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Engine performance, exhaust emission and combustion analysis of a 4-stroke spark ignited engine using dual fuel injection

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HIGHLIGHTS

- Comparing gasoline-CNG mixture to CNG, G35 shows best performance with acceptable emission.
- G35 (35% gasoline and 65% CNG) has provided higher combustion pressure.
- Engine torque and power increased by 8.6%, the BSEC and engine efficiency did not change when compared to CNG.
- The HC, CO emissions increased and NO_x decreased with using dual fuel.
- Overall burning angle has been decreased when compared to CNG.

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ABSTRACT

The world natural gas reserve is plentiful. Instead of using gasoline to power ground vehicles, usage of Compressed Natural Gas (CNG) can improve the environment and reduce energy cost. However, most engines that runs on CNG are converted from gasoline based engine. Hence, the engines are not optimized for CNG. Other problems of converted engines are loss of power due to slower burn rate of CNG and gas displacement effect of CNG, hotter exhaust gas which degrade engine's reliability, low mileage per tank and higher NO_x. Since, converted engines are gasoline base engine, a dual fuel injection engine system can be developed to reduce the stated problems. Are activity controlled approach was incorporated where both gasoline and CNG are mixed before going into the combustion chamber. With this technique, when a blend of high reactive 35% gasoline and 65% CNG was used, the engine had its engine performance such torque, power and efficiency increasing by 10%. Also, the engine emissions such as hydrocarbon was reduced by 50% and carbon monoxide emission was reduced by 75% and NO_x emission was reduced by 50% when compared with CNG baseline. Combustion of spark ignition engines converted to bi-fuel CNG is unstable and proper air and fuel mixing strategy is a concern here.

1. Introduction

The energy needs are higher and higher every year due to the demand from industrial and transportation sector especially from some high population part of the world [1,2]. Most transportation fuels are hydrocarbon base. These fuels are derived from petroleum which is a non-renewable resource. This implies that someday petroleum having high potential will be depleted [3,4] and this will cause energy crisis to the world [5]. Currently, there is a growing development trend for electric vehicles. However, with today's battery technology, the mileage of such vehicle is poor when compare to internal combustion engine. The most advanced battery has the energy density of 180Wh/kg. This is miniscule when comparing it to gasoline which could provide energy density of 1800Wh/kg after taking into account the efficiency and losses of the system [6]. Given time and money for research and development, battery technology will be advanced enough to compete with internal combustion engine in term of energy density. However, at that given time there will be a transition period when gasoline will be too expensive to be used as fuel and electric car with acceptable

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mileage will be too expensive to purchase. This is where compressed natural gas (CNG) aids the transition period that is from hydrocarbon fuel to electric.

The petroleum production in has peaked in the year 2015 [7], as shown in Fig. 1, according to the prediction curve in a case study, Malaysia a net oil exporter will become a petroleum importer in the year 2015 [8]. The petroleum production is subjected to change when new oil fields are found. However, the consumption of petroleum will always increase due to several reasons. The first reason is population growth which will increase the domestic consumption in the country. Second reason is economic growth of the country which increases transportation activity. This activity requires ample amount of fuel. With such factors considered, the increasing consumption of petroleum will counter any new oil field found.

In Fig. 2, we can see that the use of natural gas has not peaked as compared to petroleum. Hence with all this encouraging factors, it makes natural gas a good alternative transportation fuel for automotive in countries such as Malaysia [9–11]. The rise in usage of natural gas is also an indication of the shift in highlight towards better energy sustainability by not relying too much on petroleum production [12,13]. With a large natural gas reserves and the low running cost of CNG much CNG retrofit kits are being developed. However, these retrofit kits are bi-fuel system that is the engine can run either CNG or gasoline without much modification. The baseline engine was optimized for gasoline. Therefore, when it runs on CNG, the engine will be less efficient when compared to gasoline. Also, the power of the engine significantly dropped after switching to CNG [10]. Since gasoline injectors are already inside the engine, a dual fuel injection system can be implemented to improve the efficiency of the engine. Dual fuel injection means that the engine will be running on both gasoline and CNG together at a certain ratio [14]. Hence, performance analysis is crucial for this dual fuel injection system.

Another contributing factor that encourages this improvement study is that CNG vehicles require a bigger fuel tank to have the equivalent mileage of a gasoline vehicle. For example, if the vehicle is using a fuel mixture of 25% gasoline and 75% CNG, the vehicle will have 33% more mileage per tank for CNG and 400% more mileage per tank for gasoline. The parameters that will be studied are fuel composition and air fuel ratio. These parameters will be studied to provide maximum performance.

Engine that runs on CNG are notorious for NOx emission [15]. This is due to their slow burn rate of the fuel [16]. When the engine is running on gasoline, its NOx level is lower. This is since, gasoline burns faster than CNG. To illustrate this, all fuel is burnt after the expansion stroke when using gasoline. However, for CNG the fuel is still burning during exhaust stroke. Therefore, there is not enough time for the exhaust gases to cool down and reduce the NOx level, hence the creation of thermal NO_x. Since the engine was designed for gasoline, there will be reliability issue when the engine is running on CNG. When gasoline is used, it burns quickly in the combustion chamber before opening the exhaust valves. However this changes when CNG is used [17]. Natural gas burns slowly in the combustion chamber and still may burn even after the exhaust valves are open. This will create a reliability problem for the exhaust valves and higher operating temperature. Also, gasoline is a liquid fuel hence it will provide a cooling effect to the engine's combustion chamber making it cooler to operate. When the engine uses CNG alone, it does not have such cooling capabilities of the gasoline [18]. Therefore, the engine might run with higher operating temperature which may cause reliability issue.

Dual fuel injection is injecting 2 types of fuel into the combustion chamber together. This technique is similar with injecting hydrogen into the mixture however instead of injecting hydrogen, it uses any other fuel [19]. This technique offers many technical advantages and economy advantages for vehicle equipped with CNG injection system. Firstly, there is no major engine hardware modification to implement this technique. This technique requires a CNG retrofit kit which includes a gas tank, pressure regulator, refuelling valve, gas injectors and the electronic system to control the injection duration. Most taxi in are powered by CNG due to high operation costs [20]. By implementing this technique, the taxi drivers do not require major technical modification to get the vehicle running on CNG-gasoline. Using the original fuel injection system, the only changes required is on the electronic system which is plug and play.

Secondly, this technique increases the engine performance and the combustion performance. Studies has shown that dual fuel injection technique that involves hydrogen-CNG mixture on spark ignited engine decrease the ignition delay, burn duration and increase engine performance [21]. Research on different type of fuel mixture like ethanol-gasoline mixture, which was done at South America where alcohol powered vehicle are common, shows similar results that is performance improvement over gasoline [22]. Other fuel mixture such as gasoline-CNG was done and there

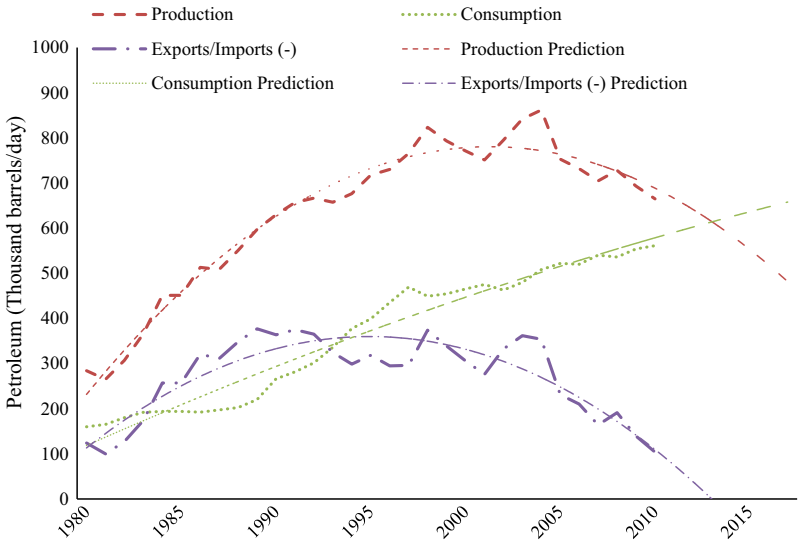

Fig. 1. Crude oil production, consumption and exports/imports in Malaysia [8].

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