Effect of Catalytic Converter on the Performance and Emissions of a Diesel Engine Operated in Dual-Fuel Mode with Raw-Biogas

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Abstract— Effect of a catalytic converter on the performance and emissions of a small diesel engine is investigated experimentally. The small diesel engine with an output power (rated) 4.41 kW is operated on single and dual-fuel modes. For the case of dual-fuel operation, the raw biogas which contain methane concentration 60% is used. The flowrate of the biogas is varied from 2 Liter/min, 4 Liter/min, and 6 Liter/min, respectively. The results show that the catalytic converter does not affect the power, specific fuel consumption and thermal efficiency of the engine. The output power, brake thermal efficiency, diesel replacement ratio, and specific fuel consumption of the compression ignition engine are the same when it is operated with and without catalytic converter. The similar facts are shown by the compression ignition engine when it is operated in pure-diesel and dual-fuel modes. However, the catalytic converter significantly affects the exhaust gas emissions. For the engine run in pure-diesel mode, the catalytic converter decreases smoke emission significantly. For the compression ignition engine run in dual-fuel mode, the catalytic converter decreases carbon oxide number, smoke emission, and hydrocarbon number significantly. It is suggested to install a catalytic converter to a diesel engine when it is run in dual-fuel mode in order to diminish the bad environmental impact.

Index Term— Catalytic converter; emission; biogas; diesel; dual-fuel

I. INTRODUCTION

Greenhouse Gas (GHG) emissions which result in global warming is a serious problem for the human being. According to a report [1], total GHG emissions were the biggest in the era of mankind from the year 2000 to 2010. In the year 2010, 49 (±4.5) Giga ton CO₂eq has been released to the atmosphere. The GHG emission mainly resulted by fossil fuel combustion activities and industrial process. It is contributed about 78% of the total GHG emission. To avoid the globe from serious problem, many countries have released their target on mitigation of the GHG emissions. For instance, Indonesia has released a target on cutting its GHG emissions by 26% from level business-as-usual (BAU) by 2020, and the target can be enhanced up to 41% by using international supports. To assist the mitigation actions, the Government of Indonesia has released a President Regulation National Action Plan in national level and Regional Action Plan for Reducing GHG emissions in provincial level [2]. As a note, the energy sector is known as the biggest GHGs emitters in the world. It includes activities that burning fossil fuel to produce electricity, heat, and mechanical energy such as in machinery and transportation. Solutions for GHG reduction are stopping deforestation and promoting sustainable energy policy which includes enhancement of energy efficiency and using renewable energy. Studies on employing renewable energy resources for sustainable development in a rural area are increasing [3], [4], [5].

One of the potential mitigation actions for reducing GHG emission is employing biofuel to substitute fossil fuel in engines. There are several types of biofuel that can be used to power engines, such as biogas, biodiesel, and bioethanol. One of the significant source of biofuel is biogas. It is resulted from anaerobic degradation of organic materials which are present abundantly in the rural areas. Such areas typically employ compression ignition (CI) engines for agricultural machinery, transportation, and small-scale power plant. There are two methodologies that can be employed to operate CI engine using biogas fuel. The first method is modified the CI into spark-engine and operated with biogas only fuel [6], [7], [8], [9] and the second method is dual-fuel mode. In the first mode, the CI needs extreme modifications, because the CI engine must be converted into spark ignition engine. The literature shows that CI engine can be operated 100% on biogas with performance comparable with diesel fuel. However, this method will be a problem if the biogas is disappeared, the converted CI engine is not easily turned back into original diesel engine.

The second alternative is CI engine operated in dual-fuel mode. When the piston at the end of the compression, the biogas and air are compressed in the combustion chamber. Here, the pilot fuel is injected it is a small amount of diesel. Since the pilot fuel gets its self-ignited, it acts as ignition source. Thus, the combustion is processed. The advantage of a CI engine run in dual-fuel mode is that it works with many varieties of gaseous fuels without significant engine modifications [10]. It is easily turned back into pure diesel operation mode, if there is no biogas. In spite of the fact that a CI engine operated in dual-fuel mode shows its practical use, there are still many challenges. The challenges are to make the performance compared with its original pure-diesel mode and to make the exhaust gases...
friendly to the environment. In order to solve the performance problems, several studies on the improvement of performance CI engine operated in dual-fuel mode are reported in the literature. A study on the effect of fuel injection system and the quality of the liquid fuel (pilot) on the performance of the diesel engine operated in dual-fuel mode was carried out by Bedoya et al. In addition, Cacua et al. [12] promote oxygen-enriched air to improve the performance. The effects of methane concentrations in a big CI engine four strokes and four cylinders which is run in dual-fuel (diesel combined with biogas) mode was reported by Makareviciene et al. [13]. An experimental investigation on the biogas combined with biodiesel operated in HCCI of diesel engine was reported by Nathan et al. [14]. The objective is to investigate the characteristics of the HCCI system to use biogas in effective way. In the prior works, the focuses were the treatment of the biogas and injection system.

Investigations on the operation parameters and combustion strategies of a CI engine run in dual-fuel mode also received more attentions. Yoon and Lee [15] reported their investigation on the influence of characteristics of time in the injection stage, the ratio of energy biogas energy to fuel, and intake charge temperature on engine characteristics, emissions, and combustions performances by using HCCI mode of diesel engine. The effects of compression ratio to the engine-performance, combustion characteristic and emissions using raw biogas on a small diesel engine 3.5 kW is reported by Ibrahim et al. [16]. The effects of combustion strategies have been investigated by Bora et al. [17] and Feroskhan et al. [18]. Park and Yoon [19] reported the optimization the injection timing for several type and size of diesel engine operated in dual-fuel mode. Luijtten CCM and Kerkhof [20] investigated the effects of injection pressure, compression ratio and pilot injection timing on a diesel engine operated in dual-fuel mode. Ambarita [21] showed that without any significant modification a small CI engine, typically used for agricultural, can be run in dual-fuel operation using un refined biogas. The consumption of diesel fuel can be reduced up to 87.5%. The combustion characteristics of the CI engine operated in dual-fuel mode has also explored numerically by Ambarita et al. [22].

The above literature shows that the investigation of exhaust gas emission characteristics of CI engine powered by biofuel has received less attention. The exhaust gas of a diesel engine typically contains hydrocarbon (HC), oxides of nitrogen (NOx) and carbon monoxide (CO). As a note, HC emission has a bad impact on the human being health. This is due to direct toxicity of some hydrocarbon compounds which are chemical carcinogens. The carbon monoxide is a toxic gas that cannot be seen or smelled and all people are at risk for CO poisoning.

A catalytic converter has been proposed to reduce the emission of a combustion engine since 1975. The catalytic converter converts harmful exhaust gases into safe compound that can be emitted to atmosphere and cause less damage to the environment. Rezk et al. [23] investigated effects of the catalytic converter position on the performance and hydrocarbon in the exhaust gas of a spark ignited engine. Michel et al. [24] reported their study on the optimization fuel consumption and pollutant emissions of gasoline-hybrid electric vehicle equipped with catalytic converter. Irawan et al. [25] proposed a design of catalytic converter made of copper manganese-coated for gasoline motor. The design is claimed to be an optimum one. Those literatures are focused the gasoline or spark ignition engines. However, only limited studies on the catalytic converter in a CI engine. Vallinayagam [26] reported a study on emission decrease from CI engine powered by biofuel made of pine oil using selective catalyst reduction and catalytic converter. Lozhkin and Lozhkina [27] proposed a numerical method of catalysis process in term of heat rejection. The model was validated to a catalytic converter coupled with a storage equipment diesel engine of city bus.

The above studies showed that reducing emissions using catalytic converter has been implemented in the spark ignition engine and diesel engine. Recently, Ambarita [28], [29] studied the performance and emission characteristics of a CI engine run in dual-fuel mode. The effects of biogas flow rate and methane concentrations were explored. The results showed that performances were comparable with pure diesel mode. However, hydrocarbon emission which has bad impact to the human being health was very high. Here, a catalytic converter is proposed to reduce the exhaust gas emissions. To the best knowledge of the author there is no study related to CI engine operated in dual-fuel mode equipped with a catalytic converter has been reported in literature. In the present work, a small diesel engine with a catalytic converter run in dual-fuel (diesel raw biogas) mode is studied experimentally. The aim is to make clear the effect of catalytic converter on the performance and emission of the small diesel engine when it is run in dual-fuel mode. The outputs of the present work are expected to supply the necessary information to reach GHG emission target and to provide technology in supporting energy for sustainable development which is safe for human health.

II. EXPERIMENTAL APPARATUS AND METHODS

The experimental apparatus and problem formulation are explained in the following subsections.

A. Experimental Apparatus

In this study an experimental apparatus has been made. Fig. 1 depicts the layout of the experimental apparatus. It comprises of a small diesel engine, a generator, a series of lights, biogas container, gas mixer, and measurements equipment. The used CI engine is typically employed to power a mini tractor in Indonesian agriculture. The characteristics of the diesel engine are presented in Table 1. It is a single-cylinder four strokes diesel engine and designed for diesel fuel. The output power of the engine is 4.86 W with a weight of 65 kg. A catalytic converter which is typically used for motorbike purchased in Indonesian market, is coupled to the CI engine. It is a three-way, Pt-Rh, honeycomb structure catalytic converter.
The used fuels are pure diesel and raw biogas. The diesel fuel is got from PERTAMINA the Indonesian government-owned fuel seller in Indonesia. The low heating value (LHV) of the diesel fuel is measured using a bomb calorie meter. The low heating value of the fuel is 42.64 MJ/kg. The raw biogas is made of fermentation of Palm Oil Mill Effluent (POME) by using digester. The biogas digester belongs to PTPN III an Indonesian government-owned Palm Oil Company. The type of the biogas digester is anaerobic mesophilic. The biogas is stored in a particularly designed tank by using a compressor. Here, the raw biogas without any treatment is used in the experiment. The methane content of the biogas is measured using Gas Chromatography, and the result is presented in Fig 2. It can be seen that the used biogas comprises of methane and carbon dioxide with a volume concentration of 60.4% and 39.5%, respectively. The calorific value of the biogas is estimated using formula suggested by Ludington [30]. Here the LHV of the used biogas is 17.69 MJ/kg. The method of using biogas as fuel to the CI engine is detailed briefly in the following. The biogas from the tank will be flowed into the intake manifold and mixed with fresh air.

### Table I

<table>
<thead>
<tr>
<th>No</th>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Engine name and model</td>
<td>Tiger Diesel Engine R175 AN</td>
</tr>
<tr>
<td>2</td>
<td>No of cylinder and no of stroke</td>
<td>Horizontal Single-cylinder and 4 strokes</td>
</tr>
<tr>
<td>3</td>
<td>Cooling system</td>
<td>Water cooled</td>
</tr>
<tr>
<td>4</td>
<td>Bore x Stroke</td>
<td>7.5 cm x 8.0 cm</td>
</tr>
<tr>
<td>5</td>
<td>Maximum output</td>
<td>4.86 kW</td>
</tr>
<tr>
<td>6</td>
<td>Rated output</td>
<td>4.41 kW</td>
</tr>
</tbody>
</table>

The diesel engine is used to rotate a generator by employing a pulley. The characteristics of the used generator are explained in the followings. The rating frequency, voltage, and maximum power are 50/60 Hz, 115-230 V, and three kVA, respectively. The output electric is employed to power a series of lights. The opacity of the exhaust is estimated by using engine smoke meter. The content of HC and CO in the exhaust gas are measured using gas analyzer. The engine smoke meter type is HD-410. The measuring range of the smoke meter varies from 0.00-100%. The absorption coefficient is from 0.00 - 21.42 m⁻¹. The oil and operation temperatures are 0 - 100°C and of -10°C - 40°C, respectively. The Gas Analyzer is HG-510 and specifications measuring a range of CO and HC are 0-9.99% and 0-9999 ppm, respectively.

Experimental procedures are explained as follows. The CI engine will be run with four loads. The first test is single-fuel (pure diesel) mode without a catalytic converter, hereafter this mode named as Pure Diesel (PD). The second mode is the single-fuel mode, but the engine is equipped with catalytic converter, hereafter named as Pure Diesel with catalytic converter PDc. The third mode is the dual-fuel engine without a catalytic converter, named as DF. And the fourth mode is the dual-fuel mode with catalytic converter, named as DFc. For the dual-fuel mode, the flow rate of the biogas varies from 2 Litre/min, 4 Litre/min, and 6 Litre/min. The CI engine is tested at two engine speeds. The first speed is 1000 rpm and the second speed is 1500 rpm. The load varies from 600Watt, 900 Watt, 1200 Watt, and 1500 Watt. Thus, there 64 experiments have been tested. In every experiment, the diesel engine is operated until steady. After steady, all of parameters are measured for 5 minutes. Every experiment is triplet and measured variables are averaged.

### B. Problem Formulation

The performance of the CI engine will be explored using the electric power resulted by generator, brake-thermal efficiency, and specific fuel consumption. The electric power $P_E$ (Watt) resulted by the generator is estimated by using the below equation.

$$P_E = V \times I$$
In the above equation the parameter $V$ [Volt] is the voltage and parameter $I$ [Ampere] is the current of the electricity. The brake-thermal efficiency is defined as electric power divided by energy from the fuel. For the diesel engine run in diesel only, it is estimated as follows.

$$\eta = \frac{P_E}{m_{\text{diesel}} \times H_{\text{diesel}}}$$

(2)

where $H_{\text{diesel}}$ [kJ/kg] is the heating value of the diesel fuel. On the other hand, for the engine run in dual-fuel, the brake-thermal efficiency is calculated by

$$\eta = \frac{P_E}{m_{\text{dual}} \times H_{\text{diesel}} + m_{\text{biogas}} \times H_{\text{biogas}}}$$

(3)

where, $m_{\text{dual}}$ [kg/s] and $m_{\text{biogas}}$ [kg/s] are the mass flow rate of diesel fuel and biogas, respectively. And $H_{\text{biogas}}$ is the biogas heating value in kJ/kg. The specific fuel consumption $sfc$ [g/kWh] is the mass of fuel divided by energy output. Here, it is a parameter to show how many grams of fuel burnt to produce 1 kWh of electric. For the diesel, it can be calculated as:

$$sfc = \frac{m_{\text{diesel}} \times 10^3}{P_E}$$

(4)

While for the dual-fuel engine, it is defined as:

$$sfc = \frac{(m_{\text{dual}} + m_{\text{biogas}}) \times 10^3}{P_E}$$

(5)

The above-formulated parameters will be used to analyze the performance of the diesel engine when it is operated in pure diesel and dual-fuel.

The final parameter to investigate the diesel engine is diesel replacement ratio. The parameter is the ratio of diesel fuel with and without biogas at the same load and condition. The ratio is calculated by

$$r = \frac{m_{\text{diesel}} - m_{\text{dual}}}{m_{\text{diesel}}} \times 100\%$$

(6)

where $m_{\text{diesel}}$ [kg/s] is the diesel mass flow rate when run with diesel fuel only and $m_{\text{dual}}$ [kg/s] is the diesel fuel when it run with biogas.

III. RESULTS AND DISCUSSIONS

Results will be discussed in two different parameters, they are engine performance and exhaust gas. The performance parameter consists of output power, diesel replacement ratio, brake-thermal efficiency, and specific fuel consumption. On the other hand, the exhaust gas emission is examined using CO number, OPC, and HC number. Effect of the catalytic converter for each mode is discussed in the following paragraph.

A. Output Power

Fig 3 depicts the electric power resulted by the diesel engine at different biogas flow rate. It can be seen that the power at low and high engine speed 1000 rpm and 1500 rpm are shown by Fig 3a and Fig 3b, respectively. The figure shows that, at low engine speed (Fig 3a), there is no effect of biogas rate to the power of the engine. The output power of the diesel engine is constant for all biogas flow rate. Variation of biogas flowrate from 0 L/min (pure diesel) to 6 L/min of biogas gives the same output power. This occurs for all engine loads. Also, the power resulted by the diesel engine with and without catalytic converter is similar. The same trend also is shown by the diesel engine at high engine speed 1500 rpm. This fact suggests that the CI engine will show the same output power when it is run on pure diesel mode and dual fuel mode. Coupling the CI engine with catalytic converter also result in the same output power. The catalytic converter does not affect the power of the diesel engine when it is operated in pure diesel and dual-fuel modes.
with increasing biogas flowrate. This is because some amount of energy input to the combustion chamber of the CI engine is supplied by biogas. Thus, diesel consumption will be decreased and replaced by biogas. At low engine speed and load, diesel replacement ratio is up to 87.5%. At the same biogas flowrate, diesel replacement ratio reduces as engine load increases. This is because, at high engine load, more fresh air is needed for the combustion process. It affects the amount of biogas that can replace the diesel fuel. On the other hand, diesel replacement ratio is lower at high speed. Fig 4b shows that the maximum diesel replacement ratio is 53.93% at biogas flow rate of 6 Litre/min. This is because, at high engine speed, the combustion process occurs at a very short time. It affects the amount of biogas can replace the diesel fuel. However, diesel replacement ratio on the CI engine at low and high engine speeds shows a similar trend. The effect of the catalytic converter to the diesel replacement ratio clearly shown in the figure. The figure shows that there is no significant effect of installing the catalytic converter to the CI engine run on pure and dual-fuel modes. This fact is shown by CI engine run at low and high engine speeds.

C. Brake Thermal Efficiency (Bte)

Fig 5 presents Bte of the diesel engine operated in dual-fuel mode with and without a catalytic converter.

![Fig. 4 Diesel replacement ratio as a function of output power](image)

![Fig. 5. Brake thermal efficiency as a function of output power](image)

It is shown that brake thermal efficiency increases as power increases. This fact suggests that at higher output power combustion process is more effective. The effect of increasing the flow rate of the biogas to Bte can be seen clearly. For the case with low engine speed, shown by Fig 5a, operating the CI engine with biogas flow rate of 2 Litre/min results in higher brake thermal efficiency in comparison with pure diesel mode. Increasing biogas flow rate will decrease brake thermal efficiency. This fact occurs for both cases with and without the catalytic converter. The same trend also is shown by the CI engine when it is operated at higher engine speed, shown in Fig 5b. The effect of the catalytic converter to the brake thermal
efficiency of the CI engine can be seen in the figure. It was shown that there is no significant difference in brake thermal efficiency of the CI engine run in dual-fuel mode with and without the catalytic converter. This fact suggests that catalytic converter does not affect brake thermal efficiency for both pure and dual-fuel modes.

D. Specific Fuel Consumption

The specific fuel consumption for the CI engine at different loads is shown in Fig 6.

![Fig. 6. Specific fuel consumption as a function of output power](image)

The figure shows that specific fuel consumption for all loads and engine speeds varies from 0.427 to 2.662 kg/kWh. In general, sfc decreases with increasing output power and engine speed. This is because at low engine load and speeds the combustion process is poor. Also, sfc increases with increasing biogas flow rate. As a note, biogas consists of methane and other gases. Even though methane is the only gas contains energy, all gas is counted as fuel. The concentration of methane gas in the present study is only 60%. This leads to higher specific fuel consumption. It can be seen that the specific fuel consumption of the CI engine operated with catalytic converter shows the similar value with the CI engine without the catalytic converter. This suggests that the catalytic converter does not affect the specific fuel consumption of the CI engine run in pure and dual-fuel modes.

E. Exhaust Gas Emission

The main objective of using the catalytic converter in the CI engine run in dual-fuel mode is to reduce exhaust gas emissions of the CI engine. In this subsection, the effect of installing the catalytic converter to the exhaust gas emissions of CI engine run on dual-fuel mode is examined. Figure 7 shows the CO number of the CI engine for all loads at engine speed 1000 rpm and 1500 rpm.

![Fig. 7. CO number vs. engine speed for all loads](image)

In the case with low engine speed, shown in Fig 7a, the average CO number of the CI engine run on pure diesel with and without catalytic converter are 0.027% and 0.02%, respectively. This reveals that there is no effect of the catalytic converter for the CI engine run in pure diesel mode. In the CI engine without catalytic converter run on dual fuel mode the average CO number for biogas flow rate of 2 L/min, 4 L/min, and 6 L/min are 0.137%, 0.16%, and 0.147%, respectively. When a catalytic
converter installed on the CI engine and run on dual-fuel mode with biogas flow rate of 2 L/min, 4 L/min, and 6 L/min, the average CO number is 0.040%, 0.032%, and 0.020%, respectively. In other words, CO number decreases significantly in the CI engine with the catalytic converter.

Fig 7b shows CO number of the CI engine at higher engine speed. The average CO number for the CI engine run on pure diesel mode with and without the catalytic converter is 0.026% and 0.0175%, respectively. Here, the catalytic converter does not affect the CO number of the CI engine run on pure diesel mode. For the CI engine without catalytic converter run on dual fuel mode with biogas flow rate of 2 L/min, 4 L/min, and 6 L/min, the average CO number are 0.102%, 0.132%, and 0.147%, respectively. These values show that CO number in the exhaust gas increases with increasing biogas flow rate. If the catalytic converter installed to the CI engine run on dual-fuel mode with biogas flow rate of 2 L/min, 4 L/min, and 6 L/min, the average CO number are 0.064%, 0.083%, and 0.112%, respectively. These facts reveal that for the CI engine run on pure diesel mode, the catalytic converter is less effective. However, for the CI engine run in dual fuel mode catalytic converter reduce CO number significantly.

Fig 8 shows the smoke emission or OPC number of the CI engine run on pure diesel and dual-fuel modes. In general, it can be seen that smoke emission of the CI engine run on pure diesel mode is higher than CI engine runs on dual-fuel mode. The effect of the catalytic converter to the CI engine is made by examining the average OPC number of the exhaust gas. At low engine speed, shown in Figure 8a, the average OPC number for CI engine run in pure diesel mode without and with the catalytic converter is 17.77% and 10.12%, respectively. The present of the catalytic converter decreases smoke emissions significantly. For the CI engine without catalytic converter run on dual-fuel mode with biogas flow rate 2 L/min, 4 L/min, and 6 L/min, the average OPC number are 8.77%, 8.30%, and 7.02%, respectively. On the other hand, the CI engine with catalytic converter run on dual-fuel mode for biogas flow rate of 2 L/min, 4 L/min, and 6 L/min, the average OPC number are 8.17%, 5.25%, and 2.50%, respectively. This shows that catalytic converter decreases the smoke emissions in the CI engine run in dual fuel mode.

Fig. 8. OPC number vs. engine speed for all loads

(a) Engine Speed 1000 rpm

(b) Engine Speed 1500 rpm

Fig. 9. HC number vs. engine speed for all loads

The smoke emissions from the CI engine at high engine speed are shown in Fig 8b. As expected, the smoke emission
increases with increasing engine speed and engine load. For the CI engine without catalytic converter run on pure diesel mode, the OPC number varies from 13.5% to 60.9% and the average of OPC number is 37.3%. On the other hand, for the CI engine with catalytic converter the minimum, maximum, and average OPC number are 6%, 18.2%, and 10.32%, respectively. Here, catalytic converter decreases smoke emission significantly. For the CI engine run in dual fuel mode, the average OPC number of the CI engine without catalytic converter run on dual-fuel mode with biogas flow rate of 2 L/min, 4 L/min, and 6 L/min are 21.65%, 17.75%, and 14.20%, respectively. In comparison with the CI engine run on pure diesel, the smoke emission of CI engine run on dual-fuel mode is lower. Smoke emission decreases with increasing biogas flow rate. For the CI engine with catalytic converter run on dual-fuel mode the average OPC number at biogas flow rate of 2 L/min, 4 L/min, and 6 L/min are 11.07%, 10.72%, and 9.85%, respectively. This shows that catalytic converter decreases the smoke emission of the CI engine when it is run in pure diesel and dual fuel modes.

Hydrocarbon emission has a bad impact on the human being health. The hydrocarbon emissions from the CI engine at low and high engine speeds are shown in Fig 9. For the CI engine without catalytic converter run on pure diesel at low engine speed, the minimum, maximum and the average HC number are 4 ppm, 9 ppm, and 7.25 ppm, respectively. When a catalytic converter is installed in the CI engine, the HC number almost the same. Hydrocarbon emission of the CI engine without catalytic converter run in dual fuel mode with biogas at the flow rate of 2 L/min, 4 L/min, and 6 L/min are 302.5 ppm, 330.5 ppm, and 400 ppm, respectively. This high hydrocarbon emission reveals that hydrocarbon inside the combustion chamber is not burnt perfectly. HC emission increases with increasing biogas flow rate. When the catalytic converter installed to the CI engine and run in dual fuel mode with biogas flow rate of 2 L/min, 4 L/min, and 6 L/min the average HC number decrease to 232.75 ppm, 274.25 ppm, and 264.75 ppm, respectively. This fact reveals that catalytic converter decreases the hydrocarbon emissions significantly.

For the CI engine with high engine speed, when the CI engine run on pure diesel mode, the hydrocarbon emission is very low for both cases with and without the catalytic converter. The average hydrocarbon emission is only 6.5 ppm. When the CI engine run in dual fuel mode, as expected, the hydrocarbon emission increases significantly. HC number of the exhaust gas at biogas flow rate 2 L/min, 4 L/min, and 6 L/min are 153.00 ppm, 211.75 ppm, and 237.00 ppm, respectively. If the catalytic converter is used to the engine the HC number for biogas flow rate 2 L/min, 4 L/min, and 6 L/min are 111.25 ppm, 186.75 ppm, and 172.25 ppm, respectively. These numbers reveal that hydrocarbon emission increases with increasing biogas flow rate. In comparison with the CI engine at low engine speed, the hydrocarbon emission decreases with increasing engine speed and load. The effect of catalytic converter decreases the hydrocarbon emission of the CI engine run in dual-fuel mode. However, the catalytic converter can’t decrease the hydrocarbon emissions back to pure diesel mode.

In the references, only limited studies on the catalytic converter in a CI engine. It was found a study on emission decreasing by using Catalytic Converter installed to CI engine reported by Vallinayagam [26]. The sfc of the present work varies from 0.427 to 2.662 kg/kWh. On the other hand, the sfc of Vallinayagam [26] work varied from 0.2 kg/kWh to 0.6 kg/kWh. This fact suggest that the results of the present works are comparable with previous work.

IV. CONCLUSIONS

In the present study effect of a catalytic converter on the performance and emissions of a small diesel engine run on dual-fuel mode has been investigated experimentally. A CI engine with a rated output of 4.41 kW, typically used in agricultural works, has been tested with and without a catalytic converter. The CI engine is operated on pure and dual-fuel modes. For dual-fuel mode, the biogas flow rate varies from 2 L/min, 4 L/min, and 6 L/min. The conclusions are as follows. The catalytic converter does not affect the performance of the engine. The CI engine shows the same output power, diesel replacement ratio, brake thermal efficiency, and specific fuel consumption when it is operated with and without the catalytic converter. The same fact is shown by the CI engine run in pure diesel and dual-fuel modes. On the other hand, the catalytic converter shows the significant effect on reducing exhaust gas emissions. For the CI engine run on pure diesel mode, the catalytic converter decreases smoke emission significantly. For the CI engine run on dual-fuel mode, the catalytic converter decreases CO number, smoke emission, and HC number significantly. It is suggested to install a catalytic converter to the CI engine run on dual-fuel mode.

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