Numerical Study of Emissions on DDF Engine with 20% CNG with Variation on Compression Ratio

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1 Introduction

The reliability of the marine engineering system was one of the parameters that must be considered in the development process of the maritime and shipping industry. The previous researcher was grouping research on engine performance improvement into three groups, namely optimization of engine design, operating system engineering, and after-treatment conditioning. The three parameters above complement each other to get maximum engine performance and minimum emissions. The exhaust emissions produced by shipping engines include CO_2, NOx, SOx, HC, CO, and PM. The latest data shows that the contribution of the shipping sector to global emissions is 2–3% and is increasing from year to year [1]. Regulations regarding emissions and their application are not only expected to reduce the effect of gas emissions but also to minimize the level of fuel consumption by increasing engine performance and reduce operating costs so that the shipping industry companies are even more competitive [2].

International Maritime Organization (IMO), an organization dealing with pollution from ships, issued its first regulation in 1978. International MARPOL convention in 1973, strengthened again in 1983, was related to emission restriction strategies and prevents and minimizes pollution by shipping activities [3]. As for matters related to air pollution by shipping activities in 1997 regulated in Annex VI MARPOL (Tier 1) with a focus on Sox and NOx, through Tier 2 began to be applied to ships built after January 1, 2011, and continued with Tier 3 for applied to ships built after January 1, 2016. This change involves continuously tightening emission limits [4]. Dual fuel using gas as one of the fuels reduces brake power by more than 30% and increases CO and HC emissions [5], so that good conditioning and treatment are needed to provide optimal benefits. In general, according to [6, 7], the performance of dual fuel is lower than single. So it takes effort to get the desired performance and emissions.

The compression ratio is the ratio of the total volume of the combustion chamber when the cylinder is in the BDC position to the combustion chamber volume at TDC. Theoretically, increasing the compression ratio will result in higher cylinder pressure and heat dissipation that increase the value of overall thermal and engine efficiency [8, 9].

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However, increasing the compression ratio will usually increase combustion noise and cause knocking, especially for gases with low ignition temperature. Different things were expressed by [8, 9], and researchers suggested that increasing the compression ratio benefits improved performance and emissions. Experimental trials were on dual fuel with biodiesel fuel—CNG. Bhaskoer [9] has experimental studies on compression ratio, EGR fraction, and temperature on dual-fuel engines. They concluded that increasing the compression ratio will increase fuel substitution and energy efficiency; otherwise, increasing the compression ratio will reduce HC and CO emissions but higher NOx.

In this article, we will discuss how the effect of the compression ratio on exhaust emissions produced on dual fuel with a ratio of 20% CNG to 0% CNG. We will see how the variation of the compression ratio affects the performance, combustion, and emissions when conditions are 20% CNG at a constant speed of 2000 rpm.

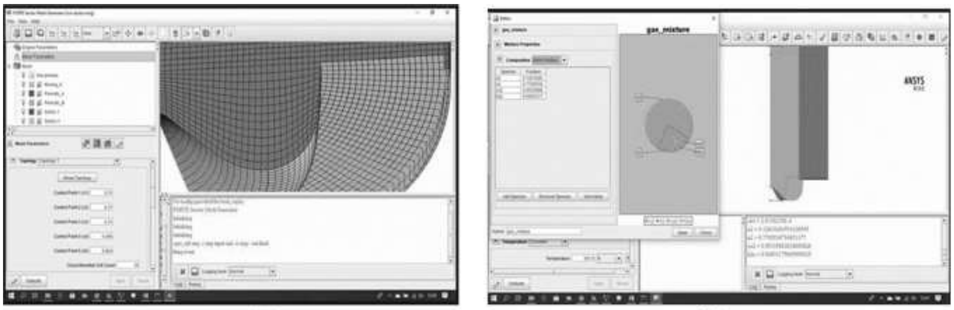
2 Material and Method

The simulation test is using single-cylinder engine data with the following specification (Table 1).

Table 1 Engine baseline

Engine (four stroke cycle)	TF 85 MH
Cylinder	1
Combustion system	Direct injection
Bore × stroke	85 × 87 mm
Displacement	493 cc
Compression ratio	18:1
Max engine at full speed	2200
Continuous power output	7.5 kw
Specific fuel consumption	171 gr/hph

The first stage in this process is modeling using solid work. The image made is an existing picture of the condition of the piston and combustion chamber. It is planned to make three piston models with different geometries to produce variations in the compression ratio to 16, 18, and 19. The geometry model created is drawn in two dimensions as many as three models, M1 compression ratio 16, M0 baseline compression ratio 18, and M2 compression ratio 19. The next step is to input the main engine data and import images from solid work to ANSYS while setting the direction of the pilot fuel spray fuel. The next process is meshing or formation into smaller cells, and then, the calculation process with the ANSYS forte solver is started. The calculation begins with determining the fuel to be used, the injection timing and the mass of fuel injected, the boundary conditions and the direction of motion of the piston, the initial conditions, and the gas mixture (Fig. 1).



(a) (b)

Fig. 1 Meshing process (**a**) and determination of initial conditions and gas mixture (**b**)

The simulation control process includes determining the crank angle you want to display, and the process running generates a graphic visualization, while the rendering process will generate contour output as we want such as displaying pressure visualization, temperature, and velocity. Variations in the compression ratio are given 16 and 19 at a fixed speed of 2000 rpm. The result of emission data operations in the form of UHC, NOx, and CO.

3 Results and Discussion

The following is the result of reading the unburnt hydrocarbon emissions in three variations of the compression ratio, namely the lower compression ratio of 16 and the higher of 19 against the baseline compression ratio of 18 (Fig. 2).

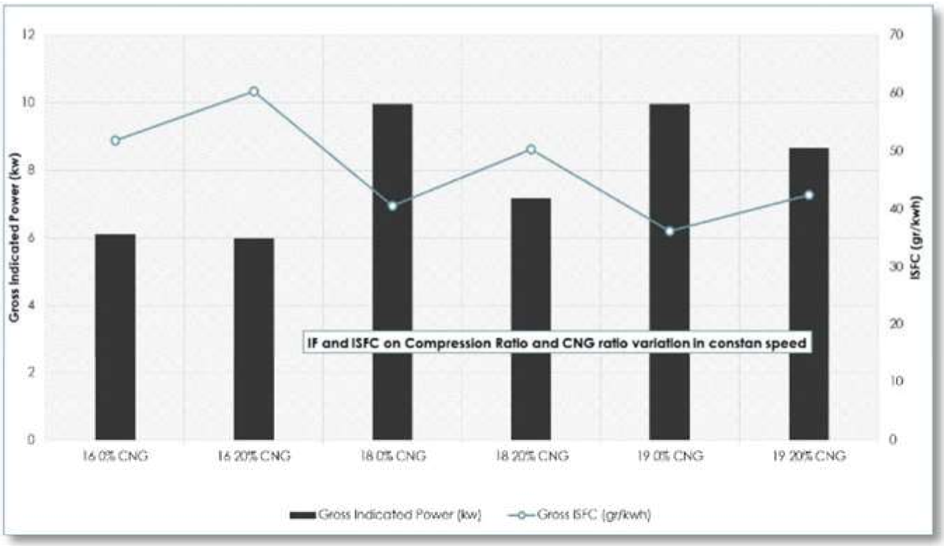


Fig. 2 Engine performance at 0 and 20% CNG on the variation of compression ratio

The more CNG will decrease the indicated power in all compression ratio variations and vice versa. Dual fuels require an increased compression ratio to compensate for the power loss because of CNG due to a single to dual-fuel switch. The level of fuel consumption is getting bigger on dual fuel with a higher percentage of CNG. The increase in consumption occurs at low compression ratios and decreases with increasing compression. The compression ratio 19 has a fuel consumption reduction of up to 15.6% on dual 20% CNG fuel compared to the baseline compression ratio condition (Fig. 3).

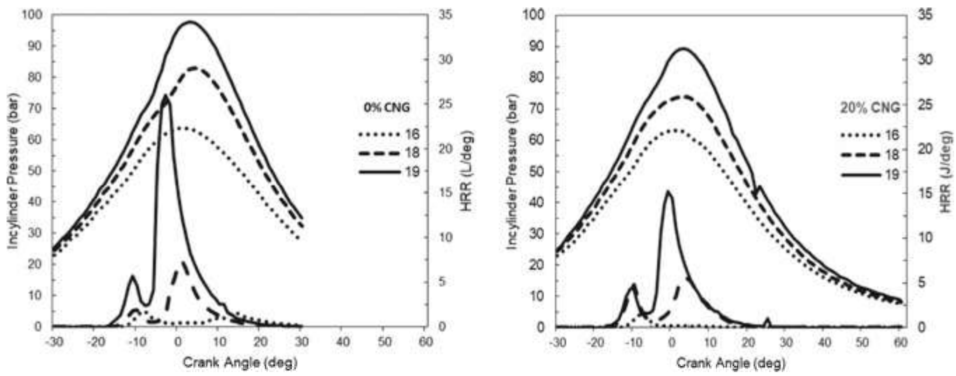


Fig. 3 Cylinder pressure and HRR at 0 and 20% CNG on variation of compression ratio

By entering 20% of the CNG mass in the picture, the cylinder pressure in all combustion chambers decreased compared to when it was 0% CNG. This condition happens because the entry of gas into the combustion chamber causes oxygen intake to be blocked. With reduced oxygen, the process of fuel oxidation is disrupted, causing the cylinder pressure to drop. The fuel mixture becomes too rich so that it reduces the quality of combustion, affects the output, and increases fuel consumption and high emissions. The increase in heat release rate also increased with a peak difference of 24% compared to the HRR at baseline. At a compression ratio of 19, the ignition delay is faster than the baseline with almost the same combustion duration. This ignition delay is faster beneficial for reducing the potential for knocking, especially at low loads. While at the compression ratio of 16, there is a decrease in pressure and temperature in the combustion chamber. In addition, the rate of energy issuance is also the slowest and the shortest (Figs. 4 and 5).

At a compression ratio of 16, an increase in temperature and pressure occurs in the bowl area, a little in the squish area, and a temperature not too high, and uneven distribution makes the potential for methane slip. At low compression pressures, the squish is largest than other models, and the heat range is less than optimal, especially in the tip area. The effect of a lower compression ratio causes a decrease in pressure, temperature, and fluid flow velocity in the combustion chamber so that it does not support the homogenization process fuel mixture (Fig. 6).

Here, at a lower compression ratio, UHC is at a higher value when compared to the baseline. Immediately after injection of diesel fuel at 18 BTDC, the UHC chart peaked at around 11,600 ppm, then sloped toward the top dead center, and continued even though

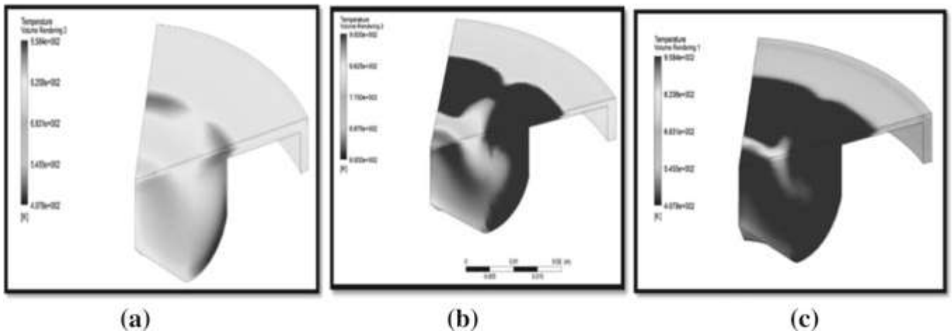


Fig. 4 Contour temperature at 0% CNG on compression ratio 16 (**a**), 18 (**b**), and 19 (**c**)

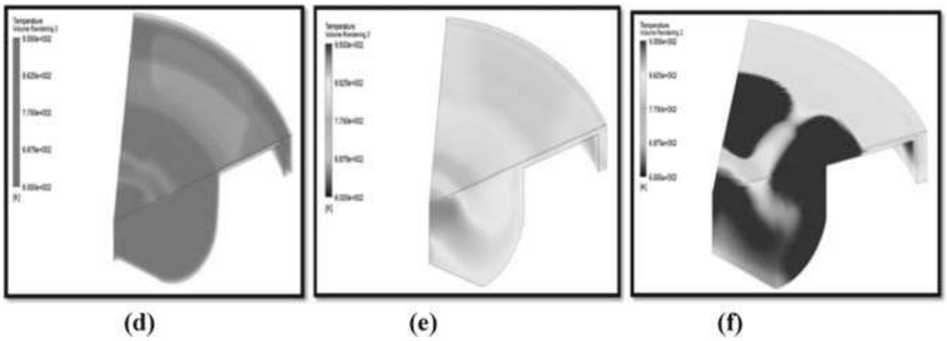


Fig. 5 Contour temperature at 20% CNG on compression ratio 16 (**d**), 18 (**e**), and 19 (**f**)

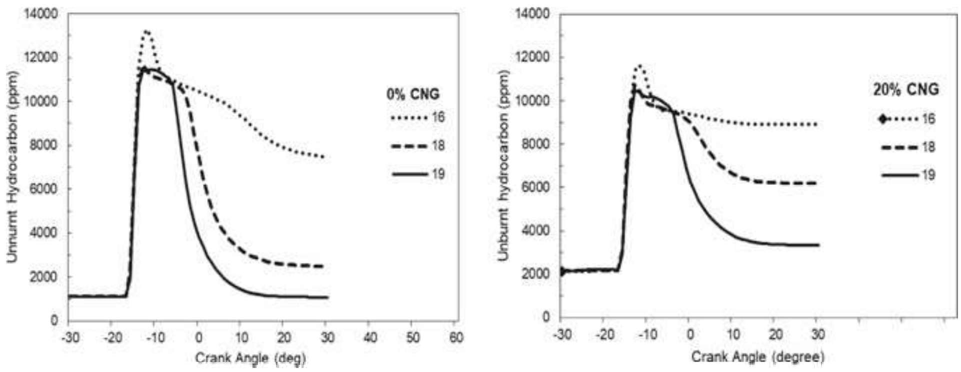


Fig. 6 Unburnt hydrocarbon at 0 and 20% CNG on the variation of compression ratio

it was not as significant as the baseline or when the compression ratio was increased. At a higher compression ratio, there is a decrease in UHC emissions of around 46% compared to the baseline.

4 Conclusion

In general, DF CNG intake in the combustion chamber causes a decrease in performance and combustion due to the reduced amount of oxygen. A high compression ratio promotes accelerated ignition delay resulting in increased performance and minimized UHC. A high compression ratio gives a more significant UHC reduction value in CNG with a low ratio decrease in UHC by 50–56% at 0% CNG and a decrease by 39–46% at 20% CNG.

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