PERFORMANCE CHARACTERISTICS OF METHANOL-DIESEL BLENDS IN CI ENGINES

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ABSTRACT

Owing to the energy crisis and pollution problems of today, investigations have concentrated on decreasing fuel consumption and on lowering the concentration of toxic components in combustion products by using non-petroleum, renewable, sustainable and non-polluting fuels. While conventional energy sources such as natural gas, oil and coal are non-renewable, alcohol can be coupled to renewable and sustainable energy sources.

In this study, the combustion characteristics of diesel fuel and methanol blends were compared. The tests were performed at steady state conditions in a four-cylinder DI diesel engine at full load at 1500-rpm engine speed. The experimental results showed that diesel methanol blends provided 12.7% increase in brake-specific fuel consumption due to its lower heating value. The results indicated that methanol may be blended with diesel fuel to be used without any modification on the engine.

مواصفات أداء خلائط ديزل- ميثانول في محركات الاشتعال بالانضغاط

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الخلاصة

أهتمت الأبحاث العلمية الحديثة بتقليل استهلاك الوقود وتقليل الملوثات السامة الناتجة من الاحتراق، بسبب الأزمة العالمية الخاصة بالطاقة ومشاكل التلوث، وذلك باستخدام أنواع من الوقود المتجدد، المتوفر وغير مسبب للتلوث، ويمكن اعتبار الكحول مصدر طاقة متجددة ومتوفرة، بينما أنواع الوقود التقليدي مثل الغاز الطبيعي، النفط والفحم غير متجددة.

في هذة الدراسة، تمت مقارنة مواصفات أداء وقود ديزل وخلائط من الديزل-الميثانول، وأجريت التجارب باستخدام محرك رباعي الاسطوانات ذي حقن مباشروعند حمل كلي وسرعة 1500 rpm، وبينت النتائج أن خلائط الديزل-الميثانول تسبب ارتفاع في استهلاك الوقود النوعي المكبحي بحدود 12.7 %، بسبب انخفاض القيمة الحرارية له، وبينت النتائج أن الميثانول يمكن استخدامه باضافتة الى وقود الديزل بدون عمل أي تحويرات في المحرك.

KEY WORDS

Methanol, diesel, equivalence ratio, engine speed, brake power, specific fuel consumption, indicated thermal efficiency, exhuast gas temperature.

INTRODUCTION

The higher efficiency of compression ignition direct injection diesel engines compared to spark ignited gasoline engines makes them desirable for automotive and truck vehicles, especially now with ever increasing crude oil prices, driven mainly by significant increases in demand (Bertoii, 1997).

As for the fuels in diesel engines, research has been conducted to identify the effects of fuel properties on diesel combustion and exhaust emissions. For example, sulfur content in fuels has been reduced in order to improve the acid rain problem and its reduction to 0.05 wt-% has been set as regulations to reduce particulate levels (Huang, 2003). Other fuel properties related to the improvement include aromatic content, ignitability, oxygen content, and viscosity and distillation temperature (Akasaka, 1996). As for oxygen content or oxygenates, the addition of lower alcohols such as methanol and ethanol to diesel fuel was effective in reducing particulate emissions without sacrificing other emission components (Nabil, 2006).

Practically, adding some oxygenated compounds to fuels to reduce engine emissions without engine modification seems to be a more attractive proposition. Methanol is regarded as one of the promising alternative fuels or oxygen additives for diesel engines with its advantages of low price and high oxygen content. However, due to the difficulty in forming a stabilized diesel/methanol blend, few reports found on this topic, and previous work was mainly concentrated on the application of diesel/ethanol blends in a compression ignition engine (Huang, 2004 & Fleisch, 1995). Therefore, much work is needed in the application of diesel/methanol blends in compression-ignition engine for clarifying the basic combustion and emission characteristics and providing an approach for attaining a stabilized diesel/methanol blend with some solvent, and the study could be expected to supply more information on engine combustion when operating on oxygenated fuels and provide more practical measures for the improvement of combustion and reduction of emissions (Huang, 2005).

However, there were problems as the methanol has inherently poor solubility to diesel fuel and poor lubricity, and its lower ignitability made it impossible to use neat alcohols or high blending ratios in conventional diesel fuel without special measures to improve ignition (Huang, 1999).

Methanol is also known as methyl alcohol and its chemical formula is CH_3OH. Commercially, methanol is most commonly produced by steam reforming of natural gas. In this process, the natural gas is first transformed into CO and hydrogen. Methanol is then produced by combining the CO and hydrogen under high temperature and pressure in the presence of special catalysts. Methanol was once made from the destructive distillation of wood (hence it's other common name, “wood alcohol”), but this process is no longer economically viable (Shi, 2005).

Methanol is poisonous and prolonged exposure to vapors and wetting of the skin are to be avoided. Methanol is more corrosive than gasoline and requires that minor changes be made in gasoline fuel system materials to be compatible (McCormic, 2000). Methanol was the alternative fuel that first received attention and serious funding from state agencies and engine manufacturers. The results of several demonstrations have been documented in a number of interim and final reports Issues related to transit vehicle characteristics that are often considered for methanol transit bus operation include performance and acceleration, vehicle range, vehicle weight limits, compatibility of fuel system materials with methanol, and travel through tunnels (Tsolakis, 2007 & Kajitani, 1997).

Because methanol is corrosive to some metals and damaging to rubber and some plastics, fuel storage tanks and dispensing equipment must be corrosion and damage resistant. These include the fuel tank, fuel lines, fuel injectors, fuel pumps, and filters. Also, because methanol is water soluble, it could be quickly diluted in large bodies of water to levels that are safe for organisms. Environmental recovery rates for methanol spills are often faster than for petroleum spills (Kapus, 1995).

Instead of the octane number, the cetane number is the key parameter for a diesel fuel. For a conventional diesel fuel, the cetane number is around 40-55. Fuels with high cetane numbers result in smoother engine operation and reduced emissions of NOx, particulate matter, hydrocarbons, and CO. Cetane numbers of 15 to18 for ethanol and methanol, is considered very low cetane numbers. In addition to the cetane number, flash point and pour point temperatures are also important parameters for a diesel fuel (Hu, 2008). Even though some cetane improving additives are capable of reducing NOx level, the amount of reduction is reported to be inadequate. Moreover, most of the additives are expensive and can promote auto-oxidation in biodiesel (Miyamoto, 1998).

The volumetric energy density of the fuel is an important parameter since it directly affects the size of the fuel storage system of tile vehicle. Unfortunately, all of the alternative fuels are less energy dense per volume compared to gasoline or diesel (Table 1). It is noticed that diesel fuel is the only fuel better than gasoline, which accounts for 12 per cent of the higher fuel economy (mpg) associated with the disel-powered vehicle (Jacobs, 2003).

Liquid fuels have a better volumetric energy density than gaseous fuels. They also are the most compatible fuels with existing distribution systems and engines. i.e. they require the least departure from the technologies in place today both the vehicle and the refueling infrastructure (Puhan, 2009).

Since methanol is not only corrosive but also insufficient in lubricating ability (Wang, 2008), elemental research has been needed to so1ve these issues. However, elemental research can be explained at another opportunity and this paper describes the operating performance of a methanol diesel engine without touching elemental research.

The objectives of this study was to form the oxygenated blends by adding methanol and solvent in diesel fuel and then study the performance characteristics in a compression ignition engine fueled with the oxygenated blends.

EXPERIMENTAL SETUP

Experimental apparatus of engine under study is DI, water cooled four cylinders, in-line, natural aspirated FIAT diesel engine whose major specifications are shown in Table 1. The engine was coupled to a hydraulic dynamometer through which load was applied by increasing the torque. The cylinder pressure was obtained by a Kistler piezoelectric sensor type 6125A, the output of the pressure transducer was amplified by a Kistler charge amplifier type 5015A, and then converted to digital signals and recorded by a data acquisition apparatus (Yokogawa: GP-IB), which was used to calculate the rate of heat release and analyze the combustion characteristics. **Fig.1** represents photo of the used engine.

Three kinds of diesel/methanol blends with different methanol additions were selected for the study. Due to the low solubility of the methanol in diesel fuel, a solvent consisting of oleic and iso-butanol was added into the diesel/methanol blends to develop the stabilized diesel/ methanol blends. Fuel properties and the constitutions of three blends are given in **Tables 2, 3** and **Fig. 2**, and the oxygen fraction in the fuel blends ranged from 5.87 to 11.1 as shown in **Table 3** and **Fig. 3**. It can be seen that the oxygen in the fuel blends come mainly from methanol addition although the mass fraction of methanol and solvent has the same level, so it is reasonable to regard the influence of oxygen in the fuel blends to be the influence of oxygen from the addition of methanol. The solvent was added to methanol in the exact wanted ratefirst. Then the mixture was added to diesel fuel to perform the combustible mixture.

The following equations were used in calculating engine performance parameters:

1- Brake power

$$bp = \frac{2\pi * N * T}{60 * 1000} \quad kW$$

2- Brake mean effective pressure

$$bmep = bp \times \frac{2 * 60}{V_{sn} * N} \quad kN/m^2$$

3- Fuel mass flow rate

$$\dot{m}_f = \frac{v_f \times 10^{-6}}{1000} \times \frac{\rho_f}{time} \quad kg/_{sec}$$

4- Air mass flow rate

$$\dot{m}_{a\,act.} = \frac{12\sqrt{h_o * 0.85}}{3600} \times \rho_{air} \quad \frac{kg}{sec}$$

$$\dot{m}_{a_{theo.}} = V_{s.n} \times \frac{N}{60 * 2} \times \rho_{air} \quad \frac{kg}{sec}$$

5- Brake specific fuel consumpotion

$$bsfc = \frac{\dot{m}_f}{bp} \times 3600 \quad \frac{kg}{kW.hr}$$

6- Total fuel heat

$$Q_t = \dot{m}_f \times LCV \quad kW$$

7- Brake thermal efficiency

$$\eta_{bth.} = \frac{bp}{Q_t} \times 100 \quad \%$$

The fuel properties show that methanol has high oxygen content, while the heat value is low, and cetane number is low compared to diesel fuel. In the experiment, the above three fuel blends with different methanol proportions were operated on the engine; meanwhile combustion characteristics were measured and analyzed at the same brake mean effective pressure (bmep), and same injection timing (38˚BTDC). Furthermore, these parameters were compared with those of pure diesel combustion in order to clarify the effect of an oxygenated additive on combustion.

DISCUSSION

The BSFC is defined as the ratio of mass fuel consumption to the brake power. The percent variation in the BSFC with methanol–diesel fuel blends compared to diesel fuel is shown in **Fig. 4**. The obtained BSFC results for different diesel/methanol blends. Due to low energy content of the methanol, there is an increasing trend in BSFC with increasing methanol content in the fuel mixture compared to diesel fuel, at low and meduim loads.

Among the tested fuels the lowest BSFC values were obtained with diesel fuel because of low fuel consumption rate. The results showed that BSFC increases significantly when the engine is fueled with the blends having high methanol content due to lower heating value and density of methanol. As shown in **Fig. 4**, BSFC values increased with about 12.7% with M05 (5% methanol), about 15.1% increament with M10 (10% methanol), and increased 22.3% with M15 (15% methanol).

Volumatric efficiency improved with increasing methanol portion in the fuel mixture, due to OH ion in its structure, as **Fig. 5** shows. This efficiency reduced with increasing load, due to injected fuel increament inside the combustion chamber.

Brake thermal efficiency (BTE) of an engine is the efficiency in which the chemical energy of a fuel is turned into useful work. Compared to diesel fuel, the changes in the BTE of the engine using methanol–diesel fuel blends are shown in **Fig. 6**. There are very slight decreases in BTE with the use of M5 and M10 compared to diesel fuel. In the test operations with the fuel blends, the engine yields relatively high BTE values for the blends up to 10%, which can be attributed to the promoted combustion due to the oxygen content of the blends.

(Irshad, 2001) stated that the fuel blends up to 10% do not cause a significant decrease in the energy content and cetane number of the fuel. In BTE, a noticeable decrease was observed in the case of M15, which results from the considerable increase in BSFC as seen in **Fig. 4**, the change in BTE relative to M0 is 6.2%, 9.3% and 23.4% for M5, M10 and M15, respectively, at constant injection timing.

Exhaust gas temperatures increased with load increase, and increased by increasing methanol percentage in the fuel mixture by 5.9% and 11.6% for M5 and M10 respectively, and reduced by 8.7% for M15 as **Fig. 7** repersents. Increasing load needs more fuel to be burned, and burning more fuel means more released heat and higher exhaust gas temperatures as a result. Increasing methanol portion in the blends M5 and M10 improve combustion charactristics, and increased the released heatby using excess oxygen in thecombustion chamber. The reduction accompanied with M15 was due to the reduction in the heating value of methanol which effect start to appear, the resulting was lower exhaust gas temperatures.

Engine speed effect on resulted brake power (bp) emplaced in **Fig. 8**, bp increased from low to meduim speeds and reduced at high speeds. Bp went down with methanol addition, M10 exhabited improvement compared to other blends, and the reduction in bp for this blend was very limitted. For the other blends the reduction was clear. The improvement when M10 was used due to volumatric efficiency amelioration, while the deterioration of bp with other blends was due to lower heating value effect which overcome the effect of better volumatric efficiency.

BSFC increased with increasing engine speed, as **Fig. 9** shows, as well as it increased with increasing methanol percentage in the blends. Increasing engine speeds means increasing injected fuel, which means BSFC increament, and as mintioned before, because of lower methanol heating value, BSFC increased with increasing methanol perentage in the blends.

Exhaust gas temperature increased with increasing engine speed and increased by using M5 and M10 and reduced for M15, as **Fig. 10** represents. Increasing engine speed needs more power which will be drawn from burning fuel, this cause more fuel to be burned and more resulted exhuast gas temperatures. These temperatures reduced with increasing methanol percentage to 15% depending on reduction of fuel total heating value, and the increaments with M5 and M10 were due to improvements in released energy because of increasing fuel oxygem content, which overcame the reduction in heating value.

CONCLUSION

Environmental protection is an important issue for the future of the world. Because of the reducing amount of petroleum reserves and its rising price, alternative fuels are intensively investigated for the full or partial replacement with diesel fuel. Therefore, in this study, the effect of methanol addition on the performance of a DI diesel engine has been experimentally investigated during the usage of methanol-blended diesel fuel. The tests were conducted at variable loads and at constant and variable engine speed. The following conclusions can be drawn from the present paper:

(1) When methanol-blended-diesel fuel was used, BSFC increased due to the lower energy content of methanol.
(2) All fuel blends yielded a decreased BTE in proportional to the methanol amount in the blend.
(3) Volumatric efficiency improved with methanol addition due to oxygen in its structure.
(4) Exhaust gas temperature increased for M5 and M10, and reduced with increasing methanol percentage to M15 in the blended fuel.
(5) M10 exhabited higher bp compared to other blends, approched nearly to diesel fuel.

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NOMENCLATURE

TDC	top dead centre
BDC	bottom dead centre
BMEP	brake mean effictive pressure
BSFC	brake specific fuel consumption
BTE	brake thermal efficiency
$m^{o}_{a, act.}$	actual air mass flow rate
$m^{o}_{a,theo}$	theoratical air mass flow rate
Q_t	total fuel heat
LCV	lower calorific value

Fig.1. a photographic picture of the exprimintal rig.

Table 1, Tested engine specifications

Engine type	4cyl., 4-stroke
Engine model	TD 313 Diesel engine reg
Combustion type	DI, water cooled, natural aspirated
Displacement	3.666 L
Valve per cylinder	two
Bore	100 mm
Stroke	110 mm

Compression ratio	17
Fuel injection pump	Unit pump 26 mm diameter plunger
Fuel injection nozzle	Hole nozzle 10 nozzle holes Nozzle hole dia. (0.48mm) Spray angle= 160^o Nozzle opening pressure=40 Mpa

Table 2, Fuel properties of diesel, methanol and blended fuel consititions

property	diesel	methanol	Solvent	
			Oleic	Iso-butanol
Chemical formula	$C_{10.8}H_{18.7}$	CH_3OH	$C_{18}H_{34}\ O_2$	$C_4H_{10}O$
Mole weight (g)	148.3	32	282	74
Density (g/cm^3)	0.86	0.796	0.8905	0.802
Lower heating value (MJ/kg)	44.40	19.68	38.65	33.14
Heat of evaporation (kJ/kg)	260	1110	200	580
Self-ignition temperature (^{o}C)	200-220	470	335	385
Cetane number	45	5	40	10
C wt%	86	37.5	76.6	64.8
Hwt%	14	12.5	12	13.5
O wt%	0	50	11.4	21.7
Blended fuel 1 wt%	79.86	8.96	10.1	1.08
Blended fuel 2 wt%	71.28	13.33	14.47	0.92
Blended fuel 3 wt%	63.94	17.66	16.6	1.8

Table 3, fuel properties of diesel/methanol blended fuel consititutions

Property	Blended fuel 1	Blended fuel 2	Blended fuel 3
Lower heating value (MJ/kg)	41.73	39.89	38.64
Heat of evaporation (kJ/kg)	333.53	367.57	405.94
Cetane number	40.41	38.4	36.21
C wt%	80.47	77.98	75.5
Hwt%	13.66	13.5	13.4
O wt%	5.87	8.52	11.1
O wt% contributed from methanol	4.48	6.67	8.83
O wt% conntributed from solvent	1.39	1.85	2.27

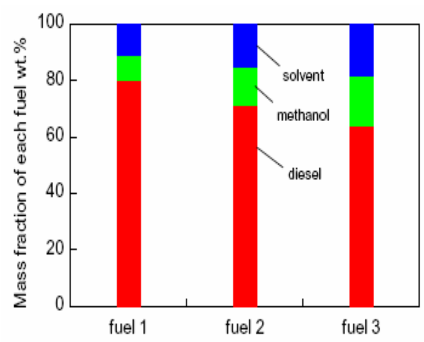


Fig 2, Consititution of the fuel blends.

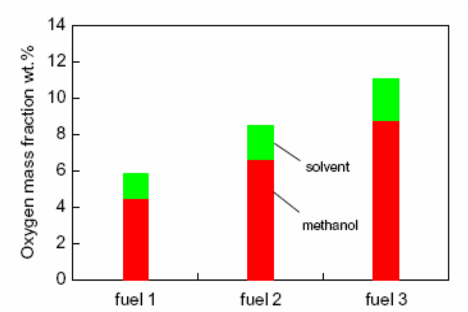
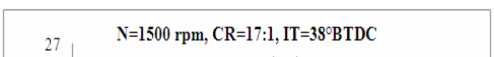
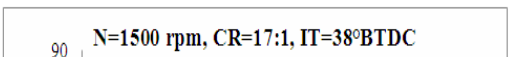


Fig 3, Oxygen mass fraction in the fuel blends





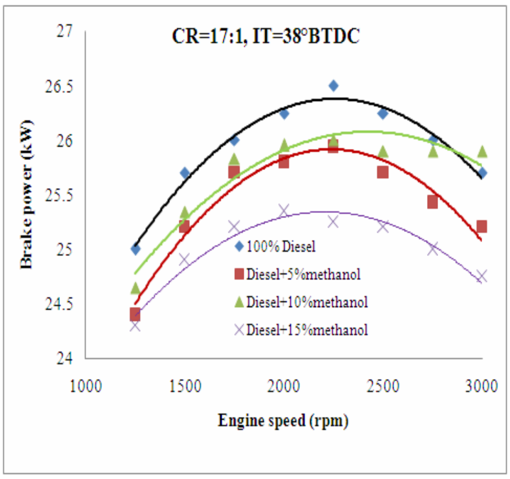


Fig 8, the effect of methanol addition on brake power for different

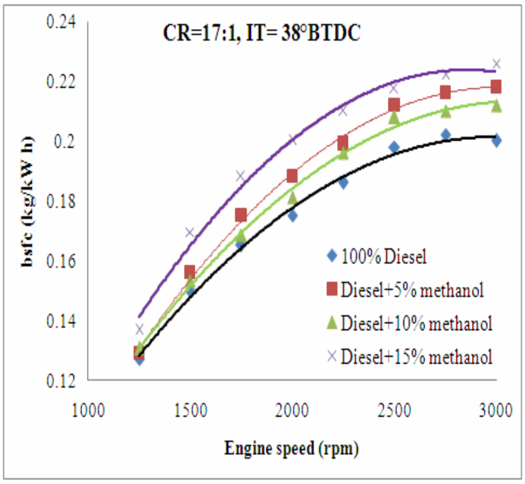


Fig 9, the effect of methanol addition on BSFC for different