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Effect of fuel injection timing of hydrogen rich syngas augmented with methane in direct-injection spark-ignition engine

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ABSTRACT

The product of gasification of solid biomass, also called syngas is believed to be good fuel for internal combustion engines in the move from the carbon based fuel to zero emission fuels. The only problem is its lower calorific value which is placed at one third of that of compressed natural gas (CNG). There are latest efforts to enhance the hydrogen rich syngas by augmenting it with methane so that the calorific value can be improved. This paper presents experimental results of the effect of the start of fuel injection timing (SOI) on the combustion characteristics, performance and emissions of a direct-injection spark-ignition engine fueled with a 20% methane augmented hydrogen rich syngas of molar ratio of 50% H_2 and 50% CO composition. The engine was operated at fully open throttle and the start of fuel injection (SOI) was varied at 90, 120 and 180° before top dead center (BTDC). The experiment was conducted at lean mixture conditions in the low and medium engine speed ranges (1500–2400 RPM). The spark advance was set to the minimum advance for a maximum brake torque in all the test parameters. The methane augmented hydrogen rich syngas was observed to perform well over wide range of operation with SOI = 180°CA BTDC. However, SOI = 120°CA BTDC performed well at lower speeds recording improved performance and emissions. Limitation of operable load was observed for both SOI = 120°CA BTDC and 90°CA BTDC due to an insufficient time for complete injection of fuel at lower relative air–fuel ratio (λ) with higher speeds.

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Introduction

A major concern about the long-term availability of fossil fuels was first surfaced in the 1970s geopolitical situation in the Middle East. However, the issue of transport driven environmental pollution has come in to attention in the 1940. These two scenarios have forced nations to deal with other alternative energy sources and draw energy policies favorable to alternative sources. Over the years, different alternative fuels have been proposed and researched and yet the transport sector is still mainly dependent on the much polluting and unsustainable fossil based fuels. Natural gas, hydrogen, alcohols (ethanol and methanol) and biodiesel are most common alternative fuels which have received greater attention over the period. However, their degree of success was not to the satisfaction of the end user. Besides, the transport sector faces different challenges in the coming three to four decades according to the World Energy Council (WEC) [1]. Based on the scenarios developed by WEC, the transport sector fuel demand will increase by 82% from its 2010 level if the government intervention is minimal. On the fuel mix, the sector will still heavily depend on fossil fuels in 2050 [1]. It is claimed that the government intervention critically affects the global energy scenario of the transport sector. The alternative fuel sector needs to be supported with suitable policies [1]. The common biofuels such as bioethanol and biodiesel will have hindrance due to their competition of resources with food. On the other hand, hydrogen has been on the target for the past 30 years. Even though the prospect of hydrogen in the transportation sector is high, currently it is marred by the production and storage associated challenges [2,3]. The biggest challenge in the production is lowering the production cost. Syngas is believed to be a transition from the carbon based to the hydrogen based energy in the transport sector. Syngas can be produced from different feedstock such as coal, solid biomass, heavy liquid hydrocarbons and gases. Lower calorific value syngases have been investigated for their performance and emission in spark ignition engines by different authors since their wide spread application in 1940s. It was noted that their feasibility was limited due to the power loss in the carbureted spark ignition engines. Since the inception of the direction-injection fueling system in spark ignition engines and the advancement in the solid fuel conversion technologies, the interest of such gaseous fuels again resurfaced. The same authors have investigated lower and medium calorific value syngases in direct-injection (DI) spark-ignition (SI) engine at wider operation conditions [4–6]. The results on the combustion, performance and emissions was found to be promising except for their higher brake specific fuel consumption (BSFC). The current study is focused on the hydrogen rich medium calorific value syngas augmented with methane fueled in DI SI engine investigated at wider range of fuel injection timing (SOI). Methane augmentation is enriching of syngas with small quantity of methane for the improvement of the calorific value of syngases.

Methodology

Experimental procedure

The work bench used is a four-stroke, single cylinder, DI SI research engine. The engine has compression ratio of 14:1 with displacement volume of the engine is 399.25 m^3 (cylinder bore of 76 mm and stroke 88 mm) and two inlet and two outlet valves, the schematic diagram shown in Fig. 1. The inlet valve opening and closing are 12°CA before top dead center (BTDC) and 48°CA after top dead center (ATDC), respectively while the exhaust valve counterparts at 45°CA before bottom dead center (BBDC) and 10°CA ATDC. The rated power of the engine is 13 kW at 5000 rpm [5]. The engine is coupled with an eddy current type electric dynamometer. Engine parameters such as the start of the injection (SOI), ignition timing (the minimum ignition advance for a maximum brake torque) and air–fuel ratio are controlled by Engine Control Unit (ECU) connected to a remote interface installed in a computer programmed to dictate the engine operation with pre-loaded engine maps of parameters. With the usage of interface software, it is possible to manually alter the engine operating conditions. The interface software can also be used to measure the engine operating parameters by using the various sensors connected to the ECU. The engine parameters that can be controlled from the computer are the SOI and the injection duration, the spark timing and the air fuel ratio. The engine is also equipped with further sensors like induction air temperature, exhaust air temperature, engine oil temperature, engine coolant temperature, room temperature, relative humidity and room atmospheric pressure.

The original natural gas injector is used for the study without any alteration; specification can be referred from Refs. [7,8]. The fuel injection is kept at 18 bar and the type of injector used in this experiment is narrow angle injector (NAI) with a spray angle of 30°. The fuel rail is kept at atmospheric temperature. BOSCH mass flow sensor (MAF) fitted to the engine inlet manifold is used to measure the engine inlet manifold air flow rate. The engine is investigated with wide open throttle. The fuel under investigation in the current study is methane augmented hydrogen rich syngas (50% H_2 and 50% CO). 20% methane by volume ratio is used for the augmentation as a result, the calorific value of the fuel is improved by 41.46% from 11.65 MJ/Nm^3 of hydrogen rich syngas. Originally the fuel injection system of the engine is calibrated to measure CNG flow rate through the injection duration, where the calibration chart is provided by the injector manufacturer. A positive displacement method is used for the calibration of the injector for the mass flow rate of hydrogen rich syngas. The fact that the study is focused at lean operation condition, fuel stratification should be attained for smoother combustion. A large piston bowl piston shape is selected to increase mixture distribution quality in the cylinder [7,9]. The schematics for the stratified charge piston head and arrangement of piston, injector and spark plug for stratified mixture formation is presented elsewhere [4].

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