100 rpm.

| Engine Fuel       | Gasoline            |
|-------------------|---------------------|
| No. of strokes    | 4 strokes           |
| Engine type       | 4 cycle spark ignition (SI) |
| No. of valves per cylinder | 2           |
| Combustion type   | Water cooled, natural aspirated |
| Compression ratio | 11                  |
| Clearance Volume  | 50 cc               |
| Cylinder Swept Volume | 500 cc         |
| Total Swept Volume| 1997 cc             |
| Bore diameter     | 87 mm               |
| Stroke Length     | 84 mm               |
| Connecting Rod Length | 130 mm       |
| Firing order      | 4-2-1-3             |
| Phase (ATDC)      | 360                 |

Table 1. Engine specifications
2.2 Fuel
Four grades of gasoline (with different RONs) were used in this study – RON 77, RON 82, RON 87, and RON 93. Their properties are shown in table 2.

| RNO | H/C | Lower heating value (kJ/kg) | Density at 15 °C (g/cm³) |
|-----|-----|----------------------------|--------------------------|
| 77  | 1.9 | 43500                      | 750                      |
| 82  | 2.1 | 43600                      | 745                      |
| 87  | 1.95| 43900                      | 730                      |
| 93  | 2.25| 44280                      | 780                      |

2.3 Numerical Simulation
In this study, the Lotus Engine Simulation (LES) software commercial package was used to numerically investigate the engine characteristics when using different grades of gasoline. LES is capable of comprehensively estimating and predicting engine performance under transient and steady-state operating conditions. The program requires all data regarding the engine’s specifications, along with the type and properties of the fuel, to run the simulation and obtain results. The engine layout used in this study is shown in figure 2.
Figure 2. Engine geometry in LES

The exhaust- and intake-valve timing used in both the experiment and numerical simulation are shown in figure 3.

Figure 3. Exhaust- and inlet-valve timing.
3. Results and Discussion

The engine’s performance is measured using several parameters, including volume efficiency, thermal efficiency, brake power, and brake-specific fuel consumption (BSFC). The experimental and numerical results revealed that increasing the octane number leads to an increase in the engine’s performance. Any differences between the simulation results and experimental values occurred because of mechanical losses, leakages, losses of fresh charge, energy release, etc.

Figure 4 shows the relationship between the brake thermal efficiency (BTE) and speed of the engine at different RONs. The useful thermal power generated by burning the fuel is the BTE criterion; any improvement in burning increases the BTE. The engine performance is directly related to the octane number, which is considered to be a standard measure. Therefore, increasing the octane number leads to a higher BTE, which is in agreement with Rashid et al. [18]. The efficiency increased by approximately 5.36% for the ON 93 model, and by about 3.69% for the ON 93 experimental model, in comparison to baseline gasoline fuel (RON 77) at an engine speed of 1870 rpm.

![Figure 4. BTE at various engine speeds.](image)

Volumetric efficiency is related to the intake of the fuel/air mixture and is a metric to measure engine performance. When the air flow into the engine is reduced, the volumetric efficiency is lower. Many factors affect volumetric efficiency, such as exhaust- and intake-valve geometry, timings, lift size, port design, exhaust and intake manifold, engine speed, compression ratio, exhaust to inlet manifold pressure ratio, fuel heat of vaporisation, the fuel vaporised fraction in the intake system, the air–fuel ratio, and the fuel type.

The volumetric efficiency was lowest at low engine speeds. In general, filling the cylinders with the charge takes sufficient time at low engine speeds. At higher speeds, the charge filling time of cylinders is short and insufficient owing to intake-valve opening, leading to induction-system choking.

For a constant air–fuel ratio, the fuel flow rate will decrease when the volumetric efficiency decreases, thereby decreasing the engine output power.

At a higher octane number, a fuel’s volumetric efficiency is increased. This is attributed to the oxygenated additives in gasoline, which have a high latent heat, leading to higher octane numbers than those of pure gasoline. Further, high volumetric efficiency is achieved when fuel evaporation is low and the heat capacity is high. This can be accomplished by allowing more air mass into the cylinders and causing charge cooling.
At higher speeds, the amount of mixture that enters the cylinders increases, and the air–fuel efficiency increases; thus, on the octane number also increases, leading an improvement in the volumetric efficiency to approximately 5.2% for the ON 93 model and about 4.54% for the ON 93 experimental model, in comparison to baseline gasoline fuel (RON 77), at an engine speed of 1900 rpm as shown in figure 5. This result is in agreement with those of Alahmer et al. [14]. The small variation between the experimental and simulation values occurred because of the losses of charge and friction caused by the airflow.

![Figure 5. Volumetric efficiency at various engine speeds.](image)

Increasing the speed of the engine leads to higher brake power, as illustrated in figure 6. Increasing the octane number improves the brake power, which agrees with previous studies [16], [18-20]. Increasing the engine speed led to an increase in the pressure differential between the engine cylinder and atmosphere at the beginning of the inlet stroke, increasing the mass flow of fresh charge and energy release in turn. Above 1900 rpm, the increasing rate of brake power was lower than that at engine speeds below 1900 rpm. An improvement of 6.4% for brake power is achieved in the ON 93 model and about 4.5% for the ON 93 experimental model, in comparison to the reference (octane number 77).

The higher brake power with gasoline fuel grade ON 93 is attributed to its slightly higher calorific magnitude and fuel’s higher hydrogen content. The gasoline fuel heating value is decreased with higher ON values because the Methyl tert-butyl ether MTBE and alcohol are added to the fuel as oxygenate components[14].
Figure 6. Brake power at various engine speeds.

Any prime mover that burns fuel and generates shaft power or rotation is the measurement of fuel’s efficiency, in other words, it’s called Brake-specific fuel consumption (BSFC). It is typically applied for comparing a shaft output with an internal combustion engine’s efficiency. BSFC is the fuel’s consumption rate divided by the power generated.

Higher octane numbers reduce the BSFC [20], [21], as illustrated in figure 7. Further, burning efficiency is higher at higher octane numbers, providing more power while using less fuel [21]. Increasing the octane number increases these improvements. RON93 have iso-octane of 93% in its content, but not limiting to n-heptane, many anti-knocking substances are included as remaining percentage. The BSFC is the lowest with 93% iso-octane, which makes the engine requests low fuel mass per unit power generated because the value of calorific in general is higher [21].

A dramatic drop in BSFC values for all engine speeds occurred between RON 77 and RON 93 owing to the development of the gasoline fuel quality at higher octane numbers. Higher octane numbers resulted in the lowest BSFC, of 8%, in the ON 93 model. The same value was about 6.2% for the ON 93 experimental model, in comparison to the reference (RON 77) between 1875 and 1900 rpm. The variation between the numerical and experimental results was below 2%, which is an indication that Lotus Engine Simulation is a reliable method to predict engine performance.
4. Conclusions

The engine performance when using RON 77, RON 82, RON 87, and RON 93 gasoline grades were numerically and experimentally investigated on a representative engine model. Analysis of the experimental and numerical results was performed. The major findings derived from this investigation are as follows:

- The octane number has a definite influence on gasoline engine performance.
- Lotus Simulation software is a reliable method to predict engine performance with minimum errors.
- The experimental values in this study were lower than the theoretical software calculations because of the losses in a gasoline engine.
- The BTE was enhanced remarkably with increasing RON.
- The best volumetric efficiency was at 1900 rpm for RON 93.
- The BSFC reduced with increasing RON.
- Higher octane numbers resulted in the lowest BSFC, at 1900 rpm.
- Brake power was improved with increasing RON.
- The variation between numerical and experimental results in all cases and conditions was below 3%.

![Figure 7. Engine speed vs. BSFC](image-url)
Nomenclature

| Symbol | Meaning                                      | Unit   |
|--------|----------------------------------------------|--------|
| RON    | Research octane number                       | /      |
| A/F    | Air to fuel ratios                           | /      |
| EVC    | Exhaust valve closing                        | /      |
| Ho     | Differential manometer                       | Cm     |
| MON    | Motoring octane number                       | /      |
| SI engine | spark-ignition engine                       | /      |
| HC     | Unburned hydrocarbons                        | Ppm    |
| ON     | Octane number                                | /      |
| IVC    | Inlet valve closing                          | /      |
| Bp     | Brake power                                  | KW     |
| (LES)  | Lotus Engine Simulation                      | /      |
| TDC    | Top dead center                              | /      |
| N      | rotational speed                             | (rpm)  |
| CR     | Compression Ratio                            | /      |
| BTE    | Brake thermal efficiency                     | /      |
| EVO    | Exhaust valve opening                        | /      |
| IVO    | Inlet valve opening                          | /      |
| BSFC   | Brake Specific fuel consumption              | kg/(kW.hr) |

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