The Effect of Moisture on Heating Values

Definitions for heating value of a biomass

The heating value of any fuel is the energy released per unit mass or per unit volume of the fuel when the fuel is completely burned (ANSI/ASABE S593.1 2011). The term calorific value is synonymous to the heating value. Typical units for expressing calorific or heating value are MJ/kg in SI units or Btu/lb in English units. The heating value of a fuel depends on the assumption made on the condition of water molecules in the final combustion products. The higher heating value (*HHV*) refers to a condition in which the water is condensed out of the combustion products. Because of this condensation all of the heating value of the fuel including sensible heat and latent heat are accounted for. The lower heating value (*LHV*), on the other hand refers to the condition in which water in the final combustion products remains as vapor (or steam); i.e. the steam is not condensed into liquid water and thus the latent heat is not accounted for. The term net heating value (*NHV*) refers to *LHV* (ANSI/ASABE S593.1 2011). The term gross heating value (*GHV*) refers to *HHV*.

Determination of heating value of a biomass

Heating value of a biomass is measured experimentally in terms of the high heating value (HHV). The standard method uses a device called bomb calorimeter. The device burns a small mass of biomass in the presence of oxygen inside a sealed container (or bomb). The heat released from combustion is transferred to a mass of fluid (air or water) that surrounds the container. The heating value is calculated from the product of mass of fluid x specific heat of fluid x net temperature increase. The calculated heating value must be corrected for heat losses to the mass of container, heat conduction through the container wall, and heat losses to the surrounding of the device. In modern calorimeters the corrections are made automatically using sensors and controllers. The resulting measured heating value is considered gross heating value (high heating value) at constant volume because the biomass combustion in the container has taken place inside the fixed volume of the container. The resulting gross heating value can be expressed based on dry mass content of the sample biomass,

$$HHV_d = \frac{HHV}{1-M} \qquad \text{(Eq. 1)}$$

where HHV_d is the gross heating value of the biomass in MJ/kg of bone dry biomass, *HHV* is the gross heating value determined by the calorimeter. *M* is the moisture content of the biomass in decimal wet mass fraction.

The high heating value can be estimated from the composition of the fuel (Gaur and Reed 1995),

$$HHV_d = 0.35X_C + 1.18X_H + 0.10X_S - 0.02X_N - 0.10X_O - 0.02X_{ash} \qquad \text{(Eq. 2)}$$

where *X* is the mass fractions (percent mass dry basis) for Carbon (C), Hydrogen (H), Sulfur (S), Nitrogen (N), Oxygen (O), and ash content (ash). The unit of *HHV* in Equation 2 is in

MJ/kg dry mass. Equation 2 shows that the elements Carbon, Hydrogen, Sulfur increase the heating value whereas the elements Nitrogen, Oxygen, and ash suppress the heating value.

Net heating value of biomass

The *HHV* or *GHV* for woody biomass (including bark) that is determined experimentally is around 20 MJ/kg (8600 Btu/ lb) dry mass basis and for herbaceous biomass it is around 18.8 MJ/kg (8080 Btu/ lb) dry mass basis (Oberberger and Thek 2010). For a moist fuel, the heating value decreases because a portion of the combustion heat is used up to evaporate moisture in the biomass and this evaporated moisture has not been condensed to return the heat back to the system. An estimate of the *LHV* or net heating value (*NHV*) is obtained from the measured *HHV* by subtracting the heat of vaporization of water in the products.

$$LHV = HHV(1 - M) - 2.447M \quad \text{(Eq. 3)}$$

where *LHV* is the gross (or lower) heating value MJ/kg, M is the wet basis moisture content (mass fraction decimal). The constant 2.447 is the latent heat of vaporization of water in MJ/kg at 25^{o}C. A more accurate estimate of the net heating value from equation 3 can be obtained by including the heat released by the combustion of the hydrogen content of the biomass.

High and low heating value at constant pressure

In practice, the gases evolving from combustion of a biomass are expanded without much constraints. In other words during combustion the volume expands but the pressure in the combustion zone does not change much. This situation is often present in a boiler combustion chamber with unrestricted exhaust system. For these cases equation 3 developed from constant volume measurement is converted to heating value at constant pressure according to equation 4,

$$HHV_p = HHV - 0.212X_H - 0.0008(X_O + X_N) \quad \text{(Eq. 4)}$$

where HHV_p is the high heating value at constant pressure for dry biomass. X_H, X_O, *and* X_N are the mass fraction (percent dry mass) of the biomass. For wet biomass, the net heating value at constant pressure is calculated from

$$LHV_{p,w} = HHV_p(1.0 - M) - 2.443M \quad \text{(Eq. 5)}$$

M is the wet basis moisture content (mass fraction decimal). $LHV_{p,w}$ is the net heating value of biomass at constant pressure per unit of wet biomass.

Example of using equations 1-5

The high heating values of two biomass species poplar and stover along with their ultimate analysis were measured. The moisture content of the samples was 35% wet mass basis. The table below lists the measured data.

Measured Moisture, Elements, and High Heating Value of Biomass								
	M (%)	Ash (%)	C (%)	H (%)	O (%)	N (%)	S (%)	HHV_d (MJ/kg)
Poplar	35	0.65	51.64	6.26	41.45	0.00	0.00	20.75
Stover	35	11.27	44.80	5.35	39.55	0.38	0.01	17.33

Estimation of HHV_d (constant volume)

Equation 2 is used to calculate high heating value

$$HHV_d = 0.35X_C + 1.18X_H + 0.10X_S - 0.02X_N - 0.10X_O - 0.02X_{ash}$$

Substituting from compositions listed in the table above

for poplar

$$HHV_d = 0.35(51.64) + 1.18(6.26) + 0.10(0.00) - 0.02(0.00) - 0.10(41.45) - 0.02(0.65)$$
$$= 21.3\ MJ/kg$$

and for stover,

$$HHV_d = 0.35(44.80) + 1.18(5.35) + 0.10(0.01) - 0.02(0.38) - 0.10(39.55) - 0.02(11.27)$$
$$= 17.8\ MJ/kg$$

The calculated HHV_d for both species are slightly higher than measured HHV_d in the table above.

Estimation of *LHV* (constant volume)

Equation 3 is used to calculate low heating value

$$LHV = HHV_d(1 - M) - 2.447M$$

Substituting for *HHV* and moisture content,

for poplar,

$$LHV = (20.8)(1 - 0.35) - 2.447(0.35)$$
$$= 12.7\ MJ/kg$$

and for stover,

$$LHV = (17.3)(1 - 0.35) - 2.447(0.35)$$
$$= 10.4\ MJ/kg$$

Calculations for of HHV_p (constant pressure)

Equation 3 is used to calculate low heating value (or net calorific value) at constant pressure

$$HHV_p = HHV_d - 0.212X_H - 0.0008(X_O + X_N)$$

Substituting from the table above for HHV_d (for constant volume) and concentrations,

for poplar,

$$HHV_p = (20.8) - 0.212(6.26) - 0.0008(41.45 + 0.00)$$
$$= 19.4\ MJ/kg$$

and for stover,

$$HHV_p = (17.3) - 0.212(5.35) - 0.0008(39.55 + 0.38)$$
$$= 16.1\ MJ/kg$$

Calculations for of LHV_p (constant pressure)

Equation 5 is used to calculate low heating value,

$$LHV_p = HHV_p(1.0 - M) - 2.443M$$

Substituting for HHV_p and moisture content,
for poplar,

$$LHV = (19.4)(1 - 0.35) - 2.443(0.35)$$
$$= 11.8\ MJ/kg$$

and for stover,

$$LHV = (16.1)(1 - 0.35) - 2.443(0.35)$$
$$= 9.6\ MJ/kg$$

The table below shows the application of equation 5 to calculate the net heating value of biomass at various levels of moisture content. Increasing moisture content diminished the net heat value of biomass to the point that at slightly higher than 80% moisture content, much of the heat content of the biomass is used up to evaporate its moisture.

Effect of Moisture Content on the Net Heating Value of Biomass at Constant Pressure									
	Moisture content percent wet mass basis								
Biomass	0	10	20	30	40	50	60	70	80
Poplar	19.4	17.3	15.1	12.9	10.7	8.5	6.3	4.1	1.9
Stover	16.1	14.3	12.4	10.6	8.7	6.8	5.0	3.1	1.3

List and Definition of Symbols

Symbol	Definition
LHV	Lower heating value
HHV	Higher heating value
GHV	Gross heating value
NHV	Net heating value
HHV_p	High heating value at constant pressure
HHV_d	Bone dry gross heating value of the biomass
M	Moisture content wet mass basis
X	Mass fraction percent dry mass basis
Subscripts	
ash	Ash
C	Carbon
d	Dry mass basis
H	Hydrogen
N	Nitrogen
O	Oxygen
p	Constant pressure
w	Moist biomass
Units	
Btu	British thermal unit
°C	Degrees Celsius
MJ	Mega (10^6) Joule (SI unit)
kg	Kilogram
lb	Pound mass

References

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TAPPI Gross heating value of black liquor, Test Method T 684 om-11http://www.tappi.org/Bookstore/Standards--TIPs/Standards.aspx

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