



Estimation of Higher heating Value of Biomass from Proximate and Ultimate Analysis: A Novel Approach

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ABSTRACT

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Biomass is the organic matter formed by photosynthesis that occurs on the earth's surface. They contain all forms of waste compost, including urban solid waste, municipal bio solids, animal wastes, forestry and agricultural wastes, and some industrial wastes. Efficient use of biomass oil would aid in the resolution of issues caused by fossil fuels. However, the biggest issue about using this energy is due to the gas composition of biomass material. As a result, properties of biomass are the critical parameter for assessing the fuel content of a special biomass substance in energetic applications. Gasification is the most mature thermo-chemical conversion technique available among the various methods of transforming biomass materials to bio resources. In this context, proximate and ultimate analysis has been used to classify two groups of biomass material that carry out in this experiment. The proximate analysis results have been obtained by the TGA technique while the ultimate analysis results will obtain by the GC mechanism. Then, based on the proximate analysis data various empirical equations containing linear and nonlinear terms were evaluated in order to predict the higher heating values (HHV) of the entire sample range. Since, the biomasses used in this analysis have different properties and fuel characteristics, the estimated HHV for the wood pellet sample are between 15.33 and 19.71 MJ/kg, while the rubber seed sample is between 15.18 and 18.64 MJ/kg. According to the experimental findings, the HHV of wood pellet is at around 2.95 MJ/Nm³ while the HHV of rubber seed of about 4.99MJ/Nm³. The comparison on the theoretical analysis have been show 0.19% compared to the results on wood pellet while the rubber seed have at around 2.07% difference compare each other. The experimental results on wood pellets, the findings reveal a 15.35% difference, while rubber seed indicates a 13.81% difference. Nonetheless, the finding and analysis on the properties, the results can be considered within reasonable limits.

1. Introduction

The majority of industrialized industries now use a significant volume of fossil fuels [1]. However, since fossil fuels are scarce renewable resources, which cannot be regenerated and will be exhausted in the future; in the meantime, their dramatic price increases compel us to look for new energy

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resources [2]. The key consequences of greenhouse gas emissions have steadily forced alternative energy sources to play a greater part [3]. As a green energy source, biomass may be seen as an option to meet rising industrial demand [4]. The demand for bioenergy systems in small scale industry is growing at a higher pace due to its lower investment cost [5].

A chemical reaction that transforms carbonate elements into raw chemical substrates or gaseous fuels is known as gasification. Gasification of fossil fuels is popular in the biomass method for the manufacture of syngas (CO, H₂, N₂, O₂, CO₂), and a few hydrocarbon elements or compounds make up the majority of the syngas (CH₄, C₂H₄, C₂H₆, etc.) [6]. The gasification process produces heat in an oxygen deficient environment. It necessitates the use of a medium reaction, such as air, oxygen, subcritical steam, or certain gaseous mixtures [7].

The most effective way to use biomass materials is the HHV. The final and proximate study of biomass content parameters can be readily compared. To imagine HHV forecasting linear and non-linear equations, assume of it as a dependent parameter with proximate and ultimate analysis components as separate parameters. HHV has been used to establish observational relationships as a function of two, three, and four independent variables using proximate analysis [8]. One of the most widely used methods for studying the key reaction of solid decomposition is thermogravimetric analysis (TGA).

Gas chromatography (GC) was used to analysis gases and vapours from extremely volatile components in its early stages of growth. The fundamental principle of GC is that the higher the compound's propensity for the stationary step, the more it will be held by the column and the longer it will take for it to be eluted and identified. Thus, the centre of the GC is the column in which component separation occurs, to which must be applied the source and regulation of carrier gas movement through the section, a means of sample introduction, and a means of identification of the components [9].

The latent heat in the water products of combustion is let to condense into liquid waters with HHV values. The HHV adjustment is a low heat value (LHV) owing to moistening of biomass or water vapour generated when the hydrogen in the fuel is combusted [10]. The present research study aims to improve the recent discoveries on the BPG and formulate the suitable surrogate fuels combustion processes. It also helps to address the research gaps in the present theoretical techniques, the status of experimental gasification methods, and discussed the future research directions pertaining to biomass combustion. Hence, the aim of this paper is to develop a number of linear and non-linear analytical equations that can be used to compare to the experimental results when analysing the HHV values of biomass samples based on their proximate and ultimate research outcome values.

2. Methodology

2.1 Properties of Biomass Material

For the gasification experiments in this study, two separate biomass ingredients, namely, wood pellets and rubber seed, were used. The images of all the two types of biomass materials are shown in the Figure 1. Table 2 summarizes the findings of the proximate analyses. Besides, the TGA machine is used to perform the analysis for all biomass materials. As shown in Table 3 is the results of the ultimate analysis of the two types of biomass materials, which are wood pellet and rubber seed. In this study, the proximate analysis results of wood pellet and rubber seed are obtained by the TGA system and as shown in Figure 3 is the results from the TGA system. In addition, both the Figure 6 and 7 shown the area of the syngas in the graphs. Note that the results of the ultimate analysis or both biomass materials are calculated based on the equation as listed in Table 1.

Table 1
 Equations for calculate the ultimate analysis results

Syngas	Equations
Hydrogen	Volume of hydrogen = [(Area of hydrogen/1491) *(15)]
Oxygen	Volume of oxygen = [(Area of oxygen/3375) *(5)]
Nitrogen	Volume of nitrogen = [(Area of nitrogen/19562) *(40)]
Carbon monoxide	Volume of carbon monoxide = [(Area of carbon monoxide/15902) *(20)]
Methane	Volume of methane = [(Area of methane/4148) *(5)]
Carbon dioxide	Volume of carbon dioxide = [(Area of carbon dioxide/19804) *(15)]



(a)



(b)

Fig. 1. Biomass materials used in present study (a) wood pellet (b) rubber seed

Table 2
 Properties of biomass

Property	Wood pellet	Rubber Seeds
Proximate analysis		
Volatile Matter (%)	78.89	77.79
Fixed Carbon (%)	12.22	11.39
Ash (%)	0.83	4.23
Moisture Content (%)	8.06	6.61

Table 3
 Ultimate analysis of biomass materials

Property	Wood pellet	Rubber Seeds
Ultimate analysis		
Hydrogen (%)	1.49	0.10
Oxygen (%)	8.91	2.59
Nitrogen (%)	62.88	67.96
Carbon monoxide (%)	14.63	3.88
Methane (%)	2.67	11.96
Carbon dioxide (%)	48.77	35.51

2.2 Theoretical Equation to Determine HHV

HHV and biomass composition are essential properties that decide the energy content and how clean and effective a system is. From the overall study of biomass, there are a number of associations for estimating HHV. In the other hand, proximate analysis only includes normal laboratory instruments and can be used for calculation or estimation. Figure 2 shows the image of the DJ

machine. This machine can measure the properties of biomass on the Table 2. Figure 3 shows the image of the properties of the biomass content which obtained by the machine.



Fig. 2. Thermogravimetric Analyzer

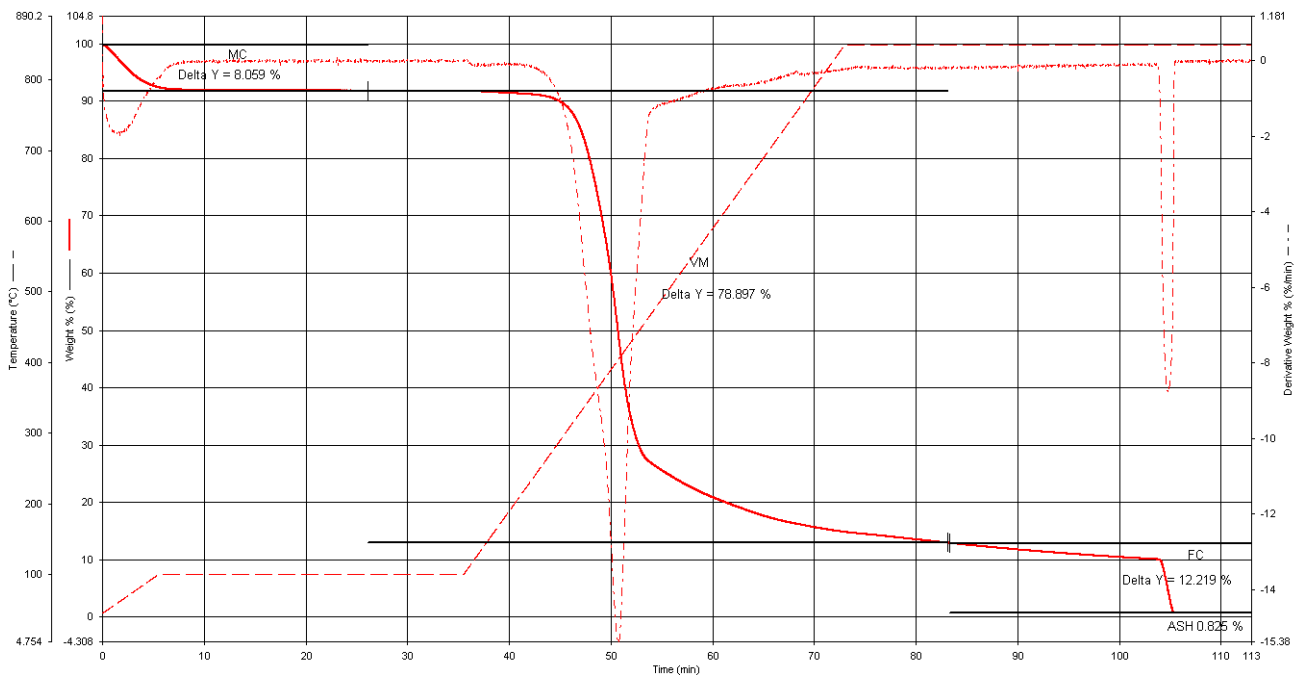


Fig. 3. The properties of the biomass content

The HHV of biomass was calculated using the majority of the equations used. The weight percentages of volatile matter and fixed carbon in the fuel sample were used to develop proximate analysis models. When establishing the quality and authenticity of data, the analytical approach used is crucial [11]. Table 4 shows the predicted equations of HHV by using proximate analysis. The criteria of equation which include few independent variables for prediction of the HHV.

Table 4
 Predicted equations of HHV using proximate analysis

No.	Equations	Criteria for selection	References
(1)	$HHV = -19.81996 + (0.36458 \times VM) + (0.50963 \times FC) + (0.19723 \times ASH)$	Assuming fuel HHV to be a linear function of volatile and nonvolatile and inorganic constituents	[12]
(2)	$HHV = -3.00488 + (0.19496 \times VM) + (0.34970 \times FC)$	Predicting HHV of lignocellulosic and carbonaceous materials from proximate analysis	[13]
(3)	$HHV = 15.92365 + (0.17527 \times FC) - (0.30807 \times ASH)$	Assuming fuel HHV to be a non-volatile	[12]
(4)	$HHV = -17.507 + (0.3985 \times VM) + (0.2875 \times FC)$	Prediction of HHV of biomass material such as herbaceous and woody biomasses	[14]
(5)	$HHV = 10.982 + (0.1136 \times VM) - (0.2848 \times ASH)$	Predict the HHV of agriculture waste from proximate analysis	[14]

Note:
 HHV = Higher heating value
 VM = Volatile matter
 FC = Fixed Carbon
 ASH = Ash Content

2.3 Set Up of Apparatus and Methods

The current studies were carried out on a bench scale fixed bed downdraft gasification system that was run at atmospheric pressure throughout. A downdraft gasifier, as well as control and measurement mechanisms, make up the gasification scheme. Figure 4 shows the gasification system's design. The biomass steadily descended through the gasifier drying, pyrolysis, partial oxidation, and reduction zones under gravity's control. The gas was gathered at the bottom of the gasifier during the gasification process, and the gas emitted from the gasifier reached the cyclone, where the fly ash in the product gas was produced. The producer gas which collected after filter of the gasification system was then analyze by the gas chromatograph to determine the intensity of the syngas (H_2 , O_2 , N_2 , CO , CH_4 , and CO_2). At this stage, the peak temperature of the gasification is operated at around 700°C.

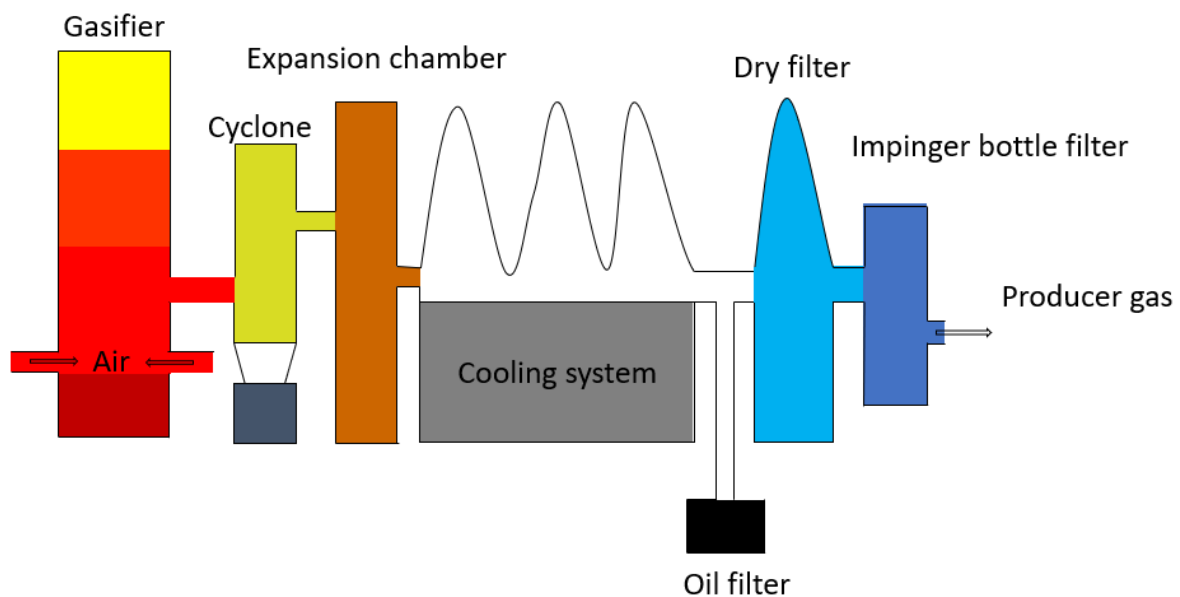


Fig. 4. Scheme of gasification

Figure 5 shows the image of the Agilent gas chromatograph machine. The content of syngas (H_2 , O_2 , N_2 , CO , CH_4 , and CO_2) are measured by this machine. The hydrogen, which vaccines 3ml of producer gas, and the five other gases, which vaccine 2.5ml of producer gas by the biomass material, are used to measure syngas content.

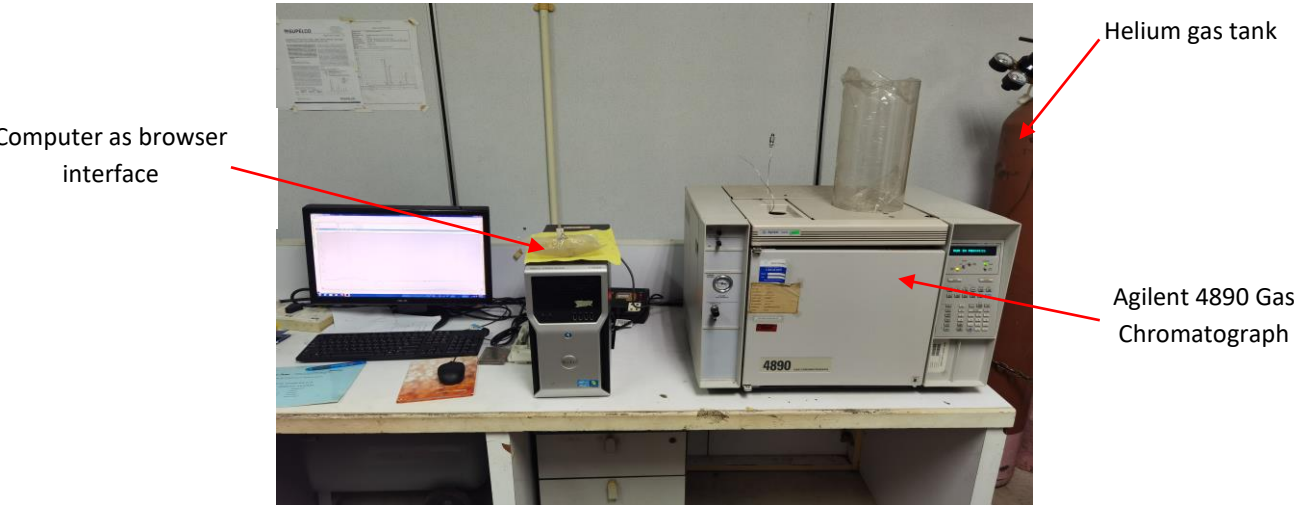


Fig. 5. Agilent gas chromatograph

Figure 6 shows the schematic diagram of analysis using GC. As can be seen, the syngas fuel sample is inserted via the injector port located at the top of the machine. With the help of Helium gas as the carrier gas, the syngas fuel sample is forced to flow through the heated capillary column in the GC oven. The chemical compound of the syngas can be determined by calculating the residential time of the gas inside the capillary column and the signal is detected by using the ionization analyzer located at the downstream of the GC.

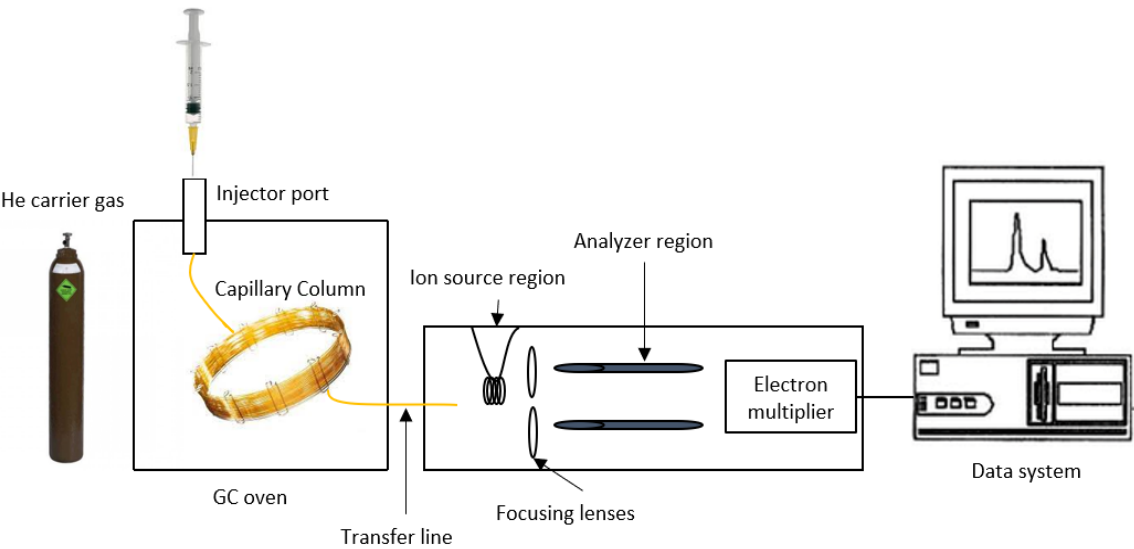


Fig. 6. The schematic diagram of GC

Figure 7 shows the sample of hydrogen content which obtained by the Agilent gas chromatograph. Figure 8 shows the sample of 5 other gaseous substances content which obtained by the Agilent gas chromatograph. The area of the gas content which can determine the percentage of the ultimate analysis on the Table 3.

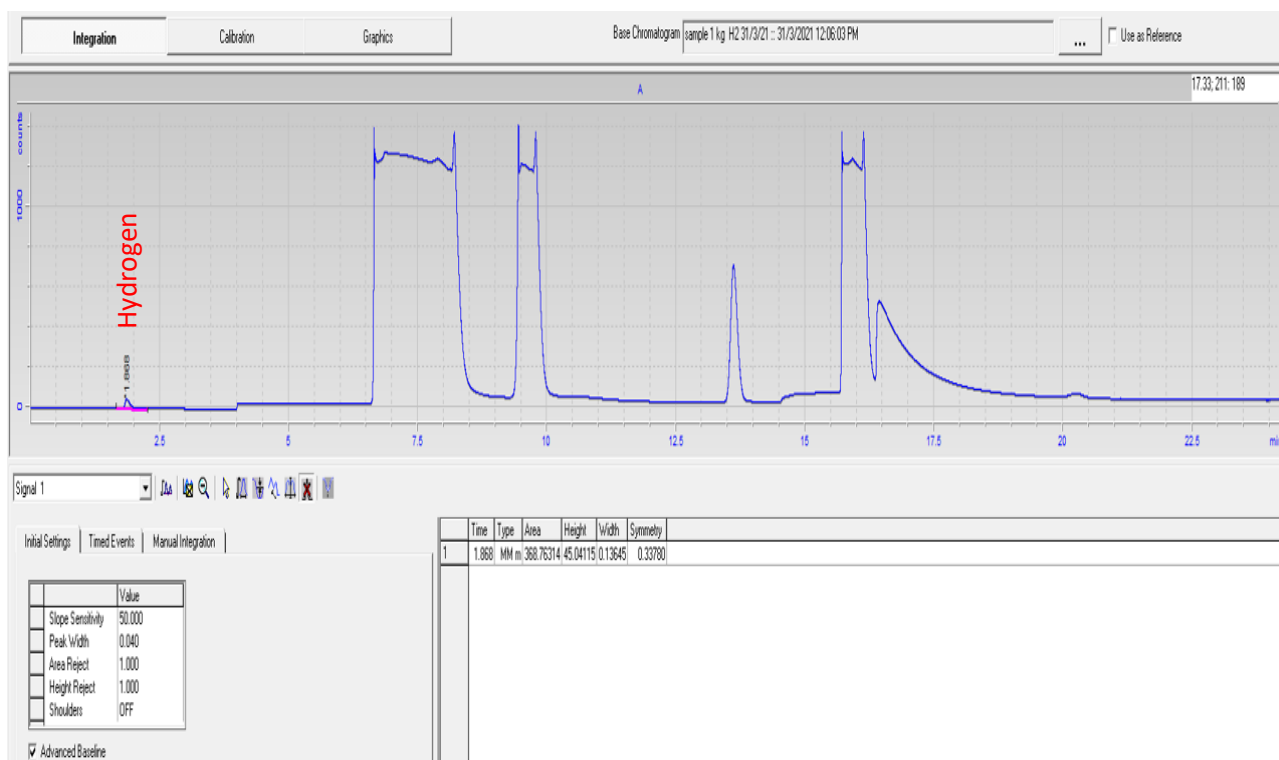


Fig. 7. The hydrogen content graph obtained by the Agilent gas chromatograph

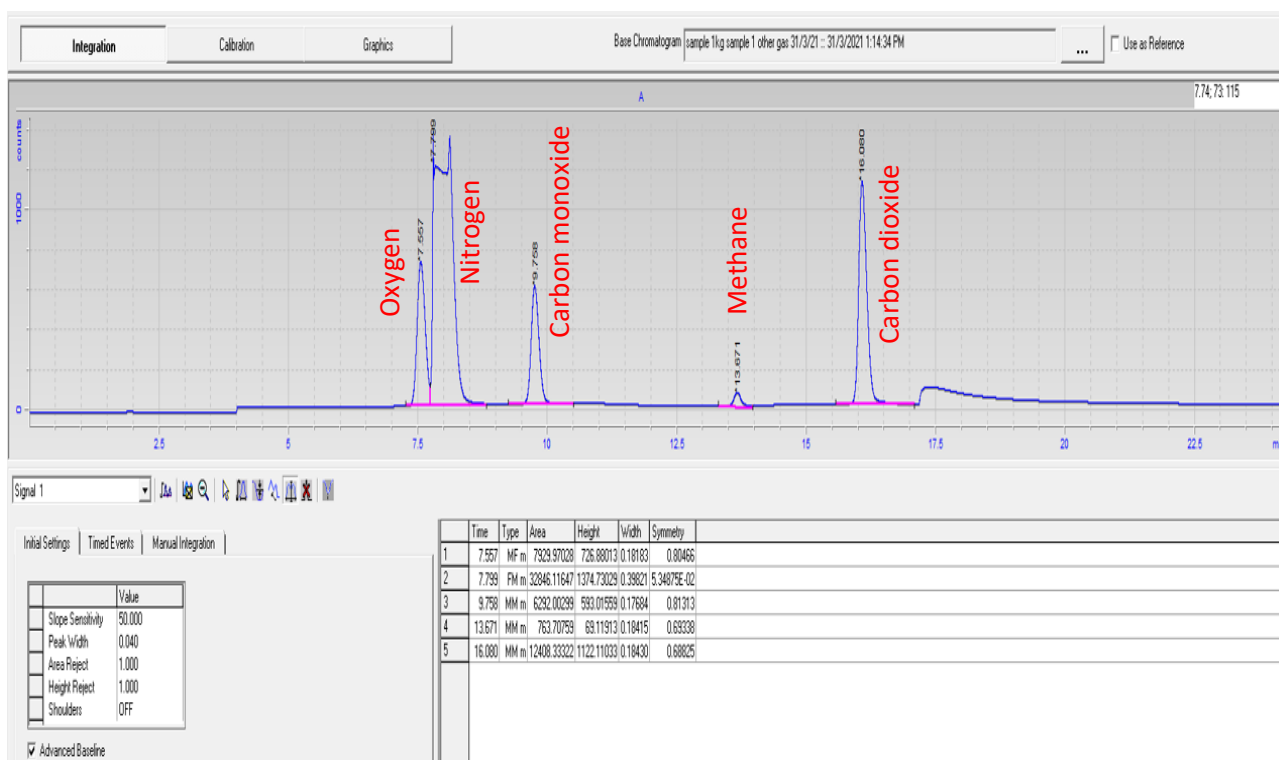


Fig. 8. The 5 other gaseous substances obtained by the Agilent gas chromatograph

3. Results and Discussion

3.1 Theoretical Analysis of HHV

Some analytical equations have been established to determine mathematical relationships between the HHV values of biomass samples and their proximate analysis outcomes values. In the

case of proximate analysis, these equations in Table 4 contain both linear and non-linear terms of volatile matter, fixed carbon, and ash content. Figure 9 displays the HHV results obtained by using equations based on the properties of biomass material. Figure 9 indicate that for the proximate analysis values, the HHV values of expected equations range from 15.33 to 19.71MJ/kg on wood pellet, while Nhuchhen *et al.*, [15] measured dry wood samples and obtained the HHV result of about 16.41 to 17.48MJ/kg. Figure 10 shows the HHV values of predicted equations range from 15.18 to 18.64 MJ/kg on rubber seed, Reshard *et al.*, [16] tested rubber seed samples and obtained an HHV result of around 18.93MJ/kg and J.Singh *et al.*, [17] obtained an HHV value of around 17.12MJ/kg from the experiment. Based on the Eq. (1) as given in Table 4, the percentage difference was 13.08% and 6.78% at values of 15.33MJ/kg compared to 16.41MJ/kg and 17.48MJ/kg who obtained by Nhuchhen *et al.*, while the percentage difference between rubber seed was 21.97% and 11.99%, compared to 18.93MJ/kg and 17.12/kg. In comparison to the other four equations, this one displays the greatest difference in percentage. Besides, the Eq. (4) shows the percentage difference with 0.19%, and 6.12% were obtained at values of 17.45MJ/kg, compared to 16.41MJ/kg and 17.48MJ/kg, respectively, on the wood pellet, while the percentage difference between rubber seed is 12.10% and 2.07%, which obtained a value of around 16.77MJ/kg, compared to 18.93MJ/kg and 17.12MJ/kg, respectively, on the wood pellet. This equation can be present is most suitable to estimate for HHV values on the biomass materials. These values of biomass samples yield very similar results regardless of the form of equation studied.

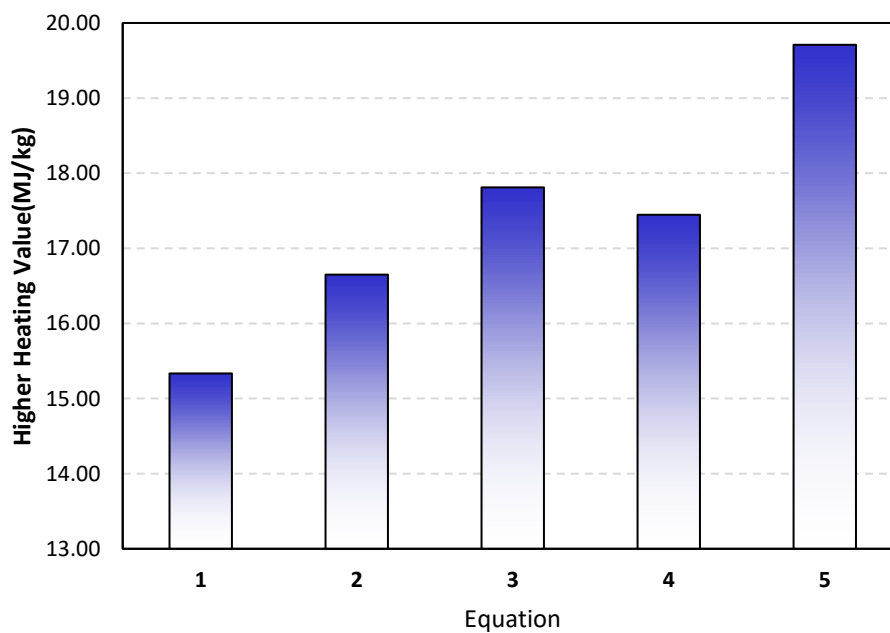


Fig. 9. Results of higher heating value of theoretical equation of wood pellet

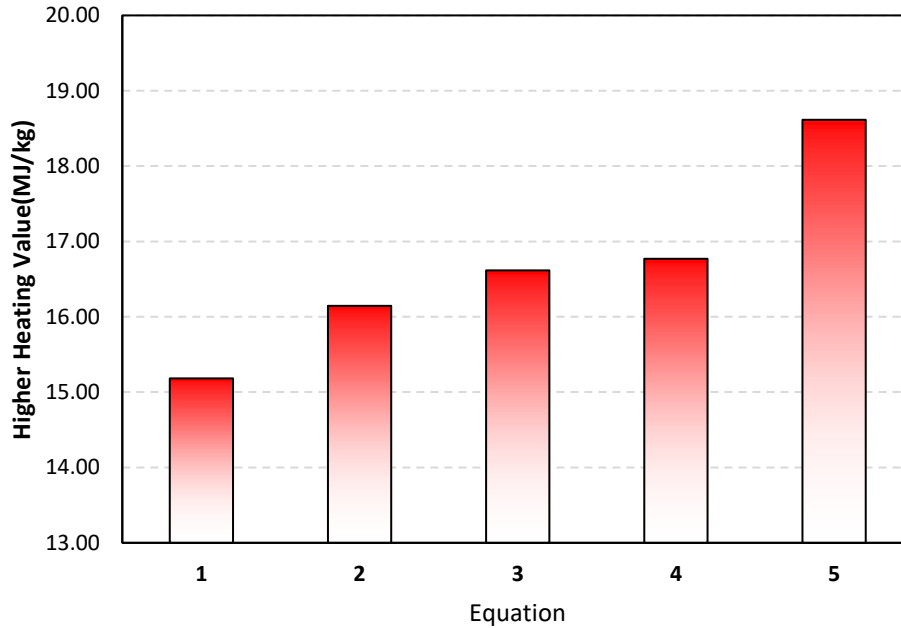


Fig. 10. Results of higher heating value of theoretical equation of rubber seed

3.2 Experimental Analysis of HHV

Syngas produced from the gasification of biomass feedstock is one of the possible renewable energy sources with environmentally clean fuel properties. The experimental study findings were analysed, the HHV value depend on the effect of different biomass energy sources. The concentration of combustible gases determines the consistency of the producer gas which are H_2 , CO and CH_4 . As a result, the combustible gas compositions were measured and the HHV were computed. The HHV results of the ultimate analysis were calculated by the equation has been shows as below

$$HHV = (37.7/100 \times \text{volume of the hydrogen} + 12.12/100 \times \text{volume of carbon monoxide} + 12.04/100 \times \text{volume of methane}) \quad (6)$$

The formula is obtained by calibrating the gas composition and GC technique. Figure 11 indicates that for the ultimate analysis values, the HHV values of obtained from the experimental range about 2.95 MJ/Nm^3 on wood pellet, while Mansur *et al.*, [18] simulate the wood pellet samples and obtained an HHV result ranging from 3.44 to 6.02 MJ/Nm^3 from the experimental design output. It also shows the HHV values obtained from the experimental results vary around 4.99 MJ/Nm^3 on the rubber seed, while Singh *et al.*, [19] obtained the HHV result of rubber seed from the experimental study at around 5.73 MJ/Nm^3 . When compared to the results on wood pellets, the experimental findings reveal a 15.35% difference, while rubber seed indicates a 13.81% difference.

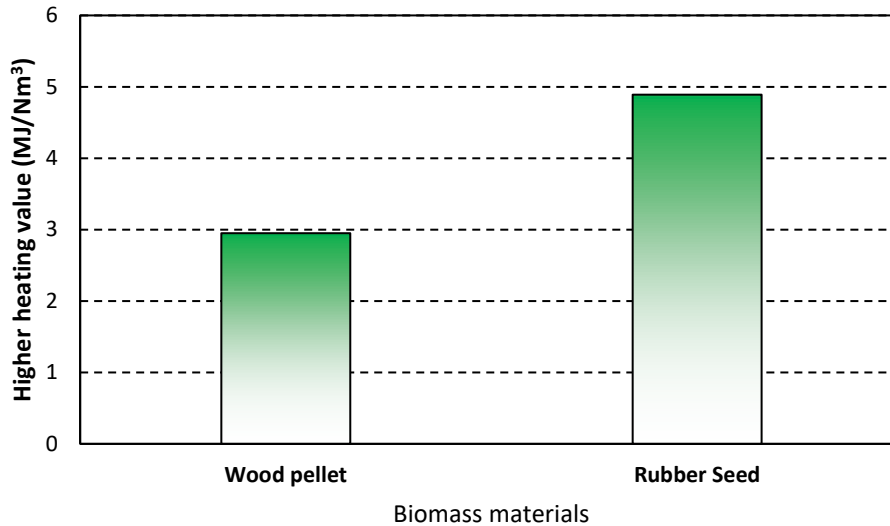


Fig. 11. Experimental results of HHV of wood pellet and rubber seed

4. Conclusions

To evaluate and build any bio-energy system, the heating value of biomass is essential. As a result, biomass materials representing a broad variety of renewable energy sources were described in this study by comparing their properties using proximate analysis. The proximate research findings, such as volatile matter, fixed carbon, and ash, were used to estimate the HHV of the biomass materials using certain linear and non-linear analytical equations, and the HHV ranged from 15.18 to 19.71MJ/kg for both biomass samples. The ultimate analysis, which included hydrogen, carbon monoxide, and methane, were used to measure the HHV of the biomass compounds, and the HHV for both biomass samples ranged around 3MJ/Nm³ to 5MJ/Nm³. Overall, wood pellet and rubber seed have the potential to be used as an alternative solid fuel and feedstock supply, as well as a bio-resource for processing.

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