Supported by the European Commission under the Intelligent Energy - Europe Programme

1. Wood biomass as a fuel

Material for 5EURES Training sessions. Page compiled by Markus Huhtinen, NCP, Finland.

Contents of this section:

1.1 Chemical composition of wood

Logging residues pile ready for chipping

The combustion of wood is a chemical reaction. If the burning process is complete, one can write the following formulas:

$C + O_2 \rightarrow CO_2 + 32.8$ MJ/kg (carbon)

$2H_2 + O_2 \rightarrow 2H_2O + 142.1$ MJ/kg (hydrogen)

In practice the burning process is never complete. The combustion always produces small amounts of unburned hydrocarbons (CO, C_xH_y).

The main components of wood cells are cellulose, hemicellulose and lignin, forming some 99 % of the wood material. Cellulose and hemicellulose are formed by long chains of carbohydrates, whereas lignin is a complicated component of polymeric phenolics.

Lignin is rich in carbon and hydrogen, which are the main heat producing elements. Thus it's calorific value is higher than that of cellulose and hemicellulose (carbohydrates).Wood and bark also contain so-called extractives, such as terpenes, fats and phenols. The amount of wood extractives is relatively small compared to the amount of extractives from bark and foliage.

The nitrogen (N) content of wood is about 0,75 %, varying somewhat from one tree species to another. For example, nitrogen-fixing alder (alnus sp.) contains twice as much nitrogen as most coniferous trees.

Wood has practically no sulphur (S) at all, as it's share in wood is 0,05 % at the highest (Pohjonen 1994).

Compared to many other fuels, the wood has a relatively low carbon content (some 50 % of dry weight) and high oxygen content (some 40 %), which leads to relatively low heating value per dry weight.

Birch has high heating value per volume unit.

Table 1.1: Average chemical contents of wood fuels

	Share, % of dry matter weight
Carbon	45-50% (solid 11-15%, volatile 35%)
Hydrogen	6.0-6.5%
Oxygen	38-42%
Nitrogen	0.1-0.5%
Sulphur	max 0.05

Table 1.2 Heating values of some fuels

Wood (dry)	18.5-21.0 MJ/kg
Peat (dry)	20-21 MJ/kg
Coal	23.3-24.9 MJ/kg
Oil	40.0-42.3 MJ/kg

1.2 Properties of wood fuels

The most important fuel properties are:

- Moisture content
- Density
- Heating value

Energy units:

1 kWh = 3.6 MJ

1 MJ = 0.278 kWh

1 kcal = 4.187 KJ

1 kcal = 1.163 kWh

The sources of information:

Savolainen, Berggren (editors): Wood Fuels Basic Information Pack Jyväskylä 2000

Puhakka et. al.: Hakelämmitysopas Joensuu 2001

Kärkkäinen: Puutiede. Hämeenlinna 1985

Hakkila: Puun ja puutavaran ominaisuuksia, Tapion Taskukirja, 19. painos Helsinki 1993

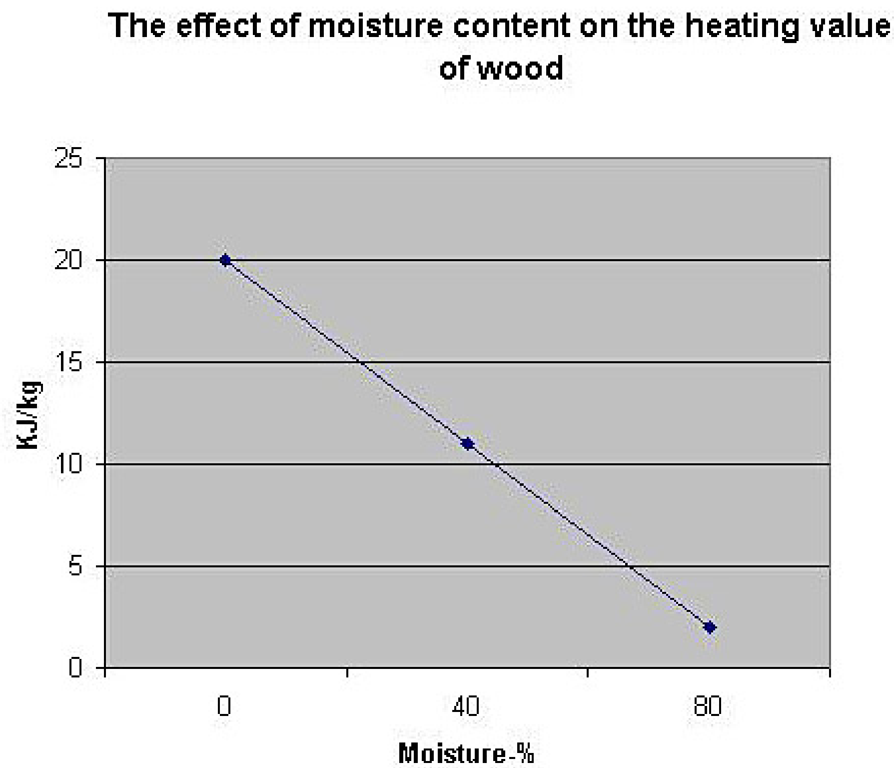
Pohjonen: Puu energialähteenä. Tapion Taskukirja, 22. uudistettu painos, Helsinki 1994

Wilen et al: Biomass feedstock analyses, VTT Publication 282, Espoo

- Particle size distribution
- Ash content and properties
- Chemical composition
- Amount of volatiles
- Results of proximate and ultimate analysis

The *moisture content* has big effect to the net calorific value reached at the burning process. The moisture content is stated as weight % of the wet base (as received).

Moisture content influences significantly the net calorific heating value. Vaporising water requires energy from the burning process (0.7 kWh or 2.6 MJ per a kilogram of water), thus reducing the net heating value of the fuel (Figure 1).



The moisture content of wood fuels varies from 20 to 65 % and is influenced among other things by:

The Norway Spruce stand has high proportion of needles, bark and branches.

1996

Nurmi : Heating values of whole-tree biomass in young forests in Finland. Acta Forestalia Fennica 236. Tampere 1993

- Climatic conditions
- Time of the year
- Tree species
- Part of the stem
- Storage phase

It is quite common to use the 40 % moisture content as a standard when the energy value of forest area is estimated. A moisture content of 15 % can be reached in optimal Nordic conditions without extra energy input for drying (Hakkila 1983).

If the moisture content is 70-80 %, the energy content of wood can no longer support the burning process.

Basic density (kg/m3) indicates the relationship of dry mass to solid volume measure (or how much dry wood weighs per a solid measure of wood).

Solid volume content of fuel is needed when so called **bulk measure** of fuel is converted into **solid measure.**

Bulk density of the Northern European woody biomasses is in the range of 200-350 kg per loose m3.

Table1.2. The bulk density of Northern European woody biomasses (Wilen et al. 1996).

Woody biomass	kg/m3	kg dry/m3	Moisture, w%
Wood chips	238	229	3,87
Forest residues chips, Fi	313	293	6,30
Forest residues chips, Swe	271	254	6,32
Sawdust (pine)	177	150	15,30
Spruce bark	289	274	5,25
Pine bark	230	219	4,74
Salix ssp	227	222	2,39

The **particle size** of wood fuels varies from sawdust-like needle and bark material to sticks of wood and branch pieces. Especially the forest chip quality is very variable. The more stemwood the raw material contains, the more even the particle size distribution will be.

Uncommercial roundwood stored for chipping .

Heating value of wood fuels

It is important to recognize different terms of heating values:

Calorimetric value *= Amount of energy created when one kg of absolutely dry wood is burned and all water created in burning process is condensed (HHV, combustion heat).*

Dry wood effective heating value *= Amount of energy created when one kg of absolutely dry wood is burned and water created in the burning process vaporizes (LHV).*

Effective heating value *= Amount of energy created when one kg of moist wood is burned and water content of the fuel and water created in burning process vaporize (LHV.*

The calorific heating value of wood does not vary much from one tree species to another (18.7-21.9 MJ/kg), but is slightly huigher in coniferous species than in broadleaved or deciduous tree species.

Similarly, there are some difference between the **effective heating values** of Nordic tree species. The conifers have slightly higher values than deciduous trees due to their higher lignin and resin contents.

Table 1.3. Stemwood qualities (Hakkila 1978, Nurmi 1993)

Tree species	Density kg/m3	Dry mass kg/m3	Net Cal. value of dry wood/kg
Pine (*Pinus ssp*)	385	162	19.3
Birch (*Betula ssp*)	470	183	19.2
Alder (*Alnus ssp*)	370	179	19.0

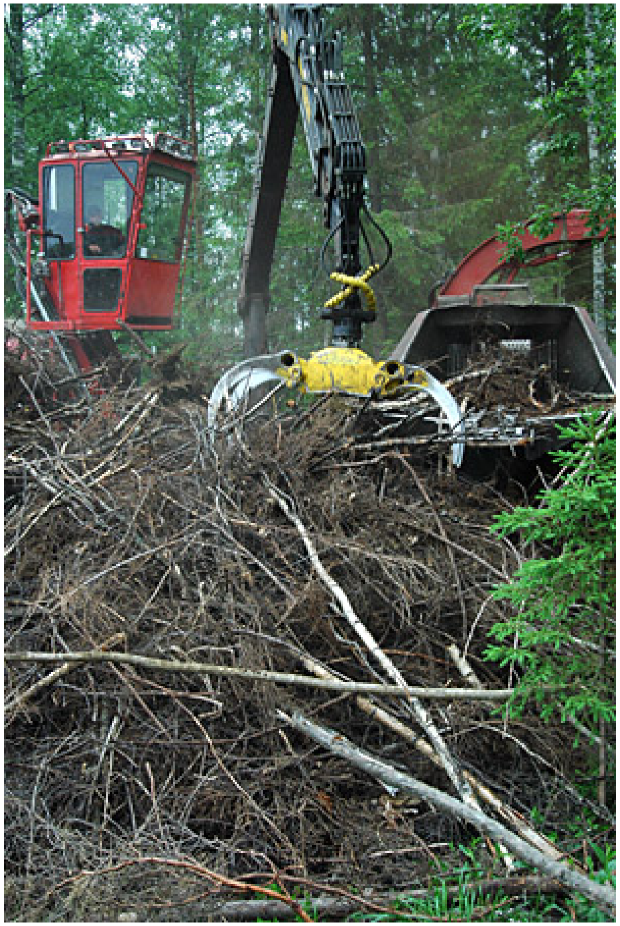
Branches and other logging residues have high heating value

Heating values per volume unit

The heating values are normally given per kilogram of solid wood. For wood the value range is 18.5-21.0 MJ/kg. However, in forestry it is quite normal to measure the amount of stemwood as solid cubic meters (m3). The denser species naturally have higher heating value per m3 of solid stemwood (tables 1 and 2).

Table 1.4. Effective heating values of tree species, MJ/m3.

Tree species	Moisture	content		
	0 %	20 %	40 %	60 %
Pine	7511	7274	6876	6080
Spruce	7266	7034	6646	5871
Birch	9555	9256	8756	7757
Alder	6840	6626	6268	5553



Roadside chipper in action

Ash content and properties

Ash content means the amount of solid wastes after complete burning process of the fuel. It can be expressed as weight % of the dry base or as a weight % of the as received (ar) material. High ash content of the fuel generally reduces it's heating value. The ash content of wood biomasses ranges from 0.08 to 2.3 %

Amount of volatiles

The combustibles of solid fuels can be shared into two groups: *volatile matters* and components combusting as *solid carbon*. The share of volatile matters wood is typically high, 80 % of the energy originating in the combustion of volatile matters.

Results of proximate and ultimate analysis

In the so-called *proximate analysis* of wood fuels, such properties as solid carbon, volatile materials and moisture contents are defined. In *ultimate analysis* one defines the share of most important elements such as C, H, O, N, S, Cl, F and Br.

1.3 Tree components

The tree biomass can be dividide into different components, depending mainly on the minimum diameter of industrially usable logs. If we assume that the minimum top diameter of industrially usable logs is 5 cm we can use following figures (Hakkila 1983):

Table1.5. Stemwood, treetops and branches biomass, % of the total harvest.

	Pine	Spruce
Industrially usable stemwood w. bark	52	27
Needles	7	19
Bark	5	12
Industrially unusable wood in branches and treetops	13	19
Trunkwood (>5 cm)	23	23
Total	100	100

Heating values of different tree components

The bark, crown and stumps of the tree have typically somewhat higher effective heating values than the stemwood.

Table 1.6. Tree component heating values

Tree species	Stem without bark	Bark	Whole stem	Crown	Whole tree
Scots Pine	19.31	19.53	19.33	20.23	19.52
Norway spruce	19.05	18.80	19.02	19.77	19.29
Birch (Betula ssp)	18.65	22.61	19.17	19.70	19.30
Grey alder	18.67	21.57	19.00	20.03	19.18
Trembling aspen	18.67	18.57	18.65	18.61	18.65

Stumps are harvested at UPM logging site near Jyväskylä

- Wood energy and environment

Page and images by Markus Huhtinen 2.9.2005