Original Research Paper

The Experiment Study of Performance, Combustion Process and NO_X Emission of Diesel Engine with EGR System Using Angle Globe Valve

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Abstract: Exhaust Gas Recirculation (EGR) is technology to reduce NO_X emission of diesel engine. This technology could circulate some exhaust gas into the combustion chamber. The adiabatic combustion temperature could decrease and reduce the reaction of oxygen in nitrogen. This method could inhibit the formation of NO_X during the combustion process because NO_X formation reactions occur at high temperatures. EGR has some effects such as decreased engine performance, SFOC increases and changes in the combustion process. In order to suppress the negative impact, the research carried out by replacing the EGR valve using a type angle globe valve. Experiments conducted using a single cylinder diesel engine YANMAR type TF85-MHDI. The result obtained in this study is the emission of NO_X can be reduced up to 15.6 g/kWh or 44.2% of the engine condition without EGR. The experimental results indicate that the use of angle globe EGR valve can reduce the SFOC up to 35.29 gr/kWh. Results of power, torque and BMEP also better compared EGR standard. While in the combustion process showed that the use of EGR valve angle globe causing peak of combustion pressure becomes lower and the Rate of Heat Release (ROHR) is lowered.

Keywords: Exhaust Gas Recirculation (EGR), Angle Globe EGR Valve, Engine Perform, Combustion Process, NO_X

Introduction

Most of the marine transportation mode selected is the ship with the engine in the form of a diesel engine. The diesel engine has a higher thermal efficiency compared with other types of propulsion, besides the diesel engine has the characteristics to meet the high torque and power making it suitable for main propulsion of the ship (MAN, 2017).

The developments of technology in the diesel engine lately are very sophisticated. The technology developments are not only intended to look for better efficiency, but also lead on environment friendly technology. There are some technology-based environmental friendly ever published such as the technology Exhaust Gas Recirculation (EGR), Selective Catalytic Reduction (SCR), Ammonia Scrubber, Air Humidifier, Direct Water Injection (DWI), Water Fuel Emulsification, Diesel Particulate Filter (DPF), etc. (Schill, 2012).

Exhaust Gas Recirculation (EGR) system is the simplest of NO_X reduction technology (Krishnan *et al*., 2016; Hussain *et al*., 2012). The works of EGR is by circulating a portion of exhaust gas return into the combustion chamber. Mixing of air with the exhaust gas into inert gas is producing low adiabatic combustion temperature and reducing the reaction of oxygen to nitrogen so that the formation of NO_X decreased. However, there are several disadvantages when using EGR, such as decreasing the value of the engine performance, increasing the fuel consumption and the Particulate Matter (PM) (Ge *et al*., 2015; Jothithirumal and Jamesgunasekaran, 2012).

This research has been developed EGR system capable of reducing NO_X while weakness is low. One way to fix the EGR system is to use this type of EGR

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valve that has a small value of minor head loss. In this case the selected valve types Angle Globe Valve as an EGR valve with a special design in order to obtain the value of minor head loss is small.

To understand the influence of the EGR valve angle type globe valve, it is necessary to conduct experiment of diesel engine in order to know the performance of the engine, the combustion process and levels of NO_X. To analysis the performance of the engine needs to be done in order to measure the extent of achievement of power, torque and fuel efficiency of diesel engine produced after modifed its EGR with angle globe valve types. Additionally it is necessary to investigate the combustion process and NO_X after modifications.

Methods

The method used in this research is the experimental method. Before performing the experiment, there are some step should be prepared such as design and manufacture of EGR systems and engine set up. The experimental results are divided into three types including engine performance, combustion process and NO_X emission.

Design and Manufacturing System EGR

Some of the data required to estimate the size of the components that can be made. The intake and exhaust manifold of diesel engine is 34.25 mm and 32 mm respectively. Variable data retrieval for % EGR is 30% maximum. Based on this condition, the estimate of the channel for the EGR system piping is 1 inch or 25.4 mm. The inner diameter of the inlet and outlet port angle globe valve is 25.4 mm. Figure 1 is a design angle globe EGR valve. Angle globe EGR valve is designed for the input and output side angle of 90°C. Part tapered shape designed to direct the fluid from the input side to the output side. This design can be expected to be better than the type of valve on the market because there is no obstacle when the flow of air over the globe. Additionally valve is designed to be easy to maintain the inside of the valve against the crusts of carbon that settles the burn.

Engine Set – Up

At this stage in the process of setting up a diesel engine, EGR components and equipment for the testing process. Engine set up showing at Fig. 2 This arrangement is to install sensors which consist Hardware Vibrasindo TMR-Card Board and TMR-Crankangle-Rotary Encorder on Yanmar diesel engine type TF 85 MH-in. Then do the installing process software/tool called TMR Instruments to display the results of the combustion process in the engine computer screen. After that, the engine is connected to a dynamometer test equipment performance. Output dynamometer connected to power load or dummy load. Burret also is prepared as SFOC gauges on each load received by the machine.

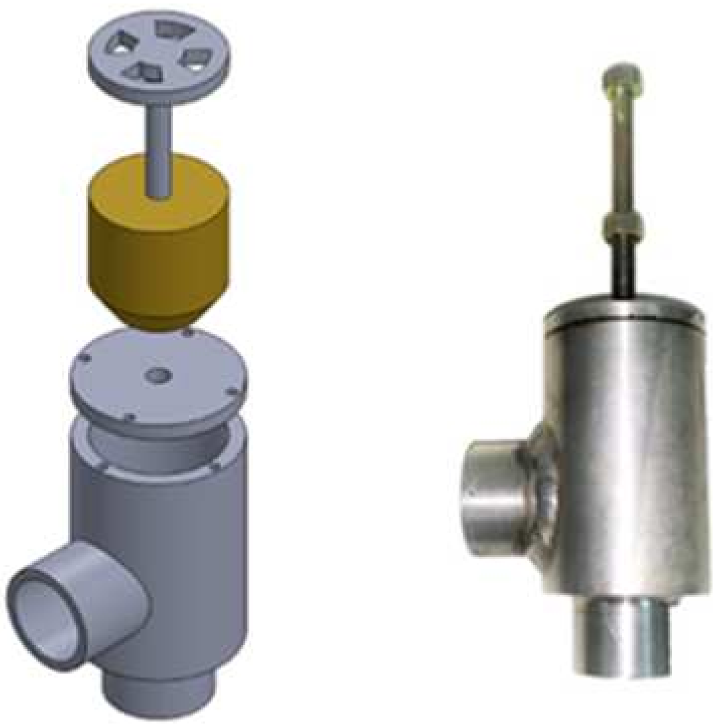

Fig. 1: 3D design modelling and results of the angle globe EGR valve

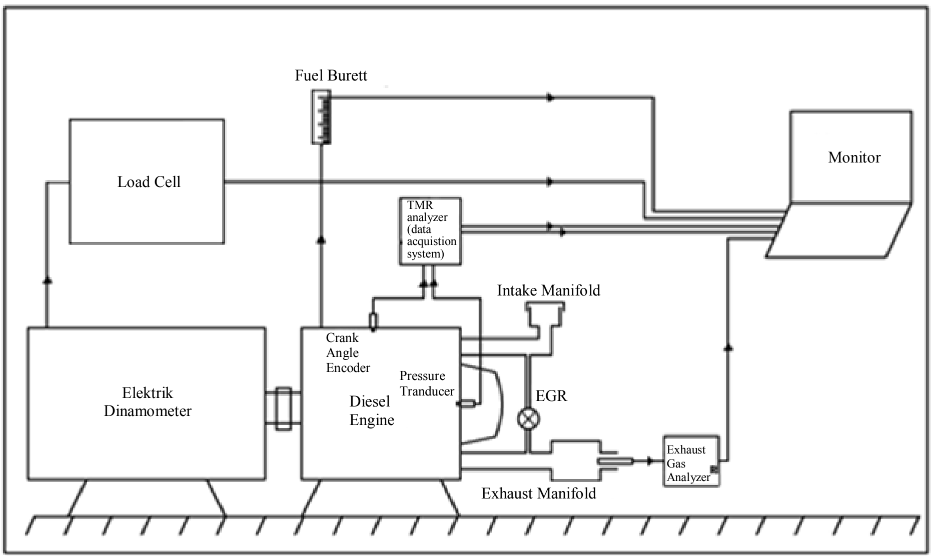

Fig. 2: Engine set-up

Experiment

The experiments were done after the previous steps have been accomplished. These experiments used Yanmar engines TF85-MH. The purpose of this is done an experiment where it is expected a good result in terms of:

1. Engine Perform in which to do the test achievement can be seen inside the power, torque and BMEP SFOC
2. Combustion process that includes characterizing the combustion process in diesel engines. The focus of data collection in this case only accentuated the pressure chart combustion process and heat release rate
3. NO_X levels in which it is known drop in the amount of NO_X in the exhaust gas after installation with a variation of EGR valve. MARPOL Annex VI has been used in this research (MARPOL, 1998)

Experimental Investigation

This experiment is conducted after the previous stage has been done. This experiment uses Yanmar TF85-MHDI engine. The suitable results are:

1. Diesel engine performance such as power, torque, SFOC and BMEP
2. Combustion process of diesel engine consisting of diagram of pressure and heat release
3. NO_X emission products from engines with COLD-EGR

Result and Discussion

Engine Performance

Figure 3 shows a curve of SFOC versus Power by using EGR. The variation of EGR used was 0% to 30% in the speed of 2100 rpm. Based form the curve can be explains that the use of 10% AGV produces SFOC lowest at 3.8 kW with SFOC of 264.56 g/kWh. From the experimental results explain that the use of EGR with 10% using the EGR valve angle globe has more efficient fuel consumption than diesel engines without EGR or 0% EGR. The lowest of SFOC at 0% EGR is 300.18 g/kWh, 10% AGV is 264.56 g/kWh, 20% AGV is 345.10 g/kWh, 30% AGV is 396.21 g/kWh, 10% BV is 314.56 g/kWh, 20% BV is 355.10 g/kWh, 30% BV is 406.21 g/kWh.

In this research, capacity of gas EGR against engine speed such as 0%, 10%, 20% and 30% with two variations of the type of valve. AGV is an EGR system using the angle globe EGR valve. BV is an EGR system using a ball valve EGR valve. Figure 4 is represents the value of 100% power. This value is obtained from the lowest point of SFOC described in the previous graph.

In the Fig. 3 and 4, the power seen at the beginning speed while using 10% AGV, a power has increased about 5.02% compared with 0% and 10% EGR BV. At 1800 rpm the use of 0% and 10% EGR BV only on the maximum power of 3.06 kW, while in 10% of AGV the power is 3.22 kW. However, at the end of the speed, the power at 0% EGR, 10% BV and 10% AGV have same value. From this graph it can be known that at lower speed is better use AGV EGR system with a percentage of 10% EGR.

When using 20% AGV seen that there is a decrease of about 3% power compared with 0% and 20% EGR BV. But in 20% AGV increased while above 1900 rpm. Currently 20% of AGV, at 2000 rpm power looks to be at the same point with the 0% and 20% BV. But the trend graph showed at 20% BV, the power lower than 0% and 20% AGV. The use 20% EGR show that peak power is at 2100 rpm and after that decreased. From the graph can be calculated that use 20% AGV has 6.1% greater power compared with 20% BV. Rated peak power of 20% AGV is 4.04 kW while 20% BV is 3.81 kW.

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The use of 30% EGR shows that the power has dramatically decreased. This is caused by too much of recirculation of gas introduced into the combustion chamber. This can reduce the capacity of O2 for the combustion process and consequently became very rich mixture. Note that the exhaust gases are inert it can be bind O2. However, from the graph at Fig. 4 can be seen that the power at 30% AGV still better than 30% of BV. From the graph it can be calculated that the use of 30% AGV provide higher power about 10.85% compared to 30% BV.

From the overall analysis the conclusion that the use of angle globe EGR valve provide a better value than the ball valve on the variation of the percentage of EGR. Whereas the impact of the addition of EGR percentage above 10% could lead to power diesel engines declined. But its still needs to be reviewed again how much the effect of decreasing the current NO_X flue gas analysis at a later explanation.

Figure 5 is a performance comparison graph of torque against speed on EGR capacity of 0%, 10%, 20% and 30% with two variations of the type of valve. AGV is an EGR system using the EGR valve angle globe. BV is an EGR system using a ball valve. Based on the graph, use 10% AGV is able to increase the torque of the diesel engine speed of about 4.9% at the beginning. While the use of 10% BV has a value of torque equal to 0% EGR.

The use of 20% EGR, changes in torque at the beginning speed is not too significant. Then the torque continues to increase very significantly until before 2,100 rpm speed. The use 20% AGV at a 2100 rpm speed the torque reaches a peak of 18.357 Nm and uses 20% BV 17.769 Nm reach the top. Based on the graph indicates that the use of the EGR valve type angle globe valve provide better torque than the use of EGR valve type bowl valve.

While the use of EGR percentage of 30%, resulting in a drastic drop in engine torque of 200% of the engine condition without EGR (0% EGR). But from the graph shows that a 30% AGV has a better value than the 30% BV.

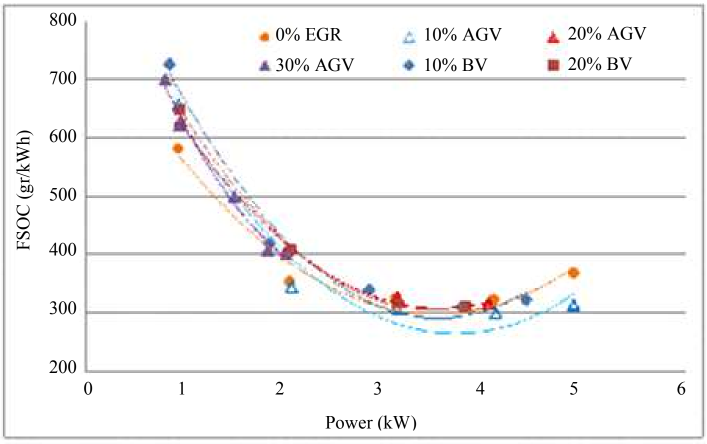

Fig. 3: SFOC performance result at 2100 RPM

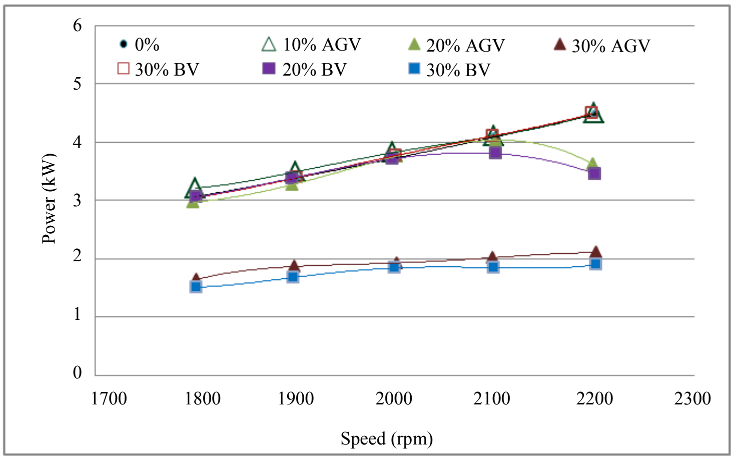

Fig. 4: Performance result of power vs speed

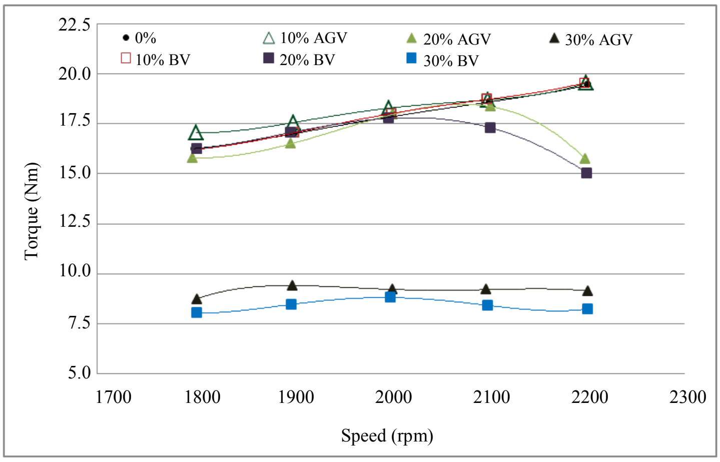

Fig. 5: Performance result of torque Vs Speed

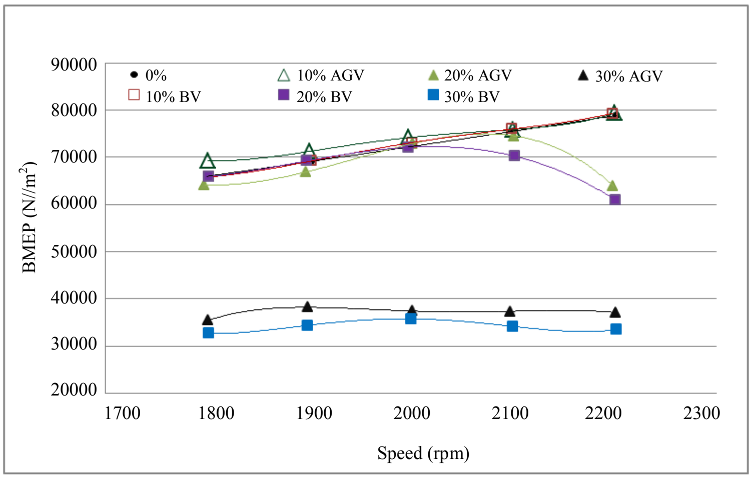

Fig. 6: Performsnce variation% Vs RPM at EGR using the angle globe valve and ball valve

Figure 6 is a performance comparison graph of BMEP against speed on EGR percentage of 0%, 10%, 20% and 30% with two variations of the type of valve. AGV is an EGR system using the EGR valve angle globe. BV is an EGR system using a ball valve. Based on the graph in Fig. 6, use 10% AGV is able to increase BMEP around 5.10% at the beginning speed.

While the use of 10% BV, the BMEP has an equal to 0% EGR. At the beginning of speed, the change of BMEP is not significant for using 20% EGR. However at 2100 rpm, BMEP decreased. On the use of 20% AGV highest BMEP is at 2100 rpm with a value of 74 472 N/m^2 and the use of 20% BV peak torque is at 2100 rpm with a value of 70 189 N/m^2. The graph shows that the use of EGR valve angle type globe valve provides BMEP better than the use of EGR valve ball valve types. While the use of EGR percentage of 30%, resulting in a dramatically drop in engine BMEP approximately 206% of the engine condition without EGR (0% EGR). From the graph shows that a 30% AGV has a better value than the 30% BV.

Performance results that have been done using EGR percentage variation of 0, 10, 20 and 30%, then used as a benchmark for adopted of the combustion process and NO_X levels. Due to the results of a diesel engine with 30% EGR performance decrease drastically, then for the next stage EGR with 30% discontinued and is not recommended for use.

Combustion Process

The processes of combustion products that have been analyzed include graphs of combustion pressure and the rate of heat release. The data of the combustion process obtained through experiment. Variable of data retrieval combustion process results are determined by the rules of the IMO MARPOL Annex VI on a chapter of test cycle. The rules used in the test cycle is 100% speed of diesel engine with an engine load including 25, 50, 75 and 100%.

Figure 7 is the ratio of the variation of combustion pressure EGR at speed 100% rpm with a load of 50%. The graph shows that the use of EGR resulted in peak power shifted a few degrees to the left. The use of EGR to the 50% load is seen in the graph that the peak power value increased compared with the diesel engine without the use of EGR or when the EGR is in 0% (0% EGR). The graph also shows that the current combustion control period, the graph with EGR 10% AGV is coincide with chart 0% EGR. It shows that the power engine is not too much is lost due to the addition of 10% EGR. When a leading to the after burning period, the graph looks 10% AGV is greater than 0% EGR. While the trend graphs with EGR 10, 20% BV and 20% AG are below graph 0% EGR, it indicates there is a loss of disappearance of pressure that can result in decreased power engines.

Figure 8 is zooming in combustion pressure at 100% rpm and 50% load. Detailing conducted to determine the point of maximum pressure on the variations in the use of EGR in diesel engines. The peak pressure of 0% EGR found on 3,6°CA after TDC with the pressure is 70.9 Bar. The peak pressure of 10% AGV found on 3°CA after TDC with the pressure is 73.85 Bar. At 20% AGV peak pressure found on 3°CA after TDC with the pressure is 71.9 Bar. At 10% BV peak pressure found in 3°CA after TDC with the pressure is 75.27 Bar. While 20% BV peak pressure found in 2.6°CA after TDC with the pressure is 72.14 Bar.

Figure 9 is a comparison of the Rate of Heat Release (ROHR) at 100% RPM and 50% load. The graph shows a comparison of changes in the process of heat loss or heat release when the EGR system is applied to a diesel engine. At 0% EGR or condition of the engine without EGR system, the starting point of heat release between the fuel and air occurs in 7.4°CA before TDC. At the time of the addition of EGR capacity of 10% using the AGV initial heat release occurs in 6.4°CA before TDC.

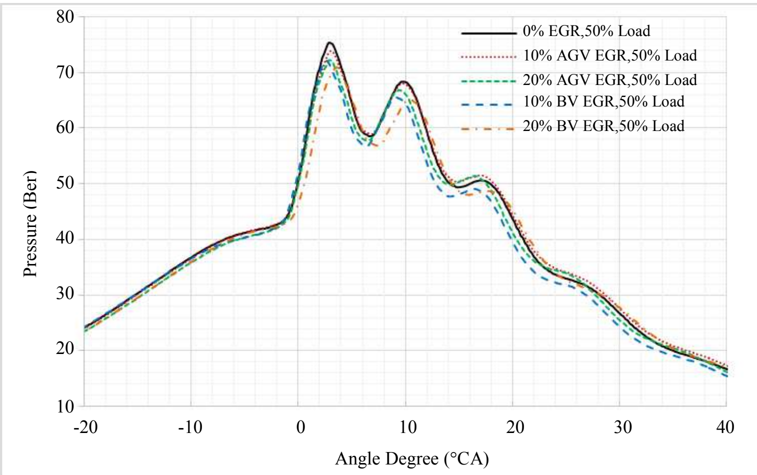

Fig. 7: Combustion pressure at 100% RPM and 50% load

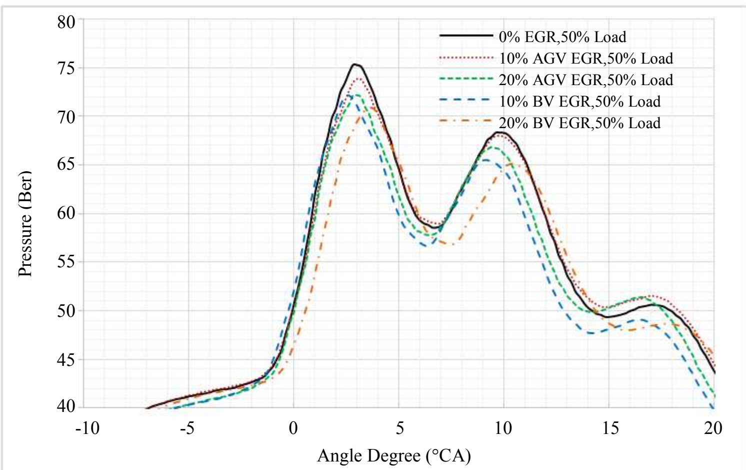

Fig. 8: Maximum of combustion pressure at 100% RPM and 50% load

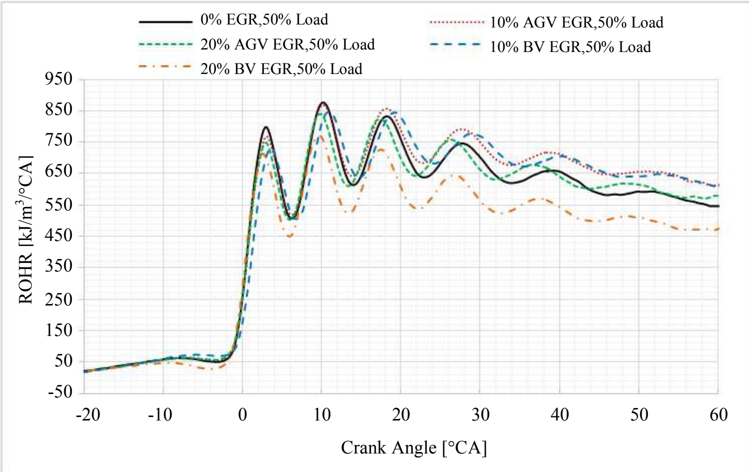

Fig. 9: Rate of Heat Release (ROHR) at 100% RPM and 50% load

At the condition of 10% BV initial heat release occurs in 6°CA before TDC. At 20% AGV initial heat release occurs in 6.2°CA before TDC. In 20% BV of the initial heat release occurs in 8°CA before TDC. From these results explain that the use of EGR and the choice of EGR valve different in at 100% rpm and 50% load can lead to early heat release is increasingly moving towards the right of degrees of crankshaft rotations on the condition of 10% AGV, 10% BV and 20% AGV but use 20% BV ROHR early shows are to the left of the condition of 0% EGR.

While the peak of ROHR condition at 0% EGR occurs in 10°CA after TDC to the value of the energy release of 874.5 KJ/m^3/°C. In 10% AGV, the peak of ROHR occurs in 10.2°CA after TDC to the value of the energy release of 870 KJ/m^3/°C. At 10% BV, the peak of ROHR occurs in 10.6°CA after TDC to the value of the energy release of 843.6 KJ/m^3/°C. In 20% of AGV, ROHR peak occurs in 9.6°CA after TDC to the value of the energy release of 844.3 KJ/m^3/°C. At 20% BV, the peak of ROHR occurs in 9°CA after TDC to the value of the energy release of 658.6 KJ/m^3/°C. From the graph shows that the addition of EGR by 10% resulting in peak of ROHR moves a few degrees to the right of the condition of 0% EGR while the addition of 20% resulted in peak ROHR move a few degrees to the left of the condition of 0%. In addition, from the graph above shows that the addition of EGR resulted in peak ROHR are on the wane. The use of 20% BV ROHR showed significant decrease compared with the use AGV 10, 10 and 20% AGV BV.

NO_X Emission Test Results

Results diesel engine combustion process is not perfect result in the emergence of toxic emissions. One among these is the NO_X emissions. NO_X formed during the combustion process takes place. NO_X can be formed as oxygen and nitrogen are free to meet the conditions of combustion chamber temperatures are very high. International Maritime Organization (IMO) has issued a standard on NO_X emission limits that are allowed from diesel engine exhaust emissions. A complete these rules have been discussed in MARPOL Annex VI.

Exhaust Gas Recirculation (EGR) is a technology used to reduce NO_X emissions. EGR exhaust gas can circulate back into the combustion chamber, so that when the temperature of the combustion process to be reduced. In this research necessary to test the levels of NO_X after the diesel engine is modified by adding the EGR system, particularly with applications EGR valve angle globe valve types. NO_X emission results obtained from the experiments of the diesel engine is like Fig. 10.

NO_X emission levels produced at 0% EGR or standard diesel engine condition without EGR system ranging from 25-100% load respectively were 11.4, 10.9, 8.4 and 4.6 g/kWh. When the loads of engine 25% and 50%, the NO_X emissions did not qualify of TIER 1 it considered very dangerous. The load of engine 75% the NO_X emission level is in the category standard of TIER 1. While at 100% load conditions of 0% EGR is in the category TIER 2. As described in Chapter II that qualifying of TIER 1 the NO_X emissions is between 7.7 to 9.8 g/kWh for round more than 2000 rpm. Qualifying of TIER 2 diesel engine NO_X emissions is between 1.96 and 7.7 g/kWh for round more than 2000 rpm speed. A qualification of TIER 3 is a diesel engine NO_X emission of less than 1.96 g/kWh for round more than 2000 rpm.

NO_X emission levels produced at 10% load BV ranging from 25-100% respectively was 9.6, 9.2, 6.0 and 2.7 g/kWh. The condition of a load of 25% and 50% of NO_X emissions qualify as TIER 1. Meanwhile the engine load 75% and 100%, NO_X emission levels are in the category standard of TIER 2.

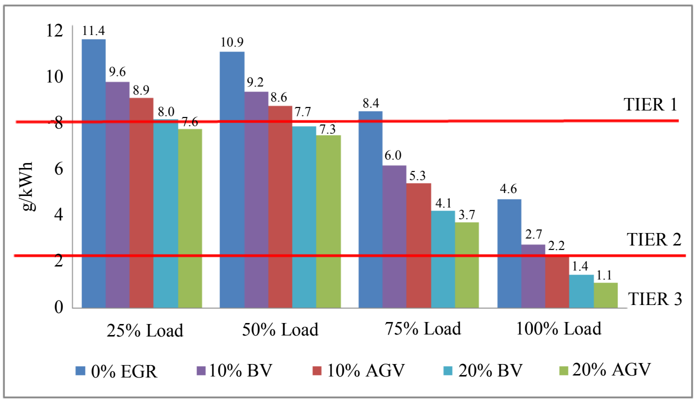

Fig. 10: The bar chart on the NO_X levels at 100% RPM and load variations

NO_X emission levels produced at 10% AGV ranging from 25-100% loads respectively were 8.9, 8.6, 5.3 and 2.2 g/kWh. The condition of loads of 25 and 50% of NO_X emissions qualify as TIER 1. Meanwhile, the engine loads at 75 and 100%, the NO_X emission levels are in the category of standard of TIER 2.

NO_X emission levels produced at 20%BV ranging from 25-100% loads respectively were 8.0, 7.7, 4.1 and 1.4 g/kWh. The condition of a load of 25%, the NO_X emissions qualify is in TIER 1. Such as the engine loads 50 and 75%, the NO_X emission levels were in the category of standard of TIER 2. Meanwhile, the engine load 100%, NO_X emission level that was in qualifying of TIER 3.

NO_X emission levels produced at 20% AGV ranging from 25-100% loads respectively were 7.6, 7.3, 3.7 and 1.1 g/kWh. The engine loads 25, 50 and 75%, the NO_X emission levels were in the category standard of TIER 2. Meanwhile, when the engine was 100% load, the NO_X emission levels at TIER 3 qualification.

Figure 10 show the use of EGR by 10% with type EGR angle globe valve is capable to reduce NO_X emissions by 29.2%. While the use of EGR by 20% with type EGR angle globe valve is capable to reduce NO_X emissions by 44.2%. In addition, the used of Angle Globe EGR Valve (AGV) have the function of reducing NO_X better than the Ball-type EGR Valve (BV). When the use of EGR 10% AGV has a value of 9.1% NO_X reduction is better than BV. Meanwhile, when the use of EGR 20% AGV has a value of 7.1% NO_X reduction is better than BV. Thus, the use of AGV is highly recommended because it can improve the function of EGR as a tool for reducing NO_X emissions of diesel engine.

Conclusion

Based on experiments conducted at the hot and cold EGR system mounted on a diesel engine with that then I as the author draw the following conclusion:

1. The result of SFOC with 10% EGR using angle globe EGR valve could be decrease until 35,29 gr/kWh or lower by 10.3% compared to a diesel engine without EGR system. However, using of EGR with a percentage of more than 10% EGR may result in increased SFOC. The use of 10% EGR with angle globe EGR valve also able to improve the value of power, torque and BMEP at 1800-2000 rpm. However, there is a downward trend in the graph result of power, torque and BMEP on the use of EGR system with a percentage of 20% and more
2. The use of EGR can result in peak pressure during the combustion process could be lower. Besides the use of EGR resulting heat release value to decrease
3. By using the EGR system with Angle Globe EGR Valve (AGV), NO_X emission levels generated in diesel engines can be reduced up to 15.6 g/kWh or 44.2%. in general condition, the emission levels of diesel engine after installed EGR could be able to penetrate in TIER 2 spesification and the condition of 20% EGR with 100% load levels can penetrate the TIER 3 spesification

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Author's Contributions

Aguk Zuhdi Muhammad Fathallah: Participated in all experiments, coordinated the data analysis and contributed to the writing of the manuscript.

Achmad Maulana Yasin: Design and develeped of new EGR prototypes, engine set up, experiment, data colecting, draft report.

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Ethics

This article is original and contains unpublished material. The corresponding author confirms that all of the other authors have read and approved the manuscript and there are no ethical issues involved.

References

Ge, J.C., S.K. Min, K.Y. Sam and J.C. Nag, 2015. Effects of pilot injection timing and EGR on combustion, performance and exhaust emissions in a common rail diesel engine fueled with a canola oil biodiesel-diesel blend. Energies, 8: 7312-7325. DOI: 10.3390/en8077312

Hussain, J., K. Palaniradja, N. Alagumurthi and R. Manimaran, 2012. Effect of Exhaust Gas Recirculation (EGR) on performance and emission characteristics of a three cylinder direct injection compression ignition engine. Alexandria Eng. J., 51: 241-247. DOI: 10.1016/j.aej.2012.09.004

Jothithirumal, B. and E. Jamesgunasekaran, 2012. Combined impact of biodiesel and exhaust gas recirculation on NOx emissions in DI diesel engines. Proc. Eng., 38: 1457-1466. DOI: 10.1016/j.proeng.2012.06.180

Krishnan, A., V.C. Sekar, J. Balaji and S.M. Boopathi, 2016. Prediction of NOx reduction with exhaust gas recirculation using the flame temperature correlation technique. Proceedings of the National Conference on Advances in Mechanical Engineering, Mar. 18-19, Engineering College Kota, Kota, India, pp: 378-385.

MAN, 2017. Tier III two-stroke technology. MAN Diesel and Turbo, Augsburg, Germany.

MARPOL, 1998. MARPOL 73/78 Annex VI regulations for the prevention of air pollution from ships and NO_x technical code. International Maritime Organization, London.

Schill, L., 2012. Alternative catalysts and technologies for NOx removal from biomass-and wastefired plants. Ph.D. Thesis, Technical University of Denmark.