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The Effect of Dual Fuel Producer Gases with Y-Shaped Mixing Chamber on Single Cylinder Spark Ignition Engine Operation

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ABSTRACT

In the operation of SI engines, alternative biomass fuels such as rice husk can be utilized. This will contribute limit the consumption of fossil fuels. The dual-fuel approach can also be employed on SI engines. One of the solutions that can be employed in dual-fuel SI engines with gasoline is producer gas, a flammable gas created by biomass gasification. However, the numerous methods of incorporating gases into SI engines necessitate substantial investigation. In this study, producer gas and gasoline are combined and fed into an SI engine. The dual fuel is used to power the single-cylinder SI engine. The most optimal operation of the Y-shaped mixing chamber is investigated. Experiments were conducted to determine the optimal air-producer gas ratio values based on the SI engine's ability to operate in time at idle. Two variables were chosen as inputs: air producer gas ratio and fuel mixture percentage. According to the study's findings, an air-producer-gas ratio of 1.5:1 with 50% gasoline results in better mixing. The single-cylinder SI engine has been running smoothly and longer than other parameters without knocking.

Keywords: *rice husk; producer gas carburettor; dual fuel; mixing chamber; biomass.*

1. INTRODUCTION

Producer gas is a renewable energy source that is easier to obtain than fossil fuels. It is typically composed of combustible gases such as Hydrogen (H_2), Carbon Monoxide (CO), traces of Methane (CH_4) and non-combustible gases such as Nitrogen (N_2), Carbon Dioxide (CO_2), tar, oil and ash. Non-combustible gases reduce the efficiency of combustible gases. [1]. Regarding climate and geographical conditions, biomass is regarded as the most important type of renewable fuel. [2-4].

A dual-fuel reciprocating engine is not an entirely new concept. The fundamental concept can be traced back to 1939 when the National Gas and Oil Engine Co. in Great Britain produced the first commercial dual-fuel engine. The engine, powered by town gas or other types of gaseous fuels, was relatively simple to operate and was primarily used in areas where low-cost

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stationary power generation was required [5]. Dual-fuel engines have since become available in various markets, including mobile and stationary applications. Locomotives, automobiles, and the electric power generation industry all use these engines.

Dual-fuel engines can also be operated on the spark ignition (SI) engine [6–8]. Under lean-state conditions, the engine can run steadily. With this in mind, as fuel prices rise, many owners and operators are now looking for alternatives to conventional fuel. One solution is to use producer gas in a dual-fuel SI engine. Ando et al. [7] investigated the emissions and performance of a heavy-duty, gas-powered SI engine. They examined and compared the SI engine powered by natural gas. According to the observations, power de-rating throughout the producer gas operation exceeded 50% due to reduced volumetric efficiency and NOx and CO emissions.

Furthermore, according to the authors' research and analysis [8], they have also succeeded in using producer gas as a second fuel in a SI engine. They concluded that producer gas has lower cylinder pressures and heat release rates than propane. For the studied mixtures, the power loss due to the lower calorific value of the producer gas did not exceed 10%. For the producer gas, flame propagation in the combustion chamber is slower than for propane. The effect of producer gas on combustion stability is moderate. All of these phenomena were heightened in the case of the producer gas by grape kernels.

Rice husk has been selected as a biomass feedstock. It is one of Malaysia's biomass sources because the components are readily available and easy to harvest. Rice husks are well-known as a fuel source for power generation via gasification technology. The decision was made due to the unusually high demand for energy in households and industry. Although useful, rice husks can degrade into hazardous waste if not properly managed. To address future challenges, gasification is a thermo-chemical process that converts carbonaceous materials such as rice husks into gaseous products using a gasifier with a gasifying medium such as air, oxygen, or steam, alone or in combination [9]. Several researchers [10–12] have studied and worked on converting rice husk to producer gas. One type of gasifier system is a downdraft gasifier, which is the most effective gasifier system. Downdraft gasifiers are easy to build and operate, and their low tar percentage makes them appealing. In the reactor, the gasifier has its sequence. It is impractical to divide the gasifier into many zones; however, process separation is required to understand and differentiate the zones. Among them are drying, pyrolysis, partial oxidation, and reduction zones. The drying zone is the top zone (or bunker portion), where moisture is converted to water vapour during drying. Conversion occurs due to heat transfer between hot gases from the oxidation zone and biomass in the drying zone. The pyrolysis zone (heat decomposition zone) follows, where biomass molecules decompose into condensable gases, tar, and char. Following that, partial oxidation (or combustion zone) is used, in which volatile components from biomass are oxidized via exothermic chemical processes, generating heat at peak temperature with gaseous fuels such as CO, H_2, CO_2, and H_2O. The final zone's reduction zone produces the producer's gas and undesirable byproducts such as tar [13-14].

In summary, the literature on single-cylinder SI engine operation with producer gas in dual fuel mode suggests that Biomass energy systems rely heavily on producer gas engines. With significant gasoline fuel substitution, converting SI engines to dual fuel mode with producer gas as induction fuel and gasoline as pilot fuel can significantly reduce smoke emissions. . In contrast, Y-shaped mixing device (carburetor) can be proposed for dual fuel mode operation, which can significantly improve mixing performance while lowering engine emissions. The

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effect of a Y-shaped mixing chamber carburetor is studied in this paper to use a single-cylinder SI engine operated with dual fuels such as producer gas and gasoline. An experiment was carried out to determine their potential and suitability based on the ability of the single-cylinder SI engine to operate at idle.

2. METHODS

2.1 Producer Gas

Rice husk has been selected as a biomass feedstock. This is because according to statistics [15], Malaysia produces approximately 1.7 million metric tons of rice annually. This demonstrates that we have the potential to be a new source of bio-energy production in Malaysia.

One type of gasifier system used to produce producer gas from biomass-based materials such as rice husk is the downdraft gasifier. A downdraft gasifier was designed and built on a lab scale using mild steel and a 1-kilogram capacity of rice husk. It is simple to manufacture and operate, and it is appealing due to the low tar content of producer gas. The gasifier has its sequence in the reactor. It is unrealistic to divide a gasifier into multiple zones, but separation of the process is required to understand and differentiate the zones. Drying, pyrolysis, partial oxidation, and reduction zones are among them. Figure 1 and Figure 2 depict images of the downdraft gasifier and rice husk feedstock, respectively. Table 1 shows the analysis of the feedstocks' proximate (used furnace), ultimate (used elemental analyzer), and gross heating value (used Bomb Calorimeter).

Figure 1: Lab Scale Downdraft Gasier

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Figure 2: Rice Husk Feedstock

Table 1: Ultimate, Proximate and Gross Heating Value of Feedstock

Ultimate Analysis (mass % dry basis)		Proximate Analysis (mass % dry basis)		Gross heating value HHV (MJ/kg)
Carbon	38.5	Volatile	56.2	14.50
Hydrogen	5.35	Fix Carbon	20.1	
Oxygen	39.6	Ash	16.3	
Nitrogen	0.4			
Sulfur	0.2			

2.2 Spark Ignition Engine (SI engine)

A single-cylinder spark-ignition engine running on producer gas was used for the experiments. Table 2 contains engine specifications. 500 ml of gasoline is poured into the single-cylinder SI engine. It is carried out in three conditions, with throttle openings of 0, 25, and 50%.

Table 2: Technical Specification

Modenas Engine	
Type	4 stroke, SOHC, 1 cylinder
Bore & Stroke	55.0 x 49.5 mm
Displacement	97.2 cubic cm
Compression Ratio	9
Carburetor	SPACO AV18P-9006

2.3 Y-Shaped Mixing Chamber

The development of a Y-shaped mixing chamber using a 3D printer. The material used is polylactic acid (PLA). This component is printed at the Industry Laboratory 1, Central for Mechanical Engineering, UiTM Cawangan Pulau Pinang. It is strong, flexible with good machinability and has higher temperature resistance. Table 3 shows the material properties of Polylactic Acid.

Table 3: Material Properties Polylactic Acid

Material Property	Polylactic Acid (PLA)
Density (Mg/m3)	1.25
Young's Modulus E (GPa)	3.5
Elongation at break (%)	6
Melting (softening) temperature T_m(ºC)	160
Glass Transition Temperature (ºC)	60
Tensile Strength (MPa)	36-55
Ultimate Tensile Strength UTS (MPa)	35
Strength to weight ratio (kN-m/kg)	40
Shear Modulus G (GPa)	2.4

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Solidworks 2017 was used to develop the Y-shaped mixing chamber development design. The design data is transferred to the 3D printer to print the design. The internal diameter is 70 mm, and the outer diameter is 80 mm. The air channel is 80 mm long, and the producer gas channel is 49.74 mm long. The width of the Y-shaped mixing chamber was 54 mm. The assembly area between the Y mixing chamber and the carburettor has a diameter of 60 mm. Ball valves regulate the flow rate of the air and producer gas channels. The function controls the air/fuel ratio by adjusting the perception volume. Figure 3 depicts a 3D printer and a 3D design of a Y-shaped mixture chamber.

(a) (b)

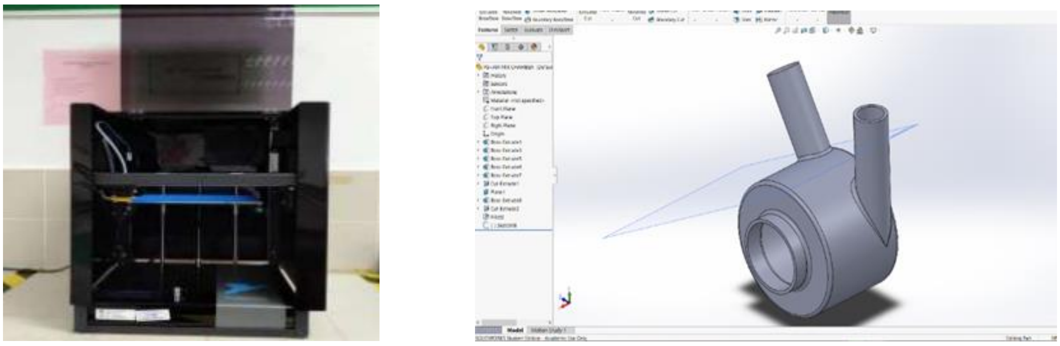

Figure 3: (a) 3D Printer Machine [21] (b) Design of Y-Shaped Mixing Chamber

2.4 Experiment setup

Rice husk is being used to fill the entire downdraft gasifier. It is weighed with a weighing scale before being loaded into the reactor and allowed to burn at full capacity. The downdraft gasifier produces low-tar producer gas at temperatures ranging from 200 to 250 ^{o}C. The producer gas temperature was reduced to 40 ^{o}C by channelling it through the heat exchanger. The producer's low tar content was then reduced by a clean cum cooling system. Finally, the producer gas is routed to the Modenas SI engine via a carburettor with a Y-shaped mixing chamber. The experiential setup is depicted in Figure 4.

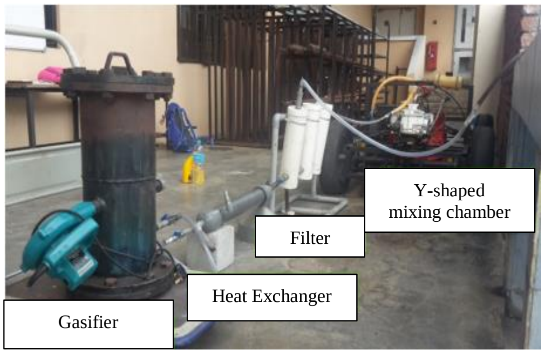

Figure 4: Experiment Setup

The carburettor has a Y-shaped mixing chamber installed. Two pipes with ball valves have been connected to the Y-shaped mixing chamber's air intake and producer gas supply. One of the producer gas pipe channels is linked to the cleaning cum cooling system output. The Modenas SI engine was initially started with fully throttled 100% gasoline. After the SI engine had stabilized, the producer gas ball valve was opened to angles of 39, 37, and 36 degrees.

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Simultaneously, the ball valve for the air channel opened to 51 degrees, then to 53 and 54 degrees. As determined by Equation 1, these opening conditions resulted in air-producer gas ratios of 1.3:1, 1.4:1, and 1.5:1. According to the authors [16, 17], the carburettor designed for producing gas must be capable of maintaining the required air-producer gas ratio in the range of 1.2 to 1.5. The fuel was then reduced to 50%, with throttle openings of 50%. The engine's time to combustion can be measured. The procedure is then repeated with 25%, and 0% throttle openings. Figure 5 depicts the Y-shaped mixture chamber experiment setup.

$$APG\ Ratio = \frac{Angle\ Air\ ball\ valve}{Angle\ PG\ ball\ valve} \quad (1)$$

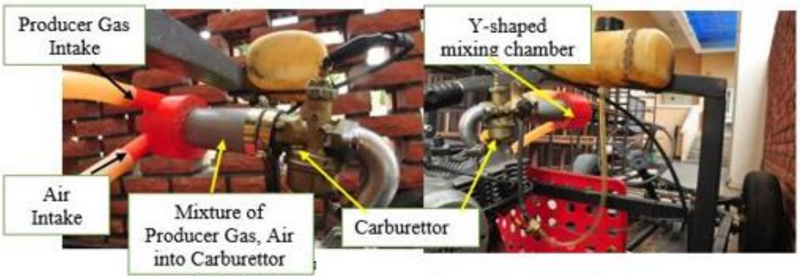

Figure 5: Experiment Setup of The Y Shaped Mixing Chamber

A knock sensor is used to measure the knock signal. The knock sensor is mounted on the cylinder block, and the signals received are saved on the computer for later examination. The engine's working condition was maintained between 1800 and 9000 rpm.

3. RESULTS AND DISCUSSION

Table 4 and Figure 6 show the average engine operating time concerning the air-producer gas ratio and gasoline percentage. The graph shows that increasing the air-producer-gas ratio from 1.3:1 to 1.5:1 with three different types of gasoline increases engine run time. It was discovered that the best air-producer gas ratio for a single-cylinder SI Modenas engine is 1.5:1. It means that the air-producer gas ratio must be lean to operate for a longer time and consistently. More information will be provided below.

Table 4: Overall results

Air Producer Gas Ratio	0% Gasoline Engine Operating Time, min	25% Gasoline Engine Operating Time, min	50% Gasoline Engine Operating Time, min
1.3:1	1.4	5.4	13.4
1.4:1	6.3	8.4	15.4
1.5:1	6.7	11.5	16.7

3.1 100% Producer Gas and 0% gasoline

Three air-producer gas ratios have been performed in this condition. The engine's operating time is short for the 1.3:1 air-producer-gas ratio. The engine runs for 1.8 minutes in the first trial, 1.5 minutes in the second, and 1.1 minutes in the third. The average engine run time for this condition is 8.4 minutes (Table 4). The engine's running time is gradually reduced. One of the reasons is that the producer gas that was routed to the engine contained tar. The tar is

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deposited on the SI engine's spark plug. The effect is that the ignition spark becomes weaker as more tar is deposited on it. Aside from that, there is engine knocking while the engine is running. This is because the air/producer gas ratio mixture inside a cylinder is lean, with insufficient fuel and too much air, causing the mixture to burn unevenly and causing the engine to stop.

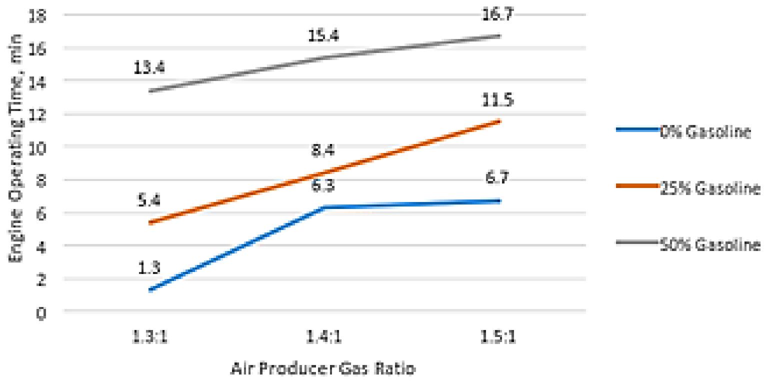

Figure 6: Average time engine operating vs. air producer gas ratio at various gasoline percentages.

For the air producer gas ratio of 1.4:1, the time of the SI engine running for the first trial is 7.0 minutes, the second trial is 6.2 minutes, and the third trial is 5.8 minutes. The SI engine running time gradually decreases as more trials are done. The reason is the tar content in the producer gas deposited to the engine's spark plug, which causes the spark to weaken as more tar is deposited to it. A weak spark will cause the mixture of air and producer did not burn completely in the cylinder, leading he engine to stop running. The more trial is done, the more tar is deposited to the spark plug since only one spark plug is used for one air/producer gas ratio condition. Next, there is a knocking engine that occurs during the engine running. However, the intensity of the engine knocking is lesser compared to the 1.3:1 ratio.

The engine operating time is longer than before when the -producer gas ratio is 1.5:1. The first trial lasts 7.4 minutes, the second 6.5 minutes, and the third 6.4 minutes. The trend on engine time running for this condition is similar to the previous condition in that the more trials performed, the less time the engine can run. The engine knocking is the least severe of the three conditions. The more air producer gas ratio supplied to the SI engine, the less the engine knocks. As a result, the engine runs longer. Researchers [18–20] also stated that increasing the syngas or producer gas supplementation ratio significantly reduces knocking.

3.2 75% Producer Gas and 25% gasoline

In this case, for the 1.3:1 air producer gas ratio, the SI engine runs for a short time, but it is better than the time for 0% gasoline. The first trial's engine time is 5.6 minutes, the second trial's time is 5.4 minutes, and the third is 5.1 minutes. The average engine run time for this condition is 5.4 minutes (Table 4). As more trials are completed, the time spent running the engine decreases gradually. The reason is that the tar content of the producer gas is still deposited, which makes the spark produced by the spark plug weaker as more trials are conducted. This condition has no engine knock. It is due to the presence of 25% gasoline.

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The SI engine runs the second longest for 25% gasoline when the air producer gas ratio is 1.4:1. The engine runs for 8.6 minutes in the first, 8.4 minutes in the second, and 8.2 minutes in the third. The average engine run time for this condition is 8.4 minutes (Table 4). As more trials are completed, the time spent running the engine decreases gradually. However, the engine can run longer. The engine knocking is also absent in this condition.

The engine runs the longest on 25% gasoline when the air producer gas ratio is 1.5:1. For the first trial, and the engine ran for 11.8 minutes. The second trial lasts 11.4 minutes, while the third lasts 11.2 minutes. As before, the engine runtime is gradually reduced. This is the result of tar deposition on the spark plug. If the tar content of the producer gas is reduced, the engine can run longer. The SI engine also runs without a knock.

3.3 50% Producer Gas and 50% gasoline

The engine runs quickly when the air producer gas ratio is 1.3:1 with 50% gasoline. However, it is better than the time spent running the engine at 0% and 25% gasoline. The first trial's engine run time is 13.8 minutes, the second trial's time is 13.3 minutes, and the third trial's time is 13.1 minutes. The average engine run time for this condition is 13.4 minutes (Table 4). The time it takes for the engine to run decreases gradually as more trials are completed. The engine's sound is smoother than in the previous condition. There is no engine knocking, either.

The engine runs for the second longest time at 50% gasoline when the air producer gas ratio is 1.4:1. The first trial's engine time is 15.7 minutes, the second trial's time is 15.3 minutes, and the third trial's time is 15.1 minutes. The average engine run time for this condition is 15.4 minutes (Table 4). The time it takes for the engine to run decreases as more trials are completed. However, compared to the air-producer-gas ratio of 1.3:1, the average engine running time is 2 minutes longer. Because the available producer gas is richer, the SI engine is better, so the engine can run longer.

The engine ran the longest for 50% gasoline when the air producer gas ratio was 1.5:1. For the first trial, the engine ran for 17.5 minutes. The engine time for the second trial is 16.8 minutes. The engine time for the third trial is 15.2 minutes. The average engine run time for this condition is 16.7 minutes (Table 4). As more trials are completed, the time spent running the engine decreases gradually. This condition requires the engine to run for a longer period. It can be stated that the air-producer gas ratio and gasoline were in proper proportions and produced the best chemical combustion. As a result, the engine can run more efficiently. The engine stops running due to tar buildup on the spark plug. If the producer gas produced had a lower tar content, the SI engine would run longer.

4. CONCLUSION

The study's objectives were met when the Modenas single-cylinder SI engine was successfully operated in dual fuel mode, namely producer gas and gasoline. The engine performs best when the air/producer gas ratio is 1.5:1, and the gasoline is 50%. Compared to other parameters, the SI engine has been running smoothly and longer without knocking. It means that the air-producer-gas ratio must be lean to operate for a longer period and consistently. However, because only one spark plug was used, the single-cylinder SI engine was shut down due to tar deposited on the spark plug. This situation can be avoided by modifying the gas producer's cleaning cum cooling system. This study also demonstrated that biomass materials, such as rice

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husk, can be used as fuel while reducing the use of fossil fuels in the operation of internal combustion engines. Renewable energy conversion is feasible and available for future use.

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CONFLICT OF INTEREST

The authors declare no conflict of interest regarding the publication of this paper.

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