Evaluation of Solid Biomass Fuel for Some Iraqi Agricultural Wastes Using Proximate and Ultimate Analyses

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Abstract. In this study, the characterizations of some Iraqi biomass agricultural residues have been investigated utilizing proximate, ultimate and caloric value analyses. This provides a preliminary evaluation for these types of solid biomass in terms of their potential for use directly or indirectly as fuels, especially for thermo-chemical processes such as combustion, gasification, and pyrolysis processes. For this work, five different types of Iraqi agricultural waste materials, namely Dodona trees, kernels of dates, corn silk-husk, sunflower seed husks, and reeds were studied. These materials are abundant wastes in Iraq, especially in the central and southern regions. The proximate analysis of moisture content, volatile matters, ash content, and fixed carbon tests were experimentally conducted for those five biomass materials, according to the British Standards Institution. In contrast, ultimate analysis was primarily represented by elements analysis. Carbon (C), Hydrogen (H), Oxygen (O), Nitrogen (N), and Sulfur (S) were calculated theoretically using highly accurate correlations. These correlations depended mainly on proximate analysis element results. A similar procedure of calculations was followed for the caloric value estimation. The results of this study show that for moisture content, Dodona tree and reed stalks have highest percentage, whilst the other biomass materials fall within the typical standard analysis 6–10 %. A good result was obtained for ash content. It shows a low weight percentage, which ranged from 0.77 to 3.5%. Given a high percentage of volatile matters for all materials except Dodona tree, these materials can be considered have high reactivity. The results for the important characteristic, higher heating values (HHV) for all biomass materials, were located in a typical range, 16–20 MJ/kg. In general, the results show that most of these interesting biomass materials have positive potential for fuel energy utilization.

Keywords: Solid biofuel, Renewable bioenergy, Solid biomass characterizations, Biomass proximate analysis, Ultimate analysis, Caloric value.

1. Introduction

Recently, due to the limited availability, environmental effects and elevated cost, of fossil fuels, interest has turned to other energy resources. Plant materials are considered important, promising and attractive renewable fuel resources for energy supply [1],[2]. These biomass materials can be practically utilized by conversion into different forms of biofuel – solid, liquid and gas – through the processes of thermochemical reaction. These include combustion, gasification, and pyrolysis [3]. In addition, biomass plant materials can neutralize CO₂ gas in the atmosphere and produce a smaller volume emission gases, depending on the feedstock type and thermochemical process design and conditions [4].

International Energy Agency studies have stated that Iraq is considered to have the world’s fifth most plentiful fossil oil reserves and the 13th highest fossil gas reserves in the world [5]. Although Iraq mainly depends on its fossil fuels for energy consumptions, it has a huge amount, millions of tons, of
agricultural residues which could be used as bio-renewable energy for biofuel production. Biomass plant wastes from some Iraqi agricultural residues, such as reed stalks, Dodona trees, date palm kernels, sunflower seed husks, and corn, have induced researchers to evaluate their potential as a source for energy production.

Any biomass material is intended for actual or possible use as a source of bioenergy must undergo preliminary evaluation and characterization prior to any thermochemical process. Many physical and chemical analyses that have been used for this purpose. A physical analysis is mainly represented by the proximate analysis, which provides a good estimation of moisture content, volatile materials, ash content, and fixed carbon in weight percent, experimentally.

The higher heating value (HHV) is an essential physical test to determine the chemical energy content of solid fuels[2]. Thermo-gravimetric analysis (TGA) has recently gained favor, especially prior to any thermochemical process[6].

Composition analysis, which provides a weight percent estimation of cellulose, hemicellulose, and lignin is another important physical test[7]. Chemical analysis, represented by ultimate analysis, provides a weight percent composition of the biomass elements mainly carbon (C), hydrogen (H), oxygen (O), nitrogen (N), and sulfur (S) [2].

In the literature are many research papers that refer to the importance of the proximate and ultimate analyses and calorific value test in solid biomass fuel evaluation and characterization. Bora Disco, Mahanta, & Bora [8] conducted a thorough characterization of five Indian lignocellulose biomass materials for bioethanol production using compositional, ultimate, and proximate analysis. They concluded that these biomaterials have good potential for biofuels production.

The results of proximate, ultimate and higher heating value analyses for five different plum fruits, which are grown in Croatia, were studied by N. Voca and et al. [2]. This study aimed to test the thermal value of those biomass materials, and concluded that these types of biomass could be characterized as environmentally agreeable solid biomass fuels.

Kezhen Qian and et al. evaluated the biomass feedstock types and their influences on the produced biomass char through a gasification conversion process using proximate and ultimate analyses. They concluded that different types of biomass raw materials noticeably affected the specifications of the solid biochar product. [9].

Harmandeep Singh and et al. analyzed four biomass residues in Punjab for evaluation purposes utilizing proximate, ultimate, and higher heating value analyses. The aim of their study was to provide a characterization database for different types of biomass [10].

Yaning Zhang and et al. investigated the physical properties of some agricultural residues which had significant effects on the design and functionality of combustion and gasification thermochemical processes. They found that these biomass materials had various physical properties[11].

Jianfeng Shen and et al. [12] developed high and validated correlations for estimating the atomic components of the solid biomass. depending mainly on biomass proximate analysis. These elements were carbon (C), hydrogen (H), and oxygen (O).

In this paper, the characterization and evaluation of five different types of Iraqi biomass agricultural residues were investigated. These biomass materials are Dodona tree, reed stalks, date palm kernels, sunflower seed husks, and corn. A simple proximate analysis technique was used to estimate moisture content, volatile matters, ash content and fixed carbon in weight percent, experimentally. An empirical correlation for ultimate and higher heating value HHV analyses was used to estimate elemental raw biomass composition and its chemical energy content, respectively. The main analyzed elements are carbon (C), hydrogen (H), and oxygen (O).
2. Materials and methodology

2.1 Solid biomass materials collection
All biomass materials in this study are available in the city of Kerbala, Iraq. Date palm kernels, corn stalk, and sunflower seed scales were collected as waste materials while Dodona trees and reed stalks were collected from their plants by cutting them. These Iraqi biomass raw materials are shown in Figure 1.

![Figure 1: Iraqi biomass agricultural residues raw materials](image)

2.2 Solid biomass materials preparation for tests
According to standard analysis for solid biomass fuels, a standard procedure of preparing a sample test for each collected biomass material and for each type of required test was followed. This standard is belong for British Standard Institution (BSI) Standards Publication Solid Recovered Fuels [13]. All standard test samples for all biomass materials were prepared with a particle size of 1 mm or less. Initially, some of the raw biomass, such as reeds stalks, Dodona tree and corn were cut to a small size. Thereafter all biomass types were ground using a high-speed grinder machine, model 200A, to very small particle size 1mm and below as shown in Figure 2. Subsequently, all the ground biomass materials were sieved using a U.S.A standard test sieve analysis apparatus-(Type Simpson Technologies – ASTM E-11 specification) to the desired standard particle size for the test sample as shown in Figure 2. Finally, all ground biomass materials were packed and stored in sealed transparent bags.
2.3 Proximate analysis

The proximate analysis provides the composition of the solid biomass fuels in terms of overall components such as: moisture content ($M$), ash content ($Ash$), volatile matter ($VM$), and fixed carbon ($FC$).

2.3.1 Moisture content test

The moisture content test is one of the proximate analyses for solid biomass fuels. All five interesting biomass materials were subjected to this test. The Standard British Institution (BSI) procedure entitled Solid biofuels – Determination of Moisture content – Oven dry Method [14] was followed for this test. The test sample of solid biomass fuel was dried at a temperature of 105 °C for 2–3 hours. This test was repeated three times and the mean value of the moisture content was determined to the nearest 0.1%.

The moisture content is determined from the following equation (1):

$$M_{ad} = \frac{(m_3 - m_1)}{(m_2 - m_1)} \times 100$$ .......................... (1)

Where

$M_{ad}$ = Percentage of the moisture content as analyzed.
$m_1$ = The mass in gm of the empty crucible plus lid;
$m_2$ = The mass in gm of the dish plus lid plus sample before drying;
$m_3$ = The mass in gm of the dish plus lid plus sample after drying.

2.3.2 Ash content test

Ash content is the inorganic residue materials remaining when the solid biomass fuel is completely combusted under air environment conditions. It consists mainly of silica, calcium, iron, aluminum and small quantities of sodium, titanium, magnesium, and potassium. Ash content was determined by following the BSI guidance Solid Biofuels – Determination of Ash Content under code BS EN 14775: 2009 [15].

Three empty silica dishes were heated in the furnace to 550 °C for 60 min. Then these dishes were removed from the furnace and allowed to cool to ambient temperature in a desiccator, without silica gel material. After cooling, the empty dishes were weighed to the nearest 0.1mg. 1gm of the sample was placed on the bottom of three dishes and weighed and then placed in a cold furnace. The samples were heated to 250 °C with a heating rate of 4.5 – 7.5 °C/min and then maintained at this temperature for 60 min. Then, the temperature in the furnace was raised to 550 °C with heating rate 10 °C/min and maintained at this temperature for at least 2 hours. The dishes were removed and allowed to cool to the ambient temperature in a desiccator without desiccant. Finally, the three dishes with ash were weighed and the amount of ash content (as analyzed) was calculated according to the following formula equation (2) [5]:

$$Ash_{ad} = \frac{(m_3 - m_1)}{(m_2 - m_1)} \times 100$$ .......................... (2)

Where

$Ash_{ad}$ = Percentage of the ash content as analyzed.
\( m_1 \) = The mass in gm of the empty dish.
\( m_2 \) = The mass in gm of the dish plus sample before heating.
\( m_3 \) = The mass in gm of the dish plus sample after heating.

The mean value of the ash content for three test samples was determined to the nearest 0.1%.

### 2.3.3 Volatile matters test

The volatile matters of solid biomass fuels are the non-condensable gases and condensable vapors that can be produced when the biomass fuel is heated to a certain temperature. The amount of volatile matters produced depends mainly on the nature of the feedstock, rate of heating, pyrolysis temperature and reactor design. Volatile matters were determined by following the BSI under the title *Solid Biofuels – Determination of the Content of Volatile Matter* under Code BS EN 15148:2009 [16]. A sample of biomass fuel was heated under an inert environment at 900 °C for 7 min. Three empty silica crucibles with their lids were heated in the furnace to 900°C for 7 min. Then these crucibles were removed from the furnace and allowed to cool to ambient temperature and then stored in a desiccator. After cooling, the empty crucibles with their lids were weighed to the nearest 0.1mg, then 1gm of the sample was placed on the bottom of three crucibles and these were weighed together with their lids and then inserted into a heated furnace at 900 °C for 7min. The crucibles were removed and permitted to cool to 50 or 30 °C, and then cooled to the ambient temperature in a desiccator. Finally, the three crucibles with lids plus content were weighed. Consequently, the amount of volatile matter content (as analyzed) was determined according to the following equation (3) [6]:

\[
VM_{ad} = \left( \frac{m_3-m_1}{m_2-m_1} \right) \times 100 - M_{ad} \hspace{1cm} \text{……………………… (3)}
\]

Where

\( Ash_{ad} \) = Percentage of the ash content as analyzed.
\( m_1 \) = The mass in gm of the empty crucible and lid.
\( m_2 \) = The mass in gm of the crucible and lid plus sample before heating.
\( m_3 \) = The mass in gm of the crucible and lid plus content after heating.
\( M_{ad} \) = The weight percentage of moisture as analyzed.

The mean value of the volatile matter content for three test samples was determined to the nearest 0.1%.

### 2.3.4 Fixed carbon calculation

In general, fixed carbon is a solid carbon in solid biomass fuels, which stays in the char after pyrolysis and devolatilization processes. It was calculated as shown in the empirical equation (4) [4]:

\[
\% FC = 100 - \left( \% \text{ of } M_{ad} + \% \text{ of } Ash_{ad} + \% \text{ of } VC_{ad} \right) \hspace{1cm} \text{……………………… (4)}
\]

### 2.4 Ultimate analysis:

The ultimate analysis provides the composition of the elements of the solid biomass in weight percentage, which represents the composition of any hydrocarbon material. The major elements are carbon, hydrogen, and oxygen, while sulfur and nitrogen are minor elements. This analysis is not simple and is highly expensive. In addition, the apparatus and equipment of this analysis are not easily available. For these reasons, high and accurate predicted correlations to calculate the elemental composition of the interesting Iraqi biomass materials, based on proximate analysis, were used in this research [12].
2.4.1 Carbon element C

The following correlation, Equation (5), in terms of fixed carbon FC, volatile matters VM, and ash content Ash was used to compute the carbon element (C) composition in weight percent [12]:

\[ C = 0.635 \times FC + 0.460 \times VM - 0.095 \times Ash \] ............................. (5)

2.4.2 Hydrogen element H

The following correlation, Equation (6), in terms of fixed carbon FC, volatile matters VM, and ash content Ash was used to computing the hydrogen element (H) composition in weight percent [12]:

\[ H = 0.059 \times FC + 0.060 \times VM + 0.010 \times Ash \] ............................. (6)

2.4.3 Oxygen element O

The following correlation, Equation (7), in terms of fixed carbon FC, volatile matters VM, and ash content Ash was used to computing the oxygen element (O) composition in weight percent [12]:

\[ O = 0.340 \times FC + 0.469 \times VM - 0.023 \times Ash \] ............................. (7)

2.5 Higher heating value HHV

Higher heating value (HHV) can be defined as the amount of heat liberated by the unit mass or volume of solid biomass fuel. It is an important characteristic for any biomass fuel to indicate its quality, especially for thermochemical conversion processes. Experimentally, HHV can be determined by bomb calorimeter.[17]. For the same reasons that justified the use of empirical correlations in the ultimate analysis, an accurate empirical mathematical equation based mainly on proximate analysis was also used to estimate the HHV for the interesting biomass materials of this study. The following Equation (8) was used for this purpose [17]:

\[ HHV = 20.7999 - 0.321(VM/FC) + 0.0051(VM/FC)^2 - 11.2277(Ash/VM) + \\
4.4953(Ash/VM)^2 - 0.7223(Ash/VM)^3 + 0.0383(Ash/VM)^4 + 0.0076(FC/Sha) \] ............................. (8)

3. Results and discussion

3.1 Effects of moisture content (MC)

Figure 3 presents the values of the moisture content percentage for all five Iraqi biomasses. It can be seen that Dodona trees biomass has the highest value at 29.66%, whereas date kernel has the lowest value at 6%. The moisture content of sunflower seed husk and corn were found to be the same. Typical moisture contents of freshly cut woody biomass are in the range of 30 to 60% [18], whereas the typical standard analysis, for desired solid biomass fuel, of moisture content is 6–10% [19]. For thermochemical processes such as gasification and pyrolysis, moisture content directly affects the process performance. A higher percentage impacts negatively on the efficiency of the process, thermal energy inside the gasifier or pyrolizer, producer gas quality, composition, and low heating values [20] and [21] and[22]. On the other hand, the higher moisture in the biomass feedstock is sometimes desirable for the thermochemical process, because it can promote and enhance steam reforming reactions and water gas reaction. This is useful for adjusting syngas composition[23]. According to this principle, Dodona tree is not desired given this moisture percentage, unless it can be pre-dried. Also, a little bit of drying treatment is needed for reed biomass material, while for date kernel, SF seed husk and corn there is no need for any drying treatment due to their typical and low moisture content percentages. It can be
concluded that high moisture in the biomass was not economically feasible for any thermochemical conversion process [24].

![Moisture content weight percentage for five Iraqi biomass agricultural residues](image)

**Figure 3: Moisture content weight percentage for five Iraqi biomass agricultural residues**

3.2 Effect of volatile materials VM

Figure 4 highlights the values for the volatile matters percentage for five Iraqi biomass materials. It can be observed that date kernel biomass has the highest value at 86%, whereas Dodona has the lowest value of 61.84%. The rest of the biomass materials (reed stalks, SF seed husk and corn) have 79.46, 83.69, and 81.11 %, respectively. These values were measured as the analyzed basis. These values are located in the volatile matter content range of the biomass materials (48–86 wt% on a dry basis). [25].

Volatile material is a measure of the solid biomass fuel’s reactivity and that means its tendency to react chemically. Thus, the biomass material which has greater volatile matter is considered more reactive and can be easily gasified or pyrolyzed, producing a high amount of producer gas and low amount of char [26]. However, according to the study results, Dodona trees had the lowest reactivity compared to the four other materials, with date kernels showing the highest reactivity. These results indicate that Dodona trees are more suitable for char production than for gas in gasification and pyrolysis processes. Whereas the rest of the materials are suitable for gas production, but with one main problem – that this gas is not clean due to the high tar yield. It can be noted that a typical amount of volatile matters for solid biomass fuels is in the range between 61–76% [19].
3.3 Effect of ash content

Ash

The values of ash content percentage for five Iraqi biomass materials are shown in Figure 5. It can be seen that SF seed husk biomass has the highest value at 3.18%, whereas reed biomass has the lowest value, of 0.77%. The ash content values of the remaining materials, Dodona tree, corn, and date kernel, are 1.53, 2.43, and 2.51%, respectively. The typical range for ash content in biomass is 1–15% [19]. What is interesting about these results is that these values of ash content, of all five interesting biomass materials, are all values at the lower end of the typical range. This gives a most significant finding – that these materials can be effectively used in fluidized bed combustors, gasifiers and pyrolizers and have a slightly negative effects on the heating value of the biomass fuels. It can be concluded that these five collected biomass materials have high potential to produce solid, gas and liquid biofuels in the future.
3.4 Effect of fixed carbon FC

The values of fixed carbon FC percentage for five Iraqi biomass materials are shown in Figure 6. It can be observed that Dodona tree biomass has the highest value, of 6.97%, whereas SF seed husk biomass has the lowest value at 4%. The fixed carbon values of the other materials, corn, reeds stalk, and date kernels, are 6.91, 5.77, and 5.49%, respectively. Due to the high values of volatile matters in these biomass materials, as shown in section 3.2, and due to the determination of fixed carbon by differences including moisture content, volatile matters, and ash content, all these indicate why the value of fixed carbon is low. Fixed carbon represents all solid carbon that remains in the char after all volatile matters have been released from raw biomass material by any heating at high temperature – excluding ash materials. This gives an indication that these biomass materials are not suitable for solid biofuel production, but are more appropriate for biogas and bio-liquid fuels.

![Figure 6: Fixed carbon percentage for five Iraqi biomass agricultural residues](image)

3.5 Effect of carbon element (C)

The results of carbon element (C) in terms of weight percentage for five Iraqi biomass materials are displayed in Figure 7. All five biomass materials are approximately identical except for the Dodona tree biomass material. The maximum value is for the date kernel at 42.81 wt%, whereas the minimum value is for Dodona tree. The values of the remaining materials: reeds stalk, SF seed husk and corn, are 40.14, 40.74, and 41.48 wt%, respectively.

Carbon, hydrogen, and oxygen represent the principal elements for determining the biomass fuels’ effectiveness and are the fundamental components of any solid biomass fuel material. [8]. The typical composition of carbon, hydrogen, and oxygen of biomass materials are 38–58, 5–8, 32–47 wt %, respectively [19].

The composition of these three elements plays an essential role in solid biomass conversion in thermochemical processes of combustion, gasification, and pyrolysis. They affect, specifically, the gas quality, liquid biofuel quality, and emission gases.
These elements have a marked effect on the stoichiometric mass air-fuel ratio in design calculations for the thermochemical conversion process, combustion and gasification. These elements are involved in many oxidation reactions, water–gas reactions, hydrogen gasification, and Boudouard reaction. In addition, the higher amount of carbon element in the solid biomass material produces higher heat energy at the thermochemical conversion process. [27].

![Carbon element weight percent for five Iraqi biomass agricultural residues](image)

**Figure 7:** Carbon element weight percent for five Iraqi biomass agricultural residues

### 3.6 Effect of Hydrogen element H

The results of hydrogen element (H) in terms of weight percentage for five Iraqi biomass materials are presented in Figure 8. Clearly, all five biomass materials have a slight difference in their hydrogen weight percentages except Dodona tree material, which has the lowest value of 4.36 wt%. The maximum value is for the date kernel at 5.66 wt%. The values of the other materials, reed stalks, SF seed husk and corn, are 5.3, 5.37, and 5.5 wt%, respectively. The effects of this element on the potential and efficacy of biomass fuels have been sufficiently explained in section 3.5. Also, the effect of atomic ratio H/C has been discussed in section 3.8.
3.7 Effect of oxygen element (O)

The results of oxygen element (O) in weight percentage for five Iraqi biomass materials are illustrated in Figure 9. It can be seen that all five biomass materials have slight differences in their oxygen weight percent except Dodona tree material, which has the lowest value of 31.34 wt%. The maximum value is for the date kernel at 42.14 wt%. The values of the other materials: reed stalks, SF seed husk and corn are 39.21, 40.54, and 40.34 wt%, respectively. The effects of this element on the potential of biomass fuels have been sufficiently explained in section 3.5. Also, the effect of atomic ratio O/C has been discussed in section 3.8.
3.8 Atomic ratio H/C and O/C effects

The values of two parameters H/C and O/C atomic ratios for five Iraqi biomass materials are shown in Table 1a and 1b, respectively. It can be seen that for all five biomass materials, both atomic ratios H/C and O/C are convergent. Their ranges are 1.58–1.6 and 0.72–0.75, respectively. The typical atomic ratio of H/C of the solid biomass is almost 1.5[4].

These ratios are usually used to classify the solid fuels in order to understand the heating value of the fuel. When these ratios increase, the value of heating value decreases. For example, when O/C ratio increases from 0.1 to 0.7 the higher heating value HHV of biomass material decreases from 38 MJ/kg to 15 MJ/kg [4] and [8]. Van Krevelen’s diagram is a good tool to show the sequence of biomass materials regarding their higher heating values based on H:C and O:C ratios [1].

In summary, this similarity of these two ratios for these five biomass materials provides a good indication that these materials can be classified as one group in terms of their chemical properties and can be treated as one raw biomass material, especially in the thermochemical conversion process used to produce biofuel materials.

| Iraqi Biomass Materials | H/C Atomic Ratio |
|-------------------------|------------------|
| Dodona tree             | 1.6              |
| Reeds stalk             | 1.58             |
| Kernel of date          | 1.59             |
| SF seed husk            | 1.58             |
| Corn                    | 1.59             |

3.9 Effect of higher heating value HHV

Figure 10 highlights the values of the higher heating value HHV in MJ/kg unit for five Iraqi biomass materials. It can be observed that Dodona tree biomass has the highest value of 18.1 MJ/kg, whereas SF seed husk has the lowest value of 15.85. The rest of the biomass materials, reed stalks, date kernels and corn, have 17.27, 16.68, and 17.41, respectively. The typical value of the higher heating value HHV for biomass materials is in the range 16–20 MJ/kg [19]. This typical range suggests that these solid biomass fuels have a good potential for biofuel production, based upon higher heating value characteristics.
Figure 10: Higher heating value HHV in MJ/kg for five Iraqi biomass agricultural residues

4. Conclusion

This study set out to assess the feasibility and potential of some Iraqi solid biomass agricultural residues. Five biomass materials were selected for this assessment study. Proximate, ultimate and caloric value analyses techniques were used for this purpose. These analyses are represented by moisture content (MC%), volatile matters (VM%), ash content (Ash %) and fixed carbon (FC%) for the first analysis and carbon element (wt% C), hydrogen element (wt% H), and oxygen element (wt% O) for second analysis, and higher heating value HHV for the third analysis. This research has shown that for moisture content results Dodona tree has high percentage at around 29.96 %, but this is an unhelpful percentage, whereas the rest of the biomass materials are within the typical standard analysis 6–10 %, except for reed stalks which have 14%. For volatile matters, the results show that all materials have a percentage within 79.5–86% except Dodona tree, which has the lowest value of 61.84%. These findings indicate that in general, these biomass materials have high reactivity due to their high percentage of volatile materials.

For ash content, the results show a low percentage, ranging from 0.77 to 3.5%, that can be used for fluidized bed gasifiers and pyrolyzers. Also, results show that for fixed carbon the quantities are very low, ranging between 4 and 6.97%. This finding indicates that these materials are not suitable for high-quality char production. The elemental analysis findings for the five biomass materials indicate that these materials have a typical standard range for their major elemental composition C, H, and O. They ranged 38–58%, 5–8%, and 32–47%, respectively. Finally, the findings for higher heating values (HHV), indicate that these biomass materials hold the acceptance range of chemical energy 16–20 MJ/kg.

Thus, it can be concluded in general, that these collected five Iraqi biomass agricultural residues have high potential and could be candidates to produce three types of biofuels: biogas, bio-liquid, and biochar through thermochemical conversion processes: pyrolysis, gasification, and combustion.

References

[1] P. Mckendry 2002 “Energy production from biomass ( part 1 ): overview of biomass,”
J. Bioresour. Technol., vol. 83, no. July 2001, pp. 37–46.

[2] A. Matin and I. Sedak 2016 “Proximate, Ultimate, and Energy Values Analysis of
Plum Biomass By-products Case Study: Croatia’s Potential,” *J. Agr. Sci. Tech.*, vol. 18, pp. 1655–66.

[3] M. Alhwayzee 2018 “Experimental Investigation of the Effects of Some Significant Parameters on the Pyrolysis of Solid Biomass Materials,” *J. Ser. I O P Conf. Sci. Mater.*

[4] P. Basu 2010 *Biomass Gasification and Pyrolysis-Practical Design and Theory*. Elsevier Ink.

[5] International Energy Agency 2012 “Iraq Energy Outlook,” pp. 1–142.

[6] J. F. Saldarriaga, R. Aguado, A. Pablos, M. Amutio, M. Olazar, and J. Bilbao 2015 “Fast characterization of biomass fuels by thermogravimetric analysis,” *J. Fuel*, vol. 140, pp. 744–51.

[7] H. Yang 2007 “Characteristics of hemicellulose, cellulose and lignin pyrolysis,” *J. Fuel*, vol. 86, pp. 1781–88.

[8] Y. Disco, P. Mahanta, and U. Bora 2017 “Comprehensive characterization of lignocellulosic biomass through proximate, ultimate and compositional analysis for bioenergy production,” *Renew. Energy*, vol. 103, pp. 490–00.

[9] K. Qian *et al.* 2013 “Effects of Biomass Feedstocks and Gasification Conditions on the Physiochemical Properties of Char,” *J. Energies*, vol. 6, pp. 3972–86.

[10] H. Singh, P. K. Sapra, and B. S. Sidhu, “Evaluation and Characterization of Different Biomass Residues through Proximate & Ultimate Analysis and Heating Value,” *vol. 2*, no. 2, pp. 6–10, 2013.

[11] Y. Zhang, A. E. Ghaly, and B. Li 2012 “Availability and physical properties of residues from major agricultural crops for energy conversion” *J. Ame. Jour. of Agr. and Bio.*, vol. 7, no. 3, pp. 312–21.

[12] J. Shen, S. Zhu, X. Liu, H. Zhang, and J. Tan 2010 “The prediction of elemental composition of biomass based on proximate analysis,” *J. Energy Convers. Manag.*, vol. 51, no. 5, pp. 983–87.

[13] “BSI Standards Publication Solid recovered fuels — Methods for the preparation of the test sample from the laboratory sample,” 2011.

[14] En 14774-3 2009 “Solid biofuels - Determination of moisture content - Oven dry method - Part 3: Total moisture - Reference method,” pp. 1–8.

[15] BS EN 14775:2009, 2009 “Solid biofuels - Determination of ash content,” *Management*, pp. 1–140.

[16] CEN (European Comitie for Standardisation 2009 “EN 15148:2009 Solid biofuels - Determination of the content of volatile matter,”

[17] D. R. Nhuchhen and P. A. Salam 2012 “Estimation of higher heating value of biomass from proximate analysis: A new approach,” *J. Fuel*, vol. 99, pp. 55–63.

[18] W. E. M. Hughes and E. D. Larson 1998 “Effect of Fuel Moisture Content on Biomass-IGCC Performance,” *J. Eng. Gas Turbines Power*, vol. 120, no. 3, p. 455.
[19] I. A. Legonda 2012 “Biomass gasification using a horizontal entrained-flow gasifier and catalytic processing of the product gas,” PhD thesis, Cardiff University, Cardiff, UK

[20] R. Marsh et al. 2008 “Biomass and waste co-firing in large-scale combustion systems,” J. Proc. ICE-Energy, no. August, pp. 115–26.

[21] V. Kirsanovs, A. Žandeckis, D. Blumberga, and I. Veidenbergs 2014 “The influence of process temperature, equivalence ratio and fuel moisture content on gasification process: A review,” Conf. Pap., vol. 2, no. JUNE.

[22] A. Molino, S. Chianese, and D. Musmarra 2015 “Biomass gasification technology: The state of the art overview,” J. Energy Chem., vol. 000, pp. 1–16.

[23] S. V Vassilev, D. Baxter, L. K. Andersen, and C. G. Vassileva 2010 “An overview of the chemical composition of biomass,” J. Fuel, vol. 89, no. 5, pp. 913–33.

[24] K. Rajendran 2017 “Effect of Moisture Content on Lignocellulosic Environmental Impacts,” MDPI, vol. 5, no. 78.

[25] J. M. Vargas-moreno, A. J. Callejón-ferre, J. Pérez-alonso, and B. Velázquez-martí, 2012 “A review of the mathematical models for predicting the heating value of biomass materials,” J. Renew. Sustain. Energy Rev., vol. 16, no. 5, pp. 3065–83.

[26] P. Basu 2006 Combustion and Gasification fluidised Beds, Taylor & Francis Group, LLC, no. 1.

[27] I. Barmina et al. 2013 “EFFECTS OF BIOMASS COMPOSITION VARIATIONS ON GASIFICATION AND COMBUSTION CHARACTERISTICS,” J. Eng. Rural Dev. Jelgava, no. 5, pp. 382–87.