Higher Heating Value and Lower Heating Value Variation

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Summary

The heat content of wood fuel is necessary for efficiency calculations as well as for air emission reporting when the reporting convention is based on the mass of pollutant emitted per unit of heat delivered. There are three common ways of defining lower heating values (LHV) and several methods for measuring the heat content of fuel, including ASTM D5865 and ASTM E711 as specified in section 8.3.3 of draft standard B415.1 (August 29, 2009). OMNI split a sample of Douglas fir fuel and submitted it to two laboratories, one using method D5865 and one using E711. Values were then calculated for each of the three different lower heating value conventions. The variability in results is shown in Table 1. For comparison the lower heating values calculated from default value (HHV) from B415 are also shown in Table 1.

Table 1
Heating Values

	Lab A – Huffman Labs (ASTM D 5865[1])		Lab B – Twin Ports Testing (ASTM E 711[2])		B415[3] Default Values
	As Received	Moisture Free	As Received	Moisture Free	
HHV @ constant V	7854 Btu/lb	**8747 Btu/lb**	6845 Btu/lb	**8036 Btu/lb**	**8516 Btu/lb**
HHV @ constant P[4]	7853 Btu/lb	**8746 Btu/lb**	6843 Btu/lb	**8034 Btu/lb**	**8513 Btu/lb**
Moisture (dry basis)[5]	22.650%	22.650%	22.650%	22.650%	21.951%
LHV_1	7276 Btu/lb	**8223 Btu/lb**	6368 Btu/lb	**7476 Btu/lb**	**7869 Btu/lb**
LHV_2	7039 Btu/lb	**7985 Btu/lb**	6130 Btu/lb	**7238 Btu/lb**	**7639 Btu/lb**
LHV_3	6870 Btu/lb	**7817 Btu/lb**	5962 Btu/lb	**7070 Btu/lb**	**7467 Btu/lb**
Carbon (wt. %)	46.23%	51.49%	44.38%	52.10%	48.73%
Hydrogen (wt. %)	6.15%	5.58%	5.07%	5.95%	6.87%
Nitrogen (wt. %)	0.04%	0.04%	0.05%	0.06%	0.06%[6]
Oxygen (wt. %)	46.75%	41.97%	35.59%	41.81%	43.90%

[1] ASTM D 5865-07a: Standard Test Method for Gross Calorific Value of Coal and Coke

[2] ASTM E 711-87: Standard Test Method for Gross Calorific Value of Refuse-Derived Fuel by the Bomb Calorimeter

[3] CAN/CSA-B415.1-00: Performance Testing of Solid-Fuel-Burning Heating Appliances

[4] calculated per ASTM D 5865

[5] by electrical resistance moisture meter per EPA Method 28; converted to dry basis

[6] D. Bushnell, et al., "Biomass fuel characterization: Testing and evaluating the combustion characteristics of selected biomass fuels," OSU 1989.

Note: Split samples of Douglas Fir were sent to two laboratories.

The latest draft of CSA B415.1 §8.3.3 states, "The calorific value of a representative sample of the fuel to be used in each appliance test series shall be determined in accordance with ASTM Standards D6865 or E711."

LHV_1 accounts for the vaporization of H_2O formed during combustion.
LHV_2 accounts for combustion H_2O and the vaporization of free H_2O.
LHV_3 accounts for combustion H_2O, the vaporization of free H_2O, and the conversion of bound H_2O to free H_2O.

Sample Effect on Efficiency:
By the previous version of B415, LHV_2 would be used.
For the dry sample from Lab A, $LHV_2 = 7985$ Btu/lb
If an appliance were determined to have a 75% efficiency, then

$$0.75 = x / (7985 \ Btu/lb)$$
$$x = 5989 \ Btu/lb$$

Using the revised B415 and LHV_3,

$$Efficiency = (5989 \ Btu/lb) / (7070 \ Btu/lb) * 100\%$$
$$= 85\%$$

Sample Calculations

<u>Converting HHV at constant volume to HHV at constant pressure:</u>

From ASTM D 5865, the energy associated with the change in volume of the gaseous phase for the combustion reaction may be expressed as

$$Q_{v-p} = 0.01 * RT * (H_{ad} / (2*2.016) - O_{ad} / 31.9988 - N_{ad} / 28.0134)$$

where

$R = 8.3143$ J/(mol*K)
$T = 298.15$ K
H_{ad} = as-determined % hydrogen in the analysis sample, excluding sample moisture
O_{ad} = as-determined % oxygen in the analysis sample
N_{ad} = as-determined % nitrogen in the analysis sample

So for the moisture free sample analyzed by Lab B,

$$Q_{v-p} = 0.01 * 8.3143 \ J/(mol*K) * 298.15 \ K * (5.95 / (4.032 \ g/mol) - 41.81 / (31.9988 \ g/mol) - 0.06 / (28.0134 \ g/mol)$$

$$= 4.138403297 \text{ J/g}$$

$$= 4.138403297 \text{ J/g} * (0.947817 \text{ g*Btu}) / (2.2046226 \text{ lb*J})$$

$$= 1.779192937 \text{ Btu/lb}$$

$$= 1.78 \text{ Btu/lb}$$

$$HHV_{const.P} = HHV_{const.V} - Q_{v\text{-}p}$$

$$= 8036 \text{ Btu/lb} - 1.78 \text{ Btu/lb}$$

$$= 8034 \text{ Btu/lb}$$

<u>Calculating LHV_1:</u>

Since $LHV_1 = HHV$ – energy needed to vaporize combustion H_2O,

then

$$LHV_1 = HHV_{const.P} - h_{vap} * (H_{ad}) * (\text{molar ratio of } H_2O \text{ to } H)$$

where

h_{vap} = heat of vaporization of water at 25 °C
    = 43985 J/mol
    = 1049.7 Btu/lb

So for the moisture free sample analyzed by Lab B,

$$LHV_1 = 8034 \text{ Btu/lb} - 1049.7 \text{ Btu/lb} * (0.0595) * (18.01528 / 2.01588)$$

$$= 7476 \text{ Btu/lb}$$

<u>Calculating LHV_2:</u>

Since $LHV_2 = HHV$ – energy needed to vaporize combustion H_2O – energy needed to vaporize free H_2O,

then

$$LHV_2 = LHV_1 - h_{vap} * (\%M_{db} / 100)$$

where

$\%M_{db}$ = percent moisture of the wood sample on a dry basis

So for the moisture free sample analyzed by Lab B,

$$LHV_2 = 7476 \text{ Btu/lb} - 1049.7 \text{ Btu/lb} * (22.650 / 100)$$

$$= 7238 \text{ Btu/lb}$$

Calculating LHV_3:

Since LHV_3 = HHV – energy needed to vaporize combustion H_2O – energy needed to vaporize free H_2O – energy needed to convert bound H_2O to free H_2O,

then

$$LHV_3 = LHV_2 - Q_{bw}$$

where

Q_{bw} = energy required to bring bound water to the energy level of free water

$$= MR_{bw} * \{ (1 / \%M_{wb}) * [467.9415 * \%M_{wb} - 32.31411 * (\%M_{wb})^2 + 1.040786667 * (\%M_{wb})^3 + 4.68014E\text{-}2 * (\%M_{wb})^4 - 6.588278E\text{-}3 * (\%M_{wb})^5 + 2.569851667E\text{-}4 * (\%M_{wb})^6 - 3.48937E\text{-}6 * (\%M_{wb})^7]\}$$

and

MR_{bw} = mass rate of bound water in lb/s

$\%M_{wb}$ = percent moisture of the wood sample on a wet basis

$$= (\%M_{db} / (\%M_{db} + 100)) * 100\%$$

So for the moisture free sample analyzed by Lab B,

$MR_{bw} = 1$ lb/s (assumed value)

$\%M_{wb} = (22.650 / (22.650 + 100)) * 100\%$

$$= 18.467\%$$

Simplifying Q_{bw} leads to

$$Q_{bw} = 467.9415 - 32.31411 * \%M_{wb} + 1.040786667 * (\%M_{wb})^2 + 0.0468014 * (\%M_{wb})^3 - 6.588278E\text{-}3 * (\%M_{wb})^4 + 2.569851667E\text{-}4 * (\%M_{wb})^5 - 3.48937E\text{-}6 * (\%M_{wb})^6$$

$$= 467.9415 - 32.31411 * 18.467 + 1.040786667 * (18.467)^2 + 0.0468014 * (18.467)^3 - 6.588278E\text{-}3 * (18.467)^4 + 2.569851667E\text{-}4 * (18.467)^5 - 3.48937E\text{-}6 * (18.467)^6$$

$$= 186.1965$$

Therefore

$$LHV_3 = 7238 \text{ Btu/lb} - 186.1965 \text{ Btu/lb}$$

$$= 7070 \text{ Btu/lb}$$