Properties of wood fuels used in Finland – BIOSOUTH -project

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Abstract

The properties of wood fuels are based on the literature published in Finland and of research carried out at VTT Processes. Also the current situation of standardisation of solid biofuels (woody part) is included in this report.

The main properties of the fuels considered in this publication are:

- calorific value
- chemical composition
- moisture content
- density, particle size and other fuel handling properties
- ash content, ash melting behaviour and ash composition
- concentrations of harmful substances, such as alkalis and heavy metals.

Properties of different kinds of wood fuels, such as small-size trees, logging residues, bark, stumps and log wood, are presented in comparison tables. The material comprises both commercial fuels and fuels under research. Definitions for fuels and properties, analysis methods for different properties, and formulas for calculation of values are presented in the publication. The publication also includes summary tables of fuel properties, and the fuel quality classifications in Finland and in CEN TC 335 standardisation.

Preface

The essential properties of wood fuels used in Finland are summarised in this publication. The work was supported by an EU-funded project: “Techno-economic assessment of the production and use of biofuels for heating and cooling applications in South Europe” (BIO-SOUTH, EIE/04/255/507.38609). The publication includes properties of solid wood fuels, based on data from written sources, on information obtained from institutes and industrial plants, and on determinations performed by analytical laboratories of VTT Processes.

Definitions related to fuel properties were collected from quality standards (CEN/TS 14588) for wood fuels and from literature references studied during the work. The analytical methods used for fuels are described primarily as applied at VTT Processes, completed with information and data from literature references and CEN/TC 335 standardisation.

Report is available on Internet at www.bio-south.com.

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Symbols and abbreviations

The symbols and abbreviations used in this publication comply with the SI system of units as far as possible.

d	dry (dry basis)
daf	dry, ash-free, see informative annex C
ar	as received
A	Designation for ash content (w-%, dry basis), CEN/TS 14961 *
ρ	Density [kg/m^3]
BD	Designation for bulk density, [kg/m^3 loose], CEN/TS 14961 *
DE	Designation for particle density as received [kg/dm^3], CEN/TS 14961
D	Designation for diameter [mm], CEN/TS 14961 *
DU	Designation for mechanical durability [w-%], CEN/TS 14961 *
E_{ar}	Energy density as received [MWh/m^3 loose, solid or stacked volume (amount of energy/volume unit),
E	Designation for energy density as received [kWh/m^3 or kWh/kg, unit is to be stated in brackets], CEN/TS 14961*
F	Designation for amount of fines (< 3,15 mm, w-%), CEN/TS 14961
L	Designation for length, [mm] CEN/TS 14961*
M_{ar}	Total moisture content as received [w-%] on wet basis
M	Designation for moisture content as received [w-%], CEN/TS 14961*
P	Designation for particle size distribution [w-%], CEN/TS 14961*
$q_{V,gr}$	Gross calorific value [MJ/kg] at constant volume
$q_{p,net}$	Net calorific value [MJ/kg] at constant pressure

*Designation symbols are used in combination with a number to specify property levels in the quality table of the CEN/TS 14961. For designation of chemical properties

chemical symbols like S (sulphur), Cl (chlorine), N (nitrogen) are used and the value is added at the end of the symbol.

m^3	For wood: solid cubic metre (~ 2.5 bulk-m^3)
bulk or loose m^3	Bulk cubic metre
stacked m^3	Piled cubic metre, stacked cubic metre

Definitions for woody biomass and properties

WOODY BIOMASS

bundled biofuel, bundle
solid biofuels which has been bound together and where there is a lengthwise orientation of the material

forest wood
woody biomass from forests and/or tree plantations

fuel wood; energy wood
wood fuel, in which the original composition of the wood is preserved

hog fuel
fuel wood in the form of pieces of varying size and shape, produced by crushing with blunt tools such as rollers, hammers, or flails

over-size particles
a batch of particles exceeding a specific limit value

stemwood
part of tree stem, branches removed

stump
part of the tree stem below the felling cut. in total-tree utilisation the root system is included in the stump.

thinning residues
woody biomass residues originating from thinning operations

whole tree
felled, undelimbed tree, excluding root system

wood chips
chipped woody biomass as pieces of a defined particle size produced by mechanical treatment with sharp tools such as knives. wood chips have a sub-rectangular shape with a typical length of 5 to 50 mm and a low thickness compared to other dimensions.

wood fuels, wood-based fuels, wood-derived biofuels
all types of biofuels originating directly or indirectly from woody biomass.

wood-processing industry by-products and residues
woody biomass residues originating from the wood processing as well as the pulp and paper industries

woody biomass
biomass from trees, bushes and shrubs

PROPERTIES

ash
residue obtained by combustion of a fuel. Depending on the combustion efficiency the ash may contain combustibles. Adopted to ISO 1213-2:1992

ash deformation temperature, DT
temperature at which first signs of rounding due to melting, of the tip or edges of the test piece occur. Adopted to ISO 540:1995

ash flow temperature, FT
temperature at which the *ash* is spread out over the supporting tile in a layer, the height of which is one-third of the height of the test piece at the ash hemisphere temperature.Adopted to ISO 540:1995

ash fusibility; ash melting behaviour
characteristic physical state of the ash obtained by heating under specific conditions.Ash fusibility is determined under either oxidizing or reducing conditions. Adopted to ISO 540:1995

ash hemisphere temperature, HT
temperature at which the height of a test piece, prepared from *ash* by a specific procedure, is equal to half the width of the base, and its shape becomes approximately hemispherical. Adopted to ISO 540:1995

ash sphere temperature, ST
temperature where the height of a pyramidal and truncated-cone test pieces is equal to the width of the base, or the edges of a cubical or cylindrical test pieces are completely round with the height remaining unchanged. Adopted to ISO 540:1995

basic density
ratio of the mass on dry basis and the solid volume on green basis

bridging; arching
tendency of particles to form a stable arch across an opening and hindering flow.Adapted to Woodcock and Mason. Bulk Solids Handling

bulk density
mass of a portion of a solid fuel divided by the volume of the container which is filled by that portion under specific conditions. Adopted to ISO 1213-2:1992

bulk volume, loose volume
volume of a material including space between the particles

calorific value, heating value (q)
energy amount per unit mass or volume released on complete combustion

char
solid partially or non-agglomerated carbonaceous material produced by pyrolysis of solid biofuels. Adopted to ISO 1213-2:1992

combined sample
sample consisting of all the increments taken from a sub-lot. The increments may be reduced by division before being added to the combined sample.

common sample
sample collected for more than one intended use. Adopted to ISO/FDIS 13909

density
ratio of mass to volume. It must always be stated whether the density refers to the density of individual particles or to the bulk density of the material and whether the mass of water in the material is included.

dry ash free basis
condition in which the solid biofuel is free from moisture and inorganic matter

dry basis
condition in which the solid biofuel is free from moisture. Adopted to ISO 1213-2:1992

dry matter
material after removal of moisture under specific conditions.

dry matter content
portion of dry matter in the total material on mass basis.

energy density
ratio of net energy content and bulk volume.The energy density is calculated using the net calorific value determined and the bulk density.

extraneous ash
total ash from contaminants entering the material at harvest, logging, treatment, transport, storage etc.

fixed carbon
remainder after the percentage of total moisture, total ash, and volatile matter are subtracted from 100. Adopted to ISO 1213-2:1992

flowability
ability of a solid to flow

foreign material; impurities
material other than claimed, which has contaminated the biofuel.

general analysis sample
sub-sample of a laboratory sample having a nominal top size of 1 mm or less and used for a number of chemical and physical analyses. Adopted to ISO/FDIS 13909.

green basis
condition based on fresh material at specific total moisture.

gross calorific value (q_{gr})
absolute value of the specific energy of combustion, in joules, for unit mass of a solid fuel burned in oxygen in calorimetric bomb under the conditions specified. The result of combustion are assumed to consist of gaseous, oxygen, nitrogen, carbon dioxide and sulphur dioxide, of liquid water (in equilibrium with its vapour) saturated with carbon dioxide under conditions of the bomb reaction, and of solid ash, all at the reference temperature and at constant volume. Old term is higher heating value. Adopted to ISO1928:1995.

gross density
ratio of the mass of a wooden body and its volume, including all cavities (pores and vessels), based on specific total moisture.

increment
portion of fuel extracted in a single operation of the sampling device. Adopted to ISO/FDIS 13909.

inorganic matter
non-combustible fraction of dry matter.

laboratory sample
combined sample or a sub-sample of a combined sample or an increment or a sub-sample of an increment sent to a laboratory

lot
defined quantity of fuel for which the quality is to be determined. Adopted to ISO/FDIS 13909.

mass-reduction
reduction of the mass of a sample or sub-sample.

mechanical strength, mechanical durability
ability of densified biofuel units (e.g. briquettes, pellets) to remain intact during loading, unloading, feeding, and transport.

moisture
water in a fuel. See also total moisture and moisture analysis sample.

moisture analysis sample
sample taken specifically for the purpose of determining total moisture. Adopted to ISO/FDIS 13909.

natural ash
total ash of uncontaminated fuel.

net calorific value (q_{net})
under such conditions that all the water of the reaction products remains as water vapour (at 0.1 MPa), the other products being as for the gross calorific value, all at the reference temperature. The net calorific value can be determined at constant pressure or at constant volume. Old term is lower heating value. Net calorific value as received ($q_{net,ar}$) is calculated by the net calorific value from dry matter ($q_{net,d}$) and the total moisture as received. Adopted to ISO 1928:1995.

nominal top size
aperture size of the sieve used in the CEN method for determining the particle size distribution of solid biofuels through which at least 95 % by mass of the material passes. Adopted to ISO/FDIS 13909.

organic matter
combustible fraction of dry matter.

oscillating screen classifier
device containing one or multiple oscillating (flat) screens used to separate material into size classes for calculation of particles size distribution.

over size particles
portion of particles exceeding a specific limit value.

particle density
density of a single particle

particle size
size of the fuel particle as determined. Different methods of determination may give different results.

particle size distribution
proportions of various particle sizes in a solid fuel. Adopted to ISO 1213-2:1992.

proximate analysis
analysis of a solid biofuel reported in terms of total moisture, volatile matter, ash content and fixed carbon measured at specified conditions. Adopted to ISO 1213-2:1992.

sample
quantity of material, representative of a larger quantity for which the quality is to be determined. Adopted to ISO/FDIS 13909.

sample size reduction
reduction of the nominal top size of a sample or sub-sample.

size analysis sample
sample taken specifically for the purpose of determining particle size distribution.

solid volume
volume of individual particles.Typically determined by a fluid displaced by a specific amount of material.

stacked volume
volume of stacked wood including the space between the wood pieces.

sub-lot
part of a lot for which a test result is required. Adopted to ISO/FDIS 13909.

sub-sample
portion of a sample.

test portion
sub-sample of a laboratory sample consisting of the quantity of material required for a single execution of a test method.

total ash
mass of inorganic residue remaining after combustion of a fuel under specified conditions, typically expressed as a percentage of the mass of dry matter in fuel. Old term is ash content.

total carbon (C)
sum of carbon in organic and inorganic matter as a portion of the fuel. Adopted to ISO 1213-2:1992.

total hydrogen (H)
sum of hydrogen in organic and inorganic matter. Adopted to ISO 1213-2:1992. In CEN/TS 14588 also the hydrogen in water is calculated but not in Finnish analysis.

total moisture, M_T
moisture in fuel removable under specific conditions. Indicate reference (dry matter / dry basis, or total mass / wet basis) to avoid confusion. Old term is moisture content. Adopted to ISO1928:1995.

total nitrogen (N)
sum of nitrogen in organic and inorganic matter as a portion of the fuel. Adopted to ISO 1213-2:1992.

total oxygen (O)
sum of oxygen in organic and inorganic matter and in the moisture as a portion of the fuel. For solid biofuels a calculation method for total oxygen is available.

total sulphur (S)
sum of sulphur in *organic* and *inorganic matter* as a portion of the *fuel*. Adopted to ISO 1213-2:1992.

ultimate analysis, elementary analysis
analysis of a fuel reported in terms of its total carbon, total hydrogen, total nitrogen, total sulphur, and total oxygen measured at specified conditions. Adopted to ISO 1213-2:1992.

volatile matter
mass loss, corrected for moisture, when a fuel is heated out of contact with air under specific conditions. Adopted to ISO 1213-2:1992.

volume
amount of space that is enclosed within an object. It must always be stated whether the volume refers to the solid volume of individual particles, the bulk volume, or the stacked volume of the material and whether the mass of moisture in the material is included.

wet basis
condition in which the solid biofuel contains moisture.

Source: CEN/TS 14588

1. Introduction

Wood fuel properties described in this report are based on Finnish literature and the results of analyses carried out at VTT. The most significant fuel properties are

- calorific value
- chemical composition of fuel (elementary analysis, i.a.. alkalis and metals, metalloids, heavy metals and trace elements)
- moisture content
- ash content and ash melting behaviour
- density and other handling properties.

Fuel properties of the following wood fuels are summarised in this publication: wood chips, hog fuel, chopped wood, sawdust, bark, briquettes and pellets.

Determination methods of fuel properties and calculation formulas are presented. Fuel properties are compared and Finnish and CEN 335 wood fuel quality classes are presented in annexes.

2. Sampling and determination methods of properties for wood fuels

2.1 General

In Finland the quality of wood fuels is determined for fuel types by choosing for each delivery batch the limit values for the energy density, moisture content and particle size of the fuel as received from the quality table in App.1. The energy density is dependent on net calorific value, moisture content, bulk density and particle size of the fuel concerned. When choosing limit values for energy density and moisture, the interdependence of different characteristics should be considered by using characteristic values typical of different wood fuels, presented, e.g., in the table of App.1.

In deliveries of different wood fuel blends or mixtures (e.g., bark/sawdust, cutter chips/grinding dust/other wood residues), the parties should agree upon the application of quality classification and the quality determination of fuel considering the use and safety issues.

Quality limits for other characteristics of the fuel can be specified case by case for mechanical properties of the fuel (i.a., oversize particles) and other properties, if they deviate from the values given in the Appendix 1 or if the method of determination for these properties deviates from that required for the quality limits in this manual.

When preparing delivery agreements, differences in properties due to possible seasonal variations should also be considered and agreed by parties separately.

Sampling described in chapter 2.2 in based on the method used in Finland (Impola 1998) and agreed with wood fuel producers and users. CEN/TC 335 is developing four technical specifications for sampling and sample reduction (CEN/TS 14778-1 Methods for sampling, CEN/TS 14778-2 – Methods for sampling delivered in lorries, CEN/TS 14779 – Methods for preparing sampling plans and sampling certificates) and CEN/TS 14780 – Methods for sample preparation.

These methods are preliminary tested in BioNorm project (Pre-normative work on sampling and testing of solid biofuels for development of quality assurance systems, www.ie-leipzig.de/BioNorm/Standardisation.htm).

2.2 Sampling and sample preparation

2.2.1 General

The purpose of sampling is to obtain a sample that represents the whole fuel batch as well as possible. The purpose of sample treatment is to reduce the sample in such a manner that its representativeness is maintained.

The requirements for the amount, volume and handling of samples are set in such a manner that the procedure is sufficient for the most demanding appropriate determination, i.e., for moisture determination for a delivery batch based on drying in a drying oven. Instead of this procedure, other procedures of equal reliability and representativeness can also be used. In particular when a method not requiring sampling is agreed upon for moisture determination, the sampling and sample treatment for the determination of other properties can deviate from those presented above.

The sampling and sample treatment equipment and methods used for commercial quality determination should always be tested in a manner agreed jointly.

The delivery site of the fuel should be the primary sampling point. If it is technically difficult to take a representative sample from wood fuel at the delivery site, a sampling point should be chosen, where a representative sample can be taken from the fuel batch in the safest manner and with moderate costs. The most reliable representative sample is obtained from a continuous fuel stream.

Single samples (increments) should be taken (priority order)

a) from continuous fuel stream; primarily in the reception, but also during loading or re-loading
b) directly from the load, mechanically according to chapter 2.2.2.1
c) at the receiving station during discharge or from a receiving pocket immediately after discharge
d) during loading from a loading probe or from a slope of the stockpile
e) from a stockpile or a fuel heap. It is not recommended to take samples from a stockpile for commercial purposes, as it is unsafe to obtain a representative sample and sampling is also excessively laborious.

2.2.2 Sampling method

Sampling is the stage causing most inaccuracy in determination results. Consequently, particular attention should be paid to sampling, and it should be carried out systematically and with care. The most exact result is obtained by mechanical sampling. This is possible when taking samples from continuous fuel streams or loads.

Different sampling procedures in Finland are presented in the order of superiority in the following chapters. A procedure of sampling and handling suitable for wood fuels is shown in Figure 1.

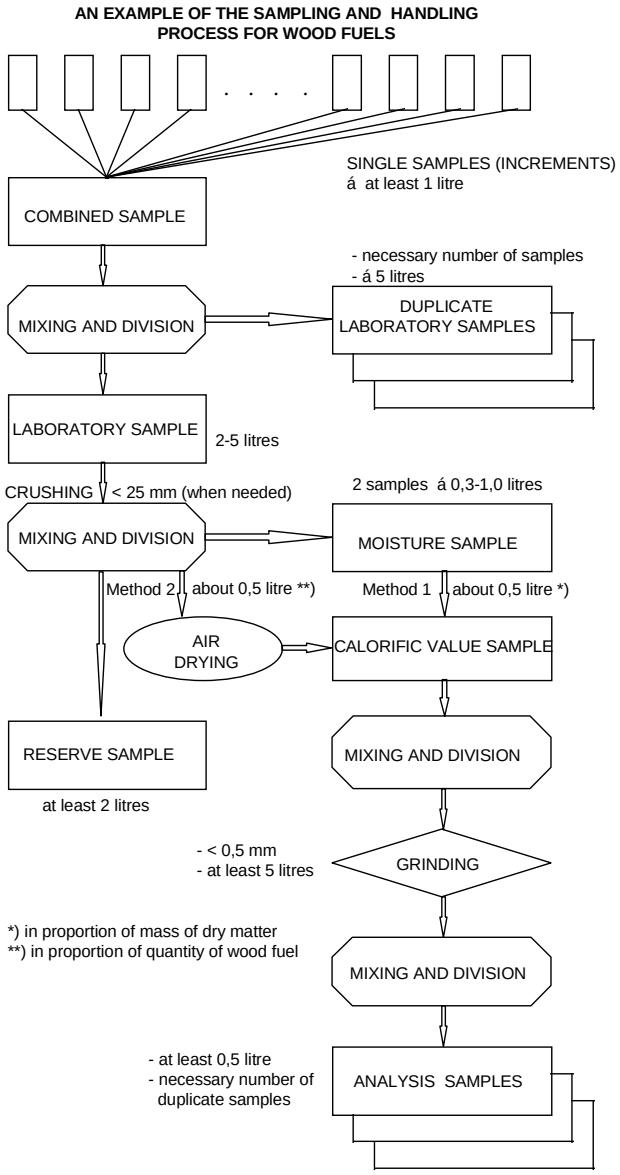


Figure 1. Sampling procedure of wood fuels in Finland (Impola 1998).

2.2.2.1 Mechanical sampling from continuous fuel stream

Single samples are taken mechanically in such a manner that the entire width of the stream is proportionally represented in the sample.

Examples:

- Sampling from the discharge end of the conveyor with a slot probe, should be carried out in such a manner that the probe moves at a constant rate of not more than 1.5 m/s through the entire falling fuel stream, preferably along a direct line. If the path of the probe is a circumference, the radius of curve, calculated from the outer end of the probe, should be at least five times the length of the slot. The probe should be empty at the start of the movement and should not be filled more than to the height of 3/4 during the movement. The width of the slot probe should be at least 100 mm when the particle size of wood fuel is less than 60 mm, and otherwise at least 300 mm.

- Sampling from non-continuous fuel stream (e.g., scraper or screw conveyors) can also be performed by opening the bottom of the conveyor over its entire width in such a manner that the whole non-continuous batch of fuel, e.g., the fuel remaining between the scrapers, is collected for the sample.

2.2.2.2 Manual sampling from continuous fuel stream

The sample is taken manually from continuous fuel stream according to the principles given above. From a halted conveyor, the entire width of the fuel stream for a length of at least 100 mm is taken when the particle size of wood fuel is less than 60 mm, and otherwise for a length of at least 300 mm.

2.2.2.3 Mechanical sampling during loading, discharge or from a fuel load

Single samples are taken mechanically with such sampling equipment that the sample is representative.

2.2.2.4 Manual sampling during loading or discharge

During loading or discharge the samples are taken manually with a standard-size shovel systematically in such a manner that no sorting or selection occurs.

At the receiving site the samples are collected from the falling fuel stream or from a receiving pocket during discharge or immediately after over the whole length of the load at regular intervals. In smaller plants increments are taken several places of the truck load (Fig. 2).

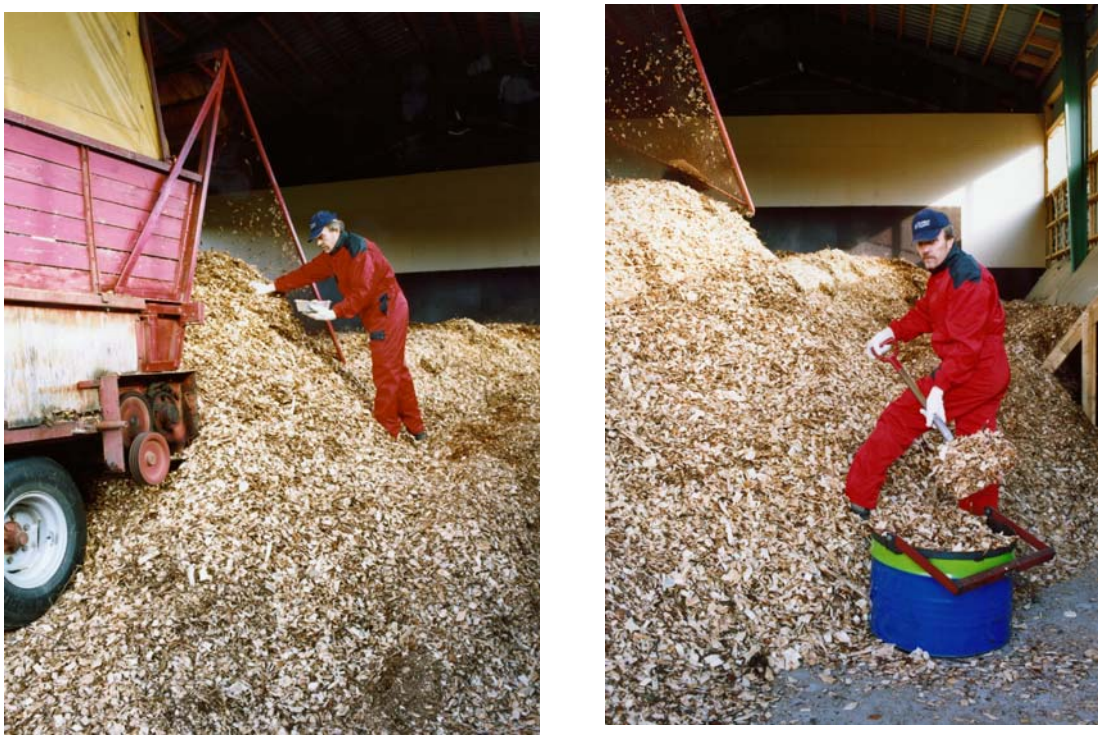


Figure 2. Manual sampling in small sized (2.5 MW_{th}) district heating plant. On the left sampling for moisture content and on the right for bulk density. Contact is based on volume, measurement of moisture and bulk density.

The sample should not be taken from the surface of a discharge pocket, load or heap, neither from the bottom or from the lower slopes of heaps. A single sample should not be taken directly from the fuel load or from a moving conveyor for safety reasons.

During loading the sample is taken from the loading probe. If this is not possible, the sample can also be taken from the slope of the stockpile at regular intervals.

When taking samples manually from a fuel with a large particle size, single pieces should not be selected and the sample should contain fines in the same proportion as the wood fuel batch subject to sampling.

2.2.2.5 Number of increments

When samples are taken from a conveyor system, the number of increment should be at least 4 per 100 m^3 fuel.

If samples are taken from fuel loads, the number of increments taken in continuous fuel deliveries should be as follows:

Load size, m^3	Number of increments/load
< 50	2
50 - 120	4
> 120	6

When the average size of the delivery batch is less than 300 m^3 or when determining load-specific properties (e.g., medium moisture of the load), the number of increments should be at least double.

2.2.3 Volume of increment

- When taking samples from a continuous fuel stream mechanically or manually or in such a manner that the entire transverse section is included in the sample according to the average value principle or mechanically directly from the fuel load, the volume of the increment should be at least **10 litres**. If the fuel stream is non-continuous (e.g., scraper or screw conveyors), the volume of the increment should be at least equal to that of one non-continuous batch (the fuel amount between two scrapers or screws).
- When taking samples mechanically or manually during loading or discharge (e.g., large falling fuel streams, receiving pocket, loading probe, stockpile slope) with a sampling shovel in such a manner that the representability is based on taking increments from different sites of the fuel batch or fuel stream, the volume of the increment should be at least **one litre** when the particle size is < 60 mm, and at least 5 litres when the particle size is > 60 mm.
- In all sampling systems the increment are taken in such a manner that the mouth diameter of the sampling device or shovel is at least 100 mm when the particle size of wood fuel is < 60 mm and at least 300 mm when the particle size is > 60 mm.
- The volume of a increment (volumetric efficiency of the sampler or sample shovel) should be kept constant irrespective of fuel quality.
- In manual sampling, increments are collected with a long-handled sampling shovel.

2.2.4 Preparation and handling of samples

When handling and storing samples care should be taken that the properties of the samples do not alter. The samples should be stored in a tightly closed container in a cool room. The moisture which might possibly condense on the walls of the container should be mixed in the sample prior to further treatment. In case the sample is frozen it shall be thawed at room temperature prior to handling.

2.2.4.1 Preparation of combined sample

The increments taken from the same delivery batch or from its part are mixed to form a combined sample in such a manner that the procedure is appropriate to the reliability of sampling. At least two combined samples of about the same size are prepared for a delivery batch of > 2 000 m^3 if some other formation principle of the combined sample is not more appropriate to the case concerned.

The combined sample is formed for each deliverer and if necessary for each delivery site and fuel sort.

The combined sample can also consist of parts obtained by homogenising and dividing single samples.

2.2.4.2 Preparation of laboratory sample

The combined sample is mixed and if necessary crushed, after which the necessary number of samples are separated from it with a reliable divider or division method. The volume of the laboratory sample should be 2–5 litres for wood fuels. If the particle size of the fuel is > 60 mm, the sample is crushed prior to the preparation of the laboratory sample.

Preparation of sample for moisture determination

Two moisture samples of 0.3–1.0 litre, each are separated by dividing from the laboratory samples and dried to determine the moisture content. The size of the moisture samples is dependent on the moisture determination method applied.

The remaining laboratory sample is stored in air-tight container (reserve sample) for a period agreed.

In principle, the determination of moisture content should be carried out within 24 hours from sampling.

2.2.4.4 Preparation of sample for calorific value determination

Either method 1 or 2.

Method 1:
- A partial sample of about 0.5 l is separated from a dried moisture sample by weighting the fuel amount represented by the combined sample with the dry matter mass.

- Partial samples are collected over a fixed period (not longer than a month) for each deliverer and if necessary for each delivery site.

Method 2:
- A partial sample of about 0.5 l is separated by reducing from the remainder of the laboratory sample (reserve sample) in proportion of weight of the amount of fuel as received (mass or volume) represented by the combined sample.

- The partial samples are air-dried and collected over from a fixed period (not more than one month) for each deliverer and if necessary for each delivery site

2.2.4.5 Preparation of analysis sample

A partial sample of at least 5 litres is separated by reducing from the mixed sample and that is ground to a < 0.5 mm particle size sample for calorific value determination. An analysis sample of at least 0.5 litre and a necessary amount of duplicate samples for control analyses are separated from the ground and mixed partial sample.

2.2.5 Sampling for particle size determination

A combined sample of at least 20 litres is collected from several single samples in such a manner that it represents the entire fuel batch studied.

2.2.6 Marking of samples

All samples should be marked with such data that the samples can be identified unambiguously. Such data are, e.g., deliverer, delivery batch(es), sample name (e.g., laboratory sample) and the fuel amount represented by it, sampling date and if necessary place, and the name of the operator.

2.3 Determination of most important properties

Determination methods have been developed both for solid and liquid fuels in Finland by VTT. The development work is usually based on international methods. In this chapter, primarily determination methods developed for solid fuels are described (Nieminen & Ranta, 1982). Also some of the new CEN methods for some physical and mechanical properties are shortly described (Alakangas 2005).

The most significant properties determined are ultimate analysis, elementary analysis, calorific value, and ash content and ash melting behaviour. Data is also often required about density, particle size and other fuel handling properties. Heavy metal contents and contents of different metals or alkalies either in the fuel or ash are also often determined for environmental or combustion-technical reasons. As regards dust fuels, data is also required on properties related to safety, i.a., on temperature of spontaneous ignition and on dust explosion properties (ISO 6184/1) (Wilén et al. 1999).

Proximate analysis of fuels comprises the determinations of moisture content, volatile substances, fixed carbon and ash with specified methods. The proximate analysis is used for assessing the quality of fuels and, besides determinations of calorific value, as a basis for fuel trade (Ranta & Korhonen 1983).

2.3.1 Determination of moisture content

The determination methods of moisture content are mainly based on the ISO 589 method for analysing wood fuels in Finland. Other method used is SS 18 71 84 (Biofuels and peat). In CEN/TC 335 three new technical specifications are developed for analysis of moisture content. The CEN/TS 14774-1 – Reference method is a method of determining the total moisture content by using oven. The sample is dried at a temperature of 105 ^{o}C in air atmosphere until contant mass is achieved and percentage moisture content calculated from the loss in mass of the sample and includes a procedure for the correction of buoyancy effects.

The size of samples used in moisture content determinations is dependent on the weighing accuracy and on the particle size of the fuel concerned. When the weighing accuracy is 0.01 g, at least two 30–100 g samples, and when 0.1 g, two 200–400 g samples are weighed for the determination. In CEN/TS 14774-1 the sample mass shall be minimum 300 g but preferabley more than 500 g. For large particle size samples with a nominal top size of 100 mm, a sample mass of 1–2 is preferred. Accurancy in CEN method is 0.1 g.

In Finland ISO 589 is used and the samples are dried in an air-conditioned heating chamber at 105±2 °C to standard weight. Usually, a drying time of 16 hours is sufficient, when the sample layer is not more than 30 cm thick. Drying time shall not exceed 24 hours. Possible dry samples shall be removed from the heating chamber before placing moist samples in it.

After drying, the samples are let to cool to room temperature in an exsiccator before weighing. If there is no exsiccator available, the samples can be weighed hot immediately after removal from the heating chamber. The accuracy of reporting is 0.1 percentage units.

If moisture determinations are compared with each other, the method applied shall be agreed upon in advance (cooling in an exsiccator/weighing hot).

In moisture determinations, it shall be controlled that the vessels used absorb no moisture and that the vessels endure the drying temperature.

The moisture content of the samples is calculated for the mass change during drying in accordance with formula (1)

$$M_{ar} = \frac{(m_2 - m_3) + m_4}{(m_2 - m_1)} \times 100 \qquad (1)$$

where

m_1 is the mass in grams of the empty tray

m_2 is the mass in grams of the tray and sample before drying

m_3 is the mass in grams of the tray and sample after drying

m_4 is the mass in grams of the reference tray before drying (weight at room tempereature)

2.3.2 Determination of calorific values

The net calorific value of solid fuels for dry matter is determined in accordance with standards ISO 1928, DIN 51900, ASTM D 1989-96 and ASTM D 3286-96 (Nieminen & Ranta 1982).

Gross calorific value is the absolute value of the specific energy of combustion, in joules, for unit mass of a solid biofuel burned in oxygen in a calorimetric bomb under the conditions specified. The products of combustion are assumed to consist of gaseous oxygen, nitrogen, carbon dioxide and sulfur dioxide, of liquid water (in equilibrium with its vapour) saturated with carbon dioxide under the conditions of the bomb reaction, and of solid ash, all at the reference temperature.

Net calorific value at constant volume is the absolute value of the specific energy of combustion, in joules, for unit mass of the biofuel burned in oxygen under conditions of constant volume and such that all the water of the reaction products remains as water vapour (in a hypothetical state at 0.1 MPa), the other products being as for the gross calorific value, all at the reference temperature.

As the third calorific value, the *net calorific value as received* can be given. This calorific value is the lowest one, as the energy used for evaporating water contained naturally in the fuel and water formed in combustion are reduced when calculating the calorific value. The calorific value is usually given as megajoules for kg fuel (MJ/kg, 1 MJ = 0.2778 kWh).

2.3.2.1 Gross calorific value

In CEN/TS 14918 method about 1 g±0.1 of air-dry (equilibrium moisture content) analysis sample is burnt in high-pressure oxygen in a bomb calorimeter under specified conditions (Fig. 3). The effective heat capacity of the calorimeter is determined in calibration experiments by combustion of certified benzoic acid under similar conditions, accounted for in the certificate. The corrected temperature rise is established from observations of temperature before, during and after the combustion reaction takes place. The duration and frequency of the temperature observations depend on the type of calorimeter used. The duration and frequency of the temperature observations depend on the type of calorimeter used. Water is added to the bomb initially to give a saturated vapour phase prior to combustion, thereby allowing all the water formed, from the hydrogen and moisture in the sample, to be regarded as liquid water.

The gross calorific value is calculated from the corrected temperature rise and the effective heat capacity of the calorimeter, with allowances made for contributions from ignition energy, combustion of the biofusels) and for thermal effects from side reactions such as the formation of nitric acid. Furthermore, a correction is applied to account for the difference in energy between the aqueous sulfuric acid formed in the bomb reaction and gaseous sulfur dioxide, i.e. the required reaction product of sulfur in the biofuel.



Figure 3. Analysis of gross calorific value. Photo VTT.

The net calorific value at constant volume and the net calorific value at constant pressure of the biofuel are obtained by calculation from the gross calorific value at constant volume determined on the analysis sample. The calculation of the net calorific value at constant volume requires information about the moisture and hydrogen contents of the analysis sample. In principle, the calculation of the net calorific value at constant pressure also requires information about the oxygen and nitrogen contents of the sample.

As the moisture content of the actual analysis sample is of interest merely in connection with the calculation to other bases, it is recommended to calculate a value for the gross calorific value at constant volume for the dry fuel, using the following equation (2):

$$q_{V,gr,d} = q_{V,gr} \times \frac{100}{100 - M_{ad}} \qquad (2)$$

where

$q_{V,\mathrm{gr,d}}$ is the gross calorific value at constant volume of the dry (moisture-free) fuel, in joules per gram;

M_{ad} is the moisture in the analysis sample, in percentage by mass;

$q_{V,\mathrm{gr}}$ is the gross calorific value at contant volume of the fuel as analysed, in joules per gram.

The result shall be reported to the nearest multiple of 10 J/g with unambiguous statements concerning the states constant volume, gross (liquid water), and moisture basis (e.g. dry or "as sampled").

2.3.2.2 Net calorific value

The energy of vaporization (contant volume) for water is at 25 ^{o}C is 41.53 kJ/mol. This corresponds to 206 J/g for 1% (weight) of hydrogen in the fuel sample or 13.05 J/g for 1 w-% of moisture, respectively. The net calorific value at contant volume is derived from the corresponding gross calorific value according to equation (3) (CEN/TS 14918).

$$q_{\mathrm{p,net,\,d}} = q_{V,\mathrm{gr,d}} - 212{,}2 \times w(\mathrm{H})_{\mathrm{d}} - 0{,}8 \times \left[w(\mathrm{O})_{\mathrm{d}} + w(\mathrm{N})_{\mathrm{d}} \right] \qquad (3)$$

where

$q_{\mathrm{p,net,\,d}}$ is net calorific value for dry matter at constant pressure (MJ/kg)

$q_{\mathrm{V,r,\,d}}$ is gross calorific value for dry matter (MJ/kg)

$w(\mathrm{H})_{\mathrm{d}}$ is the hydrogen content, in percentage by mass, of the moisture-free (dry) biofuel (including the hydrogen from the water of hydration of the mineral matter as well as the hydrogen in the biofuel substance)

$w(\mathrm{O})_{\mathrm{d}}$ is the oxygen content, in percentage by mass, of the moisture-free biofuel;

$w(\mathrm{N})_{\mathrm{d}}$ is the nitrogen content, in percentage by mass, of the moisture-free biofuel;

NOTE $\left[w(\mathrm{O})_{\mathrm{d}} + w(\mathrm{N})_{\mathrm{d}} \right]$may be derived by subtracting from 100 the percentages of ash, carbon, hydrogen and sulphur.

2.3.2.3 Net calorific value of fuel as received

Net calorific value as received is calculated according to equations 4 or 5. In both below cases (a) and (b), the calorific value can be either determined for that particular lot or a typical value can be used. If the ash content of the fuel is low and rather constant, the calculation can be based on the dry basis equation (4) with a typical value of $q_{p,net}$, however if the ash content varies quite a lot (or is high) for the specific biofuel then the using the equation for dry and ash-free basis (4) with a typical value of $q_{p,net,daf}$ is preferable.

a) Dry basis

The net calorific value (at constant pressure) on as received (the moist biofuel) can be calculated on the net calorific value of the dry basis according to equation (4).

$$q_{p,net,ar} = q_{p,net,d} \times (\frac{100 - M_{ar}}{100}) - 0{,}02443 \times M_{ar} \quad (4)$$

where

$q_{p,net,ar}$	is the net calorific value (at constant pressure) as received (MJ/kg)
$q_{p,net,d}$	is the net calorific value (at constant pressure) in dry matter (MJ/kg)
M_{ar}	is the moisture content as received [w-%]
0,02443	is the correction factor of the enthalpy of vaporization (constant pressure) for water (moisture) at 25°C [MJ/kg per 1 w-% of moisture]

b) Dry and ash-free basis

The net calorific value (at constant pressure) on as received (the moist biofuel) can be calculated from a net calorific value of the dry and ash-free basis according to an equation (5).

$$q_{p,net,ar} = [(\frac{q_{p,net,daf} \times (100 - A_d)}{100}) \times (\frac{100 - M_{ar}}{100})] - 0{,}02443 \times M_{ar} \quad (5)$$

where

$q_{p,\mathrm{net,ar}}$	is the net calorific value (at constant pressure) as received (MJ/kg)
$q_{p,\mathrm{net,daf}}$	is the net calorific value (at constant pressure) in dry and ash-free basis (MJ/kg)
M_{ar}	is the moisture content as received [w-%]
A_{d}	is the ash content in dry basis [w-%].
0,02443	is the correction factor of the enthalpy of vaporization (constant pressure) for water (moisture) at 25 °C [MJ/kg per 1 w-% of moisture]

The result shall be reported nearest 0.01 MJ/kg.

2.3.2.4 Energy density as received

The wood fuels for small-scale heating plants and households are traded usually as volume basis and energy content (net calorific value) is informed often as MWh per bulk volume. Bulk density and moisture content is measured or estimated.

The energy density as received can be calculated according to equation (6).

$$\mathrm{E_{ar}} = \frac{1}{3600} \times q_{\mathrm{p,net,ar}} \times \mathrm{BD_{ar}} \qquad (6)$$

where

$\mathrm{E_{ar}}$	is the energy density of the biofuel as received (MWh/m^3 of bulk volume)
$q_{\mathrm{p,net,ar}}$	is the net calorific value as received (MJ/kg)
$\mathrm{BD_{ar}}$	is the bulk density, i.e., volume weight of the biofuel as received (kg/m^3 bulk volume)
$\frac{1}{3600}$	is the conversion factor for the energy units (MJ to MWh)

The result shall be reported to the nearest 0.01 MWh/m^3 of bulk volume.

2.3.3 Ash content, A_d

The method is based on ISO 1171 and DIN 51719 standard methods. New CEN/TS 14775 is developed also for ash content. Difference in the ash content determined in

Finland is that it is measured at a higher temperature, 815^{o}C (ISO 1171), compared to the CEN method temperature 550 ^{o}C±10 ^{o}C. This is explained by the loss of volatile inorganic compounds, further oxidation (higher oxidation state) of inorganic compounds and the decomposition of carbonates forming CO_2.

VTT and other laboratories in Finland are currently using the ISO 1171:1197 method. An analysis sample of 1–2 g of dry (or equilibrium moisture content) is weighed at an accuracy of 0.001 g in an annealed constant-weight incineration crucible. Simultaneously, samples from the analysis sample at equilibrium moisture content are weighed for the determination of analytical moisture content. The crucibles should be 30–40 mm in diameter and 10–20 mm in height. The crucible with contents is placed into a furnace of room temperature. The temperature of the furnace is raised to about 500°C in 60 minutes. During the next 60 minutes the temperature is raised to 815±15°C and kept at least 60 minutes at this temperature. After incineration the crucible with contents is cooled in an exsiccator and weighed. Two parallel determinations are carried out for the samples. The ash contents shall not differ from each other by more than the percentage given for the material concerned (for wood by no more than 0.2), or else the determination shall be repeated.

The ash content of the sample is calculated according to equation 7.

$$A_d = \frac{m_2 \times 100}{m_1} \times \frac{100}{100 - M_{ad}} \qquad (7)$$

where A_d is ash content for dry matter (%)

m_1 is mass of sample in analysis moisture content (g)

m_2 is mass of incineration residue (g)

M_{ad} is analytical moisture content of sample (%).

The result is given at the accuracy of 0.3 w-% as a mean of parallel determinations.

2.3.4 Ash melting behaviour

The determination is performed according to standards ISO 540, DIN 51730 or ASTM D 1857. Deformation temperature (DT), sphere temperature (ST), hemisphere temperature (HT) and flow temperature (FT) are determined in oxidising atmosphere. In CEN/TS 15379-1 method under preparation also a shrinkage starting temperature (SST) is introduced (Fig.4). This is temperature before deformation tempature and it indicates at which temperature the first sign of skrinking of the test piece occurs. The fusibility of ash is of great significance in slagging and fouling of boilers. Slagging occurs in the radiation region of the furnace. Such deposits are usually thick and their surface is often

clearly fused. Fouling occurs in the convection region of the boiler, where the temperature of deposit is lower and the ash deposit is mainly in fixed form.

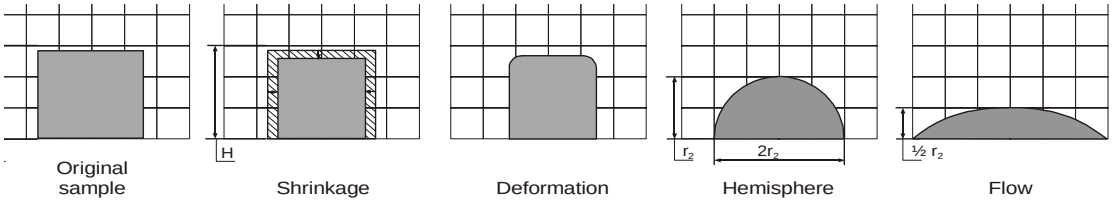


Figure 4. Different temperatures of ash melting behaviour (CEN/TS 15379-1)

2.3.5 Chemical analyses

Chemical analyses, the most significant one being determination of elemental composition, can be carried out employing either or different analysers or the following methods (Nieminen & Ranta 1982, SFS 5875 and CEN/TC335):



Figure 5. Analysis of carbon, hydrogen and nitrogen by CHN-analysator.

Sulphur	ISO 334, DIN 51724, ASTM D 4239 , ASTM E 775, ASTM E 778, ISO 351, or BS 1016; part. 106.4., Solid Biofuels: Determination of total content of sulphur (S) and chlorine (Cl)(CEN/TS 15289)
Carbon and hydrogen	ISO 609 tai ISO 625, DIN 51721, ASTM D 5373, ASTM E 777, ASTMD 4372, ASTM D 3179, Determination of total carbon (C), hydrogen (H) and nitrogen (N) content – Instrumental method (CEN/TS 15104)
Nitrogen	ISO 333 tai ISO 625, DIN 51722,ASTM D 5373-93, ASTM 778-87, ISO 609, ISO 625, ISO 1994, Determination of total carbon (C), hydrogen (H) and nitrogen (N) content – Instrumental method (CEN/TS 15104)
Phosphorus	ISO 622, DIN 51725, ASTM 2795
Chlorine	DIN 51727, ASTM D 2361-95, ASTM D 4208, ASTM E 776, ISO 352, ISO 587, or BS 1016; part 8. Determination of total carbon (C), hydrogen (H) and nitrogen (N) content – Instrumental method (CEN/TS 15104) or Methods for the determination of water soluble chloride (Cl), sodium (Na) and potassium (K) (CEN/TS 15105)
Volatiles	ISO 562, DIN 51720, ASTM E 897, ASTM D 3175 or BS 1016; sect. 104.3. Solid Biofuels - Methods for the determination of the content of volatile matters (CEN/TS 15148).
Heavy metals	ISO 601 (As), ISO/DIS 15238 (Cd), ISO/DIS 15237 (Hg), ISO/DIS 8983 (Cr, Cu, Mn, Ni, Pb, V and Zn), Solid biofuels - Determination of minor elements (As, Ba, Be, Cd, Co, Cr, Cu, Hg, Mo, Mn, Ni, Pb, Se, Te, V and Zn)
Other chemical analyses	DIN 51723, ASTM D 3761, ASTM D 5987, ASTM E 885. Solid Biofuels - Determination of major elements (Al, Si, K, Na, Ca, Mg, Fe, P and Ti)(CEN/TS 15290)

In CEN/TS 15296 methods for calculation analysis to different basis are presented (See App.3.

2.3.6 Volume and density

Bulk density as received (BD) is obtained by dividing the weighed mass of the load by its volume (Fig. 6). The bulk density can also be determined with the aid of a box method according to the instruction of VTT (ENE38/24/97). A box of 125 litres (0.5 x 0.5 x 0.5 m) is filled with the fuel and weighed. The box method gives slightly smaller values of bulk density than those calculated for loads at stations. The following standards for the determination of bulk density in different situations are also available: ASTM E 1109, DIN 517052, ISO 1013 and ISO 567. There is also the CEN method for the determination of bulk density (CEN/TS 15103). This method is applicable to all solid biofuels with a nominal top size of maximum 100 mm. Bulk density is not an absolute value, therefore conditions for its determination should be standardised in order to gain comparative measuring results. The nominal top size is defined as the aperture size of the sieve where at least 95% by mass of the material passes (see CEN/TS 14588). Bulk density of solid biofuels is subject to variation due to several impacts such as vibration, shock, pressure, biodegradation, drying and wetting. Measured bulk density can therefore deviate from practice conditions during transportation, storage or transhipment.



Figure 6. Measurement of bulk density in small-sized heating plant in Finland.

In CEN/TS 15103 the container shall be cylindrically shaped and manufactured of a shock resistant, smooth-surfaced material. The container shall be resistant to deformation in order to prevent any variation in shape and volume. The container has to be waterproof. For easier handling grips may be fixed externally. The height-diameter-ratio shall be within 1.25 and 1.50. The large measuring container has a filling volume of 50 l (0.05 m^3) volume. The volume may deviate by 1 litre (= 2 percent). It shall have an effective (inner) diameter of 360 mm and an effective (inner) height of 491 mm. The small measuring container has a filling volume of 5 litres (0.005 m^3) volume. The volume may deviate by 0.1 litre (= 2 percent). It shall have an effective (inner) diameter of 167 mm and an effective (inner) height 228 mm. For fuels with a nominal top size up to 12 mm and for pellets with a diameter equal or below 12 mm the small container.

Before use, the mass and filling volume of the container shall be determined. The filled container is then shock exposed to allow settling. This is done by dropping it freely from 150 mm height onto a wooden board which is lying on an even, horizontal and hard floor. Repeat the shock exposure for two more times and finally weigh the container.

The *volume* of wood load is determined at the receiving site of the station prior to unloading by inspecting the filling degree of the load space or by some other respective measuring system in the vehicle. If no such measurement is carried out, the volume given in the delivery note is considered as the volume of load.

Wood is usually measured with a pile method. The frame volume is determined by measuring the length, height and width of the pile. The frame volume is converted to *solid volume* with the aid of percentage coefficients. Compaction ratios are used when converting bulk volumes to solid volumes (Tapion taskukirja 1997).

The *basic density* of wood is determined, e.g., by immersing a fresh piece of wood in a water vessel. The weight of water mass displaced by the piece gives its volume. The wood piece is then dried in an oven (103^{o}C, 48 h) and weighed. The basic density is obtained by dividing the weight of the dried wood piece by its green volume (Tapion taskukirja 1997).

2.3.7 Particle size

The particle size of solid biofuels and particle size distribution are determined for a sample of at least 20 litres with sieving methods and sieve series agreed upon. When selecting mesh sizes for the sieve, e.g., the particle size limits given for wood fuels in quality classification tables shall be considered. The particle size distribution of fines is

determined with analysers (e.g. Malvern 2600 C) i.a., according to a French standard NF X 11-666 (App.1, Impola 1998, Wilén et al. 1999).

In the CEN/TS 15149 particle size distributiona, Part 1, describes the reference method for size classification of samples with a nominal top size of 3.15 mm and over. Part 2 describes the reference method for all samples with a nominal top size below 3.15 mm. For the test an appropriate number of either circular or rectangular sieves with a minimum effective sieve area of 1 200 cm^2 is required for samples with a nominal top size of 3,15 mm and over and 250 cm^2 with a nominal top size of 3,15 mm and below. The geometry of the apertures, the thickness of the sieves, the hole distances and the diameter of the holes shall be in accordnce with the requirements of ISO 3310-2 for part one and ISO 3310-1 and ISO 3310-2 for part 2.

The frame of the sieves shall have a height that enable the sieves to contain the sample and allows a free movement of the sample during the sieving process. It is recommended to use sieves with hole diameters of 3.15 mm, 16 mm, 45 mm and 63 mm, if the measurement aims at the determination of conformity with CEN/TS 14961. For further resolution in the size distribution and for avoiding any overloading of one fraction the addition of an 8 mm sieve to the sieve set is also recommended. For further size distribution determination of the fraction that passes the last sieve (see CEN/TS 15146-2).

If a mechanical device is used, the shaking operation shall be horizontally oscillating (one or two dimensional), using an appropriate stroke-frequency according to the type of material. The minimum size of the test sample for the determination of the size distribution shall be 8 liter and shall have been sampled according to the CEN/TS 14778-1, CEN/TS 14778-2 and the CEN/TS 14779. For fine grade biofuels, where 100% of the particles pass the sieve holes of 45 mm diameter, a smaller sample size of minimum 4 liter can be used. For sawdust it is recommended to use the following sieve set: 3.15 mm round holes; 2.8 mm mesh wire cloth; 2.0 mm mesh wire cloth; 1.4 mm mesh wire cloth; 1.0 mm mesh wire cloth; 0.5 mm mesh wire cloth and 0.25 mm mesh wire cloth.

2.3.8 Other CEN standards for solid biofuels

There is several other CEN methods under preparation for physical and mechanical properties:

- Solid Biofuels - Methods for the determination of the particle density (CEN/TS 15150)
- Solid Biofuels - Methods for the determination of the mechanical durability for pellets (CEN/TS 15210-1) and briquettes (CEN/TS 15210-2)
- Solid Biofuels - Methods for the determination of bridging properties
- Method for determination of size distribution of disintegrated pellets

One of important standards is mechanical durability of pellets and briquettes. The test sample is subjected to controlled shocks by collision of pellets against each others and against the walls of a defined rotating test chamber. The durability is calculated from the mass of sample remaining after separation of abraded and fine broken particles. The pellets tester shall consist of a dust tight enclosure. This box (Fig. 7) shall be made of rigid material (e.g. steel plate aluminium or plexiglas) with smooth and flat surfaces, and it has the dimensions of (300 x 300 x 125) mm; it shall rotate at 50 rpm about an axis, which is perpendicular to and centred in the 300 mm sides. A 230 mm long baffle is affixed symmetrically to a diagonal of one 300 mm x 300 mm side of the box. The minimum size of the sample shall be 2.5 kg. Divide the sample into four equal portions according to CEN/TS 14780. Take one portion for the determination of the total moisture content according to CEN/TS 14774 - Part 1 or 2. Weight two of the remaining sample portions and then separate fines by hand sieving using a sieve.

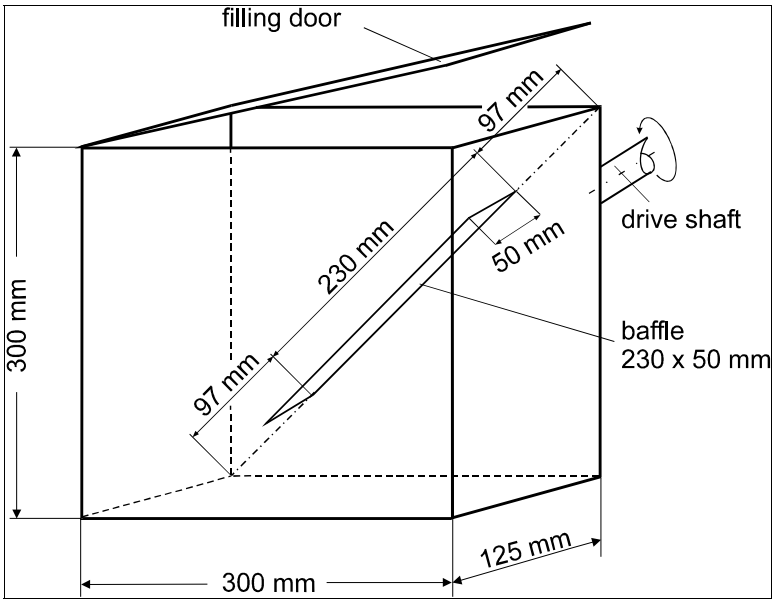


Figure 7. Pellet tester (1=Filling door, 2= Drive shaft and 3= Baffle) CEN/TS 15210-1

Take a test portion of (500±10) g. For pellets above 12 mm diameter (500±50) g is allowed. Place the test portion of the sieved pellets, weighed to the nearest 0.1g, in the tumbling box device. Tumble the sample at (50±2) rpm for 500 rotations. After this number of rotations the sample is removed and passed manually through a sieve. The sieving has to be done completely. The sample remaining on the sieve shall be weighed. The percent of whole pellets (particles remaining on the sieve) shall be calculated (particles remaining on the 3.15 mm sieve).

The mechanical durability of pellets shall be calculated using the equation (8):

$$DU = \frac{m_A}{m_E} \times 100 \qquad (8)$$

where

DU is the mechanical durability, in percent

m_E is the mass of pre-sieved pellets before the tumbling treatment in grams

m_A is the mass of sieved pellets after the tumbling treatment in grams

The result shall be calculated to two decimal places and the mean result shall be rounded to the nearest 0.1 percent for reporting.

3. Properties of Finnish wood fuels

3.1 General

The main significant structural constituents of wood are cellulose, hemicelluloses and lignin. Scots pine, Norway spruce and birch contain 40–45% cellulose and 25–40% hemicellulose for the weight of dry matter. The hemicellulose content of Scots pine and Norway spruce is lower (25–28%) than deciduous tree, like birch (37–40%). The lignin content of coniferous tree ranges 24–33% and that of deciduous tree 16–25%. Lignin binds wood fibres together and gives wood the necessary mechanical strength. Lignin contains an abundance of carbon and hydrogen, i.e., heat-generating substances. Wood also contains extractives (terpenes, fatty substances and phenols), being compounds that can be extracted from wood with neutral organic solvents. For example, wood resin is composed of these substances. The percentage of extractives in wood is usually about 5%, while it may be as high as 30–40% in bark. The resin content of Scots pine ranges 2.5–4.8%, that of Norway spruce 1.0–2.0% and birch 1.1–3.6% (Jensen 1977, Hakkila & Heiskanen 1978, Kärkkäinen 1971, Sjöström 1978, Verkasalo 1988).

The content of volatiles is high in wood, 80–90%. Hence, it is a long-flame fuel and requires a large combustion chamber (Kytö et al. 1983).

The division of wood biomass to stemwood, bark, branches and leaves/needles ranges within large limits according to wood species and age.

The elemental composition of wood comprises mainly carbon, hydrogen and oxygen (Tables 1 and 2), their proportion of dry matter mass being about 99%. The nitrogen content is clearly less than 0.2%, alder having the highest nitrogen content. The nitrogen content of Scots pine and Norway spruce is about 0.05%, of birch 0.08–0.1%, of trembling aspen 0.06% and of grey alder 0.19%. The sulphur content of wood is less than 0.05% (Table 3). The elementary analysis of different wood species varies only slightly (Moilanen et al. 1996, Laine & Sahrman 1985, Wilén et al. 1996, Nurmi 1993).

Table 1. Comparison of wood and bark elements (Moilanen et al. 1996).

Element, w-% dry basis	Wood	Bark
C	48–50	51–66
H	6–6,5	5,9–8,4
N	0,5–2,3	0,3–0,8
O	38–42	24,3–40,2
S	0,05	0,05
Cl	< 0,01	< 0,01–0,03

Table 2. Element contents of different wood species (Taipale 1996, Wilen et al. 1996).

Wood fuel	Elementary analysis, w-% dry					
	C	H	N	O	S	Cl
Whole tree chips, Scots pine	51,8	6,1	0,3	41,19 (calculated))	0,01	0,0042
Logging residues chips/hog fuel	51,3	6,1	0,4	40,85 (calculated)	0,02	0,0076
Wood chips, coniferous trees					0,02–0,045	
Wood chips, deciduous trees					0,02–0,09	
Sawdust, Scots pine, without bark	51	5,99	0,08	42,82 (calculated)	0	< 0,0050
Willow	49,7	6,1	0,4	42,59 (calculated)	0,03–0,05	0,0037
Scots pine bark *	52,5	5,7	0,4	39,65 (calculated)	0,03	0,0085
	54,5	5,9	0,3	37,7		
Norway spruce bark*	49,9	5,9	0,4	41,43 (calculated)	0,03	0,0279
	50,6	5,9	0,5	40,2		
Birch bark	56,6	6,8	0,8	34,2		

* values from two sources.

Table 3. Sulphur contents of dry matter in various parts of coniferous tree and deciduous tree (Hakkila & Kalaja 1983).

Coniferouos trees	Sulphur content, dry (w-%)	Deciduous trees	Sulphur content, dry (w-%)
Stem	0,0116	Stem	0,0090
Bark from stem	0,0343	Bark from stem	0,0341
Branches	0,0203	Branches	0,0218
Neeedles	0,0673	Leaves	0,0965
WHOLE TREE	0,0236	WHOLE TREE	0,0212

The sulphur content of willow dry matter is on average 0.03% (Tahvanainen 1995). Mineral and heavy metal contents of wood fuels are presented in Tables 4 and 5.

Table 4. Mineral contents of dry matter in various parts of coniferous tree and deciduous tree (Hakkila & Kalaja 1983).

Wood species/part	Major elements in dry matter, w-%				Minor elements in dry matter, ppm				
	P	K	Ca	Mg	Mn	Fe	Zn	B	Cu
CONIFEROUS TREE									
Stem	0,01	0,06	0,12	0,02	147	41	13	3	2
Bark from stem	0,08	0,29	0,85	0,08	507	60	75	12	4
Branches	0,04	0,18	0,34	0,05	251	101	44	7	4
Needles	0,16	0,60	0,50	0,09	748	94	75	9	6
WHOLE TREE	0,03	0,15	0,28	0,05	296	85	30	6	4
DECIDUOUS TREES									
Stem	0,02	0,08	0,08	0,02	34	20	16	2	2
Bark from stem	0,09	0,37	0,85	0,07	190	191	131	17	13
Branches	0,06	0,21	0,41	0,05	120	47	52	7	4
Needles	0,21	1,17	1,10	0,19	867	135	269	21	10
WHOLE TREE	0,05	0,21	0,25	0,04	83	27	39	6	5

Table 5. Heavy metal contents of wood fuels and wood parts (Taipale 1996).

Wood	Heavy metal content in dry matter, mg/kg								
	As	Cd	Cr	Cu	Hg	Pb	V	Zn	Ni
Wood without bark	0,04–0,4	0,1-0,4	1-2	0,6-6	0,01–0,02	0,6–14	0,3–5,0	5–40	
Branch, Norway spruce		0,23	0,15	6,68		9,25		71,2	3,34
Bark				4,6				90	
Needle,Norway spruce		0,09	0,06	2,48		0,30		14	1,62
Needle, Scots pine		0,30	0,08	3,76		1,25		65	1,45
Leave, birch		0,30	0,08	3,76		1,25		65	1,45
Willow		0,8–1,7	3	2–4		0,4–2,0		40–105	

The ash content of stemwood without bark is usually less than 0.5%, that of coniferous less than 2% (cf. Table 6). The composition of wood ash is presented in Table 8. The ash content of wood is usually lower than that of other solid fuels (Kytö et al. 1983, Wilen et al. 1996).

Sintering of wood ash starts at 900–1000 ^{o}C (Solantausta & Asplund 1979a). Deformation temperature (IT) ranges according to different sources 1150–1490 ^{o}C, sphere temperature (ST) 1 180–1 525 ^{o}C, hemisphere temperature (HT) 1 230–1 650 ^{o}C and flow temperature (FT) 1 250–1 580 ^{o}C (Kytö et al. 1983, Wilen et al. 1996) (Table 7).

The composition of wood ash is presented in Table 8 and heavy metals in grate and fly ash from wood combustion in Table 9.

Table 6. Ash content of wood (Taipale 1996, Wilén et al. 1996, Tahvanainen 1995).

Wood fuel	Ash content, dry matter (w-%)
Log wood	0,5 / 1,2
Whole tree chips, Scots pine/ Whole tree chips, mixture of different wood species	0,6 / 0,5
Wood chips, birch	0,4–0,6
Wood chips, logging residues	1,33
Wood chips, logging residues, Norway spruce	2,0–6,0
Hog fuel, stumps	0,50
Wood chips, willow	1,7
Sawdust with bark/sawdust without bark, Scots pine	1,1 / 0,08
Cutter shavings	0,40
Bark, Scots pine	1,70
Bark, Norway spruce*	2,34 / 2,8
Bark, birch	1,60

* from two sources.

Table 7. Ash melting behaviour of wood ash (Wilén et al. 1996).

Fuel type	Ash fusion temperature, °C							
	Oxiding atmosphere				Reducing atmosphere			
	DT	ST	HT	FT	DT	ST	HT	FT
Whole tree chips, Scots pine	1 210	1 125	1 250	1 275	1 230	1 240	1 245	1 290
Logging residue chips	1 175	1 205	1 230	1 250	1 175	1 225	1 245	1 260
Sawdust, Scots pine	1 150	1 180	1 200	1 225	1 135	1 165	1 185	1 205
Bark, Norway spruce	1 405	1 550	1 650	1 650	1 565	1 580	1 650	1 650
Bark, Scots pine	1 340	1 525	1 650	1 650	1 375	1 504	1 506	1 507
Willow	1 490			1 580	1 570			1 580

Table 8. Composition of ash for certain wood fuels (w-%) as oxides of the main components (Taipale 1996, Kytö et al. 1983, Moilanen et al. 1996).

Wood	CaO	K_2O	P_2O_5	MgO	Fe_2O_3	SO_3	SiO_2	Na_2O	Al_2O_3	TiO_2
Birch 1)*	57,80	11,50	7,70	7,70		3,80	3,80	7,70		
Birch 2)*	46,00	15,00	14,90	11,60	1,30	2,60	0,90	8,60		
Scots pine	42,00	15,20	1,00	16,00	5,50	4,50	4,60	3,00		
Norway spruce	36,70	29,60	1,00	10,00	8,50	4,20	1,00	3,20		
Willow	30,80	26,50	4,80	5,10	0,20	2,10	0,43	0,30	0,30	0,02
Bark, Scots pine 1)*	40,00	3,30	2,60	2,60	5,00	3,70	14,50	2,00		
Bark, Scots pine 2)*	40,60	7,60	4,80	4,50	0,30	2,00	1,30	0,50	5,30	0,10
Bark, Norway spruce	50,50	3,50	2,60	4,20	1,80	1,60	21,70	2,80		
Bark, birch	60,30	4,10	3,50	5,90	1,00	4,80	3,00	0,70		
Sawdust, Scots pine	41,80	12,30	5,20	11,80	1,90	1,90	8,30	0,20	2,00	0,10

* from source Kytö et al. has two values.

Table 9. Contents of heavy metals, formed in wood combustion, in bottom and fly ashes (Taipale 1996).

Element	Composition, mg/kg	
	Bottom ash	Fly ash
As	0,2–3,0	1–60
Cd	0,4–0,7	6– 40
Co	0–7	3–200
Cr	60,0	40–250
Cu	15–300	200
Hg	0–0,4	0–1
Mn	2 500–5 500	6 000–9 000
Ni	40–250	20–100
Pb	15–60	40–1 000
Se		5–15
V	10–120	20–30
Zn (	15–1 000	40–700

The moisture content of green (fresh) wood ranges usually 40–60% (Tables 10 and 11). It is dependent on growth site, wood species and age, and also varies in different parts of the tree. The moisture content of growing deciduous tree varies seasonally. In a living tree, the cell wall is impregrated with water and the cell lumen and spaces are filled with water. When wood is dried, the so-called free water, i.e. that in lumens, escapes. The bound, i.e., water of cell walls escapes last. The physical properties of wood begin to change as soon as this bound water begins to escape, i.e., the saturation point of wood cells is surpassed. The volume of wood is reduced during drying.

Usually, the combustion and size of boiler used determinates, how moist wood can be used. The larger plants can use moist fuels, while, e.g., household wood should be dry. Households and farms normally dry wood prior to use. An old method of drying is seasoning stems on the field. In this method the trees (usually small-size trees) are felled in early summer and left on the plot for seasoning, when the evaporation capacity of leaves and needles is utilised. The trees can also be collected unlimbed or delimbed on heaps for drying. The firewood logs and chopwood are also dried in piles and heaps. The moisture content of wood fuel burned in fireplaces should be 15–20%. In central heating boilers, the storage moisture content of chips should not exceed 25% for durability reasons. If wood chips are used in a station of less than 1 MW, the moisture content should not exceed 40% (Laine & Sahrman 1985, Linna et al. 1983, Siltanen & Rantasalo 1984, Simola & Mäkelä 1976).

Table 10. Moisture content of different wood parts (Kytö et al. 1981, Pellikka& Saviharju 1983, Taipale 1996).

Wood part	Moisture content, w-%	
	Scots pine	Norway spruce
Stem	45–50	40–60
Branches	50–56	42–46
Top	60	60 (50*)
Bark:		
Outer bark	36–60	38–58
Other bark	53–67	47–63

* from Northern Finland

Table 11. Moisture contents of wood fuels (Pellikka & Saviharju 1983, Immonen & Seppälä 1984, Taipale 1996, Tahvanainen 1995).

Wood fuel	Moisture content, w-%	
	Unpressed	Pressed
Log wood, fresh	45	
Log wood, summer seasoned	25	
Log wood, one year seosoned	20	
Stem wood chips, fresh	50	
Stem wood chips, dried on the stand	40	
Stem wood chips, dried, one year	25–30	
Logging residue chips, Scots pine	60	
Logging residue chips, Norway spruce	50–57	
Logging residues, chips from branches	50	
Hog fuel from stumps	35	
Chips from willow	35–40	
Screening residue from wood chips	50–55	
Sawing residue		
Sawdust and chips, fresh	50–55	
Sawdust from dried timber	5–15	
Chips from endings,slabs	15	
Grinding dust	5–10	
Grinding dust, dry (furniture)	15–20	
Gutter shavings, dry (furniture)	5–10	
Gutter shavings, air dry	15–20	
Residues from carpenter industry	5–10	
Residues from carpenter industry, air dry	15–20	
Residue from plywood industry	35–50	
Slabs from plywood industry	5–10	
BARK,PULP WOOD		
Scots pine, dry transportation		
• dry debarking	40–50	
• wet debarking	60–70	55–62
Scots pine, wet transportation and storage in water	70–85	55–62
Birch		
• dry debarking	65–70	55–62
• wet debarking	40–50	
TIMBER BARK		
Coniferous tree		
• dry handling	40–50	
• wet handling	60–80	55–62
Birch	35–50	

The net calorific value of wood dry matter ranges 18.3–20.0 MJ/kg. The calorific value of tops, branches and small trees is slightly higher than that of whole-tree (Kytö et al. 1983, Nurmi 1993, 1997 and 2000). For example, the calorific value of Scots pine branches is 19.99 MJ/kg and that of stemwood 19.53 MJ/kg (Nurmi 2000). The greatest differences between different parts of trees have been measured for alder and Trembling aspen. The calorific value of wood is low compared to those of other solid fuels. This sets requirements for wood handling and combustion equipment. The wood fuels require more storage space than the other solid fuels (Laine & Sahrman 1985, Wilén 1996). Variations in the net calorific value of wood are presented in Tables 12–15.

Table 12. Net calorific values of different wood species for dry matter (MJ/kg (Nurmi 1993, 2000).

Wood species	Stem without bark	Bark from stem	Whole stem	Top	Leaves/Needles	Whole tree	Stump
Scots pine(Pinus sylvestris),							
small-size tree	19,31	19,53	19,33	20,23	21,0	19,53	22,36
older tree			19,55	20,09	21,04	19,63	
Norway spruce (Picea abies) small-size tree	19,05	18,80	19,02	19,77	19,22	19,29	
older tree			19,16	19,41	19,19	19,24	19,18
Downy birch (Betula Pubescens),							
small-size tree,	18,62	22,75	19,19	19,94	19,77	19,30	
older tree			19,06	19,33	19,36	19,09	18,61
Silver birch, (Betula pendula) small-size tree	18,61	22,53	19,15	19,53	19,72	19,21	
older tree			18,96	19,61	19,76	19,05	18,50
Grey alder (Alnus incana); small-size tree	18,67	21,57	19,00	20,03	20,57	19,18	
older tree			19,14	19,74	20,54	19,22	19,27
Black alder (Alnus glutinosa),							
small-size tree	18,89	21,44	19,31	19,37	20,08	19,31	
older tree			18,90	19,47	19,78	19,00	18,91
Trembling aspen (Populus tremula),							
small-size tree	18,67	18,57	18,65	18,61	19,18	18,65	
older tree			18,62	18,96	19,02	18,66	18,32

Table 13. Net calorific value of different branch parts (D>5 and D< 5 mm) for dry matter, MJ/kg (Nurmi 1997).

Wood species	Wood without bark			Bark				Leaves/Needles	Tops without leaver or needles
	>5 mm	< 5 mm	Whole branch	Inner bark	Outer bark	< 5mm	Whole bark		
Scots pine	20,01	19,96	19,99	19,28	20,36	31,39	20,30	21,04	20,09
Norway spruce	19,36	19,23	19,30	17,87	20,77	20,27	19,60	19,19	19,41
Downy birch	18,68	18,57	18,64	18,49	28,53	20,58	21,03	19,36	19,33
Silver birch	18,53	18,65	18,57	19,07	29,87	20,13	21,78	19,76	19,61
Grey alder	18,83	19,11	18,88	20,11	25,15	21,85	21,69	20,54	19,74
Black alder	18,48	18,66	18,51	19,55	23,92	21,76	21,29	19,78	19,47
European Trembling aspen	18,76	19,00	18,81	18,46	20,48	19,69	19,20	19,02	18,96

Table 14. Net calorific value of different top parts for dry matter (Nurmi 1997).

Wood part	Scots pine	Norway spruce	Dowing birch	Silver birch	Grey alder	Black alder	Trembling aspen
Bark	20,30	19,60	21,03	21,42	21,69	21,25	19,20
Wood without bark	19,99	19,30	18,64	18,57	18,87	18,51	18,81
Top without needles or leaves	20,09	19,41	19,33	19,61	19,74	19,47	18,96
Leaves/ Needles	21,04	19,19	19,36	19,76	20,37	19,78	19,85
Top with leaves or needles	20,33	19,33					

Table 15. Net calorific values of different wood fuels for dry matter (Pellikka & Saviharju 1993, Hakkila et al. 1978, Laine & Sahrman 1985, Tahvanainen 1995, Taipale 1996, Wilén 1996).

Wood fuel	Wood species	Net calorific value of dry matter, MJ/kg
Round wood with bark	Scots pine	19,3
	Norway spruce	19,1
	Birch	19,5
Whole trees from young stands	Scots pine	20,5
	Norway spruce	19,6
	Birch	19,6
Whole trees from thinnings	Scots pine	19,6
	Norway spruce	19,2
	Birch	19,0
Logging residues chips without needles	Scots pine	20,4
	Norway spruce	19,7
	Birch	19,7
Logging residues chips with needles	Scots pine	20,5
	Norway spruce	19,8
Logging residue chips		19,3
Roots and stumps	Scots pine	19,5
	Norway spruce	19,1
Sawdust		18,9
	Scots pine, without bark	19,0
Gutter shavings		18,9
Bark	Scots pine	20,0
	Norway spruce	18,6
	Birch	22,7
Wood chips	Willow	16,2

The density of wood (basic density) may range depending on site, genetic genotype and age, and there may also be differences in stemwood densities of trees grown at the same site (see Tables 16–18). The density of birch usually ranges 470–500, Scots pine 380–420, Norway spruce 380–400, grey alder 360–370, trembling aspen 400, rowan 540, oak 600, ash 590, juniper 510, and young willows 380 kg/solid m^3 (Kytö et al. 1983, Björklund 1984, Björklund & Ferm 1982, Hakkila et al. 1978, Tahvanainen 1995).

Table 16. Basic densities in different parts of various wood species (Kytö et al. 1983).

Wood species	Basic density, kg/m³				
	Whole tree	Stem	Branches	Stump	Bark
Scots pine	385	390–410	450	450	300
Norway spruce	400	380–400	610	410	340
Birch	475	490	530	510	550
Alder	370	360–430	405–440		
Trembling aspen	385	360	450		
Beech		575–625	750		

Table 17. Average basic densities of different wood types (Hakkila et al. 1978).

Wood type	Wood species	Basic density, kg/m³
Round wood with bark	Scots pine	390
	Norway spruce	380
	Birch	490
	Alder	360
Whole tree from thinnings	Scots pine	385
	Norway spruce	400
	Birch	475
	Alder	370
Logging residue chips without needles/leaves	Scots pine	405
	Norway spruce	465
	Birch	500
Logging residue chips with needles	Scots pine	395
	Norway spruce	425
Residues from timber sawing, with bark	Coniferous tree	415
Stump and root wood	Scots pine	475
	Norway spruce	435

Table 18. Basic density, moisture content, and bark percentage of different saplings in wintertime (Hytönen & Ferm 1984).

Year	Basic density, kg/m³	Moisture,w-%	Bark content, w-%
1	284	64	34
2	356	57	22
4	360	57	13
5	382	56	11

The wood fuels can be classified according to their trade form (chips, bark, chopped log wood, refined wood fuels, like pellets briquettes, and wood charcoal), or their origin, as

in the CEN classifies the wood fuels (Fig.8). The CEN classification for wood fuels is as follows:

- 1.1 Forest and plantation wood (include fuels produced from wood or wood parts grown in forests or agricultural land).
- 1.2 Industrial by-products and residues (include wood fuels obtained as industrial by-products or wood residues).
- 1.3 Used wood (recyclable wood fuels from society).
- 1.4 Blends and mixtures (The mixing can be either intentional (blends) or unintentional (mixtures).

In this publication wood fuels are described on the basis of their traded form (wood chips, hog fuels, pellet, briquettes, sawdust, bark and log wood), and used wood fuels are not included in this publication.

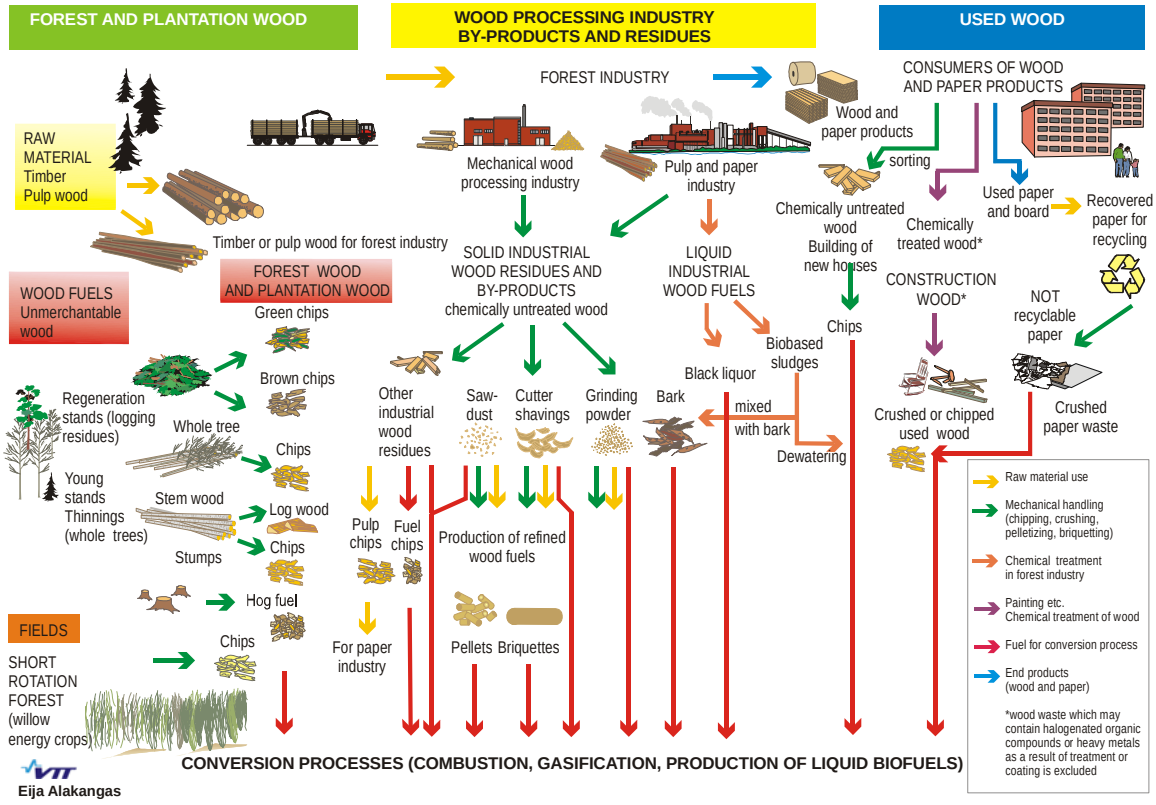


Figure 8. Classification of wood fuels according to their origin.

Table 19. Classification of origin and sources of Woody biomass (1) according the CEN/TS 14961

1.1 Forest and plantation wood	1.1.1 Whole trees	1.1.1.1 Deciduous
		1.1.1.2 Coniferous
		1.1.1.3 Short rotation coppice
		1.1.1.4 Bushes
		1.1.1.5 Blends and mixtures
	1.1.2 Stemwood	1.1.2.1 Deciduous
		1.1.2.2 Coniferous
		1.1.2.3 Blends and mixtures
	1.1.3 Logging residues	1.1.3.1 Fresh/Green (including leaves/needles)
		1.1.3.2 Stored
		1.1.3.3 Blends and mixtures
	1.1.4 Stumps	1.1.4.1 Deciduous
		1.1.4.2 Coniferous
		1.1.4.3 Short rotation coppice
		1.1.4.4 Bushes
		1.1.4.5 Blends and mixtures
	1.1.5 Bark (from forestry operations)*	
	1.1.6 Landscape management woody biomass	
1.2 Wood processing industry, by-products and residues	1.2.1 Chemically untreated wood residues	1.2.1.1 Without bark
		1.2.1.2 With bark *
		1.2.1.3 Bark (from industry operations)*
		1.2.1.4 Blends and mixtures
	1.2.2 Chemically treated wood residues	1.2.2.1 Without bark
		1.2.2.2 With bark *
		1.2.2.3 Bark (from industry operations) *
		1.2.2.4 Blends and mixtures
	1.2.3 Fibrous waste from the pulp and paper industry	1.2.3.1 Chemically untreated fibrous waste
		1.2.3.2 Chemically treated fibrous waste
1.3 Used wood	1.3.1 Chemically untreated wood	1.3.1.1 Without bark
		1.3.1.2 Bark*
		1.3.1.3 Blends and mixtures
	1.3.2 Chemically treated wood	1.3.2.1 Without bark
		1.3.2.2 Bark*
		1.3.2.3 Blends and mixtures
1.4 Blends and mixtures		

NOTE 1 Cork waste is included in bark sub-groups.

NOTE 2 For the avoidance of doubt, demolition wood is not included in the scope of this Technical Specification. Demolition wood is “used wood arising from demolition of buildings or civil engineering installations” (see CEN/TS 14588).

3.2 Wood chips and hog fuel

Wood chips or hog fuel (Fig. 9) are produced from whole-tree wood, delimbed trees, forest residue, or other wood material. Wood chips are produced from undelimbed trees, or from delimbed small-size trees. Logging residue chips or hog fuel are produced from tops, branches and bush final cuttings. Stump chips or hog fuel are produced from stumps. Sawmill chips are produced as by-products of sawing (Hakkila 1992).



Figure 9. Wood chips (left) and hog fuel (right).

Wood chips are used in heating boilers of buildings, at heating power plants and industrial heat and power plants. Moisture content is the most significant property of fuel chips or hog fuel. The average target length of chips is usually 30–40 mm.

When the moisture content is known, the most significant factor of uncertainty is *solid volume factor*, being dependent on technical systems of chipping, crushing and transports. The *solid volume factor* of wood chips indicates the ratio of solid volume and bulk volume, i.e., how many solid cubic meters is obtained from one bulk cubic meter. Factors affecting the solid volume factor are chip size and shape, wood species, branches, moisture content, season, loading method and settling (Hakkila 2000).

The chip size is not uniform, and small chips fill spaces between larger ones during loading and transport. The wood chips made of whole-trees and logging residue contain more fines than, e.g., more homogeneous pulpwood chips, and hence the fuel chips are usually more compact. The solid volume factor can be increased significantly by mixing sawdust among chips. The higher the ratio of the diagonal measurement of wood chip to its thickness is, the lower the solid volume factor of the chips (Hakkila 2000) are.

Chips made of brittle wood species, e.g. grey alder, contain a higher portion of fines than usually, and hence are more compact. Oversized particles are formed from green branches, especially from flexible deciduous tree branches, and these reduce the solid volume factor of wood chips. The proportion of oversized branch particles is lower in dry raw material, and hence the drying of raw material improves the solid volume factor of chips. Frozen raw material is brittle and produces more fines in chipping, and consequently the solid volume factor of chips made of frozen wood is usually higher than normally (Hakkila 2000).

By blowing wood chips through the chipper pipe, a more compact load is achieved than from chips falling freely from a conveyor, a tip platform, a bucket of front-loader, or a bin. However, the result is dependent on the blow power of the chipper and on the curve and distance of blow. The load is more compact, if the pipe blows on the load than to the rear. During the transport, air spaces between larger chips are filled by smaller chips, and consequently, the load becomes more compact and settles. Settling is dependent on initial solid volume factor, transport distance, levelness of roads and possible freezing of chips (Hakkila 2000).

Settling is stronger after the start of transport, but stabilizes as soon as after 0–20 km. If rather the volume than the mass of chips restricts the load size, the significance of the initial compactness to the economy of transport is greater than that of the final compactness. However, the final compactness is decisive if the load is measured on the basis of frame dimensions at the receiving station. However, it is not always possible to forecast the effect of different factors on the solid volume factor, as the effects may also be equipment-specific. Usually the solid volume factor of wood fuel chips ranges 0.37–0.45 and that of bark crush 0.3–0.4. As a rule of thumb, 0.4 can be applied to wood chips (Hakkila 2000).

Quality specifications have been prepared for an unambiguous determination of the quality of wood fuels (Appendix 1). These specifications define the procedure, by which the quality and energy amount of wood fuels – fuel chips, sawdust and bark – can be given and defined unambiguously and appropriately. The quality specifications and classification are used primarily in wood fuel trade as an appendix to delivery contracts. Other users are, i.a., planners of stations and equipment, and fuel producers. Quality security involves, that the average chip size and moisture content of wood chips meet the requirements and there are no raw humus, stones or metals, long sticks or twigs among chips (Impola 1995, 1998).

The preparation of European prestandards (CEN/TC 335 - Solid biofuels standardisation) for solid biofuels started in 2000 and available in Spring 2006. Fuel specifications and classes according the technical specification (CEN/TS 14961) for wood fuels are presented in App.2.

3.2.1 Logging residue

3.2.1.1 General

Logging residues offer a usable and quantitatively significant raw material source for the production of wood fuels. The amount and composition of logging residue formed in the logging of merchantable wood varies in large limits at different logging sites. In first-thinning of birch stands, primarily tops unsuitable for merchantable wood, and branches remain in the forest, and the accrual is rather insignificant. In regeneration cuttings of Norway spruce stands, on the contrary, the accrual of logging residue is significantly higher and comprises primarily branches and needles, and also a significant amount of refused logs, if there have been butt-rot stems at the logging site. Hence, the logging residue chips/hog fuel obtainable from final felling Norway spruce stands offer the best possibilities to generate heat energy at a competitive price from wood chips (Alakangas et al. 1999).

Logging residue can be harvested either after logging fresh with needles or after drying over a summer season, when a significant proportion of needles and a small amount of bark and thin branches remain at site. The recovery of dried logging residue and the feasibility of harvesting are reduced (Alakangas et al. 1999, Hakkila 2004).

The quantity of logging residues at logging sites is dependent on wood species and quantity, height and branches of wood stands and amount of rotten wood. The quantity of Norway spruce logging stands is more than double compared to that of Scots pine and birch stands. The logging residue obtained from large trees contains more branches than that of small trees. If there are rotted wood in the stand, the amount of refused logs increases significantly. The logging residue at a typical Norway spruce regeneration site in Southern Finland amounts to about 100 m^3/ha, the quantity of merchantable wood being 200–250 m^3/ha.

3.2.1.2 Fuel properties of logging residue

When the logging residues are left to dry at the logging site for a couple of summer months, the moisture content decreases from 50–60%:as low as to 20–30%. During drying needles fall off, thin branches break and bark also loosens partly. The wood content of the logging residue increases and the moisture content decreases. On the other hand, the amount of harvestable logging residue decreases even by 20–30% due to falling off of needles. The recovery of dried logging residue, about 45%, is also lower than that from fresh logging residues.

Fresh logging residue chips/hog fuel comprise on average 40% wood, 23% bark, and 37% needles. The corresponding values for chips/hog fuel made of dried logging residues are: >60% wood, <30% bark, <10% needles (Alakangas et al. 1999).

The amount of recovered Norway spruce logging residues is usually 25–30% of that of stemwood harvested from the logging site.

The most significant operational properties of logging residue chips are dry mass for bulk cubic meter, i.e., density, as well as moisture content, net calorific value at the power station, and particle size distribution.

Moisture content affects the net calorific value, as water evaporation requires energy. The higher the proportion of dry matter in the cubic meter of chips/hog fuel and the lower the moisture content, the greater the energy yield of the stand is.

The main component of the tree top consists of leaves or needles. The proportion of needles is 25.5% in Scots pines and 37.6% in Norway spruces in final fellings in Southern Finland. The *net calorific value* of Scots pine branch mass without needles is 20.09 MJ/kg and that of Norway spruce 19.41 MJ/kg (see also Tables 12–14, Fig.10). The net calorific values of needles are 21.04 and 19.19 MJ/kg, respectively. Hence, the calorific value of Scots pine needles is higher than that of other top mass, while the difference of Norway spruce needles and branches is insignificant. Consequently, the falling off of Scots pine needles has a greater effect on the average calorific value than that of Norway spruce needles. In experiments carried out in Mikkeli, Finland, the average net calorific values ranged 19.8–20.1 MJ/kg (gross calorific heating value 21.2–21.4 MJ/kg). It may be concluded that the average net calorific value remains unchanged, although the net calorific heating value of residues decreases through falling off, rottening and release of extractives, the ratio of carbon and hydrogen remaining practically unchanged during storage. Hence, only the moisture content is of significance to the net calorific value (Hakkila et al. 1995, Nurmi 1993, Nurmi 1999).

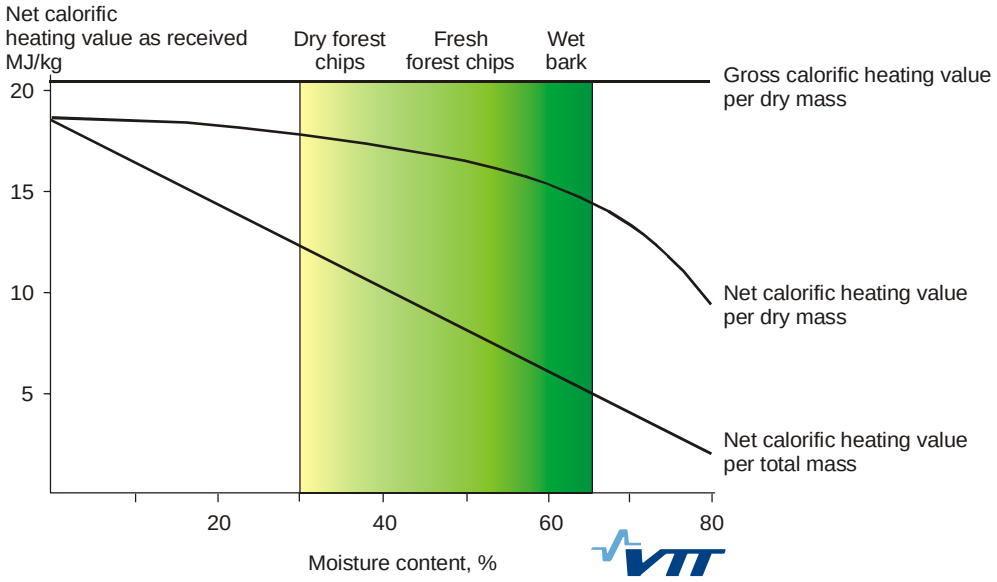


Figure 10. Dependence of the net calorific value of wood fuels on different moisture content (Hakkila 2004)

The dry matter content of bulk cubic meter of chips/hog fuel ranges in wide limits. It is dependent on the basic density of wood and on the solid volume factor of chips. The average basic density of Norway spruce logging residue, containing no green matter, is 465 kg/m^3 and of that containing green matter 425 kg/m^3 (Hakkila 1985).

The solid volume factor of chips/hog fuel is dependent most on technical details of the chipper/crusher, uniformity of size distribution, as well as blowing capacity of the chipper and loading method. Drying time of logging residue and settling during long-distance transports also affect solid volume factor values. The solid volume factor is required when converting bulk dimensions to solid ones, e.g., when agreeing upon chipping and transport fees. Usually, a solid volume factor value of 0.40 is used. It is a useful average value. Solid volume factor values of logging residue chips/hog fuel are presented in Table 20 (Uusvaara & Verkasalo 1987, Hakkila 2000).

Table 20. Solid volume factor of logging residue chips/hog fuel (solid m^3/loose m^3) in different seasons (Verkasalo 1988).

Type of chipper or crusher and loading method	Time of the year	Fresh	One year seasoned
Drum chipper, blow from the back of the load	Summer Winter	0,36 0,38	0,39 0,41
Crusher, belt conveyer	Summer Winter	0,39 0,39	0,39 0,39

Needles reduce the solid volume factor of wood chips/hog fuel, and hence, the fuel made of seasoned logging residue are more compact than those made of fresh lone. Another reason is also the higher content of fines in fuel made of seasoned logging residue (Uusvaara & Verkasalo 1987, Hakkila 2000).

The *particle size* and moisture content of logging residue chips/hog fuel are inhomogeneous. The particles sizes range from sawdust-like needle and bark material to wood and branch sticks. The raw material, the chipper or crusher, the condition of chipper blades and the mesh size of the screen affect the chip size. The more stemwood the raw material contains, the more homogeneous the size distribution of chips. The chips made with crushers are coarser than those made with chippers (Alakangas et al. 1999).

The *moisture content* of fresh logging residue is 50–60 w-% of the whole mass. However, the moisture content of logging residue chips/hog fuel ranges 25–65 w-%. The moisture content is dependent, i.a., on season and storage. In summertime, moisture contents of less than 30 w-% can be reached, as the raw material dries at site, while in wintertime the moisture content may be as high as 65 w-%, as snow and ice may end up among chips/hog fuel (Fig. 11). The moisture content has a significant effect on the energy density of fuel. In practice, the energy density of logging residue chips/hog fuel ranges 0.6–1.0 MWh/bulk m^3 (Alakangas et al. 1999).

A method of covering of stockpiles with kraft paper is commonly used in Finland. Paper protects the stockpile from wetting, and hence wood can also be chipped/crushed under bad weather conditions. The cover paper can be crushed among logging residues, and hence, it does not remain at the storage site. Figure 12 shows an example of moisture contents of logging residues, at logging site, in a covered stockpile and in an uncovered one, measured in studies of VTT Processes. The moisture content is given both as w-% and as (H_2O)/loose m^3. The results indicate that the moisture content of logging residues was 7–10 percentage units lower in the covered stockpiles than in the uncovered ones. According to VTT, the logging residues dry most efficiently at the beginning of the storage period, i.e. by 14–20% more during the two first months than later on. During this period, evaporation was by more than 100 mm higher than the precipitation. In October the moisture contents begin to rise due to rains (Hillebrand & Nurmi 2000).

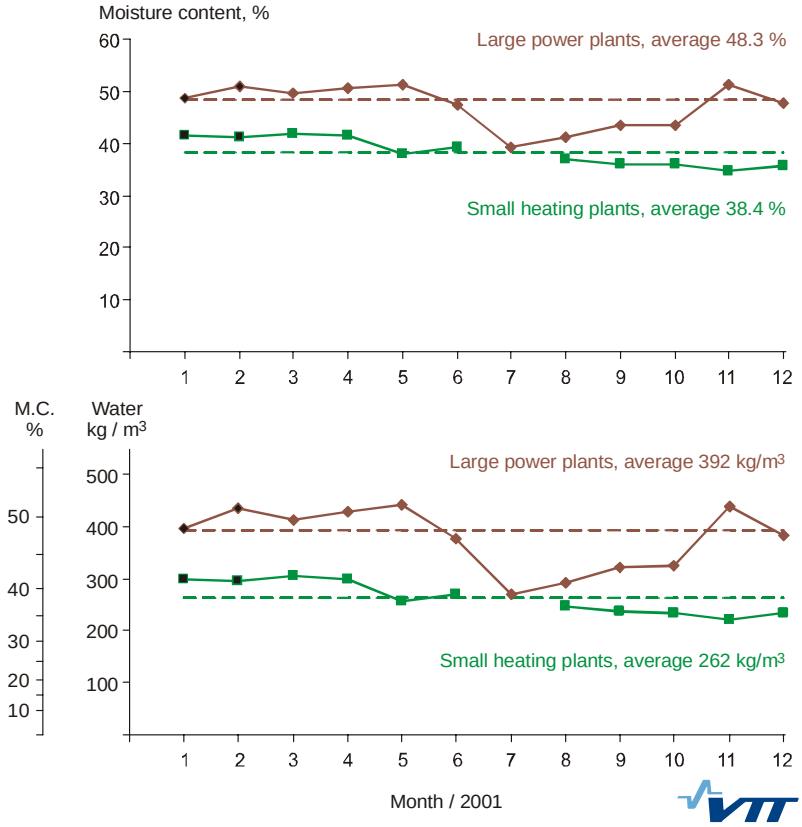


Figure 11. Seasonal variations in the delivery moisture content of wood chips at the large and small heating plants, Finland (Hakkila 2004).

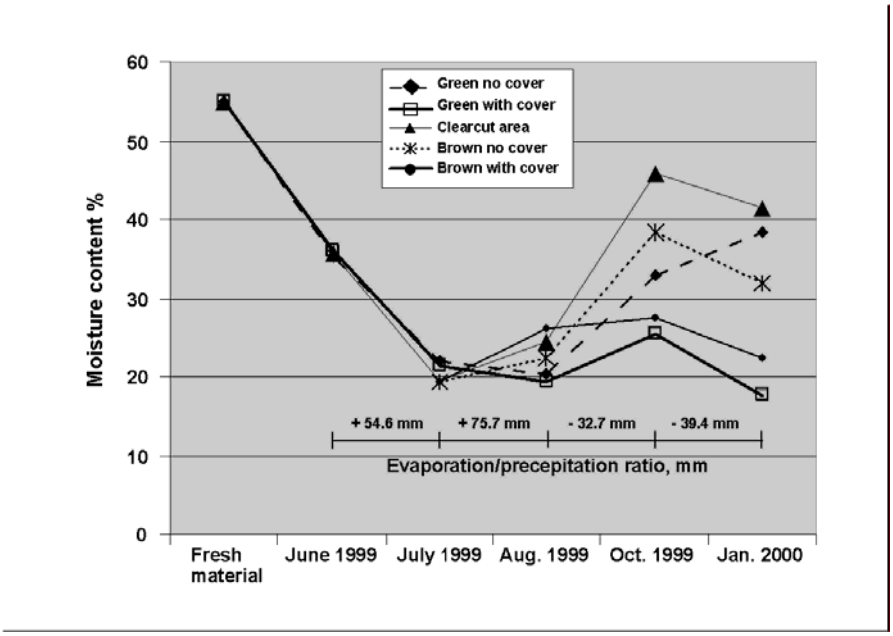


Figure 12. Moisture content of logging residue in uncovered and covered stockpiles at site (line graph indicates evaporation-rain, mm) (Hillebrand & Nurmi 2000).

There are different types of receiving, conveying and combustion equipment at heating and power plants. Therefore, the site of use sets certain quality requirements on chips/hog fuel, the most significant being moisture and chip size distribution. Long sticks in the fuel batch may cause arching and bridging in handling equipment. The handling properties of homogeneous, relatively finely fractioned logging residue chips/hog fuel do not differ significantly from those of sawing by-products, sawdust and bark.

Moist logging residue chips/hog fuel can well be used at large multifuel power plants around the year, if the station is designed for wet wood fuels. For example, at district heating stations designed for fuel peat the logging residue chips/hog fuel are not suitable alone for use in wintertime, as it is not possible to achieve a sufficient output in the boiler by burning chips. Wet logging residues may also get frozen or arched in bins and on conveyors in wintertime. Moisture may also hamper mixing. For example, warm peat and cold, moist chips are difficult to blend. At smaller stations, moist logging residues can be used usually only in summertime, when the station is operated at partial load and there is no danger of freezing in the handling chain (Impola 1995).

As a consequence of nutrient content, the ash melting temperature of logging residue ash is lower than that of bark ash. The highest nutrient content is in needles and leaves. The proportion of needle mass is very significant in logging residues. The proportion of needles in the dry mass of a living tree top is about 35% and in the dry mass of logging residue 30%. The respective percentages for Scots pine are 23 and 20%. Green needles do not fall off until dry, and hence, the needles fall off mainly in summertime (Nurmi 1999).

The *ash melting behaviour* is of significance especially in such combustion technologies, where ash melting may prevent, e.g., combustion air from flowing. It is also of use to know the ash melting behaviour to prevent the boiler from fouling as a consequence of ash softening. The composition of ash, and the combustion equipment and conditions may affect ash melting behaviour. Although the deformation temperature of forest residue chips/hog fuel (about 1 175 ^{o}C) is high, sintering of ash particles may start at significantly lower temperatures.

The *ash content* of wood material in Norway spruce stem and branches ranges 0.30–0.63% for dry matter. The ash content of branch mass containing bark is 1.9% and of bark 3.0%. The ash content of needles is higher (4.2–5.1%). During a test of intermediate storage, the ash content of both needles and logging residue increased and ranged 4.5–5% in the heaps stored over the longest period. There was also less ash in covered heaps than in uncovered ones (Nurmi 1999).

Chlorine (Cl) is also included in nutrients. Chlorine may cause hot corrosion in superheaters of steam boilers at > 480°C temperatures. This problem does not appear in smaller boilers, as the temperature remains below 480°C. It would be favourable for combustion if the needle or leaf mass or forest residue chips loose or if the chips are dry, when the chlorine and potassium contents decrease to a fraction of that in chips or hog fuel containing an abundance of green matter (Antikainen 1998, Veijonen et al. 2003).



Figure 13. Logging residue bundles and timber (Timberjack).

Wet wood chips or hog fuel that contain green matter (Fig.10) may increase fouling due to higher *alkali contents*, i.a., potassium (K) and sodium (Na) being problematic in combustion. The nitrogen, potassium, phosphorus and calcium contents of, e.g., Norway spruce needles for dry mass unit are manyfold compared to those of stemwood with bark (Fig. 13). The sodium content of Norway spruce needles ranges 0.020–0.040% and the chlorine content is <0.4%. The sodium content of Scots pine needles is very low and the chlorine content is <0.2%. Chlorine migration to the surface of the superheater pipe should be prevented. Alkalis operate as medium in migration. Therefore, it is advisable to use a sulphurous fuel, e.g., peat or coal, in cocombustion, when the alkalis are sulphated and chlorine is released as chlorohydric acid and carried with flue gases out of the system without causing any harm. Cofiring of peat and logging residues is also an efficient way to reduce fouling and the risk of hot corrosion in the boiler. The main methods of preventing corrosion in the convection zone of the boiler are the use of high-

alloyed superheater materials and prevention of chlorine migration from the furnace to the surface of the superheater pipe. The site of superheaters is also of significance. (Mälkönen 1974, 1977, Raiko et al. 1995, Antikainen 1998, Hakkila et al. 1998, Veijonen et. al 2003).

Wood chips/hog fuel can be burnt in the boilers of power plants on the following conditions (Antikainen 1998):

- Wood chips or hog fuel are blended with other fuel, e.g., peat or coal.
- Wood chips or hog fuel made of branches containing an abundance of green matter are not burnt in large quantities alone, and if wood chips or hog fuel are used as the main fuel, 15–20% peat is blended with wood residue chips or hog fuel.

3.2.2 Whole tree and stem chips



Figure 14. Storage of small-size trees.

Whole-tree chips are used at smaller heating stations and in heating boilers in homes and at farms. The chips are made of undelimbed stemwood, being either unmercantable stemwood or wood defective for industrial use (i.a. underproductive forests, seeding stands, first thinnings). *Stem chips* are made of delimbed stemwood, usually

unmerachanble stem wood. Stem wood consist usually of stemwood with bark, remained in the forest during harvesting and forestry actions. Whole-tree chips are presently used mostly for heating houses and at smaller district heat stations, where the fuel quality requirements are stricter than at larger stations. The moisture content of fuel chips used for house heating shall be lower (max 40%) and the chip sizes more homogeneous. Combustion technology also sets restrictions on chip size, e.g., at small gasification stations.

Cut smallwood is piled close to the logging road and stored in stemwood stockpiles for later chipping and transport to customers (Fig. 14).

Most essential characters of elements, calorific heating values, ash contents and composition of small-sized wood are presented in Tables 21–24.

Table 21. Element contents of different parts of small-sized trees (Nurmi 1993).

WOOD SPIECIES/ELEMENT	WOOD PART			INNER BARK		OUTER BARK		BARK	NEEDLES/ LEAVES
	Stem	Branches		Stem	Branches	Stem	Branches	Branches	
		> 5mm	< 5mm		>5mm		>5mm	> 5mm	
CARBON CONTENT, dry, w-%									
Scots pine	52,34	53,53	50,83	40,83	52,33	55,75	56,35	54,99	52,20
Norway spruce	52,43	53,36	50,37	49,70	50,20	55,56	56,10	54,02	51,30
Downy birch	50,97	50,97	48,39	52,20	52,49	72,64	68,37	57,82	49,12
Silver birch	47,43	48,67	48,05	48,00	48,60	66,71	64,34	50,24	48,68
Grey alder	49,09	48,21	49,17	49,67	48,34	64,09	60,58	51,53	49,75
Black alder	46,64	47,90	48,45	50,29	50,09	58,52	62,06	53,97	50,95
Trembling aspen	46,21	46,84	50,23	48,95	47,81	52,71	52,94	48,05	48,23
HYDROGEN, dry, w-%									
Scots pine	6,09	6,03	5,23	6,17	6,36	5,68	6,12	6,70	6,82
Norway spruce	5,86	5,61	5,14	5,59	5,62	5,85	5,77	5,95	6,28
Downy birch	5,86	5,80	5,15	5,79	6,10	9,37	8,43	6,55	6,13
Silver birch	5,22	5,25	5,18	5,10	5,01	9,41	8,40	5,33	6,08
Grey alder	5,77	5,16	5,71	6,15	5,94	8,59	7,66	6,48	6,22
Black alder	5,01	5,84	5,89	5,77	5,57	6,37	7,56	6,23	5,90
Trembling aspen	4,98	5,09	5,98	5,74	5,73	6,42	6,18	5,77	5,95
NITROGEN, dry, w-%									
Scots pine	0,08	0,10	0,19	0,48	0,55	0,15	0,38	0,68	0,88
Norway spruce	0,01	0,03	0,14	0,47	0,52	0,33	0,43	0,74	0,79
Downy birch	0,12	0,18	0,28	0,63	0,86	0,28	0,47	12,0	1,73
Silver birch	0,07	0,18	0,28	0,33	0,65	0,79	0,59	0,74	1,59
Grey alder	0,44	0,59	0,83	1,49	1,74	1,28	1,23	1,72	2,79
Black alder	0,20	0,46	0,62	1,06	1,26	1,15	1,06	1,33	2,22
Trembling aspen	0,15	0,29	0,61	0,84	1,30	0,59	0,88	1,00	2,50

Table 22. Net calofic value of dry matter for different stem wood and whole trees (Nurmi 1993).

Wood species	Net calorific value of dry matter, MJ/kg	
	Stem	Whole tree
Scots pine	19,33	19,53
Norway spruce	19,02	19,29
Downy birch	19,19	19,30
Silver birch	19,15	19,21
Grey alder	19,00	19,18
Black alder	19,31	19,31
Trembling aspen	18,65	18,65

Table 23. Amount of ash in fuel chips made of green small-sized wood (Hakkila & Kalaja 1983).

Raw material for wood chips	Ash content, dry w-%				
	Birch	Alder	Trembling aspen	Scots pine	Norway spruce
Delimber stem	0,68	0,92	0,92	0,74	1,04
Whole tree without needles or leaves	0,79	1,08	1,09	0,8	1,25
Whole tree with needles or leaves	0,98	1,25	1,3	0,86	1,56

Table 24. Ash content for dry matter in different parts of small-sized wood (Voipio & Laakso 1992).

Wood species	Relative stem hight 20 %			Relative stem hight 80 %			Branches >5mm			Branches <5mm		Needles and leaves
	Wood without bark	Inner Bark	Outer bark	Wood without bark	Inner bark	Outer bark	Wood without bark	Inner bark	Outer bark	Wood without bark	Outer bark	
Scots pine	0,3	1,2	1,0	0,3	1,8	1,2	0,4	1,9	1,5	0,7	1,8	2,2
Norway spruce	0,3	3,5	3,3	0,5	3,0	2,6	0,5	5,1	3,9	1,0	2,9	4,2
Downy birch	0,3	2,7	0,7	0,4	2,3	0,6	0,7	4,6	2,0	1,1	3,4	4,9
Silver birch	0,3	2,0	0,5	0,4	1,8	0,5	0,5	3,2	0,9	0,7	2,4	4,2
Grey alder	0,4	3,2	2,4	0,6	3,2	1,7	0,7	2,9	2,0	1,0	2,2	5,4
Black alder	0,3	2,5	1,4	0,4	2,1	1,5	0,5	2,0	1,5	0,7	2,1	4,8
Trembling aspen	0,4	5,0	11,1	0,5	4,9	10,2	0,7	5,5	6,8	2,0	5,2	8,7

Properties of whole tree chips have been studied at first-thinning Scots pine stands in recent years (Tables 25–27). The basic density was on average 395 kg/m^3 for debarked green stemwood and 376 kg/m^3 for unbarked stemwood. The basic density of bark was 266 kg/m^3. The average moisture content of newly felled first-thinning Scots pines was 58.3% for unbarked stemwood and 52.4% for top mass. This has a great effect on the

calorific value of first-thinning Scots pine wood, being 1.64 MWh/m^3 for fresh unbarked Scots pine, 1.71 MWh/solid m^3 for debarked wood and 1.18 MWh/solid m^3 for bark (Hakkila et al. 1995).

Table 25. Net calorific value and ash content for solid cubic meter of first thinning Scots pine wood (Hakkila et al. 1995, Nurmi 1993.)

Biomass component	Net calorific value, dry, MJ/kg	Net calorific value as received in moisture content of 40 w-%, MWh/m^3 solid	Net calorific value as received in moisture content of 50 w-%, MWh/m^3 solid	Ash content, w-% dry	Ash amount in biomass, kg/m^3
STEM					
Wood without bark	19,31	1,95	1,86	0,40	1,6
Bark	19,53	1,32	1,26	2,55	6,8
Wood with bark	19,33	1,86	1,78	0,62	2,3
BRANCHES					
Wood with bark	20,23	1,97	1,89	1.03	3,9
Needles	21,0	2,01	1,92	2,35	8,8
Living top	20,49	1,99	1,90	1,48	5,6
Whole top	20,38	2,02	1,93	1,25	4,9
WHOLE TREE	19,56	1,89	1,81	0,76	2,9

Table 26. Average mass proportions and basic densities for biomass components of first thinning Scots pine wood in Southern Finland (Hakkila et al. 1995).

Biomass component	Fraction, w- %	Basic density, kg/m^3
STEM		
Wood without bark	89,5	395
Bark	10,5	266
Wood with bark	100	376
LIVING BRANCHES		
Wood without bark	9,2	424
Bark	5,4	311
Wood with bark	14,6	382
Needles	7,5	373
Living top	22,1	379
Dried branches	5,9	424
Whole top	28,0	388
Whole tree	128,0	379

Table 27. Average properties of first thinning Scots pine stands in Southern Finland (Hakkila et al. 1995).

Property	Whole stem	Stem		Unmerchantable top tree, cm		
		>6 cm	>8 cm	6–8	4–6	1–4
PROPORTION OF BARK						
Thickness	4,5	4,6	5,0	2,4	2,3	1,8
Portion in volume, volume-%	15,4	15,2	15,6	13,5	17,4	25,5
Dry matter content, w- %	10,1	9,8	9,8	10,5	13,9	21,4
BASIC DENSITY, kg/m^3						
Wood without bark	395	397	399	377	371	365
Wood with bark	376	377	379	361	352	340
Bark	267	266	265	275	274	278
WATER CONTENT OF WOOD WITH BARK						
Moisture, w-%	59	58	58	61	62	63
Moisture, dry basis, u, %	141	140	138	158	164	170
COMPOSITION, kg/m^3						
Wood without exctratives	327	329	331	312	293	258
Wood with acetone exctraction	11	11	11	11	10	9
Bark	38	37	37	38	49	73
Water	530	528	523	570	577	578
Total = basic density	906	905	902	931	929	918
ENERGY DENSITY, MWh/m^3, fresh						
Wood with bark	1,85	1,85	1,86	1,78	1,73	1,67
Wood without bark	1,94	1,95	1,96	1,85	1,82	1,79
Bark	1,18	1,17	1,17	1,21	1,21	1,23
ASH FROM WOOD WITH BARK, kg/m^3	2,3	2,3	2,3	2,3	2,5	2,9

As for logging residue, the density values of whole tree chips are affected by the chipper/crusher employed, and the season and wood species (Table 28). The angle of slope and friction coefficient of chips are given in Table 29.

Table 28. Solid volume factors of whole tree chips (Uusvaara & Verkasalo 1987).

Wood species	Disc chipper, blow from the back of the load Summer Winter	Disc chipper, blow from the top of the load Summer Winter	Disc chipper,tip-up Summer Winter	Drum chipper, blow from the back of the load Summer Winter	Drum chipper, tip-up Summer Winter
Scots pine, whole tree chips	0,47 0,50	0,48 0,49	0,45 0,48	0,46 0,49	0,41 0,44
Scots pine, stem chips		0,49 0,50	0,42 0,42		
Birch, whole tree chips	0,44 0,46	0,45 0,50	0,38 0,43	0,43 0,44	0,40 0,42
Birch, stem chips	0,44 0,44	0,43 0,46	0,46 0,46	0,43 0,44	
Norway spruce, whole tree chips	0,44 0,44	0,44 0,44	0,39 0,39		
Alder, whole tree chips		0,54 0,54	0,48 0,48		0,52 0,53
Alder, stem chips		0,56 0,56			
Logging residues, fresh				0,36 0,38	
Logging residues, seasoned				0,39 0,41	

Table 29. The angle of slope and the friction coefficient of chips on different underlays (chip size 5–55 mm, moisture content 9.2 %) (Rautalin et al. 1986).

Material	Angle of slope		Friction coefficient	
	Average	Deviation	Average	Deviation
Steel plate, Fe 37, unpainted	24,4	1,28	0,48	0,02
Steel plat, painted by "Miranol"	23,5	2,17	0,43	0,04
Plywood covered with water resistant material	21,9	1,72	0,40	0,03
Painted plate, "Inerta 51 HB"	23,5	1,13	0,43	0,02
Painted plate, "Inerta 160"	27,0	1,90	0,51	0,03
Chipboard	29,4	3,06	0,56	0,05
acrylic plastic	28,4	1,77	0,54	0,03

3.3 Bark and stumps

Wood bark consists of outer bark and inner bark. The layer of cambium between bark and wood develops wood in its inside and bast in its outside, through which it transfers photosynthesis products from the top to the trunk and to the roots. The proportion of bark ranges 10–20% in stemwood, but the percentage can be as high as 60% in small branches. The proportion is calculated for the total volume or total mass of unbarked

wood. It can be determined, e.g., with callipers, a xylometer or with a gauge punched through the bark (Hakkila et al. 1995, Leino 1975, Impola et al. 2000).

As bark contains a significant amount of lignin, its calorific value is high. The value is also practically equal at different heights of the stem. On the other hand, the calorific values of different wood species range within wide limits, those of deciduous tree being as a rule clearly higher than those of coniferous tree. Trembling aspen is an exception, the calorific value of its bark being even lower than that of Scots pine and of the same magnitude as that of Norway spruce. The calorific values of outer bark are clearly higher than those of inner bark for coniferous tree, on average 20–32 MJ/kg for outer bark and 19–20 MJ/kg for inner bark. The net calorific value is higher for stem bark than for branch bark. Net calorific value for dry matter for pine bark ia 19.3 MJ/kg and for spruce bark 19.9 MJ/kg. There are also differences in calorific value between different wood species and size, the variations being higher for smallwood than for stems. The calorific value of fresh first-thinning Scots pine bark is 1.2 MWh/solid m^3 for dry matter and 1.3 MWh/solid m^3 at 40% moisture content, due to a low basic density (Table 25). The habitat of the tree also affects the calorific value of bark (Nurmi 1993 and 2000, Table 12, Hakkila et al. 1995).

In practice, the high moisture and ash contents decrease considerably the fuel value of bark. Hence, it is often rather a matter of bark waste disposal than energy production in bark combustion. Wood bark is generally used as fuel in boilers of wood-processing industries and heating stations. The bark produced as by-products of wood-processing industries consists mainly of coniferous tree bark. The inhomogeneity of bark causes problems in bark handling and, when used in blends, in handling and feed equipment.

Fuel properties of bark may be upgraded, i.a., by compressing, drying or blending it among other fuels. Bark can be dried by heat or mechanically with a bark press. It is not always possible to compress coniferous tree bark sufficiently well, and consequently, the dry matter content often remains less than 40%. In bark screening, it is recommendable to separate large bark parts more carefully from small pieces, to avoid problems caused by large pieces in compression. The achievable dry matter content is highly dependent both on the temperature of bark and on particle size. Heat drying is rarely employed and requires large plants, cheap waste heat or flue gases being utilised. Data on bark properties is given in Tables 30–35 (Juvonen & Johanson 1986, Öhman 1980, Impola et al. 2000).

The quality of bark fuels can be upgraded significantly by blending, e.g., cutter shaving among bark. This improves the value and applicability of both fuels, and bark drying may not be needed (Juvonen & Johanson 1986).

Stumps may remain among peat production or must be removed, e.g., from building or road sites or can be exctracted from final cutting areas.



Figure 15. Extraction of stumps from final felling areas and hog fuel produced from stumps.

Stumps are extracted mainly from final felling areas (Fig. 15) on fresh mineral soils. Soil disturbance is minimised as organic substances bind releasing nutrients and metals. In principle, the target is similar to that of conventional soil preparation, i.e., the humus layer is opened to as small extent as possible. 70–85% of humus surface is left untouched. Humus (organic material) can be in part covered or mixed with mineral soil. This procedure secures that the release of nutrients, heavy metals and aluminum to the groundwater is as small as possible. The ecological impact on the soil does not deviate significantly from that of normal soil preparation (Leinonen et.al 2005).

About 1/4 of stumps and greater part of all roots are left in the soil for forming rotten wood for use of organisms and for securing humus porosity required to maintain its oxygen content. A filtration zone is left along ditches and watercourses. It binds the humus and nutrients contained in surface waters to vegetation. The width of this zone should be 7–10 m (Leinonen et al. 2005).

Stumps can also be extracted from paludified final felling sites, where the peat layer is thin and the nutrient content is equal to that of fresh mineral soils. Stumps shall not be extracted from essential peatlands (Leinonen et al. 2005).

It is difficult to chip stumps, and therefore they are usually crushed. Hog fuel from stumps contain typically thick pieces: the crush made employing the sieve with the largest mesh size (40 mm and 8 mm sieves) contained 34.3% of pieces of 8 mm in diameter and the crush produced without any sieve 44.1% (Pulkkinen 1996).

According VTT study at a power plant in Finland, the particle size distribution with a slow-speed cruchers is presented in Table 35. Most of the particles were between 13 – 30 mm (Impola & Rinne 2005).

As stump wood is best used when it is at least one year old, it is an excellent choice for fuel at winter when other wood fuels tend to be moist. Stump wood has good storage properties, i.e. is it thought not to decompose or moisten even under long storage periods, which makes it a good choice for e.g. peak-load fuel. In the large roadside storages in summer well dried stumps and roots are preserved better than logging residues and other energy wood. In general, the moisture content of stump fuel remains under 40 w-% also during the winter months. The moisture contents of all other biofuels are considerably higher in the winter; for example, residual chips 45–55 w-% and by-products of forest industry (bark and sawdust) 50–60 w-%. In the winter loose snow and ice increase sometimes the moisture content of stumps. The amount of snow can be reduced by developing storage methods (Leinonen et al. 2005).

Dry stump fuel has good energy density and net calorific value. Therefore stumps and roots are an ideal fuel at the large power plants to decrease the average moisture of whole fuel blend. So, the plants use easily moistening logging residue and other energy wood storages in summer and autumn, and well preserving stump storages in the winter.

At the power plant the biggest problems related to stump fuel are (mineral-) soil, stones and other impurities, which increase the ash content. Ash contents of crushed stumps have been measured at a power plant. Ash content variations between different deliveries are very big. The lowest ash contents of stump deliveries are 2–3 % and the highest ones as much as over 20%. However, the average ash contents consequent upon mineral soil and stones has been decreased last years being about 8%. The ash content of fine fractions (<3 mm) was 41%.

At earlier measurements carried out at VTT, the net calorific value of stumps from peatland was on average 19.3 MJ/kg for dry matter, the mass of dry matter 182 kg/bulk m^3, the average moisture content 34% and ash content 0.2%. The maximum calorific value was measured for Scots pine stumps (22.36 MJ/kg, Table 12), as the percentage of extractives in the organic substances of stumps is high (18–20%). The net calorific value for spruce stumps is 16.9 MJ/kg. The particle size distribution of crushed stumps is presented, together with bark, in Table 30 (Laine & Sahrman 1985, Pulkkinen 1996, Impola & Rinne 2005).

Table 30. Net calorific value of different parts of stumps and bark for dry matter, MJ/kg (Nurmi 1997).

Wood species	Wood material of root	Bark from root material	Whole root	Stump	Stump and roots
Scots pine	19,32	20,43	19,51	22,36	21,02
Norway spruce	19,33	19,55	19,38	19,18	19,32
Downy birch	18,60	19,65	18,84	18,61	
Silver birch	18,50	20,18	18,97	18,50	
Grey alder	18,83	20,38	19,28	19,27	
Black alder	18,93	19,66	19,17	18,91	
Trempling aspen	18,30	19,73	18,78	18,32	

Table 31. Typical elemental analyses for bark (w-% for dry matter) (Leino 1975).

Bark	C, w-%	H, w-%	S, w-%	O + N, w-%	Ash content, w-%
Scots pine	54,4	5,9	-	38,0	1,7
Norway spruce	50,6	5,9	-	40,7	2,8
Birch	56,6	5,9	-	35,0	1,6

Table 32. Ash melting behaviour of bark (Leino 1975).

Bark	Ash deformation temperature, °C	Ash hemisphere temperature, °C	Ash sphere temperature, °C	Ash flow temperature, °C
Scots pine	1 010	1 240	1 385	1 400
Norway spruce	1 020	1 250	1 400	1 420
Birch	935	1 180	1 440	1 460

Table 33. Ash content and elemental composition of ash of bark for different wood species, w-% (Raiko et al. 1995, Alakangas et al. 1987).

Wood species	Ash, %	SiO_2	Fe_2O_3	P_2O_5	CaO	MgO	Na_2O	K_2O	SO_3	Other*
Scots pine	1,8	14,5	3,8	2,7	40,0	5,1	2,1	3,4	3,7	22,9
Norway spruce	3,4	21,7	1,8	2,7	50,5	4,2	2,8	3,5	1,6	7,8
Birch	1,6	3,0	1,0	3,0	60,3	5,9	0,7	4,1	4,8	15,6
Oak	1,5	11,1	3,3		64,5	1,2	8,9	0,2		9,3

* calculated.

Table 34. Basic density of the bark of certain wood species (Kärkkäinen 1985).

Wood species	Basic density, kg/m³	Wood species	Basic density, kg/m³
Scots pine, normal bark	300	European larch, outer bark	285
Scots pine, outer bark	310	Siberian larch, outer bark	325
Norway spruce, normal bark	365	Hassel	280
Norway spruce, outer bark	410	Douglas spruce	310
Silver birch, round wood	560	Poplar	410
Downy birch, round wood	530	Oak	425
Downy birch, small-size round wood (pulp wood)	500	Box alder	455
Downy birch, branches	505	Whitebeam tree	460
Grey alder, small-size round wood (pulp wood)	390	Marple	530
Black alder, branches	425	Peech	580
Downy birch, 1 year old tree	535		
Willow, 1 year old tree	490		
Goat willow	408		
Elm	358		
Mountain birch	560		
Dwarf birch	545		

Table 35. Average particle size distributions of bark and stump hog fuel (Laine & Sahrman 1985, Impola & Rinne 2005).

Mesh size, mm	100	78	60	45	40	30	25	20	13	10	7	6	4	3	Bottom
CRUSHED BARK															
Amount not passing the sieve, w-%		1,7			13,0			24,5		23,3		2,9	0,8		33,8
Deviation, %		2,0			10,6			6,0		4,4		4,6	1,3		19,9
CRUSHED STUMP															
Amount not passing the sieve, w-%	1,6	2,8	5,0	10,2		28,5	20,9		26,4	35,1	12,2	8,5		13,6	20,9
Deviation, %	1,9	2,4		1,0			1,4			2,2		1,0			4,8

3.4 Sawdust and cutter shavings

Sawdust used as fuel is obtained as a by-product of timber sawmills, and cutter shavings from planing machines. Sawdust is usually of wet and light material. However, its moisture content can vary within wide limits (from air-dry to 70%). Sawdust is burnt with other fuels in boilers of wood processing industries and heating stations. Cutter

shavings are usually as dry and light, that they cannot be burnt as such but among heavier and moister fuels. Cutter shavings are also used by wood processing industries and heating stations. Compressed products like pellets and briquettes can also be produced from sawdust and cutter chips.

Average properties of sawdust and cutter shavings are presented in Tables 36–38.

Table 36. Average properties of sawdust and cutter shavings (Hakkila et al. 1978, Laine & Sahrman 1985).

Property	Sawdust	Cutter shavings
Typical moisture content,w- %	50–55	5–15
Net calorific value, dry, MJ/kg	18,9–19,2	18,9
Basic density (kg/m^3)	380–480	380- 480
Bulk density of fuel in typical moisture content, kg/loose m^3	250–300	80–120
Energy density, MWh/loose m^3	0,4–0,7	0,5
Ash content	0,4–1,1	0,4

Table 37. Particle size distribution of sawdust (Laine & Sahrman 1985).

Mesh size, mm	40	15	10	8	4	2	1	0,5	0,25	Bottom
Amount not passing the sieve, w-%	2,0	3,2	5,9	3,7	13,8	19,2	30,3	14,4	4,9	2,6

Table 38. Angle of flow and friction coefficient for sawdust (4.0 mm sieve fraction, moisture content 10 w-%) (Rautalin et al. 1986).

Material	Flow angle		Friction coefficient	
	Average	Deviation	Average	Deviation
Steel plate, Fe 37, not painted	37,1	0,90	0,77	0,02
Painted steel plate, "Miranol"	30,25	1,64	0,58	0,03
Ply wood, blastic covered	33,02	0,68	0,65	0,01
Painted plate, "Inerta 51 HB"	32,71	0,50	0,64	0,01
Painted plate, "Inerta 160"	27,71	1,42	0,53	0,02
Glass plate	32,37	0,79	0,63	0,01
Acryl plate	28,17	3,33	0,54	0,06

3.5 Log wood

Log wood (billets) are about 1 m long split or round blocks for fuel use. Log wood is produced either only from birch, or mixed blocks also from other wood species. Log wood is burnt in top- and underfeed boilers and fireplaces or stoves (Immonen & Seppälä 1984).

Chopped wood (small trees) are 0.25–0.50 m long cut and splitter wood blocks. The use of chopped wood as fuel requires manual work, as automatic feed cannot be employed. The use is facilitated to some extent, if the fireplace or the boiler is equipped with a storage bin for, e.g., 24-hour fuel requirement. Chopped wood is used mainly by small heat consumers and is also suitable for recreational use (Virtanen et al. 1984, Immonen & Seppälä 1984).

Chopped wood, cut to the length of 33 cm and splitted or stripped, is easy to handle and most generally used. New fireplace or stove types require shorter firewood with length of 25 cm.

In Finland chopped wood can be divided into three quality classes (Figure 16, App.1), i.a., on the basis of the following properties (Pirinen 1997):

- length,
- thickness,
- moisture content
- cut surface
- cleanness
- colour
- decay and mould
- portion of wood species.



Figure 16. Quality classes for chopped wood, class 3, 2 and 1 (TTS-Institute).

Chopped wood of 25 cm and 33 cm in *length* are used mainly in open fireplaces and ovens, while that of 50 cm in length is suitable for use in central heating boilers and baking ovens.

Thickness gives the maximum diameter of chopped wood. The thickness recommended is 4 cm, and the maximum thickness 10–15 cm, depending on the quality class (compare CEN classification in App. 2, Fig. 17). If the diameter of the stem or block exceeds 10 cm, the wood is chopped to four parts and if less than 10 cm, the wood is cleaved. It is not necessary to cleave smaller, 4–5 cm thick wood blocks, but both sides should be stripped. However, the proportion of such chopped wood should not exceed 5–25% of the total quantity, depending on the quality class.

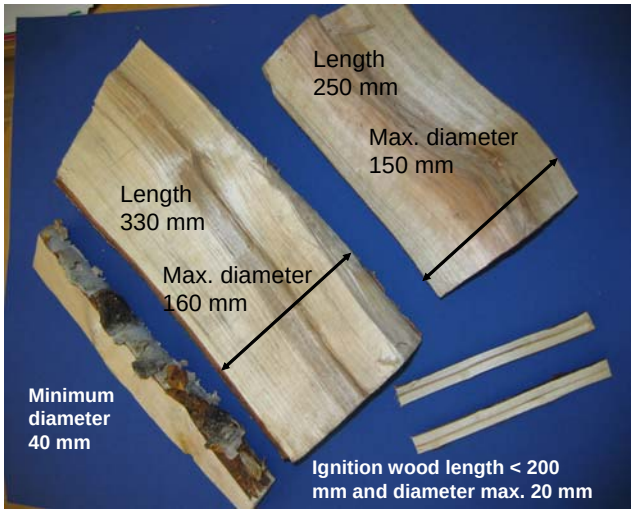


Figure 17. Particle size distribution of log wood in CEN/TS 14961.

The *moisture level* of all chopped wood should be sufficiently *low* for combustion. The moisture content of the first-class chopped wood should be <20%. This level is achieved by drying chopped wood over summer. Calorific values of chopped wood for different moisture contents are presented in Table 40.

Bulk measuring is the most generally used *method of measuring chopped wood*. Chopped wood is stacked into a box of certain size, or heaped. Usually, a measuring box or platform of 1–3 m^3, e.g. a trailer, is used. Chopped wood can be loaded into the box either by hand or with a loader coupled to a farm tractor. A traditional method of measuring fuel wood is to measure 1 m long logs in a pile. The principle of this method is equal to that of pulp wood measuring. (Kouki 1997, Pirinen 1995, 1996). Conversion factors between different measuring units are presented in Table 40.

Table 39. Calorific value of different wood species and of chopped wood produced from wood mixtures for typical moisture content (Pirinen 1997).

Wood species	Net calorific value as received,	Moisture content, w-%	Energy density	
	kWh/kg	%	kWh/loose m^3	kWh/stacked m^3
Scots pine	4,15	20	810	1 360
Norway spruce	4,10	20	790	1 320
Birch	4,15	0	1040	1 750
		10	1030	1 730
		20	1010	1 700
		30	990	1 660
		40	970	1 620
		50	930	1 550
Alder	4,05	20	740	1 230
Aspen	4,00	20	790	1 330
Mixture of different deciduous trees (50 % of alder and 50% aspen)		0	790	1 330
		10	780	1 310
		20	760	1 280
		30	740	1 250
		40	720	1 200
		50	680	1 140
Mixture of different coniferous trees (50% of spruce and 50% pine)		0	830	1 380
		10	810	1 360
		20	800	1 340
		30	780	1 310
		40	760	1 270
		50	720	1 200

Table 40. Conversion factors of measuring units for chopped firewood (Pirinen 1995 and 1996).

Unit	Loose m^3	Stacked m^3	Solid m^3
Loose cubic meter, log length 330 mm	1	0,60	0,40
Stacked cubic meter, log length 330 mm	1,68	1	0,67
Stacked cubic meter, log length 1000 mm	1,55	1	0,62
Solid cubic meter	2,50	1,50	1

For example one loose cubic meter is equal to 0,40 solid cubic meter (400 litres of wood).

In studies at VTT Processes, the average net calorific value for dry matter measured for log wood and chopped wood was 18.73 MJ/kg (standard deviation 0.67 MJ/kg), and ash content 1.2% (standard deviation 0.8%) (Alakangas et al. 1987).

Drying of chopped firewood is dependent on initial moisture content, storage site, and weather. The most significant climatic factors are relative atmospheric humidity, precipitation, temperature, and wind conditions. In a normal summer, drying of chopped wood made of fresh wood (moisture 40–50%) to combustion moisture content (20–25%) takes at least two months under a shelter outdoors in Finland. Fresh chopped wood shrinks by 6–7% during drying. Shrinking starts only at 23–25% moisture content, i.e., at the so-called saturation point of wood fibres. Storage over winter, e.g., in a shed, does not reduce the moisture content of wood essentially, as the most favourable drying season of wood is from April to early September. The cut surfaces of first-class chopped wood should be even and smooth. In practice, this requires the use of circular saw or chain saw. Machines operating in guillotine principle always leave the ends uneven, and hence, such chopped wood is always classified in the second or third class.

Plastics, soot, metals, pesticide chemicals or other detrimental substances, snow or ice are allowed among chopped firewood. Moulder is not accepted in the first-class chopped wood. The colour of chopped wood should be like that of sound wood. No blackening or other colour defect is accepted. The use of wood colour as a quality criterion concerns primarily chopped wood to be used in clean indoor rooms. In decayed wood, the amount of wood suitable for combustion and hence, also energy content are smaller than in sound one.

The chopped firewood is sorted on the basis of the main wood species. Among the first-class chopped birch wood no other wood species are accepted. Coniferous tree is not accepted among chopped deciduous tree, while there are no limitations for deciduous tree among chopped coniferous tree.

3.6 Wood briquettes and pellets

3.6.1 Wood briquettes

Wood briquettes are compressed from dry sawdust, grinding dust and cutter chips. Usually no binding agents are used, as the own constituents of wood (lignin) stick the briquette together. The cross section of wood briquettes is usually round or square. The length or diameter is 50–80 mm. In round briquettes there may be a hole of 10–20 mm in diameter. During compression, the moisture content of wood is less than 15%. The dry mass of wood briquettes is on average 1 000 kg/ bulk m^3. Compared to other fuels, the wood briquettes are heavy and dry. Analytical results obtained at VTT Processes are presented in Table 41 (Laine & Sahrman 1985).



Figure 18. Wood briquettes.

In Finland, cylindrical briquettes are manufactured in several places with annual production of 35 000 tons. Most of the wood briquettes are used as crushed in power plants. The dry matter density of briquettes is 1 080 kg/m^3, volume weight 650 kg/bulk m^3, diameter 65 mm and length 10–200 mm. The net calorific value as received is about 4.8 kWh/kg (17.3 MJ/kg), moisture content about 6% and ash content about 0.5%. Some enterprises of mechanical wood-processing industry use small briquette presses for producing discoidal briquettes. The durability of these briquettes is not as good as that of cylindrical briquettes (Suur-Savon Sähkö 2000).

Table 41. Properties of cylindrical wood sawdust briquettes (Laine & Sahrman 1985).

	Net calorific value of dry matter, MJ/kg	Moisture content, (in production phase), w- %	Volatiles w-%	Ash content, dry, w-%
Wood briquettes	18,93 average Deviation 0,19	5,4 Deviation 0,4	83,6 Deviation 0,7	0,3

There is no quality classification in force for briquettes in Finland and CEN classification is presented in App.2.

3.6.2 Wood pellets

Wood pellets are compressed, cylindrical, sometimes quadratic grains, diameter being 8–12 mm and length 10–30 mm (Fig. 19). For example, industrial wood residues, bark and wood chips can be used as raw materials. Wood pellets are suitable for heating one-family houses, farms and block buildings. Equipment designed especially for pellets are used in the combustion of wood pellets. At big heating or power plants the pellets are crushed prior to feeding, e.g., into pulverised combustion boilers. In Finland, wood pellets are produced in different part of Finland and annual production is 200 000 tons, of which more than 80% is exported.



Figure 19. Wood pellets.

The bulk density (BD) of wood pellets is 600–750 kg/bulk m^3 and the particle density (DE) 1 100–1 500 kg/m^3. The ideal moisture content with regard to power demand, strength and equipment capacity is 10–15% in wood pelletisation. The success of

pelletisation is indicated by the amount of fines (F) among pellets after compression (see App.2 for CEN classification).

The wood pellets get wet, swell and break when coming into contact with water. The pellets endure direct moisture poorly, and therefore the wood pellet storage must be protected from rain (Kytö et al. 1983).

The moisture content of pellets is low, 7–12%. The ash content is also low, about 0.5%. The weight of a bulk density of pellets ranges 650–700 kg m^3. The net calorific value of pellets ranges 4.7–5.0 kWh/kg (16.9–18 MJ/kg). Hence, the energy content of pellets is 3 000–3 300 kWh/loose m^3, which is equal to 300–330 litre of light fuel oil. One tonne of pellets takes about 1.5 m^3 of storage space and is equal to 470–500 litre of light fuel oil. When exposed to water, the wood pellets get damp, swell and disintegrate. The pellets stand poorly direct moisture.

TTS Institute has carried out a study in which they research properties of pellets. Five pellet producers havee delivered their sample pellet batch for inclusion in the tests. Results are presented in Table 42. There were minor differences in the elemental analysis between the products, and these complied with natural variation of wood. All five manufacturers had used untreated wood as raw material for their pellets and the products did not contain any harmful additive. The concentrations obtained were below all international requirements known at the time. There were no major differences between the pellet batches in their net calorific heating value. The net calorific heating value as received varied within the range 4.63–4.98 MWh/ton. The differences observed were caused by moisture differences of the pellets, which varied within the range 5–10%. The raw material used was debarked wood, which explains why the ash content of the product was low (0.2–0.4%). If only bark is used as rawmaterial, ash content of pellets are 2–3%. If forest residues are rawmaterial, ash content of pellets is depending about the seasoning. For seasoned forest residues ash content is about 2% and for fresh logging residues up to 6%. The bulk density of moist pellets varied within the range of 560–690 kg/$m^3$and the energy density varied within the range of 2.59–3.43 MWh/m^3 loose Also, the length and durability of the pellets showed considerable product-specific variation (Tuomi 2001, Kallio M. & Kallio, E. 2005).

Table 42. Properties of Finnish wood pellets (Tuomi 2001).

Property	Unit	Product 1	Product 2	Product 3	Product 4	Product 5
C	%,dry	49,80	49,70	49,72	49,39	49,12
H	%,dry	6,12	6,11	6,13	6,10	6,03
N	%,dry	0,16	0,16	0,05	0,07	0,08
S	%,dry	0,005	0,006	0,004	0,005	0,007
Cd	mg/kg	0,06	0,08	0,07	0,11	0,06
Cr	mg/kg	0,48	1,59	0,36	0,48	0,31
Zn	mg/kg	7,83	0,04	7,55	7,56	8,00
Cu	mg/kg	1,14	2,76	1,02	1,22	1,10
Ni	mg/kg	0,26	0,26	0,24	0,21	0,30
Fe	mg/kg	9,28	8,19	8,79	7,59	29,79
Cl	mg/kg	6,88	5,82	6,85	5,73	7,38
Na	mg/kg	61,52	30,32	15,23	7,78	53,35
Mg	mg/kg	64,42	65,74	62,02	85,43	67,21
Ca	mg/kg	0,57	0,59	0,54	0,62	0,64
K	mg/kg	0,31	0,35	0,35	0,26	0,46
Mg	mg/kg	0,11	0,12	0,13	0,09	0,12
P	mg/kg	0,02	0,03	0,03	0,02	0,03
Moisture content	w-%	5,2	6,6	9,1	8,5	9,7
Ash content	dry-%	0,28	0,30	0,25	0,24	0,37
Diameter	mm	8	8	8	8	8
Length, average	mm	16	14	19	7	14
Length, max.	mm	22	25	37	10	25
Length, min.	mm	10	7	8	4	6
Number of pellets/100g	Pieces	110	120	110	300	140
Durability.average (Amandu-Kahl)	kp	21	20	21	17	19
Durability, max	kp	21	21	21	21	21
Durability, min.	kp	20	18	20	9	17
Durability, fine dust (ASTM E 1288-89) <2.36 mm	%	1,8	1,1	1,3	1,9	2,6
Bulk density, as received	kg/loose m^3	690	680	630	600	560
Basic bulk density, moisture free	kg/loose m^3	655	635	575	550	505
Net calorific heating value, dry	MJ/kg	19,0	18,9	19,0	18,8	18,7
Net calorific heating value, dry	MWh/t	5,28	5,26	5,28	5,23	5,20
Net calorific heating value as received	MJ/kg	17,9	17,5	17,0	17,0	16,7
Net calorific heating value as received	MWh/t	4,98	4,87	4,74	4,73	4,63
Energy density	MWh/ loose m^3	3,43	3,31	2,98	2,84	2,59
Energy density	GJ/ loose m^3	12,3	11,9	10,7	10,2	9,3

4. Comparision of wood fuels

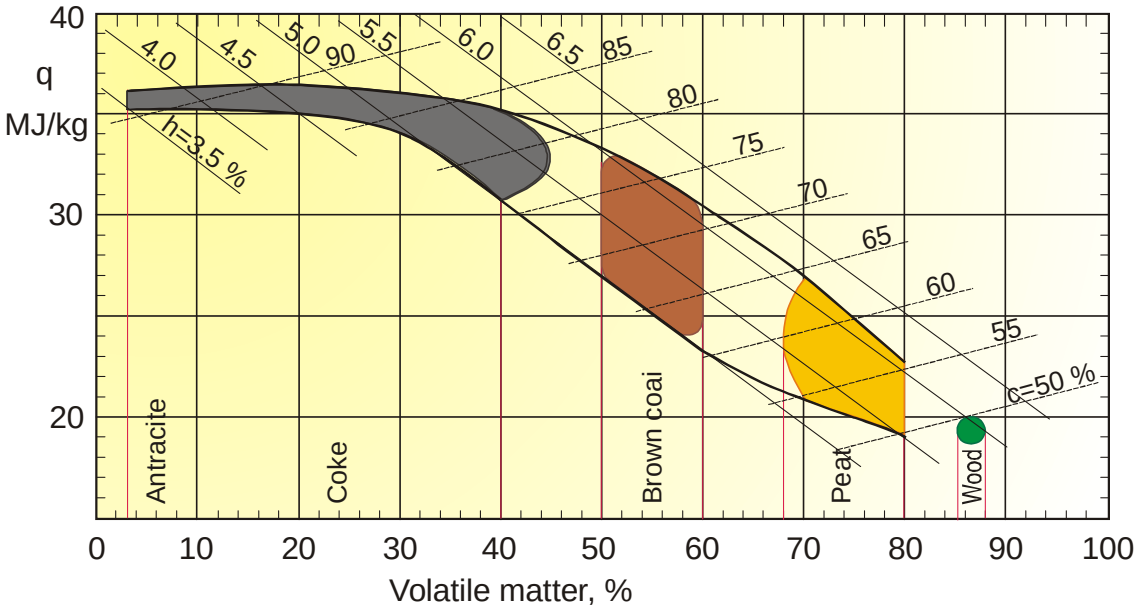


Figure 20. Comparison of carbon and hydrogen contents in different fuels.

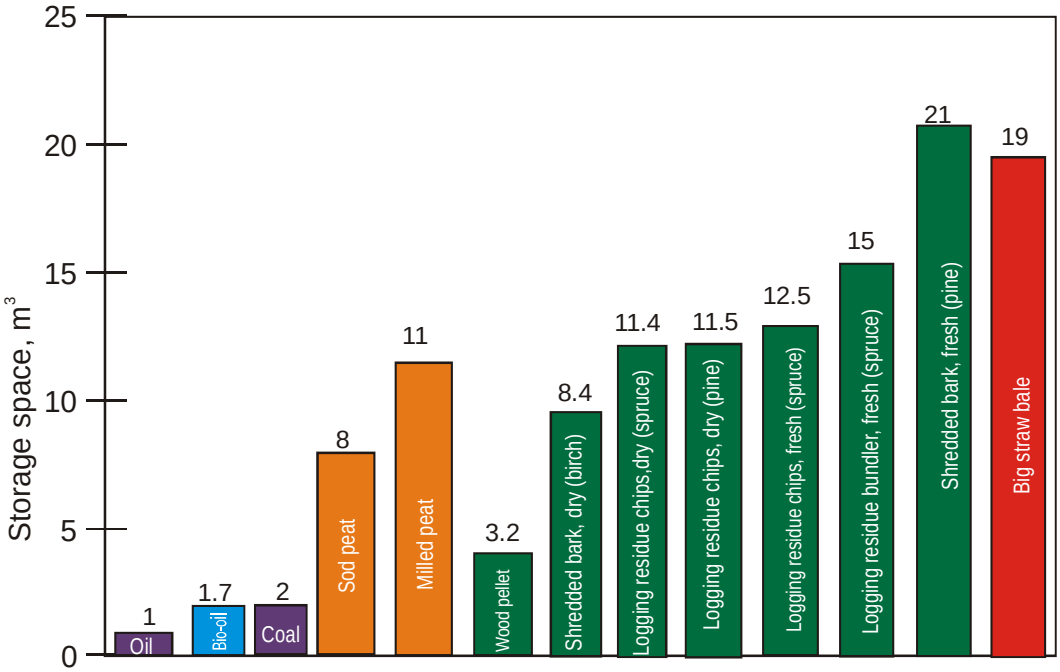


Figure 21. Comparison of fuels on the basis of volume and energy amount (Hakkila 2000).

Table 43. Classification of biofuels on the basis of detrimental substances (Fortum Engineering).

FUEL	High alkaline content (Na + K)	High chloride content	High sulphur content	High moisture content	High ash content
Ply wood residues	X				
Logging residue chips	X				
Olive stones	X				
Aspen, bark	X				
Rubber tree	X	X			
Straw	X	X			
Reed canary grass	(X)	(X)			
REF		X			
RDF		X		(X)	(X)
Bark				X	
Peat			(X)		
Biosludge	X	(X)		X	X
Primary sludge				X	X

(X) depends on the fuel quality.

Table 44. Comparison of properties of different wood fuels (Impola 1998, Alakangas et al. 1997, Pirinen 1996).

	Logging residue chips	Whole tree chips	Log chips	Stump chips	Coniferous tree bark	Birch bark
Moisture content, w-% (fresh chips)	50 - 60	45 - 55	40 - 55	30 - 50	50 - 65	45 - 55
Net calorific value in dry matter, MJ/kg	18.5 - 20	18.5 - 20	18.5 - 20	18.5 - 20	18.5 - 20	21 - 23
Net calorific value as received, MJ/kg	6 - 9	6 - 9	6 - 10	6 - 11	6 - 9	7 - 11
Bulk density as received, kg/loose m^3	250 - 400	250 - 350	250 - 350	200 - 300	250 - 350	300 - 400
Energy density, MWh/ m^3 of bulk volume	0.7 - 0.9	0.7 - 0.9	0.7 - 0.9	0.8 - 1.0	0.5 - 0.7	0.6 - 0.8
Ash content in dry matter, w-%	1 - 3	1 - 2	0.5 - 2	1 - 3	1 - 3	1 - 3
Hydrogen content in dry matter (H), w-%	6 - 6.2	5.4 - 6	5.4 - 6	5.4 - 6	5.7 - 5.9	6.2 - 6.8
Sulphur content in dry matter (S), w-%	< 0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Nitrogen content in dry matter (N), w-%	0.3 - 0.5	0.3 - 0.5	0.3 - 0.5	0.3 - 0.5	0.3 - 0.5	0.5 - 0.8

Table 44 (continued) Comparison of properties of different wood fuels (Impola 1998, Alakangas et al. 1997, Pirinen 1996).

	Wood residue chips	Saw residue chips	Sawdust	Cutter chips	Grinding dust	Plywood residue	Uncovered wood
Moisture content, w-%	10 - 50	45 - 60	45 - 60	5 - 15	5 - 15	5 - 15	15 - 30
Net calorific value in dry matter, MJ/kg	18.5 - 20	18.5 - 20	19 - 19.2	19 - 19.2	19 - 19.2	19 - 19.2	18 - 19
Net calorific value as received, MJ/kg	6 - 15	6 - 10	6 - 10	13 - 16	15 - 17	15 - 17	12 - 15
Bulk density as received, kg/loose m^3	150 - 300	250 - 350	250 - 350	80 - 120	100 - 150	200 - 300	150 - 250
Energy density, MWh/ m^3 of bulk volume	0.7 - 0.9	0.5 - 0.8	0.45 - 0.7	0.45 - 0.55	0.5 - 0.65	0.9 - 1.1	0.65 - 0.8
Ash content in dry matter, w-%	0.4 - 1	0.5 - 2	0.4 - 0.5	0.4 - 0.5	0.4 - 0.8	0.4 - 0.8	1 - 5
Hydrogen content in dry matter (H), w-%	5.4 - 6.4	5.4 - 6.4	6.2 - 6.4	6.2 - 6.4	6.2 - 6.4	6.2 - 6.4	6 - 6.4
Sulphur content in dry matter (S), w-%	< 0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.1
Nitrogen content in dry matter (N), w-%	0.1 - 0.5	0.1 - 0.5	0.1 - 0.5	0.1 - 0.5	0.1 - 0.5	0.1 - 0.5	0.1 - 0.5

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Appendix 1. Finnish quality tables for different wood fuels

WOOD CHIPS, SAWDUST AND BARK (FINBIO)

Energy density as received MWh/ m^3 of bulk volume, minimum

	Chips	Sawdust	Bark
E1	0.9	0.7	0.7
E2	0.8	0.6	0.6
E3	0.7	0.5	0.5
E4	0.6	0.4	0.4

Moisture content, w-%, maximum

	Chips	Sawdust	Bark
K1	40	30	40
K2	50	50	50
K3	60	60	60
K4	65	65	65

Particle size 95 % < mm

	Chips	Sawdust	Bark
P1	30	5	60
P2	45	10	100
P3	60	20	200
P4	100	30	Unstripped

Source: IMPOLA, R. 1998. Puupolttoaineiden laatuohje. (Quality instructions for wood fuels). Jyväskylä, FINBIO, Publication 5. 33 p.

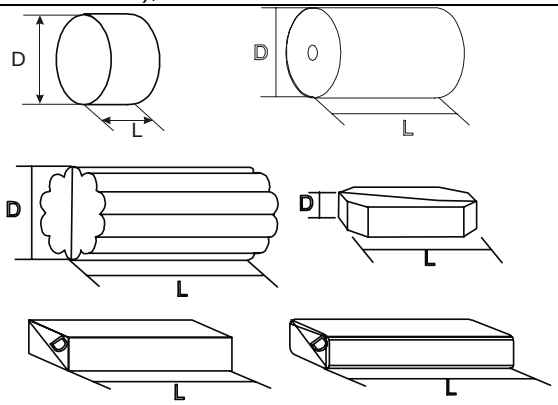
QUALITY CLASSIFICATION OF CHOPPED FIREWOOD

Chopped firewood	**First class**	**Second class**	**Third class**
Wood species* – Birch (only) – Deciduous tree – Coniferous tree	not other wood species no coniferous tree no limits for deciduous tree	upper limit ≤5% for other deciduous tree upper limit ≤5% for coniferous tree no limits for deciduous tree	upper limit ≤10% for other deciduous tree upper limit ≤10% for coniferous tree no limits for deciduous tree
Length	33 cm or 50 cm±2 cm (25 cm ±1 cm)	33 cm or 50 cm±4 cm (25 cm ±3 cm)	33 cm or 50 cm±6 cm (25 cm ±4 cm)
Thickness, diameter	4 - 10 cm	4 - 12 cm	4 - 15 cm
Moisture content	not more than 20w-%	not more than 25w-%	not more than 30w-%
Cut-off surface	even and plain	uneven ends allowed	uneven ends allowed
Proportion of incompletely chopped/ debarked wood	not more than 5%	not more than 15%	not more than 25%
Purity	no foreign substances	no foreign substances	no foreign substances
Mould	not allowed	single spots allowed	small occurrences allowed
Colour	no colour defects allowed	small colour defects allowed	colour defects allowed
Decay	not allowed	only hard decay allowed, upper limit ≤5 vol%	decay allowed, upper limit ≤5 vol% of hard decay and ≤1 vol% of soft decay

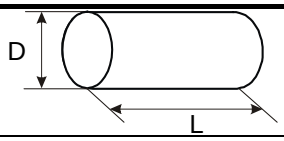
* does not concern mixed chopped firewood

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Appendix 2A. Specification of properties for briquettes (CEN/TS 14961)

	Master table		
	Origin: Table 19		Woody biomass
	Traded Form		Briquette
Normative	**Dimensions** (mm) Diameter (D) or equivalent (diagonal or cross cut), mm		
	D40	25 ≤ D ≤ 40	
	D50	≤ 50	
	D60	≤ 60	
	D80	≤ 80	
	D100	≤ 100	
	D125	≤ 125	
	D125+	≥ 125 actual value to be stated	
		Length (L)	
	L50	≤ 50	
	L100	≤ 100	
	L200	≤ 200	
	L300	≤ 300	
	L400	≤ 400	
	L400+	≥ 400 actual value to be stated	Examples of briquettes
	Moisture (w-% as received)		
	M10	≤ 10 %	
	M15	≤ 15 %	
	M20	≤ 20 %	
	Ash (w-% of dry basis)		
	A0.7	≤ 0,7 %	
	A1.5	≤ 1,5 %	
	A3.0	≤ 3,0 %	
	A6.0	≤ 6,0 %	
	A10.0	≤10,0 %	
	Sulphur (w-% of dry basis)		
	S0.05	≤ 0,05 %	Sulphur is normative only for chemically treated biomass or if sulphur containing additives have been used
	S0.08	≤ 0,08 %	
	S0.10	≤ 0,10 %	
	S0.20	≤ 0,20 %	
	S0.20+	> 0,20 % (actual value to be stated)	
	Particle density (kg/dm^3)		
	DE0.8	0,80 to 0,99	
	DE1.0	1,00 to 1,09	
	DE1.1	1,10 to 1,19	
	DE1.2	≥ 1,20	
	Additives (w-% of pressing mass)		
	Type and content of pressing aids, slagging inhibitors or any other additives have to be stated		
	Nitrogen, N (w-% of dry basis)		
	N0.3	≤ 0,3 %	Nitrogen is normative only for chemically treated biomass
	N0.5	≤ 0,5 %	
	N1.0	≤ 1,0 %	
	N3.0	≤ 3,0 %	
	N3.0+	>3,0 % (actual value to be stated)	
Informative	Net calorific value, $q_{p,net,ar}$ (MJ/kg as received) or energy density, E_{ar} (kWh/m^3 loose)		Recommended to be stated at the retail level
	Bulk density as received (kg/m^3 loose)		Recommended to be stated if traded by volume basis
	Chlorine, Cl (w-% of dry basis, %)		Recommended categories Cl 0.03, Cl 0.07, Cl 0.10 and Cl 0.10+ (if Cl > 0,10 % the actual value to be stated)

Appendix 2 B —Specification of properties for pellets (CEN/TS 14961)

	Master table		
	Origin: According Table 19		Woody biomass (1), Herbaceous biomass (2), Fruit biomass (3), Blends and mixtures (4)
	Traded Form		Pellets
Normative	**Dimensions** (mm)		
	Diameter (D) and Length (L) [a]		
	D06	≤ 6 mm ± 0,5 mm and L ≤ 5 x Diameter	
	D08	≤ 8 mm ± 0,5 mm, and L ≤ 4 x Diameter	
	D10	≤ 10 mm ± 0,5 mm, and L ≤ 4 x Diameter	
	D12	≤ 12 mm ± 1,0 mm, and L ≤ 4 x Diameter	
	D25	≤ 25 mm ± 1,0 mm, and L ≤ 4 x Diameter	
	Moisture (w-% as received)		
	M10	≤ 10 %	
	M15	≤ 15 %	
	M20	≤ 20 %	
	Ash(w-% of dry basis)		
	A0.7	≤ 0,7%	
	A1.5	≤ 1,5 %	
	A3.0	≤ 3,0 %	
	A6.0	≤ 6,0 %	
	A6.0+	> 6,0 % (actual value to be stated)	
	Sulphur (w-% of dry basis)		
	S0.05	≤ 0,05 %	Sulphur is normative only for chemically treated biomass and if sulphur containing additives have been used
	S0.08	≤ 0,08 %	
	S0.10	≤ 0,10 %	
	S0.20+	> 0,20 % (actual value to be stated)	
	Mechanical durability [a] (w-% of pellets after testing)		
	DU97.5	≥ 97,5 %	
	DU95.0	≥ 95,0 %	
	DU90.0	≥ 90,0 %	
	Amount of fines (w-%, < 3,15 mm) after production at factory gate		
	F1.0	≤ 1,0 %	[a] At the last possible place in the production site
	F2.0	≤ 2,0 %	
	F2.0+	> 2,0 % (actual value to be stated)	
	Additives (w-% of pressing mass)		
	Type and content of pressing aids, slagging inhibitors or any other additives have to be stated		
	Nitrogen, N (w-% of dry basis)		
	N0.3	≤ 0,3 %	Nitrogen is normative only for chemically treated biomass
	N0.5	≤ 0,5 %	
	N1.0	≤ 1,0 %	
	N3.0	≤ 3,0 %	
	N3.0+	> 3,0 % (actual value to be stated)	
Informative	Net calorific value, $q_{p,net,ar}$ (MJ/kg as received) or energy density, E_{ar} (kWh/ m^3 loose)		Recommended to be informed by retailer.
	Bulk density as received (kg/m^3 loose)		Recommended to be stated if traded by volume basis
	Chlorine, Cl (weight of dry basis, w-%)		Recommended to be stated as a category Cl 0.03, Cl 0.07, Cl 0.10 and Cl 0.10+ (if Cl > 0,10 % the actual value to be stated)
[a] Maximum 20 w-% of the pellets may have a length of 7,5 x Diameter.			

Appendix 2 C —Specification of properties for wood chips (CEN/TS 14961)

	Master table			
	Origin: According to Table 19.		Woody biomass (1)	
	Traded Form		Wood chips	
Normative	**Dimensions** (mm) [a]			
		Main fraction > 80 % of weight	Fine fraction < 5 %	Coarse fraction max. length of particle,
	P16	3,15 mm ≤ P ≤ 16 mm	< 1 mm	max 1 % [a] > 45 mm, all < 85 mm
	P45	3,15 mm ≤ P ≤ 45 mm	< 1 mm	max 1 % [a] > 63 mm
	P63	3,15 mm ≤ P ≤ 63 mm	< 1 mm	max 1 % [a] > 100 mm
	P100	3,15 mm ≤ P ≤ 100 mm	< 1 mm	max 1 % [a] > 200 mm
	Moisture (w-% as received)			
	M20	≤ 20 %	Dried	
	M30	≤ 30 %	Suitable for storage	
	M40	≤ 40 %	Limited for storage	
	M55	≤ 55 %		
	M65	≤ 65 %		
	Ash (w-% of dry basis)			
	A0.7	≤ 0,7 %		
	A1.5	≤ 1,5 %		
	A3.0	≤ 3,0 %		
	A6.0	≤ 6,0 %		
	A10.0	≤ 10,0 %		
	Nitrogen, N (w-% of dry basis)			
	N0.5	≤ 0,5 %	Nitrogen is normative only for chemically treated biomass	
	N1.0	≤ 1,0 %		
	N3.0	≤ 3,0 %		
	N3.0+	> 3,0 % (actual value to be stated)		
Informative	Net calorific value $q_{p,net,ar}$ (MJ/kg as received) or energy density, E_{ar} (kWh/m^3 loose)		Recommended to be specified when retailed.	
	Bulk density as received (kg/m^3 loose**)**		Recommended to be stated if traded by volume basis in categories (BD200, BD300, BD450)	
	Chlorine, Cl (weight of dry basis, w-%)		Recommended to be stated as a category Cl 0.03, Cl 0.07, Cl 0.10 and Cl 0.10+ (if Cl > 0,1 % the actual value to be stated)	

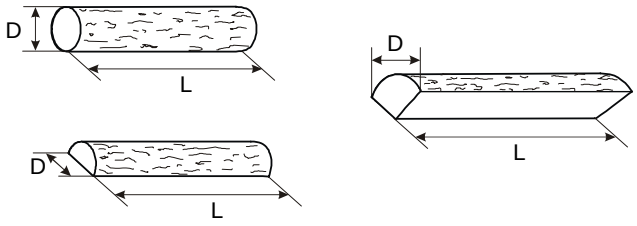
[a] The numerical values for dimension refer to the particle sizes passing through the mentioned round hole sieve size (3,15 mm, 16 mm, 45 mm, 63 mm and 100 mm). Dimensions of actual particles may differ from those values especially the length of the particle.

Appendix 2 D —Specification of properties for hog fuel (CEN/TS 14961)

	Master table			
	Origin: According to Table 19.		Woody biomass (1)	
	Traded Form		Hog fuel	
Normative	**Dimensions** (mm) [a]			
		Main fraction > 80% of weight	Fine fraction < 5 % of weight	Coarse fraction, max. length of a particle, mm < 1 % of weight
	P45	3,15 mm ≤ P ≤ 45 mm	< 1 mm	> 63 mm
	P63	3,15 mm ≤ P ≤ 63 mm	< 1 mm	> 100 mm
	P100	3,15 mm ≤ P ≤ 100 mm	< 1 mm	> 200 mm
	P300	3,15 mm ≤ P ≤ 300 mm	< 1 mm	> 400 mm
	Moisture (w-% as received)			
	M20	≤ 20 %	Dried	
	M30	≤ 30 %	Suitable for storage	
	M40	≤ 40 %	Limited for storage	
	M55	≤ 55 %		
	M65	≤ 65 %		
	Ash (w-% of dry basis)			
	A0.7	≤ 0,7 %		
	A1.5	≤ 1,5 %		
	A3.0	≤ 3,0 %		
	A6.0	≤ 6,0 %		
	A10.0	≤ 10,0 %		
	Nitrogen, N (w-% of dry basis)			
	N0.5	≤ 0,5 %	Nitrogen is normative only for chemically treated biomass	
	N1.0	≤ 1,0 %		
	N3.0	≤ 3,0 %		
	N3.0+	> 3,0 % (actual value to be stated)		
Informative	Net calorific value $q_{p,net,ar}$ (MJ/kg as received) or energy density, E_{ar} (kWh/m^3 loose)		Recommended to be specified when retailed.	
	Bulk density as received (kg/m^3 loose)		Recommended to be stated if traded by volume basis in categories (BD250, BD350, BD450)	
	Chlorine, Cl (weight of dry basis, w-%)		Recommended to be states as a category Cl 0.03, Cl 0.07, Cl 0.10 and Cl 0.10+ (if Cl > 0,10 % the actual value to be stated)	

[a] The numerical values for dimension refer to the particle sizes passing through the mentioned round hole sieve size (3,15 mm, 16 mm, 45 mm, 63 mm and 100 mm). Dimensions of actual particles may differ from those values especially the length of the particle.

Appendix 2 E — Specification of properties for log woods (CEN/TS 14961)

	Master table		
	Origin: According Table 19.		Woody biomass (1.1)
	Traded Form		Log woods
Normative	**Dimensions** (mm)		
	Length (L) and thickness (D) (maximum diameter of a single chop)		
	P200-	L < 200 mm and D < 20 ignition wood	
	P200	L = 200 mm ± 20 mm and 40 mm ≤ D ≤ 150 mm	
	P250	L = 250 mm ± 20 mm and 40 mm ≤ D ≤ 150 mm	
	P330	L = 330 mm ± 20 mm and 40 mm ≤ D ≤ 160 mm	
	P500	L = 500 mm ± 40 mm and 60 mm ≤ D ≤ 250 mm	
	P1000	L = 1 000 mm ± 50 mm and 60 mm ≤ D ≤ 350 mm	
	P1000+	L > 1 000 mm actual value has to be stated and D has to be stated	
	Moisture content (w-% as received)		
	M20	≤ 20 %	Oven-ready log
	M30	≤ 30 %	Seasoned in the storage
	M40	≤ 40 %	Seasoned in the forest
	M65	≤ 65 %	Fresh, after cut in the forest
	Wood To be stated if coniferous or deciduous wood or mixture of these is used.		
Informative	Energy density, E_{ar} (kWh/m^3 loose or stacked)		Recommended to be specified when retailed.
	Volume, m^3 solid, stacked or loose as received		To be stated which volume is used when retailed (m^3 solid, m^3 stacked or m^3 loose)
	Proportion of split volume		No split (=mainly round wood) Split: more than 85 % of volume is split Mixture: split and round wood as a mixture
	The cut-off surface		To be stated if the cut-off surface of log woods are even [a] and smooth [a] or ends of log woods are uneven
	Mould and decay		If significant amount (more than 10 % of weight) of mould and decay exists it should be stated. In case of doubt particle density or net calorific value could be used as indicator.

[a] Use of chainsaw is considered to be smooth and even.

Appendix 2 F —Specification of properties for sawdust (CEN/TS 14961)

	Master table	
	Origin: According to Table 19.	Woody biomass (1)
	Traded Form	Sawdust
Normative	**Moisture** (w-% as received)	
	M20 ≤ 20 % M30 ≤ 30 % M35 ≤ 35 % M55 ≤ 55 % M65 ≤ 65 %	Dried Suitable for storage Limited for storage
	Ash (w-% of dry basis)	
	A0.7 ≤ 0,7 % A1.5 ≤ 1,5 % A3.0 ≤ 3,0 % A6.0 ≤ 6,0 %	
	Nitrogen, N (w-% of dry basis)	
	N0.5 ≤ 0,5 % N1.0 ≤ 1,0 % N3.0 ≤ 3,0 % N3.0+ > 3,0 % (actual value to be stated)	Nitrogen is normative only for chemically treated biomass
Informative	Net calorific value $q_{p,net,ar}$ (MJ/kg as received or energy density, E_{ar} (kWh/m^3 loose)	Recommended to be specified.
	Bulk density as received (kg/m^3 loose)	Recommended to be stated if traded by volume basis in categories (BD200, BD300, BD350)
	Chlorine, Cl (weight of dry basis, w-%)	Recommended to be stated as a category Cl 0.03, Cl 0.07, Cl 0.10 and Cl 0.10+ (if Cl > 0,10 % the actual value to be stated)

NOTE Particle size for sawdust is considered to be homogenous. Particle size distribution could be specified if requested.

Appendix 3 G —Specification of properties for bark (CEN/TS 14961)[a]

	Master table		
	Origin: According to Table 19.		Woody biomass (1.1.5, 1.2.1.2, 1.2.2.2, 1.3.1.2, 1.3.2.2)
	Traded Form:		Bark
Normative	**Moisture** (w-% as received)		
	M40	≤ 40 %	
	M50	≤ 50 %	
	M60	≤ 60 %	
	M70	≤ 70 %	
	Ash (w-% of dry basis)		
	A0.7	≤ 0,7 %	
	A1.5	≤ 1,5 %	
	A3.0	≤ 3,0 %	
	A6.0	≤ 6,0 %	
	A12.0	≤ 12,0 %	
	Nitrogen, N (w-% of dry basis)		
	N0.5	≤ 0,5 %	Nitrogen is normative only for chemically treated biomass
	N1.0	≤ 1,0 %	
	N3.0	≤ 3,0 %	
	N3.0+	> 3,0 % (actual value to be stated)	
	Shredding		
	To be stated if bark is shredded into pieces or unshredded		
Informative	Net calorific value, $q_{p,net,ar}$ (MJ/kg as received) or energy density, E_{ar} (kWh/m^3 loose)		Recommended to be specified.
	Bulk density as received (kg/m^3 loose)		Recommended to be stated if traded by volume basis in categories (BD250, BD350, BD450)
	Chlorine, Cl (w-% of dry basis)		Recommended to be stated as a category Cl 0.03, Cl 0.07, Cl 0.10 and Cl 0.10+ (if Cl > 0,10 % the actual value to be stated)

[a] Also cork is included.

Calculation of analyses to different bases

Formulae for calculation of results to different bases (CEN/TS 15296)

Given	Wanted			
	As analysed (air dried, ad)	**As received** [a] (ar)	**Dry** (d)	**Dry, ash free** (daf)
As analysed (air dried, ad)		$\frac{100 - M_{ar}}{100 - M_{ad}}$	$\frac{100}{100 - M_{ad}}$	$\frac{100}{100 - (M_{ad} + A_{ad})}$
As received (ar)	$\frac{100 - M_{ad}}{100 - M_{ar}}$		$\frac{100}{100 - M_{ar}}$	$\frac{100}{100 - (M_{ar} + A_{ar})}$
Dry (d)	$\frac{100 - M_{ad}}{100}$	$\frac{100 - M_{ar}}{100}$		$\frac{100}{100 - A_{d}}$
Dry, ash free (daf)	$\frac{100 - (M_{ad} + A_{ad})}{100}$	$\frac{100 - (M_{ar} + A_{ar})}{100}$	$\frac{100 - A_{d}}{100}$	

[a] Note that the formulae given calculating results to the “as received” basis may be used to calculate them to any other moisture bases

