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EXPERIMENTAL INVESTIGATION ON PERFORMANCE OF A SPARK IGNITION ENGINE RUNS WITH ALCOHOLIC BLEND-GASOLINE

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Abstract

In this paper performance resulted from a single cylinder spark-ignition engine fuelled with 20% by volume of methanol, ethanol, and butanol was studied and compared to gasoline. The experiments were conducted at variable speed and maximum torques. The conditions of stoichiometric air–fuel ratio at wide-open throttle were used. The tests were perfumed at higher useful compression ratio of the used Iraqi gasoline.

The test results show that the higher compression ratio for the tested gasoline was 7.5:1. So an Iraqi conventional gasoline has engine HUCR=7.5:1 and its OST= 19 ºBTDC, this compression ratio can be considered low.

Adding 20% of alcoholic blends by volume to gasoline improved the engine performance. Within the tested speed range, alcoholic blends produced higher brake powers, volumetric efficiency and thermal efficiency. In addition, it resulted in lower exhaust gases temperatures. The brake specific fuel consumption of the tested alcoholic blend was higher than that for gasoline.

Keywords: *methanol, ethanol, butanol, compression ratio, specific fuel consumption, exhaust gas temperature, performance*

1. Introduction

Due to the concerns of the lack in energy supply and the global warming, in recent decades, a greater emphasis made to improve the fuel economy and reduce the tailpipe emissions from vehicles [1]. Alcohol fuels, in particular methanol, ethanol and butanol, resulted in faster combustion and advanced auto-ignition than gasoline. Their use leads to lower HC, NOx and CO exhaust emissions [2]. Methanol used as a vehicle fuel by itself in transportation, blended with gasoline, or as a gasoline octane enhancer and oxygenate. Many literatures indicated a little doubt that methanol can improve the performance of the vehicle engine [3]. Schefter results show that employing hydrated ethanol blends leads to achieve higher pressures and lower intake temperatures. The combustion efficiency and combustion thermal efficiency do not affect by the water content in ethanol [4].

N-butanol or butyl alcohol can be used as a fuel for IC engine with gasoline without any engine modification. N-butanol produced from biomass (bio-butanol) as well as from fossil fuels (petro-butanol). Bio-butanol as well as petro-butanol has the same chemical properties. N-butanol characterized by it is less corrosive than ethanol. Compared with ethanol, it has higher energy content that is closer to gasoline. In addition, n-butanol has less water contamination. Butanol can be distributed using the same infrastructure used to gasoline. Many researches showed that butanol can be used a sole fuel in SI engines. Other researchers studied and improved that it can be blended with gasoline and used as a fuel [5, 6]. Butanol has higher heating value accompanied with higher stoichiometric air-fuel ratio, which allowed for blending it with higher levels in gasoline without changes in engine design. However, butanol has a lower latent heat of vaporization compared to ethanol that reduces the fuel atomization, evaporation, and combustion during cold start. Due to these properties, Wegg supported the replacement of bio-butanol instead of ethanol in spark ignition (SI) [7].

Diaz conducted many experimental studies clarified that methanol in gasoline engines, especially high-percentage-methanol blends or neat methanol, increases engine torque, efficiency, and power compared to baseline gasoline tests depending on the superior fuel octane rating [8]. Some of alcohols properties as an engine fuel are attractive. For instance, the initial boiling point of methanol (63ºC) is much closer to gasoline (32.8ºC). Methanol density is (913.2 kg/m^{3}at 20ºC) and its flash point is (-22ºC) [9].

Bio-ethanol is the most commonly alcohol used in SI engines because of its high octane number and its renewable nature [6]. Adding ethanol fuel to gasoline improves the combustion efficiency by enhancing the mixture-burning rate due to its high combustion velocity [10, 11]. The charge cooling effect as well as, high heating value of a stoichiometric mixture for ethanol blends (per unit mass of air); cause the increase of thermal efficiency [12, 13].

Many researchers concluded that at cold engine starts, methanol is more robust to than ethanol due to higher combustion stabilities and higher rates of vaporization. The high knock resistance ability of methanol supports the utilization of SI engines with higher compression ratio [14, 15]. Many researchers investigated methanol suitability as a fuel for both spark and high compression ratio. They concluded that it is suitable for the two systems, although they observed that when they used 15% methanol-gasoline blend, the brake power, mechanical efficiency, and thermal efficiency demonstrated a reduction [16-18].

The aim of recent paper is to study the differences when using methanol, ethanol and butanol as blends with Iraqi gasoline.

2. Experimental setup

2.1 Experimental apparatus

Experiments performed employing spark ignition engine, type (PRODIT GR306/0001). The engine is a single cylinder, water-cooled, four strokes and variable compression ratio engine. Fig. 1and 2 show the general arrangement of the experimental rig, while table (1) illustrates engine specifications. The engine rig is coupled to an air tank damped out the pressure variations in air that was entering into carburettor. A manometer used to measure the drop in air pressure across the used orifice to calculate the air volume drawn into the cylinder. The fuel supplied to the carburettor from the fuel tank through a measuring fuel gauge (burette). The engine torque was measured by means of a hydraulic dynameters. Several thermocouples type K (Ni-Cr/Ni-AL) was used to measure the exhaust gas temperature, it was fixed at the beginning of the exhaust tube. All the measuring instruments calibrated according to specifications.

The performance of spark ignition engine fundamental equations is [19]:

– The brake power:

$$BP=w_b*N/348.067, \tag{1}$$

where:
W_b – the load in (N),
N – engine speed (RPM).

– The gasoline brake specific fuel consumption:

$$BSFC= \dot{m}_f*3600/BP, \tag{2}$$

where: $\dot{m}_f$= fuel consumption mean (kg/kw.hr)

– The alcoholic blend brake specific fuel consumption [20]:

$$BSFC = \frac{\left(\dot{m}_{alcohol}\times LHV_{malcohol}+\dot{m}_{gasoline}\times LHV_{gasoline}\right)*3600}{BP}, \tag{3}$$

where: $\dot{m}_{alcohlo}$ and $\dot{m}_{gasoline}$ are the mass flow rates (g/s) of the alcohol and gasoline fuels. $LHV_{alcohol}$ and $LHV_{gasoline}$ are the lower heating values of the alcohol and gasoline fuels respectively. BP is the engine brake power.

– The volumetric efficiency:

$$\eta_{vol}= (m_a)_{act}/(m_a)_{theo}. \tag{4}$$

– The brake thermal efficiency:

$$\eta_{bth}= BP/ \dot{m}_f*(L.C.V). \tag{5}$$

The stoichiometric air/fuel ratio was evaluated, and then equivalence ratio can be defined as [21]:

$$\emptyset = \frac{\frac{[G]}{[air]-\frac{[Alcohol]}{([AlcoholM]/[air])_{st}}}}{\left(\frac{[G]}{[air]}\right)_{st}}. \tag{6}$$

where the rate of heating energy = fuel mass flow rate × LHV. The denominator in Eq. (5) is the rate of the total heating energy of the two fuels. The MGR was varied by changing the mass flow rates of both alcohol and gasoline fuels.

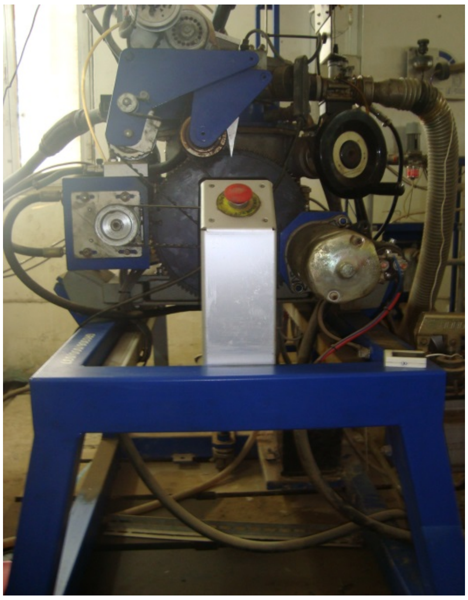

Fig. 1. Single cylinder Prodet SIE

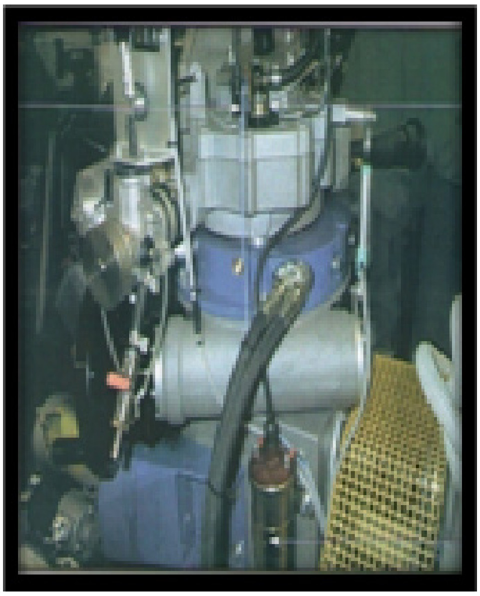

Fig. 2. Single cylinder Prodet SIE

Tab. 1. Engine specifications

Manufacturer	PRODIT	No load speed range	500-3600 RPM (Otto cycle)
Cycle	OTTO or DIESEL, four strokes	Load speed range	1200-3600 RPM (Otto cycle)
Number of cylinders	1 vertical	Intake start	54° before T.D.C
Diameter	90 mm	Intake end	22° after T.D.C
Stroke	85 mm	Exhaust start	22° before T.D.C
Compression ratio	4-17.5	Exhaust end	54° after T.D.C
Max .power	4 kW 2800 RPM	Fixed spark advance	10° (spark ignition)
Max .torque	28 Nm at 1600 RPM	Swept volume	541 cm^3

3. Materials

Combustion tests were carried out using, the Iraqi gasoline with ON=82 produced by Al Doura refinery as the baseline fuel. Moreover, blends of 20% methanol, ethanol and butanol by volume with gasoline were tested. The used alcohols possessed high octane number and are often used as an octane improver in reformulated gasoline blends. In this study, the mixtures are prepared on the volume basis. Alcohols were blended with 20% by mass. The alcohols blended with gasoline; this blend is known as M20 for 20% methanol, E20 for 20% ethanol, and B20 for 20% butanol. The fuel properties were determined in the Fuel Laboratory of the Department of Chemical Engineering, UOT. Tab. 2 shows some of the gasoline, methanol, ethanol and butanol properties.

Tab. 2. Properties of the typical gasoline, methanol and ethanol

Property	Gasoline	Methanol	Ethanol	Butanol
Chemical formula	various	CH_3OH	C_2H_5OH	C_4H_9OH
Oxygen content by mass [%]	0	50	34.8	21.6
Density at NTP [kg/l]	0.74	0.79	0.79	809.8
Lower heating value [MJ/kg]	42.9	20.09	26.95	33.6
Volumetric energy content [MJ/l]	31.7	15.9	21.3	29.2
Stoichiometric AFR [kg/kg]	14.7	6.5	9	8.6
Energy per unit mass of air [MJ/kg]	2.95	3.12	3.01	3.08
Research octane number	89-95	109	109	96
Motor octane number	85	88.6	89.7	78
Boiling point at I bar [ºC]	25-215	65	79	117.7
Heat of vaporization [kJ/kg]	180-350	1100	838	582
Reid vapour pressure [psi]	7	4.6	2.3	3
Flammability limits in air [λ]	0.26-1.6	0.23-1.81	0.28-1.99	0.29-1.99
Laminar flame speed at NTP, Ø=1 [cm/s]	28	42	40	41
Adiabatic flame temperature [ºC]	2002	1870	1920	1967
Specific CO_2 emissions [g/MJ]	73.95	68.44	70.99	72.3

4. Test

The tests conducted at steady-state conditions. The engine was permitted to run until its steady state conditions were reached, and then, the tests were performed. The engine was firstly warmed up with the coolant and lubricating temperatures stabilized. All the tests were carried out at stoichiometric air–fuel ratio (AFR).

The first set of experimental tests started with pure gasoline, and the tests results were taken as a database performance level on the basis of which the comparison will be carried out. The experiments were performed for gasoline starting from CR=6:1, and on, to find used gasoline higher useful compression ratio. All blends were tested at this HUCR of gasoline. All the tests were conducted at wide-open throttle carburettor conditions. The tests were repeated three times and average values were presented to reduce the experimental uncertainties.

The blends tests carried out in this work were done under constant spark timings, 19ºBTDC and the maximum brake torque. The gasoline-alcohols blends variations tested at wide range of engine speeds.

5. Results and discussion

Figure 3 shows that brake power (BP) curve at CR=7.5:1 declined at low and high speeds. Engine operation at constant spark ignition with valuable fuels (gasoline-alcoholic blends) and maximum engine torque caused engine knock at these brake powers. The occurrence of engine knock required reducing engine torque to get rid of knock. The methanol portion in M20 caused higher octane number and high knocks resistance. Butanol blend revealed higher bp than ethanol.

BSFC depends on resulted brake power as equations 2 and 3 represents. BSFC increased as the speed increased. Brake power increase at constant speed reduced engine fuel consumption and verse versa, as Fig. 4 declares. If gasoline is taken as the baseline then operating the engine with M20, E20 and B20, the bsfc increased with about 12.26, 11.9 & 14.27% respectively. These increments were due to the lower heating values of the alcoholic blends compared with gasoline.

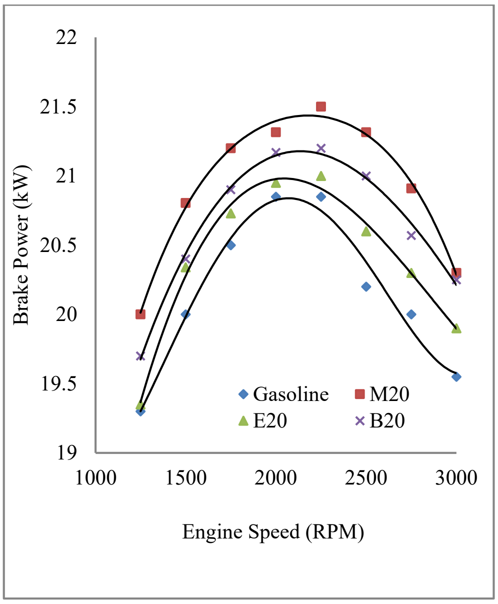

Fig. 3. The effect of engine speed on bp for the tested fuels

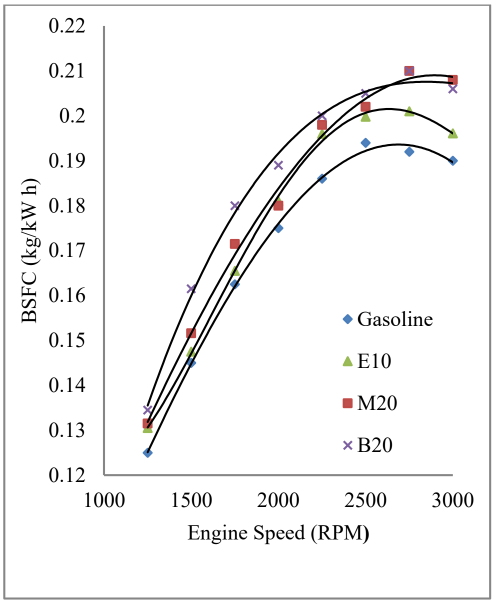

Fig. 4. The effect of engine speed on bsf for the tested fuels

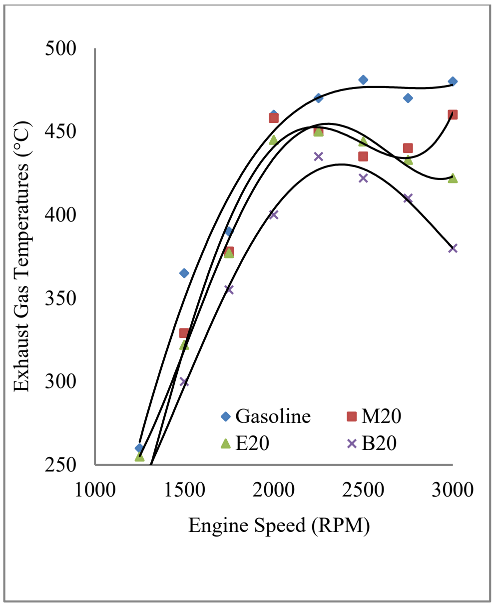

Fig. 5. The effect of engine speed on Exhaust gas temperatures for the tested fuels

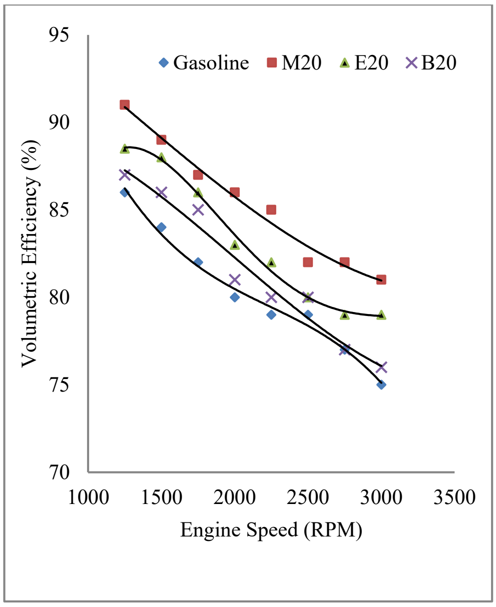

Fig. 6. The effect of engine speed on the volumetric efficiency for the tested fuels

Increasing engine speed means more fuel is needed to give more energy, and higher exhaust gas temperature resulted as Fig. 5 manifests. The three studied alcoholic blends addition reduced exhaust gas temperatures.

Figure 6 represents the effect of engine speed on volumetric efficiency for the studied fuels. Adding alcoholic blends increased volumetric efficiency due to its oxygen content in its structure that required less air for combustion. Volumetric efficiency decreased with the increase of engine speed, due to less time available for suction.

Brake thermal efficiency increases by increasing the brake power or reducing the value of {$\dot{m}_f$* *(LHV)*}, as equation 5 clarifies. Fig. 7 illustrates that due to the aforementioned reason, alcoholic blends surpassed gasoline brake thermal efficiency at the studied conditions. The increments were about 2.87 and 1.12, and 1.77% for M20, E20 and B20 respectively.

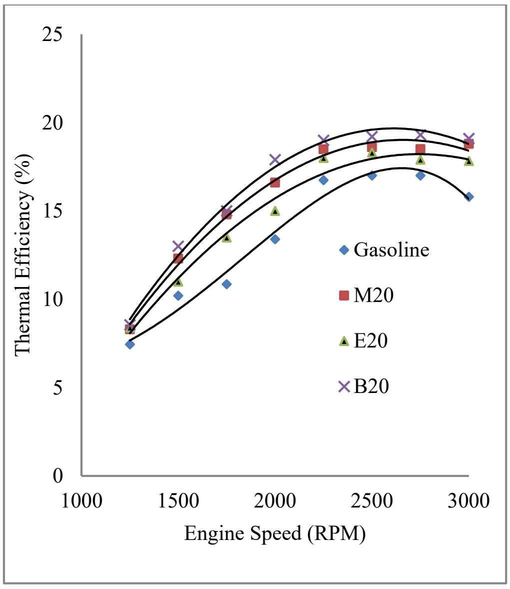

Fig. 7. The effect of engine speed on the thermal efficiency for the tested fuels

6. Conclusion

The effect on of alcoholic blended in volume with pure gasoline on the spark-ignition combustion process was investigated. A single-cylinder SI engine variable compression ratio operating at variable speeds and wide-open throttle was used in this study. The spark timing leaved constant with operation at maximum brake torque and the knocking limit. Blend of methanol, ethanol and butanol of 20% were used. The stoichiometric mixture for all tested fuels was used in this work. Conclusions can be summarized as follows:

1. Iraqi conventional gasoline has engine HUCR=7.5:1 and its OST= 19 ºBTDC, this compression ratio can be considered low. Adding 20% of alcoholic blends by volume to gasoline improved the engine performance.
2. The leveraging effect of alcoholic blended fuels on improving engine performance could be attributed to factors such as the cooling effect of the added fuel.
3. Operating the engine with M20, E20 and B20 increased the brake thermal efficiency compared to gasoline operation.
4. Exhaust gas temperature decreased with alcohols addition due to its lower heating values compared with gasoline.

Finally, from the test matrix, it was found that the alcoholic blends appeared to be a good nominated fuel compared to the conventional Iraqi gasoline operation.

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NOMENCLATURE

BTDC	Degree before top dead Centre
BSFC	Brake specific fuel consumption
BP	Brake power
CR	Compression ratio
CA	Crank angle
EGR	Exhaust gas recirculation
HUCR	Higher useful compression ratio
OST	Optimum spark timing
SIE	Spark ignition engine
$\dot{m}_f$	Fuel flow rate
η_{bth}	Brake thermal efficiency
η_{vol}	Volumetric efficiency