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# The effect of the number of syn-gas purification nozzles of the water scrubber method on the characteristics of gasification combustion results

**Fisal Yuliansyah[1], Fuad Dwi Hanggara[2*], Dwi Irawan[1]**
[1]Mechanical Engineering Department, Universitas Muhammadiyah Metro Lampung, Metro, 34112, Indonesia
[2]Mechanical Engineering Department, Universitas Islam Negeri Maulana Malik Ibrahim Malang, Malang, 65144, Indonesia
*Corresponding author: fuaddh31@uin-malang.ac.id

## Abstract

The product of the gasification process contains several impurities, including tar, ash, CO2, and other contaminants. To achieve efficient syngas results, the syngas must undergo a filtration or purification process, which can increase its energy density. The purpose of this study was to determine the effect of the number of purification nozzles on the characteristics of the resulting flame, the duration of the flame produced during the gasification process, and the rate of heat absorption in the water generated from the syngas purification process. The water scrubber method employed in the syngas purification process utilized an updraft gasification reactor. The biomass used in this study was rubber wood, with a venturi nozzle size of 0.15 mm and a pressure of 0.12 Pa. The tests varied the number of purification nozzles to 2, 3, and 4. The use of 4 nozzles had a significant effect on the combustion characteristics, resulting in a blue flame with a duration of 33 minutes. The configuration with 3 nozzles produced a flame that exhibited a mixture of blue and orange colors, with the blue flame being more dominant, lasting 38.2 minutes. In contrast, the configuration with 2 nozzles resulted in a bluish-red flame, predominantly red in color, with a duration of 45 minutes. The heat absorption rates in the water produced for the configurations with 2, 3, and 4 nozzles were measured at 539 J/s, 449.1 J/s, and 414.62 J/s, respectively.

**Keywords:**
Biomass, gasification, purification, nozzle, syn gas, updraft.

## 1 Introduction

Indonesia is one of the countries with the highest energy consumption, primarily from fossil fuels. Consequently, a concerted effort is required to reduce dependence on petroleum and develop renewable energy sources. Currently, renewable energy sources such as geothermal, solar, hydro, wind, and biomass can be utilized to decrease petroleum consumption. The biomass process known as gasification involves a thermochemical reaction that transforms solid materials into gas fuel (syngas) [1].

Currently, renewable energy sources such as geothermal, solar, hydro, wind, and biomass can be utilized to decrease petroleum consumption. The process of biomass conversion is known as gasification. Gasification is a thermochemical method that transforms solid fuel into gaseous fuel (syngas) within a gasifier, employing gasification agents such as hot steam, air, and others [2].

Gasification produces combustible gases such as carbon monoxide (CO), hydrogen ($H_2$), methane gas, inorganic impurities like $NH_3$ and HCN, $H_2S$ content, fine dust, and organic impurities as tar [3]. Contaminants persist in the generated gas, adversely affecting its quality. Consequently, it is necessary to refine the gas composition to enhance its efficiency. Following the combustion process in the reactor, the syngas, which remains mixed with tar, can be filtered or purified using filtration media or cleanup gasifier equipment [4].

Gasification purification it can also be done using the water scrubber method, that involves rinsing syn-gas with water medium to bind syn-gas particulates [5].

## 2 Literature Overview

### 2.1 Energy

The term "energy" refers to the strength that can be applied to carry out many types of activity processes [5]. Energy can also be referred to as the ability to perform labor. All objects have energy, including humans, animals, plants, machines, and natural elements like the sun, wind, and water. There are two kinds of energy: renewable energy and nonrenewable energy.

### 2.2 Biomass

Biomass is a non-fossilized, biodegradable organic material derived from plants, animals, and microorganisms. It encompasses products, by products, residues, and wastes from agricultural, forestry, and other related industries, as well as non-fossilized and biodegradable organic materials originating from industrial and domestic waste [6].

### 2.3 Gasification

Gasification is the thermodynamic transformation of solid or liquid biomass into combustible gas that can be used as an energy source or for creating value-added items and additives. In the gasification process, there are four methods used to transform solid fuel (biomass) into flammable syn-gas: drying (drying raw materials), decompression of heat or pyrolysis, oxidation or combustion, and reduction (gasification) [7].

### 2.4 Updraft Type Reactor

In updraft gasification reactor tubes, the combustion area (heat source) is located beneath the fuel and moves upward. This is illustrated in Fig. 1. The subsequent illustration demonstrates how the produced syngas ascends through the unburned fuel, while the fuel continues to descend. This gasification reactor has been successfully tested with rice husk fuel [8].

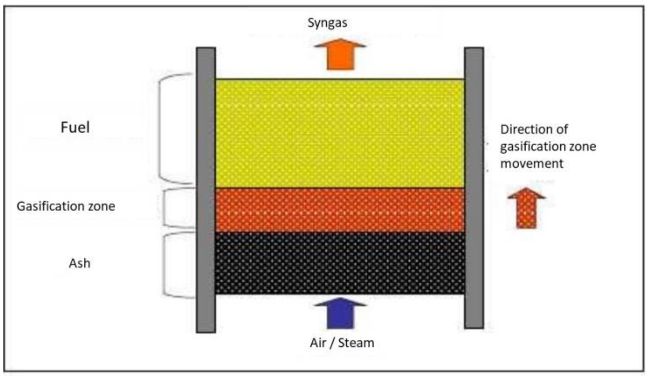


Fig. 1. Updraft type reactor.

In this sort of reactor, the heat generated by the combustion area (heat source) going through the biomass fuel can also be used to dry the biomass, which is then gasified and evacuated through the reactor's output pipe at the top.

### 2.5 Syn-Gas

Syn-gas can be generated from a variety of hydrocarbons, including coal, coke, petroleum, and biomass. Syngas, also known as synthetic gas, can be generated through the gasification of biomass fuels [4]. Syngas generated during the biomass gasification process provides various advantages. For example, the biomass-fueled gasification process releases no pollutants into the atmosphere. Second, biomass gasification may reduce dependence on nonrenewable resources, such as fossil fuels.

Biomass fuel gasification lead gas contains hydrogen, carbon monoxide, carbon dioxide, methane, aliphatic hydrocarbons, benzene, toluene, and insignificant amounts of ammonia, hydrochloric acid, and hydrogen sulfide [9].

### 2.6 Purification

Synthetic gas can be purified of solid particles using cyclones, filter cloth/filtration systems, electrostatic filters, and/or liquid scrubbers. Achieving high-purity gas is essential in the synthetic gas production process, which necessitates the implementation of cleaning and conditioning methods for biomass gasification by products. Cleaning is employed to remove undesirable pollutants resulting from the biomass gasification process, while conditioning is intended to adjust the H/CO ratio as needed [10].

Water quenching effectively eliminates inorganic contaminants. The hydrolysis process converts carbonyl sulfide (COS) and hydrogen cyanide (HCN) into hydrogen sulfide ($H_2S$) and ammonia. Ammonia can be removed by washing with water, followed by the adsorption of hydrogen sulfide, which can also be eliminated through water treatment. Wet scrubbers are devices that employ a liquid medium to remove pollutants. In a wet scrubber, contaminated gas passes through the washing liquid and comes into contact with it through spraying or other techniques [11].

In terms of organic contaminants, tar is the most unneeded component throughout the biomass gasification process. The separation of syn-gas from tar, liquid, cyclone, catalytic cracking, and thermal cracking at high temperature.

### 2.7 Combustion Flame

The shade of color of the fire is a visual display of the shape of the flame, which has a variety of colors based on the amount of temperature and heat in the fire; approaching temperatures that can affect the color of the fire provides the phases of fire heat [12]:

1. White fire heats exceed 2000ºC. White fire, that might reach heats of over 2000ºC, is commonly used in iron alongside other manufacturing sectors.
2. Blue flames usually reach heats around 1500ºC and 2000ºC. This flame is frequently found on gas stoves. This blue fire has a lower in luminance than the white fire, but more powerful than the yellow, orange, and red flames that we often see.
3. Yellow fire, with heats between 1200ºC to 1500ºC, is less efficient than blue fire. Yellow fire usually happens by burning kerosene.
4. Orange fire is generated by burning wood or charcoal. The orange fire has a lower efficiency level than the yellow fire, with heats varying between 1000ºC to -1200ºC.
5. Red fire is the lowest type, with a temperature below 1000ºC. Red fire is a fire that is less than complete combustion and occurs on the outside of the flame.

## 3 Research Methodology

This study examined the outcomes and characteristics of combustion gases produced during the purification process of gasified syngas. The experiment varied the number of water nozzles on the purification tube, ranging from two to four. The primary material utilized was dried rubber wood cut to a size of 5 cm. The research was conducted at the Mechanical Engineering Laboratory of Muhammadiyah Metro University (Fig. 2).

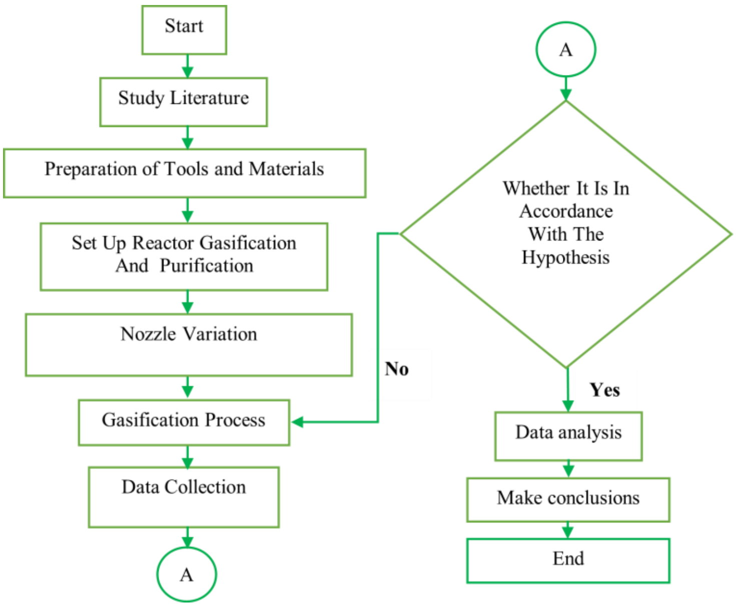


Fig. 2. Research flowchart.

### 3.1 Components Used

1. An updraft type gasification reactor with a height of 72 cm, and a reactor tube diameter of 38 cm, with a capacity of 20 kg of rubber wood biomass.
2. Purification tube with a height of 40 cm, and a diameter of 70 cm.
3. 0.15 mm vented nozzle
4. DC pump with a voltage of 12 V.
5. A series of pipes as air ducts to the reactor and syn-gas ducts from the reactor to the purification tube and to the burner with a diameter of 3.175cm.
6. Blower which serves to encourage the flow rate of combustion gas to the burner.
7. Ash / ash disposal hole with a diameter of 14 cm.

### 3.2 Testing Steps

The following are some of the steps which were carried out in the research :

1. Prepare materials in this study such as rubber wood and clean water media.
2. Dry all the biomass completely
3. After drying completed, cut the rubber wood with a length of 5 cm.
4. Prepare the tools used: thermocouple, reactor, blower, and stopwatch.
5. Place the biomass material into the reactor and then lighting the fire on the rubber wood using kerosene as the initial lighter. After that, turn on the blower as an air supply to the reactor, the temperature in the reactor can be recorded every 10

minutes. The critical stage of this research is the combustion process. The prepared biomass, now inside the reactor, is ignited using kerosene as an initial accelerant. Following ignition, a blower is activated to supply air to the reactor, and a water pump is engaged for the purification tube. Temperature readings within the reactor are recorded at 10-minute intervals. To study the impact of air flow on the combustion process, researchers vary the opening of the compressor hose valve, thereby adjusting the air flow rate into the reactor. This systematic approach allows for a comprehensive examination of the rubber wood combustion process and its response to different air flow conditions (Fig. 3).

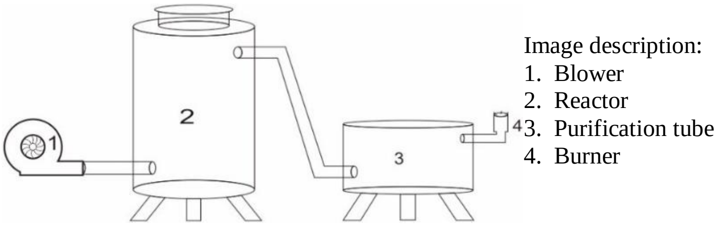


Fig. 3. Schematic of the syn-gas purification device resulting from the gasification process.

### 3.3 Schematic of Installing Two Nozzles on a Purification Tube

Two nozzles were used in parallel with the slope of 30º-45º. The nozzle's tilt angle was designed to ensure that the water released is uniformly distributed in the purification tube (Fig. 4).

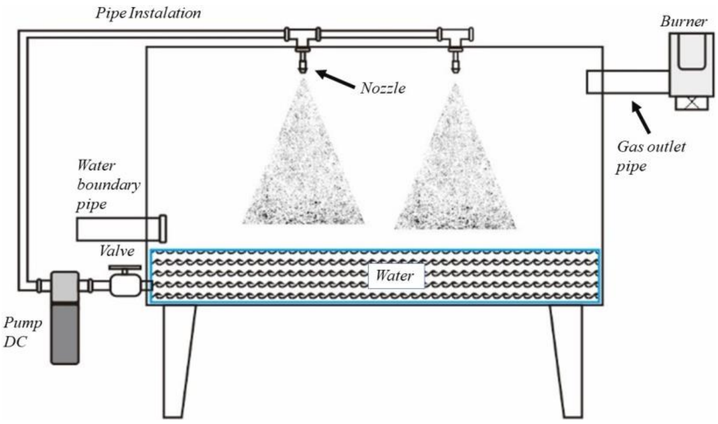


Fig. 4. Embed 2 nozzles on the syn-gas purification tube.

### 3.4 Schematic of Installing Three Nozzles on a Purification Tube

If three nozzles were set up in parallel, two of them generated a slope of 30º-45º, while one nozzle was vertical. The nozzle's tilt angle was designed to ensure that the water released is uniformly distributed in the purification tube (Fig. 5).

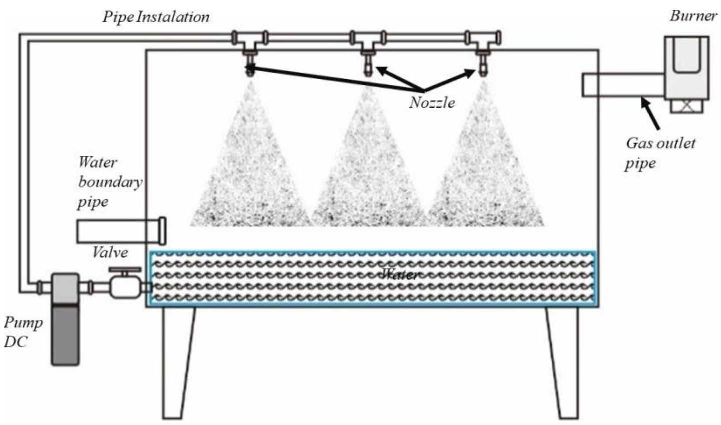


Fig. 5. Embed 3 nozzles on the syn-gas purification tube.

### 3.5 Schematic of Installing Four Nozzles on a Purification Tube

While four nozzles were used, they were set up perpendicularly opposed to parallel (Fig. 6).

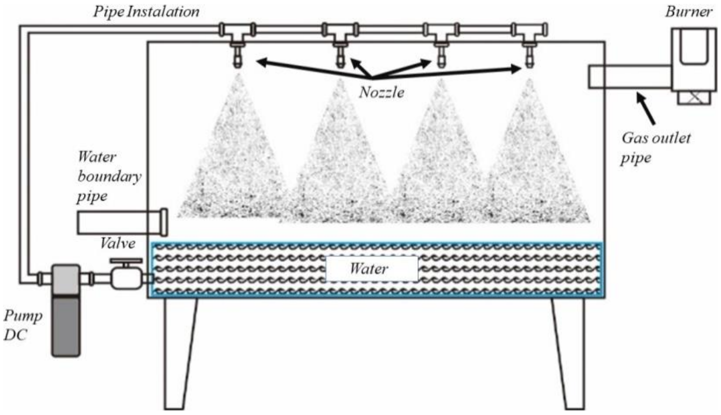


Fig. 6. Embed 4 nozzles on the syn-gas purification tube.

## 4 Results and Discussion

The purification tube was equipped with four nozzles that generate syngas, which can be utilized for both residential and industrial applications. This study identifies three distinct characteristics of syngas associated with variations in the number of nozzles: the length of the flame, the color of the flame, and the calorific value of the water absorption produced by each configuration.

Data were collected three times throughout the testing process to ensure reliability. Temperature data were obtained and recorded every ten minutes. The data are:

### 4.1 The Effect of Temperature Distribution on Nozzle Variations

#### 4.1.1 Gasification Temperature Distribution Using 2 Nozzle Variations

The data obtained shows the combustion temperature with rubber wood biomass with purification variation of 2 nozzles. Temperature T1 (reactor temperature) shows 106.8ºC to the highest temperature of 697.6ºC and shrinks at 70-90 minutes, meaning that the biomass has begun to burn out. The purification tube temperature (T2) varied between 46.9ºC to 65.2ºC. When filtered and aerated with water media, the temperature dropped. The temperature at T3 (burner pipe) was 41.7ºC, with a maximum of 59.8ºC. The chilled gas in the T2 tube forced the temperature at T3 to drop [13] (Fig. 7).

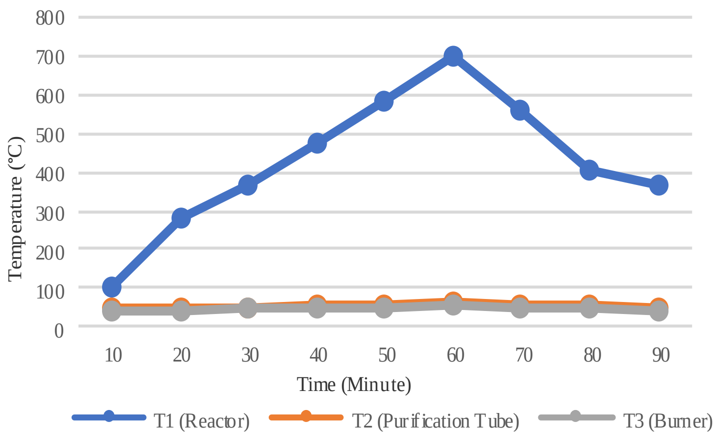


Fig. 7. Gasification temperature distribution graph using 2 nozzle variations.

#### 4.1.2 Gasification Temperature Distribution Using 3 Nozzle Variations

Based on the results, it is known that the combustion temperature of rubber wood biomass with eliminating alterations of three nozzles, Temperature T1 (reactor temperature) fluctuates between 104.8ºC to 656.6ºC and drops after 70-90 minutes, indicating that biomass is burning away. The purification tube temperature (T2) fluctuates between 44.8ºC to 62.4ºC. Filtered and aerated with water substrate, the temperature drops. T3 (burner pipe temperature) reaches 40.2ºC with a maximum of 55.9ºC. The chilled gas in the T2 tube causes the temperature at T3 to drop (Fig. 8).

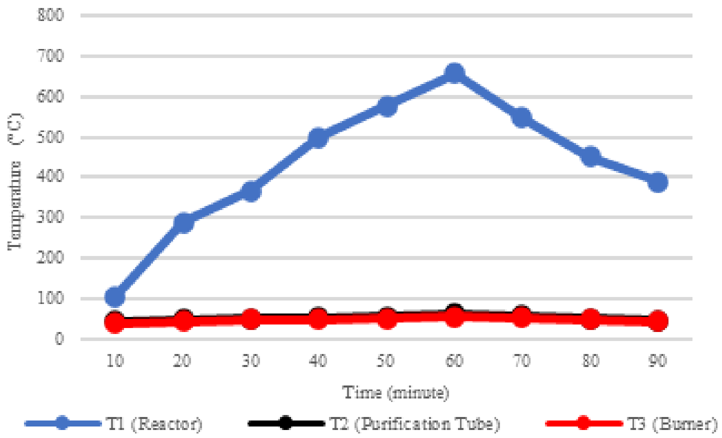

Fig. 8. Gasification temperature distribution graph using 3 nozzle variations.

#### 4.1.3 Gasification Temperature Distribution Using 4 Nozzle Variations

The data obtained shows that the combustion temperature with rubber wood biomass with purification variation of 4 nozzles, Temperature T1 (reactor temperature) shows 105.2ºC to the highest temperature of 689.6ºC and drops at 70-90 minutes, meaning that the biomass has begun to burn out. The purification tube temperature (T2) varies between 43.1ºC to 55.2ºC. Filtered and aerated with water media, the temperature drops. The temperature at T3 (burner pipe) is 40.3ºC, with an upper limit of 51.3ºC. The chilled gas in the T2 tube causes the temperature at T3 to drop (Fig. 9).

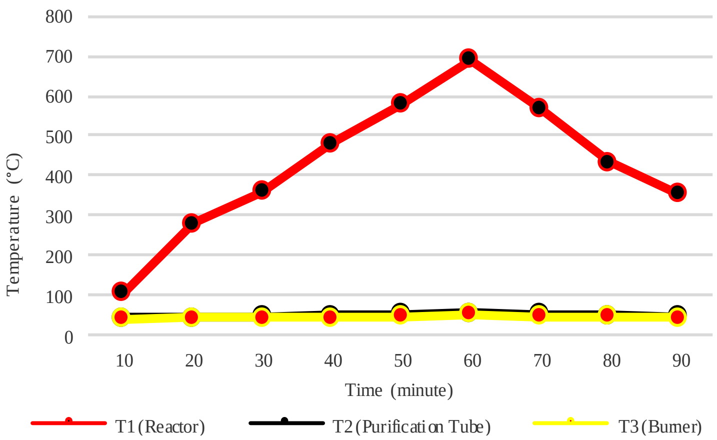

Fig. 9. Gasification temperature distribution graph using 4 nozzle variations.

### 4.2 Calculation of Heat Value Absorbed by Water

Analyze the heat value absorbed by water, we use the equation:

$$Q = \dot{m}.Cp.\Delta T$$
$$Q = 1 \text{ kg} \times 4200 \text{ J/kg}^{o}\text{C} \times (100^{o}\text{C} - 23^{o}\text{C})$$
$$Q = 323.400 \text{ J}$$

Formula:
$Q$ = heat value
$m$ = Mass of water (kg)
$Cp$ = Specific heat capacity of water (J/kg$^{o}$C)
$\Delta T$ = Final water temperature - initial water temperature ($^{o}$C)

From the calculations, the heat value absorbed by 1 kg of water to reach a temperature of 100°C is 323.400 J. To determine the heating rate required to heat 1 kg of water, we can use the equation:

$$P \,.\, t = \dot{m}.Cp.\Delta TI$$
$$P = \frac{Q}{t}$$

When using a variation of 2 nozzles on the purification tube, it takes 10 minutes to heat 1 kg of water from 23°C to 100°C. The energy required is:

$$P = \frac{Q}{t}$$
$$P = \frac{323.400 \text{ J}}{600 \text{ second}}$$
$$P = 539 \text{ J/s}$$

For the variation with 3 nozzles on the purification tube, it takes 12 minutes to heat 1 kg of water from 23°C to 100°C. The energy required is:

$$P = \frac{Q}{t}$$
$$P = \frac{323.400 \text{ J}}{720 \text{ second}}$$
$$P = 449.1 \text{ J/s}$$

With 4 nozzles on the purification tube, it takes 13 minutes to heat 1 kg of water from 23°C to 100°C, producing a blue flame but with a small flame size. The energy required is:

$$P = \frac{Q}{t}$$
$$P = \frac{323.400 \text{ J}}{780 \text{ second}}$$
$$P = 414.61 \text{ J/s}$$

From the test results and calculations performed, the research data obtained with variations of 2, 3, and 4 nozzles at an air flow rate of 7 m/s produced energy outputs of 539 J/s, 449.1 J/s, and 414.61 J/s, respectively.

#### 4.2.1 Length of Flame Time

According to the results of testing the purification of syn-gas from the gasification process of rubber wood biomass, each variation in the number of nozzles results in deviations in the duration of the syn-gas flame time due to the influence of gas pollutants [14] (Table 1).

Table 1. Burner flame time

| Circuit variation | Flame time (minute) |
|---|---|
| 2 nozzle | 45 |
| 3 nozzle | 38.2 |
| 4 nozzle | 33.5 |

When the aqueous medium limits the amount of gaseous substances, the flame duration produced by the four nozzle variant is lower than that of the other types.

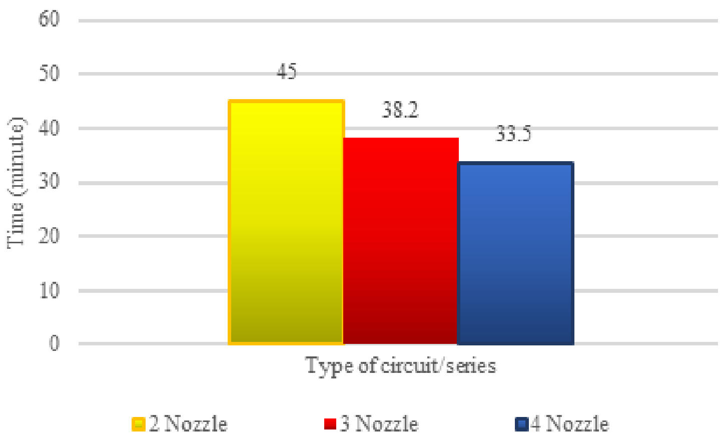

Fig. 10. Syn-gas flame time graph.

#### 4.2.2 Flame Colour

From the test results on each type of variation produces a flame of different colours, this is influenced by the content of gas impurities such as tar and ash.

A B C

Fig. 11. Flame colour.

Description:
A = Flame colour using variation 2 nozzle
B = Flame colour using variation 3 nozzle
C = Flame colour using variation 4 nozzle

In testing, a combination of two syngas purification nozzles develops a bluish-red flame, with the red color dominant the burner pad hole. And testing with a variety of three purification nozzles produces a blue flame that is slightly mixed with orange, but the blue flame is more being dominant when applying this three-nozzle variation [15]. The flame colour in the four nozzle variety is blue. The combustor face was filled with blue flames. The blue flame in the 4-nozzle variation is smaller than the one in the 2-nozzle variation.

According to the research study, as the water sprayer pressure in the trap rises, the flame size decreases. This is because a higher pressure of the water sprayer reaching the trap results in a more constrained syngas velocity, leading to a smaller or lower flame resulting from syngas dissolution [16].

## 5 Conclusions

Based on the results of syngas purification tests conducted on updraft biomass gasification production using various nozzle additions and 20 kg of rubber wood feedstock, the conclusions can be drawn:

1. The inclusion of nozzles in the purification process does not impact the reactor temperature. However, the quantity of nozzles on the purification tube affects the quality of the flame. The optimal flame quality, characterized by a blue color, is achieved using an alternative configuration of four nozzles on the purification tube.
2. Varying the number of nozzles influences the duration of the flame; a burn time of 45 minutes is recorded when using two purification nozzles. However, the flame characteristics, specifically in terms of color, result in a blue-red flame with a pronounced red component.
3. The energy produced varies depending on the number of nozzles (2, 3, and 4), yielding 539 J/s, 449.1 J/s, and 414.62 J/s, respectively. The highest energy output is achieved with the 2-nozzle configuration, which generates 539 J/s.

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