International Journal of
Science and Engineering Investigations vol. 1, issue 5, June 2012
ISSN: 2251-8843

Gross Heat of Combustion for Some Saudi Hardwoods

Sherif S. Z. Hindi [1], G. M. Abdel-Rahman[2], A.I. AL-Qubaie[3]
[1&3]Department of Arid Land Agriculture, Faculty of Meteorology, Environment and Arid Land Agriculture, King Abdulaziz University, Jeddah, Saudi Arabia
[2] Prof. Dept. Agr. Eng. – Facu. Agr. – Cairo Univ., Cairo, Egypt. Currently loaned to Dept Arid Land Agr., - Facu. Meteorology, Envi. and Arid Land Agr, King Abdulaziz University, Jeddah, Saudi Arabia.
(shindi@kau.edu.sa[1], gamal3560@yahoo.com[2], Wsbe86@hotmail.com[3])

Abstract- Physical and chemical properties of wood from six Saudi species were investigated to insure their suitability for domestic purposes. The species studied were *Prosopis juliflora*, *Casuarina glauca*, *Eucalyptus camaldulensis*, *Acacia saligna*, *Tamarix aphylla* and *Ficus retusa*. The wood properties determined were gross heat of combustion, specific gravity, void volume and its contents of ash, total extractives, lignin and holocellulose. The species differed significantly among the properties determined. *Prosopis juliflora* wood had the highest gross heat of combustion (GHC) of 4972 cal/g, while the lowest values were for *Tamarix aphylla* and *Ficus retusa* (4389 and 4242 cal/g, respectively). The GHC was found to be directly related to specific gravity (SG) and inversely to void volume (VV). Accordingly, *Prosopis juliflora* wood with the highest SG (0.861) and the lowest VV (0.437 cm^3/g) had the highest GHC value. However, the effect of the VV of wood on its GHC is not understanding but it may alert the thermal behavior during wood burning.

Further, *Prosopis juliflora* had the highest total extractives that may be responsible of its high GHC value, while this finding was not clear for the other species. Furthermore, there were no relationships found between each of lignin and holocellulose contents of wood and the GHC. However, the higher contents of holocellulose for *Acacia saligna* (76.03%) and *Casuarina glauca* (65.34%) reflects the importance of orientation of such species to fibrous products other than fuel purposes.

Keywords*- Wood; Gross heat of combustion; Specific gravity; Total extractives.*

I. INTRODUCTION

Biomass refers to organic materials that arise from plants as a result of energy storage from sunlight by photosynthesis in chemical bonds within molecules. It is traditionally used as a resource to extract valuable chemicals but more recently it has been considered as a substitute for fossil fuels in the energy sector. It was reported that sustainability in energy recovery from biomass is becoming attractive because biomass adds no additional greenhouse gases to the atmosphere [1].

Wood usage for cooking and heating is still very relevant in most developing countries especially those of sub-Saharan Africa and many parts of Asia. Therefore, sustainable means of generating it for this and other purposes are necessary bearing in mind the influence of indigenous knowledge/user's perspective on any production method regarding success and sustenance [2].

In Saudi Arabia, the potential of timber trees as plantation species is being increasingly recognized, especially for fast growing species. In addition to their benefits as windbreaks and shelterbelts, wood is used as a source of energy by direct burning especially in the remote areas, villages and during Muslim pilgrimage at Mena and Araft camps to provide heat for cooking and other conventional uses. Firewood along with charcoal are sold commercially in different regions of Saudi Arabia at big public markets as well as conventional supermarkets. The wide utilization of firewood in KSA arises from Saudi habits and their preferring to the Arabic cooking flavor.

It was stated that temperate species are better suited as fuelwood species as they contain high density wood, low ash content and low N-percentage [3].

Based on Telmo and Lousada [4], softwoods had a high calorific value between 19660.02 and 20360.45 kJ/kg, and the hardwoods had a ranging interval between 17631.66 and 20809.47 kJ/kg, in accordance to Phyllis distribution of higher heating value (HHV). The HHV at a constant pressure measures the enthalpy change of combustion with water condensed. The HHVs of 7 species of biomass shells were correlated with their lignin, fixed carbon, and volatile material contents. There was a highly significant correlation between the HHV of the woody biomass and the lignin [5 and 6] , fixed carbon, and volatile material contents [6].

The extractives of the heartwood, sapwood, bark, branch and leaves of *Gmelina arborea* positively contributed to the heating value; removal of the extractives caused reduction in the heat of combustion [7].

It was found high negative correlations of the wood heat value with holocellulose and ash, and high positive correlations with wood density, lignin, and alcohol-benzene and hot-water soluble [8].

Basic data on energy and chemical contents of wood of different species are essential to determine the utilization potential of these species as an energy source [9]. It was reported by [10] that the fuel properties and process conditions affect the combustion characteristics, altering the heat generation, heat transfer and reaction rates in a complicated manner. Further, the air flow rate is the key process parameter that determines the amount of oxygen available and convective heat transfer.

The present investigation was initiated to shed some lights on the suitability of six Saudi hardwoods for heating processes as related to important parent physical and chemical properties of wood.

II. Materials and Methods

Raw Material

Six Saudi hardwood species were selected to investigate the gross heat of combustion of wood as affected by some physical and chemical properties of wood. The study was performed during 2010 at the Agricultural Research Station, Hada Al-Sham, King Abdul-Aziz University. The species studied were mesquite (*Prosopis juliflora* D.C.), swamp she-oak (*Casuarina glauca* Sieb.), river red gum (*Eucalyptus camaldulensis* Dehn.), blue-leafed wattle (*Acacia saligna* (Labill.) H. Wendl.), tamarisk (*Tamarix aphylla* (L.) Karst.) and tiger bark ficus (*Ficus retusa* Linn.). The sex species are well known as arid conditions-tolerant for deserts and newly reclaimed lands and they have been showed a noticeable success in different regions of the Kingdom. Furthermore, these species have different physical, chemical and anatomical properties that are even worth investigating. Four healthy trees were chosen randomly from those grown at Hada Al-Sham. The ages of the selected trees ranged from 15-20 years, while diameters outside bark of them varied from 20-30 cm.

Samples Preparation

After the selected trees were felled, one disc, about 40 cm thick along the grain, was cut from the stem of one tree of each species at height of 50 cm above ground level. A diametric strip 5 cm nominal width was removed from each disc and air-dried. From each strip, five consequent defect-free samples (2.5 cm radially and tangentially and 2 cm longitudinally each) were isolated for specific gravity (SG) of wood determination as well as void volume (VV) of wood calculation. In addition, four consequent defect-free cubic samples (1.5cm^3 each) were isolated from that strip were isolated for gross heat of combustion (GHC) of wood test. The remainder volume of the strip was machined into small samples, chipped, and ground in a Wiley mill. Then wood meal was screened using different sieves depending on the standard method used for the chemical determination.

Wood properties determinations

The studied traits for wood were: Gross heat of combustion (GHC), specific gravity (SG), ash content (AC), total extractives content (TEC), lignin content (LC), and holocellulose content (HC). The GHC of wood was determined using an adiabatic oxygen bomb calorimeter (IKA, C 400) as shown in Fig. 1 in accordance to ASTM [11].

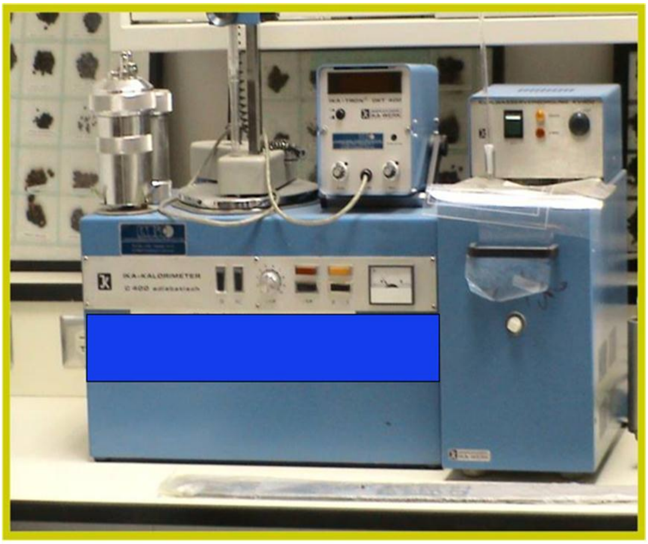

Fig.1. Calorimeter used to determine the gross heat of combustion of wood.

The calorimeter was standardized using benzoic acid pellets. Correction factors for the oven-dry wood samples, combustion of fusing wire and thermometer were included in the calculations, while those for nitric and sulfuric acids formations were not included because they are too small to consider. The specific gravity of wood was calculated based on oven-dry weight and volume in which volume was determined by mercury displacement [12]. To measure AC of wood, air-dried samples were ignited at 600 °C until all carbon is eliminated. The AC of wood was calculated as a percentage based on the oven dry weight of the parent wood [13]. The total extractives content was determined based on ASTM [14]. The process involves three steps of extraction using ethanol-benzene, ethanol and hot water. Then, each sample was divided into two equal portions. One of them was assigned for LC determination and the other for HC test. The LC was determined according to ASTM [15] using H_2SO_4 (72 %). HC was determined according to the chlorite method stated by [16] and applied by Hindi [17]. The VV of wood was theoretically calculated by subtracting the quotient of SG of wood and SG of cell wall material (CWM) from the unity considering that the SG of SWM equals 1.5.

Randomized complete block design with four replications was used in this study according to [18]. Statistical analysis of the recorded data was done using the analysis of variance procedure and least significant difference test (LSD) at $P \leq 0.05$.

III. RESULTS AND DISCUSSION

The physical and chemical properties of wood for the six hardwood species are listed in Fig's 2-7. The statistical analysis indicated that the six species tested were significantly different among the properties determined.

It is clear from Fig. 2. that *Prosopis juliflora* wood had the highest GHC (4972 cal/g), while *Ficus retusa* had the lowest values (4242 cal/g, respectively).

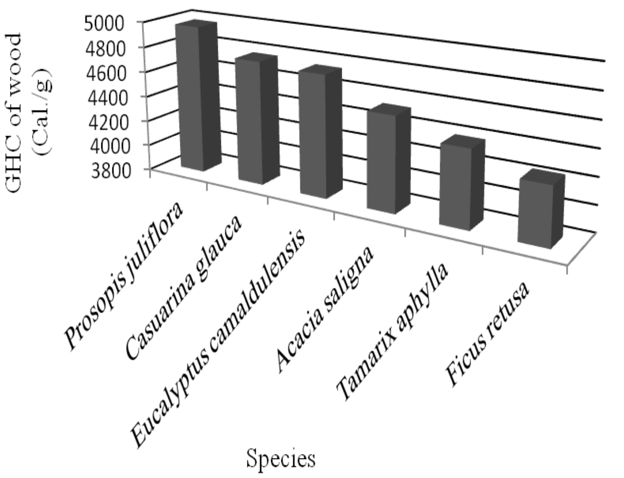

Fig. 2. Gross heat of combustion (GHC) of wood.

This is may be attributed to their SG as shown in Fig's 2 and 3 [19]. According to the positive relationship between SG of wood and its GHC (Fig. 3), *Prosopis juliflora* wood with the highest SG (0.861) had the highest GHC value, while *Ficus retusa* with the lowest SG (0.722) gave the lowest GHC. The results are in agreement with those obtained by several researchers [9], [19] , [20], [21], [13], [22], [23], [25].

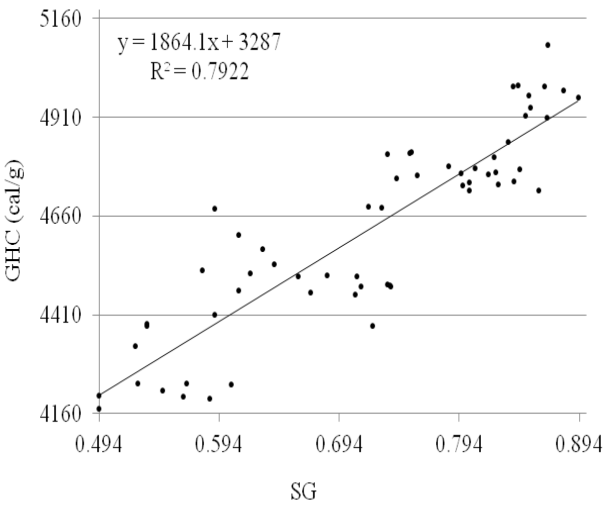

Fig. 3. The relationship between specific gravity (SG) and gross heat of combustion (GHC) of wood.

It can be also seen from Fig. 4 that *Prosopis juliflora* had the highest TEC that may be affected its highest GHC value, while this is not clear for the other species. Furthermore, there was no relationship found between each of LC and HC of wood and its GHC. However, the higher contents of HC for *Acacia saligna* (76.03%) and *Casuarina glauca* (65.34%) are a guide for orientation such species to fibrous products other than fuel purposes.

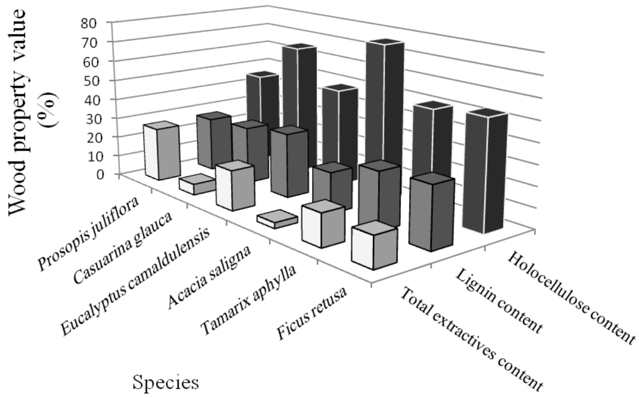

Fig. 4. Total extractives, lignin and holocellulose contents of wood .

It was stated a negative relationship between the VV of wood and its GHC (Fig. 5). However, the VV of wood had no understanding effect on the GHC itself but may alert thermal behavior during wood burning [9]. This can affect easing and duration of ignition only if other chemical factors do not interfere.

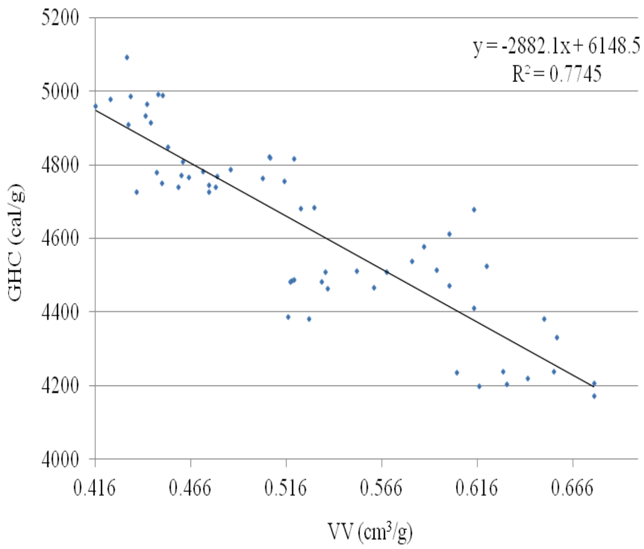

Fig. 5. The relationship between void volume (VV) and gross heat of combustion (GHC) of wood.

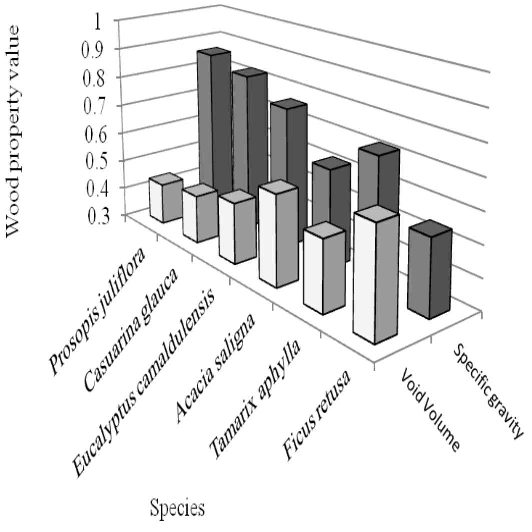

Fig. 6. Specific gravity and void volume (cm^3/g) of wood.

Accordingly, species with high VV of wood (Fig. 6) such as *Ficus retusa* (0.637cm^3/g) are expected to be faster in ignition but for less duration. On the other hand, those species with low VV of wood such as *Prosopis juliflora* (0.426 cm^3/g) may be hard to ignite and have a wide ignition period. The effect of AC of wood on the GHC appeared in the case of *Prosopis juliflora* wood with the highest GHC and lowest AC (0.641%) as well as *Tamarix aphylla* and *Ficus retusa* with the lowest GHC and the highest AC of wood values (5.46% and 2.63%, respectively) as shown in Fig. 7.

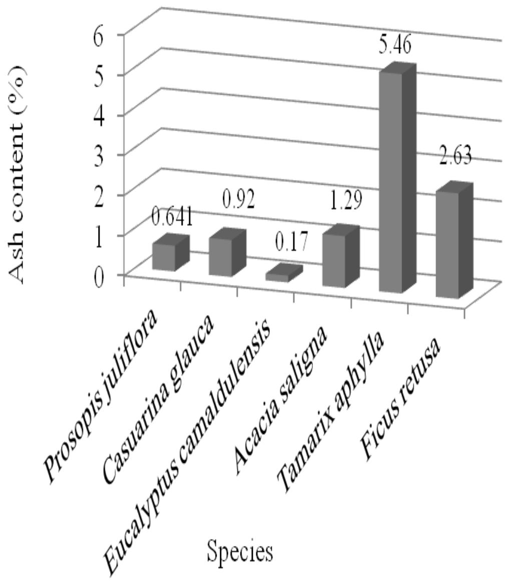

Fig. 7. Ash content of wood.

This is supported by the finding of Kumar [20]. who stated that the calorific value of mature trees was higher than that of lower age trees, but the ash content was much higher in lower age trees compared to mature trees. However, the effect of wood ash in GHC can be explained by that minerals absorb part of heat librated upon energy recovery without adding further heat.

IV. CONCLUSION

The six species studied, namely *Prosopis juliflora*, *Casuarina glauca*, *Eucalyptus camaldulensis*, *Acacia saligna*, *Tamarix aphylla* and *Ficus retusa* were significantly different in their gross heat of combustion, specific gravity, void volume and their contents of ash, total extractives, lignin and holocellulose. Among the six species studied, *Prosopis juliflora* wood had the highest values of gross heat of combustion, specific gravity and total extractives with the lowest values of ash and void volume. On the other hand, *Ficus retusa* had the lowest values of GHC and specific gravity with the highest void volume. The GHC was related directly and inversely to each of specific gravity and void volume of wood, respectively. The VV of wood had no understanding effect on the GHC itself but may alert thermal behavior during wood burning. This can affect easing and duration of ignition only if other chemical factors do not interfere. there was no relationship found between each of LC and HC of wood and its GHC.

The higher contents of HC for *Acacia saligna* and *Casuarina glauca* are a guide for orientation such species to fibrous products other than fuel purposes.

REFERENCES

[1] V. Strezov, M. Patterson, V. Zymia, K. Fisher, T. J. Evan, and P. F. Nelson. Fundamental aspects of biomass carbonization. J. Analytical. and Applied Pyrolysis. 79, 91-100 (2007).
[2] A. A. Erakhrumen. Energy value as a factor of agroforestry wood species selectivity in Akinyele and Ido local government areas of Oyo State, Nigeria. Biomass Bioenergy, 33, 1428-1434 (2009).
[3] B.P. Bhatt and N.P. Todaria. Fuelwood characteristics of some mountain trees and shrubs. Biomass. Volume 21 (3), 233–238 (1990).
[4] C. Telmo, J. Lousada. Heating values of wood pellets from different species. Biomass and bioenergy. 35 (7), 2634–2639 (2011).
[5] A. Demirbaş[a]. Relationships between lignin contents and heating values of biomass. Energy Conversion and Management. 42 (2), 183-188 (2001).
[6] A. Demirbas[b]. Relationships between heating value and lignin, fixed carbon, and volatile material contents of shells from biomass products. 25 (7), 629-635 (2003).
[7] J. A.Fuwape. 1992. Effect of extractives on heating value of *Gmlina arborea. Journal of Tropical Forest Science* 4(4) : 281-285 (1992).
[8] Khristova and A. W. Khalifa**.** Carbonization of some fast-growing species in Sudan**.** *Applied Energy,* 45*(4)*, 347-354 (1993).
[9] M. M. Megahed. Gross heat of combustion as related to lignin and extractive contents of four hardwoods. Egypt. J. Appl. Sci. 7: 252-263 (1992).
[10] C. Ryu, Y. B. Yang, A. Khor, N. E. Yates, V. N. Sharifi. and J. Swithenbank 2006. Fuel. 85, 1039-1046 (2006).
[11] ASTM. D 2015-85.1987. Standard test method for gross calorific value of coal and coke by the adiabatic bomb calorimeter. Philadelphia, Pa. U.S.A (1987).
[12] Hindi, S.S. (1994). Charcoal properties as affected by raw material and charcoaling parameters. MSc. Unpubl. Thesis, Fac. of Agric. Alexandria Univ.92 pp.
[13] ASTM, D 1102-84. Standard test method for ash in wood. Philadelphia, Pa. U.S.A. (1989).

[14] ASTM. D 1105-84. 1989. Standard method for preparation of extractive-free wood. Philadelphia, Pa. U.S.A. (1989).
[15] ASTM. D 1106-84. 1989. Standard test method for acid-insoluble lignin in wood. Philadelphia, Pa. U.S.A. (1989).
[16] Wise, L.E., Merphy, M, M. D., Adieco, M. (1946). Chlorite holocellulose, its fractionation and bearing on summative wood analysis and on studies on the hemicelluloses. Paper Trade Journal. 122, 35-43 (1946).
[17] S. S. Hindi. A. A. Bakhashwain and A. El-Feel. Physico-chemical characterization of some Saudi lignocellulosic natural resources and their suitability for fiber production. JKAU; Met. Env. Arid Land Agric. Sci. 21 (2):45 (2010).
[18] F. S. El-Nakhlawy. Experimental Design and Analysis in Scientific Research. Sci. Pub. Center, King abdul-Aziz University, Saudi Arabia (2009).
[19] F. Munalula, M. Meincken. 2009. An evaluation of South African fuelwood with regards to calorific value and environmental impact. Biomass and Bioenergy. 33 (3), 415–420 (2009).
[20] Kumar, R., Pandey, K. K., Chandrashekar, N. and Mohan, S. Effect of tree-age on calorific value and other fuel properties of Eucalyptus hybrid. J. Forestry Research. 21: 514-516 (2010).
[21] M. M. Megahed, M. M., M. L. M. El-Osta, H. A. Abou-Gazzia and A. El-Baha. (1998). Properties of plantation grown leguminous species and their relation to utilization in Egypt. Menofiya J. Agric. Res., 23, 1729-1751 (1998).
[22] W. M. Abd El-Dayem, M. M. El-Morshedy, S. S. Hindi and M. L. M. El-Osta, M. L. M. 1998. Charcoal properties made from different tree organs of *Taxodium disticum*, L. Egypt. J. Appl. Sci. 13: 242-255 (1998).
[23] S. S. Hindi (2001). Pyrolytic products properties as affected by raw material. PhD. Unpubl. Thesis, Fac. of Agric. Alexandria Univ. 201pp (2001).
[24] M. Erol, H. Haykiri-Acma and S. Kucukbayrak. Calorific value estimation of biomass from their proximate analyses data. Renewable energy. 35, 170-173 (2010).
[25] J.I. N. Kumar, K. Patel, R. Kumar and R. K. Bhoi. An evaluation of fuelwood properties of some Aravally mountain tree and shrub species of Western India" Biomass and bioenergy 3 5 (1), 4 1 1-4 1 4 (2001**).**