CLARIFYING THE USES OF HEATING VALUES

by Jun Sian Lee, edited by Professor Anthony K. Lau

ABSTRACT

Because heating value of fuels is described in many mass basis and thermodynamic conditions, the heating terms used in peer-reviewed literatures and reports have not been consistent. This short note aims to define and clarify the different uses of four most commonly used heating value terms, which are high heating value (HHV) or gross calorific value (GCV), low heating value (LHV), gross heating value (GHV) and net calorific value or net heating value (NCV or NHV), in the context of biomass fuels.

Keywords: Heating values, calorific values, biomass

1. INTRODUCTION

Heating value of fuel is defined as the energy released per unit mass of fuel in a complete combustion with oxygen. The need of the terms: high heating value and low heating value comes from the different end states of water [1]. The two end states of water, which we are concerned about, are liquid and vapour states. The water in the final product comes from two sources: the existing moisture in the fuel and the water product of the combustion. Therefore, before the differences between the two states can be explained, the process of complete combustion must be explained.

All biomass fuels, such as wood, straw, charcoal and others, contain carbon, hydrogen and oxygen, which are described in this chemical formula $C_xH_yO_z$. In a complete combustion, organic fuels react with oxygen molecules in the atmosphere to form two products: carbon dioxide CO_2 and water H_2O and to release heat. This heat released is called heat of combustion [1]. Some of

the heat released are used to vaporize the existing moisture in the fuel and the water product. Chemical equation (Eq. 1) below gives the general form of complete combustion reaction of organic fuels.

$$C_xH_yO_z + \left(2x + \frac{y}{2} - z\right) O_2 \rightarrow x\ CO_2 + \frac{y}{2}\ H_2O + heat \qquad (1)$$

Because all combustion reactions occur at temperatures above the boiling temperature of water, both the existing water of the fuel and the water product are in the vapour state after the combustion process. In a bomb calorimeter – a device to measure the heating value of fuels, the water in vapour state (both existing moisture and water product) is cooled and condensed to room temperature [3,4]. As a result, the heat of condensation is recovered. All the heat of combustion are measured by the bomb calorimeter. The total heat of combustion measured by a bomb calorimeter per unit mass is called “high heating value” (HHV) or “gross heating value” (GHV). If one does not have a bomb calorimeter, HHV can also be estimated using the equation below [5].

$$HHV\ or\ GCV = 0.3491X_C + 1.1783X_H + 0.1005X_S - 0.0151X_N - 0.1034X_O - 0.0211X_{ash} \qquad (2)$$

On another hand, if the water in vapour state are not condensed, such as the cases in traditional boilers or in dryers, the heat of condensation is lost as the flue gases, together with the water vapour, flows out to the atmosphere. This heat of combustion, less heat of condensation of water, per unit mass is called “low heating value” (LHV) or “net heating value” (NHV).

Heat balance in a complete combustion

Heat released from combustion (Heat of Combustion)

= heat to vaporize existing water + heat to vaporize water product + heat loss to environment

HHV or GHV = Heat of Combustion per unit mass

LHV or NHV = (Heat of Combustion - heat to vaporize existing water - heat to vaporize water product) per unit mass

2. DIFFERENCES BETWEEN THE DIFFERENT TERMS

One may ask, are there any difference between HHV and GHV? And how about LHV and NHV?

The short answer is yes, there are differences between the two related terms. The differences come from the mass basis in which the terms are defined. HHV is defined as the heat of combustion per unit oven dry mass, expressed in the unit J/dry g, whereas, GHV is defined as the heat of combustion per unit wet mass, expressed in the unit J/wet g. Oven dry mass refers to the mass of fuel without any moisture (moisture content equals to zero); wet mass refers to the mass of fuel, which contains moisture content above zero.

The same goes for LHV and NHV. LHV is defined in the basis of oven dry mass, whereas NHV is defined in the basis of wet mass.

You may ask: what about “gross calorific value” (GCV) and “net calorific value” (NCV)? As one may have guessed, gross calorific value is equivalent to high heating value, whereas net calorific value is equivalent to net heating value. However, the terms “gross calorific value” and

“net calorific value” are more commonly used in European countries, while the terms “gross heating value” and “low heating value” are more commonly used in North America. The different terms are summarized in Table 1.

Table 1: Summary of the heating value terms [6].

Terms	End State of Water	Basis	Notes
High Heating Value (HHV) and Gross Calorific Value (GCV)	Liquid	Dry	Measurable from bomb calorimeter if the sample is oven dried.
Gross Heating Value (GHV)	Liquid	Wet	Measureable from bomb calorimeter using sample as is.
Low Heating Value (LHV)	Vapour	Dry	Calculated from HHV.
Net Heating Value (NHV) and Net Calorific Value (NCV)	Vapour	Wet	Calculated from HHV.

The equations to convert from HHV to GCV as well as to convert from HHV to NCV or NHV are given in equations 3, 4 and 5.

3. CONCLUSION

As a final note, the terms HHV (dry basis!) and GHV (wet basis!) should only be used in the cases where the existing moisture and water product are condensed, for example, in rating the efficiency of advanced combined cooling, heat and power (CCHP) power plants and in reporting the maximum energy content in a fuel. In other cases, where existing moisture and water product are not condensed and remain in vapor state, for example, in the case of residential heating stoves, traditional boilers and dryers, the terms LHV (dry basis!) and NCV (wet basis!) should be used.

Also, one should always state their mass basis, when a heating value is reported, to avoid any confusion; if one were to express a heating value in wet basis, one must report the moisture content of the sample together with the heating value.

Appendix A gives a numerical example to illustrate the differences between HHV/GCV, GHV, LHV and NHV/NCV.

Equations to calculate GHV from HHV or GCV [1]

$$GHV = HHV\left(1 - \frac{M}{100}\right) = GCV\left(1 - \frac{M}{100}\right) \tag{3}$$

Where M is the moisture content in wet basis.

Equation to calculate NHV or NCV from HHV in MJ/kg

Complete equation

$$NHV\ or\ NCV = [HHV - 0.212X_H - 0.0008 \times (X_O + X_N)] \times \frac{100 - M}{100} - 0.0245M \tag{4}$$

Where X_H, X_O and X_N are the hydrogen, oxygen and nitrogen contents in dry basis.

Low heating value (LHV) is simply NCV when moisture content M is zero.

$$LHV = HHV - 0.212X_H - 0.0008 \times (X_O + X_N) \tag{5}$$

Hence, equation 4 can also be written as:

$$NHV\ or\ NCV = LHV \times \frac{100 - M}{100} - 0.0245M \tag{6}$$

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APPENDIX A

This example is taken from Biomass Energy Data Book 2011 [7]. The high heating values (HHV) and the ultimate analysis of two biomass species: poplar and corn stover were measured. The moisture contents of the samples were 35% wet mass basis. Table 2 lists the measured data.

Table 2. Measured moisture, elements, and high heating value of biomass

	M (%)	Ash (%)	C (%)	H (%)	O (%)	N (%)	S (%)	HHV (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

Calculate the HHV/GCV, GHV, LHV, and NHV/NCV.

a) Equation 2 is used to estimate high heating value (HHV) or gross calorific value (GCV) from elemental compositions. Recall, HHV and GSV are always in dry basis.

$$HHV = 0.3491X_C + 1.1783X_H + 0.1005X_S - 0.0151X_N - 0.1034X_O - 0.0211X_{ash}$$

Substituting from compositions listed in Table 1,

For poplar,

$$HHV = 0.3491(51.65) + 1.1783(6.26) + 0.1005(0.00) - 0.0151(0.00) - 0.1034(41.45) - 0.0211(0.65)$$

$$= 21.11 \text{ MJ/kg}$$

And for corn stover,

$$HHV = 0.3491(44.80) + 1.1783(5.35) + 0.1005(0.01) - 0.0151(0.38) - 0.1034(39.55) - 0.0211(11.27)$$

$$= 17.61 \text{ MJ/kg}$$

The calculated HHV for both species are comparable to measured HHV in Table 2.

b) Equation 3 is used to calculate gross heating value (GHV) from HHV.

$$GHV = HHV\left(1 - \frac{M}{100}\right)$$

For poplar,

$$GHV\ [@MC = 35\%] = 20.75\left(1 - \frac{35}{100}\right) = 13.49 \text{ MJ/kg}$$

And for corn stover,

$$GHV\ [@MC = 35\%] = 17.33\left(1 - \frac{35}{100}\right) = 11.26 \text{ MJ/kg}$$

c) Equation 5 is used to calculate low heating value (LHV) from HHV.

$$LHV = HHV - 0.212X_H - 0.0008 \times (X_O + X_N)$$

For poplar,

$$LHV = 20.75 - 0.212(6.26) - 0.0008(41.45 + 0.00) = 19.39 \text{ MJ/kg}$$

And for corn stover,

$$LHV = 17.33 - 0.212(5.35) - 0.0008(39.55 + 0.38) = 16.16 \text{ MJ/kg}$$

d) Equation 6 is used to calculate net heating value (NHV) or net calorific value (NCV) from LHV,

$$NHV\ or\ NCV = LHV \times \frac{100 - M}{100} - 0.0245M$$

for poplar,

$$NHV\ [@MC = 35\%] = 19.39 \times \frac{100 - 35}{100} - 0.0245(35) = 11.75\ \mathrm{MJ/kg}$$

and for corn stover,

$$NHV\ [@MC = 35\%] = 16.16 \times \frac{100 - 35}{100} - 0.0245(35) = 9.65\ \mathrm{MJ/kg}$$