

Preliminary Experimental of Biomass Gasification Process with Open Core Throat Less Downdraft Gasifier

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Abstract: Gasification has been considered a promising approach to converting biomass into useful gaseous products. Downdraft gasifiers are famous for engine applications and used for thermal applications. The product gas has to meet the individual requirements of different end users or applications. The downdraft gasifier based on open core throat less design has been developed according to its suitability for small-sized biomass. The preliminary experiment investigated gasifying characteristics by studying the temperature distribution within the gasifier. This study used three kinds of biomass: Eucalyptus wood chip, Mimosa wood twig, and wood pellet. The results showed that the temperature distribution within the gasifier for each zone corresponds with the character of the gasifying process within the downdraft gasifier. Moreover, the temperature profiles for a gasifying process for all three biomass tests were in the same pattern. The maximum temperature was in the combustion zone (T_3). The maximum temperature at the combustion zone for the Eucalyptus wood chip is the highest compared with the maximum temperature at the combustion zone of the Mimosa wood twig and wood pellet. The temperature at the combustion zone (T_3) of the Eucalyptus wood chip, Mimosa wood twig, and the wood pellet were 838, 783, and 620 °C, respectively. The temperature at the combustion zone results in the temperature at the reduction zone. The average temperature at the reduction zone for gasifying all three biomass feeds ranges from 470-514 °C. While the temperature at the pyrolysis zone and the gas exit are not significantly different for all three biomass feeds. These results showed that the reaction within the gasifier could carry out continuously with a suitable temperature in each zone as per the design.

Keywords: Gasification; Open Core Throat Less; Downdraft; Preliminary Experimental; Temperature Distribution.

1. Introduction

Biomass is one of the most potent organic materials on the earth, produced by photosynthesis reaction in green plants in the presence of sunlight. It stores solar energy in its chemical bond as chemical energy [1], which can be further evolved by breaking down the bonds [2]. However, the bulky and inconvenient form of biomass is a major barrier to its wide applications. This motivates the conversion of solid biomass into liquid and the conversion process [3]. Thermochemical conversion, including combustion, gasification, and pyrolysis, can break down the chemical bond in biomass to release the stored energy. Combustion can directly release energy by the primary bond breaking of biomass. At the same time, gasification and



pyrolysis can transfer the energy into secondary products, which are likely ideal for fueling the furnace and the engine [4]. Gasification is one of the thermochemical conversion processes that has been considered a promising approach to converting biomass into useful gaseous products. Based on the advantages of energy efficiency and ease of application, gasification is the best choice for exploding energy from biomass [5]. The biomass gasification process converts biomass into producer gas consisting of methane, hydrogen, carbon monoxide, carbon dioxide, nitrogen, and other minor components. Although gasification technologies have been developed over a century, their commercial successes on a large scale are still limited [6]. A biomass gasification plant's economic and technological successes depend on the trouble-free operation of all system components over long periods [3]. The key success factors for the gasification process depend on several factors, such as fuel properties, gasifier design, operation, and gas cleaning. The main biomass property was considered an energy source, such as moisture content, calorific value, fixed carbon and volatiles proportions, ash content, alkali metal content, and cellulose/lignin ratio [7]. Gasification and combustion are closely related to thermochemical processes but have an important difference. Gasification packs energy into chemical bonds in the product gas; combustion breaks those bonds to release the energy. The gasification process adds hydrogen to and strips carbon away from the hydrocarbon feedstock to produce gases with a higher hydrogen-to-carbon ratio. At the same time, combustion oxidizes the hydrogen and carbon into the water and carbon dioxide, respectively. A typical biomass gasification process may include the following steps: drying, thermal decomposition or pyrolysis, partial combustion of some gases, vapors, and char, and gasification of decomposed products. Gasification requires a gasifying medium such as air, oxygen, or steam to rearrange the molecular structure of the feedstock to convert the solid feedstock into gases or liquids. Biomass is first heated (dried) and then undergoes thermal degradation or pyrolysis. The pyrolysis products (i.e., gas, solid, and liquid) react among themselves and with the gasifying medium to form the final gasification product. The thermal energy necessary for drying, pyrolysis, and endothermic reactions comes from a certain amount of exothermic combustion reactions allowed in the gasifier. Gasifiers are classified mainly based on their gas-solid contacting mode and gasifying medium. Based on the gas-solid contacting mode, gasifiers are divided into three principal types: fixed bed, fluidized bed, and entrained flow bed. There is an appropriate range of applications for each: the fixed bed type is used for smaller units ($< 10 \text{ MW}_{\text{th}}$); the fluidized bed type is more appropriate for intermediate units ($5\text{-}100 \text{ MW}_{\text{th}}$); entrained flow reactors are used for large capacity units ($> 50 \text{ MW}_{\text{th}}$) [8]. The fixed bed gasifier has been the traditional process used for gasification, operated at temperatures around 1000 degree Celsius. Depending on the airflow direction, the fixed bed gasifiers are classified as updraft, downdraft, or cross draft [9]. Downdraft gasifiers are characterized by a co-current air or gas and fuel flow. In downdraft, with or without a throat gasifier, tar and other products off pyrolysis pass through the high-temperature oxidation zone of the reactor, where they are subsequently burnt or cracked. Thus, the producer gas from a downdraft gasifier contains very less tar (less than 1 % [10]. Therefore, downdraft gasifiers are also popular for engine applications and thermal applications. However, these gasifiers are highly fuel specific [11-14]. There are various methods for using producer gas produced from the gasification process. However, the product gas has to meet the individual requirements of different end users or applications. The end use of the gas determines the degree of clean-up required and can be achieved by either hot or cold gas cleaning. The benefit of hot gas cleaning is that more energy is gained from the gas. Still, the process poses significant technical simpler and produces wastewater contaminated with tar, likely posing a disposal problem [10]. Applying the product gas directly through the combustion process to produce heat for cooking or drying generally does not use a gas cleaning system. However, using a gasifier with no gas cleaning system for cooking if it still has tar or particulate in the product gas makes the pot dirty with the suit and causes a barrier for using a gasifier. Thus, primary treatments such as optimizing biomass feedstock properties and designing and operating the gasifier [15] are first implemented to remove unwanted products and contaminants in the product gas. Secondary treatments, such as a downstream cleaning system based on physical (scrubber, filters) or catalytic strategies, must be incorporated for end applications and environmental regulations [16]. Although mostly, the gasifier sizing will be designed based on suggestion information from the previous inventors. Thus, the new gasifiers that have been developed need to

investigate the results based on the references from the theoretical review before using gasifiers. Thus, this paper aims to investigate the temperature distribution within the gasifier to confirm that the reaction within the gasifier can carry out continuously with a suitable temperature in each zone.

2. Materials and Methods

2.1 Downdraft Gasifier

The Gasifier system developed and presented in this paper was designed based on the downdraft gasification process. The design and calculation of the gasifier have followed the design methodology for sizing the Imbert-type downdraft gasifier. The Imbert gasifier is the most used type of downdraft gasifier. The downdraft gasifier based on open core throat less design has been developed according to its suitability for small-sized biomass [17-19]. The main objective of developing this gasifier is to produce the producer gas that is cleaner for cooking applications to solve the disadvantage of using producer gas for cooking the particle or soot attached to the pot. The gas cleaning system, in conjunction with the gasifier, was developed. Thus, the gasifier system has been developed and comprises three main parts; gasifier, gas cleaning system, and cooking gas stove.

The gasifier was designed based on an open core throat less downdraft gasifier with biomass fuel feeding in batches. The maximum biomass fuel consumption rate is 15 kg/hr. Based on the function of each part within the gasifier, the gasifier can divide into three parts: fuel hopper, reaction chamber, and ash pit. The fuel hopper contains and fills biomass fuel; it lies at the top of the gasifier. The maximum fuel loading is about 15 kg/batch. The reaction chamber was designed with a diameter of 234 millimeters and an inner height of 356 millimeters. The reaction chamber was fabricated with 2 millimeter-thick steel plate. The ash pit is the part for collecting the ash from the reaction process within the reaction chamber. A pictorial drawing of an open core throat less downdraft gasifier showed in Figure 1.

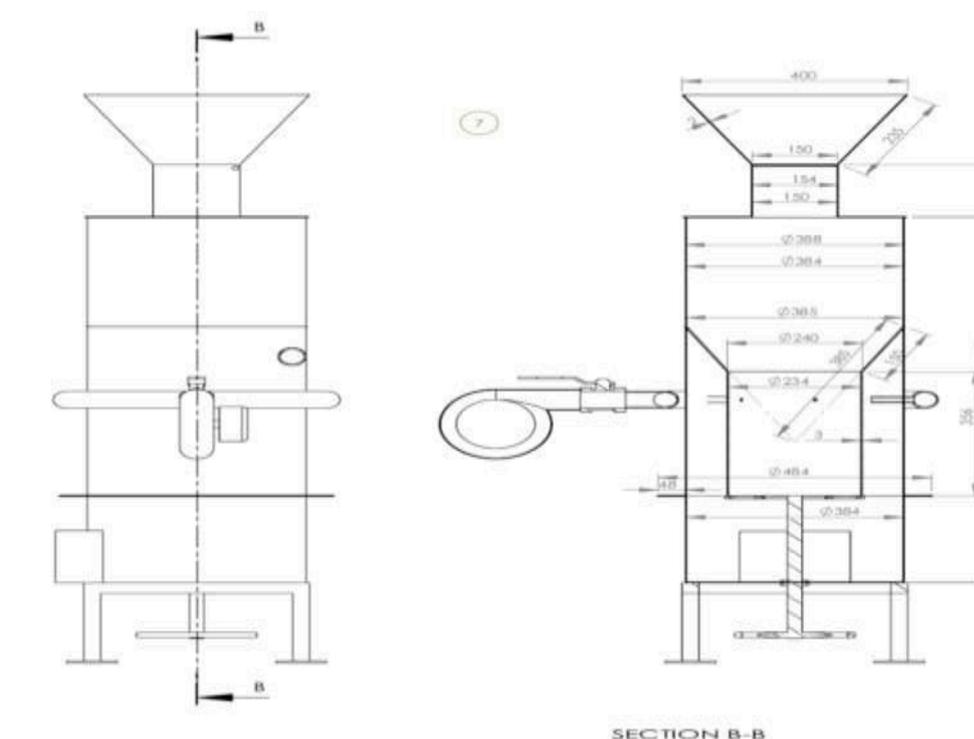


Figure 1. Open core throat less downdraft gasifier

A gas cleaning system has been developed to clean the producer gas produced from gasification. The main objective of developing the open core throat less gasifier is to use it for cooking applications. Thus the

gas cleaning equipment will be suitable for eliminating particles and tar in the producer gas. The producer gas will pass through four steps of the gas cleaning equipment in series. Four gas cleaning steps comprise cyclone, venturi scrubber, coarse bag house filter, and fine bag house filter. The producer gas from the gasifier will pass through the cyclone to separate the solid particle from the gaseous stream by vortex separation. After the gaseous stream passes through the cyclone, it will pass through the venturi scrubber to separate the tar and particles from the gaseous stream and reduce the producer gas's temperature. Then the gaseous stream will pass through two bag house filters in series, coarse bag house filter and fine bag house filter, to make cleaner producer gas before use—bag house filter made by filling with sawdust. Fine bag house filter will fill with sawdust denser than filling in the coarse bag house filter. The pictorial drawing of the downdraft gasifier system showed in Figure 2.

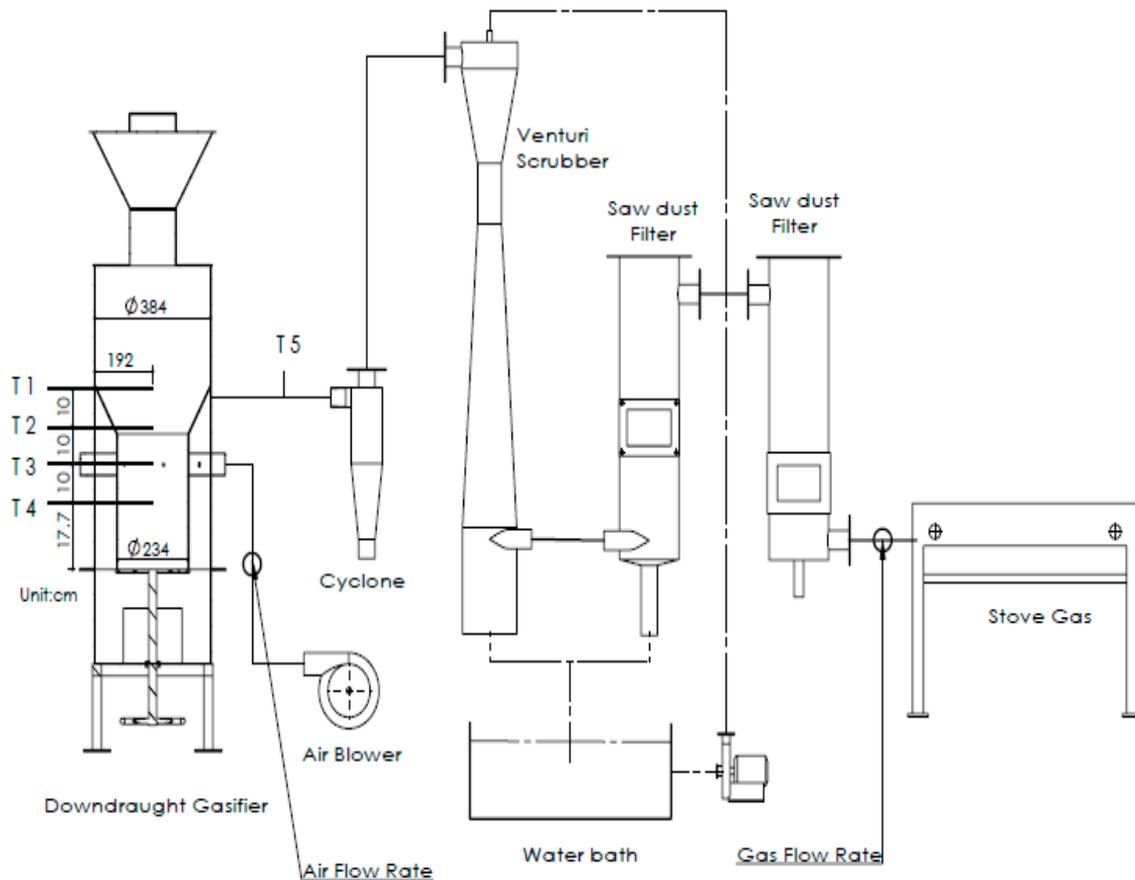


Figure 2. The pictorial drawing of the downdraft gasifier system

2. 2 Biomass

The woody biomass fuels used in this study comprise Eucalyptus wood chips, Mimosa wood twigs, and wood pellets. The photographs of the sample biomass used here are shown in Figure 3.



Figure 3. Biomass fuels were used in this study.

2.3 Experimental setup

The preliminary experimental test was conducted to study the characteristic of temperature distribution during the gasification process within the gasifier. Based on the principle of downdraft gasifier, thus, to study the characteristic of the gasification process, we installed a thermocouple within the gasifier with four ports. Four thermocouples were fixed in the gasifier along the vertical reactor to measure the temperature at different positions. The thermocouples T_1 , T_2 , and T_3 were fixed in the gasifier with a 100-millimeter gap, while T_4 was fixed with a 117.7-millimeter hole from the grate. All thermocouples were connected to a data logger and computer to acquire data. Figure 4 shows the position installed thermocouple along the vertical reactor.

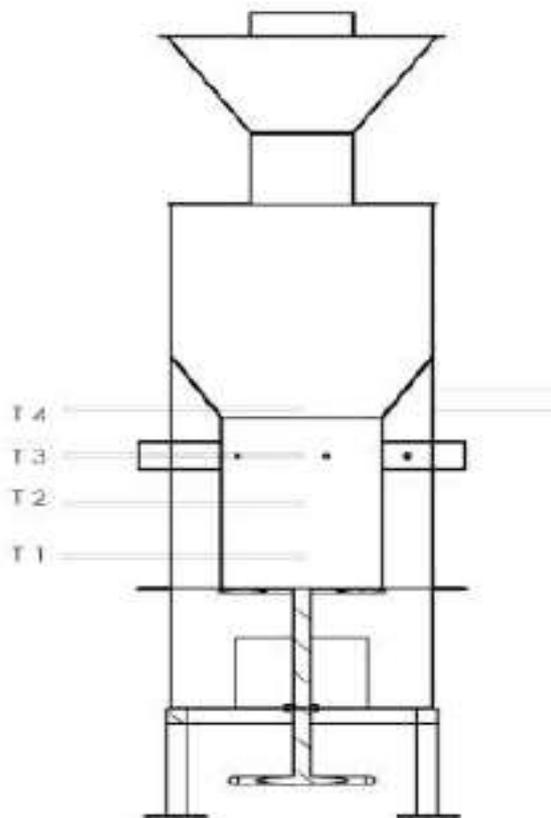


Figure 4. The temperature measurement within the gasifier.

3. Results and Discussion

3.1 Temperature distribution within the gasifier during gasified with Eucalyptus wood chip

The temperature distribution within the gasifier during the gasifying process of the Eucalyptus woodchip showed in Figure 1. The analysis results found that the temperature is highest at the thermocouple T3 port, as obvious according to the air supplied at this zone; thus, the combustion process has occurred. The temperature at the combustion zone is 789-983 °C, while the average temperature is 827 °C. At the zone underneath the combustion zone, the thermocouple T2 was installed. The recorded temperature is 461-636 °C, while the average temperature in this zone is 514 °C. Based on the theoretical review, this implies that this zone is a reduction zone. At the zone adjoining the higher combustion zone, the thermocouple T4 was installed. The temperature at this zone is 132-318 °C while the average temperature is 178 °C. This implies that this zone is the pyrolysis zone. At the zone underneath the reduction zone, the thermocouple T1 was installed. The results showed that the temperature in this zone is 95-159 °C while the average temperature is 123 °C. The graphical temperature distribution within the gasifier during gasification with Eucalyptus wood chip showed in Figure 5.

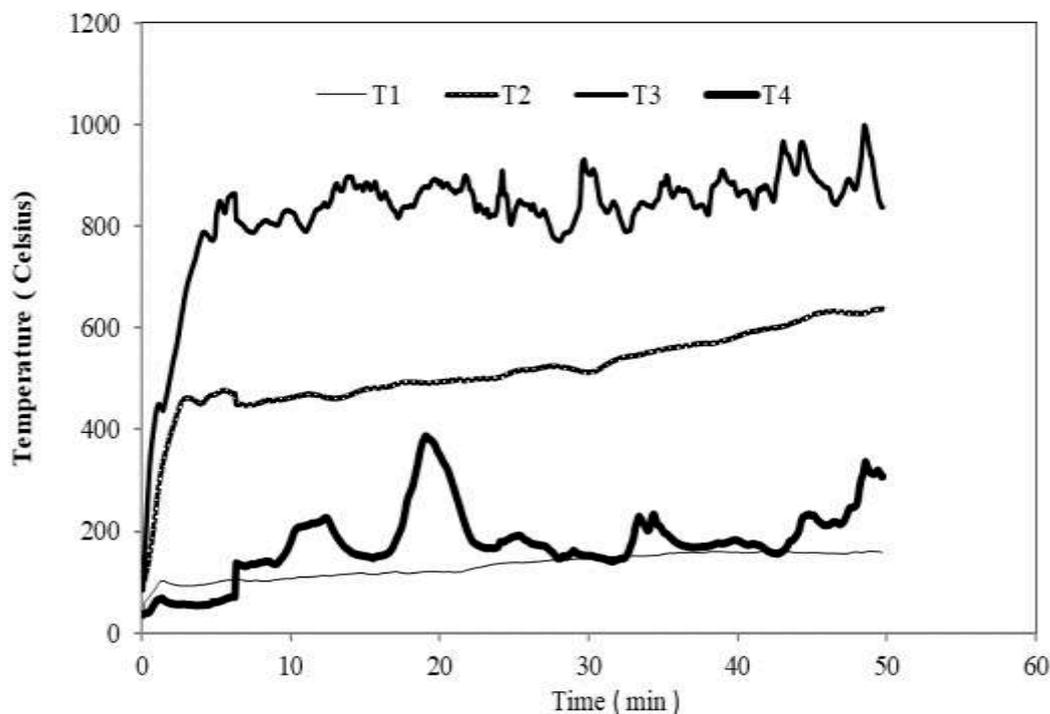


Figure 5. The graphical of temperature distribution within the gasifier during gasified with Eucalyptus wood chip

3.2 Temperature distribution within the gasifier during gasified with Mimosa wood twig

Figure 6 shows the downdraft gasifier's temperature distribution during Mimosa wood twig gasification. The analysis results of the temperature recorded and temperature distribution characteristics within the gasifier at each point showed the following results. The results showed that the temperature from every port would take around 3-5 minutes to reach a steady state. This means that the reaction within the gasifier has completely occurred. According to the basic principle of a downdraft gasifier, the combustion process will appear at the supply air zone. Heat and the combustion products from this zone will transfer to the biomass fuel, which lies next to each other in the combustion zone. Thus the author will start considering the temperature distribution from this zone. At the thermocouple T3 port, The temperature is highest, as obvious. The results showed that the temperature was 772-1044 °C while the average was 783 °C. This implies that this zone is a combustion zone. At the zone underneath the combustion zone, the thermocouple T2 was installed. The temperature at this zone is 450-590 °C while the average temperature is 501 °C. Based on the theoretical review, this implies that this zone is a reduction zone. At the zone adjoining higher with the combustion zone, the thermocouple T4 was installed. The

temperature at this zone ranges from 125-492 °C while the average temperature is 174 °C. This implies that this zone is the pyrolysis zone. At the thermocouple T₁ port, this zone underneath the reduction zone, the producer gas will exit from the gasifier at this zone. The results showed that temperature is almost steady over time. The temperature ranges from 125-130 °C while the average temperature is 120 °C. The graphical temperature distribution within the gasifier during gasification with Mimosa wood twigs showed in Figure 6.

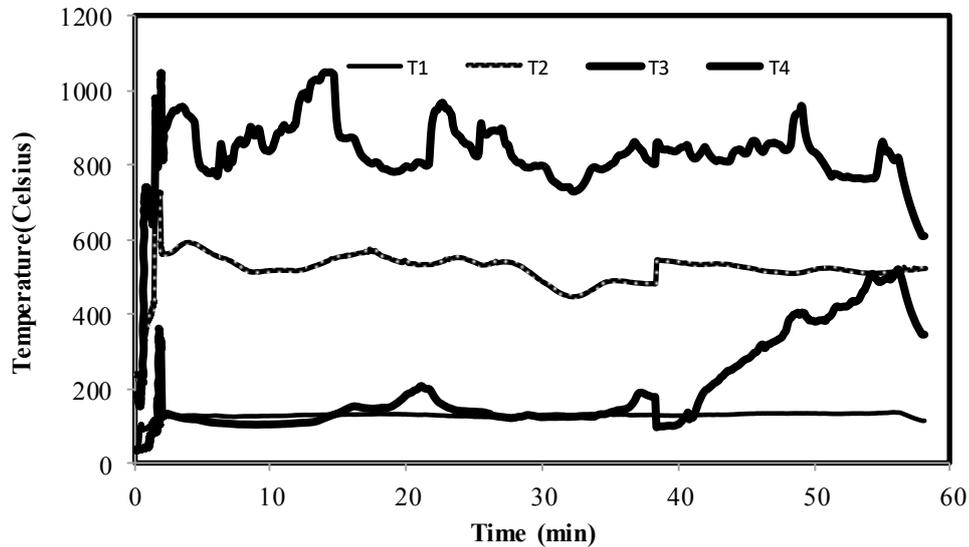


Figure 6. The graphical of temperature distribution within the gasifier during gasified with Mimosa wood twig

3.3 Temperature distribution within the gasifier operated with a wood pellet

Figure 7 shows the temperature distribution within the downdraft gasifier operated with a wood pellet. The analysis results of the temperature recorded and characteristics of temperature distribution within the gasifier at each point are as follows. The temperature from every port will take around 5 minutes to reach a steady state. At the thermocouple T₃ port, The temperature is highest, as obvious. The results showed that the temperature was 557-736 °C while the average was 619 °C. This implies that this zone is a combustion zone. At the zone underneath the combustion zone, the thermocouple T₂ was installed. The temperature in this zone is 507-547 °C, while the average temperature is 470 °C. Based on the theoretical review, this implies that this zone is a reduction zone. At the zone adjoining higher with the combustion zone, the thermocouple T₄ was installed. The temperature at this zone ranges from 125-492 °C while the average temperature is 168 degrees Celsius. This implies that this zone is the pyrolysis zone. At the thermocouple T₁ port, underneath the reaction zone, the producer will exit from the gasifier. At this zone, the temperature is steady at 133 °C.

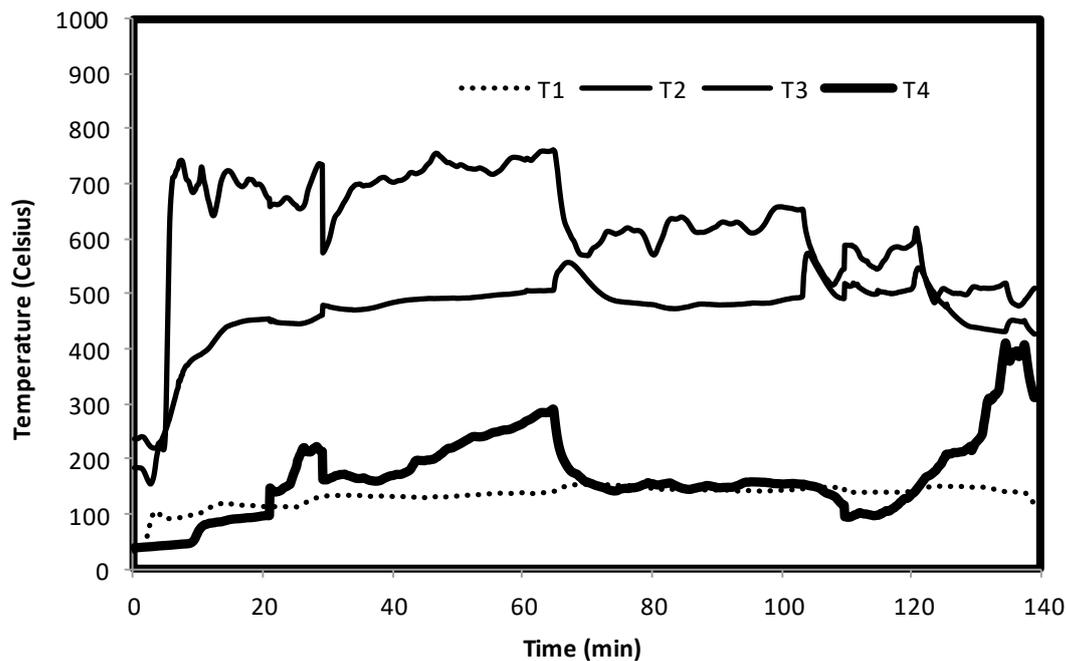


Figure 7. The graphical of temperature distribution within the gasifier during gasified with a wood pellet

3.4 The temperature profile from the gasification process of different biomass fuel

To investigate the temperature profile from the gasification process of three biomass fuels, the average temperature for each point within the gasifier was calculated and presented in graphical. The average temperature for each point within the gasifier during the gasification process of three biomass feeds along the gasifier's height was summarized as shown in Table 1.

Table 1. The average temperature for each point within the gasifier for three biomass feed

	Eucalyptus wood chip	Mimosa wood twig	wood pellet
T1	113	120	131
T2	514	501	470
T3	828	783	620
T4	179	175	168

From the average temperature at each point within the gasifier and plotted in the graph, The results showed that the temperature profile for each biomass feed is in the same pattern. The maximum temperature is in the combustion zone (T₃), and the temperature at the combustion zone results in the temperature at the reduction zone. The temperature at the pyrolysis zone and the gas exit are almost the same for all three biomass feeds.

Figure 8 shows the temperature profiles of the three biomass gasification processes over the operating time at different gasifier positions. The results showed that the temperature at the combustion zone is highest for all three biomass feeds. The maximum temperature at the Eucalyptus wood chip's combustion zone is the highest compared with that at the combustion zone of Mimosa wood twigs and wood pellets. The temperature at the combustion zone (T₃) of Eucalyptus wood chip, Mimosa wood twig, and wood pellet are 838, 783, and 620 °C, respectively. At the zone underneath the combustion zone (T₂), the combustion products will flow down through the product gas and are partly reduced chemically, and the temperature will also decrease. The reduction process will have occurred at this zone (T₂). The temperature at the reduction zone (T₂) of Eucalyptus wood chip, Mimosa wood twig, and wood pellet are 514, 501, and 470 °C, respectively. At the zone adjoining higher with the combustion zone, the thermocouple T₄ was installed, and at this zone, the pyrolysis process occurred. The temperature at the pyrolysis zone (T₄) of

Eucalyptus wood chip, Mimosa wood twig, and wood pellet are 179, 175, and 168 °C, respectively. The temperature at the gas exit (T_1) for all three biomass feeds is not a significant difference. The gas exit temperature is around 120 °C.

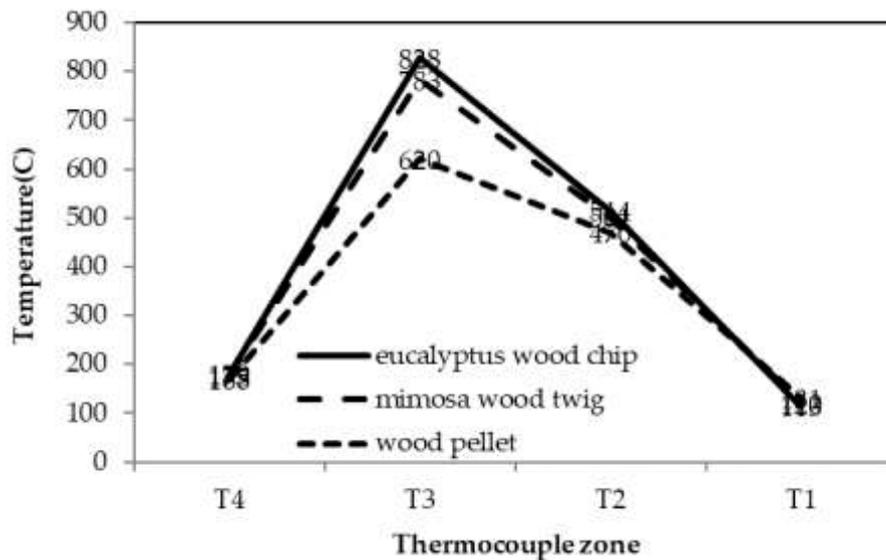


Figure 8. The temperature profiles of the three biomass gasification processes at the different positions inside the gasifier over the operating time.

4. Conclusions

The experimental study was conducted on an open core throat less downdraft gasifier. The study gives an insight into the behavior of the reaction within the gasifier. This paper aims to investigate the temperature distribution within the gasifier to confirm that the response within the gasifier can carry out continuously with a suitable temperature in each zone. The conclusions the results are as follows:

- (1) The temperature distribution for each zone of all three biomass feeds is the same pattern.
- (2) The temperature range for each zone corresponds with the characteristics of the gasifying process within the downdraft gasifier.
- (3) At the combustion zone (T_3), the highest temperature is highest according to the air supplied at this zone. The product from the combustion zone, including heat, CO_2 , and other substances, will pass through the zone underneath and adjoining higher with the combustion zone.
- (4) Based on the downdraft gasifier design, the gas exit at the bottom; thus, the combustion products in the form of gas or particulates will pass through the zone underneath the combustion zone. The reduction reaction has occurred at this zone. Producer gas will be produced from the reaction in this zone. The thermocouple T_2 was installed at this zone. The results showed that the average temperature for gasifying all three biomass is 470-514 °C. This implies that this zone is a reduction zone.
- (5) While the zone adjoining is higher than the combustion zone, only heat transfer through this zone, thus pyrolysis, will occur. The thermocouple T_4 was installed, and the results showed that the average temperature is 168-179 °C.
- (6) At the gas exit, the average temperature of the three biomass feeds is not significant difference. The average temperature at the gas exit for all three biomass feeds is 120 °C.

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