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Effect of Fuel Types on Combustion Characteristics and Performance of a Four Stroke IC Engine

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Abstract
In this study, the effect of Gasoline, Ethanol, Gasohol E10, and Kerosene on the performance and combustion characteristics of a spark ignition (SI) engine were investigated. In the experiment, the internal combustion (IC) engine includes one cylinder, two valves, and four stroke spark ignition. Performance tests were carried out for specific fuel consumption, brake specific fuel consumption, power developed, corrosion rate, and carbon dioxide (CO_2) and carbon monoxide (CO) emissions. The measurements were conducted under various engine speeds ranging from 1500 to 4500 rpm. The experimental results showed that the performance of engine was improved with the use of gasoline and gasohol E10 in comparison with the Ethanol and Kerosene. The concentrations of CO_2 and CO were presented and compared for all type of fuel examined.
Keywords: Engine performance, Flue gas emissions, Ethanol, Gasoline, Gasohol E10.

I. INTRODUCTION:

In the internal combustion (IC) engine, fuel is mixed with air (O_2/N_2) and burned in hollow cylinders. The engine converts the chemical energy released by the burned fuel into mechanical energy. The resulting explosion inside the engine comes from burning the fuel. This brings up an important point that needs to be cleared up right away. Typically, an ignition of the fuel would results in rough operation. Therefore, the fuel must be burned at a very controlled rate of mixture. Spark ignition (SI) engines use an air to fuel mixture that is compressed at high pressures. At this high pressure, the mixture has to be close from the stoichiometric ratio, and leads as a result to be chemically inert and able to easily ignite [1].

It comes as no surprise that in order for an engine to run smoothly it must have the correct type of fuel. Nowadays, it is becoming increasingly important to really know what type of fuel is being used in the engine. If the right type of fuel is not used, there is going to definitely be a problem with engine operation. For instance, gasoline is the fuel designed for spark-ignition IC engines. Basically, the gasoline is derived from petroleum, and consists of over 200 different hydrocarbons that have the correct volatility and desirable characteristics required to burn for high-quality engine performance. However, many of research centers and industrial companies are hardly working on a variety of alternative fuels to partially or even completely replace the use of gasoline. Some of these alternative fuels include, for example, Ethanol, Methanol, and Methyl Teriary Butyl Ether (MTBE). Ethanol, Methanol, and MTBE are oxygenated fuels. In view of the fact that these compounds add oxygen to the air/fuel mixture; therefore, they synthetically lean the air/fuel mixture, resulting in more complete combustion and lower emissions [2].

For the SI four cylinder engine, M.V. Mallikarjun1 and V. R. Mamilla [3] added methanol in various percentages in gasoline and also used slight modifications on the engine under different load conditions. The authors observed that, for various percentages of methanol blends (0-15%), there is an increase in the octane rating of gasoline along with increase in brake thermal efficiency, and this is indicated a better thermal efficiency and reduction in knocking. In terms of exhaust emissions, they noted that the exhaust emissions (CO and HC) are considerably decreased, but carbon dioxide (CO_2) and nitric oxides (NO_x) slightly increased. In addition to these experimental results, it was notable that for these methanol blends the combustion temperature is found to be high, and exhaust gas temperature is gradually decreased.

Ioannis Gravalos et al. [4] experimentally found that the engine brake power somewhat increased for all engine speeds as the ethanol content in the blended fuel was increased. The authors also displayed that the brake power of gasoline was slightly lower than that of E10–E30, in particular for low engine speeds. Furthermore, the engine volumetric efficiency and the density of the blend increased with ethanol percentage, and this was produced an increase in power developed. For the same trend of investigations, Al-Hasan [5]; Bayraktar [6] have been noted a comparable behaviour on various types of engines and conditions. The addition of ethanol led to a significant rose in the octane number, and therefore resulted in an improvement in the antiknock behavior and in the combustion characteristics and brake power efficiency such as combustion pressure and torque.

In contrast, Pourkhesalian et al. [7] noted that thermal power of the engine that operates on gasoline is higher than those that work on other type of fuels because the engine is essentially designed for gasoline. In addition to that reason, the octane number of the other fuels is higher than that of gasoline. As a result, the engine compression ratio may possibly be higher if the engine was dedicated to those fuels, and thus engine performance might be improved.

Saravanan et al.[8] studied the engine that is run at wide open throttle and constant speed ranging from 1500 to 5000 rpm with around 500 rpm increment. Authors noted that the volumetric efficiency is decreased by 4-10% with CNG operation. Based on these results, the brake powers of the engine are reduced by 8-16%. Regarding emissions, the results showed that the HC, CO and CO_2 are significantly reduced by 40-66%, 55-87% and 28-30 % respectively, compared to gasoline. For the same trend of this study on the engine, Ajay K. Singh, and A. Rehman [9] confirmed that the exhaust emission is a dependent parameter on the engine speed. Their results on the Hydrocarbon (HC) emission showed a clear decrease when the engine speed varies from 2100 rpm to 2400 rpm at 11 kg to 14 kg engine load, respectively.

Babazadeh et al. [10] concluded that the engine performance parameters such as brake torque, brake power, brake thermal efficiency and volumetric efficiency increase with methanol amount in the blended fuel when engine was fueled with methanol–gasoline blend. This was because of the latent heat of evaporation of ethanol is higher than that of gasoline. Authors noted that the methanol is absorbed more heat from combustion chamber in comparison with the pure gasoline. As a result, the pressure of the combustion chamber is consequently decreased in the compression process.

In this experimental work, engine performance and combustion characteristics with different fuel types were investigated. Experiments were performed at different engine speeds which were from 1500 r.p.m to 4500 r.p.m. Four different types of fuel were tested and compared. The specific fuel consumption, brake specific fuel consumption, corrosion rate, and flue gas emissions were presented and discussed for all fuels examined.This study has been carried out at Pumps Eng. Dept. of Al-Musaib Technical College in Babylon / Iraq.

II. EXPERIMENTAL PROCEDURE

2.1 Engine and Equipment

In this study, the experiments were performed on engine, one cylinder, two valves, four stroke spark ignition. The schematic diagram of experimental setup for the engine is showed in Fig. 1. The engine specification is given in Table 1.

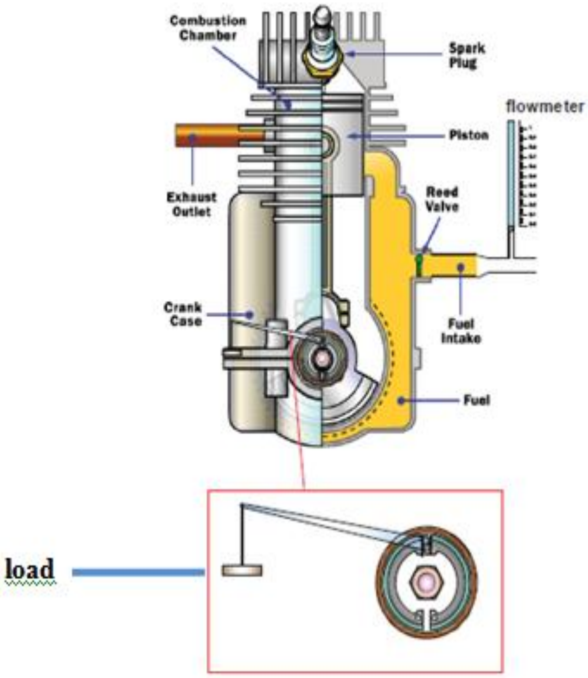

Fig. 1. The schematic diagram of experimental setup

Table 1. Specification of test

No. of Cylinder	1
Cylinder Bore (mm)	100
Stroke (mm)	150
Maximum Power (kW)	185

2.2 Types of Fuel used

In this experimental study, four different types of fuels are used and tested to improve the performance and exhaust emissions of a SI engine.

2.2.1 Gasoline

Gasoline (C_8H_{15}) is a mixture of volatile hydrocarbons with heating value about 43000- 47300 kJ/kg, and this hydrocarbon fuel is the most important component of crude oil resulted from the distillation at all.

2.2.2 Ethanol

It is one of alcohol types that have the chemical formula (C_2H_5OH) and heating value about 26950 –29710kJ/kg. It is also producing by the fermentation of the organic material which contains on carbohydrates mainly like more famous agricultures crops such as corn, wheat, barley [11].

2.2.3 Gasohol E10

It is a mixture between two types of fuels (gasoline & ethanol). It consists of blending 10% ethanol and 90% gasoline (vol. / vol.). Therefore, the selection of this fuel is based on being its most efficient type of Gasohol types. The chemical formula will be as C_8H_{15}+C_2H_5OH and its heating value near to gasoline heating value [12].

2.2.4 Kerosene

It is one of refining distillation process that is called as paraffin or paraffin oil. It is characterized with pale-yellow or colorless liquid with sensible odor. The boiling temperature is in a range between 140° C and 320° C. The flash temperature point is 25°C, and its chemical formula is C12H26 and heating value about 44116 - 47474 kJ/kg [13].

2.3 Procedure

The engine was tested performing of engine speed at 1500, 2000, 2500, 3000, 3500, 4000, and 4500 rpm at wide open throttle. Before running the engine to a new fuel blend, it was allowed to run for a sufficient time to consume the remaining fuel from the previous experimental test. The principle of engine operation used in this investigation was based on the Otto cycle for heat engines; so that it can be seen its principle of operation in Fig. 2. The following steps of engine operation, in this study, are summarized in four points:

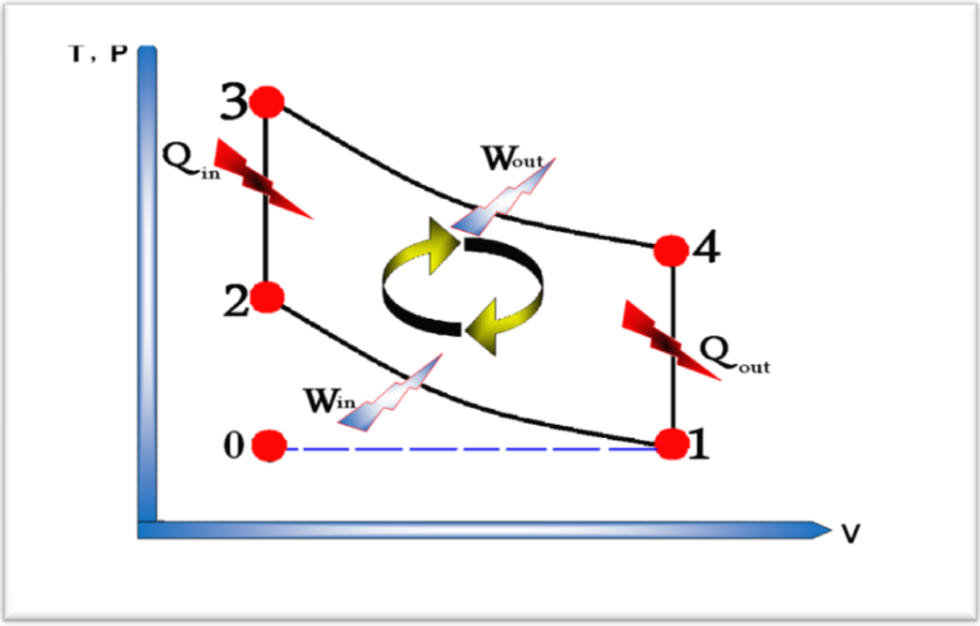

Fig. 2: Temperature and pressure versus volume in the Otto cycle for heat engines.

1. As the piston is moving from T.D.C towards B.D.C, due to adding a work from external source such as hander operating system or by self-operation system, this process generates reduction in the pressure inside the cylinder. Thus, this makes a clear difference in the pressure between inside and outside of the cylinder. As a result, a sufficient quantity of mixture (air/fuel) enters the combustion chamber after passing the tunnels of carburetor. This process is important in order to perform vaporization, and this is clearly represented in the path 0-1 in Fig.2. Also, this stroke is called a suction stroke.
2. After opposing the direction of piston due to the rotation of crank shaft, the piston moves form B.D.C towards T.D.C. This process tends to increase the pressure inside the cylinder that makes an increase in the temperature of mixture. This comes due to decreasing in the displacement volume of the cylinder. This process is represented by the curved

path 1-2 in Fig. 2. Also, this stroke is called a compression process.

3. As the spark plug is used, a high power inside the engine is generated resulting an increase in the heat and pressure due to explosion. Thus, a high value of pressure is increased at constant volume, as shown in Fig.2. Therefore, the piston is located at the same level, and it can be seen in the straight path (as referred in 2-3 in Fig.2). Because of an unstable condition of the system, an expansion process is developed in that state and this leads to increasing in volume and reducing in pressure, as represented in the path 3-4. Also, this process is called as a power stroke. It can be seen that this stroke has a significant importance in comparison with other strokes because of its ability to rotate the engine and causing a clear moving of piston from T.D.C towards B.D.C.

4. During the moving piston downward from the previous stroke, some power is saved in the fly wheel. However, this power is required to return the piston from B.D.C towards T.D.C. This process is needed so as to exit the flue gases out of the cylinder. This process is expressed in the straight line path (as referred in 4-1 path of Fig. 2), and this stroke is called as an exhaust stroke.

III. Results and Discussion

3.1 Specific fuel consumption

For performing the engine tests, the specific fuel consumption (sfc), which is equal to mass flow rate per unit time (m$\dot{f}$) divided by unit power output (p), is used to measure the engine efficiency. This is done considering the fuel supplied to produce work at different speeds of the engine, as displyed in equation (1). In Fig. 3 a-d, the fuel consumption for gasoline, kerosene, ethanol, and gasohol E10 respectively, are used to improve the engine-efficient at different applied loads. The loads on the engine were strated from 1500 to 4500 r.p.m. for all cases examined. As seen in Fig. 3 a-d, gasoline is clearly showed a less fuel consumption in comparison with the other typs of fuels used, particularly at maximum value of applied load. While the ethanol is displayed a higher fuel consumption. Both the gasohol E10 and ethanol are approximately similar in fuel consumption rates. At the minimum load, the fuel consumption of the gasoline and gasohol E10 are less than those of the kerosene and ethanol. The reason of that might be happened due to the higher energy content of gasoline and gasohol. Also, this can be attribued because of the initial tendency towads vapoization for kerosene and ethanol with respect to the gasoline and gasohol E10. At a constant speed engine of 3000 r.p.m., the fuel consumption for all types of fuel is measured, as seen in Fig. 4. The value of SFC of E10 was close to that of gasoline with respect to the higher values of kerosene and ethanol.

$$\text{sfc} = \frac{m\dot{f}}{P} \qquad (1)$$

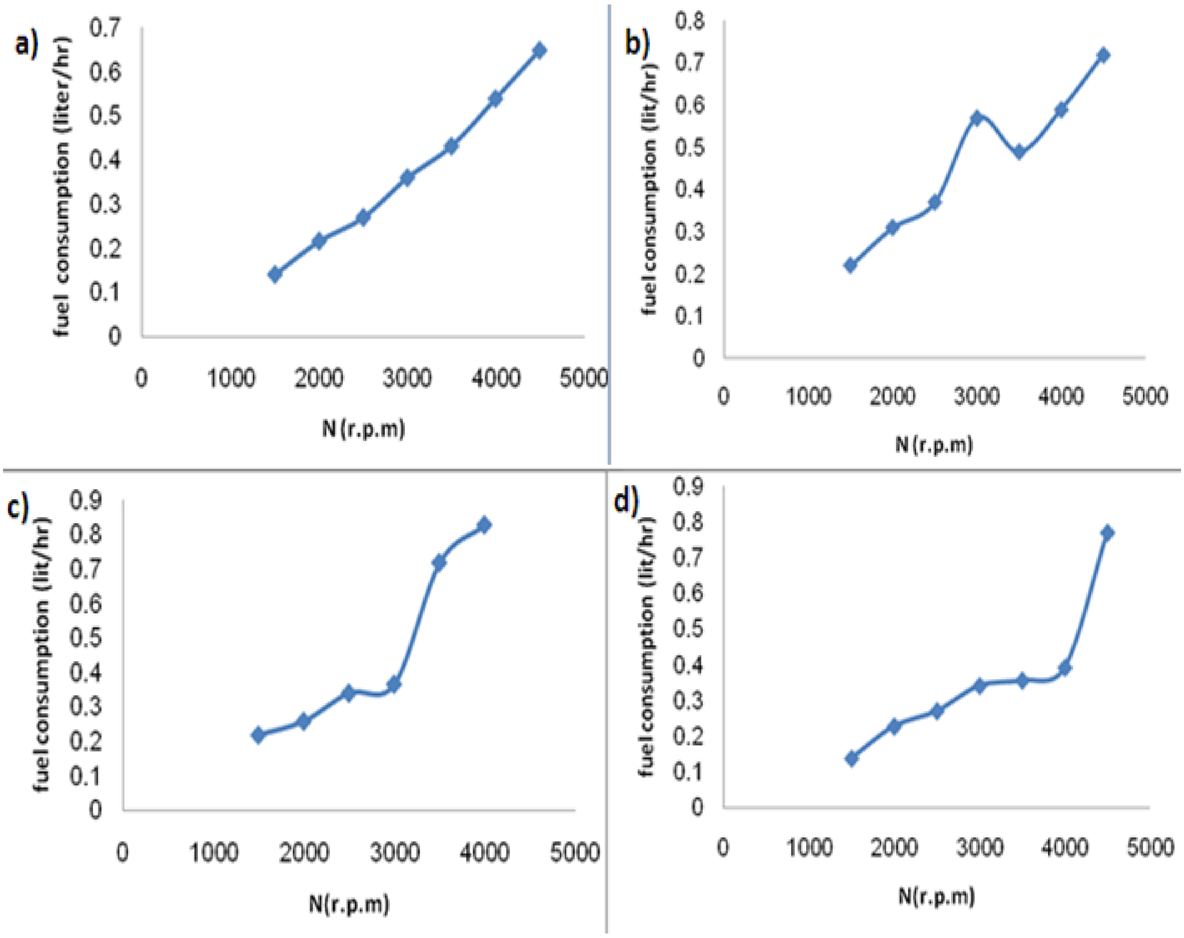

Fig. 3 a-d: The effect of speed engine on the fuel consumption for a) Gasoline, b) Kerosene, c) Ethanol, and d) GasoholE10.

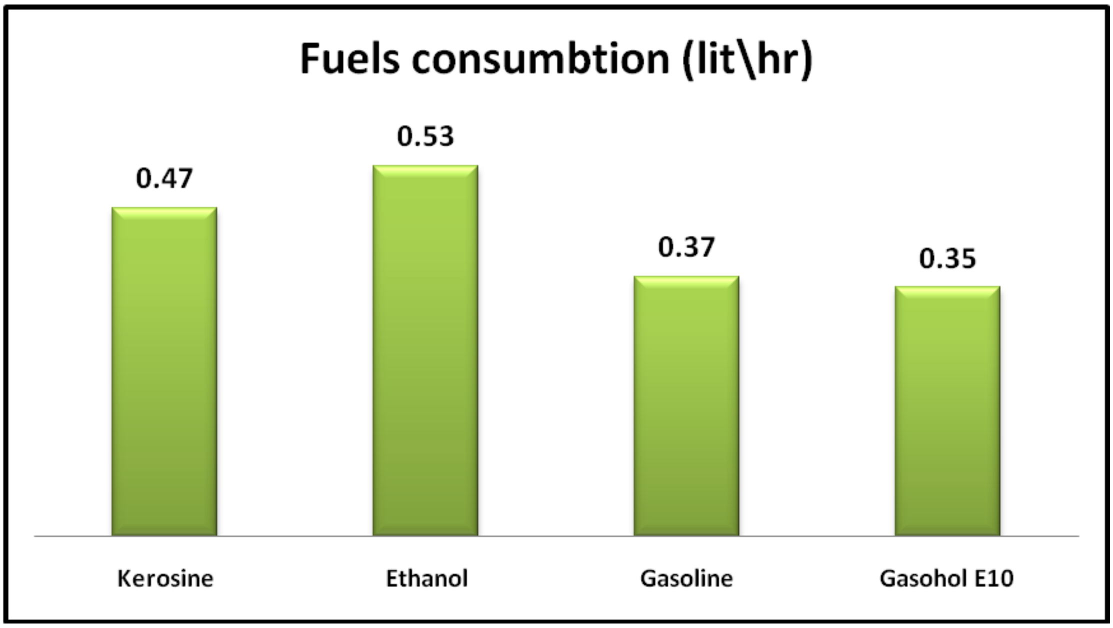

Fig. 4: The fuel consumption rate (lit/hr) for kerosene, ethanol, gasoline, and gasohol E10 at 3000 r.p.m.

3.2 Brake specific fuel consumption

The brake specific fuel consumption (BSFC) is the fuel flow rate per unit power output. Fig. 5 shows the relationship between BSFC and engine speed for different types of fuel used in this investigation. After increasing the appling load to 3000 r.p.m, the BSFC of ethanol is highly increased comparing with other types of fuel. This is likely occurred due to the lower heating value of ethanol (26950-29710 kJ/kg). Also, this value is not good enough to rotate the engine under the perfect condition as that happened with the standart fuel (gasoline) for combustion process. However, a slight increased of BSFC for gasoline is noticed with increasing the applied loads. For kerosene, the BSFC was identical to the ethanol trend in range between 1500 and 2500 r.p.m. After 3500 r.p.m. the curve is noticebly increased due to the high density material of kerosene, and that requires a more time to perform the ignition process. For comparison, gasohol E10 was approximentaly close to behaviour of gasoline consumption with increasing the engine speed beacuase of the improvement of chemical stucture of E10.

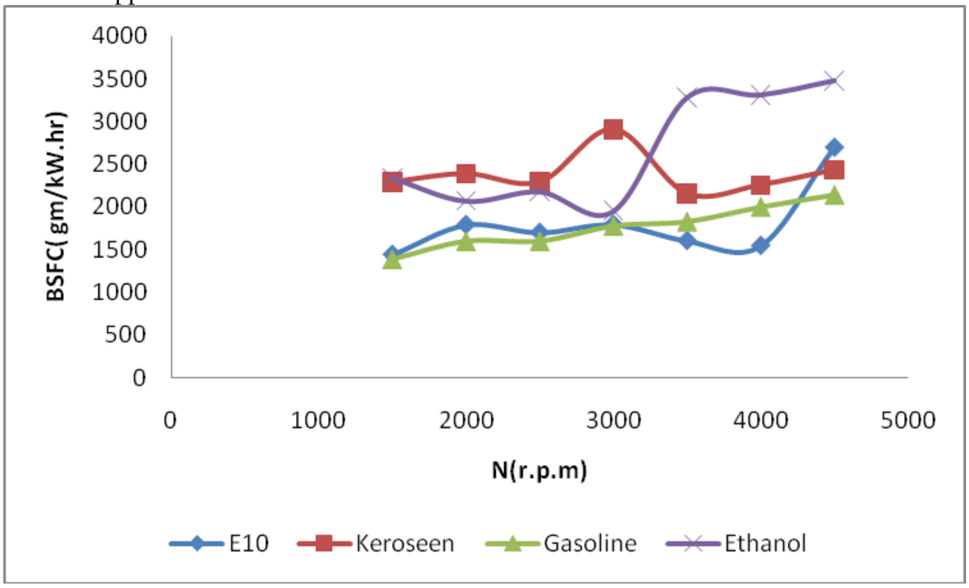

Fig. 5. The effect of fuel types on the BSFC at different applied loads.

3.3 Power developed

The comparison of indicated power (W_i), friction power (W_f), and efficiency for fuel tests are showed in Table 2. The friction power is given as (W_f = W_i-W_b). The results are indicated a better thermal efficiency and reduction in knocking for all fuel used except for Kerosene that displayed a less thermal efficiency.

Table 2: The values of indicated power, friction power, and efficiency for all fuel tested.

Fuel Type	Indicated power (W)	Friction power (W)	Efficiency (%)
Kerosene	237.92	53.105	77.67
Gasoline	199.4	14.58	92.6
Ethanol	209.33	22.59	89.1
Gasohol	208.49	23.67	88.6

3.4 Corrosion rate

The physics properties of specimen (Al_3) used in this study for corrosion rate tests are listed in Table 3.

Table 3: The physical properties of the specimen

Properties	Mass (kg)	Volume (m^3)	Density (kg/m^3)
Value	$9.188*10^{-4}$	$5.202*10^{-8}$	17662.4

In order to add another useful parameter for comparison among the fuel examined, the tests on the corrosion rates of the selected specimen are utilized. This importance of testing is basically dependent on the knowledge of favorite type of fuel used such as abundance, less pollution, less fuel consumption, and cost-effective basis. Table 4 shows the corrosion rate (mg per dec^2 per day) tests of the fuel used for about 20 hours of testing. The values of the corrosion rates were based on the weight of specimens (mg) before (W1) and after (W2) the corrosion process, as well as the surface area (dec^2) and time. The findings are displayed interesting results on this parameter. Gasohol E10 shows a better improvement on the corrosion rate with regards to gasoline, while the values of corrosion rate for kerosene and ethanol were identical and unfavorable. They were about four times higher than that of E10.

Table 4: The experimental results of corrosion rates for kerosene, Ethanol, Gasoline, and Gasohol E10.

No.	Fuel type	W1 (mg)	W2 (mg)	Time (day)	Surface area (dec^2)	Corrosion rate (mdd)
1	Kerosene	918.8	918.2	0.87	0.0228	30.24
2	Ethanol	915.4	914.8	0.87	0.0228	30.24
3	Gasoline	892.4	892.2	0.87	0.0228	10.08
4	Gasohol	896.5	895.3	0.87	0.0228	6.57

3.5 Carbon dioxide (CO_2) and carbon monoxide (CO) emissions

The emission of carbon dioxide is globally considered the main source of greenhouse gas (GHG) emissions in which its effect on the global warming [14][15][16]. In this section, the flue gas emissions of burning all fuel types with oxygen (O_2) inside the combustion chamber were undertaken, and the concentrations of CO and CO_2 (volume fraction, vol./vol.) are clearly presented, as shown in Figs. 6 and 7, respectively. As seen in Fig. 6, the concentration of CO for kerosene and E10 are low and approximately similar, while the CO for ethanol and gasoline are high. In contract, the concentration of CO_2 for the kerosene and E10 are higher than those of ethanol and gasoline, as presented in Fig. 7. Finally, it can be concluded that the burning process of E10 shows an improvement on the flue gas concentrations in comparison with those of the ethanol, and this gives a concrete confidence about the appropriate selection of fuel type.

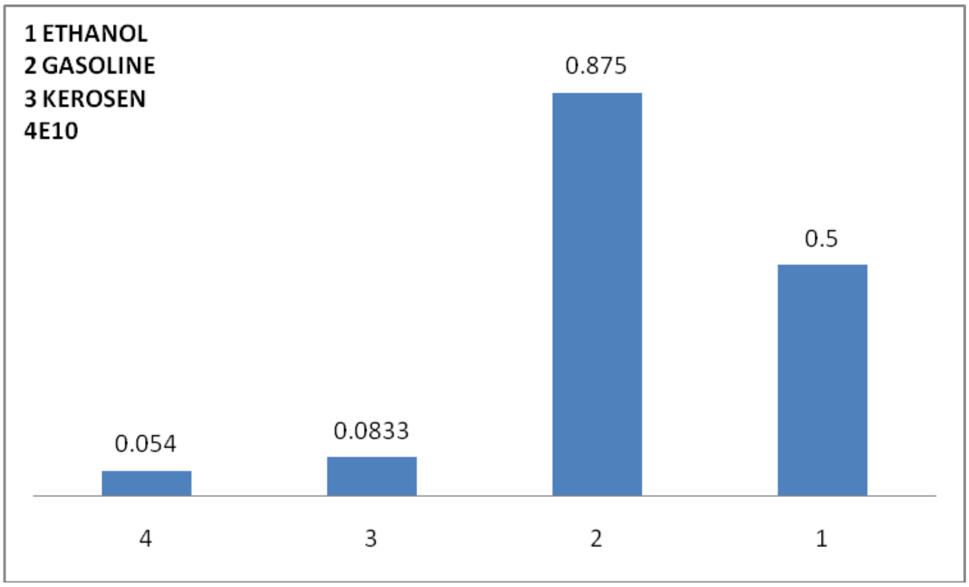

Fig. (6) The effect of fuel type on CO emission (vol./ vol.)

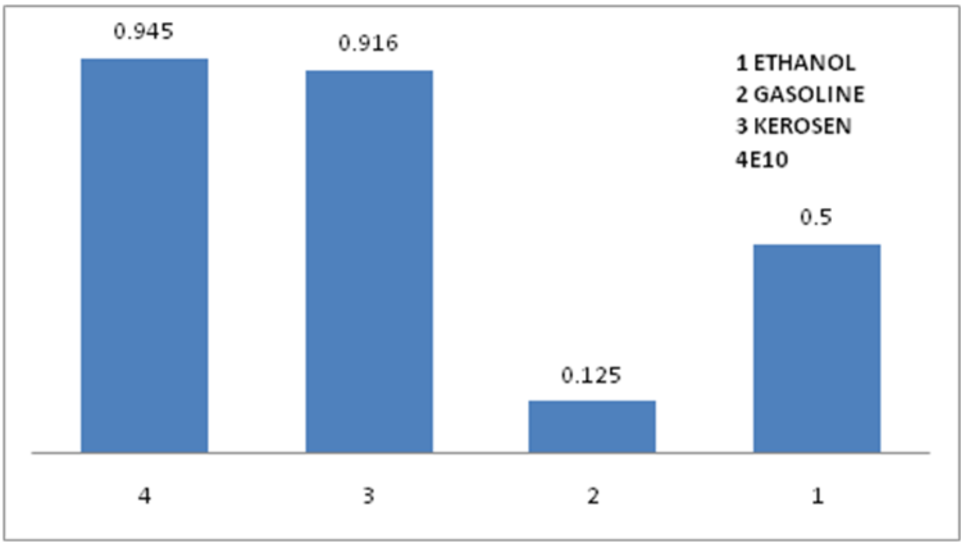

Fig. (7) The effect of fuel type on CO2 emission (vol./ vol.)

IV. Conclusion

This study has revealed that the use of variable fuel types in the IC engine has a potential improvement on the fuel consumption, power developed, corrosion rate, and species concentrations in the exhaust gases. In short, the following observations can be considered as conclusions for this experimental investigation:

1- The fuel consumption of the Gasoline and Gasohol E10, at minimum value of applied load, were less than those of the Kerosene and Ethanol. While at the maximum load, the fuel consumption of Gasoline was obviously less than those of the other types of fuel investigated.

2- Regarding the effect of fuel types on the brake specific fuel consumption (BSFC), the BSFC Gasoline and E10 were somewhat lower than those of the Ethanol and Kerosene with increasing the applied loads.

3- For Kerosene, the thermal efficiency of engine was notebly lower than those of Ethanol, gasoline, and Gasohol E10, and led negatively to an increase in knocking.

4- The corrosion rate of Gasohol E10 was showed a good improvement with the other types of fuel. Whereas the corrosion rates of the kerosene and ethanol were around four times higher than that of E10.

5- The concentrations of CO_2 and CO for Gasohol E10 were in a good level comparing with the other fuel used. This revealed a considerable improvement on the combustion characteristics and burning process in the IC engines.

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