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2015 IOP Conf. Ser.: Mater. Sci. Eng. 100 012006

(http://iopscience.iop.org/1757-899X/100/1/012006)

IOP Conf. Series: Materials Science and Engineering **100** (2015) 012006 doi:10.1088/1757-899X/100/1/012006

Experimental study on the effect of varying syngas composition on the emissions of dual fuel CI engine operating at various engine speeds

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Abstract. Using syngas as a supplement fuel of diesel in dual fuel mode is a proposed solution in the effort to protect the environment and control the serious threats posed by greenhouse gas emissions from compression ignition engines. The objective of this study was to experimentally examine the effect of syngas composition on the exhaust emission of dual fuel compression ignition (CI) engine at various engine speeds, and to compare the operating ranges of imitated syngas versus pure diesel. The study was conducted using a naturally aspirated, two strokes, single cylinder 3.7 kW diesel engine operated at speeds of 1200, 2000 and 3000 rpm. The engine was tested with three different syngas compositions. Diesel fuel was partially substituted by syngas through the air inlet. The test results disclose the impact of using syngas in CI engines on emission of CO_2, NO_x, unburned hydrocarbons and carbon monoxide. The experimental measurements confirmed that all syngas compositions are capable of reducing the emissions of CO_2 and NO_X compared with diesel fuel. Wide range of diesel replacement ratios (up to 72%) was attained without any penalty. Syngas with composition of 49% N_2, 12% CO_2, 25% CO, 10% H_2, and 4% CH_4 reduced the emissions of CO_2 and NO_x at engine speed of 1200 rpm up to 1% and 108 ppm, respectively. The lowest emission of UHC and NO_x was emitted when the engine was operating at speed of 2000 rpm and 3000 rpm, respectively with composition of 38% N_2, 8% CO_2, 29% CO, 19% H_2, and 6% CH_4. Therefore, syngas could be a promising technique for controlling NO_x emissions in CI engines. However, hydrogen content in syngas is important parameter that needs to be further investigation for its effect.

1. Introduction

Many compression ignition (CI) engines have been converted to run on gaseous fuel through dual fueling in order to improve the combustion process and achieve low exhaust emission. This was done by maintaining the engines' existing design without any modification. Dual fuel CI engines could be easily exchanged from dual fuel operation to operate on pure diesel at any time. Selection of the type of gaseous fuel to be used in dual fuel for CI engine should be on the basis of environmental considerations and economy [1]. For environmental, usage of syngas in dual fuel CI engine has the capability to control the emission of nitrogen oxides (NO_X) and carbon dioxide (CO_2) due to the lower heating value of syngas and the effective presence of nitrogen and carbon dioxide in its composition. For the economic purpose, using of syngas in CI engines allows substituting the diesel fuel and reduce the cost effectively as this fuel is produced by converting readily available natural materials [2].

Great interests have emerged in using of syngas produced from biomass gasification as alternative fuel for CI engines. However, the conditions of syngas produced from gasification of solid fuels are not consistent [3-5]. This instability affects the engine combustion and emission, leading to several researchers to focus on operation of CI engines with syngas in dual fuel mode. Sadykov et al. [6] operated a water-cooled CI engine fueled with diesel and syngas generated from the common gas. A steady speed of 1300 rpm was used while testing the engine. The operation was tested at standard conditions of an unadulterated diesel and at partial substitution of diesel by syngas on dual fuel mode. Measurements of engine exhaust emission showed that, reduction of NO_X emission has occurred with the addition of syngas to the pilot fuel in each of the ultra-lean and moderately rich mixtures; while an increment of NO_X emission was acquired in the moderate mixture. Hence, the decrease of NO_X substance with the expansion of syngas could be allocated to the weakening impact of nitrogen and carbon oxides together with the left over water held in syngas. While hydrocarbons emitted slightly with syngas expansion staying at a level (lower than 40 ppm). CO emission built extensively, this inferred that observed impact was because of an extensive CO content in syngas. Besides, because of the weakening impact of inert segments of syngas, the diminishing of the combustion temperature and relating weakening of combustion efficiency, particularly at level identical proportions, could be dependable for the increment of CO substance in exhaust emission as well.

Sridhar et al. [7] concentrated on the exhaust emission from engines working on producer gas as fuel. The emissions of NO_X and CO were measured for dual fuel operation mode and pure diesel mode. Firstly, when a CI dual fuel engine was operated utilizing high speed diesel and producer gas fuel, it was discovered that the NO_X levels were lower compared with pure diesel fuel, while the CO levels were higher due to ignition inefficiencies. At that point a 100% ultra-clean producer gas was utilized as a flash ignition engine. It was discovered to be ecologically harmful in terms of emissions; NO_X and CO levels were discovered to be much lower than a large portion of the existing emissions standards of different countries including the United States and European Union.

Ahrenfeldt et al. [8] operated a gas engine with producer gas from biomass as fuel for more than 2000 hours. Two diverse control ways were followed and investigated. Firstly, the stream rate of the producer gas was set to be steady and the engine worked with distinctive measures of air because of gas composition variation and hence stoichiometry. Secondly, the amount of air in the exhaust gas was set to be constant and distinctive amount of producer gas was utilized. Measurement was reported in term of standard emissions, load and efficiency at diverse loads ranging from 50% to 90%. Generally, the engine operation with producer gas produced high flow of unburned CO whatsoever conditions compared with current regulation for CO emission. The outflows of aldehydes were considerably lower for producer gas operation as compared to the natural gas.

Mahgoub et al. [9] studied the emission from dual fuel CI engine running on three different controllable compositions and conditions of imitated syngas at engine speed of 2000 rpm. A reduction on CO_2 and NO_X emission level was recorded for syngas/diesel dual fuel operation when compared with the operation of the engine on pure diesel fuel. A disadvantages concerning UHC and CO were observed for dual fuel operation throughout all syngas compositions used in their study due to poor combustion efficiency of syngas-diesel dual fuel operation. It can be concluded from previous studies that, dual fuel combustion using syngas as a supplement for diesel fuel affects positively (reduction) NO_x and CO_2 emissions, while it causes a considerable increase of CO and UHC emissions compared to the ones observed under normal diesel operation. This study is an extension of the previous work by Mahgoub et al. [6]. The emissions of the three imitated syngas compositions was determined at higher and lower than engine speed of 2000 rpm in order to study the effect of engine speed on the emission from dual fuel CI engine running on different syngas compositions and to find the operating ranges of imitated syngas versus pure diesel.

2. Experimental setup

The engine used in this study was a naturally aspirated, two stroke, single cylinder, 3.7 kW diesel engine with a displacement volume of 230 cc and a compression ratio of 17.6:1. This engine was used to investigate its emission by fueling different compositions of imitated syngas at engine speed of 1200, 2000, and 3000 rpm for various diesel replacement ratios. Experimental rig were incorporated into the engine setup to deliver the syngas through the air intake manifold. The rig and properties of used syngas compositions were described previously by Mahgoub et al. [10]. The schematic of experimental rig are shown in Figure 1. The properties of used syngas compositions are described in table 1.

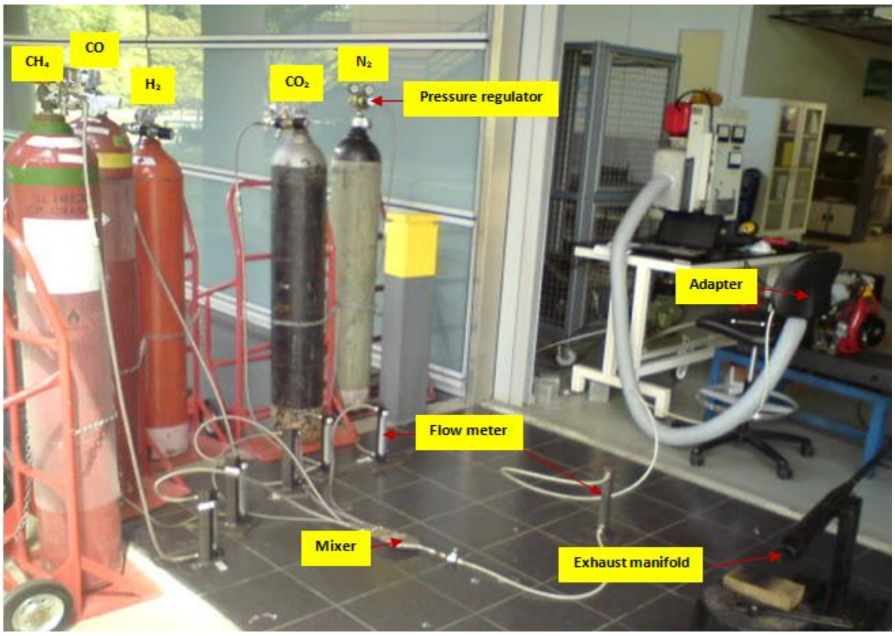


Figure 1. Schematic of experimental rig.

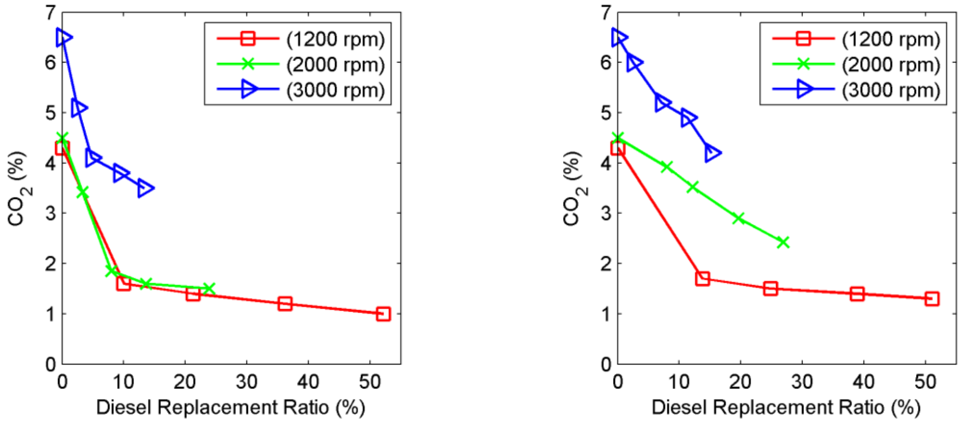
Table 1. Properties of selected syngas compositions.

Composition	N_2	CO_2	CO	H_2	CH_4	LHV (kJ/kg)	ρ (kg/m^3)
A	49	12	25	10	4	4726.19	1.1
B	51	6	22	18	3	5418.4	0.94
C	38	8	29	19	6	7444.13	0.93

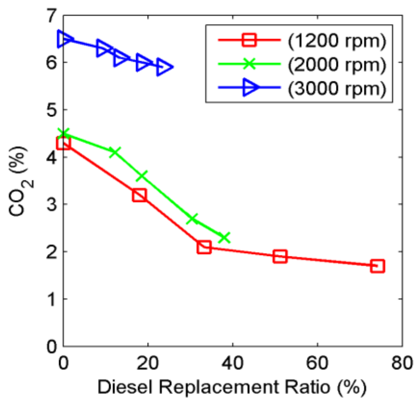
A multi-component FTIR gas analyzer (GASMET Cr-4000) was used to analyze the concentration level of CO_2, CO, UHC and NO_X emission at each diesel replacement ratio for all compositions of syngas at engine speed of 1200, 2000 and 3000 rpm.

3. Results and discussions

The engine exhaust emission evaluated for the concentration of CO_2, CO, UHC and NO_X. CO_2 concentration versus diesel replacement ratios for each syngas composition at different engine speed is given in figure 2.



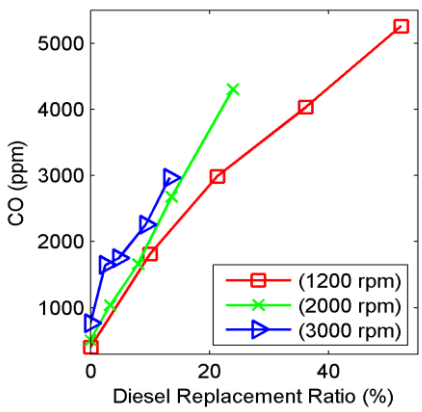
(a) 49% N_2 – 12% CO_2 – 25% CO – 10% H_2 – 4% CH_4 **(b)** 51% N_2 – 6% CO_2 – 22% CO – 18% H_2 – 3% CH_4



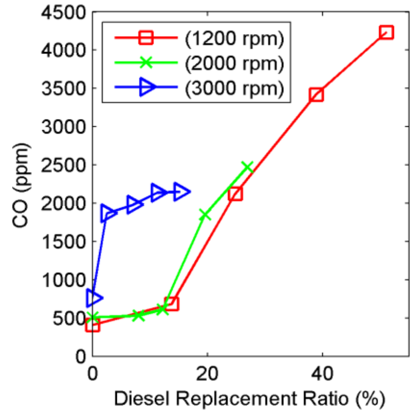
(c) 38% N_2 – 8% CO_2 – 29% CO – 19% H_2 – 6% CH_4

Figure 2. CO_2 concentration for various ratios of diesel replacement at various engine speeds.

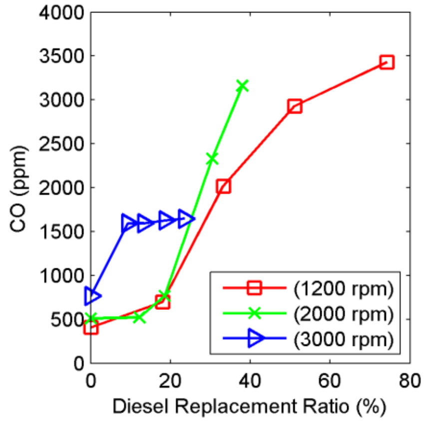
CO_2 emission increased with the increase of engine speed for all syngas compositions due to increase of in-cylinder temperature and the amount of air at higher engine speeds. This is interpreted from the measured exhaust gas temperature. This has increased oxidation rate of carbon to CO_2. The highest amount of CO_2 was at 3000 rpm for all syngas compositions which is considered as an indicator to good combustion and high power output. The trends in Figure 2 show that, the emission of carbon dioxide reduces as the amount of syngas increases. This is largely due to the displacement of the incoming air by syngas in syngas dual fuel mode which then leading to decrease on the oxidation rate and reduce the carbon dioxide formation. Although composition A contains higher amount of inert carbon dioxide compared to the other compositions, lower amount of carbon dioxide is emitted at all engine speeds. This is might be because there was no enough incoming air leading to a reduction on the oxidation rate of carbon to carbon dioxide. Figure 3 provides the variation of CO concentration as a function of diesel replacement ratios for each syngas composition at different engine speeds. CO emission increased with the increase of engine speed for all syngas compositions as an increase in engine speed shortens the oxidization time of CO to CO_2. An increase in carbon monoxide content is also explained by incomplete combustion in the cylinder because of the average cylinder temperature decline due to the lower heating value of syngas. Similar results were obtained when different producer gas to air flow ratios has been inducted into diesel engine by Ramadhas et al. [11].



(a) 49% N_2 – 12% CO_2 – 25% CO – 10% H_2 – 4% CH_4



(b) 51% N_2 – 6% CO_2 – 22% CO – 18% H_2 – 3% CH_4

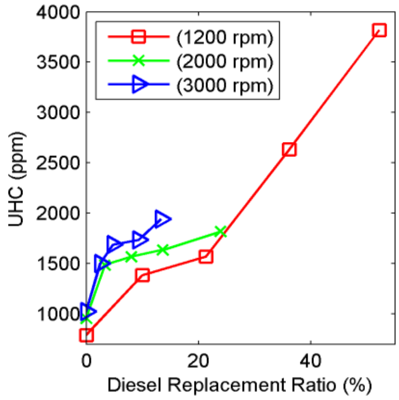


(c) 38% N_2 – 8% CO_2 – 29% CO – 19% H_2 – 6% CH_4

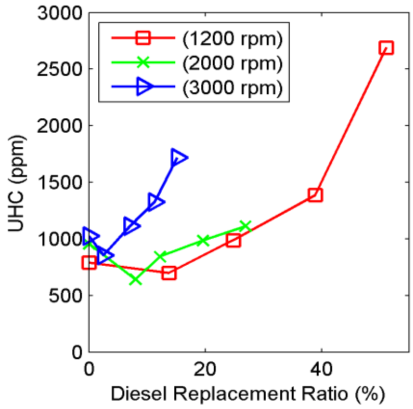
Figure 3. CO concentration for various ratios of diesel replacement at various engine speeds.

Composition A emitted the highest amount of carbon monoxide at all engine speeds due to its lower heating value which leads to an average cylinder temperature decline and incomplete combustion. While compositions B and C showing lower carbon monoxide level due to the rising in the heating value, the high level of carbon monoxide emission from composition A is due an incomplete combustion and due to the presence of higher carbon monoxide in composition A compared to other compositions.

Figure 4 shows the concentration of UHC versus diesel replacement ratio for each syngas composition at different engine speed. UHC emissions are the results of an incomplete combustion fuels. Similar to CO, UHC emissions are the result from flame quenching in crevice regions and at cylinder walls. Other causes of UHC emissions formation are due to the running of the engine on too rich fuel air ratio with insufficient oxygen and the incomplete combustion of lube oil. UHC emissions also increase due to decline of the cylinder peak temperature causing incomplete combustion. Similar results were obtained when different loads were applied by Saha et al. [12] to study the effect of syngas composition on exhaust emission of diesel engine. The poor combustion of syngas with air resulted in the HC emissions at a higher level.



(a) 49% N_2 – 12% CO_2 – 25% CO – 10% H_2 – 4% CH_4



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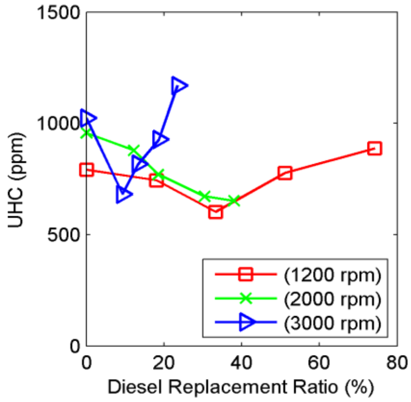
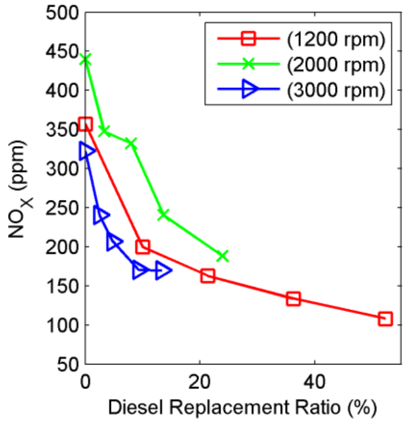


(c) 38% N_2 – 8% CO_2 – 29% CO – 19% H_2 – 6% CH_4

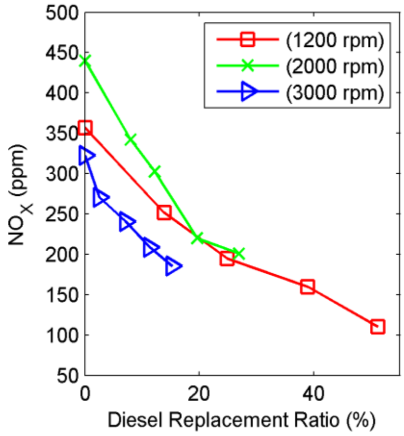
Figure 4. UHC concentration for various ratios of diesel replacement at various engine speeds.

Although the engine emitted the highest amount of CO_2 at 3000 rpm as shown in Figure 2 for all syngas compositions, which considered as an indicator to the good combustion, the highest amount of UHC was also emitted at 3000 rpm for all syngas compositions. This is because there was not enough oxygen for combustion inside the combustion chamber, or most of the oxygen consumed on the oxidation process of carbon to carbon monoxide. This can be inferred from the higher amount of CO_2 emitted from the engine as shown in Figure 3.Composition A emitted the highest UHC due to the excess oxygen concentration drop in the intake mixture inside the combustion chamber which leads to improperly combustion and higher UHC emission. The trends show that, compositions B and C emitted less amount of UHC and started to increase gradually this can be interpreted that rigorous combustion occurred in early stage then the combustion rate decreased at the later stage.

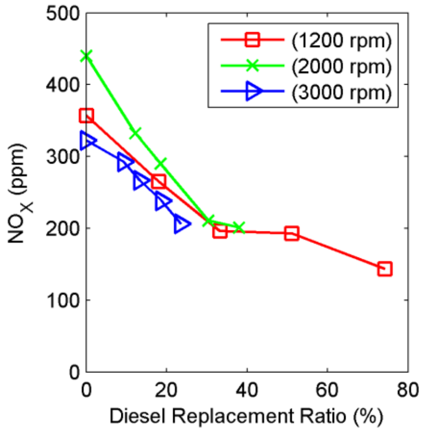
NO_X emissions are shown in Figure 5 for each syngas composition at different engine speeds. It can be seen that the NO_X emission increased with the increase of engine speed. This is due to increase of in-cylinder combustion temperature and the availability of more amount of oxygen inside the cylinder which facilitated the thermal formation of NO_X content. The engine emitted the lowest amount of NO_X at 3000 rpm for all syngas compositions. This is because insufficient oxygen remaining for thermal oxidation of nitrogen due to the consumption of the oxygen inside the combustion chamber into the process of oxidation of carbon to carbon monoxide as shown in Figure 3.



(a) 49% N_2 – 12% CO_2 – 25% CO – 10% H_2 – 4% CH_4



(b) 51% N_2 – 6% CO_2 – 22% CO – 18% H_2 – 3% CH_4



(c) 38% N_2 – 8% CO_2 – 29% CO – 19% H_2 – 6% CH_4

Figure 5. NO_X concentration for various ratios of diesel replacement at various engine speeds.

Figure 5 presented that the dual fuel effect could decrease the nitrogen oxides from combustion process in cylinders. The diminishing of nitrogen oxides in the case of syngas dual fuel mode occurred from the dilution of nitrogen in the air by syngas mixing, that it reduces the thermal nitrogen oxides effect in cylinders. The decrease in NO_X levels also may be attributed to diluting effect of nitrogen and carbon oxide components of the syngas and the lower hydrogen content which leads to lower cylinder peak temperature. More pronounced decline of NO_X emission with addition of syngas apparently is caused by the oxygen concentration drop in the intake mixture. Hence, in this study, composition A emitted the lowest NO_X content, which attributed to the temperature-lowering effect of the syngas, owing to the composition lower heating value compared to other compositions or due to oxygen concentration drop. The higher hydrogen presence of composition C have resulted the highest combustion temperature as indicated by the measured exhaust temperatures. Hence, the NO_X emission for this composition was higher as compared to other compositions at all conditions.

4. Conclusions

In the present work, an experimental study was conducted to determine the emissions of a CI engine dual fuelled with diesel and imitated syngas at various engine speeds. From the analysis of experimental data and the comparison between normal diesel and syngas dual fuel operation, the main conclusions from the study are as follows:

i. Dual fuel operation considered as a promising technique for controlling NO_X emissions on existing CI diesel engines and it affects positively carbon dioxide emissions, while it causes a considerable increase carbon monoxide and UHC emissions compared to the observed under normal diesel operation.
ii. The relative content of hydrogen in syngas composition is very important to overcome the negative effects of the presence of CO and UHC in the exhaust emission. So the engine operating on Composition C showed the lowest level of CO and UHC.
iii. Composition C can be considered the most appropriate composition compared to the other compositions because it showed the lowest level of CO and UHC.

Acknowledgements
The authors are grateful for the contributions of members at Power Generation Laboratory in Universiti Teknologi PETRONAS.

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