Modifying Single-Cylinder Diesel Engine Become Dual-fuel System to Reduce NOx Emission and Maintain Fuel Efficiency

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Abstract. Tier III of Annex VI from MARPOL 73/78 about NOx emission control soon may be implemented at a global level. There are three potential methods to fulfill the Tier III. First is derating power, second is using gas as fuel, and the third one is installing SCR. This research deals with using CNG as diesel engine fuel. This initial study was occupied a single-cylinder diesel engine. Gas cannot burn inside conventional diesel cycles. Dual fuel technology also tends to reduce fuel efficiency compared with the conventional one. Therefore, the single-cylinder engine was modified its piston crown part to overcome both problems. The modification of piston crown geometry affects the engine compression ratio. Modify the conventional diesel engine to become the dual-fuel type is concluded as a potential technique to be developed. The study results show NOx reduction up to 33.68% and the fuel efficiency increase up to 1.512% without any disruption to the engine operating conditions.

Keywords: Dual-fuel, CNG, Diesel Engine, Piston Crown, NOx Emission, Fuel Efficiency

1. Introduction

Air pollution has been growing day by day at a linear rate due to the fast-growing of industrialization in almost every sector such as manufacturing, power plants, automotive, and sea transportation. Therefore, many governments and professional institutions develop rules and regulations to control the situations and keep a better atmosphere. In the maritime sector, IMO has become a global regulator that set up a special board Marine Environmental Protection Committee (MEPC) and produce MARPOL 73/78 Regulations [1]. Technical Code of Annex VI Regulation 13 has an achievement to a comprehensive level of Tier III in detaining the NOx emission from ship propulsion and electrical power plant [2]. The NOx emission is the most important issue for diesel engines that is a dominant power plant used onboard a ship. To fulfill the Tier III requirement that is known very stringent compared with the previous Tier I at about a lower value of 80%. To achieve the Tier III level, there are three methods that can be adopted for the marine diesel engine. They are derating engine power [3], using gas as a fuel [4], and installing a more complicated SCR (Selective Catalytic Converter) unit [5]. This paper is deals with the second method, using natural gas CNG as the fuel of a diesel engine. Following the most common technology that was already settled in the marine power plant then gas will be burned on a diesel engine combustion chamber under dual-fuel technology called the diesel ignited gas engine [6].

In any methods available now, the effort in reducing emission always encounter decrement of engine efficiency and reversely, improving engine efficiency will affect in increasing emission level [7]. Moreover, gas fuel in any form and technology also faces a problem of the decreasing of overall engine efficiency. It is the most important parameter of the successful design and operation of an engine [1].
due to the relation with the fuel consumption to certain power output. It is the main reason why the use of gas as fuel should be adjusted by modifying a certain parts of the diesel engine. This paper deal with the modification of piston crown [8]. Based on the engine model Yanmar TF85MH, its piston crown was modified in seven alternatives. Basic modifications refer to the changed of the piston dimension but the results show a trendline of the changing of compression ratio. The seven models after validated are used to simulate in-cylinder parameters such as maximum pressure and temperature, gas velocity, and heat transfer flux to perform further investigations of the engine overall efficiency and NOx emission. The best modifications are a new piston structure that gives as lower NOx emission as possible and at the same time capable of maintaining overall efficiency. Later, in the comparative study, the eligible method to evaluate the efficiency is not comparing dual-fuel with a diesel engines but between dual-fuel standards with the modified dual-fuel engines [9].

2. Literatures Review

MARPOL 73/78 Annex VI Regulation 13 is used to control the NOx emission from the global maritime fleet [2]. Due to good developments of marine diesel engine technology that supported well by the inventions of any methods and products to control emissions then the MEPC regularly fit the regulation updated with the technological achievements. Tier I was ratified based on the 1997 Protocol then it was improved as Tier II that globally come into force in 2011 and finally Tier III comes into force in 2016 for a specific area called NOx Emission Control Area (ECA)[10].

![Figure 1. The Technical Code of Annex VI Regulation 13 [2].](image)

Typically, natural gas in the form of liquid natural gas (LNG) or compressed natural gas (CNG) is contains a big portion of methane gas. Fully use of natural gas as a diesel engine fuel (is called a gas engine) has been established well in the land industry such as automotive and electric power plants. But under IGF Regulation the gas engine cannot use in the ships due to redundancy reason [11]. A ship insisted to bring a certain type of fuel oil instead of gas. It is the reason why dual-fuel technology becomes the best choice for a specific application on board a ship. Technically speaking, the natural gas cannot be burned directly by in-cylinder diesel engine pressure.

There are three methods to burn fuel gas under dual-fuel technology. The first is direct injection gas engine (DIGE) technology, where a certain amount of diesel oil functioned as a pilot burner injected directly into the combustion chamber [6]. When the fresh air flowing toward the combustion chamber then a specific portion of gas is injected into the intake manifold and entering together to intake port at the expansion step. As common diesel cycle, before end of the compression stroke and just about before top dead centre, the start of injection (SOI) of fuel oil is done till performs initial flame and the start of combustion (SOC) will burn the mixing of air, gas, and fuel oil. Figure 2 shows the DIGE process.
3. Modeling and Simulation

As stated before, there are seven modifications of the piston crown structure will be studied here [7]. All of the original and seven modified models will be shown in Figure 4 below.

After the validation step then all of the modification models are simulated to investigate the combustion results based on the parameters such as; maximum pressure and temperature combustion, gas velocity or gas flow rate, and heat transfer flux that affect to the cylinder liner, cylinder head, and piston based on the CFD analysis as shown in Figure 5. From those initial simulation can be stated that the modify-3 and modify-4 give a significant drop on the four parameters studied then both modifications are not eligible for further analysis [8]. The remaining models were taken into a further investigation to calculate the overall engine efficiency and the potential NOx emission level.
4. Analysis and Discussion

Based on the data results generated from the initial simulation then the overall engine efficiency (%) and the NOx emission (g/kWh) can be calculated as shown in Figure 6 and 7. The value of 0% gas means it works at a diesel engine conventional. And the value of 25%, 50%, and 75% gas means it works at a dual fuel engine. Working with gas more than 50% portion technically is a doubt effort because of the high risk of engine knocking phenomenon that may occur [13]. It should be a clear answer to why our modification works are needed to improve the gas portion [7]. Because using more gas in practically gives benefit in terms of economic and technical aspects [14]. It is a challenge to test our modified piston to work up to 75% gas portion so that the data of conditions between 50% to 75% also can be recorded.

The modification 1 to 7 gives a higher engine compression ratio that contributes to higher engine thermal efficiency during combustion processes. The higher efficiency contributes an efficient fuel combustion processes that tend to produce higher in-cylinder maximum pressure and temperature which leads to higher NOx emission formation. On the other hand, Figure 6 and Figure 7 also show that adding the gas portion will reduce both the efficiency and NOx emission. Both the data is a contradiction situation when the lowering efficiency is a disadvantage result and the lowering NOx emission is advantage progress for the modified dual-fuel engine operations.

Understanding the trend from the above graphics then it is an interesting fact about how to evaluate the way to get the best modification. If the above graphics have been merged then new graphical data can be generated to get more valuable analysis based on the increment and decrement values only as shown in Figure 8 below. Following the previous statement before, the comparative study was only done by
comparing dual-fuel only. It means the modified piston when running with a 50% gas portion is compared to the 25% dual fuel to evaluate the increment or decrement values. Figure 8 shows that the only modify-5 can give increasing overall efficiency and reducing the NOx emission simultaneously when the modified dual-fuel engine running under a 25% gas portion. Burning 50% gas portion to modify-5 will result in lower efficiency and contribute to much lower NOx emission. In normal consequences, the modify-6 and modify-7 even give better efficiency, but they produce higher NOx emission value, so it is not acceptable to the basic criterion of this study objective. Finally, modify-5 can be chosen as the best one.

The modify-5 can reduce NOx emission of 1.63% while possibly maintain the overall efficiency of about 1.512% compared with the usage of the standard piston when burning 25% gas portion. By the interpolation method, the new piston may be operated safely up to the gas portion of 33.8%, where there is no increasing the NOx emission level, but the engine can run under the higher efficiency condition. In the 50% gas portion, the modify-5 can reduce of 35.43% NOx emission but cause a 2.76% efficiency drop. The modify-6 causes the NOx emission increase of 2.25% but the efficiency can increase 2.7% when 25% gas is burned, and NOx emission can reduce 33.61%, and efficiency drop about 1.51% when burning 50% gas portion. Finally, the modify-7 makes the NOx emission increase by 2.02% but the efficiency can increase by 3.12% when the engine burns 25% gas portion. In the same way, when the modify-7 burns of 50% gas portion then the NOx emission can be reduced by about 33.68% while the efficiency also drops in about 0.92%. For a 75% dual fuel system all of the modified piston can reduce NOx emission at least 53.78% but the overall efficiency cannot be maintained and drop significantly at least 8.9%.

5. Conclusion

The study results show that the NOx emission can be reduced up to 1.63% and in simultaneously the fuel efficiency can be maintained positively up to 1.51% without any disruption to the engine operating conditions when the engine uses the mode of 25% dual-fuel. While let the efficiency drop about 2.76%, the engine can run at 50% dual-fuel mode and capable of reducing NOx emission up to 33.61%. Finally, the modifying piston at a single-cylinder diesel engine can perform a proper modified dual-fuel diesel engine that offers reducing NOx emission and a slight chance to increase the overall efficiency indeed. Further investigation is needed to evaluate the fuel efficiency in economic aspects such as fuel prices, supply, and bunkering so it can be imagined the consequences of the efficiency drop in the dual-fuel mode compared with the diesel engine conventional that use the higher price of diesel oil.
6. References

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