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Green Energy from Palm Kernel Shell Gasification – Dual Fuel Engine Performance Analysis

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ABSTRACT. Electricity generation in Indonesia is mainly generated from non-renewable fuels. Based on these problems, this research utilizes palm kernel shells to be converted into producer gas as secondary fuel for a 5 kW diesel engine. The effect of using producer gas on fuel consumption and engine vibration is investigated in this study. Through a gasification process equipped with a cooling and gas cleaning system, low tar gas is fed to the diesel engine with variations of gas flow rate ratio to combustion air. A dummy load is installed to investigate the effect of load on diesel consumption. The diesel engine vibration increases due to using two fuel types, which were measured by installing a vibration meter. The research results show that the higher the load and the greater the ratio of producer gas injected, the less diesel consumption. At a gas ratio of 4:1 and an increase of load from 1 to 5 kW, the average diesel fuel flow rate reduces by 25 - 31%. The most significant reduction in diesel consumption occurred at a load of 5 kW at 38.49%, valued from 0.653 litres/kWh to 0.212 litres/kWh. On the other hand, increasing the gas ratio causes an increase in diesel engine vibration. The research results showed an increase in engine vibration of 5.84% - 10.25%. The largest vibration was recorded at a load of 5 kW with a value of 92.4 m/s^2

1. INTRODUCTION

Energy needs in Indonesia are still primarily supplied by fossil fuels. In 2022, the power generation capacity reached 70.96 Giga Watt (GW), coal accounted for approximately 35.36% of the energy produced, petroleum contributed 34.38%, and natural gas accounted for 19.36% of the total energy generation. The environmental and societal implications of climate change resulting from releasing greenhouse gases from fossil fuel combustion have emerged as a significant concern. These implications include the escalation of global temperatures, as well as the occurrence of phenomena such as floods, droughts, and storms. Moreover, there is a growing depletion of fossil resources such as oil, gas, and coal, accompanied by the challenge of locating these resources. The Indonesian Government aims to decrease the reliance on fossil energy and promote the adoption of new and renewable energy sources, as outlined in Government Regulation No. 79 on the National Energy Policy. The target is to achieve a minimum energy mix of 31% from new and renewable energy by the year 2050.

Indonesia has significant potential for developing renewable energy power plants due to its abundant natural resources. Palm kernel shell (PKS) is recognized as one of the viable energy sources. The by-product of the palm oil mill exhibits a high caloric content within the range of 17 to 19 MJ/kg [1-4]. In 2021, crude palm oil (CPO) production was recorded at 40.57 million tonnes, followed by 12 million tonnes of palm kernel shell (PKS) [5-7]. As reported by [8], 30 – 35 kg of palm kernel shell may replace 13 – 15 litres of diesel fuel to heat 1-ton aggregate in an asphalt mixing plant. In addition, using palm kernel shells (PKS) as an energy source also plays a significant role in mitigating carbon emissions. Using PKS as a feedstock can significantly reduce emissions by up to 90% compared to conventional fossil fuel power plants [9]. As an island country, using PKS as an energy source is attractive and promising. It is available in several dispersed regions that exhibit economic viability for operating a small-scale power plant with a capacity of up to 200 kW.

Gasification is a technological approach that can be employed to convert PKS into a clean fuel. It is a dependable and resilient process that converts solid fuel into a producer gas comprising key constituents such as H_2, CO, and CH_4. This producer gas can be employed as a substitute for fossil fuel in internal combustion diesel engines [10, 11]. Furthermore, the producer gas comprises standard combustion by-products, including CO_2, N_2, O_2, H_2O, and tar. Tar is a hydrocarbon-based liquid characterized by its dark colouration, sticky properties, and high viscosity when subjected to low temperatures. Introducing tar into an internal combustion engine can give rise to a range of complications. The presence of tar particles has the potential to impede the proper functioning of fuel filters and injectors, causing a hindrance to the flow of fuel to the engine cylinders. These conditions may result in fuel deprivation, ignition failure, and suboptimal combustion. The obstruction of injectors can also lead to an unequal dispersion of diesel fuel over the cylinders, leading to engine imbalance and decreased performance [12]. Previous studies by [13, 14] reported that the maximum limit of tar content to be fed into the internal combustion engine is 100 mg/Nm^3.

According to [15], the substitution ratio of diesel and producer gas can reach up to 60%. However, measuring the threshold distance used as an acceptable tolerance for producer gas consumption is necessary to ensure the diesel engine's safe and sustained operation over a specific duration. This study aims to investigate the impact of using PKS-based producer gas as a substitute for diesel fuel on the performance of a 5 kW diesel engine. These included the specific fuel consumption and the vibration of diesel engine.

2. MATERIALS AND METHODS

2.1 Materials

PKS in Indonesia is often found on the islands of Sumatra and Kalimantan, with many palm oil-producing factories. Previous research shows that PKS spread across Indonesia has similar characteristics with volatile matter content in the range of 65% - 70% and carbon content of 45% - 48% [16]. PKS in this study was obtained from West Kalimantan with characteristics as presented in Table 1 [16].

Table 1. Palm Kernel Shell (PKS) Characterization.

Description	Content
Proximate Analysis (dry basis)	
Moisture content	9.50%
Volatile matter	70.50%
Fixed carbon	18.30%
Ash content	1.70%
Ultimate Analysis (dry basis)	
Carbon	47.60%
Hydrogen	6.37%
Oxygen	43.93%
Nitrogen	0.31%
Sulfur	0.09%
High Heating Value (dry basis)	18.67 MJ/kg

2.2 Experimental setup

The gasification process is conducted in a fixed-bed updraft gasifier with a diameter of 0.50 m and a height of 1.10 m. As seen in Figure 1, the gasifier is equipped with a hopper and screw conveyor located at its upper section, facilitating the introduction of PKS into the reactor. The outlet route of producer gas is situated within the same area but on a distinct side. The air inlet flowed from the bottom of the reactor using an air blower. A flowmeter and valve are installed within this channel to monitor and adjust the airflow rate entering the reactor. A rotating disk accomplishes the residual PKS (solid residue) extraction from the bottom of the gasifier. This tool is linked to a gearbox mechanism to control the rotational velocity, enabling the adjustment of solid residue flow rate.

The producer gas leaves the gasifier and passes through gas cleaning equipment to reduce the tar content. The equipment is organized sequentially, comprising a dry scrubber, elutriator, heat exchanger, and wet scrubber. The dry scrubber, with a diameter of 0.5 m and a height of 0.95 m, is designed to eliminate primary tar. Within this equipment, the temperature of the producer gas is reduced to a level below 200^{o}C. Hence, the primary tar can be condensed [17] and deposited in the water trap. Next, the gas is passed through an elutriator and heat exchanger to remove secondary tar, most of which are phenol, benzene, and toluene compounds [18]. Shell and tube heat exchangers with a heat transfer area of 1.95 m2 and water as cooling media function to reduce the temperature of the producer gas to around 40ºC. In addition to reducing secondary tar content, the condensation of water vapour in the gas is employed to enhance the heating value of the producer gas. Lastly, the gas is introduced into a wet scrubber that comprises isopropyl alcohol to capture any residual tar. Isopropyl alcohol is an absorbent because tar is a complex compound exhibiting polar and non-polar characteristics [19]. Before introducing the diesel engine, a gas sample is taken to determine the residual tar content present in the gas. The gas was sucked using a vacuum pump with a constant flow rate of 15 L/minute for 10 minutes and passed through an impinger tube containing isopropyl alcohol [20].

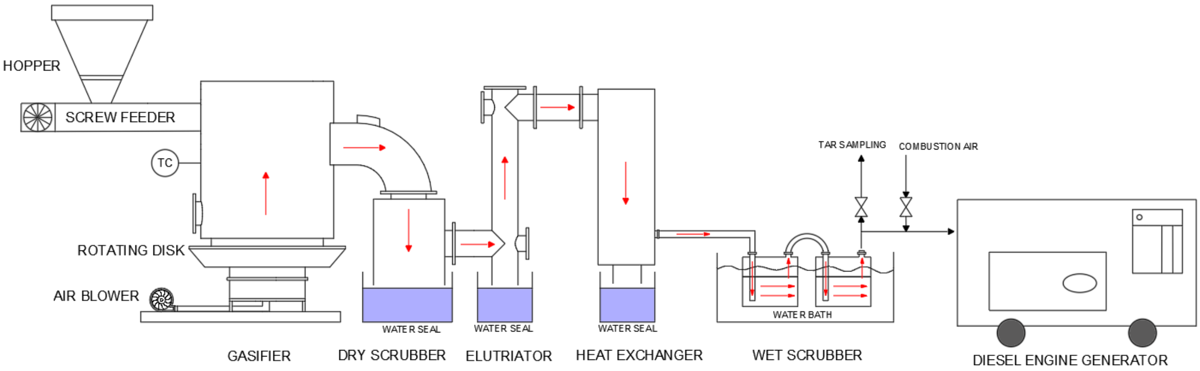

Figure 1. Palm Kernel Shell (PKS) gasification system for power production

Three type K thermocouples (TC) were installed in the reactor at a distance of 120º each to monitor the gasification operating temperature. Several bimetallic thermometers are also installed on the gas outlet, dry scrubber, and heat exchanger to monitor the operating conditions of the gas cleaning process. The low-tar content gas obtained is fed into the diesel engine as secondary fuel. In a single-fuel system, the diesel engine works by sucking in air only from outside. However, air enters with a certain amount of producer gas for a dual-fuel system. Therefore, the modifications were made to the Matrix MT 6800 S brand diesel engine with a capacity of 5 kW, as shown in Figure 2. The modification included the installation of a gas flowmeter and several valves (V1, V2, V3, V4, and V5). Variations of producer gas injection ratio volume flow rate of 1:4, 2:3, 3:2, and 4:1 were done by adjusting the air duct valve openings (V5). A 6 kW dummy load is linked to a diesel engine generator to accommodate variations in electrical load. The experiment was carried out with electrical load variations of 0, 3 kW, 4 kW, and 5 kW. The diesel engine's vibration was measured using a vibration meter.

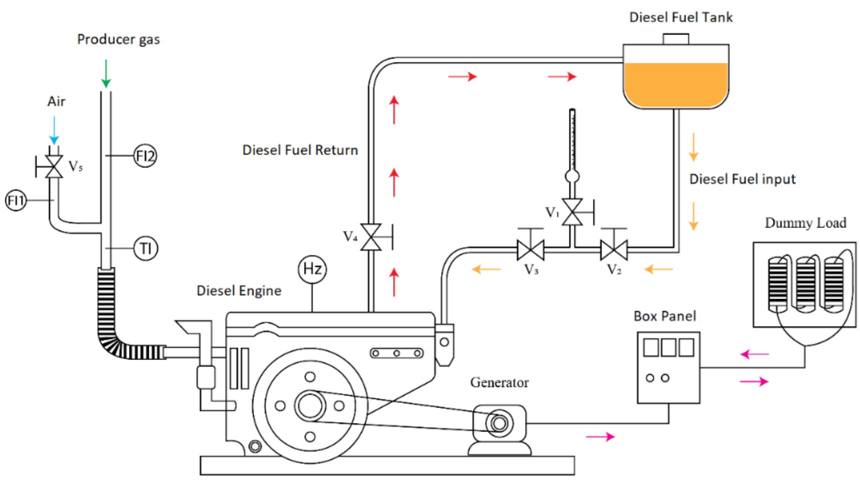

Figure 2. Dual-fuel diesel engine generator set

3. RESULTS AND DISCUSSION

Diesel is the primary fuel that generally initiates a diesel engine's combustion. Adding producer gas as secondary fuel reduces diesel fuel consumption because the producer gas aids in creating the spark within the combustion chamber. As seen in Figure 3, diesel consumption tends to decrease as the producer gas to combustion air ratio increases. Producer gas accelerates the increase in combustion chamber temperature. High combustion chamber temperatures raise atomization, resulting in better mixing of fuel and air. An increase in electricity load will also reduce diesel fuel consumption. This phenomenon occurs due to the engine operating at high diesel loads, hence achieving its maximum performance. An elevation in electrical load will also increase fuel temperature, enhancing the combustion process's efficiency [21]. The diesel fuel flow rate exhibited a drop ranging from 25.01% to 30.54% under electrical loads of 0, 3, and 4 kW, accompanied by a producer gas-to-air ratio of 4:1. The load of 5 kW resulted in the most significant decrease in diesel consumption flow rate, with a reduction of 38.49% from 0.64 liters/kWh to 0.205 liters/kWh.

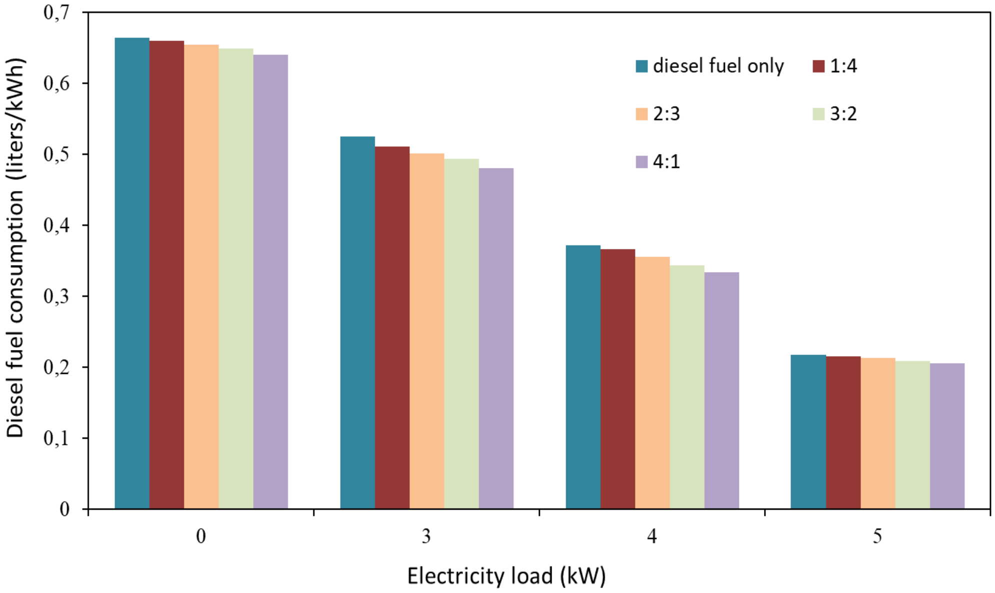

Figure 3. Diesel fuel consumption in several electricity loads and gas-to-air ratio

Typically, diesel generators only use diesel fuel as the primary fuel. Introducing gas into the diesel engine will prompt the machine to make necessary adaptations in response to the ensuing effects. The diesel engine will adjust the resulting impacts with the addition of gas. One impact variable that can be measured is engine vibration. As seen in Figure 4, an increase in the gas ratio causes an increase in diesel engine vibration. Adding producer gas increases engine vibration, ranging from 5.84% to 10.25% higher than the absence of producer gas. The most significant increase in vibration is shown in the electrical load range of 3 kW to a maximum of 5 kW. At an electrical load of 3 kW, there was an increase in engine vibration by 3.95% from 83.65 m/s^2 to 86.95 m/s^2, and at a load of 5 kW, there was an increase in engine vibration by 3.76% from 89.05 m/s^2 to 92.4 m/s^2. A similar pattern was observed in the study conducted by [22], wherein a 6.53% rise in vibration when the electrical load escalated from 1 kW to 3 kW. Applying a substantial load to the engine will result in an accelerated piston rotation, leading to an amplified level of engine vibration.

The tar concentration in producer gas also affects the diesel engine performance. The deposition of tar within the combustion chamber has the potential to diminish the overall efficiency and effectiveness of the engine. The present study measures that the tar concentration is 0.31 g/Nm^3, insufficient to satisfy the prescribed minimal criteria for producer gas utilization in a diesel engine at 0.1 g/Nm^3. One element contributing to the issue is suboptimal gasification operation temperature. A higher operating temperature leads to a lower tar content; conversely, a lower operating temperature results in higher tar content. [23, 24]. It was recorded in the present study that the gasification took place at a temperature around 600ºC. In this condition, the heating value of the producer gas is still quite low at 4.5 – 4.7 MJ/Nm^3 [25]. Previous research reported that the optimal gasification temperature was 800 – 1000^{o}C, producing gas with higher heating values at 5.3 – 6 MJ/Nm^3 [26-28]. Tar is produced especially during the pyrolysis stage of biomass gasification. When the cellulose content in biomass is not completely converted, tar production will increase significantly, especially at low temperatures. Therefore, tar content can be reduced by optimizing the gasification operating temperature. Furthermore, catalytic tar conversion and modification of gasifier configuration may reduce tar content in producer gas [29].

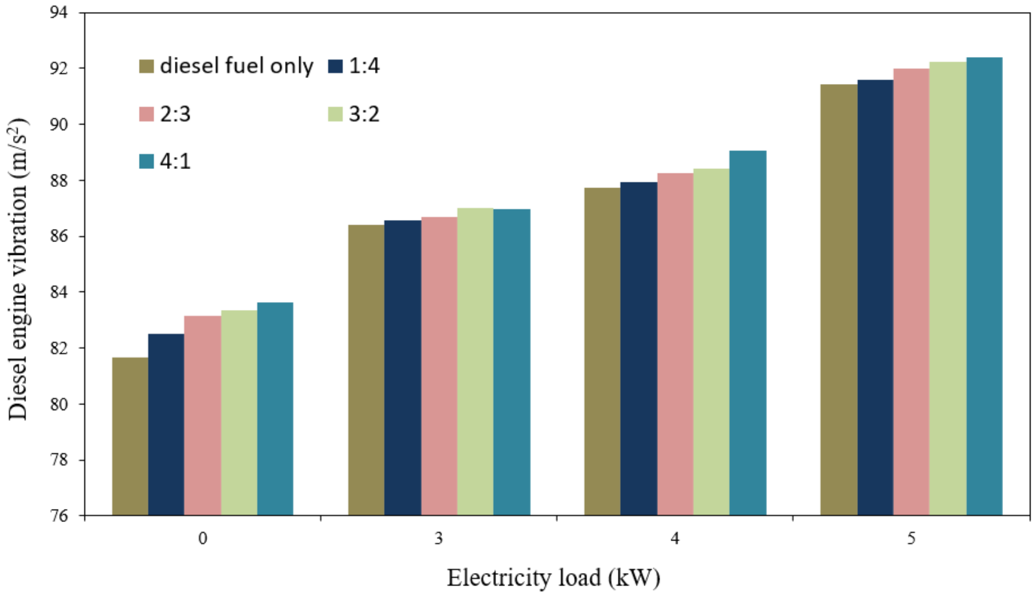

Figure 4. Diesel engine vibration in several electricity loads and gas-to-air ratio

4. CONCLUSION

The producer gas derived from the PKS gasification can be used as a supplementary fuel for diesel engines. Introducing producer gas into a 5 kW of diesel engine decreases fuel consumption by around 25% to 30% or 0.163 litres/kWh to 0.196 litres/kWh. However, the utilization of producer gas has a discernible effect on elevating the vibration levels of diesel engines, resulting in an augmentation ranging from 5.84% to 10.25%.

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