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DUAL FUEL COMBUSTION IN A CI ENGINE POWERED BY BLENDED DIESEL-BIODIESEL FUEL AND SIMULATED GASIFICATION GAS

B. K. M. Mahgoub[1], Suhaimi Hassan[1], S. A. Sulaiman[1, 2], R Mamat[3], A Abdul Adam[3] and Ftwi Y. Hagos [4]
[1]Department of Mechanical Engineering, Universiti Teknologi Petronas, Bandar Seri Iskandar, Perak, Malaysia
[2]Centre for Automotive Research and Electric Mobility, Universiti Teknologi Petronas, Bandar Seri Iskandar, Perak, Malaysia
[3]Faculty of Mechanical Engineering, Universiti Malaysia Pahang, Pekan, Pahang, Malaysia
[4]Automotive Engineering Center, Universiti Malaysia Pahang, Pekan, Pahang, Malaysia
E-Mail: m.bahaa02@gmail.com

ABSTRACT

The objective of this study was to investigate the performance of dual fuel combustion in a compression ignition engine powered by blend diesel/palm oil biodiesel (50%:50%) and simulated gasification gas. The in-cylinder pressure data was collected for each crank angle in order to investigate the combustion characteristics at constant half load over a range of pilot fuel substitution rate. Substantial differences in the in-cylinder peak pressure occurred and three phases of the dual fuel combustion process were clearly seen in the heat release rate curves when the engine load was maintained at half load. Maximum cylinder pressure was obtained with syngas dual fuelling at lower substitution rates. Lower engine efficiency of 33.84% was observed with syngas dual fuelling at the highest substitution rate of pilot fuel (28%).

Keywords: syngas, biodiesel, dual fuel, combustion.

INTRODUCTION

Internal combustion engines (ICE) has had significant impact on the human life as a lightweight source for useful generation of power and heat and combined power/heat cycle. There has been continuous research and development both on the engine hardware and on the fuel the ICEs consume for better performance and lower emissions. The main concept of ICE is the conversion of fuel energy into thermal energy and thereby into useful mechanical power using either spark or compression ignition systems. The need for reducing fossil fuel dependence and the emissions from (ICE) has drawn attention to the necessity of research for suitable renewable energy source. There are many alternatives that can be used as energy source replacements to fossil fuel, including renewable fuel and nuclear energy resources [1]. When searching for choices of embracing the utilization of what sort of alternative sources to use in ICE, the effect on the environment and economic implications is very important. Alternative gaseous fuels are the most effective sources to replace fossil diesel fuel, because it produces very much lower emissions of nitrogen oxides (NO_X), Sulphur oxides (SO_X) and carbon dioxide (CO_2) [2]. To this end, gasification gas (syngas) has received an interest from researchers recently in both CI and SI engines.

Synthesis gas is a mixture of combustible gases like hydrogen (H_2), carbon monoxide (CO) and methane (CH_4), and non-combustible gases including carbon dioxide (CO_2) and nitrogen (N_2) along with other gases. Synthesis gas is also known as syngas. Syngas has been named earlier by many different names depending on the gasification process and the gasifying agent used [3, 4]. During the Second World War it was named by town gas. Producer gas, blue water gas and gasification gas are another names for syngas. There are many materials that can be used as a feedstock to produce syngas like natural gas, naphtha, residual oil, petroleum coke fossil coal and renewable biomass [5].

Syngas from biomass gasification can be a promising alternative engine fuel, because biomass is aiding in meeting the greenhouse gas reduction targets, while at the same time the supplied energy from syngas can be generated with cheaper cost and environmentally sustainable. Furthermore, the cost level of biomass energy is considered acceptable when compared with other renewable energies [5] because fossil fuels can produce energy with higher cost for the same amount of energy produced from biomass conversion. In addition, biomass gasification is considered an economically viable system because the suitable biomass feedstock is easily available.
Biological vegetable oil and animal fats are very important resources for production of biodiesel to replace diesel fuel [6]. Biodiesel is also known as oxygenated ester-based fatty acid fuel chemically categorized in the family of long-chain acids [7]. Because this fuel contains oxygen as part of its chemical structure, very low level of CO_2 emission is emitted from it to the environment when compared to fossil-based fuels [8].

Biodiesel has similar physico-chemical features with that of fossil-based diesel fuel on the likes of lower calorific value, viscosity, density, pour pint and flash point. Such features help the fuel to draw more attention by researchers in the field [9]. Biodiesel is better than diesel with regard to the environmental friendliness and its sustainability are the most known advantages of biodiesel that it has as compared to gasoline and diesel [6]. Biodiesel is characterized by the presence of oxygen that it contains (10–11% by weight), it is free aromatic fuel with higher cetane number compared to fossil fuels. These biodiesel properties lead to lower exhaust emission when combusted in CI engines instead of diesel [10]. Little or no modification is needed for engine operation with biodiesel fuel [7].

Combustion process in syngas/diesel dual-fuel engine operation is very complicated, because it consists of several combustion modes (auto-ignition of diesel fuel, flame propagation of gaseous fuel mixture, and auto-ignition of the mixture in the end-gas). Therefore, the combustion characteristic of this type of engine should be further studied in order to facilitate understanding on what is going inside the combustion chamber on one hand and to improve the efficiency and emission by using different strategies on the other hand.

LITERATRURE REVIEW

Number of engines were powered by different types of syngas [11, 12]. Majority of the research conducted in a spark-ignition (SI) engine. Spark ignition combustion systems are not approriate for syngas dual fueling due to syngas fluctuation at high engine loads. Moreover, there is higher energy degradation with syngases when compared with other fuels. For example, CNG and gasoline have higher enegy density than syngas. Numerous researchers have carried out investigations to determine performance of syngas dual fueling in CI engines.

The study by Sadykove *et al*. [13] proved thaht syngas dual fuelling in a water cooled CI engine leads to reduced NO_X emission either at ultra lean or rich mode of operation. While the level of NO_X emission increased with moderate mixture mode of operation. Slight increase in the level of hydrocarbons emession was recorded (<40 ppm) with syngas dual fueling. Sridhar *et al* [14] obtained the same observations regarding NO_X and CO emissions with syngas dual fueling. Sridhar *et al* The performance of syngas dual fueling in a CI engine was investigated by Krishna *et al*. [15]. The syngas was produceed from gasification of coffee husk. 31% of diesel reinstatement rate was attained without any penalty on the engine.

Number of researchers have made attempts to improve the performance of dual fueling process in CI engines. Performance of Liquified petroleum gas (LPG) dual fueling in CI engine operating with blended biodiesel at various loads was assessed by Acharya and Jena [16]. An improved performance was shown for the engine with the blended biodiesel. LPG dual fueling led to increased BSFC and reduced engine efficiency at low engine loads. While, increasing the load to higher level led to improved engine performance. Similar result was observed by Sahoo *et al.* [17] when syngas was used for dual fueling in CI engine, where the improvement in engine thermal efficiency occured with syngas dual fueling over half engine load. An assessment for biogas dual fueling in DI engine operating with diesel and blended biodiesel fuel was performed by Pattanic *et al*. [18]. Higher BSFC was obtained with biogas dual fueling at low engine loads, while BSFC at higher loads was almost same to normal liquid fuels.

It can be concluded that, the performance of syngas dual fuel combustion is affected by the engine operating parameters like varying engine loads [19]. Medium range of engine load was found to be better than low and high loads. Therefore, an improvments should be made in order to maximize the engine performance and minimize the exhaust emissions.

The objective of the current work is to investigate the performance of gasification gas dual fueling combustion in CI engine operating with blended diesel-biodiesel as pilot fuel at different substitution rates.

EXPERIMENTAL SETUP

Materials and methods

TF120M Yanmar single cylinder CI diesel engine with the specifications given in Table-1 was used in the setup. Positive displacement gear pump was used as dynamometer for the engine. The engine was not modified; instead some parts including non-return valve, pressure regulator and flow meter were added to the engine test bed in order to supply syngas, in this way the engine could be easily switched from pure diesel mode to dual fuel mode at any time. The experiment test bed used to conduct this study is shown in Figure-1.

Table-1. Engine technical data.

Cylinders	1
Combustion	Direct Injection
Injection timing	BTDC 17°
Rated power output hp / rpm (kW)	10.5 / 2400 (7.8)
Maximum torque kg.fm / rpm	4.42/1800
Compression ratio	17.7
Specific fuel consumption g/hp.hr	169
Cooling System	Water Radiator
Bore x Stroke	92 x 96 mm
Displacement	0.638 liters
Fuel tank capacity	11.0 litter

The combustion data was measured in this study at constant engine speed. Optrand pressure sensor was used for in-cylinder pressure reading. Crank angle reading was measured by using magnetic type of crank angle sensor. The sensors were connected to sensor interface, then to LCS data logger through transfer cables. The specifications of pressure sensor are listed in Table 2.

Table-2. Pressure sensor specification.

Model	H35294-Q
Pressure range	0-3000 psi
Install torque	15-17 in-lbs
Input voltage	5V DC
Output voltage	0.5-4.5V DC
Sensitivity	1.76 mV/psi @ 200°C

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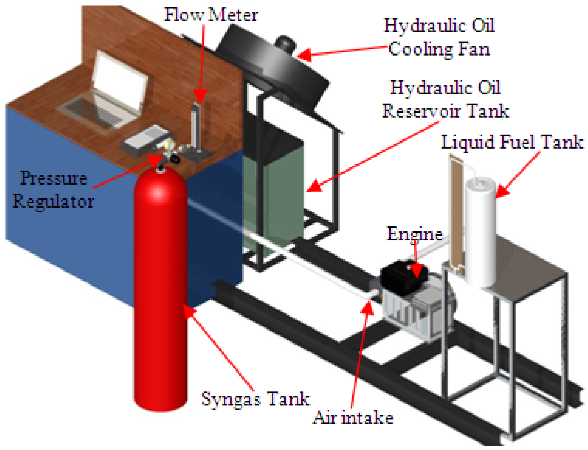

Figure-1. Experiment test bed.

Three thermocouples (K-type) were used to take the reading for air inlet and exhaust gas temperature. The thermocouples were fitted strategically in the engine air intake, exhaust pipe and the air box to get accurate measurement of intake temperature, exhaust temperature and ambient temperature.

The calculations of the combustion parameters were done and the data were analyzed and summarized. With installation and calibration of the measurement equipment, a good research basis was achieved.

Fuel preparation

A combination of three different fuels were used in this study. The base fuel was normal pure diesel. A blend of commercial biodiesel, derived from palm oil and commercial diesel was used as pilot fuel. Simulated syngas was used as a primary fuel in the present study. The blend of palm oil biodiesel and standard diesel fuel was considered: B50 (50% of biodiesel, 50% of Diesel). The used palm oil biodiesel technical properties are shown in Table-3.

Table-3. Properties of used palm oil biodiesel.

Density @ 15°C (kg/L) ASTM D4052	**0.875**
Sulphur content (%wt) IP242	<0.04
Viscosity at 40°C (CST) ASTM D445	4.5
Pour point (°C) ASTM D97	+15
Flash point (°C) ASTM D93	174
Cetane number ASTM D613	62.4
Gross heat of combustion (kJ/kg) ASTM D2332	40,335
Conradson carbon residue (%wt) ASTM D198	0.02

It was difficult to assess the performance of real produced gasification gas dual fuelling in a CI engine because the producer gas composition would fluctuate due to many factors. So as to avoid the fluctuation problem, simulated syngas containing 33% H_2, 15% CO, 3% CH_4, 14% CO_2 and 35% N_2 was used in this study. This composition was selected to be within the typical range of syngas composition produced from biomass gasification. The properties of used simulated syngas is summarized in Table-4.

Table-4. Properties of used simulated syngas

Density	**1.32 kg/m^3**
Lower heating value	6849.61 kJ/kg
Carbon content	18.0%
Hydrogen content	3.7%
Oxygen content	32.3%

RESULTS AND DISCUSSION

In this study, the test for syngas dual fuelling in CI engine was experimentally conducted at half engine load. The engine was running on blended diesel - biodiesel fuel (B50) as a pilot fuel and simulated syngas as primary gaseous fuel. The dual fuel operation data was compared with the baseline data when pure liquid fuels of diesel and B50 are used. The following sections discuss the results for performance of syngas dual fuelling in CI engine when operated with B50 and compared with the results for pure liquid fuels mode of operation.

Effect on in-cylinder pressure and heat release rate

The ignition delay of pilot fuel is affected by the reaction of syngas-air mixture surrounded by pilot spray in a dual fuel combustion process. Normally, syngas dual fuelling leads to longer ignition delay when compared to pure diesel mode of operation. In addition, the pilot fuel ignition delay increases as the presence of syngas increases in dual fuel operation. Figure-2 shows the experimental in-cylinder pressure traces for the engine operations at 1850rpm, 50% load with pure diesel (D), B50 at normal liquid fuel mode as well as dual fuelling with B50 and syngas for different pilot fuel substitution rates (PF_S). The peak cylinder pressure was higher (up to 68.06 bar) when using B50 and small amount of syngas (8% PF_S) instead of pure diesel alone. This is due to the higher oxygen content and cetane number in biodiesel compared to diesel fuel. In syngas dual fuelling operation, the overall combustion was shifted to the expansion stroke due to increased ignition delay of pilot fuel and led to reduced cylinder pressure. While the engine load was kept constant, the increase in syngas presence showed strong effect on the peak combustion pressure (reduction) with similar trend.

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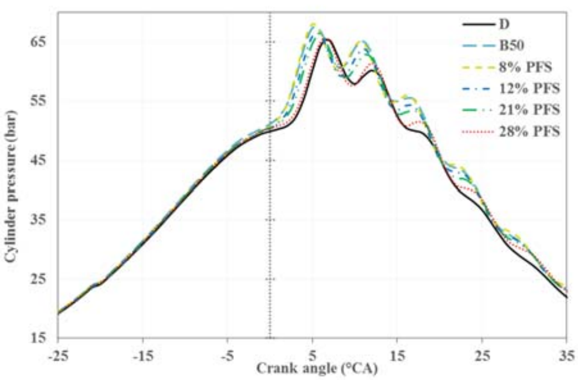

Figure-2. Variation of in-cylinder pressures with crank angle for different pilot fuel substitution rates.

The in-cylinder pressure variation can be obtained when an amount of heat added to the cylinder content. The heat release analysis helps to calculate this amount of heat. The analysis of heat release rate is considered a useful tool to investigate the combustion of any used fuel inside the combustion chamber, either for pure pilot fuel operation or dual fuel operation, but it is generally used for CI engine. Two main phases could be seen during the combustion of a DI diesel engine: premixed phase starts after the start of injection and during the ignition delay, when combustible zones of mixed air-diesel are composed and reacts rapidly upon the ignition. The diffusion phase is controlled by the air-mixture ratio, because it starts when the air depletion takes place into the combustion chamber.

Analysis of the dual-fuel combustion process divides the heat release rate into three phases as depicted in Figure-3. First the premixed combustion of the injected liquid fuel and minor part of the gasification gas remained in the spray of the liquid fuel. Most of the gasification gas and small amounts of the liquid fuel a premixed in the second stage. Finally, the diffusion combustion of the rest of both fuels occurs. It may seem phase one and two of the combustion is characterized by the amount of diesel substitution by gaseous fuel. However, this is not the case. The peak amount of heat released during the first phase is affected by the amount of pilot fuel that can be burned during this phase. Only when the amount of pilot fuel is decreased below this certain limit the importance of this phase decreases. The importance of the second phase on the other hand is determined by the amount of diesel substitution.

Figure-3 shows the experimental heat release rate traces for the engine operations at 1850 rpm, 50% load with pure diesel (D), B50 at normal liquid fuel mode as well as dual fuelling with B50 and syngas for different pilot fuel substitution rates (PF_S). By comparison of heat release rate histories for all engine operation conditions, syngas dual fuelling has led to reduced amount of released heat with longer combustion duration when compared to pure liquid fuel operation. This in turn could indicate less portion of the mixture around stoichiometry, which has high flame speed. Increasing syngas amount would decrease the turbulent mixing rate and, hence, decreasing in degree of leanness was shown. The lowest equivalence ratios showed almost same heat release rate while there was clear reduction in the heat release rate when the syngas amount has increased resulting in low premixed combustion. The effect of syngas on HRR became evident only at high equivalence ratios.

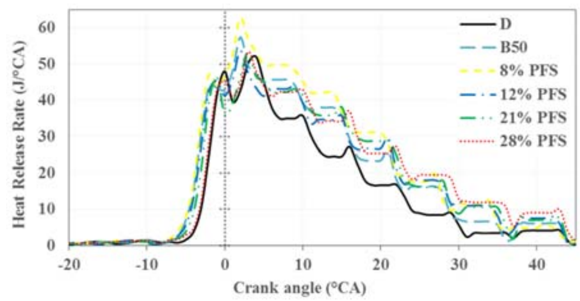

Figure-3. HRR VS crank angle for different pilot fuel substitution rates.

Effect on rate of pressure rise

Rate of pressure rise is calculated from the first derivative of combustion pressure that is much related to the engine operation. It is the measure of how fast the pressure changes in the cylinder through the combustion. The variation of rate of pressure rise for syngas dual fuelling and pure liquid modes at engine speed of 1850rpm and 50% load is given in Figure-4. The rate of pressure rise results for different substitution rates of pilot fuel (PF_S) is also shown in Figure-4. The rate of pressure rise decreased with syngas/B50 dual fuelling operation compared to normal liquid fuel operation with diesel and B50 only.

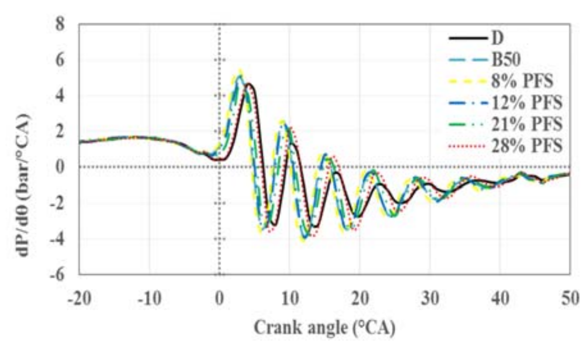

Figure-4. Rate of pressure rise vs crank angle for different pilot fuel substitution rates.

Effect on engine efficiency

The experimental results show that the performance of such gasification gas dual-fueling in a CI engine running with a blend of B50 was lower when compared to the normal pure diesel operation. Figure-5 provides the indicated efficiency for the engine operations at 1850 rpm, 50% load with pure diesel (D), B50 at normal liquid fuel mode as well as dual fuelling with B50 and syngas for different pilot fuel substitution rates (PF_S). By comparison of all engine operation conditions, the indicated efficiency has reduced by only 3.2% when blended B50 was used rather than pure diesel only, further reduction was noticed with dual fuelling of gas and B50. Maximum reduction of 15.3% in engine indicated efficiency was noticed with pilot fuel substitution rate of 28% compared to normal diesel fuel

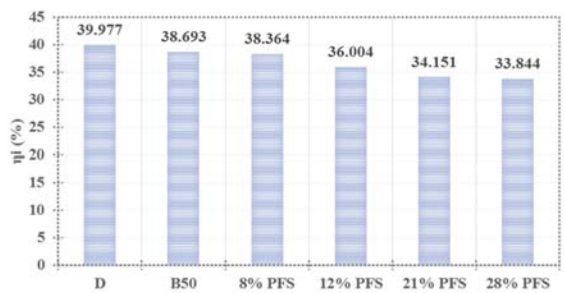

Figure-5. Indicated efficiency for different pilot fuel substitution rates.

CONCLUSIONS

The objective of this work was to experimentally investigate the performance of syngas dual-fueling in a CI engine running with pure diesel and blended diesel - palm oil biodiesel. The results for pure diesel mode was collected and compared with the data for syngas dual fuelling at different substitution rates. Based on the experimental results, the following conclusions can be drawn as the engine load was kept constant:

In dual fuel operation, the use of syngas fuel showed negative effect on engine efficiency (reduction), as the maximum combustion pressure at higher substitution rates was lower when compared to pure B50.

Maximum combustion pressure of 68.06 bar was possible for syngas dual fueling with PFs of 8%.

The three phases of the combustion process were clearly seen for syngas dual fueling operation.

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