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THE INFLUENCE OF TWO CYLINDER DIESEL ENGINE MODIFICATION (IDI TO DI) ON ITS PERFORMANCE AND EMISSION

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Abstract

Modification of combustion system from indirect injection (IDI) to direct injection (DI) was carried out on the two cylinder diesel engine, followed with tests for performance and emission. The modification from IDI to DI was conducted on a two cylinder diesel engine by removing the pre-chamber from the inside of the cylinder head, replacing the injector and its position to the top of the combustion chamber directly and also replacing the original piston with a piston that has a bowl on the crown. Performance and emission tests were conducted on 1,500 rpm with loads that vary from 0, 10, 20, 30, 40, 50, to 60 Nm. The investigation results of the diesel engine modification from IDI to DI showed several interesting phenomena. Further research is needed in order to increase the engine performance and reduce its emission.

Keywords: diesel, IDI, DI, performance, emission.

I. INTRODUCTION

Diesel engine has been widely used as power source in many devices or vehicles to help human life such as generator, ship, car, train, heavy duty vehicle, and etc [1, 2]. It has excellent superiority in high thermal efficiency, low fuel consumption, good endurance and durability compared to gasoline engine, gas turbine, steam turbine, and stirling engine [3-5]. Diesel engine is an engine which is included in the internal combustion engine category and usually called as compression ignition engine. In the compression ignition engine, the properties of fuel and the injection system have a significant effect on engine performance and its emissions. Combustion process on compression ignition engine is started when fresh air enters the combustion chamber. The diesel fuel is injected into the combustion chamber near the end of compression stroke, so the ignition occurred automatically due to the self ignition properties of diesel fuel and the increasing of the pressure and temperature resulted from air compressed in the chamber [6]. Diesel engine is divided into two categories based on the combustion system i.e. indirect injection diesel engine (IDI) and direct injection diesel engine (DI) [7]. The first technology of compression ignition engine is indirect injection diesel engine (IDI). IDI system operates when the fresh air is compressed in combustion chamber while diesel fuel is injected in prechamber or swirl chamber near the end of compression stroke. The swirl effect of the air on pre chamber or swirl chamber, high pressure, and temperature are the main factor in this system [6]. Disadvantage of Indirect Injection (IDI) system is combustion takes longer duration due to the flame propagation on the shape of combustion chamber that causing the heat dissipated on combustion wall becomes higher. Lower compression ratio and longer combustion process on IDI system lead to lower thermal efficiency than DI system [8, 9]. The advantage of IDI system is it is more adaptive to low quality of fuel and low noise. Nowadays fuel quality becomes better and legislation becomes stricter. Research and development institutions and automobile manufacturers pay more focused on current technology i.e. direct injection diesel engine (DI), Turbo Diesel Intercooler (TDI) or Homogeneous Charge Compression Ignition (HCCI). Schematic diagram of the diesel combustion system for IDI and DI as discussed by Huang [1] is depicted in Figure 1. Figure 1 (a)

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shows schematic diagram for diesel engine with DI combustion system. In the DI system, diesel fuel is directly injected into combustion chamber near the end of compression stroke. The ignition is occurred at the local mixture on combustion chamber that generates the premix burning period then the flame propagates to the centre of combustion chamber (diffusion burning period) at the same chamber. So, in the DI system, diesel fuel is injected directly into main chamber and the combustion is started and ended in the same chamber. Figure 1 (b) shows the schematic diagram of IDI combustion system of diesel engine. Its working process is different from DI system. The combustion process starts at local mixture on pre-chamber then the flame is propagated to the main chamber. Modification of diesel engine was implemented because the existing engine is using IDI system. Another consideration is that in order to obtain better thermal efficiency and low fuel consumption, modification is cheaper than buying new diesel engine with DI system to obtain better thermal efficiency and low fuel consumption. On the other hand, modification of IDI Diesel system into DI system is needed to characterize the performance of DI system as base data for the future development on HCCI system. Many literatures have discussed diesel engine of both DI and IDI combustion systems and the utilization of alternative fuel for the engine, as described by Huang [1]. However many literatures described separately and rarely discussed performance and emission test result of a diesel engine modified from IDI to DI. Therefore, this paper will describe the influence of modification of diesel engine 2 cylinder 1630 CC (IDI to DI) on the performance and its emissions. The information from this paper would be useful for researcher or academician who are interested or dedicate their research activity in the field of diesel engine.

II. INVESTIGATION PROCEDURE

Investigation procedure in this study is divided into three sections as follow:

A. Engine Testing Installation

The schematic diagram of engine testing installation is depicted in Figure 2. The study was conducted by connecting the diesel engine with an Eddy current dynamometer type Schenk W70. The dynamometer was used to measure speed and load of the engine. The AVL fuel balance, TGS hotwire anemometer, 4-gas analyzer, smoke meter, and temperature sensor were also installed on each position to measure fuel consumption, air intake velocity, gas emission, smoke index, and temperature of the engine, respectively. Meanwhile, the crank angle sensor was attached on the crankshaft to determine the crank position. The pressure transducer type Kistler 6061B as shown in Figure 3 was installed in combustion chamber to measure the combustion pressure. The first tested diesel engines was Fujikawa type 295D two cylinder IDI made in China, and the second one was the first engine which modified to DI with the same testing procedure. The diesel engine specification that used in this study is presented in Table 1.

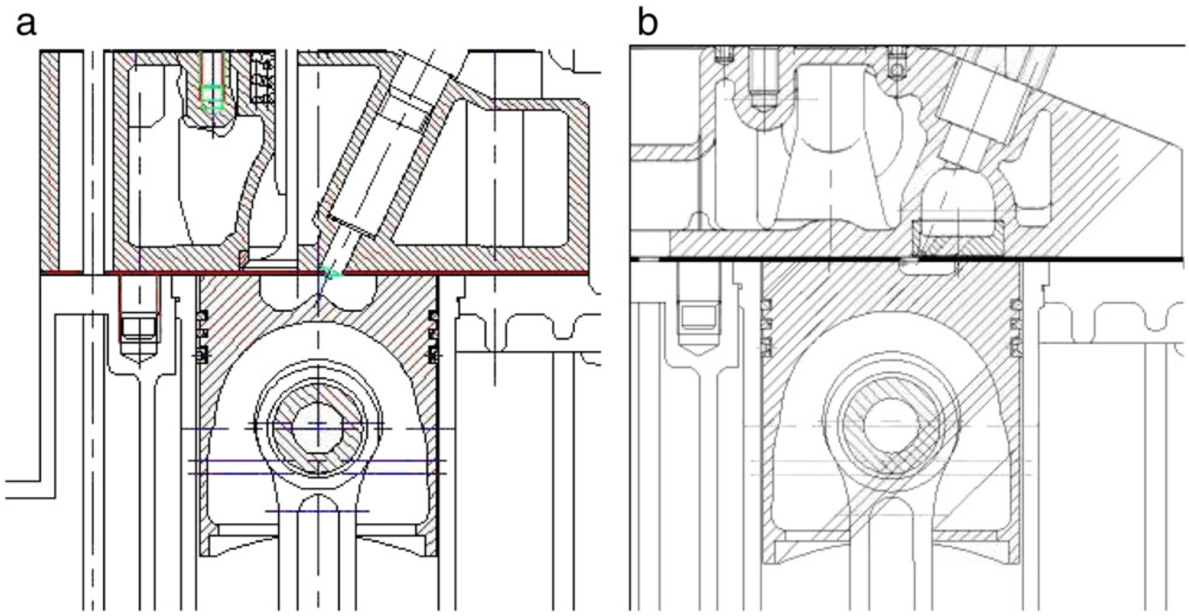

Figure 1. Diesel engine combustion system (a) DI and (b) IDI [1]

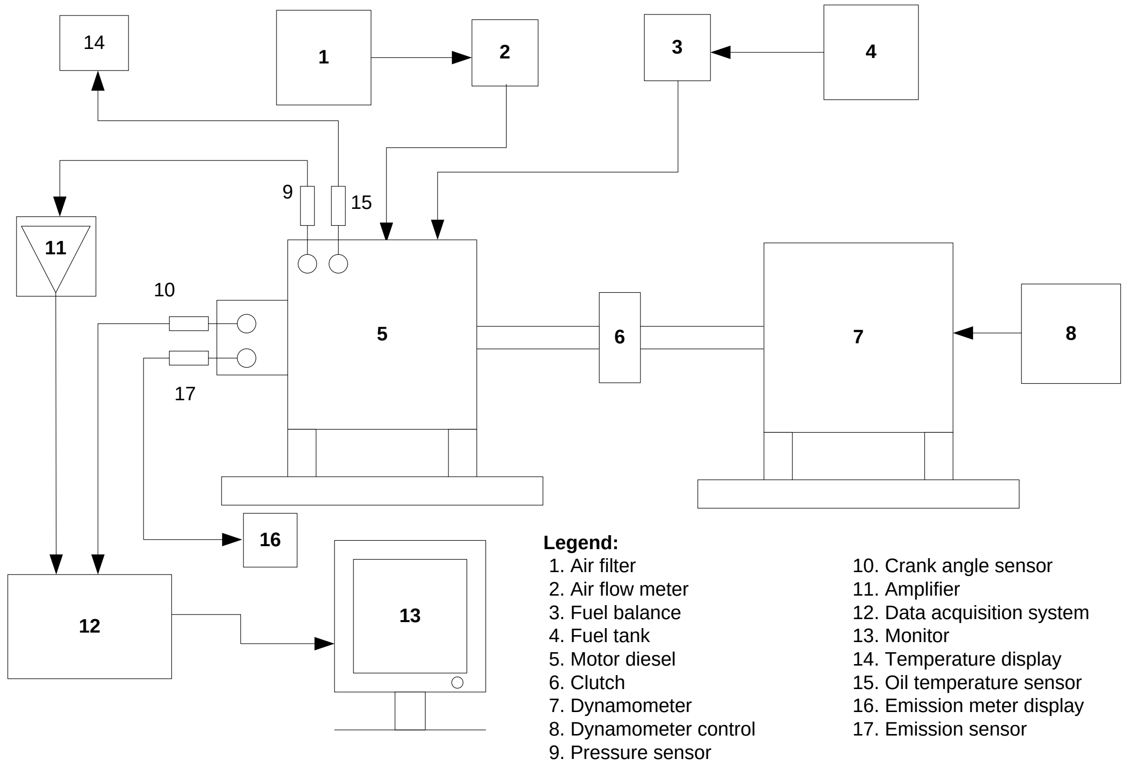

Figure 2. Schematic diagram of engine testing installation

B. Modification Process of Diesel Engine from IDI to DI

The modification of diesel engine was conducted by closing the pre-chamber in the cylinder head using tin cast as shown in Figure 4. After finished, it was then drilled with 25 mm diameter straight forward to the top of the cylinder to put cylinder iron bar (bushing) that had been prepared based on the injector that would be used. The bushing was used as adapter or buffer for the injector.

The original injector was replaced using the other injector that usually used in diesel engine Yanmar type TF 155R-di with the injection capacity and pressure that was slightly bigger and higher. The reason for using this injector is it was easy to look for and assumed that they have the same flow rate based on cylinder volume (815 cc/cylinder @ Fujikawa 295D and 800 cc single cylinder @ Yanmar 135R-di). The injector specification that was used in this study is presented in Table 2. The screws and nuts of the old injector were replaced appropriately according to the new injector condition.

To obtain an appropriate piston bowl for DI diesel engine the piston of the diesel engine Yanmar type TF 155 R-di was used with several modifications on its ring groove, piston pin hole, and reducing the length of the piston by reducing it for about 2 mm, as similar with previous study [10]. The weight of this piston was slightly heavier than the original part of the engine, so that it might have influenced the engine performances. The original piston shape of IDI

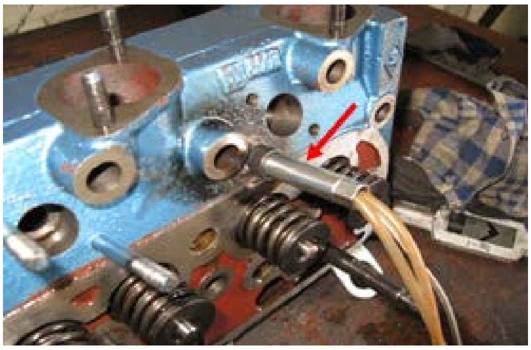

Figure 3. Pressure transducer installation

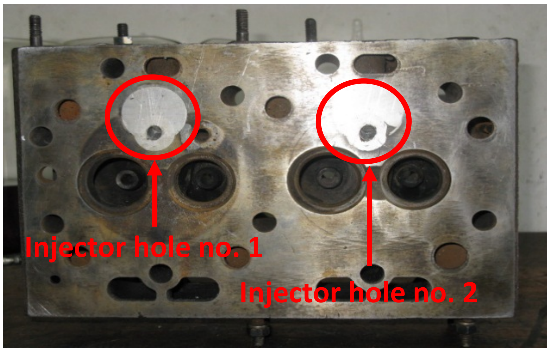

Figure 4. Cylinder head modification

Table 1.
Engine specification data

Specification	Data
Type	4 stroke diesel engine
Number of valve	4
Air intake system	Naturally aspirated
Number of cylinder/ type	2 / Vertical
Volume (cc)	1,630 cc
Diameter x stroke	95 x 115 mm
Compression ratio	19 : 1
Maximum torque	96.9 Nm at 1,500 rpm
Maximum power	13.5 kW at 1,500 rpm
Fuel system	1. IDI 2. Then modified to DI

system and Yanmar TF 135R-di are shown in Figure 5. Meanwhile, the other parts such as piston pin and connecting rod used were still the genuine parts from the original engine. The last modification done after the engine was operated on DI system was varying the injection timing by changing the position of injection pump until the appropriate condition was obtained.

C. Engine Testing

The engine testing conducted was referred to laboratory standard ISO 17025 [11] emission testing standard ISO 8178 [12] and diesel testing standard ISO 3046 [13]. The engine was operated at 1,500 rpm using diesel fuel “solar“ as the brand for diesel fuel from the national enterprises PT. Pertamina, Tbk. with load variations of 0, 10, 20, 30, 40, 50, and 60 Nm. The parameters from every condition of the operated engine were IMEP, fuel consumption, air intake air flow, oil temperature, air inlet and exhaust temperature, water temperature both inlet and outlet of radiator, smoke and CO_2 emission. The IMEP and fuel consumption data were recorded twice at

Figure 5. The piston shape; (Left) the existing IDI engine; (Right) *Yanmar TF 135R-di*

Table 2.
Injector specification data

Specification	Original	Modification
Pressure	190 ± 5 bar	200 bar
Nozzle hole	1	4
Injection volume/cycle	0.88 ml	1.01 ml

each stage of testing processes. Every measurement device and sensor was calibrated and has accuracy and uncertainty based on its specifications. The accuracy and calculated uncertainty of the measurement device in this study are presented in Table 3.

III. RESULTS AND DISCUSSION

A. Influence of Modification of IDI to DI on the IMEP Value

The mean effective pressure is the appropriate parameter for engine comparison in terms of design and output, due to independency from size and/or engine speed [14], in this case this refers to indicated mean effective pressure (IMEP). The indicated power can be calculated from the indicated mean pressure [14]. Figure 6 shows graph of IMEP comparison of diesel engine IDI and DI at 1,500 rpm. It can be seen that the IMEP value tended to increase due to the increasing engine load at 1,500 rpm engine speed, both for IDI and DI modified diesel engines. However, the testing result showed that IMEP value from IDI diesel engine was higher than DI modified diesel engine. The calculated indicated power would show that power of the diesel engine IDI system was higher than that of the diesel engine modified to DI system. This result was on contrary to the theory that has been discussed in several literatures [1, 8, 9, 15, 16]. This occurred due to the modification that was not successful

Table 3.
Accuracy and calculated uncertainty of measurement

Measurement	Accuracy
Soot density	± 1 g/m^3
CO	± 5 %
HC	± 20 ppm
Speed	± 5 rpm
Torque	± 0.2 Nm
Calculation result	**Uncertainty (%)**
Fuel volume velocity	± 2
Power	± 1
Specific fuel consumption	± 1.5
Efficiency	± 1.5

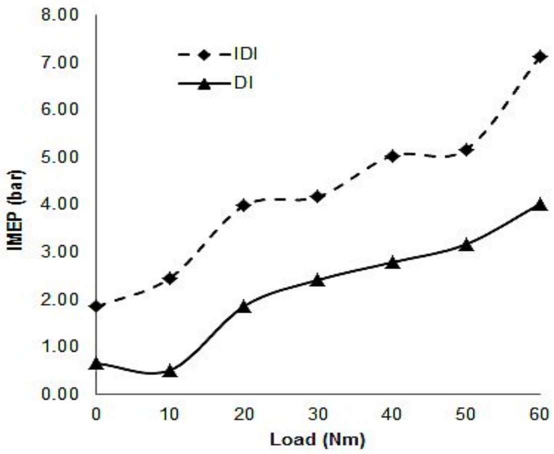

Figure 6. IMEP comparison of diesel engine IDI and DI at 1,500 rpm

and that caused a power loss. The power loss could occur because of the absence of combustion (misfire), injection timing, incorrect shape of combustion chamber, and lower compression ratio.

B. Influence of Modification of IDI to DI on the bsfc and Lambda Value

Figure 7 shows the comparison of brake specific fuel consumption (bsfc). From the figure it can be seen that the bsfc value tended to decrease with the increasing load value of both diesel engines IDI and DI. Like the IMEP, the bsfc value of IDI diesel engines was greater than DI modified engines. This indicated failure modification. Bsfc values of DI diesel engine in general are bigger than the IDI diesel engine's which also indicates a failure modification in term of performance. Normally, the IDI engine should be higher in fuel consumption than the DI engine due to double combustion processes i.e. which are firstly, combustion occurs for a half of fuel in pre-chamber then secondly, continue in main chamber which needs a longer time than DI engine to finish a combustion process [9].

The lambda values were calculated and presented as a graph in Figure 8 to clarify economic property in term of diesel engine fuel consumption. In this study, the lambda value was resulted from the calculation based on fuel consumption and air intake measurement. Referring to the literature [17] increasing lambda value shows lean combustion and decreasing lambda value show rich combustion.

In the diesel engine, the best lambda value is about 1.2 until 1.6 and the lambda value for IDI engine is lower than DI engine [7]. The results of this study were not in accordance with the existing data in the literature [7]. The reason for this condition might have been the IDI injector has been replaced with higher capacity injector. Besides, the piston replacement with several modifications was able to cause the air intake of DI became engine lower than IDI engine's.

C. Influence of Modification of IDI to DI on the Smoke Index (Bosch Index)

Emission formation on diesel engine depends on fuel properties (cetane number, flash point, and etc), combustion system, load and injection timing. Figure 9 shows the comparison of smoke emission from IDI diesel engine and modified diesel engine DI. The graphs show that the percentage of smoke emission on DI diesel engine was significantly greater than IDI diesel engine system. The lower smoke value on IDI diesel engine happened due to the correct injection operation (volume) and two steps of combustion process. The first step is called premix burning period. The premix burning

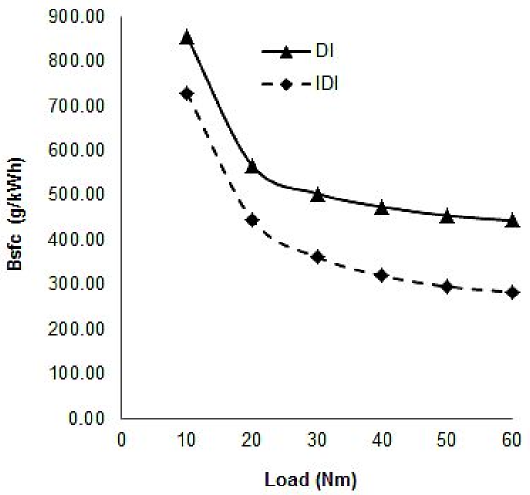

Figure 7. Bsfc comparison of diesel engine IDI and DI at 1,500 rpm

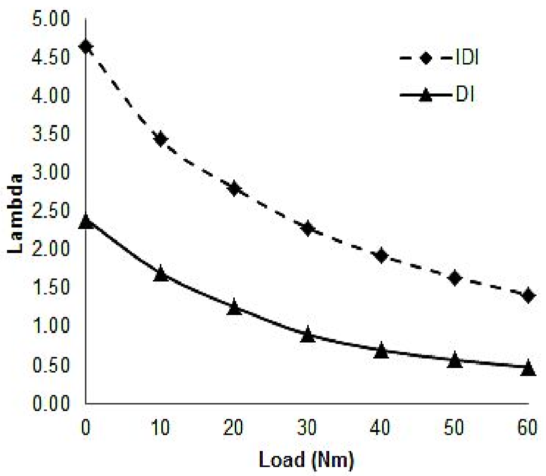

Figure 8. Lambda comparison of diesel engine IDI and DI at 1,500 rpm

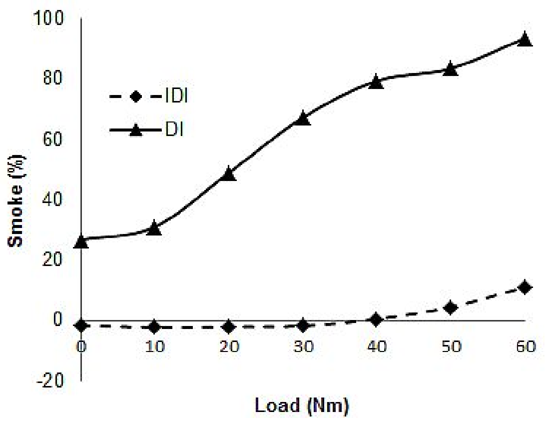

Figure 9. Smoke comparison of diesel engine IDI and DI at 1,500 rpm

period began when the slightly rich fuel mixture in the pre-chamber ignited due to the increasing of pressure and temperature of compression stroke. The combustion process in pre chamber led to the flame propagation from pre chamber to the main chamber. The pressure and temperature in main chamber would increase due to the flame propagation. The swirl effect occurred due to the flame propagation, pressure, and design of pre chamber.

The second step was the diffusion burning period or the combustion in main chamber. Since the swirl passage was far from the main chamber, the flame propagation would slightly be restricted and would cause a stratified combustion. The stratified combustion means longer combustion duration. Longer duration of combustion process provides more time to the air and fuel in main chamber to form a good flammability mixture. The proper air fuel mixture will generate a complete combustion in combustion chamber, and will produce lower smoke percentage. Meanwhile, in the modified DI system, fuel was directly injected to the main chamber at the end of compression stroke. Ignition occurred in the local mixture in combustion chamber which had stoichiometric air-fuel ratio, then propagated to the rich region mixture. The air and fuel in combustion chamber only had a little time to form a proper mixture. When the local stoichiometric mixture was igniting, the flame propagation occurred and burnt all of the mixture in combustion chamber spontaneously. The advantage of spontaneous combustion is higher pressure in combustion chamber to push the piston. The disadvantage of this system is the short preparation time to mix the air and fuel properly. In DI diesel system, the shape of combustion chamber is the main parameter to optimize the performance of diesel engine. The incorrect shape of combustion chamber will generate the poor performance and high emission. Therefore, the smoke emission of IDI diesel system in this experiment was lower than DI modified system. It was in accordance with what that has been discussed by Huang [1].

D. Influence of Modification of IDI to DI on CO Emissions

Incomplete combustion on diesel engine happens when fuel cannot mix completely with air on combustion chamber. In diesel engines, the correct operation of injectors and injector pump is essential for correct combustion. If too much fuel is supplied or a dribbling injector supplies fuel after most of the air has been used, excessive heat that generated by burning of the fuel mixture will lead the deformation of CO and Smoke [16, 18]. Figure 10 shows the comparison of CO emission from diesel engine IDI and DI. From the figure, it can be seen that CO emission from diesel engine with IDI system was reduced with the increasing engine load. The CO emission increased with the increasing engine load for diesel engine with DI system.

Overall, the CO emission of diesel engine with IDI system was significantly lower than that of diesel engine modified DI system. CO is the medium product of hydrocarbon based fuel, so that the CO emission is resulted from incomplete combustion [19]. It has been reported before [1] that combustion from IDI system can be more completed than combustion in DI system related to the design of combustion system. The CO emission from IDI was lower than DI, due to the different injection sac volume from modified injector, more nozzle hole (4 holes) and incorrect spray pattern of the injector to the piston bowl. Thus, the fuel was over supplied to the chamber. Meanwhile, the modified piston probably had inappropriate piston bowl. The injector also

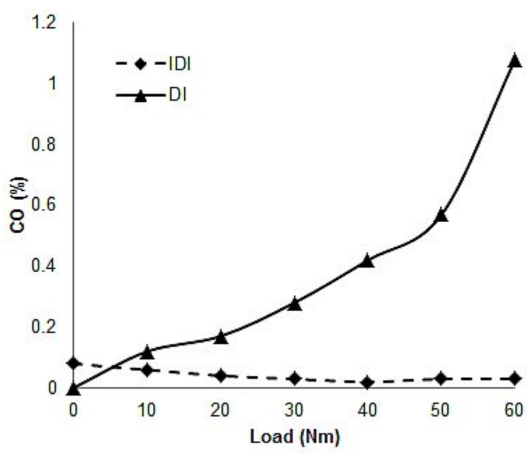

Figure 10. CO emission comparison of diesel engine IDI and DI at 1,500 rpm

probably was not in good position and the ring piston probably had a bigger gap. Thus, the combustion was uncompleted and the CO emission of modified diesel engine DI was higher than diesel engine IDI systems.

IV. CONCLUSION

Modification of 2 cylinder 1630 CC diesel engine from IDI to DI system has been conducted. The engine was successfully operated in DI system. From overall investigation it was indicated that the modification of 2 cylinder 1630 CC diesel engine from IDI to DI system was unsuccessful both of performance and its emission. The unsuccessful modification happened due to the incorrect injector flow rate, lower compression ratio, injector position to the piston bowl, and injection timing. The DI injector had higher flow rate than the original injector (approximately 12.87% higher). The bigger piston bowl from Yanmar TF135R-di generated lower compression ratio in DI engine. This condition caused the IDI engine to have 19:1 compression ratio and DI modified system to have 17:1 compression ratio. The incorrect injector position and injection timing produced more stratified mixture in combustion chamber. Stratification of air-fuel mixture in DI combustion chamber system is an undesired condition because it will generate local mixture that has stoichiometric air-fuel ratio which will ignite earlier. By adjusting the injection timing, reshaping the combustion chamber, increasing compression ratio, and increasing injection pressure the performance and emission of DI diesel engine is expected to be better.

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