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Effect of injection and ignition timings on performance and emissions from a spark-ignition engine fueled with methanol

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ABSTRACT

Optimal injection and ignition timings and the effects of injection and ignition timings on performance and emissions from a high-compression direct-injection stratified charge spark-ignition methanol engine have been investigated experimentally. The results have shown that direct-injection spark-ignition methanol engine, in which a non-uniform mixture with a stratified distribution can be formed, has optimal injection and ignition timings to obtain a good combustion and low exhaust emissions in the overall mode range. Both methanol injection timing and ignition timing have a significant effect on methanol engine performance, combustion, and exhaust emissions. At an engine speed of 1600 rpm, full load, and optimal injection and ignition timings, methanol engine can obtain shorter ignition delay, lesser cycle-by-cycle variation, the maximum in-cylinder pressure, the maximum heat release rate, and higher thermal efficiency compared to the case of non-optimized injection and ignition timings. For methanol engine, the optimization of injection timing and ignition timing can lead to an improvement of brake-specific fuel consumption of more than 10% compared to non-optimized case in the overall load range and engine speed of 1600 rpm. The best compromise between thermal efficiency and exhaust emissions is reached at optimal injection and ignition timings.

1. Introduction

With rising petroleum prices and global warming being a dominant environmental issue, it seems that the use of alternative fuels in the future is inevitable. This leading goal for both energy security and the clean air project has resulted in intense interest in the worldwide utilization of alternative fuels in burners and engines [1]. Methanol (CH_3OH), also known as methyl alcohol, is considered to be one of the most favorable fuels for engines [2]. This is because, as a liquid fuel, the storage, transportation, distribution, and applications of methanol are similar to those of traditional gasoline and diesel fuels. It can be produced from widely available fossil raw materials including coal, natural gas, and biosubstances [3]. Methanol has many desirable combustion and emission characteristics: high octane number, indicating antiknock performance; high latent heat of vaporization, allowing a denser fuel–air charge; and excellent lean-burn properties [4]. These properties make methanol a good fuel for spark-ignition Otto-cycle engines. However, methanol has a low cetane number of only 3–5 and a high auto-ignition temperature of about 470 °C, and it is difficult to apply methanol directly in compression–ignition engines. A number of ignition-assisted strategies for methanol fueling have been employed, including increased combustion ratio [5], ignition improvers [6,7], spark-ignition systems [8,9], and hot-surface-ignition systems [10,11], etc. [12–14].

Mustafa et al. [15] reported the effects of injection timing on performance, combustion characteristics, and exhaust emissions of an engine fueled with methanol and diesel blends. They found that in comparison to the values obtained at an injection timing of 20° crank angle before top dead center (CA BTDC), at a retarded injection timing (15° CA BTDC) the values of peak cylinder pressure, rate of heat release, and combustion efficiency, as well as nitrogen oxides (NO_x) and carbon dioxide (CO_2) emissions, all decreased, while the smoke number and unburned hydrocarbon (UHC) and carbon monoxide (CO) emissions increased under all test conditions. On the other hand, at an advanced injection timing (25° CA BTDC), the smoke number and the UHC and CO emissions diminished, while the peak cylinder pressure, heat release rate, combustion efficiency, and NO_x and CO_2 emissions increased under all test conditions. In terms of brake-specific fuel consumption, brake-specific energy consumption, and brake thermal efficiency, retarded and advanced injection timings gave negative results in all fuel blends compared to the original injection timing. Huang et al. [16] investigated the basic combustion behaviors of diesel/methanol blends based on cylinder pressure analysis at various fuel delivery timings. Terry et al. [17] analyzed the influence of mixture preparation on misfire at idle operation in a

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direct-injection spark-ignition engine. Kapilan et al. [18] studied the effect of injection timing and compression ratio on the performance and emissions of a two-stroke spark-ignition engine with in-cylinder injection of methanol. Bassem et al. [19] made multidimensional predictions of the effects of relative equivalence ratio, injection timing, and ignition timing on methanol combustion in a high-compression direct-injection engine with a removable integral injector ignition source insert under different engine configurations. They found that all configurations performed well at advanced injection timing and retarded ignition timing.

Most previous work has been focused on the use of diesel/methanol blends, dimethyl ether, natural gas, etc., in direct-injection compression–ignition engines [20–22], whereas little work has been reported on direct-injection spark-ignition methanol engines. The objective of the work is to investigate the effect of injection and ignition timings on combustion and emissions from a high-compression direct-injection stratified charge spark-ignition methanol engine. These results are should prove valuable in improving performance and exhaust emissions of direct-injection stratified charge spark-ignition methanol engines.

2. Experimental set-up

2.1. Test engine

The experiments were carried out on a single-cylinder, four-stroke, naturally aspirated, water-cooled, high-compression direct-injection stratified charge spark-ignition methanol engine, which was modified from a diesel engine. The engine specifications are shown in Table 1.

Table 1
Engine specifications.

Engine	Methanol engine	Diesel engine
Combustion chamber type	ω Shape	ω Shape
Bore	130 mm	130 mm
Stroke	150 mm	150 mm
Displacement	1.99 L	1.99 L
Compression ratio	16:1	16:1
Rated net power/speed	18.3 kW/2000 rpm	18.3 kW/2000 rpm
Combustion system	Direct-injection	Direct-injection
Injection pump type	6A85	6A85
Plunger diameter	9.5 mm	8.5 mm
Number of nozzle holes	10	4
Diameter of nozzle hole	0.3 mm	0.33 mm
Injector valve opening pressure	17.5 MPa	17.5 MPa
Spark-ignition system	Multi-spark-ignition	–
Cooling system	Water	Water

Table 2
Properties of methanol.

Property of methanol		
Chemical formula		CH_3OH
Relative molecular mass		32
Composition (% mass)	C	37.5
	H	12.5
	O	50.0
Density (kg/m^3)		790
Boiling point (°C)		65
RON		111
Cetane number		3–5
Flammability limit (% vol)		6.7–36
Latent heat of vaporization (kJ/kg)		1110
Lower heating value (MJ/kg)		19.6
Auto-ignition temperature (°C)		470
Stoichiometric air–fuel ratio		6.5
Flame speed (m/s)		0.523

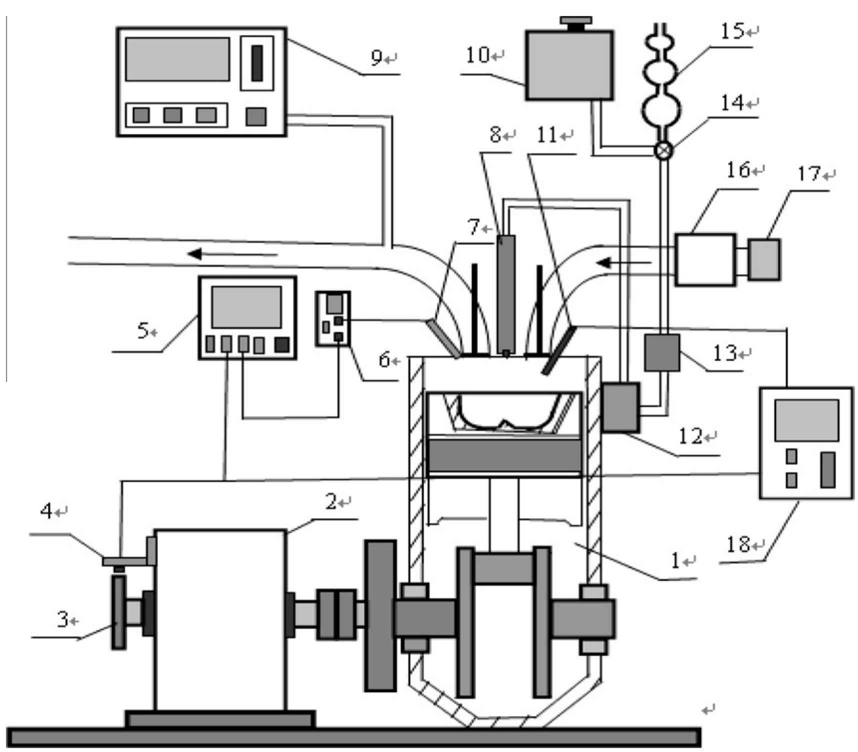

Fig. 1. Schematic layout of the experimental system (1) engine, (2) electric power dynamometer, (3) encoder, (4) TDC marker, (5) combustion analyzer, (6) charge amplifier, (7) in-cylinder pressure transducer, (8) methanol injector, (9) exhaust gas analyzer, (10) methanol tank, (11) spark plug, (12) methanol injection pump, (13) methanol filter, (14) switch valve, (15) measuring glass, (16) air stabilizing tank, (17) air filter and (18) spark-assisted system.