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An expeditious methodology for estimating the exergy of woody biomass by means of heating values

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HIGHLIGHTS

- The exergy values of sixty-four woody biomass are studied.
- Relationships for expeditious estimation of the exergy of woody biomass are observed.
- $ex_{HHV} = 342.50 + 1.04$ HHV.
- $ex_{LHV} = 2289.87 + 1.01$ LHV.

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ABSTRACT

Determination of the exergy of woody biomass is the first step to evaluate and study the material characteristics, transfer processes, and utilization systems of woody biomass from exergy aspect. This study supplies an expeditious methodology for estimating the exergy of woody biomass based on studying the LHVs (lower heating values), HHVs (higher heating values), and exergy values of sixty-four woody biomass. The results obtained from this study show that the higher LHV and HHV the woody biomass has, the higher exergy it has. A positive linear relationship between the exergy value and LHV with relative errors of −2.78% to 1.98% and a positive linear relationship between the exergy value and HHV with relative errors of −4.80% to 4.80% are obtained. These two relationships can be used to achieve an expeditious estimation of the exergy of woody biomass for engineering purposes.

1. Introduction

Woody biomass is broadly defined as wood sources from forest, woodland, or rangeland, it mainly includes fuel wood, pulpwood, urban wood wastes, mill residues, and forest residues [1]. The global woody biomass including roundwood, industrial roundwood, wood fuel, pulpwood, sawnwood, wood chips and particles, and wood residues, shown in Fig. 1, fluctuated with an average increase rate of 0.003 Gm^3 per year during the last ten years, reaching about 8.6 Gm^3 in 2013 [2]. If the conversion factor is 7.2 GJ/m^3 (average density is 0.45 t/m^3 and heating value is 16 GJ/t) [3], this woody biomass would yield 62 EJ of energy in 2013. This is about 87% of the world's renewable primary energy consumption (about 71 EJ/year) in the same year [4].

Woody biomass is the most abundant organic source on earth and is currently the most important renewable energy source in the world [5–7]. It can supply a huge amount of heat to approximate 2.5–2.7 billion people over the word for their daily cooking [8,9]. It can be fired or co-fired with coal for electricity, heating, and cooling [1]. It can be converted into combustible gases as well as liquid chemicals though pyrolysis, gasification, or biological degradation [7,10–13]. It is also an important ingredient in the production of special products like activated carbon, carbon fiber, and bio-chars [14,15]. The physical, chemical, and mechanical properties of woody biomass are therefore wildly studied. These included moisture content, particle size, bulk density, surface area, pore volume, electrical conductivity, heating values (HHV and LHV), ash compositions, and tensile stress [15–18].

Exergy is the maximum obtainable work when a matter is brought to a state of thermodynamic equilibrium with the common components of natural surroundings by means of reversible processes [19]. It is a very important method for evaluating energy materials, processes, and systems, and it is therefore widely used

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Nomenclature

Y	indicates fuel properties
M	molecular mass of ash composition (g/mol)
m	mass of ash composition (mol/kg biomass)
ex	specific exergy of woody biomass (kJ/kg)
h	evaporation enthalpy (kJ/kg)

Greek letters

β	correlation factor
η	weight percentage (%)

Subscripts

i	indicates ash composition
w	related to water/moisture
ash	related to ash
S	related to sulfur
C	related to carbon
H	related to hydrogen
O	related to oxygen
N	related to nitrogen
dry	on dry basis
wet	on wet basis
mol	on mole basis
gram	on gramme basis

Abbreviations

HHV	higher heating value of woody biomass (kJ/kg)
LHV	lower heating value of woody biomass (kJ/kg)

in the fields of resource accounting, process optimization, economy evaluation, and environment assessment [20–23]. To study the above mentioned material characteristics, transfer processes, and utilization systems of woody biomass from exergy aspect, obtaining the exergy of woody biomass is the first step. The objectives of this study are therefore (a) to detail the LHVs, HHVs, and exergy values of a large number of woody biomass, (b) to obtain relationships between exergy value and heating value (LHV and HHV) for woody biomass, and (c) to determine the relative errors between the estimated exergy and calculated exergy for validating the relationships observed in this study.

2. Materials and methods

2.1. Materials

Sixty-four woody biomass are used in this study. To comprehensively study the fuel characteristics, the moisture contents, ash contents, ash compositions (Al_2O_3, CaO, Fe_2O_3, K_2O, MgO, MnO, Na_2O, P_2O_5, SO_3, SiO_2, and TiO_2), element contents (C, H, O, N, and S), heating values (HHV and LHV) of the sixty-four woody biomass are used in this study. The ash contents, ash compositions, element contents, and heating values mentioned above are mainly

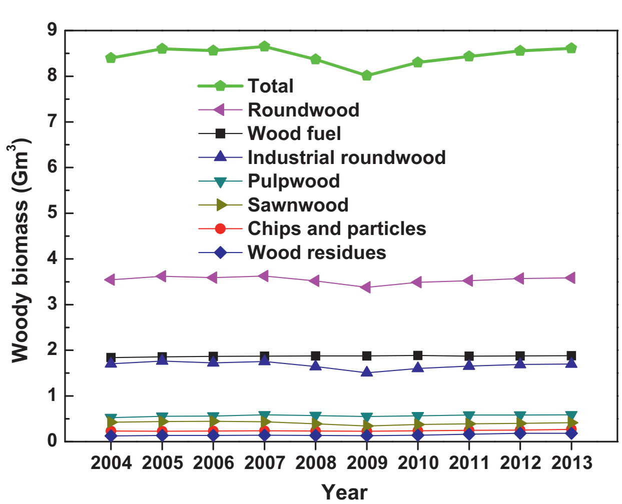

Fig. 1. Production of main woody biomass [2].

reported on dry basis or wet basis. To uniform the fuel properties on a wet basis, the following overall equation is used:

$$Y_{\text{wet}} = Y_{\text{dry}}\frac{(100-\eta_w)}{100} \tag{1}$$

where

Y_{wet}	indicates the fuel property on wet basis
Y_{dry}	indicates the fuel property on dry basis
η_w	is the moisture content of woody biomass (%)

The ash compositions are usually reported in g per kg of ash, the following overall equation can be used to transfer them to a basis of mol per kg of biomass (mol/kg biomass):

$$m_{i,\text{mol}} = m_{i,\text{gram}}\frac{\eta_{\text{ash}}}{100M_i} \tag{2}$$

where

m	is the mass of ash composition in mol per kg of biomass
M	is the molecular mass of a detailed ash composition (g/mol)
i	indicates the ash composition i
η_{ash}	is the weight percentage of ash in woody biomass (%)
mol	indicates the mass on mole basis
gram	indicates the mass on gramme basis

The moisture contents, ash contents, element contents (C, H, O, N, and S), HHVs, and LHVs of the sixty-four woody biomass were uniformed to wet basis and the values are given in Table 1. The ash compositions of Al_2O_3, CaO, Fe_2O_3, K_2O, MgO, MnO, Na_2O, P_2O_5, SO_3, SiO_2, and TiO_2 for the sixty-four woody biomass were transferred to molar content per kg of woody biomass on wet basis and the values are shown in Table 2.

2.2. Exergy of woody biomass

Szargut et al. [51] proposed the following statistical method for calculating the exergy of woody biomass:

$$ex = ex_w\eta_w + 9683\eta_s + ex_{\text{ash}}\eta_{\text{ash}} + \beta(\text{LHV} + \eta_w h_w) \tag{3}$$

where