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The effects of varying spark timing on the performance and emission characteristics of a gasoline engine: A study on Saudi Arabian RON91 and RON95

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ABSTRACT

This research aims to experimentally analyze and evaluate the influence of varying the spark timing on the performance and emission characteristics of a single cylinder, four-stroke spark ignition (SI) engine fueled by two grades of gasoline used in Saudi Arabia, RON91 and RON95. The experiments were conducted at stoichiometric conditions for five different spark timings (18 °CA BTDC, 20 °CA BTDC, 22 °CA BTDC, 24 °CA BTDC, 26 °CA BTDC and 28 °CA BTDC) at fixed compression ratio 9.5:1, wide throttle open (WOT) and engine speed 2500 RPM. The spark timing is controlled electronically using an engine control unit (ECU). The experimental results showed that as the spark timing increases, the brake power (bp) and the brake thermal efficiency (BTE) increase for both fuels. It is observed that bp and BTE of RON95 is higher than that of RON91. The specific fuel consumption (BSFC) decreases with increasing in spark timing for both fuels. However, RON95 shows lower BSFC than RON91. Combustion analysis showed a mixed response to different research octane number (RON). Generally, combustion of RON95 displayed higher peak rate of heat release (ROHR) at earlier occurrence compared to RON91. It is also found that the coefficient of variation of the indicated mean effective pressure (COV_{IMEP}) decreased with increases the spark timing for both fuels. However, RON95 displayed lower COV_{IMEP} than RON91. It is observed that NO_x and CO_2 emissions increased for both fuels as the spark timings increases. It is also detected that THC and CO emissions from both fuels decreases as spark timing increases.

1. Introduction

As a result of ever increasing demand for Internal combustion (IC) engines, coupled with stringent emission regulations, more efficient and powerful yet cleaner engines are required. Engine–fuel interaction is a complex affair that requires extensive investigation and unexhausted studies in the quest for more efficient and cleaner engines. Formulation of fuels must be made alongside ever-developing engine architecture. Improvements in engine efficiency and emissions characteristics of spark ignition (SI) engines can be accomplished by several parameters like changing compression ratio (CR) thru engine geometry or forced aspiration, stoichiometry, method of fuel supply and mixing, pre and after treatment of reactants and exhaust, etc. [1,2]. The most important parameter affecting efficiency is the compression ratio where increasing CR increases engine thermal efficiency based on the Carnot principle. However increasing CR is limited by the occurrence of the knock phenomena [3]. In its simple form Knocking in SI engines is an abnormal combustion phenomenon that takes place when the air–fuel mixture auto-ignites at the wrong timing inconsistently mostly BTDC resulting in performance problems ranging from lower efficiency to mechanical failure. The exact reason for knocking phenomena is not fully understood. It is known that increasing the CR increases propensity to knocking while increasing the Octane number of the fuel decreases the knocking propensity. These two parameters are true for fixed point operation and engines CR are typically designed to get the best efficiency from a fuel with a specific Octane number. However in addition to fixed

Abbreviations: AFR, air–fuel ratio; ATDC, after top dead center; BTDC, before top dead center; BTE, brake thermal efficiency; BSFC, brake specific fuel consumption; bp, brake power; CO_2, carbon dioxide; CO, carbon monoxide; COV_{IMEP}, coefficient of variation of the indicated mean effective pressure; IC, internal combustion; MFB, mass fraction burnt; NO_x, nitrogen oxides; PI, port injection; RON, research octane number; ROHR, rate of heat release; SI, spark ignition; ST, spark timing; SCRE, single cylinder research engine; THC, total hydrocarbon emissions; WOT, wide throttle open.

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point operation the interaction between the engine and its load during variable operation also plays an important role in causing or preventing knocking. In general when the engine is suddenly overloaded for a given throttle position, knocking is more likely to happen due to effective delay of spark timing and increased heat release before the crank shaft reached TDC. Another factor that plays a role in occurrence of knocking is the potential variability of the actual fuel from its advertised specifications including octane number. It has been found that the most practical parameter to deal with knock control during variable operation is the spark timing [4–6].

In SI engines, spark timing is a key parameter that affects the combustion and exhaust emissions. Ignition of the fuel mixture must take place sufficiently early in order to extract the maximum power from the piston movement. If the spark occurs a slight too advance, the piston will be slowed down in its upward movement. On the other hand, if it occurs too late then the piston will already be moving downwards, so both cases the work done on the piston will be reduced. In addition, If the spark occurs much too advance, the mixture in various zones of the engine chamber might be ignited as result of the ignition pressure wave, causing detonation [7]. Several investigations studied the effects of varying spark timing on fuel consumption and emissions of SI engines. Rangkuti found that retarded spark timing, relative to MBT timing, produced poorer fuel consumption and resulted in reduction of cylinder pressure and temperature in particular with lean mixtures [8]. He also noticed that the UHC emissions was reduced, the CO emissions were higher compared to MBT timing and the comparison of NOx levels regarding the throttle position were much the same at WOT and 65% throttle settings while it was significantly lower at the 40% throttle setting. Kakaee et al. studied the effects of varying spark timing in range of 41 °CA BTDC to 10 °CA ATDC at WOT and 3400 RPM speed on the performance and emissions of SI engine [9]. They revealed that the optimal power and torque is achieved at 31 °CA BTDC, the CO_2 and CO emissions has been almost constant, but HC emissions increased with rising spark timing and the lowest amount of NO_x is obtained at 10 °CA BTDC. Sayin also investigated the influence of varying spark timing at different octane numbers on performance and emissions of SI engine. The results showed that BSFC and BTE of higher RON gasoline (RON97 and RON98) improved with rising spark timing. It was also noticed that increased spark timing improved ignition delay and improved knock tolerance for RON 97 and RON98 gasoline. So, these effects increased maximum cylinder gas pressure and reduced fuel consumption. Furthermore, the concentrations of CO and HC emissions were reduced with increasing spark timing for RON 97 and RON 98 gasoline [2]. Alasfour studied the impact of varying spark timing on NO_x emissions, exhaust temperature and BTE in SI engine fueled with a 30% isobutanol gasoline blend. The experiments were performed for three different spark timing (20 °CA BTDC, 23 °CA BTDC, 27 °CA BTDC). He found that the advanced spark timing increased BTE. It also demonstrated that the advanced spark timing had a major effect on the increase level of the NO_x [10]. Topgul et al. investigated the effects of spark timing and using unleaded gasoline, ethanol blends (E0, E10, E20, E40 and E60) on engine performance and exhaust emissions at a constant speed of 2000 RPM and WOT. They showed that the increasing spark timing led to reduce the exhaust temperature, power and increase the BSFC [11].

Saudi Arabia is one of the major oil producing countries in the world. Gasoline is sold at RON91 and RON95 grades. The constituent of Saudi Arabia's gasoline is mainly characterized with low aromatic content and high LHV as compared to European countries [12,13]. Saudi Arabia was among top 15 countries in carbon dioxide emission per capita in 2009 with 18.56 tons per capita [14]. Vehicles are the major source of air pollution, which is attributed to fuel combustion, in addition to industrial zones and widespread small industries within the populous mass [15]. About 90% of total emissions of carbon monoxide, CO (16 million tons/year) are due to transportation activities. Emission of nitrogen oxides, NO_x totals to 1.1 million tons/year. About 80% of total hydrocarbon (HC) emissions originate from the transportation sector, which lead to the formation of photochemical oxidants [16]. Some engine modifications to adapt with RON for improved performance were investigated. Duchaussoy et al. studied the impact of RON on a turbocharged multi-point injection PI engine and discovered improved power, BSFC and emissions results with higher RON [17]. As turbocharging resembles increasing compression ratio, the engine benefits from better knock resistance of higher RON.

In this paper, the objective is to evaluate the effects of the spark timing on SI engine performance and exhaust emissions using a single-cylinder research engine fueled by two fuel types (RON91 and RON95). A series of experiments were carried out using two gasoline fuels under varying spark timing from 18 °CA BTDC to 28 °CA BTDC with 2 °CA increment at fixed compression ratio 9.5:1, wide throttle open (WOT) and engine speed 2500 RPM. The performance characteristics such as bp, SBFC, thermal efficiency, pressure, heat release and exhaust emissions were obtained and analyzed.

2. Experimental investigation

2.1. Experimental setup

In this investigation, the experiments were performed on a Lotus Single Cylinder Research Engine (SCRE); a four-stroke, water-cooled, naturally aspirated, and spark ignition (SI) gasoline engine. The engine specification is given in Table 1.

Fig. 1 shows the single cylinder research engine (SCRE). A 30 KW Eddy current dynamometer (Froude Hoffman, AG30) was used. The fuel consumption rate was measured in the range of 0.03–20 l/h by a PLU positive displacement meter combining a servo-controlled gear counter with a dynamic piston sensor (AVL KMA 4000). Engine performance, fuel consumption and exhaust gas emissions data were logged using Texcel V10. In-cylinder pressure data were measured by a water cooled piezoelectric sensor. The air fuel ratio (AFR) was calculated using an ECM meter (AFRecorder 2000) with measurement accuracy of 0.01–0.03. The schematic diagram of the experimental setup is shown in Fig. 2. The exhaust gas emissions of CO, THC and NOx were measured using a Horiba exhaust gas analyzer (MEXA-7170DEGR). The port fuel injection is done with a Bosch fuel injector which is actuated by the d-Space-Micro Auto-box engine control unit. It provides accurate control of the injection timing as well as the duration. The spark timing is controlled electronically that the engine is controlled in real time by an engine control unit (ECU) using a computer software so called Lotus V8 controller to control the timing throughout the engine's speed and load range. ECU read in data from various sensors about the crankshaft position, intake manifold temperature, intake manifold pressure, throttle position, fuel

Table 1
Specification of the Lotus Single Cylinder Research Engine (SCRE).

Engine type	SI engine, single cylinder, 4 stroke
Fuel system	PI
Bore (mm)	80.5
Stroke (mm)	88.2
Displacement (cm^3)	448.9
Compression ratio	9.5:1
IVO/IVC	451°/589°
EVO/EVC	131°/269 °