Design and Performance of LPG Fuel Mixer for Dual Fuel Diesel Engine

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Abstract. Small horizontal diesel engines are commonly used for agricultural machinery, however, availability of diesel fuel become one of big problems especially in remote area. Conversely, in line with government policy for conversion of kerosene into LPG for cooking, then LPG become more popular and available even in remote area. Therefore, LPG is potential fuel to replace the shortage of diesel fuel for operating diesel engine in remote area. The purpose of this study was to design mixing device for using dual fuel i.e. LPG and diesel fuel and evaluate its performance accordingly. Simulation by using CFD was done in order to analyze mixture characteristics of LPG in air intake manifold. The performance test was done by varying the amount of LPG injected in intake air at 20%, 25%, 30%, 35%, until 40%, respectively. Result of CFD contour simulation showed the best combination when mixing 30% LPG into the intake air. Performance test of this research revealed that mixing LPG in air intake can reduce the diesel fuel consumption about 0.7 l/hour (without load) and 1.14 l/hour (with load). Diesel engine revolution increases almost 300 rpm faster than when using diesel fuel only. Based on economic analysis, using the fuel combination (diesel fuel – LPG) is not recommended in the area near SPBU where the price of diesel fuel is standard. However, using the fuel combination LPG-diesel fuel is highly recommended in the remote areas in Indonesia where price of diesel fuel is comparatively expensive which will provide cheaper total fuel cost for diesel engine operation.

1. Introduction

In recent decade, Indonesian national fossil fuel consumption has increased significantly and reached 1.5 million barrel per day [1]. Percentage of fuel consumption by type during the year 2000-2014 is gasoline fuel 45.5%, diesel fuel 45.2%, aviation fuel 6.3%, and kerosene 1.5% [2]. Therefore, now the use of alternative fuels, especially on internal combustion engines has become an interesting object to continue to be developed. The use of alternative fuels cannot be separated from the two global problems of crude oil availability continues to decline and the issue of exhaust emissions are increasingly apprehensive. The current effort is to develop alternative fuels that are possible to reduce exhaust emissions and relatively low fuel costs. One effort to answer the problem is by using dual fuel.

The use of dual fuel especially for farmers and fishermen in Indonesia has not been widely used yet. Combination of diesel fuel with LPG (Liquefied Petroleum Gas) for diesel engine is technically practicable. However, the optimum composition of the mixture between LPG and air entering the combustion chamber is not clearly defined yet, especially for single cylinder diesel engine. So far, the comparison of such imprecise composition is carried out by opening the gas regulator valve by trial and error. So that affects the engine performance and efficiency of the engine that will ultimately affect the cost of fuel to be spent.

Based on these problems, the purpose of this research is to design a fuel mixture device for the application of dual fuel (Diesel fuel - LPG) for small diesel engine. The CFD software was used to analyze LPG-air mixing behavior in the mixing device. Cost analysis was also done to determine the ratio of costs incurred when using diesel fuel completely and if using a combination of dual fuel.

2. Material and method

2.1. Material

Research material used in this study were:
- 8 hp single cylinder water cooled diesel engine,
- AC electric generator 3 kW-220V and 2 kW halogen lamp
- LPG in 3 kg tank and regulator valve
- diesel fuel
- LPG-air mixture device,
- instrument for measuring LPG and diesel fuel consumption, and
- workshop tool and measurement equipment

2.2. Method

The method of this research follows typical machine design procedure including problem identification, formulation of design criteria, design analysis, design simulation, design engineering drawing, prototyping, and performance test of the prototype [4]. Design analysis and fabrication of prototype were done in workshop of the Department of Mechanical and Biosystem Engineering Bogor Agricultural University.

2.3. Construction of instrument for measurement of LPG consumption

In this research an instrument for measuring LPG consumption rate was constructed. The instrument was made using pressure loadcell to measure pressure drop in the venturi pipe passed by LPG. This instrument was equipped with microcontroller and LCD display to show real-time consumption rate of LPG as shown in figure 1.

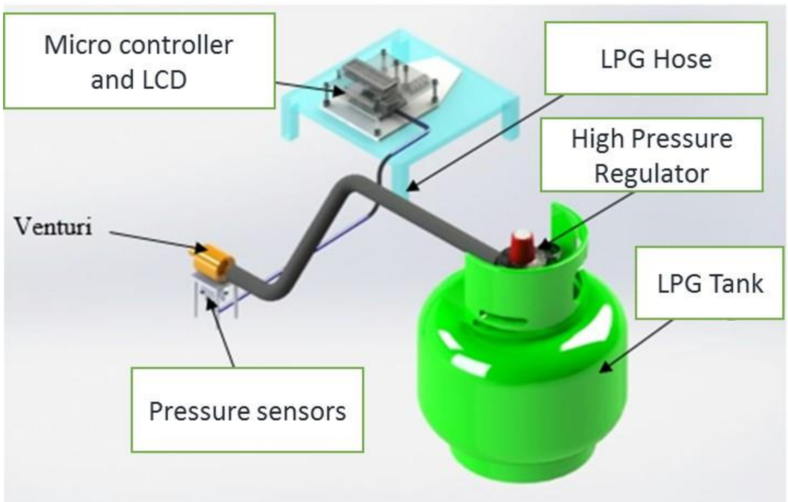
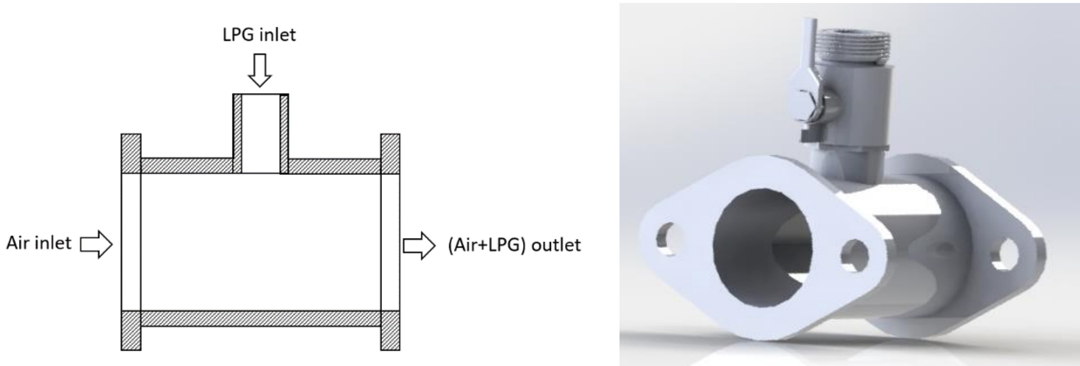


Figure. 1. Instrument for measurement LPG consumption

2.4. Design of LPG-air mixing device

In dual fuel system for diesel engine, LPG is premixed with intake air before entering the combustion chamber. Technical analysis was carried out to determine the speed of the airflow with the design made on the neck of the mixer at the maximum motor speed, so that mixing between air and LPG can take place well. Calculations used include volumetric intake rate, airflow velocity on the mixer's neck, cross-sectional area of the mixer's neck, and discharge to intake port. This LPG mixer has a total length of 50 mm, and its inlet diameter equal with the diameter of air filter outlet, which was 28 mm. The diameter of the outlet is the same as the diameter of the intake manifold was counted 28 mm. The diameter of the input port for LPG was 14 mm which was equal with the diameter of the fuel butterfly cock as an on-off valve of LPG. The engineering drawing process was done by using by Solidworks 2016 software which is shown in figure 3.



(a) (b)

Figure. 2. Schematic design (a) and engineering drawing (b) of LPG-air mixing device

2.5. Mixing analysis by CFD

Computational Fluid Dynamics (CFD) simulation was performed to analyze the mixed contours of LPG and air from the theoretical result approach at several LPG regulator valve opening positions. This CFD simulation used Solidworks software with its flow simulation menu. In performing the CFD simulation, some input parameters were used as boundary conditions in this simulation. Type of analysis used was internal flow. The internal flow concept is the flow in a container or stream bounded by the surface. The type of flow used was turbulent flow which has Reynold number (Re)> 4000. In the CFD analysis, the target of engineering parameters were pressure, velocity, volume fraction (LPG-air), and density.

2.6. Engine Performance Test

In the engine performance test, fuel consumption was measured in two conditions: 1) test without using load and 2) test with load by using halogen lamp with 2000 watt. The rotational speed of motor was set at 2000 rpm, and LPG regulator valve opening position was varied by 5% step from 5% to 100%. At each step, diesel fuel and LPG consumption were measured and engine rotational speed was noted. Measurement of diesel fuel consumption was done by calculating the time required each drop of 10 ml of diesel fuel using a stopwatch. Measurements of LPG gas consumption were carried out using gas flow rate device with varying range of LPG regulator valve opening. Setup of the performance test is shown in figure 3.

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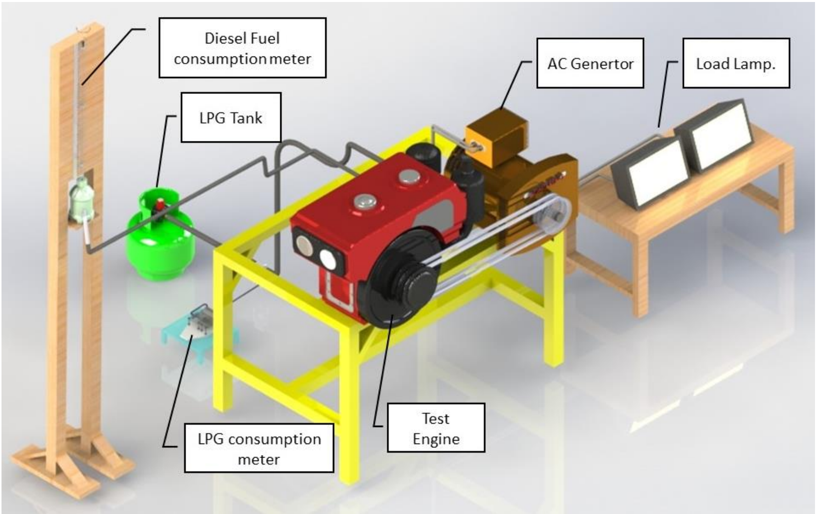


Figure. 3. Setup for performance test

3. Results and discussion

3.1. Computational Fluid Dynamic Simulation Analysis (CFD)

The CFD simulation [3] was use to analyze characteristics of LPG-air mixing which was necessary in design process of mixer device as shown in figure 5. The optimum inlet and outlet diameters of the mixing device was determine through this CFD analysis. In determining the consideration of the boundary conditions, several parameter such as atmospheric pressure, LPG pressure, and the discharge of LPG gas in each variation of valve opening were input to the program. The simulation approach was carried out by inputting the atmospheric pressure of 101325 Pa at the air inlet port and the LPG pressure at the LPG inlet port by 201260 Pa (20%), 218080 Pa (25%), 237239 Pa (30%), 260534 Pa (35%), and 332549 Pa (40%). Further data of LPG discharge inputs were 0.000167 m^3/s (20%), 0.0004 m^3/s (25%), 0.00045 m^3/s (30%), 0.000608 m^3/s (35%), and 0.000872 m^3/s (40%). The CFD simulation approach produces a mixing volume contour of LPG-air as shown in figure 4.

The results of the CFD simulation volume contour show the best mixing of LPG and evenly occur at 30% openings with mixed average yield of 0.064. The CFD simulation approach yields the same mixing result with the theoretical result of 0.064. Meanwhile, the average mixing results at valve openings were 20%, 25%, 35%, and 40% by 0.023, 0.056, 0.081, and 0.108. The mixing of LPG was strongly influenced by the speed and pressure of the LPG and air flow. The CFD simulation produced a pressure contour in the mixer as shown in figure 5.

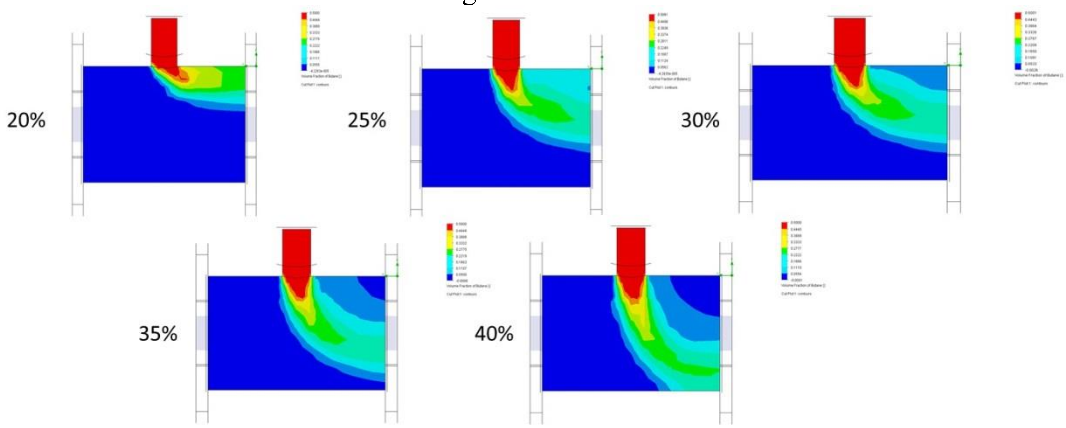
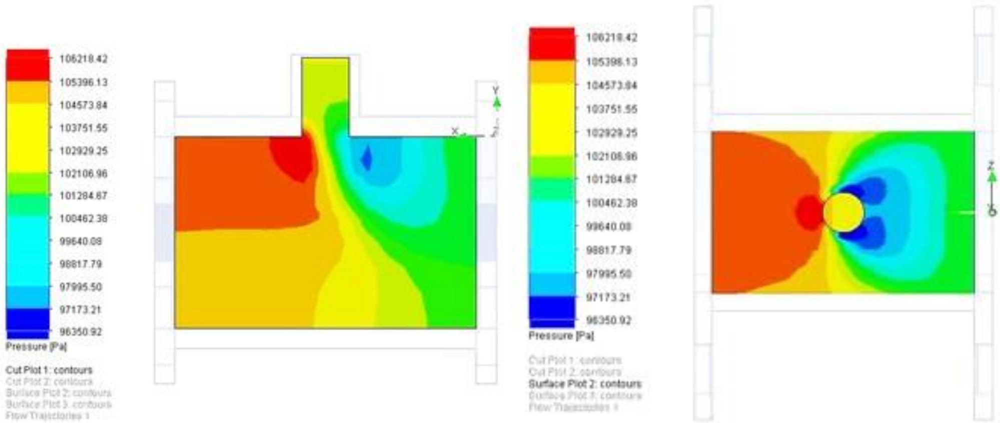


Figure 4. CFD simulation of volume fraction for LPG-air mixture at several opening position of LPG regulator valve



a. Side view b. Top view

Figure. 5. CFD simulation of pressure contour in mixer at 30% valve opening

3.2. Regulator Valve Setting

The regulator valve setting was conducted to determine the amount LPG gas inlet can be used. The test was done with engine speed of 2000 rpm. At the opening of the LPG regulator valve 5%-15%, the gas flow meter could not detect the rate of LPG discharge. Furthermore, at valve opening 20% the LPG flow rate was found to be 10 l/min, at 25% opening was 24 l/min, at 30% was 27 l/min, at 35% opening was 36.57 l/min and at 40% valve opening, the gas flow rate was 52.43 l/min. When the opening of the valve reached 45% there was an explosion in muffler, and this occurs due to the excess of LPG gas composition into the combustion chamber, resulting in the incomplete combustion and then was burned in the muffler. Thus, in this research the regulator valve can be set at the range of 20%-40% only.

3.3. Engine Performance Test

In this study, engine performance was evaluated in term of its dual fuel consumption (LPG and diesel fuel) with and without load applied to the engine. The result of fuel consumption test without using the load is shown in figure 6. It can be seen that the diesel fuel consumption rate decreased with the addition of the amount of LPG gas injected to the diesel engine. It can be explained that the flame speed of LPG in combustion chamber was much higher than the diesel itself, where the flame speed of LPG is 82 cm/s and for diesel only 30 cm/s [4]. With LPG flame speed capability is very fast this causes the combustion in the engine does not require diesel or fuel too much to make engine revolution speed remains stable. This can be shown with the stoichiometric ratio of air and diesel fuel 22: 1[5], in the presence of LPG can enlarge fuel-air ratio (F/A) is lower or in other words, it will reduce diesel fuel consumption. The highest combination of LPG and diesel fuel occurred at regulator valve opening at 40% where diesel fuel and LPG consumption were 0.054 l/h and 3.14 m^3/h, respectively.

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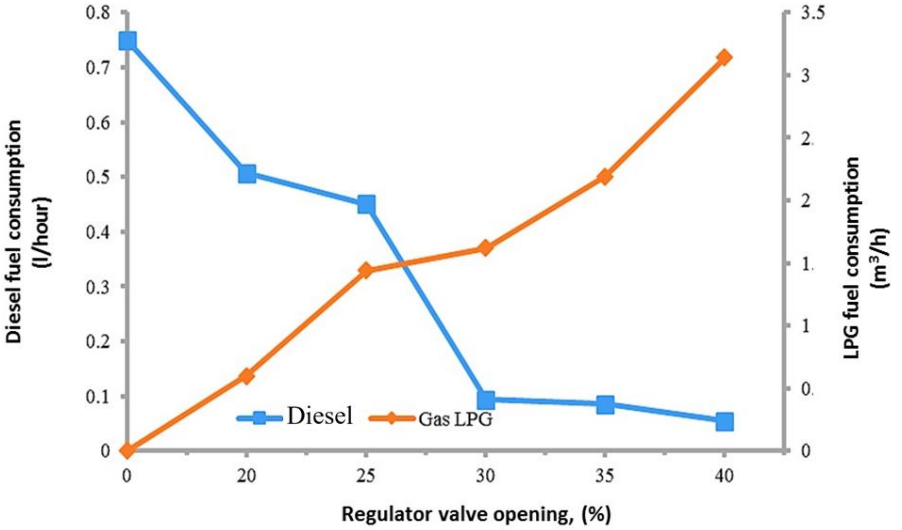

Figure. 6. Fuel consumption rate with no-load at engine speed 2000 rpm

In the engine performance test by applying load, an AC generator with 2000 watts halogen lamps were used. The dual fuel consumption rate results is shown in figure 7. This graph shows that it has similar trend as shown when the engine working without load but with higher amount of fuel consumption. The highest combination between LPG and diesel fuel occurred at regulator valve opening at 40% where diesel fuel and LPG consumption were 1.24 l/h and 3.14 m^3/ h, respectively.

Fuel consumption will increase with the level of engine rotation. In the combustion system of a gasoline engine, when the load is increased then the work of the piston that pushes and pulls will be faster or in other words need an explosion of combustion that can push the piston faster which means need more fuel [6]. This is what causes more savings when using a combination of LPG and diesel fuel at big loads.

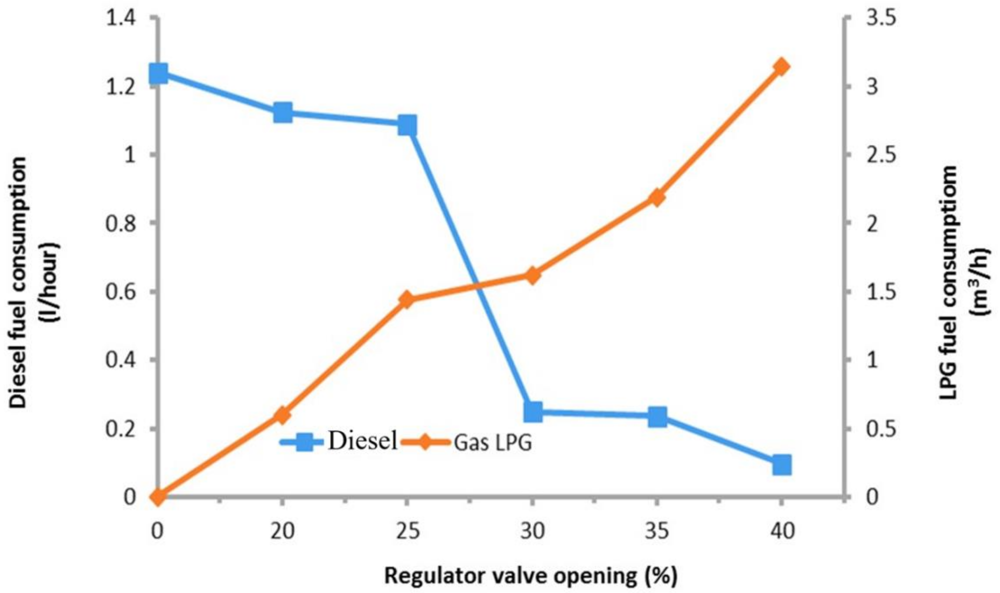

Figure. 7. Fuel consumption rate using load at engine speed 2000 rpm

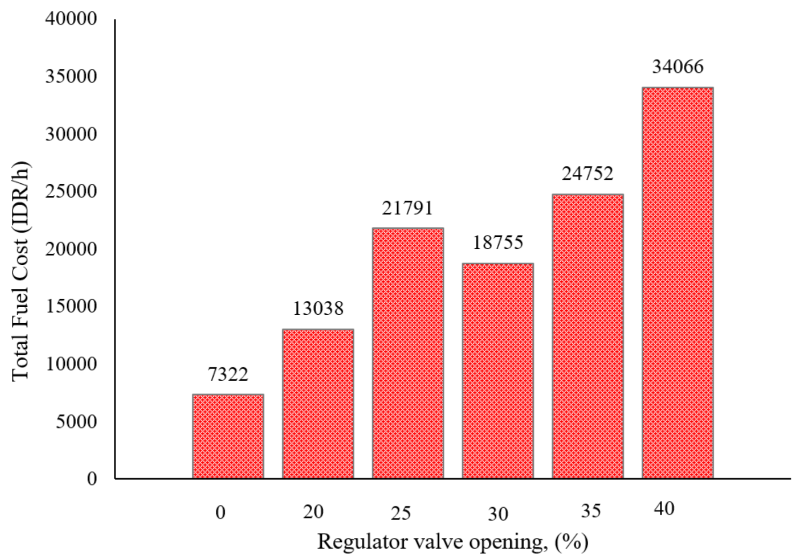

Figure. 8. Relation of total fuel cost with LPG valve opening at standard price of diesel fuel

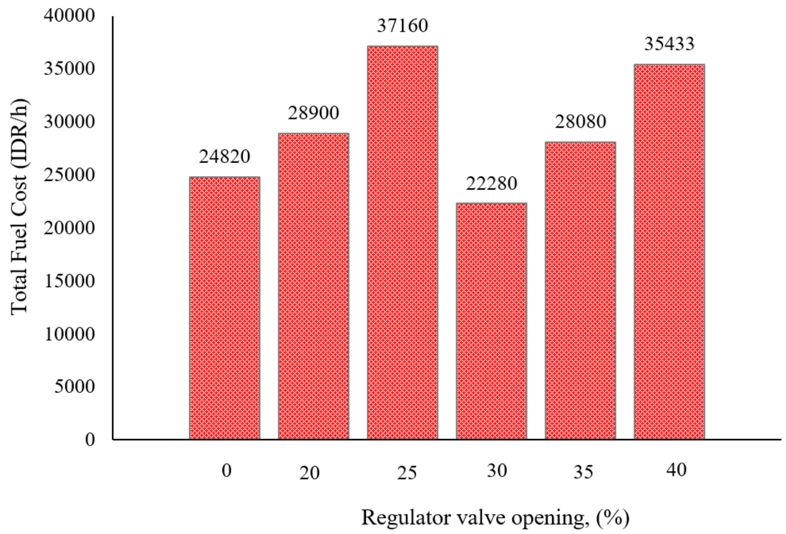

Figure. 9. Relation of total fuel cost with LPG valve opening at retail price of diesel fuel in remote area

3.4. Fuel Cost Analysis

The cost feasibility of the application of LPG in combination with diesel fuel for diesel engine was also considered. Cost analysis was divided into two, that was based on areas using standard government diesel fuel prices that are commonly sold in gas stations and based on retail price at remote areas. Pertamina standard diesel fuel price used in this analysis was Rp 5,900.-/l while diesel fuel price at remote area was Rp 20,000,-/l. This retail diesel price was the retail price used in the Sandaran village, East Kutai regency, East Kalimantan province. The price of LPG used in this analysis was the standard price of Pertamina for 3 kg LPG i.e. Rp 16,000,-/tank. The retail price of LPG is regulated by government, therefore its price is relatively constant everywhere in the country

The results of total fuel cost analysis of engine working with load on the standard price of diesel fuel can be seen in figure 9. The data showed that the lowest fuel cost was achieved when the engine operated by using diesel fuel only, i.e. Rp 7,322,-/h. The total fuel cost is increasing along with the increasing of LPG consumption and reached its maximum at 40% opening valve i.e. Rp 34,066,-/h. It means that in case of using standard price of diesel fuel, the addition of LPG or dual fuel system is not recommended due to its higher total fuel cost.

In case of fuel cost analysis by using retail price of diesel fuel in the remote area, it was found that the combination of application LPG at 30% valve opening with diesel fuel gave minimum total fuel cost of Rp 22,280,-/h at as shown in figure 10. Meanwhile, the fuel cost when using only diesel fuel was found to be of Rp 24,820,-/h with, meaning that the use of a combination of diesel fuel - LPG is more efficient at Rp 2,540,-/h than using diesel fuel only. Therefore the addition of LPG or dual fuel system in remote area is recommended due to its lower total fuel cost.

4. Conclusions

The application of LPG as dual fuel for diesel engine was technically proven. LPG was premixed with intake air in a mixing device that specially designed for this purpose. Based on fuel cost analysis, the application of LPG and diesel fuel only recommended when the price of retail diesel fuel more then three times expensive than its standard price which is commonly found in remote area. The highest fuels cost savings occur at 30% LPG valve opening which was Rp 2,540,-/h. This result also validated the CFD simulation analysis which showed that the best LPG-air mixture occurred at 30% valve openings.

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