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Effect of Octane Number on Performance and Exhaust Emissions of an SI Engine

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K E Y W O R D S

Brake specific fuel consumption; Brake thermal efficiency; NOX; Octane number; UHC.

A B S T R A C T

Spark ignition engines are very popular engines that they are running millions of vehicles all over the world. This engine emits many harmful pollutants, such as CO, UHC, and NOX. In this paper, the impact of gasoline octane number on the engine performance and exhaust emissions was studied. In the tests, four-cylinder, four-stroke engine, and two variable octane numbers (RON83 and 94.5) were used. The engine was run at different engine speeds and loads. The results from the experimental study indicated that the brake specific fuel consumption (bsfc) of RON94.5 was higher than RON83 by 13.93%, while the brake thermal efficiency (ηbth) was higher for RON83 compared to RON94.5 by 12.31%. The emitted emissions for the tested fuels were high when RON83 was used compared to RON94.5 by 65.52%, 49.11%, and 57.33% for CO, UHC, and NOX, respectively.

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1. Introduction

Internal combustion engines are expected to continue to operate vehicles, heavy and medium machines. This applies to both types of engines (spark ignition engines or compression ignition engines) in the near and medium-term as well [1]. Internal combustion engines powered by fossil fuels (gasoline and diesel) emit many dangerous pollutants to the environment. As engines are growing rapidly in all fields, it is important to reduce emissions from transportation. Internal combustion engines in vehicles and other transport equipment produce several types of emissions, such as carbon dioxide, unburned hydrocarbons (UHC), nitrogen oxides, carbon monoxide, and many other hazardous compounds. These emissions play a negative role in global warming [2].

In the last years, many researchers focused on the Octane number, since exhaust emissions and engine performance are known to have a very close relationship with gasoline quality. The Octane number is the indication of the resistance of the fuel to the knock phenomenon [3]. The Octane number of an engine is determined according to the engine design, compression ratio, atmosphere, driving conditions, and mechanical conditions [4].

The impact of the octane number of the performance and exhaust emissions of SI engines was studied by Sayin et al. [5]. They used two types of gasoline fuel RON91 and RON95. The results showed that the minimum (bsfc) was obtained with RON95. As for exhaust emissions, RON91 caused the minimum CO and UHC compared with RON95. Sayin [6] investigated the influence of octane number of the performance and emissions of gasoline run a single cylinder, four strokes and naturally aspirated engine using variable RON (91, 93, 95, 97, and 98). The results showed that performance and emissions were significantly improved with varying spark timing according to gasoline's octane number. The Engine with RON95 gasoline gave the best performance and the least emissions. Lawal et al. [7] studied the performance of the SI engine using two types of gasoline fuels (RON91and RON95). They observed an increment in the brake power and torque when using RON91 instead of RON95 at wide-open throttle (WOT).

For both RON91 and RON95, the volumetric efficiency (ηv) was increased with engine speed and it does not depend on the used octane number, as the obtained (ηv), for both fuels, was same. Binjuwair et al. [8] investigated the engine performance and emissions in the SI engine fueled by two types of gasoline (RON91 and RON95). The results revealed the increase of brake power and brake thermal efficiency (ηbth) for RON91 compared with RON95. However, the NOX concentration increased when the engine was run by RON91 compared to RON95 at the maximum engine load operation. At the low load, the RON95 gasoline emitted higher NOx than RON91. Mohamad et al. [9] studied the effect of gasoline fuel RON95 and RON97 on the performance and exhaust emissions in the SI engine. The results depicted that RON95 produced a higher engine performance for all parts-load conditions within the speed range. In terms of exhaust emissions, RON95 produced lower NOx concentration, but higher CO_2, CO and UHC emissions. Khalifa et al. [10] carried out a practical study to compare the effect of using two gasoline fuels (RON91 and RON95) on the performance and exhaust emissions of a modern fuel injection SI engine at different engine speeds and loads. The results displayed that the RON91 has a slightly higher brake power and brake specific fuel consumption (bsfc) compared to RON95. Insignificantly, CO_2 concentrations were higher at part load while at high load, there was no effect on the emitted CO2 levels. Also, the UHC concentrations were higher when RON91 was used to compare to RON95. Both fuels showed similar trends for the emitted CO and NOX concentrations in the exhaust gases. Alahmer [11] presented a comparative analysis of performance and exhaust emissions in the SI engine powered by gasoline fuels of two different octane numbers (RON90 and RON95). The results showed that the resulted brake power and (ηthb) for RON90 was higher than RON95 as well as for (bsfc). In general, the exhaust emissions (NOx and CO) of the engine were reduced when RON95 was used. On the other side, the UHC and CO_2 emissions of RON90 were lower than RON95. Rashid et al. [12] studied the impact by using three different gasoline fuels (RON 95, 97, and 102) on engine performance. The results of the investigation with RON102 manifested the highest torque and brake power in all test conditions compared to RON (95 and 97). Positive improvement in the (bsfc) was observed when RON97 was used to compare to RON (102 and 95) fuels. The (ηbth) was improved using the higher-octane rating fuels as RON102 and RON97 compared to RON95. The RON102 fuel reduced the NOX concentration compared to RON (95 and 97) fuels. RON102 fuel produced the highest UHC and CO concentration emissions compared to RON (95, 97). Osman [13] prepared different RON gasoline fuels (70, 75, 80, 85, and 90) and tested the engine performance. The results exhibited that the engine performance increased gradually according to the increase of the fuel's octane number. However, this appeared clearly in the obtained results of samples RON (70 and 90) at the speed (2800) rpm, the torque and (ηthb) were increased. At the engine speed of 3400 rpm, the brake power and exhaust temperature were increased while at (2800) rpm, the (bsfc) was decreased. Fahmi et al. [14] focused on analysing various RON95 fuel brands (at the same octane number) in the market and finding the differences in engine performance. The results indicated that all the tested gasoline brands with the same octane rating had affected the overall performance of the engine but only in small proportions that caused minor changes in the output and torque. Yew Heng Teoh et al. [15] investigated the influence of the gasoline fuel RON (95, 97 and 100) on the exhaust emissions and performance of the SI engine. The engine speed was varied from (1600 to 3200) rpm with a 400 rpm increment under full throttle conditions. The results indicated that the brake torque for RON100 is higher by (1.27% and 0.56%) than that of RON (95 and 97), respectively at all engine speeds. Thus, the RON97 resulted in lower (bsfc) by (2.47% and 4.71%) compared to RON (95 and 100). Therefore, the results

revealed that RON100 has lower (ɳbth) by (5.93% and 6.33%) than RON (95 and 97). At a higher engine speed of 3200 rpm, the exhaust gas temperature reached the highest level of 358.1°C with RON95 and followed by RON100 and RON97 with 355.2°C and 347.2°C, respectively. The concentrations of (CO) and (UHC) were found lower for the RON100 by (10.55%, 9.95%) and (28.1%, 39.9%) compared with the RON (95 and 97), respectively. While, RON95 produced lower NOx concentration compared to RON97 and RON100 by 3.4% and 12.6%, respectively.
The aim of this paper is to evaluate the variations in engine performance and exhaust emissions when it is fueled by two different ON gasoline fuels. The two Iraqi conventional gasoline fuels used are RON83 and RON94.5. The Iraqi gasoline differs from any other gasoline fuels all over the world as it contains about 500 ppm of sulfur in its chemical composition. This sulfur makes fuel behavior and the emitted emissions have a special character. From this point, this research has its importance because it will evaluate practically the performance and the emitted pollutants of high sulfur content gasoline.

2. Experimental Setup

A spark-ignition engine type Mercedes-Benz was used in this study. Fuels tested were commercial grades with RON83 and RON94.5. Figure 1 shows the experimental rig, and Table 1 lists the main technical specifications for the used engine. The engine load was adjusted using a hydraulic dynamometer, which was also used to measure the engine torque. The air consumption was measured using an air box. The intake air orifice measures the difference of pressure between the atmosphere and the intake pressure. A glass bulb of known volume and having marks on the top and bottom of the bulbs were used to measure the volumetric fuel consumption. The exhaust gas pollutants (such as CO, UHC, NO_X, and CO_2) levels were measured using an Exhaust Gas Analyzer model (EGMA HG-550) with a printer, Italy made. The exhaust gas temperatures were measured using thermocouples (type K) and a digital reader. The properties of the engine fuels used in this study are presented in Table 2.

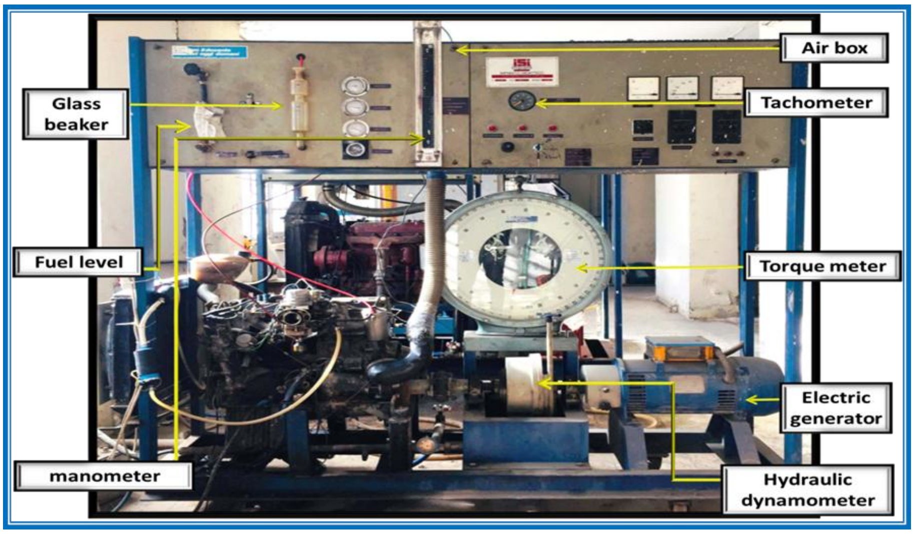

Figure 1: Photo of the experimental rig

Table 1: The technical specifications of the used engine

Engine type	Naturally aspirated petrol
Cylinders	Straight (four-stroke)
Displacement volume	1997cm3
Bore x Stroke	89 x 80.25 (mm)
Connecting rod length	150 (mm)
Compression ratio	9:1
Max. Power @ rpm	80 kW (107.5 hp) @ 5500 rpm
Max. Torque @ rpm	165 N.m (118 lb·) @ 3000 rpm
Fuel System	Carburetor type

Cooling	Water cooling system

Table 2: Properties of the fuels used in the tests

Research Octane number	83	94.5
Density at 15.60°C (kg/m3)	762.37	739
Average molecular weight	106.4	114.8
Heating value (kJ/kg)	43000	41030.64
Carbon wt.%	99.12	93.12
Hydrogen wt.%	15.5	13.1
CH composition	$C_{8.26}H_{15.5}$	$C_{7.76}H_{13.1}$
Research Octane number	83	94.5
Density at 15.60°C (kg/m3)	762.37	739
Average molecular weight	106.4	114.8

3. The Equations Used in the Recent Study

1. Brake power

$$Bp=\frac{2\pi*N*Tb}{60*1000} \qquad (1)$$

2. Mass flow rate of air

$$\dot{m}_a=\frac{5*\sqrt{h_o}}{3600}*\rho_a \quad (Kg/sec) \qquad (2)$$

3. mass flow rate of fuel

$$\dot{m}_f=\frac{V_f\times\rho_f}{t\times10^6} \quad (kg/sec) \qquad (3)$$

4. Brake spicefic fuel consumption

$$bsfc=\frac{\dot{m}f*3600}{bp} \qquad (4)$$

5. Brake thermal efficiency

$$\eta_{bth}=\frac{bp}{\dot{m}f*LHV}*100\% \qquad (5)$$

6. Volumetric efficiency

$$\eta_v=\frac{ma/\rho a}{vdis*n/60}*100\% \qquad (6)$$

7. Ideal mass flow rate of air

$$\dot{m}_{air\ (ideal)}=\frac{vdis*n*\rho a}{60} \qquad (7)$$

4. Test Procedure

In the experiments, all performance tests were conducted at high and low loads for varying engine speeds. The engine speeds were varied from 1200 to 2700 rpm with 300 rpm intervals. The fuel consumption, engine speed, torque, exhaust gas temperatures, and exhaust emission levels were taken at each tested speed. Each test process was repeated three times to confirm repeatability. The values given in this study are the average of these results.

5. Results and Discussion

Figure 2 shows the effect of tested gasoline fuels on brake power for different engine speeds under low and high engine load. The results displayed that the brake power increased with the increase of engine speed in all cases up to the maximum value of 2700 rpm. This is attributed to increasing the flame speed, turbulence in the cylinder, volumetric efficiency and added heat. Similar behavior has been reported by almost all investigators on various types of engines and fuels used [5-10]. Both RON83 and RON94.5 fuels indicated no significant difference in their brake power because of the same engine speed and load.

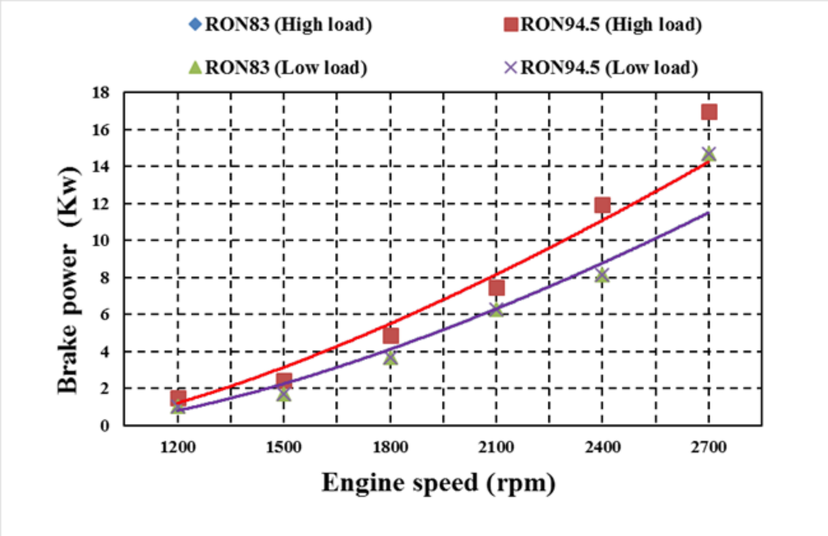

Figure 2: Variation of brake power with the engine speed

Figure 3 illustrates the variation of brake specific fuel consumption (bsfc) with the engine speed for the tested gasoline fuels at maximum and minimum load conditions. The (bsfc) represents a great indicator of the engine performance to produce power and how economic is the engine in different working conditions. The results exhibited that the (bsfc) decreased with the increase of engine speed. The engine achieved the minimum (bsfc) at (2100) rpm and at maximum load when it was fueled by RON83 fuel. This is can be attributed to the increase in brake power. The (bsfc) increased at low engine speeds because the longer time per cycle allows for more heat loss. However, at higher engine speeds, the amount of fuel supplied to the cylinder increased by a higher rate because of greater friction losses and the oxygen exhausting for combustion was reduced. Thus, the air to fuel ratio changed and this caused a very slight increase in (bsfc). Many investigators have reported similar behavior for variable engine types and gasoline octane numbers [5, 9, 10]. However, it was noticed that the (bsfc) reduced at wider throttle openings indicating that the engine economical range of operation is close to WOT. The (bsfc) values were increased at the partial loads' operation compared to WOT, as the optimum fuel quantity versus load was achieved. The (bsfc) increased when RON94.5 gasoline was used by (12.29% and 5.88%) compared to RON83 gasoline at maximum and minimum load, respectively. In spite of its higher-octane number, RON94.5 gasoline has a lower heating value (LHV) compared to RON83 gasoline.

Figure 4 depicts the effect of tested gasoline fuels on (ηbth) for different engine speeds under low and high engine load. Generally, the peak (ηbth) in all cases was reached at maximum engine speed 2700 rpm. The main reason is the increase in brake power and the reduction of fuel consumption. Many investigators have reported similar behavior with varying types of engine and fuels' octane numbers [16]. The outcomes revealed that the ηbth was higher when RON83 gasoline was used compared to RON94.5 fuel. This is can be ascribed to higher (H/C) ratio for RON83 gasoline, which causes more heat release. The high air-to-fuel ratio significantly. The RON83 gasoline showed an increase in (ηbth) by (5.20 % and 12.31%) compared to RON94.5 gasoline at high and low load, respectively. The RON83 gasoline manifested a decrease in (ηbth) by (5.48 % and 0.91 %) at 2400 and 2700 rpm and high and low load compared to RON94.5 gasoline, respectively. This is due to an increase the fuel consumption and the increase of power losses or dissipated heat.

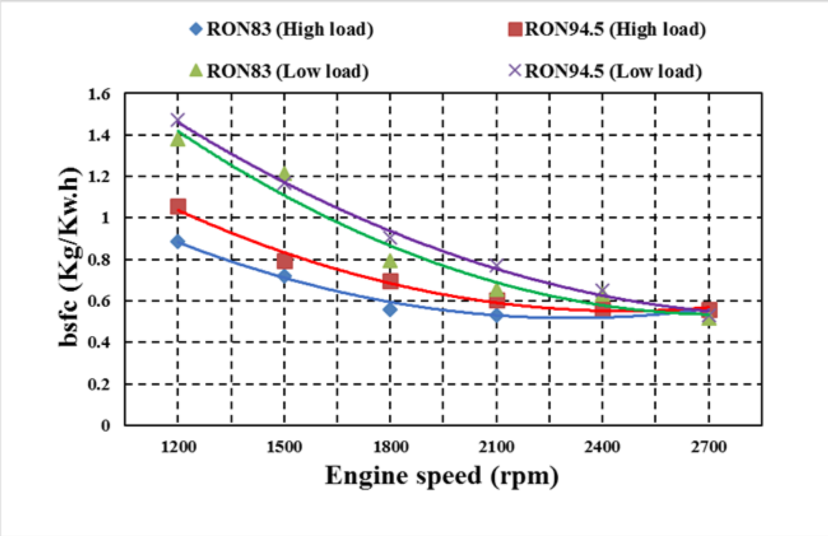

Figure 3: Variation of brake specific fuel consumption with the engine speed

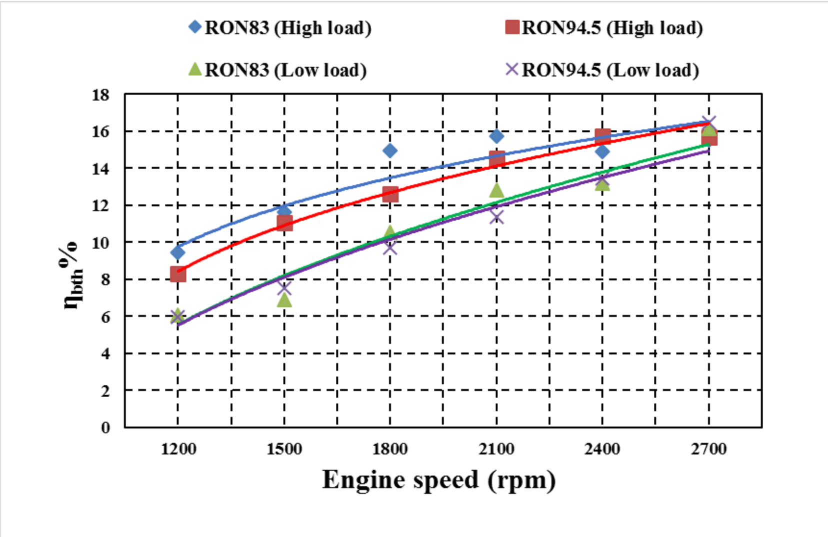

Figure 4: Variation of brake thermal efficiency with the engine speed

Figure 5 elucidates the effect of tested gasoline fuels on volumetric efficiency (ηv) for different engine speeds under low and high engine load. Outcomes revealed that the (ηv) increased with increasing engine speed and octane number. However, the results showed that the (ηv) at high load is higher than a low load due to wider throttle opening for high load, thus improved the volumetric efficiency. Many researchers have reported similar behavior on various types of engine and octane number fuels [7]. The RON94.5 gasoline showed an increase in (ηv) by (0.7%) compared with RON83 gasoline at high load. At low load, the RON94.5 gasoline was decreased by (0.61%) compared to RON83 gasoline due to reduced air proportion in the air to fuel ratio.

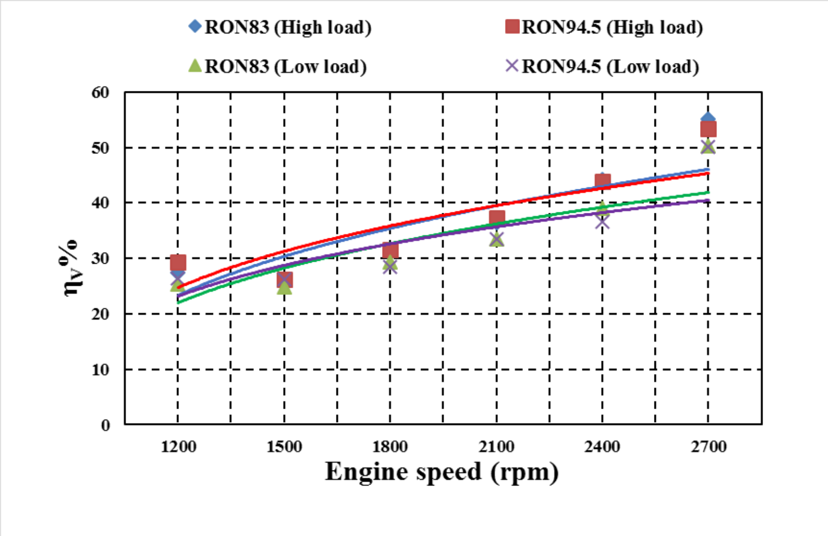

Figure 5: Variation of volumetric efficiency with the engine speed

Figure 6 evinces the effect of tested gasoline fuels on exhaust gas temperature for different engine speeds under low and high engine load. The results demonstrated that the exhaust gas temperatures increased with increasing the engine speeds and loads for both gasoline fuels. However, Figure 6 shows that the increase in the exhaust gas temperatures was associated with the increase in the octane number of gasoline fuels. The improvement in exhaust temperature is due to the enhancement in the combustion process and increases in the oxidation process of carbon and oxygen. References [13] and [6] have reported similar behavior for variable types of SI engine and octane number fuels. The RON94.5 gasoline showed an increase in the exhaust gas temperatures by (13.47% and 15.83%) compared to RON83 gasoline at high and low load, respectively.

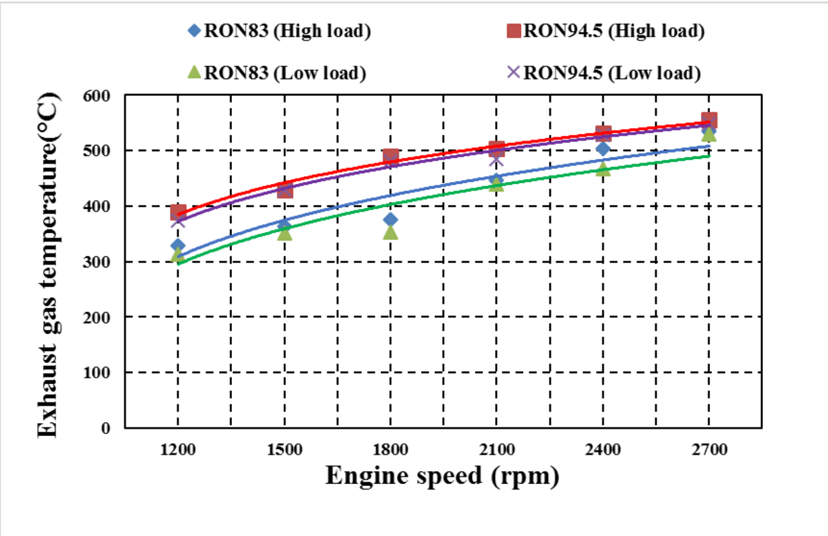

Figure 6: Variation of exhaust gas temperature with the engine speed

Figure 7 views the effect of tested gasoline fuels on air/ fuel ratio for different engine speeds under low and high engine load. Ideally, combustion in every cylinder of an engine would be exactly the same, and there would be no cycle-to-cycle variation in any cylinder. This does not happen due to variations occur within the cylinder, such as volumetric efficiency, temperature differences in the runners, evaporation rates and components of gasoline fuel, this causes variations in the air/fuel ratio [17]. The results showed that the air/fuel ratio increased with increasing the load at each tested speed. However, the air/fuel ratio decreased with increasing the octane number due to increase in the fuel consumption. The RON83 gasoline exhibited an increase in air / fuel ratio by (9.34% and 5.65%) compared to RON94.5 gasoline at high and low load, respectively.

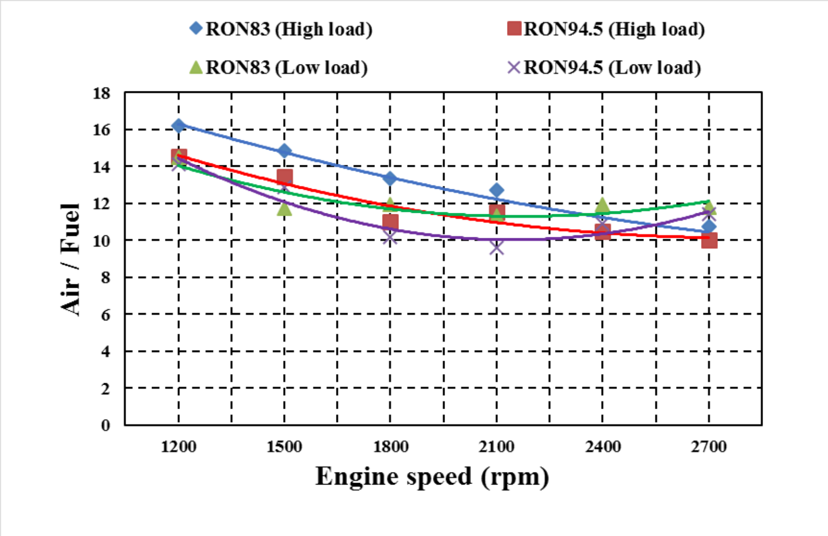

Figure 7: Variation of air to fuel with the engine speed

Figure 8 depicts the effect of tested gasoline fuels on CO emission for different engine speeds under low and high engine load. The results revealed that the CO levels increased with the increasing engine speed for both gasoline fuel types. This is ascribed to many causes, such as bad air and fuel mixing, local rich regions, increasing the rate of carbon in the fuel, incomplete combustion and also because there is not enough time to reach the equilibrium of oxidation from CO to CO_2. Higher loads would also require more fuel burned and accordingly result in higher CO emission in the exhaust. The behavior contrasted with ref. [5] observed that the CO levels decreased with increasing engine speed. This is attributed to increase in load that could probably increase the volumetric efficiency; boost the turbulence in the combustion chamber, thereby ensuring more homogenous mixture and better combustion. The CO emission decreased at low load by (1.11%) compared to the high load of RON83 gasoline. CO levels were increased at low load by (27.05%) compared to the high load of RON94.5 gasoline.

In Figure 8, the results demonstrated that the RON94.5 gasoline slightly reduced the CO concentrations compared to the RON83 gasoline due to that the increasing of oxygen content in RON94.5 gasoline leads to react the CO to the CO_2 (complete combustion) and improve in the combustion process. References [8 -18] have reported similar behavior on various types of engine and conditions. The RON83 gasoline showed an increase in CO emission by (75.13% and 65.52%) compared to RON94.5 gasoline at high and low load, respectively.

Figure 9 shows the effect of tested gasoline fuels on UHC for different engine speeds under low and high engine load. The UHC emissions will be different for each gasoline blend depending on the original fuel components. The existence of UHC in exhaust gases points out that the fuel did not burn completely or partially burned, lower temperature, lack of oxygen, no homogeneity of mixture, oil on combustion chamber walls and leakage passed the exhaust valve and cool quenching [1]. The results showed that the UHC emissions decreased with the increasing of engine speed to 1800 rpm in all cases when the engine speed increased the air to fuel ratio of mixture that becomes more homogenous in the combustion chamber. The UHC emission increased at low load by (13.49% and 14.06%) compared with the high load of RON83 and 94.5 gasoline, respectively.

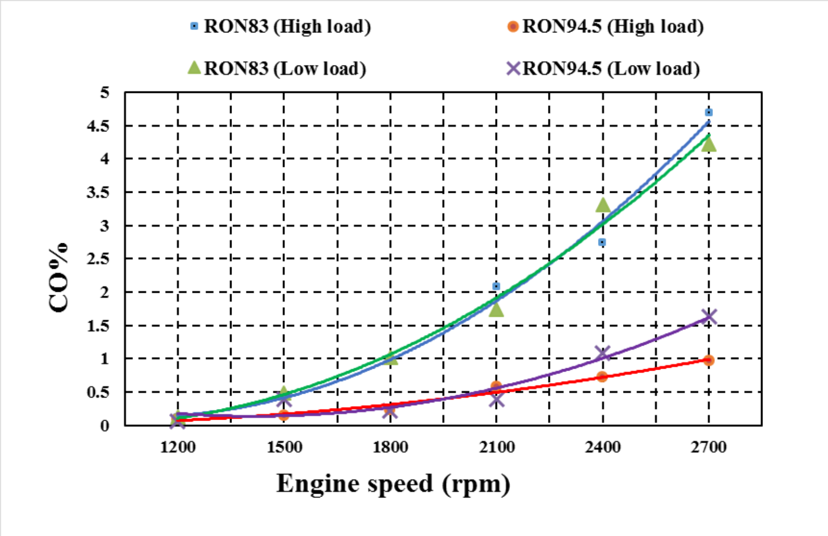

Figure 8: Variation of CO emission with the engine speed

The behavior was in contrast with researcher [19] who observed that the UHC emission was very low for low loads and it was increased at higher loads. However, the outcomes revealed that increasing octane number reduces the UHC emission because of the improvements in combustion process with increasing content of oxygen and increasing the exhaust gas temperature in RON94.5 gasoline. Ref. [10] reported similar behavior on varying types of engine and octane numbers gasoline fuels. The use of RON83 gasoline showed an increase in UHC emission by 49.44% and 49.11% compared to RON94.5 gasoline at high and low load, respectively.

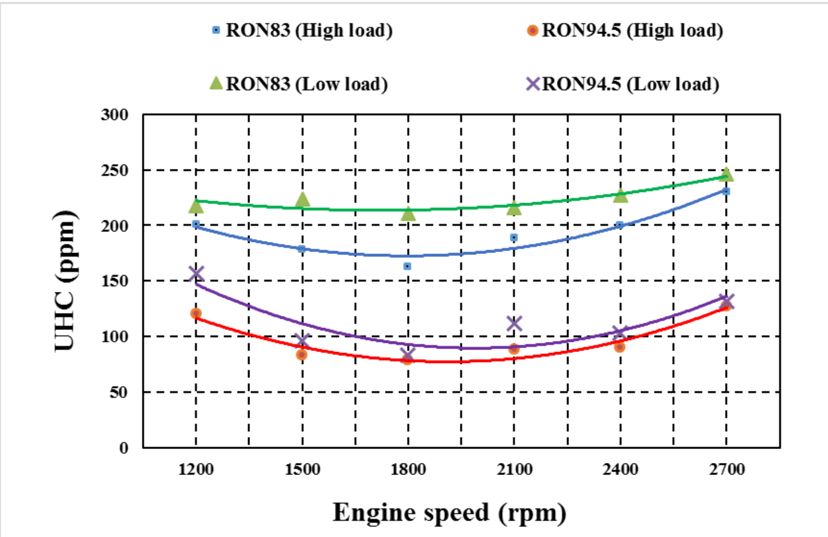

Figure 9: Variation of UHC emission with the engine speed

Figure 10 presents the effect of tested gasoline fuels on NOx levels for different engine speeds under low and high engine load. Generally, the formation rate of NO_X is directly dependent on cylinder temperature, and the amount of NO_X generated is also sensitive to the local burning rates within the cylinder. The largest amount of NO_X usually found around the spark plug vicinity, at which the temperature and pressure are the highest. The curves in this figure revealed that the NO_X concentration increased with the increasing of engine speed to achieve the maximum level for NO_X at 1800 rpm; then it was decreased with increasing engine speed. This is ascribed to the reduction in the available time for NOx gases formation. The NO_X emission was increased at high load by 25.49% and 38.76% compared to low load for RON83 and 94.5 gasoline, respectively. However, the result of tests showed that RON83 produced higher NO_X concentration compared to RON94.5 by (48.08% and 57.33%) at high and low load, respectively. This is attributed to the increase in the latent heat of vaporization for RON94.5 gasoline compared to RON83 gasoline, this led to a reduction in combustion temperature (adiabatic flame temperature) inside the combustion chamber in spite of the increase of oxygen content at the same type of gasoline (RON94.5).

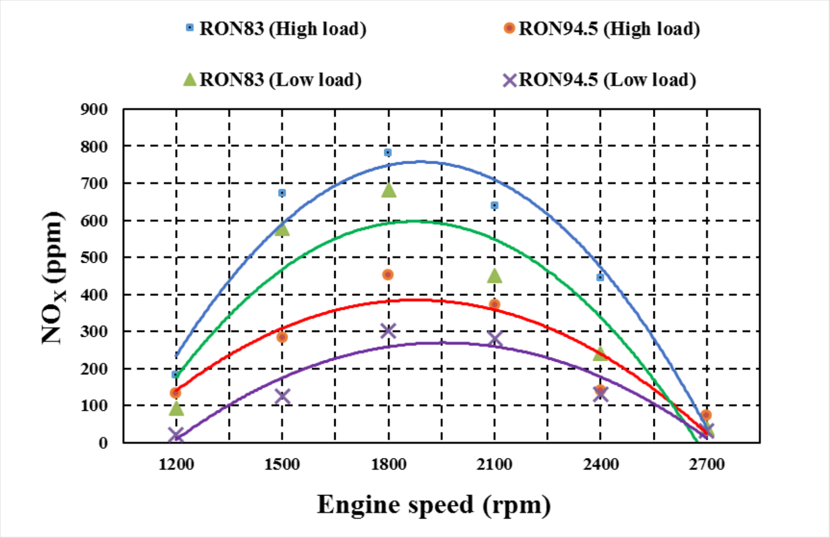

Figure 10: Variation of NOX emission with the engine speed

Figure 11 manifests the effect of tested gasoline fuels on CO_2 for different engine speeds under low and high engine load. The CO_2 is one of the basic greenhouse gases, which produced by a complete combustion of hydrocarbon fuel. CO_2 formation is affected by the (H/C) ratio in the gasoline fuel. The results depicted that the CO_2 emission increased with the increasing of engine speed in the tested fuels due to the increase of the volumetric efficiency. The CO_2 emission increased at low load by 6.06% for RON83 gasoline, while it was increased by 0.8% when RON94.5 gasoline was used. The study outcome exhibited that the CO_2 emitted by RON94.5 was less than that of RON83 gasoline. The main reason for this decrease is the reduction in the (H/C) ratio in the RON94.5 compared to RON83. The maximum deviation of the emitted CO_2 was for RON83 by (61.51% and 63.55%) comparison to RON94.5 at high and low load, respectively.

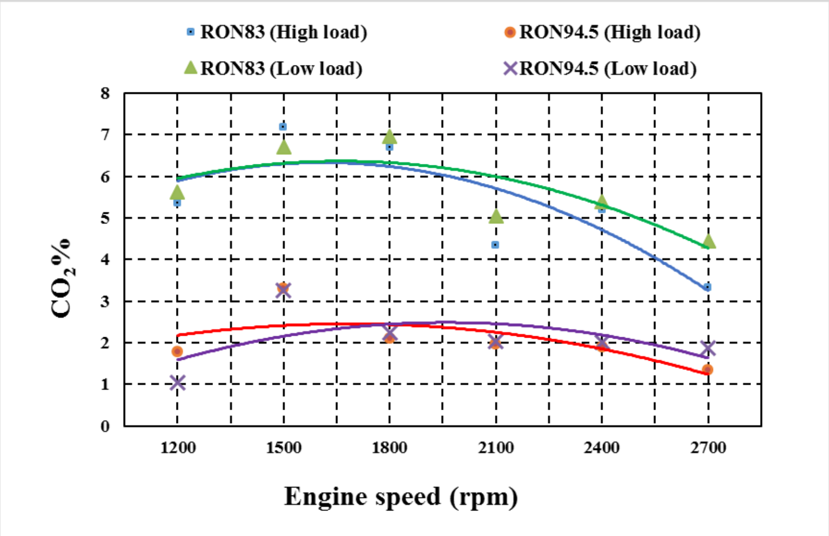

Figure 11: Variation of CO_2 emission with the engine speed

6. Conclusions

The effects of engine speed variations on the performance and exhaust emissions of the SI engine using gasoline fuels with different RON have been investigated experimentally. The conclusions from drawn this work are summarized as follows:

1. The two used fuels indicated no significance difference in their brake power at the same engine speed and load.
2. RON83 showed an increase in (η_{bth}) by (5.20 % and 12.31%) compared with RON94.5 gasoline at high and low loads, respectively.
3. The (bsfc) increased, when RON94.5 was used, by (12.29% and 13.93%) compared to RON83 gasoline at high and low loads, respectively.
4. RON94.5 displayed an increase in (η_v) by (0.7%) compared to RON83 gasoline at high load.
5. The exhaust gas temperature increased with the increasing of ON by (13.47% and 15.83%) compared to gasoline fuel RON83 at high and low loads, respectively.
6. The air/fuel ratio was decreased with increasing RON. The RON83 gasoline elucidated an increase in air / fuel ratio by 9.34% and 5.65% compared to RON94.5 gasoline at high and low loads, respectively.
7. In terms of exhaust gas emissions, the CO, UHC, NO_X, and CO_2 of RON83 were higher by (75.13% and 65.52%), (49.44% and 49.11%), (48.08% and 57.33%), and (61.51% and 63.55%) compared to RON94.5 gasoline at high and low loads, respectively.
8. The RON83 gasoline showed an increase in CO emission by (75.13% and 65.52%) compared to RON94.5 gasoline at high and low load, respectively. While the UHC emission, increased at low load by (13.49% and 14.06%) compared with the high load of RON83 and 94.5 gasoline, respectively.

Nomenclature

B_P Brake power
T_b Brake torque
BSFC Brake specific fuel consumption
CO Carbon monoxide
CO_2 Carbon dioxide
ρ_a Density of air
ρ_f Density of fuel
V_{dis} Displaced volume
N Engine speed
LHV Lower heating value
h_o Manometer reading
$\dot{m}_f$ Mass flow rate of fuel
$\dot{m}_a$ Mass flow rate of air
n Number of working strokes per minute, n = $\frac{N}{2}$ for four - stroke cycle engines.
NO_X Nitrogen oxides
ON Octane number
RON Research octane number
SI Spark ignition
V_f Tube volume
t Time
UHC Unburned hydrocarbons
WOT Wide-open throttle

Greek symbols

η_{bth} Brake thermal efficiency
η_v Volumetric efficiency

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