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ORIGINAL ARTICLE

An experimental study on the effect of using gas-to-liquid (GTL) fuel on diesel engine performance and emissions

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KEYWORDS

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Abstract Gas to Liquid (GTL) fuel is considered one of the most propitious clean alternative fuels for the diesel engines. The aim of this study was to experimentally compare the performance and emissions of a diesel engine fueled by GTL fuel, diesel, and a blend of GTL and diesel fuels with a mixing ratio of 1:1 by volume (G50) at various engine load and speed conditions. Although using the GTL and G50 fuels decreased slightly the engine maximum power compared to the diesel fuel, both the engine brake thermal efficiency and engine brake specific fuel consumption were improved. In addition, using the GTL and G50 fuels as alternatives to the diesel resulted in a significant decrease in engine CO, NOx, and SO_2 emissions.

1. Introduction

The demands to satisfy the shortage of fuel resources and meet the exhaust gas emission regulations show major challenges that attract many researchers' attention to find innovative economical solutions to match these demands. Hence, a worldwide approach is to search for new alternative cleaner fuels, which can be used either purely or in a blended form with the conventional fossil fuel [1].

The process of converting a gas to a liquid fuel can be made via a refinery process used to convert natural gas or other gaseous hydrocarbons into longer-chain hydrocarbons such as gasoline, diesel, or jet fuel. The most common technique used for converting a gas to a liquid fuel is the Fischer-Tropsch (F-T) synthesis. The first step in the F-T process is converting the natural gas, which is mostly methane, to a mixture of hydrogen, carbon dioxide, and carbon monoxide by the partial oxidation of natural gas. This mixture is called syngas. The syngas is then cleaned to remove sulfur, water, and carbon dioxide. The F-T reaction combines hydrogen with carbon monoxide to form different liquid hydrocarbons. These liquid products are then further processed using different refining technologies to be transformed into liquid fuels [2].

The Gas to Liquid (GTL) fuel derived from the Fischer-Tropsch synthesis has different properties than the conventional diesel fuel. The GTL fuel has a paraffinic nature and lower aromatic content compared to the diesel fuel [3]. Aromatics have the potential to increase the engine soot emissions as soot emissions increase with increasing the aromatic

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Table 1 Engine specifications.

Item	Value
No. of cylinders	1
Bore, mm	82
Stroke, mm	86
Capacity, cc	359.1
Maximum speed, rpm	3200
Inlet valve opens, deg	8 BTDC
Inlet valve closes, deg	43 ATDC
Exhaust valve opens, deg	40 BBDC
Exhaust valve closes, deg	8 ATDC

Table 2 Fuel properties.

Property	Diesel	GTL	G50
Density at 15 °C (kg/m^3)	866	760	792
Flash point (°C)	55	103.5	88.5
Calorific value (MJ/kg)	44.3	47.3	46.2
Calorific value (GJ/m^3)	38.363	35.95	36.59
Cetane no.	55	70	64

Table 3 Uncertainty in measurements and results.

Variable	Uncertainty (%)
Torque (N m)	±1
Speed (rpm)	±0.3
Power (kW)	±0.533
Time (s)	±1
Fuel volume (cm^3)	±0.5
bsfc (g/kW h)	±0.6
Thermal efficiency (%)	±0.7
Air flow rate (kg/h)	±0.125
CO (ppm)	±0.01
NOx (ppm)	±1
SO_2 (ppm)	±1
Pressure (bar)	±0.06

molecular weight and concentration [3]. In addition, the GTL fuel is composed of carbon and hydrogen with near zero sulfur content. The presence of sulfur in the fuel composition can have a negative impact on the environment and engine durability. During combustion, the sulfur is oxidized and reacts with water vapor to produce sulfuric acid and other corrosive compounds, which deteriorate the longevity of valve guides and cylinder liners leading to premature engine failure [3]. Moreover these corrosive compounds get mixed with the atmospheric air causing acid rains.

The GTL fuel hydrogen to carbon (H/C) ratio is higher compared to the diesel fuel [3], which can give the potential for the GTL fuel to produce lower engine emissions compared to the diesel fuel [4,5].

The GTL production has been growing especially in the countries that have large natural gas reserves such as Qatar [2]. As a consequence of strict regulations imposed on natural gas venting, the natural gas producing countries are now looking into further development of cleaner GTL fuels. Various companies such as Shell, Sasol and Chevron are pursuing GTL production technologies and attracting the gas rich countries for setting up GTL production plants to overcome the fuel shortage and produce cleaner fuels, which can have lower harmful impact on the environment.

Several studies investigated the effect of using the GTL fuel on the diesel engine emissions. Aleman and McCormick [6]

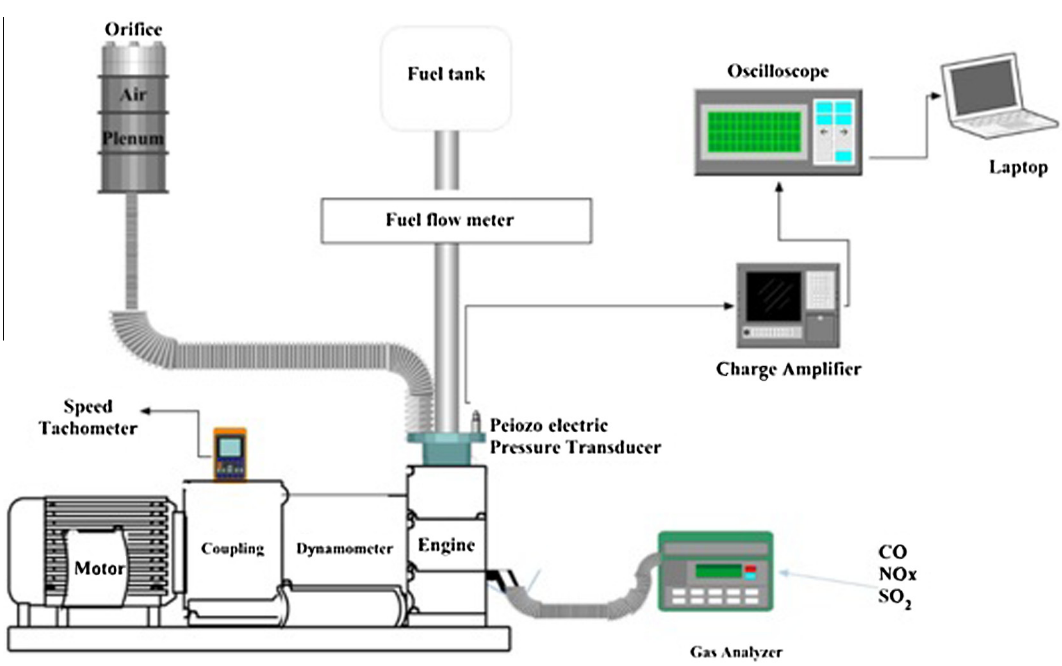

Figure 1 A schematic of experimental setup.

concluded that using the GTL fuel resulted in a decrease in both the engine NOx and particulate matter (PM) emissions by 13% and 26%, respectively, on average, compared to the conventional diesel fuel. Also, Wu et al. [7] showed that using the GTL fuel as an alternative to the diesel decreased the engine CO, HC, PM and NO_X emissions by 16.6%, 12.9%, 27.6% and 23.7%, respectively. In addition, Khan et al. [8] found that using the GTL fuel decreased engine CO, CO_2, HC, and NOx emissions by 36%, 4.2%, 47%, and 35%, respectively, compared to diesel fuel. However, Oguma et al.

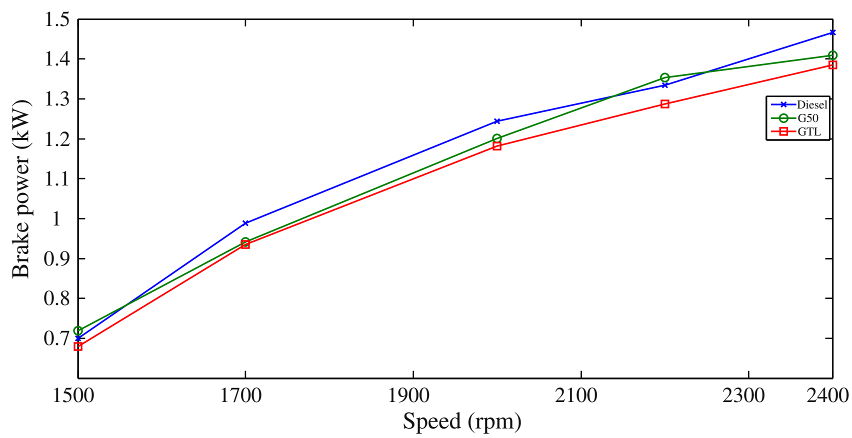

Figure 2 Change of engine brake power with changing engine speed for different fuels at the engine full load condition.

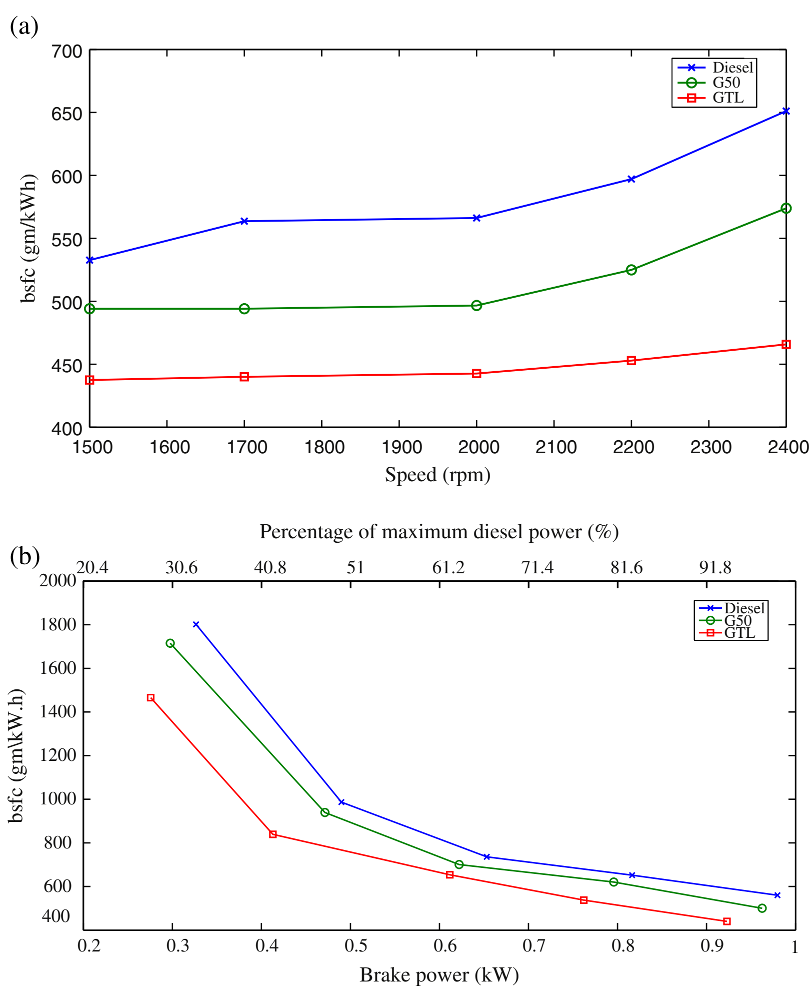

Figure 3 Changes of engine bsfc with (a) engine speed and (b) brake power for different fuels.

[9] demonstrated that the effect of using the GTL fuel on the diesel engine emissions can vary according to the composition and properties of the GTL fuel.

However, conflict results were found in the previous studies regarding the effect of using the GTL fuel on the diesel engine performance compared to the diesel fuel. Abu-Jrai et al. [10] demonstrated that the effect of using the GTL fuel on the engine thermal efficiency varied with changing the engine load. The authors showed that using the GTL fuel led to higher thermal efficiency compared to the diesel in the medium engine load conditions. Wu et al. [7] showed that using the GTL fuel decreased the engine brake specific fuel consumption (bsfc) by 2.7% compared to the diesel fuel at the lower engine speed conditions. However, Wang et al. [11] illustrated that using the GTL fuel as an alternative to the diesel decreased the engine thermal efficiency from 39.6% to 38.7% and increased the engine bsfc. It was also found that the maximum power and peak torque decreased by 1.9% and 1.3%, respectively.

It can be concluded from the previous studies that the effect of using the GTL fuel on the diesel engine performance and emissions can vary with the variations of engine operating conditions, engine specifications, the GTL fuel characteristics, and whether the GTL fuel is used purely or blended with the diesel fuel in different blending ratios. Therefore, extensive research needs to be carried out at different conditions in order to fully assess the effect of using the GTL fuel on the diesel engine performance and emissions. The results obtained from such research can help in optimizing the diesel engine for the GTL fuel operation. Hence, the aim of this study was to experimentally compare the performance and emissions of a diesel engine fueled by the neat GTL fuel, the neat diesel, and a blend of GTL-diesel fuels with a mixing ratio of 1:1 by volume (G50).

2. Experimental setup

The experimental research was carried out using the T85D-DIDACTA ITALIA engine test bed coupled to ARONA single-cylinder, four-stroke, water-cooled, direct-injection, compression-ignition engine. The engine specifications are shown in Table 1. The test engine was coupled to an electric dynamometer connected to an electric motor via a magnetic coupling as shown schematically in Fig. 1. The engine speed was measured by using a speed tachometer while the engine load was measured using a load cell. The fuel flow rate was measured by a calibrated burette and a stopwatch while the air flow rate was measured using an orifice flowmeter. K type

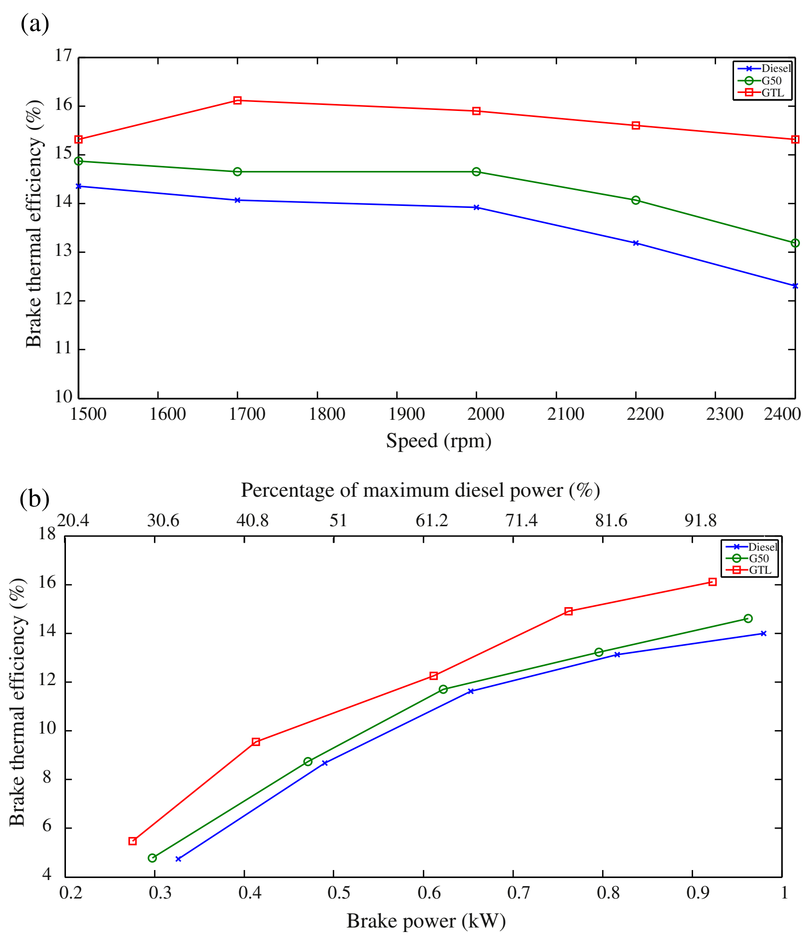

Figure 4 Variations of engine thermal efficiency with (a) engine speed and (b) brake power for different fuels.

thermocouples were used to measure the temperatures of inlet air, exhaust gases, and cooling water.

The in-cylinder pressure data were measured using the AVL QH 33D water cooled piezoelectric pressure transducer and the PALAZZOLI digital shaft encoder. The output of the pressure transducer was amplified by a charge amplifier, and then the output signal was displayed on the Instek GDS-3152 digital oscilloscope. The oscilloscope was connected to a computer in order to record the in-cylinder pressure data. The engine emissions of CO, NO_X and SO_2 were measured using the ENRAC-M700 portable emission analyzer.

Two different sets of tests were performed. One set of tests was performed at different engine load conditions and a constant engine speed of 1700 rpm while the other set of tests was obtained at different engine speeds and the engine full load condition. All the tests were conducted in the laboratories of Qatar University. The GTL fuel used in this study was supplied by a commercial company located in Qatar. Samples of the tested fuels were sent to a university laboratory in order to determine the tested fuel properties according to the standard ASTM methods as shown in Table 2. The uncertainties in measurements and results are summarized in Table 3.

The GTL-diesel fuel blend (G50) was obtained by mixing the two fuels and stirring them using an electric shaker for 30 min. Then the blend was transferred to a transparent tank for observation in order to ensure that there was no phase separation occurred in the fuel blend.

3. Results and discussion

In this section, the performance and emissions of a diesel engine fueled by the GTL fuel, diesel, and G50 were compared and discussed. The effect of changing the engine load at a constant engine speed of 1700 rpm on the engine performance and emissions for the three different fuels was described. In addition, the effect of changing engine speed at the engine full load condition on the engine performance and emissions was also discussed for the three different fuels. To ensure high accuracy, every test point was recorded three times and the mean value was used as a final result.

3.1. Engine brake power

Fig. 2 shows the variations of engine brake power with changing engine speed for different fuels at the engine full load

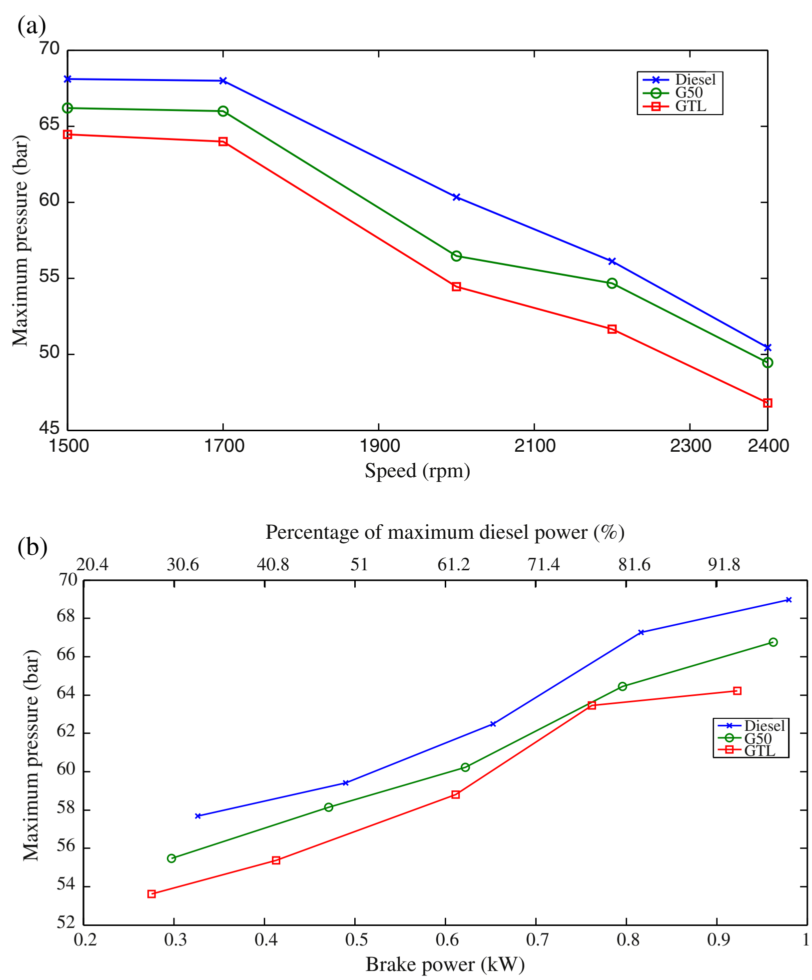

Figure 5 Maximum in-cylinder pressure variations with changing (a) engine speed and (b) brake power for different fuels.

condition. The figure shows that using both the GTL and G50 fuels decreased slightly the engine maximum power compared to the diesel fuel for the most of engine speeds. On average, the engine maximum power decreased by 3.2% and 1.2% when both the GTL and G50 fuels were used as alternatives to the diesel fuel, respectively. The energy content of the injected GTL and G50 fuels was lower compared to the diesel fuel due to their lower volumetric heating value as the volume of injected fuel per cycle was constant for the same injection duration in the unmodified diesel engine [3], which caused a decrease in engine torque and power. Theoretically, about 6% more GTL fuel volume was needed to be injected per cycle than diesel in order to obtain the same engine output power [3]. However, Yongcheng et al. [12] experimentally demonstrated that the volume of injected GTL fuel was required to be increased by only 0.91% in order to obtain the same engine power due to the improvement obtained in the engine thermal efficiency.

3.2. Bsfc and thermal efficiency

Figs. 3 and 4 show the variations of engine bsfc and brake thermal efficiency, respectively, with changing of both engine speed and brake power for different fuels. Both Figs. 3 and 4 demonstrate that using both the GTL and G50 fuels decreased the engine bsfc and increased the engine brake thermal efficiency compared to the diesel fuel. The higher cetane number of both GTL and G50 fuels compared to the diesel fuel, as shown in Table 2, resulted in shorter ignition delay periods for both the GTL and G50 fuels compared to the diesel fuel. Yongcheng et al. [12] demonstrated that using the GTL fuel reduced the ignition delay period by almost 18.7%. The shorter ignition delay of the GTL fuel compared to the diesel is because the GTL fuel has higher paraffinic content that produces much more reactive radicals compared to diesel, which has more aromatic content [3]. The shorter ignition delay period reduces the amount of accumulated fuel in the delay period, which can reduce the in-cylinder temperature and pressure rise during the premixed combustion phase leading to lower heat losses, and consequently, causing an improvement in both the engine fuel consumption and thermal efficiency. On average, using both the GTL and G50 fuels decreased the engine bsfc by 17% and 6%, respectively, and increased the thermal efficiency by 12% and 1.4%, respectively, compared to using the diesel at a constant engine speed of 1700 rpm. Also, using both the GTL and the G50 fuels at the engine full load condition decreased the engine bsfc, on average, by 22.8% and 11.1%, respectively, and increased the efficiency, on average, by 15.6% and 5.3%, respectively.

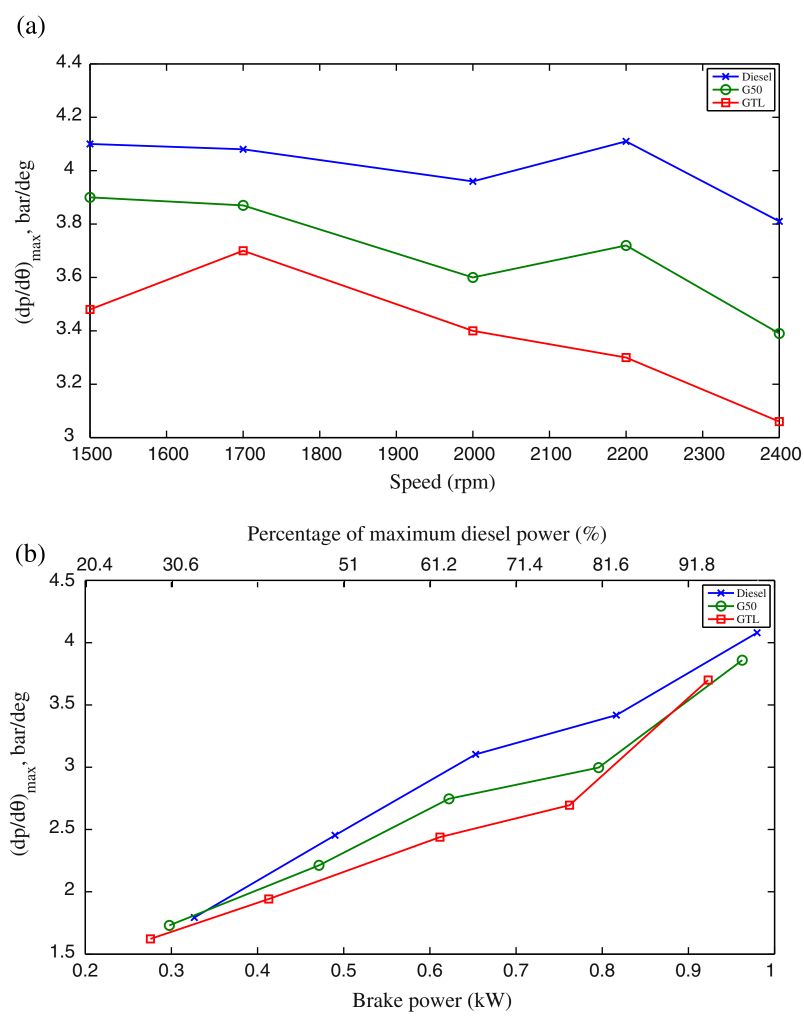

Figure 6 Variations of maximum rate of in-cylinder pressure rise with changing (a) engine speed and (b) brake power for different fuels.

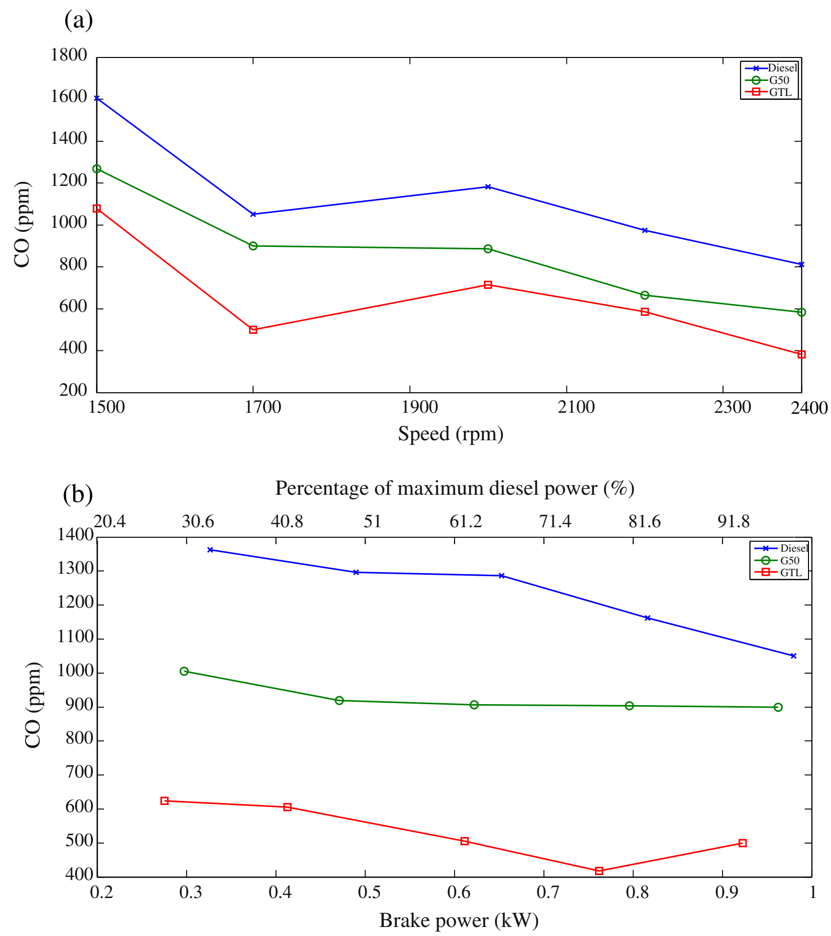

Figure 7 CO emission variations with changing (a) engine speed and (b) brake power for different fuels.

3.3. In-cylinder pressure

Figs. 5 and 6 show the variations of maximum in-cylinder pressure, and maximum rate of pressure rise, respectively, with the change of both engine speed and power. Using the GTL and G50 fuels resulted in a decrease in both the maximum in-cylinder pressure and the maximum rate of pressure rise as indicated in Figs. 5 and 6, respectively. The higher cetane number of both the GTL and G50 fuels compared to the diesel decreased the ignition delay period resulting in a reduction of the amount of fuel burned during the premixed combustion phase, which led to a decrease in both the maximum in-cylinder pressure and the maximum rate of pressure rise. The decrease of maximum rate of pressure rise indicates that using both the GTL and G50 fuels can reduce the engine knock and noise.

3.4. CO emissions

The variations of engine CO emissions with the change of engine speed and power are shown in Fig. 7. Using both the GTL and G50 decreased the engine CO emission significantly. On average, the CO emission was decreased by 43%, and 24% when both the GTL and G50 fuels were used, respectively, at the engine full load condition. Also, using both the GTL and G50 as alternatives to the diesel decreased the CO emissions by 57%, and 24%, respectively, at the engine constant speed operation. The decrease in engine CO emissions was because the hydrogen to carbon (H/C) ratio of the GTL fuel is higher compared to the diesel fuel. The H/C ratio of GTL fuel can range from 2.1 to 2.15 compared to 1.89 for the diesel fuel [3]. In addition, the presence of lower aromatic hydrocarbons, which are more stable molecules, in the GTL fuel compared to the diesel can decrease the engine CO emission [13,14]. Also, the lower distillation temperature of the GTL fuel ensures rapid fuel evaporation, which enhances the fuel-air mixing process [12,15].

3.5. NOx emissions

The changes of engine NOx emissions with the variations of engine speed and power are shown in Fig. 8. The figure shows that the NOx emissions decreased when the GTL and G50 were used as alternatives to the diesel. NOx emissions decreased by 14.8% and 8.7%, on average, when the GTL and G50 fuels were used, respectively, at the engine full load condition. In addition, NOx emission decreased by 30% and 12%, on average, when the GTL and G50 were used, respectively, at the engine constant speed operation. The amount of accumulated fuel during the delay period is lower for the GTL fuel compared to the diesel due to its shorter ignition

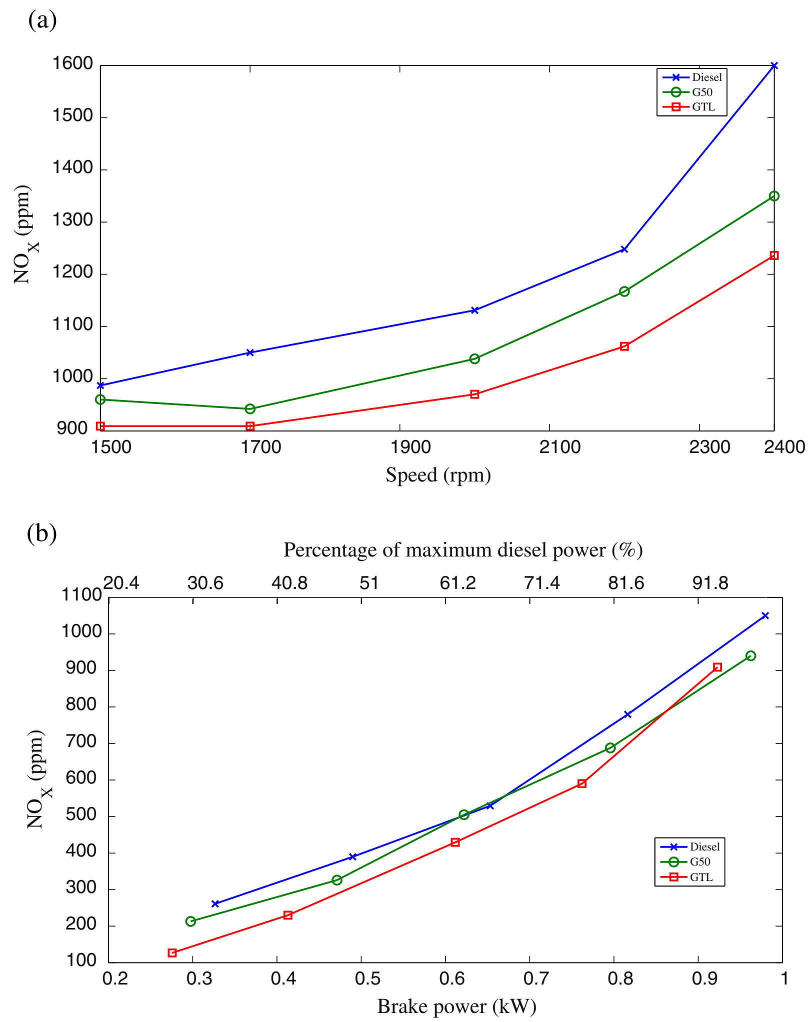

Figure 8 NOx emission variations with changing (a) engine speed and (b) brake power for different fuels.

delay period. Hence, the smaller amount of fuel burned during the premixed combustion phase can decrease the maximum in-cylinder temperature leading to a decrease in NOx emissions. In addition, the significant lower aromatic hydrocarbon content found in the GTL fuel compared to the diesel reduces the adiabatic flame temperature, which helps in reducing the NOx emissions [16].

3.6. SO_2 emissions

Fig. 9 shows the variations of SO_2 emissions with the change of engine speed and power. The figure demonstrates that SO_2 emission decreased significantly when the GTL and G50 were used as alternatives to the diesel. Using the GTL and G50 fuels decreased the SO_2 emission by 78% and 56%, respectively, at the engine full load condition. Also, the SO_2 emission decreased by 92%, and 45% when the GTL and G50 fuels were used, respectively, at the engine constant speed operation. The reduction in SO_2 emission was due to the lower sulfur content of the GTL fuel compared to the diesel. The maximum concentration of sulfur in the GTL fuel can be around 0.005 ppm compared to 11 ppm for the conventional diesel fuel and 0.0034 for the ultra low sulfur diesel fuel [17].

4. Conclusions

In this paper, the performance and emissions of a diesel engine fueled by the GTL fuel, diesel, GTL-diesel mixture (G50) were experimentally investigated and compared at the engine full load condition and at a constant engine speed of 1700 rpm. The results showed that the GTL fuel has a great potential to be used as a cleaner alternative fuel for the diesel engines. Although using the GTL and G50 fuels decreased slightly the engine maximum power compared to the diesel fuel, both the engine brake thermal efficiency and engine brake specific fuel consumption were improved. Also, the maximum rate of pressure rise decreased. In addition, using the GTL and G50 fuels as alternatives to the diesel resulted in a significant decrease in engine CO, NOx, and SO_2 emissions. The amount of reduction in engine emissions and improvement in engine performance varied with engine operating conditions. On average, using the GTL fuel decreased CO, NOx, and SO_2

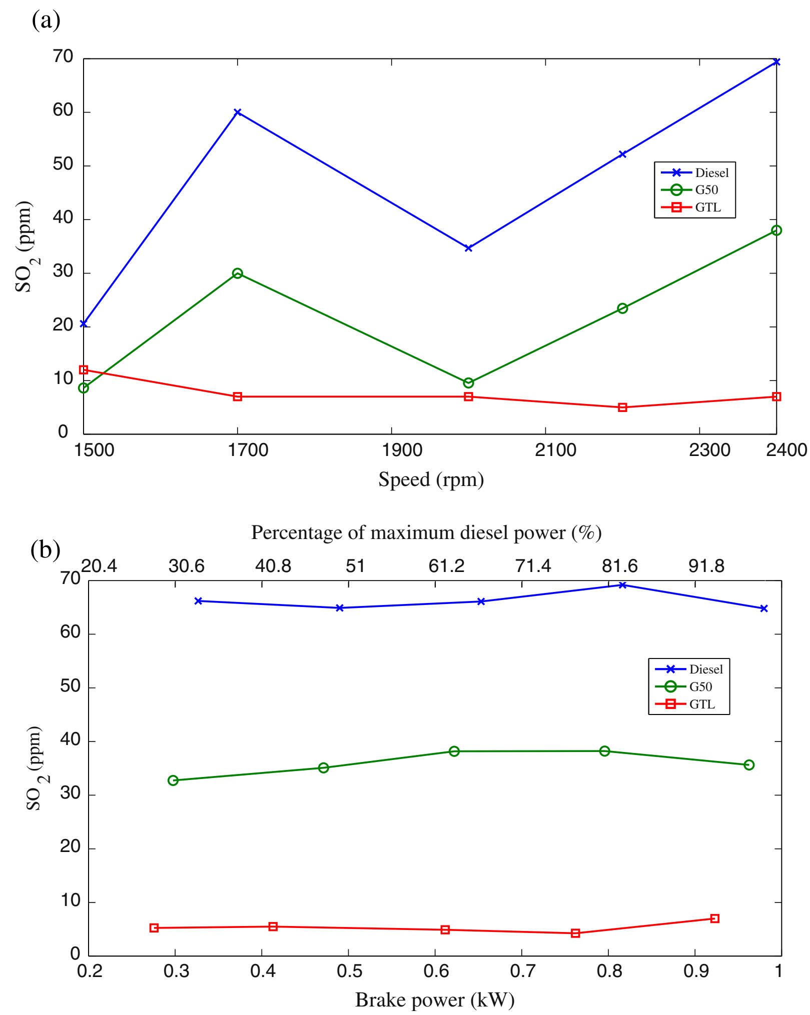

Figure 9 SO_2 emission changes with the variations of (a) engine speed and (b) brake power for different fuels.

emissions by up to 57%, 30%, and 92%, respectively, compared to diesel fuel. Also, the bsfc decreased by up to 22.8% and the thermal efficiency increased by up to 15.6%.

References

[1] A. Ibrahim, Performance and combustion characteristics of a diesel engine fuelled by butanol-biodiesel-diesel blends, Appl. Therm. Eng. 103 (2016) 651–659.

[2] A. Mallik, V. Mantri, Gas To Liquids plants face challenges in the U.S. market. U.S. Energy Information Administration, 2014, <http://www.eia.gov/todayinenergy/detail.cfm?id=15071#>, (accessed 21/4/2016).

[3] H. Sajjad, H.H. Masjuki, M. Varman, M.A. Kalam, M.I. Arbab, S. Imtenan, S.M.A. Rahman, Engine combustion, performance and emission characteristics of gas to liquid (GTL) fuels and its blends with diesel and bio-diesel, Renew. Sustain. Energy Rev. 30 (2014) 961–986.

[4] H. Sajjad, H.H. Masjuki, M. Varman, M.A. Kalam, M.I. Arbab, S. Imtenan, A.M. Ashraful, Influence of gas-to-liquid (GTL) fuel in the blends of Calophyllum inophyllum biodiesel and diesel: an analysis of combustion–performance–emission characteristics, Energy Convers. Manage. 97 (2015) 42–52.

[5] Schaberg P, Atkinson C. Calibration Optimization of a Heavy-Duty Diesel Engine with GTL Diesel Fuel. SAE paper no. 2016-01-0622.

[6] T.L. Alleman, R.L. McCormick, Fischer-Tropsch Diesel Fuels—Properties and Exhaust Emissions: A Literature Review. SAE paper no. 2003-01-0763.

[7] T. Wu, Z. Huang, W. Zhang, J. Fang, Q. Yin, Physical and chemical properties of GTL−diesel fuel blends and their effects on performance and emissions of a multicylinder DI compression ignition engine, Energy Fuels 21 (2007) 1908–1914.

[8] M. Khan, R. Tafreshi, A.J. Mokahal, M.T. Mohamed, M.Y. Hanbal, J. Elturk, Single Cylinder GTL Engine: An Experimental Comparison Between Traditional Diesel and GTL Diesel on Single Cylinder Engine. SAE paper no. 2016-01-1262.

[9] M. Oguma, S. Goto, M. Konno, K. Sugiyama, Experimental Study of Direct Injection Diesel Engine Fueled with Two Types of Gas To Liquid (GTL). SAE Paper no. 2002-01-2691.

[10] A. Abu-Jrai, A. Tsolakis, K. Theinnoi, R. Cracknell, A. Megaritis, M.L. Wyszynski, Effect of gas-to-liquid diesel fuels on combustion characteristics, engine emissions, and exhaust gas fuel reforming, Energy Fuels 20 (2006) 2377–2384.

[11] H. Wang, H. Hao, X. Li, K. Zhang, M. Ouyang, Performance of Euro III common rail heavy duty diesel engine fueled with gas to liquid, Appl. Energy 86 (2009) 2257–2261.

[12] H. Yongcheng, Z. Longbao, ShangxueW, L. Shenghua, Study on the performance and emissions of a compression ignition engine fuelled with Fischer–Tropsch diesel fuel, Proc Inst Mech Eng Part D J Automob Eng 220 (2006) 827–835.

[13] J.B. Heywood, Internal Combustion Engine Fundamentals, 1988, McGraw-Hill, New York, 2002.

[14] J. Zhang, K. He, Y. Ge, X. Shi, Influence of fuel sulfur on the characterization of PM from a diesel engine, Fuel 88 (2009) 504–510.

[15] G. Moon, Y. Lee, K. Choi, D. Jeong, Emission characteristics of diesel, gas to liquid, and biodiesel-blended fuels in a diesel engine for passenger cars, Fuel 89 (2010) 3840–3846.

[16] L. Xinling, H. Zhen, Emission reduction potential of using gas-to-liquid and dimethylether fuels on a turbocharged diesel engine, Sci. Total Environ. 407 (2009) 2234–2244.

[17] P. Soltic, D. Edenhauser, T. Thurnheer, D. Schreiber, A. Sankowski, Experimental investigation of mineral diesel fuel, GTL fuel, RME and neat soy bean and rapeseed oil combustion in a heavy duty on-road engine with exhaust gas after treatment, Fuel 88 (2009) 1–8.