Calculating the Heating Value of Biogas

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When a substance like methane (CH_4) undergoes complete combustion, the only products of that combustion are CO_2 and H_2O along with N that was in the combustion air and perhaps SO_2. The heat (energy) given off during combustion will be the low heating value (LHV) if the products of combustion remain in the gaseous state. LHV is difficult to measure. In the bomb calorimeter, the products of combustion are cooled to the temperature of the original gas & air mixture. When this cooling takes place the water produced during combustion condenses and the heat of condensation is added to "heat of combustion (LHV)". The result is the high heating value (HHV). This heat of condensation can be calculated because the mass of water produced during combustion is known.

Using the following formula for the combustion, the weight of water produced can be calculated.

$CH_4 + O_2$ >>> $CO_2 + 2H_2O$
16.042 + 64 >>> 44.011 + 36.032

36.032/16.042 = 2.246 lb H_2O/lb CH_4

Assuming the heat of condensation of water to be 1,040 Btu/lb, the heat of condensation for the combustion of methane would be 2,336 Btu per pound of methane burned.

High and low heating values for the combustion of CH_4 are given in Marks' Standard Handbook for Mechanical Engineers, eighth edition. They are

HHV = 23,890 Btu/lb or 994.7 Btu/ft^3*
LHV = 21,518 Btu/lb or 896.0 Btu/ft^3*
* At 68 °F and 14.7 psia.

The preceding information is for a dry biogas, no consideration is given for any water vapor in the biogas. Biogas from a digester will always be saturated. Generally the path from the digester to the point of use will be one of lowering temperature that will keep the gas saturated. In determining the heating value of biogas from an anaerobic digester, the assumption will be made that the biogas is saturated as it passes through the gas meter.

The only impact of water vapor in biogas will have is to change the density of the biogas and thus the pounds of methane per cubic foot. The LHV is determined entirely by the pounds of CH_4 in a cubic foot of biogas. If wet biogas were combusted in a bomb calorimeter and the resulting gases were allowed to cool to the original temperature, there is no reason the initial water vapor in the biogas would condense. The high heating value would not be increased by the heat of condensation of the initial water vapor.

Because the biogas produced on dairy farms will be utilization in an engines and/or boilers, the assumption should be made that none of water produced during combustion will be condensed. <u>The recommendation is to always use the low heating value.</u>

Biogas as it passes through a gas meter will never be at standard pressure and temperature [dry, 1.0 atmosphere and 32 F]. Therefore, corrections must be made to take into consideration the actual condition of the biogas; saturated, at some temperature above 32 F and some pressure above atmospheric.

Chemistry texts say that one-gram molecular weight of a gas will occupy 22.4 liters at standard conditions (STP) of 0° C and 1 atmosphere or 0.791 ft^3 at 32° F and 1 atmosphere. The molecular weight of the biogas depends on the relative concentration of CO_2 and CH_4, ignoring the trace gases. Table 1 presents the properties of dry biogas for a range of CH_4 levels from 40 to 70 percent by volume and the corresponding g mol wt [gram molecular weight]. Note that the gram molecular weight decreases as the concentration of CH_4, the lightest gas, increases.

Table 1 Properties of Biogas at Standard Conditions

Dry Biogas [CH_4 and CO_2] at 32 F & 1 atm					
% CH_4 by volume	g mol wt	CH_4 Percent by weight	Density lbs d.g.*/ft^3	Density ft^3/lb d.g.	LHV Btu/ft^3
40%	32.8	19.6%	0.0916	10.92	385
42%	32.3	20.9%	0.0900	11.11	405
44%	31.7	22.3%	0.0885	11.30	424
46%	31.1	23.7%	0.0869	11.50	443
48%	30.6	25.2%	0.0854	11.71	463
50%	30.0	26.7%	0.0838	11.93	482
52%	29.5	28.3%	0.0822	12.16	501
54%	28.9	30.0%	0.0807	12.39	520
56%	28.4	31.7%	0.0791	12.64	540
58%	27.8	33.5%	0.0776	12.89	559
60%	27.2	35.4%	0.0760	13.16	578
62%	26.7	37.3%	0.0744	13.43	598
64%	26.1	39.3%	0.0729	13.72	617
66%	25.6	41.4%	0.0713	14.02	636
68%	25.0	43.7%	0.0698	14.34	655
70%	24.4	46.0%	0.0682	14.66	675

* dry gas

Because the heat energy in the biogas is from burning the methane, the percent methane by weight is given. The heating value for the biogas at various concentration of CH_4 is given in the right column. A low heating value of 21,518 Btu/lb was used. The density [lb d.g./ft3] of the dry biogas is also given. Theoretically, one pound of biodegradable organic matter or volatile solids would be destroyed in the production of one pound of biogas. Again, note the pounds of volatile solids destroyed per cubic foot of biogas produced decreases as the concentration of CH_4 increases.

The volume of biogas measured at a gas meter will be dependent on the temperature and pressure assuming the gas is saturated. There are gas meters that are temperature compensated but most meters on digesters do not have this feature. The impact of gas temperature on the density of biogas with 60% CH_4 is shown in Figure 1. For comparison, the density of dry biogas at standard temperature and pressure is shown in the lower left corner.

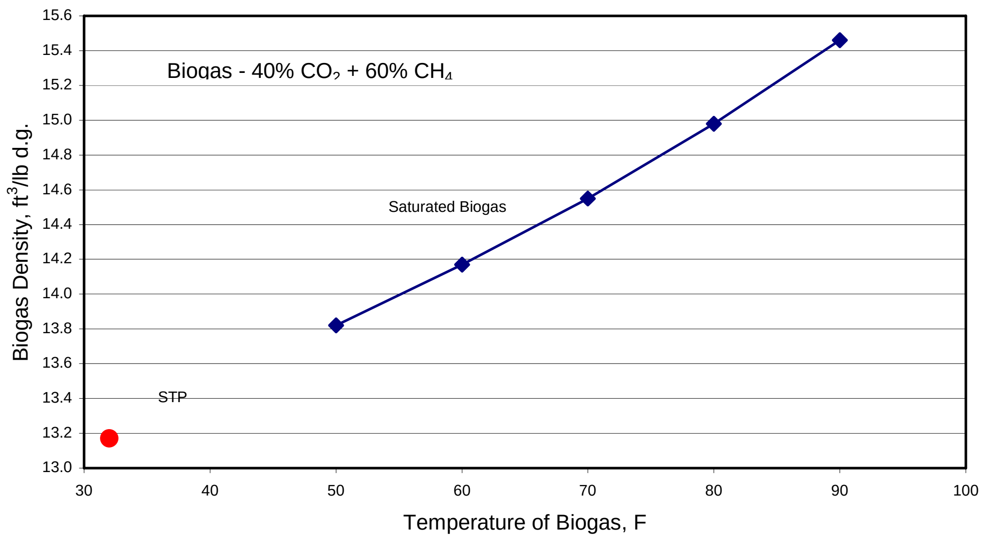

Figure 1 Relationship Between Gas Temperature and Density of Biogas

The influence of gas pressure on the density of biogas and the resulting impact on the low heating value is shown in Figure 2. As the pressure increases the density increases along

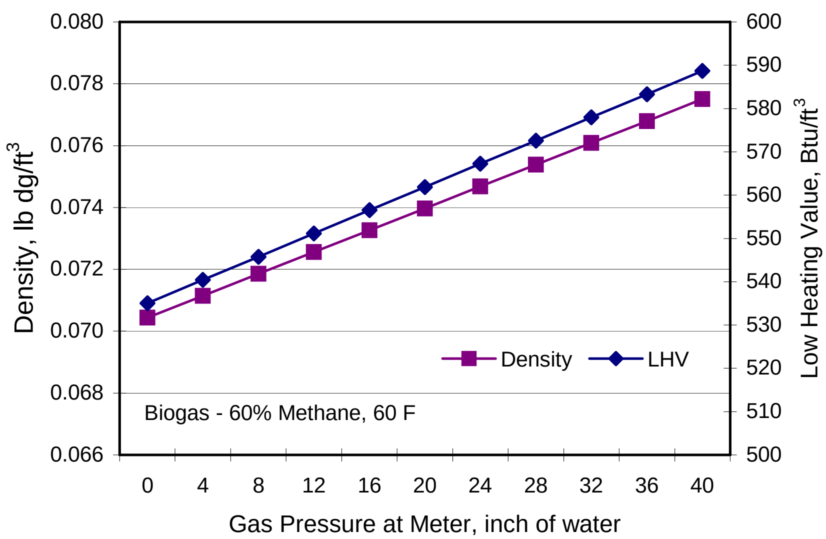

Figure 2 Relationship Between Gas Pressure and Density and LHV of Biogas

with the low heating value. Increasing the pressure from atmospheric to 40 inch of water (1.44 psig) the LHV increased 10 percent.

To calculate the heating value of the saturated biogas measured by a gas meter, temperature and pressure must be taken into consideration. The relationship of temperature, pressure and saturation with water vapor is given by the familiar equation shown below.

$$\left[760 \times V_{STP}\right] \div 273A = \left[\left(P_2 - PP_{water}\right) \times V_2\right] \div T_2$$

Where: 760 mm Hg [1 atmosphere], 273° A and V_{STP} are at standard conditions. PP_{water} is the partial pressure [mm Hg] of water vapor at T_2 in degrees absolute and V_2 is the volume of the wet biogas at T_2 (degrees absolute) and P_2 (mm Hg). Partial pressures for water vapor are shown in a table in the appendix.

Using the above equation the relationship between the volume (V_2) of the biogas measured at the meter at P_2 and T_2 and V_{STP} was determined. This will allow calculating the heating value of the wet biogas. Table 2 shows the ratio of V_{STP} to V_2 (wet biogas) at five different gas temperatures and gas pressure from 0 to 40 inches of water. For gas

Table 2 Ratio of the Volume at STP and Volume at P_2 and T_2.

	$V_{STP}/V_{wet\ biogas}$*					
Gas Pressure	Gas Temp, F [T_2]					
[P_2] In H_2O	95	85	75	65	60	55
0	0.837	0.866	0.893	0.918	0.928	0.941
4	0.846	0.875	0.902	0.927	0.937	0.951
8	0.855	0.884	0.911	0.936	0.946	0.960
12	0.863	0.893	0.920	0.945	0.956	0.970
16	0.872	0.902	0.929	0.954	0.965	0.979
20	0.881	0.910	0.938	0.964	0.974	0.988
24	0.889	0.919	0.947	0.973	0.984	0.998
28	0.898	0.928	0.956	0.982	0.993	1.007
32	0.907	0.937	0.965	0.991	1.002	1.017
36	0.916	0.946	0.974	1.001	1.012	1.026
40	0.924	0.955	0.983	1.010	1.021	1.035

* [cubic feet of biogas at standard pressure & temperature per cubic foot of wet biogas at P_2 and T_2]

meters compensated to 60 F, use the column labeled 60.

The heating value of the wet biogas flowing through a meter can be determined by multiplying the appropriate ratio from Table 2 and the LHV from Table 1 for the appropriate gas composition.

Example: Calculate the low heating value for wet biogas flowing through a gas meter at 85° F and 28 inches of water pressure. The biogas is 58% CH_4.

From Table 2, the ratio would be 0.928 and from Table 1 the LHV at 58% CH_4 is 559 Btu/ft^3. The LHV for this wet biogas would be 0.928 x 559 = 519 Btu/ft^3 of wet biogas.

Appendix:

VAPOR PRESSURE OF WATER
EXPRESSED IN MILLIMETERS OF MERCURY
(from International Critical Tables)

Temp F	Pressure
50	9.209
55	11.073
60	14.666
65	15.807
70	18.779
75	22.233
80	26.234
85	30.827
90	36.118
95	42.175

Pressure above Atmosphere			Absolute
in H_20	psig	mm Hg	Pres, mm Hg
0	0	0.00	760.0
2	0.07	3.74	763.7
4	0.14	7.47	767.5
6	0.22	11.21	771.2
8	0.29	14.95	774.9
10	0.36	18.68	778.7
12	0.43	22.42	782.4
14	0.51	26.15	786.2
16	0.58	29.89	789.9
18	0.65	33.63	793.6
20	0.72	37.36	797.4
22	0.79	41.10	801.1
24	0.87	44.84	804.8

1.8682	mm Hg/in H2O
51.71	mm Hg/psi
0.0361	psi/in H2O