WOODGAS

DENSIFICATION

PROXIMATE AND ULTIMATE ANALYSES

Biomass fuels are characterized by what is called the "Proximate and Ultimate analyses". The "proximate" analysis gives moisture content, volatile content (when heated to 950 C), the free carbon remaining at that point, the ash (mineral) in the sample and the high heating value (HHV) based on the complete combustion of the sample to carbon dioxide and liquid water. (The low heating value, LHV, gives the heat released when the hydrogen is burned to gaseous water, corresponding to most heating applications and can be calculated from the HHV and H2 fraction.)

The "ultimate" analysis" gives the composition of the biomass in wt% of carbon, hydrogen and oxygen (the major components) as well as sulfur and nitrogen (if any).

The table below, showing Proximate and Ultimate analyses, is from Appendix A of our book[1], and gives analyses of over 140 fuels, including biomass components, natural biomass (woods, agricultural products), processed biomass, other solid and liquid fuels. For ease of reading download to a spreadsheet file.

The Proximate Analysis (D-3175), gives the fixed carbon, volatile and ash content of biomass. The Ultimate Analysis gives the elemental (C, H, O, S, N) analysis. The Gross heating value The data is often published with various articles in widely scattered journals. The data have been brought together for convenience in this one place. These standard ASTM tests and are performed by many laboratories in the country, routinely on coal, but competently on biomass. They typically cost $100-$200 so it is good to be able to find collected results for various biomass materials.

Our book "Thermal Data for Natural and Synthetic Fuels", Marcel Dekker, 1998, gives an extended list of the Prox and Ult analyses of about 300 forms of biomass, most of which were collected in the thesis of S. A. Channiwala from the Indian Institute of Technology, 1992.

I have long been fascinated with the close relationship between the heat of combustion (high heating value, HHV) and the elemental composition as given in the ultimate analysis. This was first noticed by DuLong in the 19th century and brought up to date by other scientists. Most recently a Mr. S. A. Channiwala 1992 thesis, The Indian Institute of Technology, Bombay) collected data on over 200 species of biomass and fitted the following equation to the data:

$$HHV \text{ (in kJ/g)} = 0.3491C + 1.1783 H - 0.1034 O - 0.0211 A + 0.1005 S - 0.0151 N$$

(where C is the weight fraction of carbon; H of hydrogen; O of oxygen; A of ash; S of sulfur and N of nitrogen appearing in the sltimate analysis.)

He found that this equation fitted the experimental data with an average error of 1.45%, typical of the error of most measurements. This equation permits using heat values in calculations and models of biomass processes.

Other analyses can be found at the following websites:

The Energy Center of the Netherlands,

IEA, The International Energy Agency,

Biobib (Austria)

Name	Fixed	Volatiles	Ash	C	H	O	N	S	HHV	HHV
	Carbon								MEAS	CALC
	%	%	%	%	%	%	%	%	kJ/g	kJ/g
WOOD										
Beech	-	-	0.65	51.64	6.26	41.45	0.00	0.00	20.38	21.10
Black Locust	18.26	80.94	0.80	50.73	5.71	41.93	0.57	0.01	19.71	20.12
Douglas Fir	17.70	81.50	0.80	52.30	6.30	40.50	0.10	0.00	21.05	21.48
Hickory	-	-	0.73	47.67	6.49	43.11	0.00	0.00	20.17	19.82
Maple	-	-	1.35	50.64	6.02	41.74	0.25	0.00	19.96	20.42
Ponderosa Pine	17.17	82.54	0.29	49.25	5.99	44.36	0.06	0.03	20.02	19.66
Poplar	-	-	0.65	51.64	6.26	41.45	0.00	0.00	20.75	21.10
Red Alder	12.50	87.10	0.40	49.55	6.06	43.78	0.13	0.07	19.30	19.91
Redwood	16.10	83.50	0.40	53.50	5.90	40.30	0.10	0.00	21.03	21.45
Western Hemlock	15.20	84.80	2.20	50.40	5.80	41.10	0.10	0.10	20.05	20.14
Yellow Pine	-	-	1.31	52.60	7.00	40.10	0.00	0.00	22.30	22.44
White Fir	16.58	83.17	0.25	49.00	5.98	44.75	0.05	0.01	19.95	19.52
White Oak	17.20	81.28	1.52	49.48	5.38	43.13	0.35	0.01	19.42	19.12
Madrone	12.00	87.80	0.20	48.94	6.03	44.75	0.05	0.02	19.51	19.56
Mango Wood	11.36	85.64	2.98	46.24	6.08	44.42	0.28		19.17	18.65
BARK										
Douglas Fir bark	25.80	73.00	1.20	56.20	5.90	36.70	0.00	0.00	22.10	22.75
Loblolly Pine bark	33.90	54.70	0.40	56.30	5.60	37.70	0.00	0.00	21.78	22.35
ENERGY CROPS										
Eucalyptus Camaldulensis	17.82	81.42	0.76	49.00	5.87	43.97	0.30	0.01	19.42	19.46

Casuarina	19.58	78.58	1.83	48.50	6.04	43.32	0.31	0.00	18.77	19.53
Poplar	16.35	82.32	1.33	48.45	5.85	43.69	0.47	0.01	19.38	19.26
Sudan Grass	18.60	72.75	8.65	44.58	5.35	39.18	1.21	0.01	17.39	17.62
PROCESSED BIOMASS										
Plywood	15.77	82.14	2.09	48.13	5.87	42.46	1.45	0.00	18.96	19.26
AGRICULTURAL										
Peach Pits	19.85	79.12	1.03	53.00	5.90	39.14	0.32	0.05	20.82	21.39
Walnut Shells	21.16	78.28	0.56	49.98	5.71	43.35	0.21	0.01	20.18	19.68
Almond Prunings	21.54	76.83	1.63	51.30	5.29	40.90	0.66	0.01	20.01	19.87
Black Walnut Prunings	18.56	80.69	0.78	49.80	5.82	43.25	0.22	0.01	19.83	19.75
Corncobs	18.54	80.10	1.36	46.58	5.87	45.46	0.47	0.01	18.77	18.44
Wheat Straw	19.80	71.30	8.90	43.20	5.00	39.40	0.61	0.11	17.51	16.71
Cotton Stalk	22.43	70.89	6.68	43.64	5.81	43.87	0.00	0.00	18.26	17.40
Corn Stover	19.25	75.17	5.58	43.65	5.56	43.31	0.61	0.01	17.65	17.19
Sugarcane Bagasse	14.95	73.78	11.27	44.80	5.35	39.55	0.38	0.01	17.33	17.61
Rice Hulls	15.80	63.60	20.60	38.30	4.36	35.45	0.83	0.06	14.89	14.40
Pine needles	26.12	72.38	1.50	48.21	6.57	43.72			20.12	20.02
Cotton gin trash	15.10	67.30	17.60	39.59	5.26	36.38	2.09	0.00	16.42	15.85
AQUATIC BIOMASS										
Water Hyacinth (Florida)	-	80.40	19.60	40.30	4.60	33.99	1.51	0.00	14.86	15.54
Brown Kelp,Giant, Soquel Point	-	57.90	42.10	27.80	3.77	23.69	4.63	1.05	10.75	10.85
AVERAGE				47.91	5.74	40.98	0.52	0.05	19.11	19.15
LIQUID FUELS										
n-octane	0.00	-	0.00	84.10	15.90	0.00	0.00	0.00	47.80	48.09
Benzene, C6H6	0.00			92.25	7.75	0.00	0.00	0.00	41.79	41.34
Motor Gasoline	0.00			85.50	14.40	0.00	0.00	0.10	46.88	46.83
Kerosene	0.00		0.01	85.80	14.10	0.00	0.00	0.10	46.50	46.58
Methanol, CH3OH	0.00		0.00	37.50	12.50	50.00	0.00	0.00	22.69	22.65
Ethanol, C2H5OH	0.00		0.00	52.20	13.00	34.80	0.00	0.00	30.15	29.94
PYROLYSIS OILS										
LBL Wood Oil			0.78	72.30	8.60	17.60	0.20	0.01	33.70	33.53
BOM wood oil			0.66	82.00	8.80	9.20	0.60	0.00	36.80	38.02
Coke-oven tar			0.25	91.75	5.50	0.80	0.90	0.80	38.20	38.49
Low Temp Tar				83.00	8.20	7.40	0.60	0.80	38.75	37.94
SOLID FUELS										
Coal - Pittsburgh Seam	55.80	33.90	10.30	75.50	5.00	4.90	1.20	3.10	31.75	31.82
Peat, S-H3	26.87	70.13	3.00	54.81	5.38	35.81	0.89	0.11	22.00	21.70

Charcoal	89.31	93.88	1.02	92.04	2.45	2.96	0.53	1.00	34.39	34.78
Oak char (565C)	55.60	27.10	17.30	64.60	2.10	15.50	0.40	0.10	23.05	23.06
Casuarina Char (950C)	71.53	15.23	13.24	77.54	0.93	5.62	2.67	0.00	27.12	27.26
Coconut Shell Char (750C)	87.17	9393.00	2.90	88.95	0.73	6.04	1.38	0.00	31.12	31.21
Eucalyptus char (950C)	70.32	19.22	10.45	76.10	1.33	11.10	1.02	0.00	27.60	26.75
ORGANIC CHEMICALS			M				*cal/mo*	*cal/g*	*kJ/g*	
Acetone; (CH3)2CO			58	62.07	10.34	27.59	*428*	*7.38*	*30.9*	31.01
Acetic Acid; CH3CO2H			60	40.00	6.67	53.33	*209*	*3.48*	*14.6*	16.30
D-Glucose; C6H12O6			180	40.00	6.67	53.33	*670*	*3.72*	*15.6*	16.30
Phenol; C6H5OH			94	76.60	6.38	17.02	*730*	*7.76*	*32.5*	32.50
Cellulose; C6H10O5			162	44.44	6.17	49.38				17.68
Lignin (Softwood)				63.8	6.30	29.90				26.60
Lignin (Hardwood)				59.8	6.40	33.70				24.93
EXCEPTIONS										
Hydrogen, H2				0.00	100.00	0.00	0.00	0.00	141.26	117.83
Carbon Monoxide, CO				42.86	0.00	57.14	0.00	0.00	10.16	9.05
Acetylene				92.25	7.75	0.00	0.00	0.00	49.60	41.34
Carbon				100.00	0.00	0.00			32.81	34.91
Carbon dioxide, CO2				27.27	0.00	72.7%			0.00	9.45
Water				0.00	11.11	88.89			0.00	3.90

(1) "Thermal Data for Natural and Synthetic Fuels", S. Gaur and T. Reed, Marcel Dekker, 1998.