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MANUAL FOR BIOFUEL USERS

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PREFACE

BASREC, Baltic Sea Region Energy Co-operation, was established in 1999 by the Ministers responsible for Energy in Denmark, Estonia, Finland, Germany, Iceland, Latvia, Lithuania, Norway, Poland, Russian Federation, Sweden and the EU Commission.

The BASREC Working Group on Bioenergy 2003-2005 was established in accordance with the decision of the BASREC Ministerial Meeting in Vilnius in November 2002. The Work Plan for the period 2003-2005 was elaborated in accordance with the Proposal presented to the Ministerial Meeting.

A key issue for the Working group and its four Actions have been how to connect to market players. These actions comprised:

Action 1 Capacity Building.

Action 2 Standards & Market Harmonisation.

Action 3 Joint Implementation – bioenergy for climate projects.

Action 4 Research & development.

The Baltic Sea Region is characterised by vast forest resources, in particular NW Russia. At the same time forests are the main sources for solid biofuels. Another source is the agricultural sector land where straw and other residues can be used for energy production. However, still forests are mainly exploited for production of sawn products, building material and for pulp and paper production. Forests as energy resource supplier have by tradition been used in the form of wood logs. Today more efficient combustion techniques exist and the interest is growing for using residues from forests and wood-working industries for wood-fuel production both for domestic use and for export. The Baltic States are since more than ten years back an important supplier of wood chips and pellets to the Nordic countries and other European countries. Russia is now entering this market. Another great advantage is the considerable environmental and climatic advantages that production and use of bioenergy offers as well as local job opportunities.

Another characteristic for the region is that district heating systems are well developed. In the Nordic countries a large part of the district heating supply is today based on bioenergy. In Russia, the Baltic States and Poland large parts of the heating systems are based on fossil fuels, mainly coal and mazut, to some extent also gas. But the interest has grown for using wood chips and pellets for heat production, more and more also for combined heat and power production, following the increasing prices on fossil fuels and for electricity.

A great advantage when with the interest in bioenergy for energy production increasing in Russia and the Baltic states the existence of highly skilled energy specialists, experts and universities who know well the specifics and theory for production and use of wood-based fuels, but so far the practical application is not so wide-spread.

The task and target for Action 1 was therefore to develop a Manual for practical application of bioenergy for energy production and to disseminate practical experience as a means to help and simplify the work for decision-makers in municipalities, heating companies and bioenergy producing companies to make the right choice of technology and size of bioenergy production plants.

The work for developing the Manual was assigned to the Tallinn University of Technology, which has long experience both in theory and practise of bioenergy. In its first phase the Manual will be presented in English, Russian and Estonian. Hopefully it will be possible to translate and up-date the Manual to further languages in the region and with additional local experiences.

The Nordic Council of Ministers has financed the work.

Gudrun Knutsson

Ms, Chairman of the BASREC Bioenergy Working Group 2003-2005

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1. INTRODUCTION

During the last years the use of biofuels has been constantly expanding. The available modern biofuel production and combustion technologies enable effective utilization of practically all waste from the forest and wood processing industries. Also herbaceous biomass, for example straw, has found increasingly wider implementation as a fuel.

The Baltic Sea countries play an important role in the development and implementation of biofuel technologies. This manual tries to deliver to the reader the experience in the practical introduction of biofuel technologies acquired in these countries. The whole technological chain is treated here from preparing fuels in the forest or field to flue gas cleaning and ash utilization. Besides biofuels also the use of peat is considered in the manual.

The manual should be of use for anybody who already uses biofuels or intends to do so in the future. Although the authors are engineers and mostly technological aspects are being considered, they attempt to present the material in such a way that it could be used for planning and preparing biofuel projects. For this purpose a brief overview of the role of biofuels in the energy policy of the Baltic Sea countries and European Union is given.

The authors of the manual are Villu Vares, Ülo Kask, Tõnu Pihu and Sulev Soosaar from Tallinn University of Technology and Peeter Muiste from the Estonian University of Life Sciences. The figures were drawn by Malle Remmel, and computer graphics designed by Tõnu Pihu.

The manual has been edited by Villu Vares.

1.1. Energy policy development in the European Union and Baltic Sea countries

The following is a brief overview of various aspects given in the most relevant EU energy policy documents related to biofuels either directly or indirectly.

The first step taken in the EU for developing a common strategy for the use of renewable energy resources was the Green Paper (COM(96)576). The whole strategy along with the suggested measures was focused on reaching a 12 % share of renewable energy sources (RES) in the EU by 2010, i.e., the share would be twice as high as at the starting point (1995). Reaching a 12 % share by 2010 is considered a rather ambitious, but realistic target set as a political, not a legal responsibility. To achieve the goal all EU countries had to develop their own strategies. It must be taken into account that in the share at the starting point (6 %) the contribution of large hydropower plants was significant. The potential for building new large-scale hydropower plants in Europe is rather limited. Thus the use of other RES must be expanded more.

The next step was taken rather quickly – at the end of 1997 the Communication from the Commission COM(97)599 of 26/11/1997 titled as the *White Paper: Energy for the future: renewable sources of energy*, which treated the EU strategy; an action plan was published as well. In the introduction of the Paper it is stated that the energy resources in the EU countries are distributed unevenly, however the scale of the use of abundantly available sources and especially on the economically feasible level is still fairly low.

In 1995 the EU countries depended on energy imports up to 50 %. If no measures are taken for the wider use of local resources, the EU dependence on imported energy will be 70 % already by 2020. Since the renewables are domestic resources in each country, their deployment would reduce the dependence on energy imports and improve the security of supply. In addition, the use of renewable energy resources will contribute to job creation, predominantly among the small and medium sized enterprises promoting thus the regional development as well.

As a result of recent technological development, the biomass (as well as small-scale hydro and wind power plants) was estimated to be competitive in the market, in particular compared to other decentralised energy supply options. The need for high initial investments was stated as one of the most serious obstacles in deploying renewable resources. An essential obstacle was considered to be the fact that all the costs the community has to carry with the consumption of traditional fuels are not included in the price of these fuels, i.e., the externalities of the fuel sector – impacts throughout the lifecycle – are not taken into account.

Several fiscal measures were considered reasonable for promoting the use of renewable resources:

- flexible depreciation of renewable energies investments;
- favourable tax treatment for financing renewable energy by third parties;
- start up subsidies for building energy plants that use renewable energy;
- financial incentives for customers to purchase renewable energy equipment and services;
- establishing green funds for the support of capital markets financed from private banks;
- establishing national funds for supporting renewable energy;
- providing soft loans.

For solid biofuels, substitution of fossil fuels with biofuels or co-firing of the fuels, further refinement of fuels (pellets, briquettes) and also wider use of forest waste and other types of residues were considered extremely essential. Here the wider use of biofuels was combined with the EU promotion strategy of heat and power (CHP). Almost 1/3 of the new additional biomass exploitation by 2010 was estimated to fall in this category.

Agriculture was considered as a key sector in gaining goals related to renewable energy resources. It was noted that the use of renewable energy resources in turn may promote rural development and that of agriculture significantly. Therefore, it was recommended for the EU member states to give a high priority to the renewable energy projects in the rural areas:

- to support the use of biofuels in the framework of rural development programmes;
- to support regions by participating in financing innovative demonstration and implementation projects, as for example heat and power co-generation based on solar energy, wind power and biomass.

The use of biomass was considered the most perspective option for bioenergy generation. The objective of the campaign for using biomass in CHP production is to promote and support building of biomass based decentralised power plants all over the EU. This concerned the equipment and plants of the capacity from a few hundred kW to several MW where a wide range of technologies could be used depending on local conditions. The objective set in the framework of the campaign for biomass was building a 10 GW production capacity, thus increasing the production of biomass based heat from 38 Mtoe (1995) to 75 Mtoe by 2010.

In the following years wider exploitation of renewable energy resources was not that topical any more. In the following document for designing the energy policy – the Green Paper: Towards a European strategy for the security of energy supply – the Commission highlighted the topic again [1]. The Paper, issued in 2000, says that availability of all conventional energy resources in the EU is limited and their share in meeting the energy demand is reducing both relatively and in absolute amounts. The potential abundance is valid only for renewable sources. Therefore, in order to reduce the dependence on imports, much is expected from the utilization of technology-intensive renewable resources.

It was also underlined that from the point of view of supply security the potential of renewable energy resources in the EU is significant, but promotion of the use of this potential depends highly on the political and economic trends, which can be successful only in case if tangible measures will be taken for the implementation of the policy. In this case the renewables would be the only resource, which the EU could use with certain flexibility and manoeuvring potential in the medium term future.

The report points out critically that the EU success in deploying renewable energy resources has been modest. So the target to double the share of renewables in electricity generation, which has been regularly set since 1985 has not been achieved. It is underlined that in spite of the increase in energy production from renewables (in average 3 % per year), its share had not risen above 6 %, because the overall energy demand had grown more rapidly. However, the spectacular growth of more than 2000 % in the wind energy sector during the decade is pointed out.

According to the report, the analysis of the use of renewable energy resources shows that in Europe the possibilities of expansion for large-scale hydropower which accounts for one third of total renewable energy at the present time, are practically nil in the future. The conclusion is drawn that the main growth must come from the use of biomass and biofuels.

When treating the factors that hinder the use of renewable resources, the report shows that the problems are related to the nature of already existing structures, i.e., the public economic and social systems have been built on the centralized development of conventional energy sources (coal, oil, natural gas and nuclear power). Financing problems are underlined as the most significant obstacle, because utilization of a renewable resource needs high initial investment. At the same time it is underlined that the use of renewable resources may require relatively long term aid before becoming economically feasible.

A special stress is laid on the need to apply the principle of subsidiarity. It means the flexible combination of public, regional and local interests in order to give preference to the use of renewable resources. The nature of means already applied in the member states varies ranging from the research grants or certain financial tools (low interest loans, guarantee funds, etc.) to fiscal measures for direct backing the utilization of renewable resources and to the purchase obligation of renewable electricity in certain amounts.

The next steps for promoting the use of renewable energy in the EU were the Directives, which set the objectives for the production of electricity from renewable sources (2001/77/EC) and promotion of the use of biofuels for transport (2003/30/EC). Further development of the use of biomass for heat production is indirectly supported by the Directive 2004/8/EC on the promotion of cogeneration of heat and power. A certain requirement for preferring renewable energy resources is also expressed in the Directive 2002/91/EC on the energy performance of buildings, which stipulates that for new buildings with the total floor area over 1000 m^2, the member states must ensure that the technical, environmental and economical feasibility of renewables based decentralised energy supply systems is considered and taken into account before the construction starts.

The new taxation regulation, which the member states adopted from January 1, 2004 with the Directive 2003/96/EC expresses to some extent more concretely the favourable impact of the use of biofuels on the taxation. With this Directive the taxation of energy products and electricity within the Community was restructured by extending the nomenclature of energy products taxed with the excise duty from liquid fuels to solid fuels, natural gas and electricity. According to the new arrangement coal and coke are taxed, but other solid energy sources, incl. wood and peat, remain untaxed. New potentials for extending the use of biofuels emerge from the new GHG emission allowance trading system in the European Union (Directive 2003/87/EC).

In spite of a lot of attention devoted to the renewable energy resources, promotion of the use of biomass as an essential renewable resource directly for heat production has had no special consideration. Since 2001 suggestions have been made to develop a document similar to the renewable based electricity directive (*RES-E*) also on heat supply (and cooling) (*RES-H*), but up to now even no draft of the directive has been drawn up. However, production of heat from RES is becoming more actual both in the EU as a whole and in several member states. A certain impact comes from the Kyoto Protocol on reducing the greenhouse gas (GHG) emissions. Along with the need to reduce the growing dependence from imported energy and achieve sustainable development, these are the main driving factors for the use of renewable energy sources in the EU. The latest analysis (Communication of the Commission COM(2004) 366 final) indicated that if the targets set for RES-E production and liquid biofuels are met, the share of RES-E in the EU will reach only 10 % to 2010 instead of the planned 12 %. However, in the practical life, it is not sure whether these goals could be reached and therefore the share of renewable energy may remain even lower if the present development trends continue to prevail.

1.2. Use of biomass and forest resources in the Baltic Sea countries

According to Eurostat the renewables covered 5.7 % of the gross inland consumption in the EU25 countries in 2002. Biomass gave almost two thirds of renewables-based energy (65.4 % or 3.7 % of gross consumption). In almost all of the Baltic Sea countries the share of biomass in the gross inland energy consumption is higher than the EU average while remaining lower of it only in Germany (2.1 %). Traditionally, biomass has been much used in Finland and Sweden. In Finland biomass gives almost one fifth (19.6 %) of the energy and about half of the required heat is produced from wood fuels. In Sweden biomass makes 16.1 % from the total energy demand. In Latvia the share of biomass is the highest (30.3 %), which is the highest percentage in the enlarged EU (EU25).

Table 1.1. Gross inland energy consumption and consumption of renewables and biomass (2002) [2]

Country and abbreviation	Gross inland consumption	Renewables	Biomass	Renewables/ Gross inland consumption	Biomass/ Gross inland consumption	Biomass/ renewables
	Mtoe			**Share**		
Enlarged EU, EU25	1676.9	94.9	62.1	5.7%	3.7%	65.4%
The old EU countries, EU15	1475.4	85.3	53.9	5.8%	3.7%	63.2%
Denmark, DK	19.8	2.5	2.0	12.5%	10.3%	82.5%
Germany, DE	343.7	10.6	7.1	3.1%	2.1%	66.9%
Estonia, EE	5.0	0.5	0.5	10.5%	10.5%	99.9%
Latvia, LV	4.2	1.5	1.3	35.3%	30.3%	85.8%
Lithuania, LT	8.7	0.7	0.7	7.9%	7.6%	95.6%
Poland, PL	88.8	4.2	4.0	4.7%	4.5%	95.0%
Finland, FI	35.1	7.8	6.9	22.2%	19.6%	88.1%
Sweden, SE	51.5	14.1	8.3	27.3%	16.1%	58.8%
The new EU countries, EU 10	201.5	9.7	8.2	4.8%	4.1%	84.8%

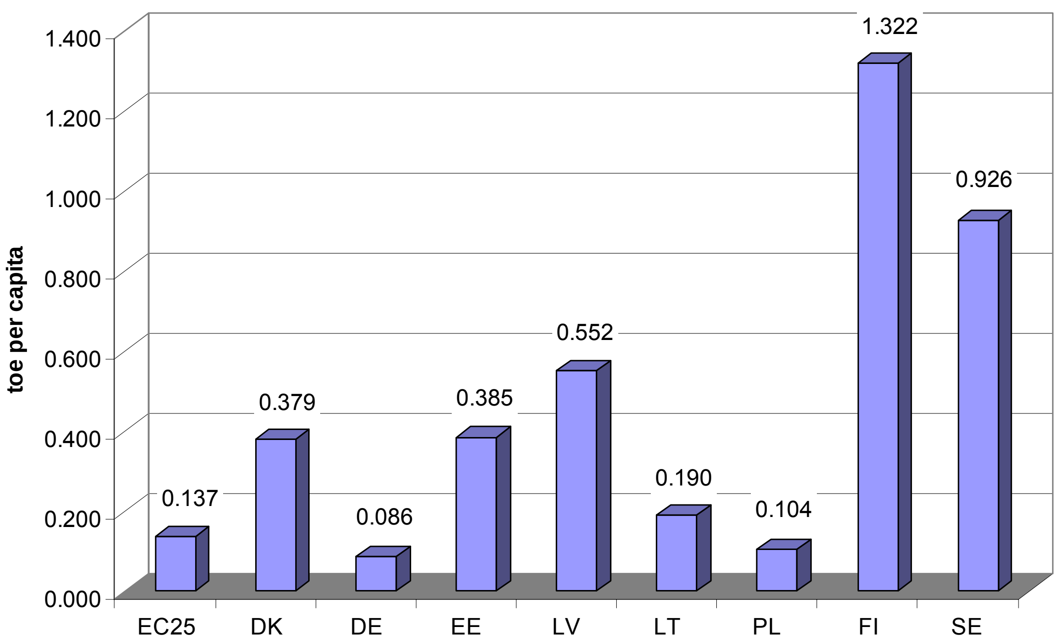


Figure 1.1. Biomass for energy use in 2002 (toe per capita)

Table 1.2. The areas of forest and other wooded land in the EU [3], [4]

Country	Area of forests	Area of other wooded land	Total	Roundwood production (2002)	Roundwood production/ forest area
	1000 ha			1000 m^3	m^3/ha
Enlarged EU, EU25	137 060	23 211	160 271	350 263	2.56
The old EU countries, EU15	113 567	22 637	136 204	264 386	2.33
Denmark, DK	445	93	538	1 446	3.25
Germany, DE	10 740	–	10 740	42 380	3.95
Estonia, EE	2 016	146	2 162	10 500	5.21
Latvia, LV	2 884	471	3 355	13 467	4.67
Lithuania, LT	1 978	72	2 050	6 300	3.19
Poland, PL	8 942	–	8 942	27 170	3.04
Finland, FI	2 1883	885	22 768	53 011	2.42
Sweden, SE	27 264	2 995	30 259	67 500	2.48
Norway, NOR [5]	7 000	5 000	12 000	8 649	1.23
New EU countries, EU10	23 493	574	24 067	85 877	3.66

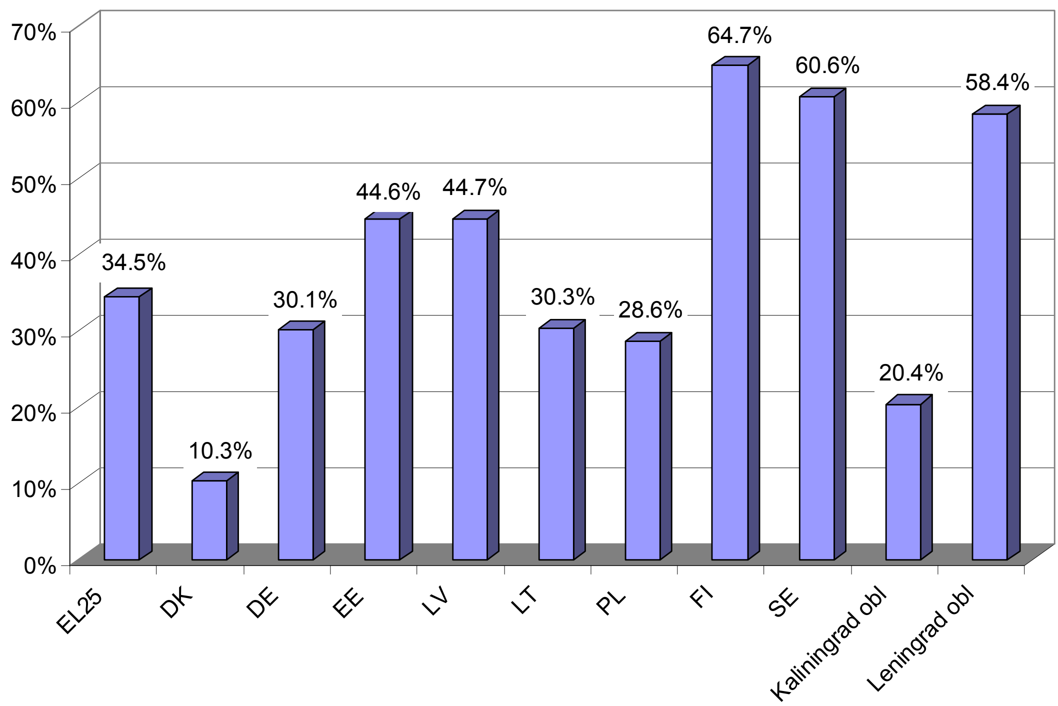


Figure 1.2. Percentage of forested area, 2002 (% of total territory)

1.2.1. Promotion of biomass for energy use

Various measures are used in the EU for promoting the use of biomass. The selection of measures differs by countries and depends on the peculiarities of technical infrastructure, natural resources, industrial traditions, but also on the geographical location and climate conditions, and last but not least, on the political will. The main tools can be classified as follows:

- regulation based on the market mechanism;
- tax exemptions;
- subsidies and grants;
- special financing schemes.

While the market regulation is used only for promoting the renewables-based electricity generation, the tax system enables influencing the use of biomass also. Usually it means either taxation of only fossil fuels or providing tax exemptions to biofuels in case of the differentiated taxation of all the fuels. Also the combination of these two versions is used (e.g., in Austria, Sweden, Germany, Finland). In some cases tax exemptions (for the income tax or VAT) are available for investments in the biofuel sector. The subsidies and grants are usually anticipated as incentives for switching from fossil fuels to biomass. As special financing means mainly soft loans (low interest rate or interest free) are used.

1.2.2. Regional practice and experience

In **Estonia** the biomass made over 99 % of the total renewable energy in 2002. 17.2 % of the fuels used for heat production were wood fuel. About 80 % of wood was used by households and in commercial sector. Approximately 20 % of wood fuels were utilized in district heating and this share is growing. In the commercial sector wood was the main fuel in 900 boilers with the total capacity of 798 MW.

No direct subsidies are available for utilizing biofuels in heat production. Several boiler conversion projects introducing the firing of wood fuels have got subsidies within the framework of international bi-lateral projects (e.g., with Sweden, Finland and Denmark). In the last years the major support has come from Joint Implementation projects and from the EU Structural Funds.

In the Long-term Development Plan for the Energy Sector a target has been set to increase the share of renewables in the primary energy balance to 13 – 15 %. No significant increase of the share of biomass is foreseen, because already today the vast majority of primary energy from the cut fuelwood and waste from wood processing is utilized in energy conversion processes, mostly for heat production. The use of forest residues may increase to some extent. From Estonia almost 500 thousand tons of woodchips are exported annually, mainly as a raw material for the pulp industry. The production of wood briquettes and pellets (total of 210 thous. t/y) is mostly (83 %) exported.

Estonia is rich in peat resources – 1.7 billion t, incl. the exploitable 775 billion t, the permitted rate for extraction is fixed at 2.78 Mt/y. In 2003 1 Mt of peat was extracted, including 362 thous. t for heating purposes: 248 thous. t of milled peat and 114 thous. t of sod peat. 27 % of milled peat and 98 % of sod peat was used in district heating. Also 120 thous. t of peat briquettes was produced, of which 84 % was exported.

In **Lithuania** the share of biomass in the primary energy balance is relatively low – 7.6 %. The annual use of wood fuel makes 3.4 Mm^3. Most of the biomass (70 %) is burnt as fuelwood by households. Only 12 – 15 % of the biomass is used in district heating. The capacity of wood based boilers exceeds 250 MW. Since 1994 woodchips are being produced, and used in bigger (over 1 MW) boiler plants. Wood pellets (over 20 thous. t/y) and wood briquettes (almost 100 thous. t/y) are produced. The peat resources are not significant (117 Mt). The annual peat production is 200 – 400 thous. t, incl. 46 – 85 thous. t of sod peat. In 2003 49 thous. t of milled peat and 18 thous. t of sod peat was used for energy generation. Also peat briquettes are produced – 10 – 15 thous. t per year. A goal has been set to increase the share of renewable energy in the energy balance to 12 % by 2010. According to the present plans, the objective to be reached is the increase in the use of wood fuels by about one fifth by 2010 and utilization of the total potential eligible for energy production (850 thous. toe) by 2020.

Latvia has to import 65 – 70 % of the primary energy sources due to the scarce resources. Therefore, renewables are important from the supply security point of view and for reduction of energy dependence. The share of wood fuels is significant (27 – 28 %) in the primary energy balance. The majority of biomass (56.1 %) is consumed by households. Biomass along with the wind power has gained priority in electricity generation. However, the amount of heat produced from biomass decreased on an average 6 % per year in the period of 1997 – 2001. The production of wood pellets has been started and the production capacity of the plants is reaching 100 thous. tons a year.

The peat resources in Latvia are extensive – the peat bogs cover about 10 % of the territory of Latvia, the total peat reserve being about 1.5 billion t. In the last years 500 thous. t of peat has been extracted yearly, but its share in the primary energy balance is still insignificant making 1.5-2.5 %.

In **Poland** about 5 % of the primary energy demand is covered by renewables, including 95 % of biomass (in 2002). Almost 30 % of Polish territory is covered with forests and this number should start growing, because the wastelands are planned to be afforested. In the energy produced from biomass (solid and liquid fuels, biogas), which made 104.2 TJ, the wood fuel based capacity made 85 %. According to estimations, wood fuels, mostly wood waste, is used in a couple of hundred of district heating boiler plants and in 110 smaller (< 500 kW) boilers. The majority of biomass (over 60 %) is used by households. Lately the production of wood pellets has been started and now the production capacity exceeds 150 thous. t per year. Some foundations have awarded grants to renewable energy projects. In the development plan for the energy sector (2000) an objective has been set to increase the share of renewables in the primary energy balance to 7.5 % by the year 2010 and to 14 % by 2020.

In **Sweden** 16 % of the consumed primary energy came from biomass. Sweden (and Finland) has the longest experience in the use of wood fuels. In Sweden the use of renewables has been promoted for several years. At the governmental level the use of biomass (along with other renewables) has been encouraged. The high taxation level of fuels and energy in Sweden is widely known. The taxes introduced initially for improving efficiency and promoting renewables have become increasingly focused on the environmental protection. The fuels are levied with the energy, CO_2- and sulphur taxes. For example, the CO_2 tax based on the carbon content of fuels is in the range of 95…126 EUR/t CO_2. Biofuels are not taxed and only the sulphur tax is levied on peat.

Biomass makes about 60 % of the used renewable resources and it is mainly used for heat and power co-generation (CHP) in district heating. The use of wood fuel in district heating shows a growing trend – in the 1990-ies the growth was almost fivefold (from 13 PJ in 1990 to 65 PJ in 2001). In 2002 the share of wood was the highest (28 %) among the fuels used for district heating. However, the majority of biomass (almost 60 %) is used for direct heat production, i.e., not in district heating – in Sweden about 400 thousand family houses are wood heated.

The production and use of wood pellets is developing fast. Over 30 manufacturers produce wood pellets: the production capacity is 1.2 Mt/a, annual production about 800 thous. t. In addition 310 thous. t was imported in 2004. The use of pellets is growing rapidly as well: in 2004 the consumption growth was about 100 thous. t, thus reaching the annual level of 1.25 Mt. The pellets are used widely: in small family houses (443 thous. t), district heating boiler plants of average capacity (151 thous. t, 20 % growth in consumption in 2004) and in big CHP plants (656 thous. t).

The peat deposits in Sweden are large and peat is successfully used in energy industry. In 2002 2.9 Mt energy peat was extracted: 1.3 Mt of sod peat and 1.6 Mt of milled peat. The share of peat among the fuels used for district heating was 6.5 %.

In **Germany** the share of biomass in the primary energy consumption was quite low being 2.1 %. The biomass, mainly in the form of wood and wood waste, but also as biogas, is for the most part used by households, which makes 57.1 % of total biomass. Heat production from biomass increased on an average 6.3 % per year in the period of 1997 – 2001. During last years the production and use of wood pellets has started; the pellets are also imported. The amounts are quite insignificant for the time being. Since 1999 investment subsidies are available for the use of biomass in heat production. The expected share of biomass in the primary energy consumption will be 3 % by the year 2010.

In **Finland** biomass is used very widely. Up to the 1990ies the use of wood in district heating was not significant. During last ten years heating with wood has grown several times. The growth has been most significant in CHP plants where now about 30 % of biomass is burnt. In electricity production the share of biomass (about 10 %) is the highest in the EU. In total almost 20 % of the national energy demand is covered by biomass. In 2003, the domestic wood based fuels were used in the amount of 5.1 Mtoe, of which the black liquor made almost a half (47 %), 21.6 % fuelwood and 31.4 % wood waste. In addition 1.7 Mtoe of wood fuels was imported, mostly from Russia, Estonia and Latvia. The use of black liquor in pulp and paper industry constitutes majority of the biomass consumption. The households use about 15 % of the total biomass.

In 1998 the production of wood pellets started. Today there are over 10 wood pellet produces with the total capacity of about 240 thous. t a year. In 2003 173 thous. t of pellets were produced, of which 77 % (134 thous. t) were exported (mainly to Sweden and Denmark). From 39 thous. t of the pellets used in Finland 37 % (14.3 thous. t) was burnt in smaller than 25 kW boilers. According to estimations, wood pellets are used in more than three thousand family houses and the number of customers is growing rapidly. The wood briquettes are produced in some tens of plants and in 2003 the whole production (35 thous. t) was consumed in Finland.

The fast development of biomass has been enabled both by the national energy policy and by encouraging attitude of local governments. The wider use of biofuels has been supported by the taxation based on the CO_2 content of fuels where Finland has been a forerunner: the CO_2 tax was introduced already in 1990. Today the CO_2 tax levied on fossil fuels for heat production is 18.1 EUR/CO_2 t, from which biofuels are exempted. For peat the tax rate is lowered and in case of the annual heat production below 25 GWh the producers are exempted from the tax. In addition, several promotion programmes have been introduced, most of which are related to the regional development and employment. For example, a subsidy up to 40 % of the investment cost from public funds can be applied for a renewable energy project. The state subsidizes wood fuel production at wood harvesting (3.5 EUR/MWh) and manufacturing of woodchips from a young forest (2 EUR/MWh). The well targeted support has given a significant result: during the last couple of years the number of woodchip fired boilers has increased from 300 to 400. Only in 2004 the collection and use of woodchips increased for 600 thous. m^3. The government has supported renewable energy R&D work significantly throughout many years, in particular the R&D on biomass. For example in 2004 the state subsidized the energy sector with 33.5 MEUR in total, including 17.6 MEUR of the subsidies for the use of wood: for wood fuel production 3.4 MEUR and wood-fired energy 14.2 MEUR.

The peat deposits in Finland are extensive: 1.1 billion toe, the peat bogs cover 28 % of the country's territory. The share of peat in the energy balance is 5 – 7 % on an average while varying significantly depending on the weather conditions: in 2000 1.5 Mtoe of peat was used for energy production and in 2004 the amount was 2.4 Mtoe. In district heating (incl. CHP plants) the share of peat among other fuels was 19 %. When up to now peat was mostly used as a basic fuel in peat-fired boilers, during the last years burning of peat and wood mixtures has started to spread more widely. In Finland peat is treated as a slowly renewable biofuel and certain abatements are available for its use.

In the Energy Development Strategy (1999, 2002) a goal has been set to increase the use of renewables by 2010 to 30 % against the year 2001 with raising the share of renewables in the primary energy balance to 27 %. This increase must be reached mostly with the growing use of biomass, thereby the use of woodchips is intended to increase almost threefold.

In **Denmark** much attention was paid on the use of renewables for energy production in the 1980ies and 1990ies. Since 1992 the state supported by subsidies and grants up to 30 % of the investments for the conversion of fossil fuels based boiler plants to biomass fired CHP plants. At the same period the CHP plants in the district heating networks were obligated to burn straw (in total 1.2 Mt/y) and woodchips (0.2 Mt/y). In 2002 12.5 % of the total demand was covered by renewables, the respective share for electricity exceeded even 20 %. The biomass became a prevailing energy source in heat supply, but due to the changes in the energy policy in 2002 and 2003, its share has started to decrease. However, growth is forecasted for the following years. It is characteristic to Denmark that the majority of biomass (63 %) is used for the centralised heat and power cogeneration. The rest is used at end users, of which over 70 % is the wood used in households.

The pellets are also widely used in Denmark. Already in 1991 the consumption exceeded 100 thous. t a year. The development was rapid in 2000 – 2002 when the consumption of pellets increased over 100 thous. t. In 2003 the growth made an exceptional leap with the consumption increasing for 200 thous. tons and reaching almost 600 thous. tons a year. Since the domestic resource is sufficient for manufacturing about 150 thous. t of pellets only, the rest (both as raw material and pellets) is imported from Sweden, Finland, the Baltic countries and even from North-America.

Russia is rich in wood resources. Almost 25 % of world forests are located on the territory of Russian Federation. In Northwest Russia, incl. Karelia the forests cover percentage is the highest.

In the Leningrad Region 4.9 Mha of land belongs to the Forest Fund of Russia and the wood reserve is estimated 865 Mm^3. Presently about 6 Mm^3 of firewood and wood residues are used while one third up to half of the waste is not utilized.

In the Kaliningrad Region the indices are 307 thous. ha and 45.5 Mm^3, respectively. About 12 – 15 % boiler plants in the region are fired with wood fuel. The residues of almost 50 wood processing plants located in the region are used in boiler plants.

In Russia the efficiency of wood utilization is low since only one fifth of the felled forest is processed, majority of wood is exported as raw timber. In energy production fossil fuels are prevailing and only 8 – 10 % of heat is produced from biomass. In the Leningrad Region (incl. St. Petersburg) the share of biofuels in the energy balance makes 2.7 %. Biofuel is used in 232 municipal boiler plants; in 47 boiler plants some preparatory work is being made for the introduction of biomass. In the development plans rapid increase in the share of biofuels is anticipated: targeted to 20 % by the year 2010.

In the last years nine wood pellets plants with the annual production capacity over 120 thous. t have been commissioned in the Leningrad Region.

2. PROPERTIES OF BIOFUELS AND PEAT

In the boiler plants of Baltic Sea countries a wide range of various wood-based fuels are burned. To some extent also straw and other biomass based fuels are used. All these fuels are considered as renewables and according to the international agreement the CO_2 emitted by the combustion of these fuels is not listed as a greenhouse gas.

In the current Manual along with solid fuels also peat is under consideration, which can be provisionally considered a slowly renewable fuel of biological origin. The CO_2 from burning peat is classified as greenhouse gas. Peat is often burned together with woodchips in the same boiler, either alternately or simultaneously, and therefore the differences in the properties of these fuels must be known and taken into account.

From the point of view of combustion technology and practical use of fuels the following properties of fuels are of most interest: chemical composition, moisture, density, fly and bottom ash content, ash melting characteristics and content of impurities (soil, dust, etc.) in the fuel.

2.1. Types of wood fuels

The wood fuels can be classified by the origin of raw material (see Figure 2.1) as fuels from the forest or short rotation forest, and recovered wood.

While fuels from the forest and energy forest can be considered environmentally friendly, the recovered wood fuels surely cannot. They are usually impregnated and painted, contain various impurities (metal, glass, plastic, etc.) and their processing is therefore complicated. Because of these impurities, crushers must be used instead of wood chippers and the requirements to the combustion technology and emissions are also stricter. The use of recovered wood fuel can rather be considered waste utilization.

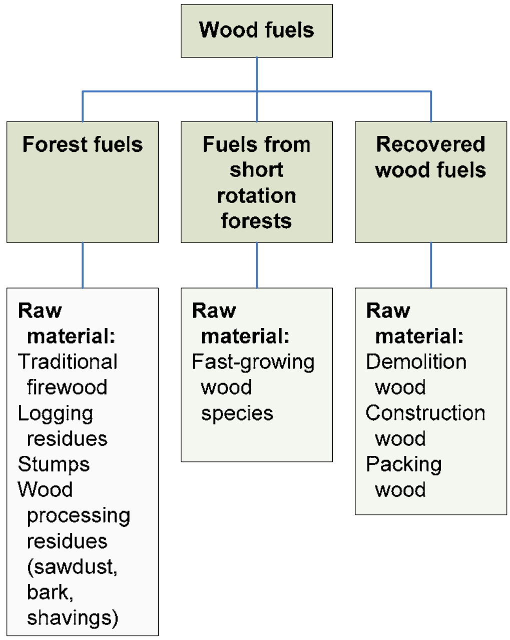


Figure 2.1. Wood fuel classification based on the origin of raw material

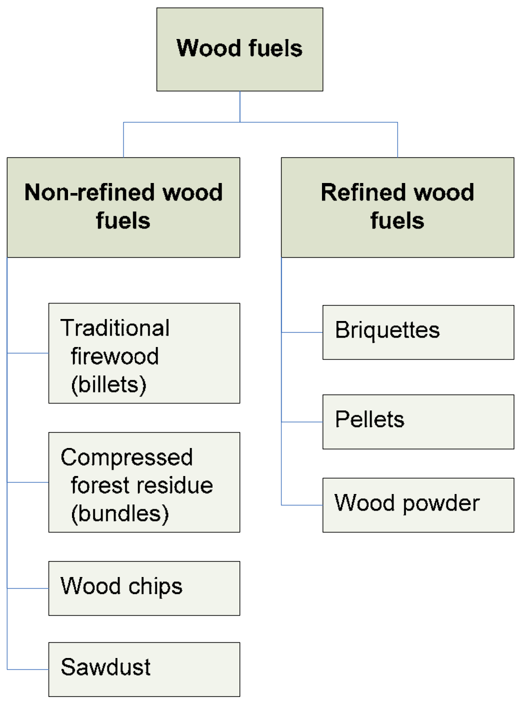


Figure 2.2. Wood fuel classification based on the upgrading level

Another option is classification of wood fuels based on the upgrading level (see Figure 2.2). The non-upgraded fuels are considered the fuels, which have only been shred or packed during processing, but the mechanical properties of which have remained unchanged. The non-upgraded fuels are traditional fuel wood, woodchips, compressed waste wood and wood processing residues (sawdust and shavings). The typical representatives of upgraded wood fuels are wood briquettes and pellets.

2.2. Properties of wood-based fuels

Wood, in particular the shell of wood cells, consists mainly from cellulose, lignin and hemicellulose. Due to the high carbon and hydrogen content, the lignin has higher calorific value than cellulose and hemicellulose. In smaller quantities the wood contains also tar, resins and phenols that can cause fouling of heat transfer surfaces and stack interior with the deposits that are difficult to remove.

2.2.1. Chemical composition, the ash, moisture, dry matter and volatiles content

All solid fuels, including wood fuels, other biofuels and peat consist of combustible and non-combustible parts. Solid biofuels and peat are considered in this Manual. Ash and moisture constitute the non-combustible part of these fuels. Ash and combustible matter together (without moisture) form the dry matter of fuel.

In the ultimate composition three components prevail: carbon (C), hydrogen (H) and oxygen (O), which make together about 99 % of dry matter (see Table 1.1 [6]). The nitrogen (N) content remains usually below 0.2 % and that of sulphur (S) below 0.05 % of dry matter. The sulphur content is of most interest in the fuel from the point of view of emissions. However, higher sulphur content may also impact the flue gas tracts and stack for the low temperature corrosion. Since chlorine (Cl) may also cause the corrosion of heat exchange surfaces, the chlorine content in fuel must also be known. For example, the chlorine content may cause problems when burning the softwood chips as the share of needles in the fuel is significant.

Although the concentration of heavy metals in the wood fuels is not dangerously high, the content could also be taken into account in case the environmental restrictions are rather strict. In the composition of different parts of fuelwood small quantities of nickel, arsenic, cadmium, chromium, copper, mercury, lead and zinc could be found.

Table 2.1. Chemical composition of wood [6], % in dry matter

Element	Wood	Bark
C	48 – 50	51 – 66
H	6.0 – 6.5	5.9 – 8.4
O	38 – 42	24.3 – 40.2
N	0.5 – 2.3	0.3 – 0.8
S	0.05	0.05
Cl	< 0.01	0.01 – 0.03

Several options can be used for expressing the content of ash, moisture, volatiles and fixed carbon[1] in a fuel (see Figure 2.3):

- content in weight percentage of dry matter (d);
- content in weight percentage of moist fuel or total weight of as-received fuel (ar);
- content in weight percentage of dry ash-free matter or combustible matter (daf).

[1] carbon remaining after heating in a standardised manner to decompose thermally unstable components and to release volatiles

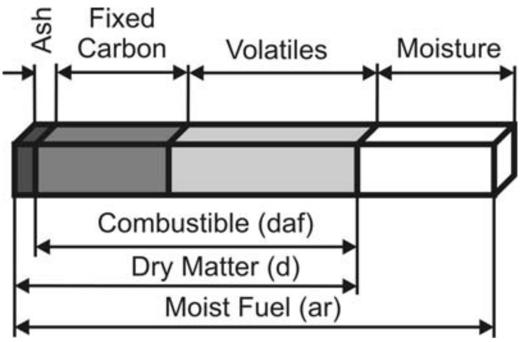


Figure 2.3. Components of solid fuel

As the moisture content of fuel varies a lot, in reference tables the content of ash and volatiles is given on dry matter basis. In practical calculations the moisture content of wet biofuel is expressed on basis of the total fuel mass, i.e. as received basis.

The following relationship is valid between the ash content in the dry matter and that in the as-received fuel [7]:

$A = A_{ar} \bullet 100/(100 – M_{ar})$,

where A is the ash content and M the moisture content.

The moisture content of fuel is determined by drying the fuel specimen in the drying stove at 105±2 °C to the constant weight [8 – 10]:

$M_{ar} = (m_1-m_2)/m_1 \bullet 100$ where

M_{ar} is the moisture content on wet basis, i.e. as-received (%),

m_1 is the weight of as-received fuel specimen,

m_2 is the weight of dried fuel specimen.

Determining the moisture content of fuel is a significant procedure at receiving fuel in the boiler plant, especially when the amount of fuel is established by weighing.

The moisture content in a standing tree remains usually within 40 – 60 % and it depends on many circumstances, incl. the site, tree species, season (higher at the period of growing, lower in winter). In addition, the moisture content in different parts of a tree varies (see Table 2.2). When wood dries, first of all the so-called free water is released and later also the bound water or cell water. With the evaporation of cell water the physical properties of wood start to change. The volume of wood shrinks with drying.

Table 2.2. Moisture content in different parts of coniferous trees [6][2]

	Moisture content in moist fuel, M_{ar}, %	
	Pine	**Spruce**
Stem	45 – 50	40 – 60
Branches	50 – 56	42 – 46
Top	60	60
Bark	36 – 67	38 – 63

Depending on the drying conditions, the moisture content of the wood will reach the saturation point, i.e., the equilibrium moisture content (EMC). In the outdoor conditions the billets dry to the moisture content of about 20 – 25 %. In indoor conditions the wood could be dried to the 8 – 15 % moisture content.

The volatile matter content is determined by a standardised method [11]: a dry fuel specimen is heated at (900±10) °C for 7 minutes. The content of volatile matter (VM) is found from the weight change based on the same principle as moisture content and expressed in weight percentage of dry (d) or dry ash free fuel (daf).

The relationship of volatile matter and bound carbon (C_{fix}) in the fuel determines, which is the share of combustion heat transferred from the flame (in the furnace volume) and which from the fuel layer. Since the volatile matter content of wood and other biofuels is high (VM_d = 80 –

[2] Data from several sources have been summarized in the referred report

90 %), during burning most of the heat is released within the furnace volume and therefore it must be large enough for the complete combustion of volatiles.

The bound carbon is expressed in percents and calculated via the content of volatile matter as a residue of ash-free dry matter after release of volatiles:

$C_{fix,d} = 100 – A_d – VM_d$

$C_{fix,daf} = 100 – VM_{daf}$

$C_{fix,ar} = 100 – A_{ar} – M_{ar} – VM_{ar}$

2.2.2. Calorific value

The calorific value is the amount of heat generated by a given fuel mass when it is completely burned and it is measured with a so-called bomb calorimeter [12]. The higher or gross calorific value and lower or net calorific value (q_{gr} and q_{net}, respectively) can be found via the calorific value measured in the bomb calorimeter.

The higher calorific value is calculated assuming that the water vapour in flue gas both from the fuel moisture content and as a combustion product of hydrogen has completely condensed. The condensation heat of water vapour in flue gases is not taken into account for calculation of the lower calorific value. The higher the moisture content and hydrogen content are, the bigger is the difference between the gross (higher) and net (lower) calorific values.

Mostly, the flue gas is discharged from the boiler to the stack at the temperature of over 100 °C, i.e., at the temperature much higher than the dew-point and under such conditions the condensation energy of water vapour remains unused. For some so-called clean fuels, for example natural gas and wood fuel, 15 – 20 % of additional heat due to water vapour condensation can be gained by cooling the flue gas to about 40 – 60 °C. Thus for “common” boilers the lower (net) calorific value is applied and for the equipment with water vapour condensation the higher (gross) calorific value is used.

In practice, the calculation of boiler efficiency is usually based on the lower calorific value of fuel, but for this value the efficiency of boilers with water vapour condensation may turn out to be even over 100 %! Naturally this is not the case of breaching the energy conservation law, but this is a tradition and agreement that allows comparing the efficiency of different boiler types.

The calorific value is usually expressed in MJ/kg or kJ/kg while the mass can be either that of a moist (ar), dry (d) or dry ash-free (daf) fuel. The calculation formulae for the net (lower) and gross (higher) calorific values are (H_d – hydrogen content by the weight % in dry fuel; calorific value in MJ/kg):

$q_{gr,ar} = q_{gr,d} \bullet (1 – M_{ar}/100)$

$q_{gr,d} = q_{gr,daf} \bullet (1 – A_d/100)$

$q_{net,d} = q_{gr,d} – 2.442 \bullet 8.936 \bullet H_d/100$

$q_{net,ar} = q_{net,d} \bullet (1 – M_{ar}/100) – 2.442 \bullet M_{ar}/100$

$$q_{net,ar} = q_{gr,ar} – 2.442 \bullet \{8.936 \bullet H_d/100 \bullet (1 – M_{ar}/100) + M_{ar}/100\}$$

The calorific value of wood depends on the wood species relatively insignificantly (see Table 2.3) while for some deciduous trees (birch, alder) the calorific value of bark exceeds the respective characteristic of the main wood matter. Using the data from the table and given relationships of calorific values, the expected calorific value of wood fuel can be calculated for each moisture and ash content level at the given conditions.

Table 2.3. Net calorific value of most widely spread wood species, $q_{net,d}$, MJ/kg [13]

Tree species	Stem without bark	Bark	Stem total	Branches and tops	Tree total
Pine (Pinus sylvestris)	19.31	19.53	19.33	20.23	19.52
Spruce (Picea abies)	19.05	18.80	19.02	19.17	19.29
Downy birch (Betula pubescens)	18.68	22.75	19.19	19.94	19.30
Silver birch (Betula pendula)	18.61	22.52	19.15	19.53	19.29
Grey alder (Alnus incana)	18.67	21.57	19.00	20.03	19.18
Black alder (Alnus glutinosa)	18.89	21.48	19.31	19.37	19.31
Aspen (Populus tremula)	18.67	18.57	18.65	18.61	18.65

While in manuals the calorific value is usually given per moist matter weight unit, in boiler plants it is often expedient to use energy density as received, i.e. the fuel energy content could be expressed in energy units per unit used for accounting of received fuel (E_{ar}, MWh/m^3 loose). For example, woodchips (the most widely used wood fuel) are often measured in loose cubic meter. In order to relate the data on the calorific value given per weight unit and energy density given per volume unit, we should know the bulk density of the fuel.

If the energy content of the received fuel is calculated by calorific value and weight of moist fuel, the moisture content should be measured as exactly as possible. The possible inaccuracy in measuring of fuel moisture content may cause significant inaccuracy in calculated energy content of received fuel as well.

In case of typical moisture content of wood fuel (to 50 %) the impact of potential error of moisture measurement on the accuracy of calculated energy per weight of dry mass is significantly less than that per weight of total mass (see Figure 2.4).

When considering the described circumstances, it is worth knowing that the content of dry matter either in the solid cubic meter or in the loose cubic meter of woodchips depends on the moisture content insignificantly. Thus, when measuring the amount of fuel delivered to the boiler house (e.g., woodchips) in loose cubic meters and knowing the calorific value per dry mass (or energy density per loose cubic meter), the energy content of fuel can be defined quite accurately and there is no need for a highly precise definition of moisture content. Thus, weighing the received fuel and defining the moisture content operatively and precisely is not the only possibility for establishing the energy content in fuel and installing expensive weighing equipment on fuel trucks is not inevitable for the correct settling of accounts with fuel suppliers.

The calculation accuracy of the energy content in woodchips per dry mass unit for the moisture content of 35±5 % is less than 1.7 %, the same per total mass unit is 9.24 %.

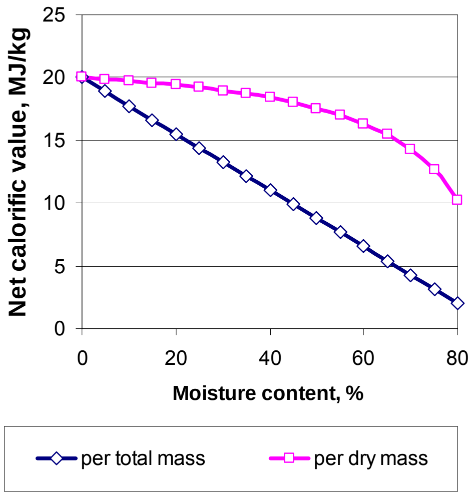


Figure 2.4. Dependence of the net calorific value of wood fuels (as received) on different moisture content

2.2.3. Fusibility of ash

Although the ash content of wood fuel and other solid biofuels is low (to some percents), the fusibility characteristics of ash have direct impact on the boiler performance. The ash melting may cause slagging of the furnace and formation of hard deposits on the convective heat transfer surfaces.

Several standards are available for establishing the fusibility characteristics, incl. ASTM D 1857, ISO 540, and DIN 51730.

With the ASTM standard the changes in the shape of a standard ash cone by burning it in the acidifying (oxidizing) environment are defined (see Figure 2.5):

- 1 – the initial state: before heating the peak of ash cone is sharp;
- IT – initial point of deformation: the sharp peak is rounding;
- ST – softening temperature, the ash cone deforms to such extent that the height of the structure reduces to the size of its diameter (H = B);
- HT – the point of formation of hemisphere or, the cone collapses and becomes dome-shaped (H = 1/2·B);
- FT – flow temperature, the liquid ash dissipates along the surface.

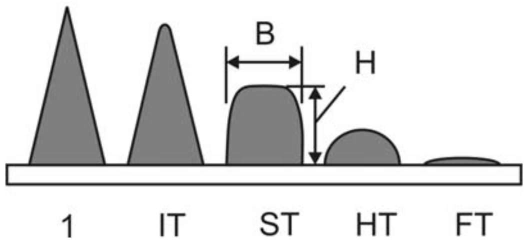


Figure 2.5. Fusibility characteristics of ash

The fusibility characteristics of wood ash may vary extensively depending on tree species, site of growth, impurities in the wood fuel (e.g., soil), and also the differences in the ash from different parts of tree are essential. According to different references, the fusibility characteristics of wood ashes vary within the following limits [6]:

- beginning of deformation (initial temperature) IT = 1150 – 1490 °C;
- softening temperature ST = 1180 – 1525 °C;
- the point of hemisphere formation HT = 1230 – 1650 °C;
- flow temperature FT = 1250 – 1650 °C.

Table 2.4 [6] shows the fusibility characteristics of some fuel ashes. While for bark the softening temperatures of ash are usually rather high (over 1500 °C), and as a rule, do not cause slagging of the grate, for sawdust and woodchips the softening temperatures are considerably lower. Therefore, the combustion regime must be carefully monitored in order to avoid the slagging problems.

Table 2.4. Fusibility characteristics of wood ash [6]

Fuel	Values of melting characteristics, °C			
	IT	ST	HT	YP
Woodchips total, pine	1210	1225	1250	1275
Slashings	1175	1205	1230	1250
Sawdust, pine	1150	1180	1200	1225
Bark, spruce	1405	1550	1650	1650
Bark, pine	1340	1525	1650	1650

Fusibility of ash depends on its mineral composition and even minor differences in the composition may change the fusibility characteristics significantly. According to the fuel and ash composition, the fusibility characteristics cannot be reliably predicted in practice.

If a boiler plant must use the fuels with unknown fusibility characteristics of ash, application of express analysis methods may be expedient, which are intended to be standardized in the future [14]. The method is test burning of a small amount of fuel (2 kg) on a clean grate. After the test slagging is checked either visually or by a simple empirical method. Since in practice, due to the low ash melting temperature, slagging on the grate is a serious problem, introduction of the simple express method in the lab of the boiler plant may allow using of problematic fuels after testing. Earlier these fuels were rejected due to the fear of possible slagging.

2.2.4. Volume and bulk density of fuels

Usually the main characteristics of solid fuels are determined per mass unit (on wet or dry basis), but the amount of many solid biofuels and peat are measured in volume units and therefore it is expedient to present certain properties of these fuels (in particular the energy content) per volume units.

As many medium and small scale boiler plants measure the received fuel (wood chips) amounts by volume, the bulk density of woodchips is especially important to know. It is worth knowing that the accuracy of determination of energy density (heat content per volume unit) depends less on the accuracy of fuel moisture content than determination of heat content per total mass of the fuel.

The dry matter content of fuel as received per unit of mass does not depend much on the moisture content. At the same time, the heat content per dry mass is less dependent on the moisture content than the heat content per total (as received) mass of fuel (see Figure 2.4 and section 2.2.2).[3]

The volume of fuel as received is expedient to be measured from the volume and filling level of the fuel truck container before unloading. It should be noted that during transportation the load density may increase to some extent, i.e., the bulk density of fuel after loading on the truck is to some extent smaller than at the arrival in the boiler house.

For establishing the bulk density of fuel a box (container) with typical sizing could be used. It should be weighed before and after filling with the fuel. According to the VTT recommendations (ENE38/24/97 [6]), a 125-litre box sized 0.5 x 0.5 x 0.5 m should be used. As the box (container) is not shaken or vibrated while using the

[3] The statement is valid for the typical moisture content of fuel, i.e., to the moister level of 60 – 65%.

container method, the bulk density of fuel is a bit lower than that of the fuel delivered in the trucks.

For measuring the bulk density in different situations several standards can be applied: ASTM E 1109, DIN 517052, ISO 1013 and ISO 567, in addition the CEN standard is being developed [15].

In statistics the amount of timber and wood fuel is usually given in solid cubic meters. When using this unit, it is important to know the density of wood matter (density of the fuel as received ρ_{ar}, kg/m^3 solid).

2.3. Straw and its characteristics

Along with wood based fuels, another solid biofuel group fired in boiler plants is straw and energy grass harvested from the agricultural land. Several other types of biomass can be grown by farming, which are mostly used for converting into liquid biofuels or gas. As the production and practical implementation of other solid fuels of agricultural origin are still in the phase of testing, only straw as a fuel is considered in this book.

In the Baltic Sea countries wheat, rye, barley and oats are grown and the straw of these crops can be used as a fuel. In some countries (e.g., in Sweden) the grain of these crops has also been burned. The latter is related to the state subsidies available to farmers whose unsold excess crop can be used this way. Since as a rule, the grain is not grown for later burning the crop, it is not expedient to advertise burning of crops and burning of crops is not considered in this Manual.

The ultimate composition (see Table 2.5) and calorific value of the dry matter of straw does not differ much from the respective indices of wood, although the calorific value is a bit lower (see Table 2.6). Considering the typical moisture content of straw (it should remain below 20 %), the calorific value of straw is rather higher than that of woodchips (the typical moisture content of woodchips is 35 – 55 %).

Table 2.5. Ultimate composition of the dry matter in straw [6]

Content of elements in dry matter, %	**Interval**	**Average**
C	45 – 47	46
H	5.8 – 6.0	5.9
N	0.4 – 0.6	0.5
O	39 – 41	40
S	0.01 – 0.13	0.08
Cl	0.14 – 0.97	0.31

The properties of straw depend highly both on the site, time of growing and weather conditions at the time of growing as well as on the soil quality and fertilizing. For example, the chlorine content in the straw of early harvested crop (the so-called yellow straw) is up to 4 times higher than that of late harvested straw while the maximum Cl content reaches even 0.97 % and this exerts strong impact on the corrosion of heating surfaces.

The volatile content in straw varies in the range of 60 – 70 %, which is to some extent lower than that of wood-based fuels. The ash content in straw is high compared to wood fuels – the ash content of dry matter remains within 4.5 – 6.5 %. At the same time the fusion temperature of straw ash may be significantly lower than that of wood-based fuels (see Table 2.7). Softening of the straw of rye, barley and oats begins at very low temperatures (735 – 840 °C). This must be considered when selecting the combustion technology and combustion regime of the furnace.

Table 2.6. Ash content and net calorific value of the straw of different crops [6]

Crop	Ash content of dry matter, A_d, %	Lower calorific value of dry matter, $q_{net,d}$, MJ/kg	Lower calorific value of fuel as received at the moisture content of 20 %, $q_{net,ar}$, MJ/kg
Rye	4.5	17.0	13.6
Wheat	6.5	17.8	13.8
Barley	4.5 – 5.88	17.4	13.4
Oats	4.9	16.7	12.9
Straw on average	5.0	17.4	13.5

Table 2.7. Fusibility characteristics of the straw of different crops [6]

Crop	ST, °C	HT, °C	FT, °C
Wheat	1050	1350	1400
Rye	840	1150	1330
Barley	765	1035	1190
Oats	735	1045	1175

The most significant problem related to the practical use of straw is small bulk density, which for the uncompressed straw is only 30 – 40 kg per loose cubic meter and that makes the storage and transport of straw expensive. Straw is mainly supplied as compressed big bales.

At harvesting the moisture content of straw is usually 30 – 60 %, but for the combustion the moisture content must be less than 20 %. Although during the storage period the humidity of straw drops by 2 – 6 %, the moisture content of straw during harvesting should not exceed 25 %. The straw with higher moisture content must be dried before storage or in the storage space. Drying avoids self-heating and suppuration of moist straw in the storage.

2.4. Peat properties

Peat is an organic deposit formed from the accumulation of decomposed remains of plants in the oxygen-poor environment of excess water. Peat consists mainly of partially decomposed remains of plants and humus. The most essential indices of peat are decomposition degree, moisture content, mineral (ash) content, density and calorific value.

Although peat is of biological origin, it is not considered a renewable biofuel usually, but a slowly renewable fuel of biological origin. The CO_2 emitted to the atmosphere during its combustion is accounted as a greenhouse gas (GHG) similarly to fossil fuels.

The degree of decomposition of the organic material in peat (degree of humification) is usually expressed in the linear 10-point von Post humification scale and denoted H1 – H10. Thereby H1 is morphologically almost intact and H10 is the material in which the original structure of the material cannot be distinguished by the naked eye.

The peat fuel is usually older peat with a higher decomposition degree where the vegetation structure cannot be discerned at all or only to some extent.

The main types of peat fuel are the milled peat (see Figure 2.6), sod peat (see Figure

2.7), peat briquettes and peat pellets. Chapter 3 (see section 3.7) gives a brief introduction of the production technologies of these fuels.

The typical composition of fuel peat is the following [6]:

- ash content 4 – 6 %;
- content of fixed carbon (C) in dry matter 23 – 31 %;
- content of volatiles in dry matter 65 – 70 %;
- moisture content in the fuel as received:
  - in the milled peat on average 48 %,
  - in the sod peat on average 35 %,
  - in peat briquettes on average 10 %.

The peat structure and properties depend highly on the decomposition degree (see Table 2.8 and Table 2.9, [6]).

Figure 2.6. Milled peat

Figure 2.7. Sod peat

Table 2.8. Impact of humification degree on the composition of peat fuel as received, in weight percents [6]

Components	**Poorly decomposed (H1 – H2)**	**Moderately decomposed (H5 – H6)**	**Well decomposed (H9 – H10)**
Cellulose	15 – 20	5 – 15	-
Hemicelluloses	15 – 30	10 – 25	0 – 2
Lignin	5 – 40	5 – 30	5 – 20
Humus	0 – 5	20 – 30	50 – 60
Bituminous matters	1 – 10	5 – 15	5 – 20
Nitrogen-rich substances (reduced to content of protein)	3 – 14	5 – 20	5 – 25

Table 2.9. Impact of humification degree on the ultimate composition of dry matter in peat, in weight percents [6]

Decomposition degree	Content of chemical elements in dry matter, %			
	Carbon, C	Hydrogen, H	Nitrogen, N	Oxygen, O
Poorly decomposed (H1 – H2)	48 – 50	5.5 – 6.5	0.5 – 1	38 – 42
Moderately decomposed (H5 – H6)	53 – 54	5.0 – 6.0	1 – 2	35 – 40
Well decomposed (H9 – H10)	58 – 60	5.0 – 5.5	1 – 3	30 – 35

Peat belongs to the humus-based fuel formation series (land plants – peat – lignite – coal – hard coal) and when comparing the fuels of this series, we can see that the carbon content in the fuel increases with the rise of decomposition degree, which is naturally applicable to peat as well (see Table 2.9). Some properties of poorly decomposed peat make its use as a fuel complicated. The poorly decomposed peat is hygroscopic and may be damped by air humidity, its low bulk density and compressibility cause difficulties to conveyer transport and combustion. Hence, as we mentioned above, well decomposed peat is used as a peat fuel.

The ash fusion characteristics of peat (see Table 2.11) are a bit lower than the respective characteristics of wood. The ash content and properties of ash depend on the bog type, conditions of peat formation and amount and properties of impurities (sand) in it. Thus the data in the table need to be updated for each specific peat.

Table 2.10. Average values of the characteristics of milled peat and sod peat according to the VTT data [6]

	Moisture content, M_{ar}, %	Ash content, A_d, %	Volatile content in dry matter, %	Calorific value $q_{net,ar}$, MJ/kg	Bulk density, kg/m^3	Energy density, $q_{net,ar}$, MWh/m^3
Milled peat	48.5	5.1	68.6	9.6	341	0.89
Sod peat	38.9	4.5	68.9	11.9	387	1.27

Table 2.11. Ash fusion characteristics according to the data of VTT and Vapo [6]

	Ash fusion temperatures (min – average – max) °C,		
	Softening point	Hemisphere point	Flow point
Milled peat (VTT)	1100 – 1130 – 1190	1200 – 1253 – 1375	1205 – 1290 – 1430
Sod peat (VTT)	1040 – 1136 – 1335	1145 – 1273 – 1415	1175 – 1308 – 1490
Sod peat (Vapo)	1130 – 1218 – 1340	1160 – 1252 – 1380	1180 – 1292 – 1470

2.5. Quality certificates and classes for solid fuels

Presently the European Committee for Standardization (CEN) is organizing elaboration of specifications for several solid biofuels. With the specifications they try to standardize:

- terminology and definitions;
- specifications and quality classes for fuels;
- fuel sampling;
- determination of mechanical and physical properties.

The need for the implementation of specification requirements results from the extending use of solid biofuels and international trading of several fuel types. The fuel quality classes facilitate the buyer and seller communication and concluding agreements since both parties must use the same terms defined in specifications and show all the required characteristics of the fuel.

Here is a brief description of specifications and quality classes for biofuels [16], [17].

2.5.1. Basis of solid biofuel classification

The classification of solid biofuels starts with determining the origin of fuel based on which the biofuels are grouped:

- wood-based biomass;
- herbaceous biomass;
- fruit biomass;
- blended biofuels and biofuels with additives.

In the Baltic Sea countries a wide variety of wood-based biofuels and some herbaceous biofuels (mostly straw) are in practical use.

The wood-based biomass represents a biomass from wood and shrubs harvested either from the forest or plantations (energy forests), recycling biomass, etc. (see Figure 2.1).

Both wood-based and herbaceous fuels can be chemically processed and contain impurities and chemicals that have influence on the properties of the fuel. For example, in recycled wood the impurities could be nails, metal parts of electric cables, resins and glues, etc. (in the demolished wood). The content of such impurities must be classified with high accuracy based on the danger they may constitute to the environment.

The biofuels are produced, marketed and used in quite various traded forms, the typical examples of which are given in the Table 2.12.

Depending on the type of biofuel, the fuels are classified in two categories based on:

- normative or obligatory indicators;
- informative indicators, which are recommended to be given, but they are not obligatory.

The indicators used for the classification of the properties of fuels (either normative or informative) can be (see Table 9.3 – Table 9.9):

- the origin and source of fuel;
- traded form (see Table 2.12);
- moisture content of fuel as received (M_{ar});
- ash content of fuel (A);
- distribution of the fuel particle size (P);
- density of the fuel particles (DE);
- bulk density of fuel (BD);
- mechanical durability of pellets (DU);
- carbon (C), hydrogen (H) and nitrogen content (N) of fuels;
- content of water soluble chlorine (Cl), sodium (Na) and potassium (K);
- total sulphur content (S) and chlorine content (Cl);

- content of chemical elements (Al, Ca, Fe, Mg, P, K, Na and Ti). This croup contains elements, the content of which is higher than the usually known level;
- content of microelements (As, Cd, Co, Cr, Cu, Hg, Mn, Mo, Ni, Pb, Sb, Se, Sn, V and Zn). The content of these chemical elements is low, but determination might be required due to environmental restrictions.

Table 2.12. Typical examples of traded forms of biofuels

Fuel	Typical particle size	Common preparation method
Briquettes	Ø > 25 mm	Mechanical compression
Pellets	Ø < 25 mm	Mechanical compression
Fuel powder	< 1 mm	Milling
Sawdust	1 mm – 5 mm	Cutting by sharp tool
Wood chips	5 mm – 100 mm	Cutting by sharp tool
Hog fuel	Varying	Crushing by blunt tool
Logs, billets	100 mm – 1000 mm	Cutting by sharp tool
Bark	varying	Debarking residue from trees. Can be shredded or unshredded
Small straw bales	0.1 m^3	Compressed and bound into quadrangular bales
Big straw bales	3.7 m^3	Compressed and bound into quadrangular bales
Round straw bales	2.1 m^3	Compressed and bound into cylindrical bales

2.5.2. Some examples of fuel classification

For classifying the most frequently used biofuels, the majority of fuel quality indices are split into classes within which the respective fuel characteristic may vary in limits insignificant for the user. For example, the class M20 of woodchips moisture content shows that the moisture content of fuel as received must not exceed 20 %. The next moisture class M30 defines the moisture range of 20 % – 30 % for the fuel as received. The same principle is used to denote other fuel characteristics. (see Table 9.3 – Table 9.9).

Each consumer group and type of combustion equipment needs or prefers fuels with certain characteristics. It is necessary or expedient that the smaller the combustion unit is, the higher must be the quality of fuel for this unit.

In general, for household users the characteristics of high quality wood briquettes and pellets should be the following (see Table 2.14 and Table 2.13 [16], [18])

Table 2.13. The characteristics of high quality wood pellets for household users

Origin	Chemically untreated wood excluding bark
Moisture	M10 (< 10 %)
Mechanical durability	DU97.5 (> 97.5 % of the pellet weight must remain intact in testing)
Amount of fines	F1.0 or F2.0 (amount of fines (< 3.15 mm) less than 1 % or 2 %)
Dimensions	D06 or D08 (the pellet diameter 6±mm and length less than 5 diameters or the pellet diameter 8±mm and length less than 4 diameters). Up to 20 % of pellets weight may have the length of 7.5 diameters.
Ash content	A0.7 (< 0.7 %, dry basis)
Sulphur content	S0.05 (< 0.05 %, dry basis)
Additives	< 2 %, dry basis. Only products from the primarily agricultural and forest biomass that are not chemically modified are approved to be added as pressing aids. Type and amount of the additive has to be stated
Net calorific value	E4.7 (> 4.7 kWh/kg = 16.9 MJ/kg

Table 2.14. The characteristics of high quality wood briquettes for household users

Origin	Chemically untreated wood excluding bark
Moisture	M10 (< 10 %)
Density of briquettes	DE1.0 (1.00 – 1.09 kg/dm^3, dry basis)
Dimensions	According to the Table 9.4
Ash content	A0.7 (< 0.7 %, dry basis)
Additives	< 2 %, dry basis. Only products from the primarily agricultural and forest biomass that are not chemically modified are approved to be added as pressing aids. Type and amount of the additive has to be stated
Net calorific value	E4.7 (> 4.7 kWh/kg = 16.9 MJ/kg)

The requirements of DH boiler plants and other bigger fuel consumers to the fuel properties depend on the peculiarities of the combustion equipment, conveyers and storages. For example, as a rule, for a household user fuel should be as dry as possible, but in the boiler plant a boiler furnace might be constructed presumably for moist fuel.

A very important factor of non-upgraded natural wood fuels is the distribution range of fuel particle size, which is represented in the name of the traded form. The particle size and its distribution define both the combustion technology and particularly the construction of fuel feeders.

The typical specification of woodchips delivered to the DH boiler plants could be considered the class P45 where the distribution of particles in the fuel would be the following:

- fine fraction – particles with the size to 1 mm form less than 5 % of the fuel mass;
- main fraction – particles with the size in the range of 3.15 mm ≤ P ≤ 45 mm form 80 % of the fuel mass;
- coarse fraction – less than 1 % of the particle mass may contain particles with the size over 63 mm.

As deviations of the content of both fine and coarse fractions influence the work of fuel conveyers and the combustion conditions in the furnace, both fine and coarse fractions are determined in the fuel specification (see Table 9.3).

2.5.3. Classification of peat fuel

Classification of peat fuel is in principle similar to that of solid biofuels, except the difference in the fuel origin and partially in traded forms. The most widespread traded forms of fuel peat are given in Table 2.15 [19].

In addition to the data on the supplier, name and signature of the responsible person, date and place of signing, the peat fuel quality certificate must include the table with normative and informative parameters of the fuel.

2.6. Fuel sampling and defining quality

The fuel quality assessment must be carried out according to the agreed standards and procedures briefly described above in the section 2.2. Although, the amount of fuel for determination its properties might be quite small, a small fuel specimen must reflect the average characteristics of bigger fuel amounts (e.g., load of a big truck). That is why the fuel samples must be taken in several spots, which might have different characteristics; the samples have to be mixed and divided into smaller portions so that the final specimen would be a representative sample and the analysis results could be transferred to the total fuel quantity [20].

Table 2.15. Major traded forms of fuel peat [19]

Fuel name	Typical shape and particle size	Common preparation method
Briquettes	Diameter or the smallest particle size > 25 mm	Mechanical compression
Pellets	Ø < 25 mm	Mechanical compression
Sod peat	Ø < 80 mm, cylindrical	Cutting, forming, air-drying and turning, harvesting, storage
Milled peat	Ø < 25 mm	Milling, air-drying and turning, harvesting, storage
Peat mixtures with wood based or herbaceous biomass	Varying	Crushed wood mixed with peat, straw or other herbaceous biomass

3. PRODUCTION OF SOLID BIOFUELS

3.1. Distribution of biomass in the forest, technological and environmental restrictions to the fuel production

3.1.1. Distribution of tree biomass

In Estonia the forest management is usually dealing with the commercial timber resources (saw logs, pulpwood, traditional fuel wood) and does not pay attention to logging residues, although from the point of view of power engineering it is a very valuable raw material. The distribution of tree biomass and energy potential of logging residues has been thoroughly investigated in Finland. The data given in Figure 3.1 show that the tops, branches, stumps and roots make an essential part of tree biomass.

The use of traditional firewood for energy purposes has started to decrease. There are several reasons for that: the minimum diameter of wood for pulp industry and sawmills has decreased and the same raw material is being used in the panel industry and for charcoal production. At the same time various other wood processing facilities, where smallwood is refined have emerged. Therefore, alternative options should be looked for in power engineering, the most perspective of which is the use of logging residues. The possibility to harvest wood for heating emerges already by cleaning, but even bigger amounts are available by thinning and (regeneration) final felling. So for example the data on the forests in South-Finland show (see Table 3.1) that throughout the whole rotation period logging residues can be collected 155 – 310 m^3/ha.

Although roots and stumps make a significant part of tree biomass, their collecting has not been expedient up to now, because of excess energy cost. The last year studies in Finland have shown that they could still be a significant supplement to the traditional resources of firewood. Figure 3.2 shows the data on the calorific value of stumps. Based on the data, the energy content of stumps harvested from 1 ha of forest land is estimated about 140 – 160 MWh.

	Distribution of biomass, %			
	Pine		Spruce	
Stem	100	69	100	59
Top, branches	23	16	45	27
Stumps, roots	22	15	24	14
Total	145	100	169	100

Figure 3.1. Distribution of wood biomass in final fellings [21]

3.1.2. Technological and environmental restrictions for fuel production

During the last years in the wood fuel production certain attention has been paid to the loss of minerals at taking the biomass out of the forest. Since distribution of minerals in different parts of wood varies, the loss of minerals can be influenced with the selection of technology. The respective Danish data is shown in Table 3.2. The data in the table allow the following conclusion: if the logging residues are dried before chipping and the foliage and needles fall off, the loss of minerals will decrease significantly. An additional measure for compensating the loss of minerals is taking the ashes of burnt wood back to the forest. The wood ash contains tiny amounts of heavy metals (Cd 0 – 0.08 g/kg of ash, Pb 0.02 – 0.6 g/kg of ash) and therefore the ashes cannot be taken back to the forest in big amounts [22]. It is recommended to take the ashes back to the same place where the logging residues were collected.

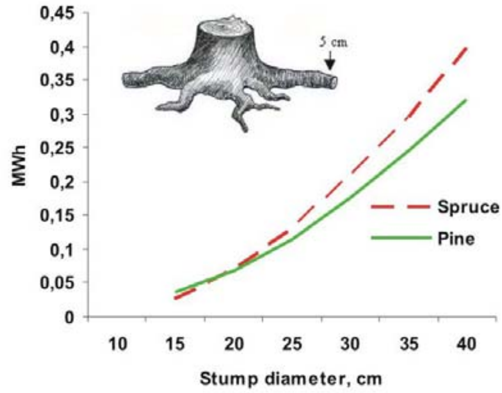


Figure 3.2. The heating value of stump-root system depending on the stump diameter [21]

Table 3.1. Biomass yield of coniferous forests in southern Finland [21]

Felling type	**Stand age, years**	**Yield of timber, m^3/ha**	**Logging residues**	
			m^3/ha	**toe/ha**
Cleaning	10 – 20	–	15 – 50	3 – 9
1st thinning	25 – 40	30 – 80	30 – 50	6 – 9
2nd thinning	40 – 60	50 – 90	20 – 40	4 – 8
3rd thinning	50 – 70	60 – 100	20 – 40	4 – 8
Final felling	70 – 100	220 – 330	70 – 130	13 – 24
During the rotation period		360 – 600	155 – 310	30-58

Table 3.2. Loss of minerals during the 70-year rotation period in case of different technologies [22]

	N	**P**	**K**	**Mg**	**Ca**
Loss of minerals, kg/ha					
Stems	170	54	205	23	234
Chipping with pre-drying	214	58	213	26	259
Chipping of green trees	252	61	230	30	294
Increased removal of nutrients, %					
Chipping with pre-drying	26	7	4	13	11
Chipping of green trees	48	13	12	30	26

3.2. Technologies and equipment for wood fuel production

The traditional firewood (billets) is mainly used by households where it is a prevailing type of biofuel. No changes have taken place in the production technology of firewood billets. Up to now the firewood logging operations in farm forests have mostly been a manual operation with the chainsaws. The logging machines (harvesters) have been introduced in the regeneration felling where the firewood is cut together with commercial timber. In the last years use of integrated machines for cross-cutting, splitting and loading billets can be noticed as a new trend. The equipment for this use will be introduced in section 3.3.

The development of woodchips production technologies has been remarkably rapid. A push for the rapid development in this field was caused by the oil crisis of the 1970-ies. The industrial countries which depended on oil had to revise their resources of renewables and develop technologies for the biofuel production. The logging residue was a type of fuel that had not been used before and was introduced only then, especially in Sweden and Finland. As a result of long-term R&D work, woodchips production technologies (both from whole trees and logging residues) have been developed. The implementation of tree-section technology (harvesting of commercial timber and firewood in the same system) was **not** successful.

3.2.1. Whole tree chips

At the cleaning of young forest great quantities of wood material is generated that cannot find industrial use, but can be used as firewood. At thinning the maturing forest also the amount of commercial timber may be so small that it is more expedient to use all the cut material for producing woodchips. The woodchips made of such undelimbed whole trees are called whole-tree chips [23]. The technology outline is given in Figure 3.3.

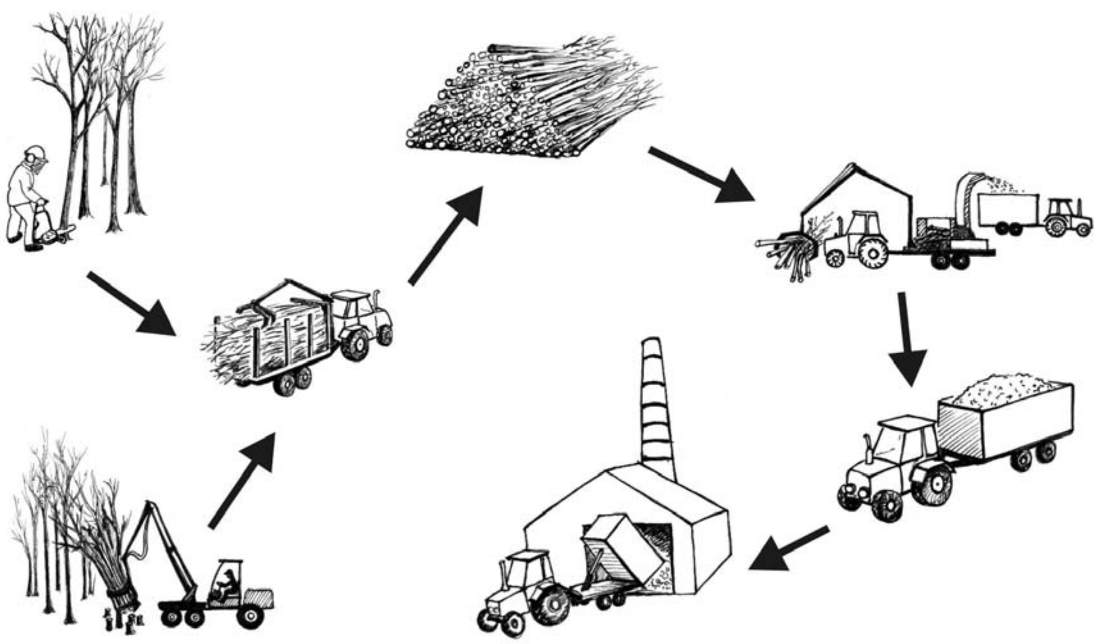


Figure 3.3. Whole tree chipping technology

In farm forests the thinning is usually a manual operation, either by a clearing saw or power saw. In order to mechanise the work and improve efficiency in large-scale production units, an accumulating felling head foreseen for bunching the cut smallwood is being installed on harvesters (see section 3.3.4). Cutting is done by a guillotine cutting blade. For thinning also a chipper-forwarder can be used where the grapple of the loader is replaced by a cutting head (see Figure 3.4). This allows to use one machine for cutting and extraction of whole trees.

Figure 3.4. Cutting and bunch skidding of whole trees at thinning, photo by P. Muiste

The whole trees can be collected manually, but in case of larger volumes forwarders or other logging tractors are used. The hauled material can be chipped either fresh (see Figure 3.5) or stored in piles (see Figure 3.6) and chipped when there has developed a demand for woodchips. Wood storage in big piles provides lower moisture content, and thus a higher calorific value. When drying, the foliage and needles drop off and the loss of minerals in the forest decreases.

Figure 3.5. Whole tree chipping, photo by P. Muiste

Figure 3.6. Stored undelimbed smallwood, photo by P. Muiste

3.2.2. Woodchips from logging residues

Compared to the harvesting of commercial timber, at collecting the logging residues the following aspects must be considered:

- the bulk density of residues is small and the residues are distributed all over the felling area. That makes the haulage and processing of the residues labour consuming, the respective equipment is expensive;
- due to the low energy content, the transport is expensive and economically feasible trucking distance limited.

Due to these aspects the total logistic chain must be designed very carefully in order to reduce the production cost. To begin with, an appropriate site and option for chipping the logging residues must be established. The most frequently used technologies are (see Figure 3.7):

1. chipping of logging residues in the cutting area;
2. chipping of logging residues at the roadside storage;
3. transport of unprocessed logging residues and chipping in the terminal;
4. baling of logging residues.

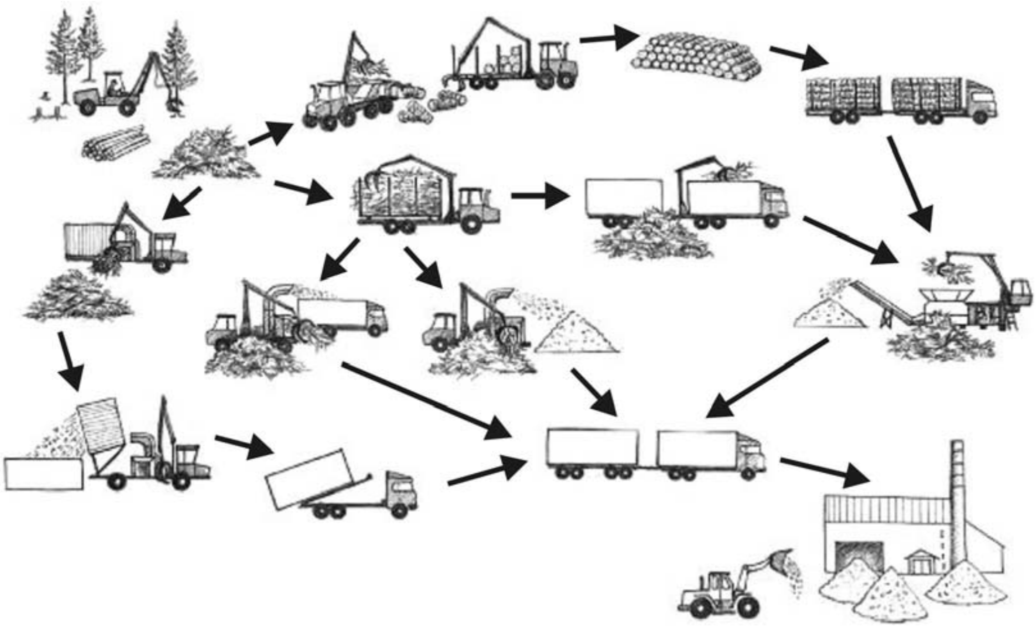


Figure 3.7. Production of woodchips from logging residues

If after regeneration cut the logging residues have to be collected, it should be taken into consideration already during the cutting process. In the cutting areas with the soft soil the cutting should be planned for the winter period in order to avoid the need to use the mats of branches for improving the carrying capacity of forest roadways (see Figure 3.8). If it has been done, it is not expedient to haul logging residues from such a cutting area, because instead of wood chippers, crushers should be used for refining the material mixed with soil and stones and the quality of the fuel produced from this material would not meet the requirements.

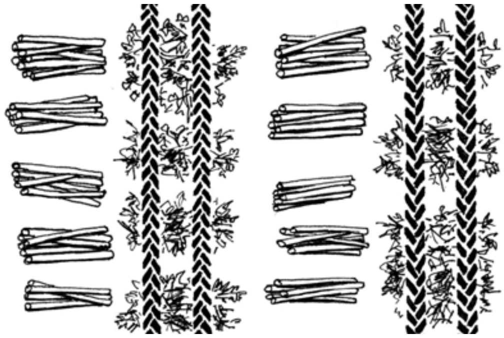


Figure 3.8. Use of logging residues for branch mats on the haulage roadways [24]

It is not necessary to use the logging residues for branch mats on the soils of high carrying capacity and the woodchips can also be produced. It is easier to gather logging residues if harvester is used and the delimbed branches and tops are piled or heaped along the haulage roadways (see Figure 3.9).

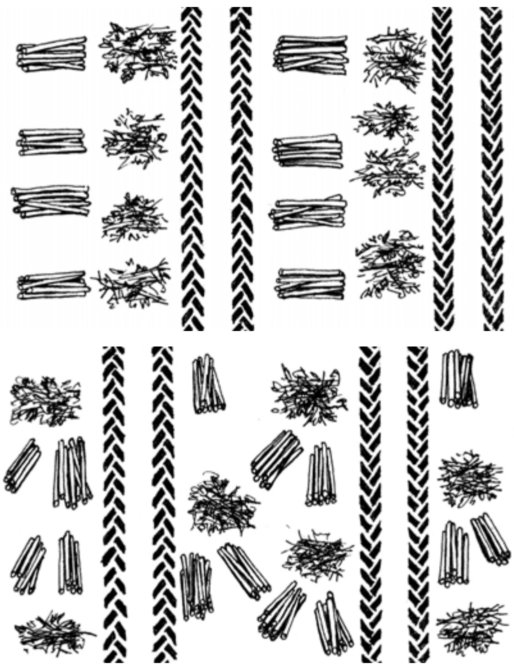


Figure 3.9. It is recommended to store delimbed branches separately during cutting operations

3.2.2.1. Wood chipping in the cutting area

For chipping in the cutting area a mobile chipper is used (see Figure 3.10 and Figure 3.12). The chipper container needs to be lifted high and tilted to dump the chips into the truck body (see Figure 3.11). When using trailer-trucks (see Figure 3.13), the transport of woodchips can be organized independent from the collection and thus the waiting time of the truck driver can be shortened. The woodchip trailer-trucks are more expensive compared to the traditional trucks adapted for the transport of woodchips, but for the high cost of labour power this alternative is reasonable.

Figure 3.10. Collection and chipping of logging residues with a mobile chipper-forwarder Chipset 536C, photo by P. Muiste

Figure 3.11. Dumping of the container of mobile chipper, photo by P. Muiste

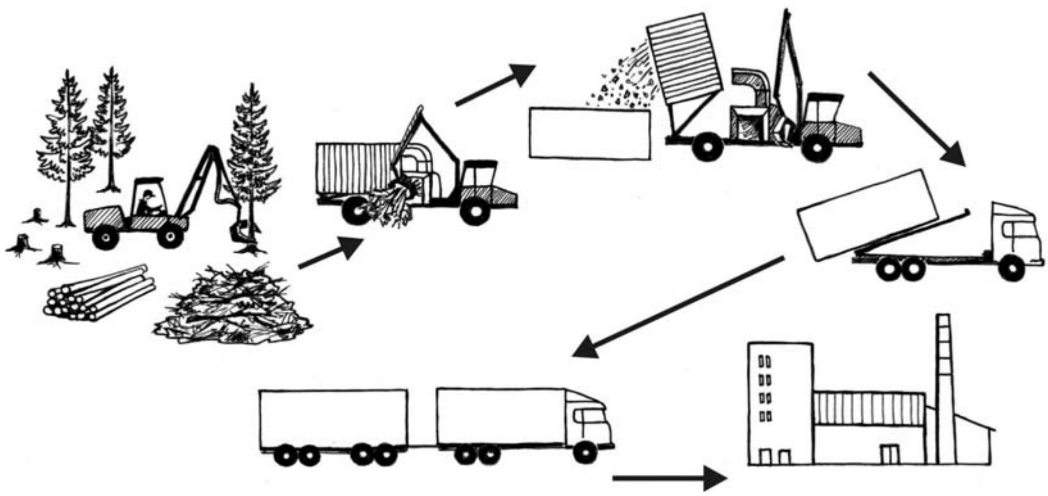


Figure 3.12. Haulage and chipping of logging residues in the cutting site with a mobile chipper-forwarder, transport with a woodchip trailer-truck

Figure 3.13. Lifting of the filled container on the truck, photo by P. Muiste

Chipping in the cutting site was widely spread up to the mid 90ies, but now it has become less common, because chipping and baling at the roadside landing has proved to be more productive and efficient. For example in Sweden the share of the former method has dropped to 10 % [25]. The mobile chippers used for collecting logging residues in the cutting area are very expensive vehicles. Since most of their working time is used for moving and collecting logging residues, it would be less expensive to do this work by traditional logging tractors (forwarders). For improving the production rate, the mobile chippers are bigger today, but at the same time less manoeuvrable and heavier. Therefore they could be used on Estonian soft soils only in winter. When chipping in the cutting area the fresh branches and tops are chipped and therefore the moisture content of such woodchips is high.

3.2.2.2. Chipping of wood at the roadside landing

In the Nordic countries the most wide-spread method is chipping at the roadside landing (see Figure 3.14), the share of which reaches 80 % in Sweden [25]. This method could be considered the most appropriate in the conditions of Estonia too. In this case a traditional forwarder (the load space of which has been enlarged for the better use of the carrying capacity) is used for collecting the logging residues (see Figure 3.15 and Figure 3.16). The logging residues piled in high bunches at the roadside and covered with waterproof tarred paper will be chipped with a mobile chipper next winter (see Figure 3.17, Figure 3.18 and Figure 3.19) and then transported in a special truck for logging residues (see Figure 3.20). If the trucking distance from the roadside landing to the end user is short, it may become expedient to install a chipper on the woodchips trailer-truck (see Figure 3.14b).

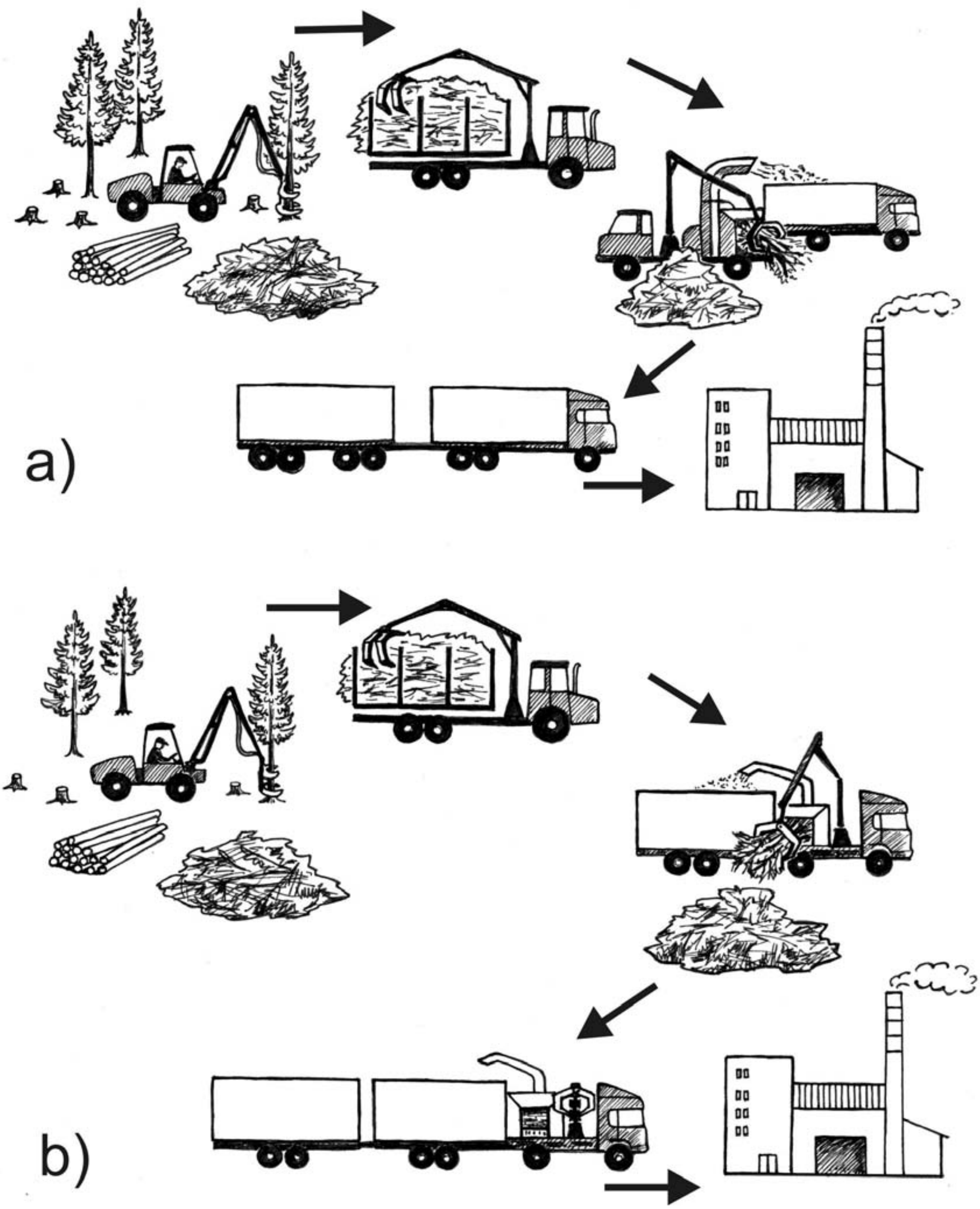


Figure 3.14. Roadside chipping of logging residues

a) Haulage of logging residues with a forwarder, chipping at the roadside landing with a mobile chipper and transport with a special trailer-truck

b) Haulage of logging residues with a forwarder, chipping at the roadside landing with a mobile chipper and transport with a chipper trailer-truck

Figure 3.15. Haulage of logging residues in the cutting area, photo by P. Muiste

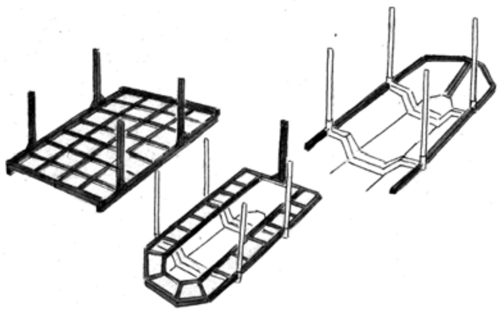


Figure 3.16. Some options for adapting the forwarder for the haulage of logging residues [26]

Figure 3.17. Storage of logging residues, photo by P. Muiste

Figure 3.18. The logging residues stored under waterproof paper, photo by P. Muiste

Figure 3.19. Chipping of logging residues, photo by P. Muiste

Figure 3.20. Woodchips transport with a trailer-truck, photo by P. Muiste

3.2.2.3. Chipping of logging residues in the processing terminal at the user

When processing logging residues in the terminal at the user, it is possible to use highly efficient stationary electric drive equipment that makes the chipping process less expensive. In big terminals the fuel quality could be better checked and the produced fuels can be separated by fractions. The haulage of logging residues to the terminal may be either as unprocessed residues (see Figure 3.21 [22]) or compressed into bales (see Figure 3.22).

In the first case the logging residues are hauled with a forwarder and transported on the road with special vehicles. Since the bulk density of logging residues is low, the carrying capacity of trailers cannot be fully utilized. For the compaction of the load, the trucks are equipped with hydraulic grapples, which allow compacting the branch mass. Since in the Nordic countries the use of bigger trailer-trucks with the total weight of 60 tons and length up to 24 meters is permitted, often the transport of unprocessed logging residues is economically feasible. However, this method has not been widely used. For example, in Sweden the share of it is less than 10 %. According to the standards valid in most of the EU countries, the total permitted weight of a trailer is 40 tons and length 18.35 meters. Therefore, the transport of unprocessed logging residues is often not feasible.

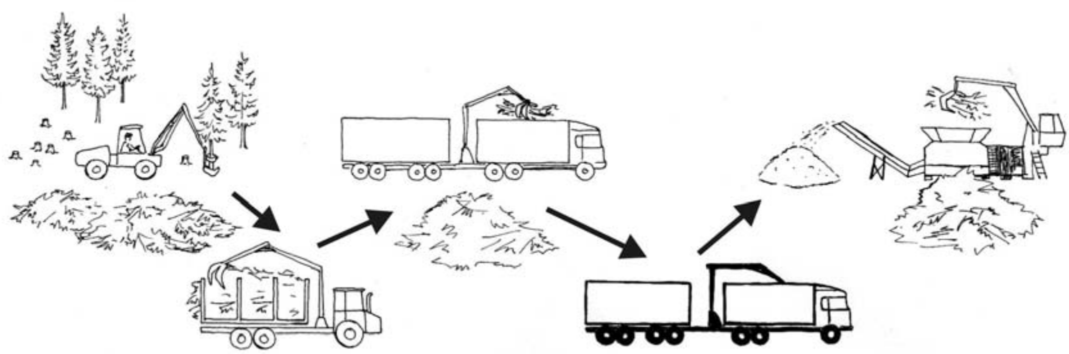


Figure 3.21. Transport with a trailer-truck

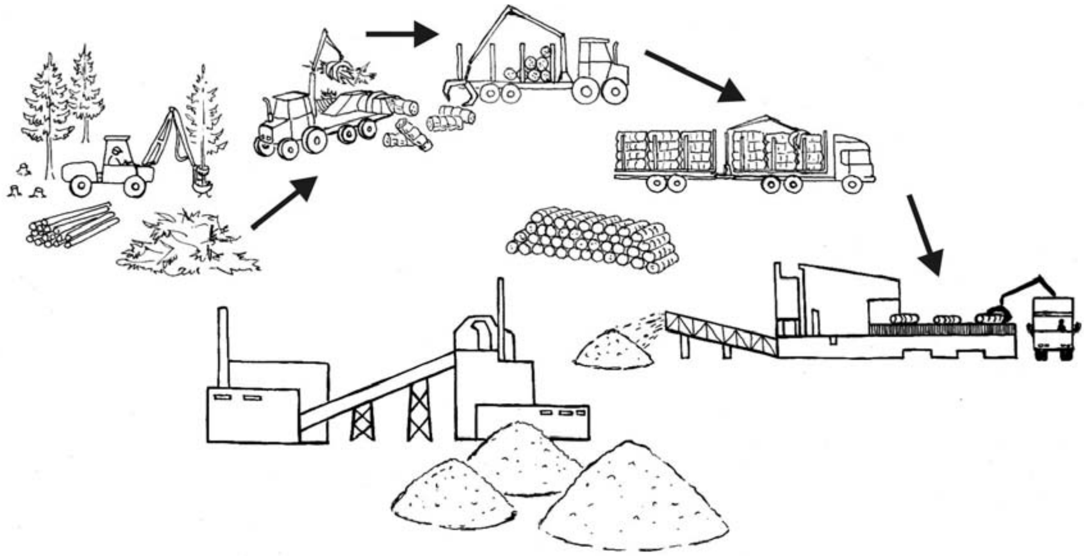


Figure 3.22. Baling of logging residues, haulage with traditional forwarders and logging trucks, chipping in the terminal

A new technological solution for the transport of logging residues is compacting of the mass before transportation (see Figure 3.22). The base for the logging residues baler is usually a forwarder to enable baling the residues directly in the cutting area. Compared to other technologies this one has a number of benefits:

- the existing forwarders and logging trucks can be used for transporting the bales of branches;
- the bales of branches can be easily stored and dried and they are available around a year;
- storage of the bales of branches in the terminal at the user reduces the damage from pests and fire;
- for chipping the bales of branches high efficiency stationary chippers can be used;
- well-organized logistics allows expanding the harvesting area to 200 km (in Sweden it is for woodchips 60 – 75 km [25]).

The resource unexploited to the present day is roots and stumps, the use of which may become economically feasible due to the increasing fuel prices. Excavators are used for stump rooting, forwarders for haulage and closed box trucks for the road transport. For the comminution of raw material crushers must be used instead of chippers, because the impurities like pebbles and soil may damage the chipper blades. The impurities cause also fuel combustion problems, as the ash content increases and the furnace grate slagging might occur.

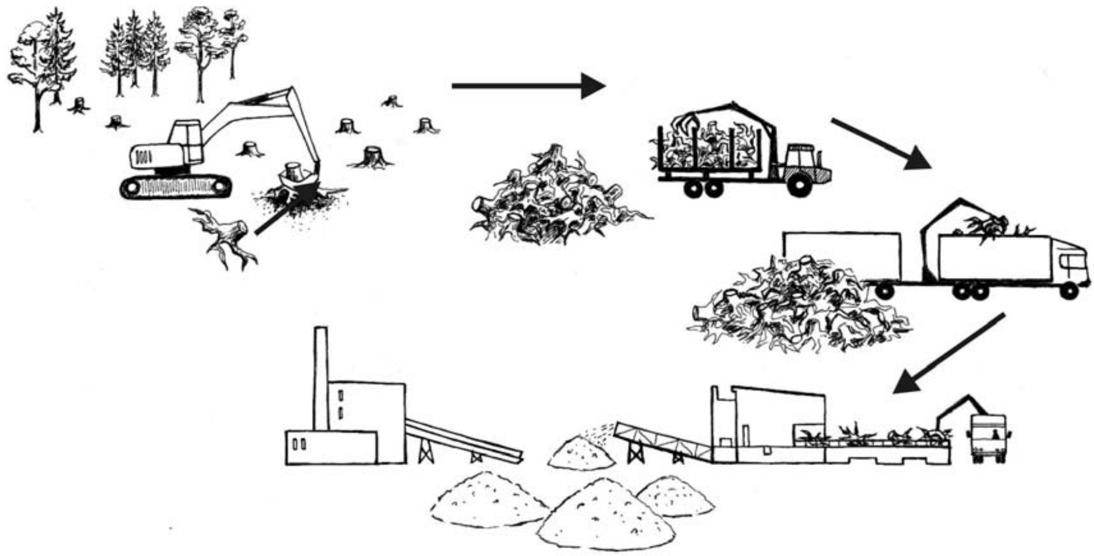


Figure 3.23. Stump rooting and haulage with a forwarder, transport with a special truck and crushing in the terminal

3.2.3. The tree-sections and the whole tree technology

In the 1980ies the part-tree technology and whole-tree technology were tested (see Figure 3.24 and Figure 3.25) with the objective to bring a saw log, pulpwood and firewood out of the forest by one integrated operation method [27]. In the first case the felled stems were cross-cut into sections of appropriate length with a chain saw or harvester. In the second case no cross-cutting was done. Different from traditional cutting, the felled trees were not delimbed and the final processing took place in the interim storage or terminal. Traditional forwarders were used for wood haulage in the forest. For the road transporting, trucks of special construction with a box opening to the side were needed. The main advantage of this technology was cost efficient raw material processing, as in the terminal less expensive electric motors could be used instead of internal combustion engines. It was quite complicated to follow the commercial wood processing quality standards in the terminal and it was the main disadvantage of this method. Another problem under the conditions of most of the EU countries (except Finland and Sweden) would be the restriction to the vehicle weight and length. It raises the transport cost of tree sections and prohibits the transport of long logs.

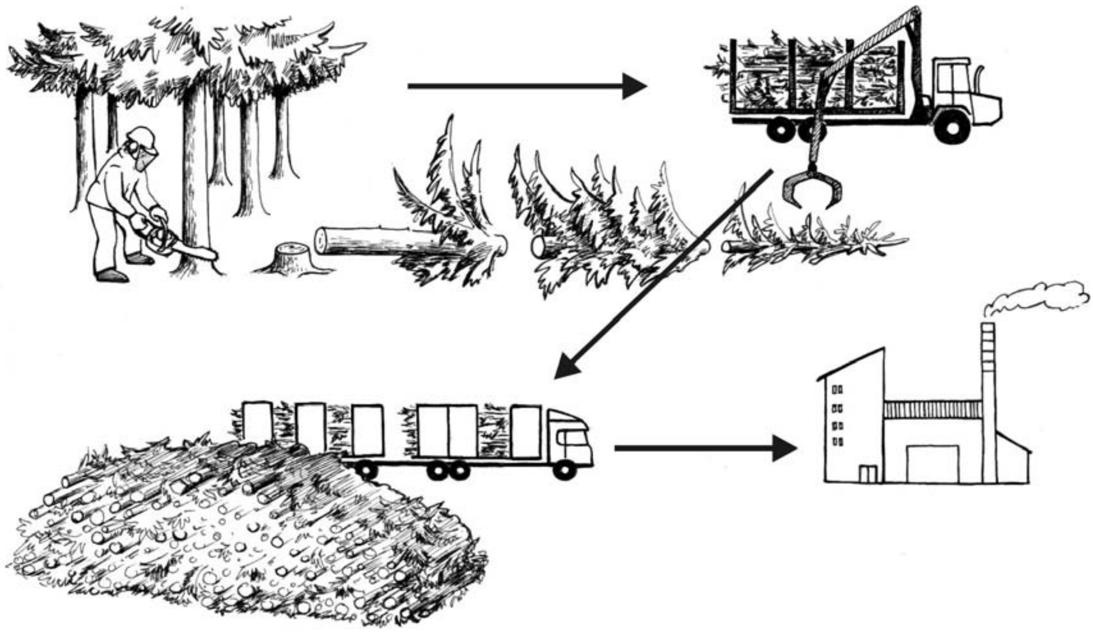


Figure 3.24. The part-tree technology

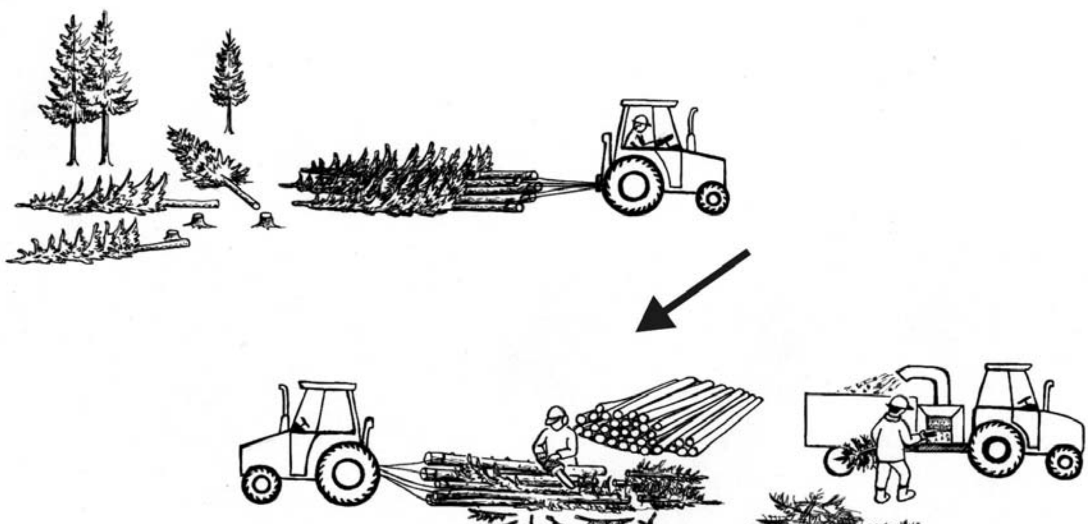


Figure 3.25. The whole-tree technology

3.3. Machinery and equipment for the production of wood fuels

3.3.1. Wood chippers and crushers

The wood chipping is an important operation that defines the type of all the technology in the production chain and it influences the woodchips price formation significantly. The product range of chippers is wide. The chippers might be equipped with different drives and could be mounted on different vehicles.

3.3.1.1. Operation principles

For chipping of wood three types of chippers are used: disc chippers, drum chippers and screw chippers. Hammer mills, roll splitting and crushing devices, jaw crushers, etc. are used for crushing the wood containing impurities (soil, pebbles, nails, etc.). These, mainly stationary units are used in large-scale production. Different from chippers, the material processed by crushers is of non-homogeneous size and form.

The disc chipper. The operative part of disc chipper is a massive and well-balanced steel disc (see Figure 3.26 and Figure 3.27), on which 2 to 4 blades are fixed radially. With regulating the blade distance from the anvil the chip size can be changed within 12 – 35 mm. The material is conveyed to the blades at a small angle, or if the disc is tilted, horizontally. The woodchips are removed by a fan and blowing pipe. The tree stems are fed in the chipper either manually or by a manipulator. The advantages of disc chipper are simple construction, low cost and low energy consumption. Therefore, it is the most wide spread chipper in farm forests. Since the cutting angle is fixed, the size of the produced woodchip is more uniform than for other chippers. A disadvantage is its sensitivity to impurities and large size (with a small feeding hole).

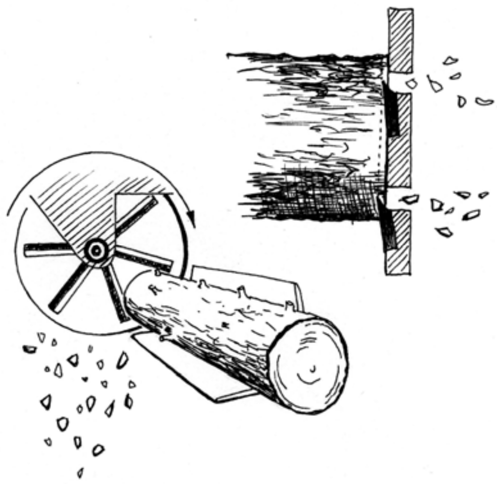


Figure 3.26. A disc chipper

Figure 3.27. The operative part of a disc chipper, photo by P. Muiste

The drum chipper. The operative part of the chipper is a rotating drum equipped with blades (see Figure 3.28 and Figure 3.29). The material is fed from one side, usually with the feeding rollers or chain conveyor and the woodchips are removed by a fan and blowing pipe. Similar to the disc chipper, the drum chipper provides chip size changing options by adjusting the distance between the anvil and blades.

An advantage of the drum chipper is a big feeding hole in spite of the small size of the chipper. The disadvantages include sensitivity to impurities and high price. Compared to the disc chipper, the energy cost of drum chipper is 50 to 75 % higher and the chips size might be rather different, because the cutting angle depends on the diameter of the stem. The drum chipper is a better tool for shredding logging residues than a disc chipper.

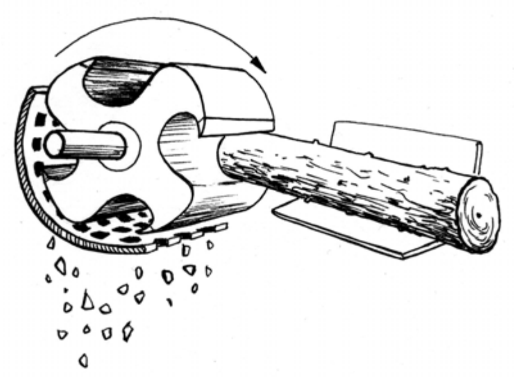


Figure 3.28. A drum chipper

Figure 3.29. The operative part of a drum chipper, photo by P. Muiste

The screw chipper. The operative part is a rotating screw blade that acts as a feeder (see Figure 3.30), which is equipped with hard alloy blades at the edges. Simultaneously with cutting the screw blade pulls the material through the chipper and it is especially convenient to use for manual feeding. The chip size depends on the shape of the operative part. The woodchips produced with a screw chipper are of non-uniform size and generally coarser than the ones produced with either a disc or drum chipper. Special devices are needed for sharpening the blades.

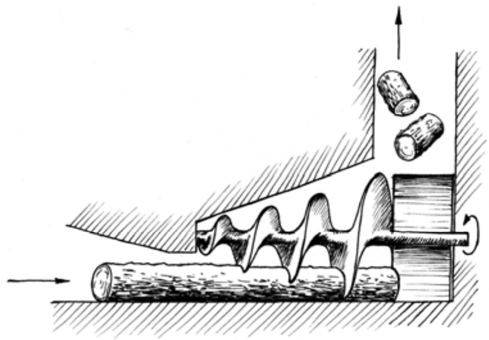


Figure 3.30. A screw chipper

The wood crushers. The demolition wood from buildings can also be used as a fuel, but due to the impurities (soil, pebbles, metal and glass), chippers cannot be used for the shredding of such wood. For the shredding of such material, crushers of different operation principles are used. The most wide spread are hammer mills, roll crushers and jaw crushers (see Figure 3.31 – Figure 3.33). Differently from chippers, these units produce the crushed wood of non-homogeneous size and shape. The units are of high capacity and expensive and therefore economically feasible only for large-scale production.

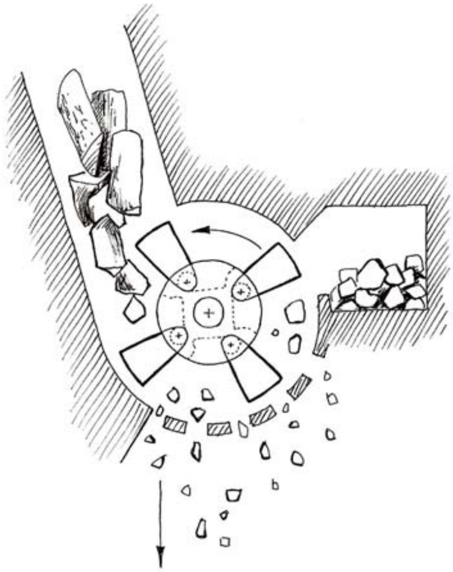


Figure 3.31. A hammer mill

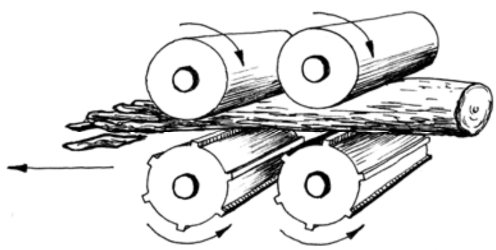


Figure 3.32. A roll crusher

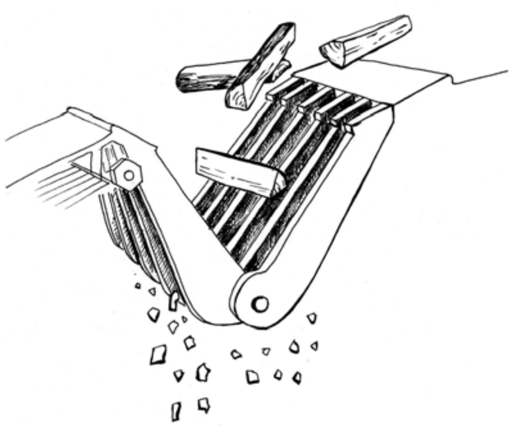


Figure 3.33. A jaw crusher

3.3.1.2. The chipper drives

Depending on the function and capacity of a chipper, different drives can be used. The power transmission for low-capacity equipment comes usually from the tractor power take-off shaft. For bigger ones a separate engine is used to drive the chipper and such a device could be mounted either as a fixed unit or on different base vehicles, for example, a forwarder or a truck. All the machines from small manually fed chippers to the modern mobile chippers have their own field of use. When selecting the unit, the amount and quality of raw material, technology to be used, the woodchip quality requirements, logistics, need for reorganization, etc. must be considered.

For the use in farm forests, simple manually fed chippers driven by the tractor power take-off shaft are better suitable (see Figure 3.34).

Figure 3.34. A disc chipper driven from the power take-off shaft of an agricultural tractor Junkkari HJ 10 [28]

Technical specification: capacity 4 – 10 m^3 chips per hour; power demand 25 – 80 kW; diameter of the chipped tree up to 30 cm; chip size 10 – 30 mm.

In large scale production, the use of mobile chipper-forwarders could be economically feasible. Usually, an old forwarder may be used as a base, and on that base a chipper of suitable capacity can be mounted (for example Bruks 604CT or Bruks 804CT, see Figure 3.35). A more expensive solution is a mobile chipper-forwarder of special design (see Figure 3.36 – Figure 3.38).

Figure 3.35. A mobile chipper-forwarder, photo by P. Muiste

Figure 3.36. A mobile chipper-forwarder, Silvatec 878 CH [29], photo by P. Muiste

The capacity of the unit 205 kW; disc diameter 1200 mm; feeding hole 350 by·350 mm; container volume 16 m^3; reach of hydraulic arm 6 m.

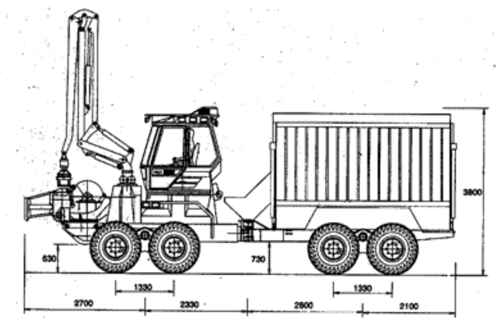


Figure 3.37. A mobile chipper-forwarder Chipset 536 C [30]

The capacity of the unit 223 kW; maximum stem diameter 350 mm; container volume 15 m^3; capacity 60 m^3/h; reach of hydraulic arm 8.3 m.

Figure 3.39. A combine as a base vehicle [31]

The capacity of the unit is 185 – 370 kW, drum diameter 600 mm, feeding hole 690 by 350 mm, capacity 50 – 80 m^3/h, reach of hydraulic arm 7.5 m.

Figure 3.38. A mobile chipper-forwarder, Erjofanten 7/65, photo by P. Muiste

Figure 3.40. An excavator as a base vehicle of chipper, photo by P. Muiste

Also, old grain crop combines (see Figure 3.39), excavators (see Figure 3.40) or trucks (see Figure 3.41) can serve successfully as base vehicles of the chippers for chipping logging residues in the cutting area or at the roadside. A special modification of the latter is a trailer-truck adapted for container transport and equipped with a chipper (see Figure 3.42).

Figure 3.41. A chipper mounted on the Giant truck [32]

The capacity of the unit 403 kW; drum diameter 900 mm; width of feeding hole 1400 mm; production capacity 120 – 200 m^3/h; reach of the hydraulic arm 10 m.

Figure 3.42. The Moha trailer-truck equipped with a chipper [32]

The most powerful chippers mounted on trailers are with capacity up to 300 m^3 per hour (see Figure 3.43).

Figure 3.43. The disc chipper Morbark mounted on a trailer 30 [33]

The capacity of the unit 600 kW; maximum stem diameter 760 mm; disc diameter 2100 mm; 3 blades.

3.3.2. The baling machine of logging residues

The development of packing equipment for logging residues was started in Sweden and one of the results of this work was Fiberpac 370 (see Figure 3.44). No demand developed for this machine in Sweden, but there was a demand in Finland where the use of woodchips was growing. Therefore, the rights for the technology were bought by Timberjack and as a result of development work, a comprehensive modification Timberjack 1490D (see Figure 3.45) has reached the phase of series production. Also, other producers have shown interest in the baler, but their interest is mostly focused on mobile equipment. For example, Pinox 330 [34] and Valmet WoodPac (see Figure 3.46) can be easily mounted on a forwarder frame and this allows using the base vehicle both for wood haulage and baling logging residues. The capacity of these machines is 10 – 30 bales of logging residues per hour.

Figure 3.44. The Fiberpack 370 at the exhibition of Elmia Wood 2001, photo by P. Muiste

Figure 3.45. The Timberjack 1490D [35]

Figure 3.46. The Valmet WoodPac [36]

Figure 3.47. The baled logging residues, photo by P. Muiste

The bale weight 400 – 600 kg; length 3.1 – 3.2 m; diameter 700 – 800 mm and calorific value 1 MWh.

Figure 3.48. A simple logging truck-trailer can be used for the transport of baled logging residues, photo by P. Muiste

3.3.3. Chopping machines

The billets are still the main fuel for ovens, fireplaces and stoves in rural areas. Splitting wood can be a pleasant way of spending time and a physical exercise, but stocking firewood in bigger amounts for winter is a hard physical job. A man tries to make his work easier in any possible way and for this purpose various machines for chopping logs have been invented.

The choppers with a splitting screw are of the simplest design and lowest price. The chopper is three-point mounted to a tractor toolbar and driven from the power take-off shaft (see Figure 3.49). The split log length can reach 0.7 meters and according to the literature. The average splitting capacity of the chopper is 2 m^3 an hour. An electric motor could be used as a drive as well.

Figure 3.49. Wood chopper combined with a debarker [37]

Quite often the chopper is combined with a disc saw or chain saw (see Figure 3.50). Hence, such a device enables making billets in the forest.

Figure 3.50. The log chopper Hakki Pilke Eagle with a splitting screw and disc saw [38]

The choppers with a hydraulic drive are of the same productivity, but more convenient to use (see Figure 3.51). However, these choppers are more expensive than splitting screw choppers.

Figure 3.51. Choppers with a hydraulic drive [39]

Also, log splitters/cutters foreseen for the simultaneous cross-cutting, splitting and loading of firewood on the tractor trailer are used (see Figure 3.52). The assembly is fixed on the tractor toolbar and driven from the tractor power take-off shaft. The transmission must be equipped with a safety coupling. Considering the high productivity and high price, it is not expedient to buy such a machine to satisfy the needs of only one farm. However, the payback period will be very short when it is used for preparing the commercial firewood.

Figure 3.52. The combined log splitter/cutter Japa 2000 [40]

Hydraulic chain saw and hydraulic wedge; the maximum log diameter 300 mm; maximum log length 600 mm; power demand 7.5 kW, capacity 7 – 14 m^3/h

3.3.4. Accumulating felling heads

When thinning a young forest, a lot of wood material is produced. It cannot be used as a raw material in wood processing industry, but could be utilised as a fuel. The accumulating felling heads have been developed (see Figure 3.53) for bunching the cut smallwood. This unit can cut and bunch automatically up to 10 stems that improves the efficiency of cleaning significantly. The cutting tool of such a felling head is a guillotine-blade instead of a chain saw.

3.4. Impact of storage conditions on wood fuel quality

Wood fuel quality depends on storage conditions significantly. The Swedish data [26] on logging residues and woodchips is given in the following tables (see Table 3.3 and Table 3.4).

Figure 3.53. The accumulating shear heads Timberjack 720 and Timberjack 730 [35]

Table 3.3. Quality variation of logging residue depending on the storage method [26]

Storage method	Loss of biomass, %	Change of calorific value, %
In small piles in the cutting area till August	- 10	0
In small piles in the cutting area till October	- 25	- 23
In big 4m high uncovered piles from May to September	- 1	+ 4
In big 4m high covered piles	- 2	+ 4 … +10

Table 3.4. Quality variation of wood chips depending on the storage method [26]

Storage method	Biomass loss, %	Change of calorific value, %
In small (<60 m^3) covered heaps from May to November	- 18	- 7
In small (<60 m^3) uncovered heaps from May to November	- 20	- 18
In small (<60 m^3) uncovered heaps from May to January	- 23	- 23
In big (>6000 m^3) covered and compacted heaps from June to January	- 10	- 5
In big (>6000 m^3) uncovered and compacted heaps from June to January	- 12	- 12
In big (>6000 m^3) covered and uncompacted heaps from June to January	- 7	- 1
In big (>6000 m^3) uncovered and uncompacted heaps from June to January	- 8	- 4

This data shows that for long term storage of wood fuels big piles should be preferred, both for logging residues and woodchips.

3.5. Production of refined fuels

3.5.1. General

Wood is of cellular structure and therefore the energy content of unrefined wood per volume unit is not high. In order to get more homogeneous wood fuels with higher calorific value compressing is used. In the course of processing the cavities in the wood are compressed under high pressure and temperature. The density of the processed wood fuel may reach 1300 kg/m^3, which is not much less than the density of the material that constitutes the cell walls of wood fibres (according to [41] on average 1500 kg/m^3). The compressing procedure consists of the following processes:

- the press applies pressure on the raw material;
- the temperature rises due to the friction:
    - o between the particles of pressed material and
    - o between the press and pressed material;
- as a result of high temperature and pressure the cellular structure of wood is disrupted;
- due to heat the lignin in the wood softens and binds the particles of pressed wood.

Since no chemical processes take place during pressing, the calorific value per mass unit does not increase, but per volume unit it increases. Regarding the benefits of pressed wood fuels compared to traditional woodfuel, the following could be noted:

- due to the low moisture content and high calorific value, transport and storage of refined fuels is less expensive;
- the dry fuel will not start to disintegrate under the impact of fungi and microorganisms an thus it can be stored for a longer period;
- the homogeneous moisture content and standard size of pressed fuels allow more accurate regulation of the combustion regime in the furnace, thus providing higher efficiency.

A shortcoming of pressed wood fuels is the higher price compared to the unprocessed fuels. The pressed wood fuels are produced in the form of briquettes (typical size 30 – 100 mm) and pellets (6 – 12 mm). The briquettes are good for burning in ovens and fireplaces while the pellets suit better for automatic combustion units.

3.5.2. The briquettes

For the production of wood briquettes the ram and screw extruders are used (see Figure 3.54 and Figure 3.55 [42]) utilising sawdust or shavings as raw material. Before pressing, the material goes through additional grinding and drying processes (the moisture content must remain below 12 – 14 %).

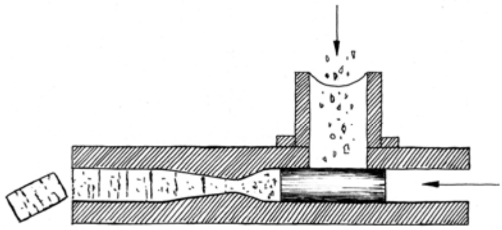


Figure 3.54. A ram extruder

The ram extruder works in cycles – with each working stroke a certain amount of material is pressed through a conic tube and these stroke layers can be well identified in the produced briquettes. For driving the press a flywheel is always used to smooth the engine load. The lifetime of the piston in the working press is quite long, as there is only relatively slight friction between the pressed material and piston, but the mould tube wears out fast. The piston presses are quite reasonably priced and therefore widely used.

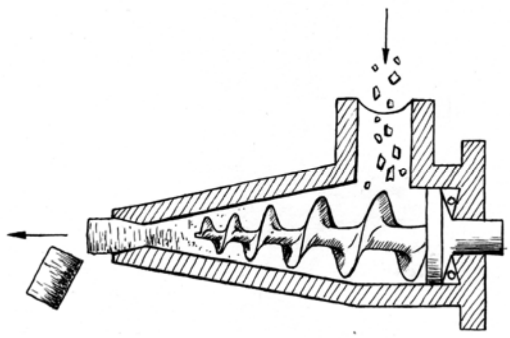


Figure 3.55. A screw extruder

The screw press is of less weight compared to the ram press, because it has no heavy pistons and flywheels. The production flow is continuous and the final product can be cut into pieces of appropriate length. The density of briquettes produced with a screw press is higher than that of piston press produced ones. The screw press does not make much noise, because no impact load is applied there. Higher energy cost and fast fatigue of the screw could be noted as drawbacks of these presses. In order to reduce the energy cost of pressing, the mould tube could be heated. In this case the outer surface of briquettes will be charred and it makes the ignition easier. The charred outer surface hinders also moisture absorption.

3.5.3. Pellets

The most widely used pelletizers [43] are with ring die (see Figure 3.56), the ones with flat die are less used (see Figure 3.57). During pressing operation the temperature of the wood material rises, lignin softens and it is extruded under the pressure of rollers through the conic openings of the matrix (see Figure 3.58).

Figure 3.56. Pelletizer with ring die

Figure 3.57. Pelletizer with flat die

The pellet making includes four phases:

1. Drying of raw material.

   The moisture content of the raw material for pellet production depends on the storage conditions. Since usually outdoor storage facilities are used, the moisture content of raw material must be taken to the required level before pelletizing (12 – 17 %). An excessively dry material may be self-charred during pelletizing, on the other hand, if raw material is too moist, the wood particles would not be bound.

2. Grinding of raw material.

   The particle size of raw material (sawdust and shavings) for pellet production may vary in big range. Therefore, the raw material must be homogenized before extrusion and usually a hammer mill is used for this purpose.

3. Pellet pressing.

   Pressing pellets with matrix presses.

4. Cooling.

   The pellets leaving the press are hot and for avoiding the self-ignition the pellets must be cooled in an intermediate hopper before storing.

The favourable properties of pellets as a bulk material allow developing of a flexible distribution system (see Figure 3.59). An efficient logistics system can be established for both big and small consumers. Pellets are suitable for the automatic feeding systems of burners and fuel oil can be easily replaced by pellets. Therefore, pellets are considered as competitive alternative even to light fuel oil.

Figure 3.58. The cylindrical matrix of pelletizer, photo by P. Muiste

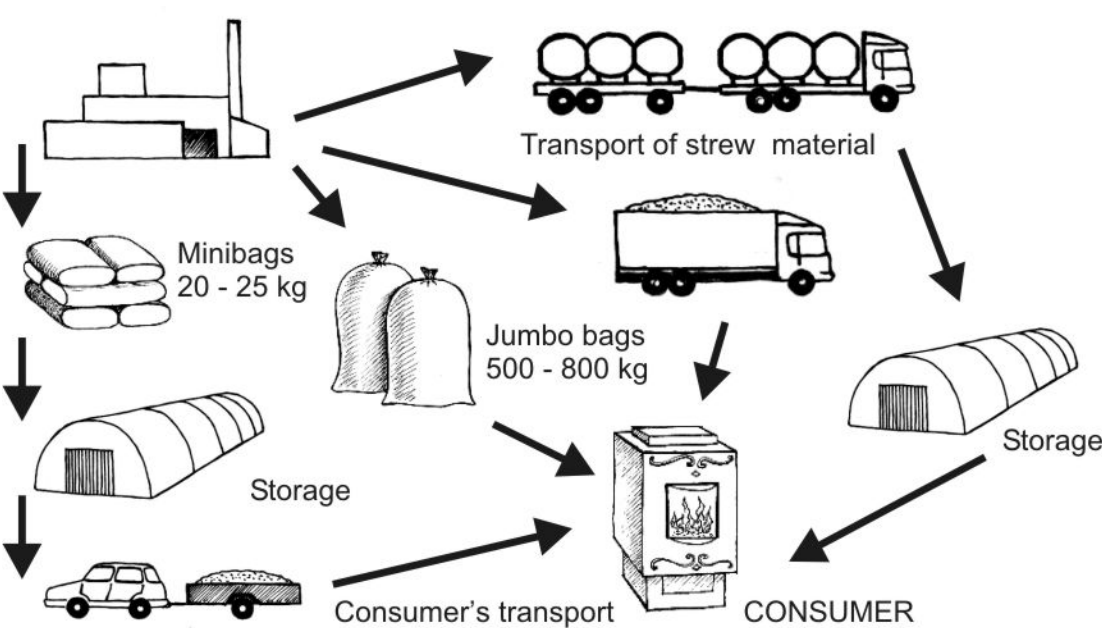


Figure 3.59. The pellet supply diagram

3.6. Handling of straw as a fuel

Straw is a residual product of cereal production, which can be utilised as a boiler fuel.

After harvesting with combines the straw is left in the field where it should be collected as soon as possible. Chaff cutting of straw for the use in boiler plants has been tried. For chaff cutting a tow or self-propellered chaff cutter and cutter loader may be used (see Figure 3.60). Since the bulk density of chaffed straw is very low, such a harvesting technology is suitable only for very small shipping distances.

Figure 3.60. A self-propellered chaff cutter in operation [44]

In the present cereal production practice straw is predominantly pressed into bales of different size, the density of which ranges from 110 (90) to 165[4] kg/m^3 depending on the baling technology and bale size and weight [44]. In agriculture various farm tractor trailers and other suitable equipment are used for collecting the straw bales from the field [44].

Figure 3.61. Straw collected from the swaths and pressed into big bales of about 500 kg [44]

Figure 3.62. Loading of straw bales with a tractor mounted fork lifter [44]

Figure 3.63. Fastening the load of straw bales securely with straps for transport [44]

[4] By [44] the bale density has been increased over the years and now the average bale density in Denmark is 139 kg/m^3

The straw must be stockpiled during a short period of grain harvesting (usually in August). Large storages are required for storing straw in case it is used as a main fuel throughout the heating period. The straw must be collected and stored at the moisture content not higher than 25 % in order to preserve the high quality (i.e., to avoid overheating and rotting) (see section 2.3). If the moisture content of stored straw is higher, it must be dried.

Usually, cold air blowing through the straw is sufficient for drying. For doing this, the floor of the storage must be equipped with air channels, where the air is blown by a fan. The same technological method has also been used for drying and storing the hay used as a fodder in order to keep the moisture level appropriate. Such barns could be well used for straw too, but in Estonia for example, they have been out of use for the last 15 years and are mostly demolished.

3.7. Production of peat fuels

Before starting peat harvesting the mire or peat bog must be prepared for it. In the first stage the vegetation is stripped off, surface levelled and attempts made to root out stumps (see Figure 3.64). If the stumps are too deep in the ground and remain in the bog soil, they may disturb the operation of peat harvesting machinery.

Figure 3.64. Vegetation stripping and levelling of peat bog surface with the screw leveller RT-6.0H made by the Finnish SUOKONE OY

In the natural condition the peat layer is soaked with water and the moisture content of peat exceeds 90 %. Before starting peat harvesting the surface water table must be lowered. For this purpose a network of drainage ditches is built in the peatland. The soft peat soil allows making ditches by pressing (see Figure 3.65). The surface water and rainwater discharged via drainage ditches includes organic additives, solid particles, also iron, phosphorus and nitrogen compounds and therefore the water quality must be controlled before being discharged into a natural water body, and if necessary, it must be screened and cleaned [45], [46].

In general, certain environmental requirements and restrictions are set to the peat production that may differ significantly across the countries.

In the Baltic Sea countries the peat is harvested from the surface of peatland and at first the layers of weakly decomposed peat are cut, then the well decomposed peat layers will be reached, from which mainly peat fuel is produced.

Figure 3.65. Pressing of drainage ditches in the bog soil with the ditcher OJ-1.3K made by the Finnish SUOKONE OY

Peat can also be extracted through the whole depth of peat deposit at the same time. This type of peat production is implemented in Ireland, but the attempts to use it in Estonia have failed and to our knowledge this technology has not been tested anywhere else in the Baltic Sea countries.

The peat production is a seasonal activity. In spring the production can be started directly after the snow and soil have melt. In early spring the relative air humidity is low and it creates especially favourable conditions for drying the peat in the air. In the second half of summer the relative air humidity increases and from August no more peat is cut for drying.

The climate conditions have strong impact on the peat production. In a rainy summer the peat production may remain several times lower than in a dry summer.

3.7.1. Milled peat

Milled peat makes a significant share in the peat production (incl. peat fuel). The surface layer of peatland is milled and the peat is left to air-dry. For accelerating the drying process the peat layer is harrowed and after drying to certain moisture content the peat is collected and stockpiled at the bog edge or nearby a peat briquette plant. For stockpiling such a location must be chosen where the peat trailers could have access throughout the winter. As a general rule, no big amount of peat is stockpiled at boiler plants.

In order to avoid moistening of stockpiled peat, the surface layer of stacks is either compacted or covered with a plastic film. As a rule, building a shed or closed storage for peat is too expensive and there is no direct need for such expenditures.

The milled peat is mainly used as a fuel in big combustion plants. Besides, a major share of milled peat is used for manufacturing peat briquettes. Peat pellets can also be produced from the milled peat.

3.7.2. Sod peat

Huge peat cutters with driers have been used for peat harvesting in Eastern regions of the Baltic Sea region (incl. Estonia) up to the sixties of the last century, but presently the most widespread technology is the one where peat moss is milled from the bog surface with a disc cutter, pressed in sausage-like pieces and left in rows to air-dry on the bog surface (see Figure 3.66). A 0.5 m deep and 10 cm wide groove that the cutter leaves in the bog surface usually collapses at once and there remains no visible furrow in the surface.

For accelerating the drying process, a sod peat layer is harrowed and the peat is ridged to make its collection easier.

Figure 3.66. Milling of peat moss from the raised bog surface and extrusion of sod peat with the PK-1S sod cutter of Finnish SUOKONE OY

The dependence of sod peat drying speed on weather conditions is somewhat lower than that for the production of milled peat, because the contact of sod peat with the peatland surface is less extensive. In Finland a technological solution has been developed where the sod peat is extruded in wave-like rows and this allows further speeding the peat drying process (see Figure 3.67). In average 2 to 3 harvests of sod peat (incl. drying) can be collected during one summer.

Both the milled peat and sod peat are stockpiled at the bog edge in places accessible to heavy-duty peat trailers.

The quality of sod peat depends highly on the share of crushed pieces and fine fraction in it (see section 2.5.3). Although much effort is put in decreasing the sod peat grinding, for the production of high-quality sod peat, the fine fraction has to be screened out and left on the bog surface.

Figure 3.67. The wave-like extruded sod peat that provides minimum contact with the bog surface and therefore dries faster

3.7.3. Upgraded peat fuels

Among the upgraded peat fuels briquettes produced from the milled peat are most widely spread. As a rule, the peat briquette plants are located close to peat bogs. In order to provide fluent manufacturing of briquettes around a year, the milled peat must be produced during the summer to cover full year need for raw material. In order to avoid shutdowns in briquette production due to the lack of raw material, during favourable summers the milled peat is harvested and stocked for the next year which could be rainy and unfavourable for peat cutting.

Also, pellets can be produced from the milled peat. The pelletizers similar to these used in wood briquettes manufacturing are used (see section 3.5.3, Figure 3.56 and Figure 3.58).

Two different peat pellet production technologies have been implemented: the pellet production in the bog or in the plant. When producing in the bog, the milled peat used for manufacturing the pellets must be as dry as possibly, because the further drying depends only on the energy released due to extrusion. When pellets are produced in the plant, they are dried with an additional drier in the production process and as a result a lower moisture content of pellets can be obtained than in case of the on-site (in the bog) production.

Up to now the peat pellets have not gained such popularity as wood pellets. Even in Finland, which is the most significant peat producer and developer of technologies among the Baltic Sea countries, the peat pellets have been produced only in short periods. In relation to the rapid expansion of the use of wood pellets, increasing demand for peat pellets can be also forecasted.

4. COMBUSTION TECHNOLOGIES OF BIOFUELS AND PEAT

A boiler plant operating on biofuel or peat consists mainly of the following units (see Figure 4.1):

- fuel terminal, which may consist of several spaces, e.g., the fuel reception area, main storage area, automated storage or an automated section of the main storage area, etc.;
- fuel handling equipment for the fuel conveyance from the main storage area to the automated storage and further on to the furnace;
- boiler and furnace;
- flue gas cleaning equipment (multi-cyclone, bag filter, etc.) and stack;
- ash handling equipment;
- combustion air fans, flue-gas exhauster, safety and control devices.

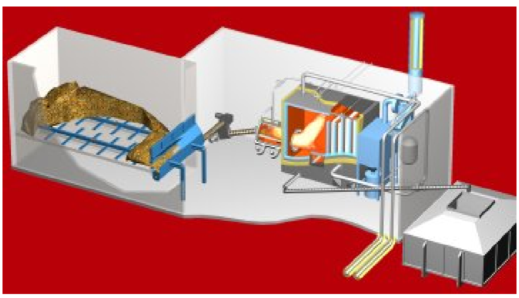


Figure 4.1. Layout of the equipment in a biofuel fired boiler plant, Thermia OY, Finland

The lower is the fuel quality and the more diversified fuel is used, the more complicated are both the flow sheet and technological solution of the combustion equipment and the boiler plant as a whole. For optimizing the expenses and cost of the produced heat, in small scale plants it is expedient to use the fuel of better and more uniform quality, for example pellets. More complicated technological solutions are required for burning moist woodchips, bark and waste. As a rule, it is economically feasible in large plants.

The central technological part of a boiler plant is the boiler with a furnace. Combustion processes and furnace constructions depend highly on the properties of fuel (calorific value, volatile and moisture content, etc). In order to select the most appropriate equipment for burning biofuels and peat, combustion peculiarities of these complicated fuels must be understood.

4.1. Combustion of biofuels and peat

The fuel contains three chemical elements during the combustion of which heat evolves: carbon (C), hydrogen (H) and sulphur (S), which burn completely based on the following integrated chemical reactions:

$C + O_2 \rightarrow CO_2$ + heat

$2H_2 + O_2 \rightarrow 2H_2O$ + heat

$S + O_2 \rightarrow SO_2$ + heat

For burning atmospheric oxygen is used, and the combustion products are carbon dioxide (CO_2), water vapour (H_2O) and sulphur dioxide (SO_2). Although useful heat is released from the sulphur burning also, sulphur is considered an extremely objectionable fuel constituent, because of its environmental and corrosive impact.

4.1.1. Fuel combustion zones and stages

Combustion peculiarities of moist solid fuel can be studied based on the grate combustion example where some processes take place in the fuel bed and others freeboard in the combustion chamber.

The processes on the grate are the following (see Figure 4.2):

- after fuel has been fed to the grate the temperature of the fuel layer starts raising and drying process begins;
- when the fuel temperature reaches 100 – 105 °C, the volatiles (first of all hydrocarbons) will be released. The structure of fuel particles will become porous as a result of this process;
- depending on the type of fuel, it ignites in the temperature range of 220 – 300 °C [47]: softwood at 220 °C, hardwood at up to 300 °C and dry peat at 225 – 280 °C;
- carbon combustion ceases at the temperature of 800 – 900 °C and the ash will fall down from the grate.

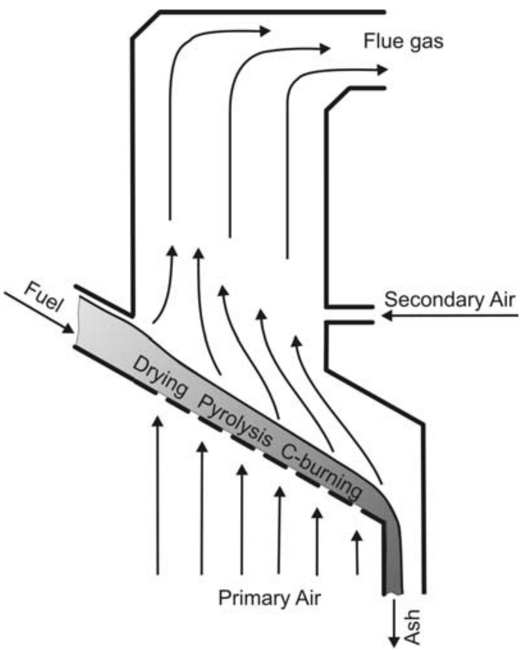


Figure 4.2. Combustion zones of moist biofuel on the sloping grate

The processes on the grate could be split in two: endothermal or heat absorbing (drying and pyrolysis) and exothermal or heat releasing processes (burning). Since there is no direct contact between the fuel particles in the combustion and drying zones, mainly radiation of the flame and hot surfaces of combustion chamber heat fuel bed in the drying zone and in the upper part of the pyrolysis zone.

The moister the fuel is the more heat is required for drying and heating up to the ignition point. Therefore, for burning moist fuel there are no heat absorbing surfaces (i.e., relative cool surfaces) in the furnace or their contribution is insignificant. The constantly high temperature of ceramic furnace walls is necessary to keep the drying zone within the upper part of the grate and to provide good conditions for ignition of the fuel.

For burning a dry fuel, cooling of the furnace walls may be indispensable. A dry fuel does not require much heat for drying, and due to very hot encasing surfaces radiation of these surfaces and flame may increase the fuel bed temperature over the ash softening point and as a result, the ash will become sticky or will melt. The melting ash slags the grate and blocks primary air inlet through the grate. In addition, the temperature of ceramic surfaces in the combustion chamber may become dangerously high; as a result, the ceramics cannot resist and may start melting. Hence, the structure of each furnace is foreseen for the combustion of fuels with the certain level of moisture content.

The major part of heat from biofuel and peat is released in the combustion chamber and not in the fuel bed, because the volatile content of these fuels is high. Combustion of the volatiles (i.e. products of pyrolysis) begins in the furnace space at the temperature of 500 – 600 °C. For the ignition of volatiles, certain temperature must be achieved and in addition fresh oxygen-rich air must be fed into the combustion chamber. The air supplied under the grate is called primary air and the additional air necessary for the volatile combustion is called secondary. While burning fuels with high volatile content (biomass and peat) the demand for secondary air exceeds that of primary air.

4.1.2. About temperature control options in the fuel bed

The behaviour of volatiles and relationship between the processes taking place in the fuel bed on the grate and in the combustion chamber has direct impact on the temperature field of the furnace.

The main exothermic reaction on the grate is carbon combustion:

$C + O_2 = CO_2 + 405.8$ kJ

The hot carbon dioxide formed as a result of the previous reaction may react with glowing carbon particles in an oxygen-poor region. As the reaction is endothermic, the fuel bed is cooled:

$CO_2 + C = 2\ CO – 160.7$ kJ

The second fuel bed cooling reaction may take place between water vapour (contained in the combustion air) and glowing carbon particles:

$H_2O + C = CO + H_2 – 126.7$ kJ

The result of the two last reactions is that the generated carbon monoxide (CO) and gaseous hydrogen (H_2) enhance heat release in the furnace volume, because in addition to the volatiles (hydrocarbons) combustion, carbon monoxide and hydrogen are also burned there:

$H_2 + ½\ O_2 = H_2O + 241$ kJ

$3\ CO + 1½\ O_2 = 3\ CO_2 + 849.8$ kJ

The conclusion is that the heat used to generate carbon monoxide and hydrogen in the fuel bed on the grate is released in the combustion chamber.

The share of endothermic reactions that cool the fuel bed can be increased by blowing flue gases through the fuel bed. This method is called the flue gas recirculation method and it can be applied if drier fuels (or fuels with higher calorific value and with less volatile content) have to be burned in the furnaces designed for combustion of moist fuels.

The principal objective for controlling the temperature of the grate and in the fuel bed burning on the grate is to avoid ash melting and grate slagging (see also section 4.1.1). When the furnace is used for burning different fuels alternately, for example sod peat and woodchips, utilization of flue gas recycling appears a highly appropriate measure for reduction of the grate temperature and for avoiding ash melting in case of peat fuelling.

4.1.3. Heat losses and combustion efficiency

Boiler efficiency is defined as the ratio of heat output and input. Heat input can be calculated by using data on fuel consumption and calorific value. The objective of combustion is to utilize heat input by fuels as fully as possible. The calculation of combustion heat losses is based on flue gas (exhaust gas) analysis. The analysis of moist or dry flue gas can be taken for the basis. The methodology based on the dry flue gas analysis is described here for calculation of heat losses. The methodology is well compatible with the modern measuring techniques and allows highlighting the role of water vapour in the losses from the moist fuel and hydrogen burning [48].

The heat losses from burning include:

- heat loss with the physical heat of dry flue gas;
- heat loss due to the content of carbon monoxide (CO), hydrocarbons (C_mH_n) and other combustible gaseous components in the dry flue gas. The loss is the heat wasted due to the chemically incomplete combustion;
- heat loss with bottom and fly ash that consists of two parts – physical heat of the ash and heat wasted if there is unburned carbon in the ash;
- heat loss due to the latent heat of vapour in exhaust gas. Vapour content in exhaust gas depends on moisture and hydrogen content in the fuel.

Usually the water vapour in flue gases is in the form of superheated steam. Hence, this loss component is the energy content in the water vapour (in particular, the evaporation and superheating heat) and it is taken into account when the higher (gross) calorific value is taken for the basis of calculating the combustion efficiency.

In order to find the combustion efficiency, the so-called indirect heat balance method is mainly used:

efficiency = 100 – total loss,

where the total loss and efficiency are given in percents.

The heat loss from the combustion must not be considered the same as that from the boiler or boiler plant, because the latter contains still several additional losses, for example losses due to radiation and convection from the outer boiler surface, blowdown losses in case of steam boiler, losses due to air flow through the boiler in hot reserve, etc.

4.1.4. Characteristics of combustion efficiency

In practice, the heat combustion losses are determined by the flue gas analysis. The modern measuring devices display the results, incl. percentage of heat losses, on the screen.

The flue gas analysers can measure directly the flue gas temperature, content of CO_2 or O_2 and CO. Using the measurement results and data on fuel properties the main combustion losses can be easily calculated and displayed. Usually, other minor heat losses might not be considered in practice.

The most significant heat loss is that via the flue gas physical heat and it depends on the temperature and on the excess air factor λ. The last one is defined as a ratio of actually supplied combustion air to that of theoretically required for the complete combustion. The excess air factor λ is used as the most important characteristic describing the combustion process.

Based on the flue gas analysis, the following simplified relationship can be used for defining the excess air factor:

$\lambda = CO_{2,max}/CO_{2,measured}$,

where $CO_{2,max}$ shows the maximum possible carbon dioxide content while burning the fuel and its value depends on the specific fuel. For some fuels the values of $CO_{2,max}$ are given in Table 4.1.

Table 4.1. $CO_{2,max}$ values for some fuels

Fuel	**$CO_{2,max}$, %**
Coal	18.8
Fuel oils	15.9
Wood	20.2
Peat	19,6
Natural gas	12.1

Several gas analyzers do not measure the carbon dioxide content directly, but calculate it through the oxygen content:

$CO_{2,measured} = CO_{2,max} \cdot (1 - O_2/20.94)$

The expedient value of excess air factor depends highly both on the combustion technology and type of fuel, but for the complete combustion it must be higher than 1. When burning wood fuels and peat it is rather difficult to distribute combustion air very evenly all over the combustion zone and therefore, in order to achieve the complete combustion the value of excess air factor must be over 1.4. At the same time, while burning liquid or gaseous fuels, the optimal excess air factor ranges from 1.02 to 1.1.

The heat loss from chemically incomplete combustion can be defined very precisely based on the CO content. The high CO content (over 0.5 %) refers also to the possible presence of unburned carbon particles in flue gases that can be easily detected due to dark colour of smoke.

Accordingly, in order to reduce heat loss from chemically incomplete combustion it is important to keep CO content in exhaust gas as low as possible. Reduction of CO emission to the atmosphere might be required also due to health protection and environmental restrictions (see section 6.2).

4.2. Combustion technologies

Considering the wide scale of properties of biofuels and peat, many different techniques for combustion of these fuels can be applied:

- pulverized combustion – is used in single cases, for example for co-combustion of wood grinding powder together with liquid fuel;
- grate combustion technologies with a wide range of grate construction. Grate types might be divided into two groups – fixed or solid grates and moving grates;
- combustion in fluidized bed – either bubbling or circulating fluidized bed;
- fuel gasification and combustion in the oil or gas firing boiler.

A certain combustion technology is either technically or economically most expedient in the certain range of boiler capacities. In the conditions of Finland the boilers with the capacity up to 5 MW are usually grate boilers, fluidized bed technologies are mainly used in case of large scale boilers [49] (see Table 4.2).

Differently from Finland and other Scandinavian countries, the fluidized bed technologies for burning wood fuels and peat have not gained much popularity neither in the Baltic countries nor in Poland and Russia, although some positive examples on the implementation of fluidized bed technology can be given and in the future the situation may change.

Table 4.2. Typical capacities for different combustion technologies in Finland [49]

Combustion technology	Minimum capacity, MW	Typical capacity, MW
Fixed grate furnace	0.01	0.05 – 1
Mechanical grate furnace	0.8	2 – 15
Bubbling fluidized bed	1	> 5
Circulating fluidized bed	7	> 20
Fuel gasification	0.3	2 – 15

The boilers could be classified also according to field of their implementation. In each field there is expedient to use boilers with certain capacity, most appropriate technological solution and preferred automation level (see Table 4.3).

Table 4.3. Boiler classification according to the field of implementation [49]

Field of implementation	Typical capacity
Family house boilers	15 – 40 kW
Boilers in big buildings	40 – 400 kW
DH boilers	0.4 – 20 MW
Industrial boilers	1 – 80 MW
Boilers for burning household waste	10 – 30 MW

4.2.1. Grate furnaces

The grate furnace technologies are the most widespread in the medium and low capacity range. Historically, the grate furnaces have been divided as furnaces with manual or mechanical (automatic) fuel feeding. Presently, the share of manually fed boilers has become very small and even in one-family houses more and more boilers are equipped with automatic feeding systems. Due to low ash content in wood fuels, manual ash removal could be accepted even for quite big boilers.

In this manual the main attention is focused on the boilers of DH plants, but also the boilers for small houses and for local heating are shortly described.

A great number of different grate types could be classified as follows:

- solid or fixed grate;
- moving inclined grate;
- travelling grate;
- special grates for fuels of specific properties, for example for burning municipal waste.

The furnaces with special grates and chain grates are not treated in detail in this manual. Waste utilization requires complicated technological solutions for combustion and fuel handling as well for cleaning of exhaust gases and fulfilling the environmental requirements. Waste incineration projects have to be planned and carried out in co-operation or under the supervision of environmental specialists.

4.2.1.1. Furnaces with solid grate

Mostly the solid (fixed) inclined grate is mounted in the furnace under an angle, which provides the fuel falling under gravity from the drying zone of the grate to the carbon (coke) combustion zone (see Figure 4.2). The inclination angle of solid grate is approximately equal to the angle of fuel falling down. Depending on the fuel type and construction of grate elements, the following slopes have been recommended for the grates [50]:

- fixed inclined grate with bars for burning air-dry sod peat, sawdust and shavings: 32 – 36°;
- step grate for burning sawdust: 38 – 40°;
- step grate for burning sod peat: 30°.

The solid inclined grate is made of grate components or bars installed in the same direction with the fuel flow; the step grate consists of steps perpendicular to the fuel flow. The step grate is well suitable for burning sawdust and moist fuel.

In addition to the plane inclined grates also conical (retort) grates are used where the fuel is underfed with a screw feeder (see Figure 4.3) or fed from the top [51].

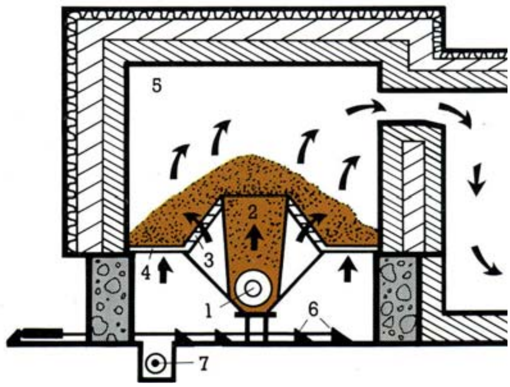


Figure 4.3. Underfed pre-furnace with a conical grate (retort grate) for burning very wet fuel, SERMET, Finland

1 – screw feeder; 2 – fuel funnel 3 – inclined grate; 4 – horizontal grate; 5 – combustion chamber; 6 – ash scraper; 7 – screw conveyer for ash

4.2.1.2. Furnaces with mechanical grates

Compared to the fixed (solid) grate furnaces moving of the grate fire bars enables better control over the advance of fuel bed and more smooth distribution of fuel on the grate and as a result, more efficient combustion can be achieved and the content of hazardous components in flue gases will decrease. An integrated solution is a double grate design where the upper part is fixed for drying and pyrolysis zones and the part with less inclined moving grate for the combustion zone.

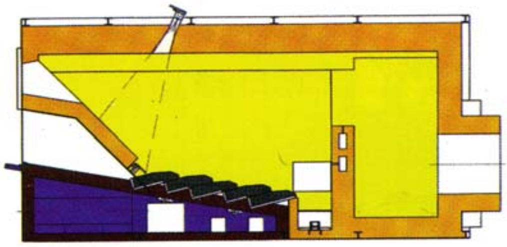


Figure 4.4. The Swedish Hotab furnace with the grate consisting of fixed and moving inclined parts

A typical example of the furnace with a mechanical grate is the TRF furnace of Swedish company KMW where the fixed grate bars are located consecutively with the moving bars. The checkered moving of grate fire bars provides even thickness and smooth advancing of the fuel bed.

The furnace in Figure 4.5 is a pre-furnace completed with a separate boiler. The walls of the pre-furnace have no heating surfaces and this type of furnace suits well for burning moist fuel (35 – 55 %). The ceramic walls of the furnace are cooled with the combustion air that provides air preheating and thus improves the combustion conditions.

For burning very wet fuels, the furnace walls have usually ceramic lining and no cooling (see also Figure 4.3) and the temperature of lining is sufficiently high to provide enough heat radiating from the walls for fuel drying, releasing volatiles and creating suitable combustion conditions on the grate and in the combustion zone. If a dry fuel is burned in a uncooled furnace, the temperature will start to rise fast both in the fuel bed and in flame. The result can be ash melting, slagging of the grate and its air ports, also damaging or even melting of the furnace lining.

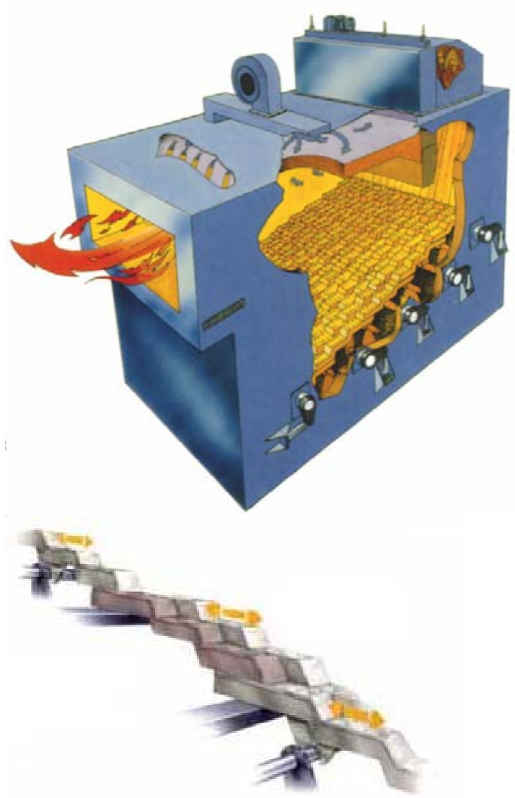


Figure 4.5. The Swedish KMW ENERGI AB TRF furnace with checkered grate bars

An underfed combustion chamber with the rotating conical (retort) grate patented by Wärtsilä (named as BioGrate, see Figure 4.6) allows combustion of fuels with rather wide range of moisture, incl. fuels of extremely low and very high (up to 65 %) moisture content.

In case of the BioGrate furnace, the fuel is fed by a screw feeder from below onto the centre of the conical shaped grate where it is distributed over the whole cone surface. Practically any biofuel can be used that can be fed with a screw feeder.

The conic grate consists of concentric rings where the fixed and rotating rings are mounted alternatively and each second rotating ring moves in the opposite direction, i.e. one clockwise and the other anti-clockwise. In the BioGrate furnace the grate rotation distributes fuel into a very smooth fuel layer over the circumference and entire grate surface. The grate rings are driven by hydraulic drives.

Figure 4.6. The Wärtsilä patented BioGrate furnace with an underfed rotating conical grate

The key to the high combustion efficiency and minimum emission level is an expedient air distribution and control system, which contains speed controlled air fans. In addition, the controllable flue gas recirculation is used and that enables the user to control the heat release on the grate and provides clean combustion at the low NOx and CO emissions for a wide range of fuels.

The outer diameter of conical grate depends on the furnace capacity, while for the lowest capacity of 3.5 MW the diameter is 4.15 m and for the highest capacity of 20 MW it is 9.5 m.

When the furnace for biofuels and peat is designed as a pre-furnace, it must be connected to a matching boiler in the boiler plant. Many producers design and supply a furnace and boiler as a factory-built assembly, especially the equipment of lower capacity. In this case, ash handling can be better arranged from under the grate, under vertical fire tubes and under the flue gas cleaning equipment (see Figure 4.7).

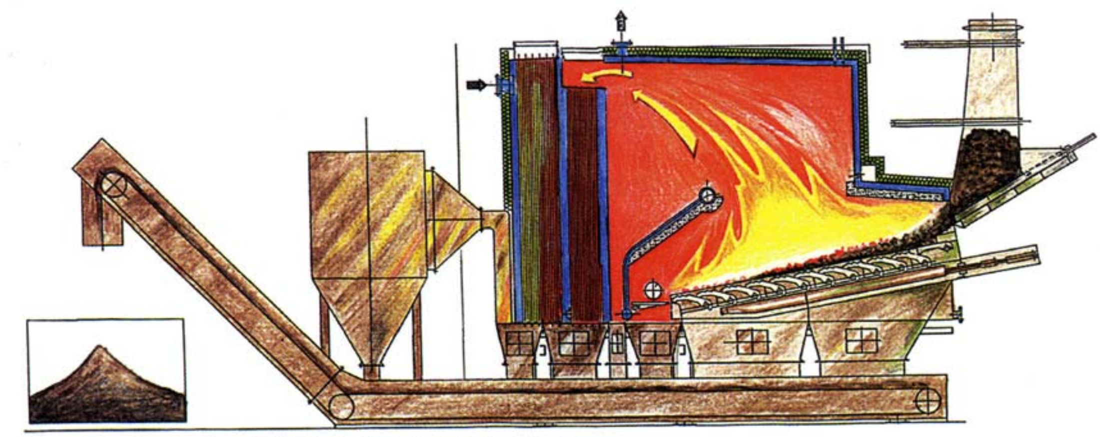


Figure 4.7. The integrated PMA type boiler plant for solid fuels of Finnish company Putkimaa OY with the capacity range of 1 – 10 MW

When dry fuel is burned in the boiler, the furnace walls require cooling with heating surfaces installed in it. The cooling conditions of furnace lining set the fuel type to be burned and its moisture content. For burning dry fuel, e.g., pellets or joiner or furniture industry residues, first of all the cooling furnace walls keep the temperature in the combustion chamber within the acceptable range. Besides, it may be necessary to design the combustion space of volatiles in a way that the fuel bed will not be entirely exposed to the flame radiation.

When burning moist fuel in a cooled furnace, the temperatures on the grate will remain low, as the drying conditions of fuel are insufficient. The result is involvement of fuel particles in the ash and incomplete combustion of volatiles, which reduce the combustion efficiency rapidly. Also, unburnt gases and soot may occur in the stack and on heating surfaces and flue gas ducts may be covered with tar.

In the furnace wall the combustion air channels can be located for cooling the wall. At the same time, the combustion air is pre-heated and it improves the burning conditions of wet fuel. This type of furnaces is widely used and they are well applicable for moderately moist fuels, for example woodchips with the typical moisture content ranging within 35 – 55 %.

An additional option to control the temperature in the furnace is the flue gas recirculation method (see section 4.1.2). This method enables decreasing the heat release and temperature on the grate. Correspondingly, in the volatiles combustion zone the heat release will increase.

4.2.1.3. Travelling (chain) grate

In large scale boilers the chain grate suits well for burning several fuels in the same furnace. For example, in 1984 two steam boilers with the chain grate furnaces have been reconstructed in Borås (Sweden). The output of each boiler is 60 – 90 tons steam per hour. The cross-section of the boiler furnace is shown in Figure 4.8. The main fuel is woodchips, but peat and coal could also be used.

With changing the travelling speed of the chain grate, the speed of fuel flow can be flexibly controlled, complete combustion of carbon can be achieved and ash falling from the grate should not contain combustible matter. During boiler operation switching from one fuel to another, for example from woodchips to coal, as well travelling speed of the grate, as well amounts and shares of primary and secondary air must be changed.

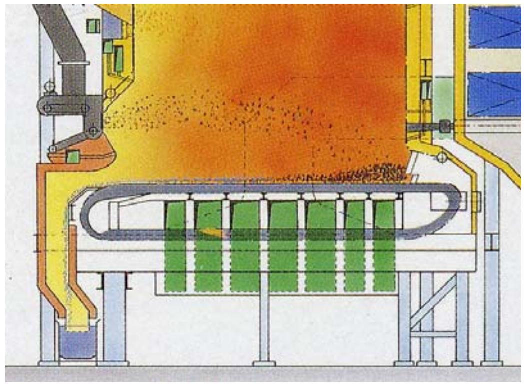


Figure 4.8. Travelling (chain) grate in the boiler of the Borås CHP plant (Sweden)

The reason why coal is used in the Borås energy centre is quite interesting. In order to supply two mainly woodchips fired high capacity boilers with woodchips, tens of trucks of fuel must be delivered a day. The drivers' salaries and haulage costs are much higher on red letter days than on week days. Construction of such a big mechanized woodchips storage, which would accommodate a fuel supply for several weekend days is economically irrational. Therefore, for optimizing the transport costs the boilers are switched to coal in case of several subsequent red letter days, e.g., the Christmas, New Year or Easter holidays.

4.2.2. Fluidized bed furnaces

With gradual increasing of the velocity of combustion air forced into the fuel bed, a state can be reached where the fuel bed is carried up by the air, the fuel particles start to suspend in the air flow. It seems like the bed begins to boil and this is where the term *fluidized bed* comes. The described fluidized bed is called a bubbling or stationary fluidized bed. The moisture, released volatiles, ash and also fine fuel particles are carried out of the fuel bed. Fine fuel particles and volatiles are burning in the combustion chamber above the fluidized bed (see Figure 4.9).

When the air velocity is increased to the level higher than needed for the bubbling fluidized bed, the burning fluid particles are carried away with the airflow. In the cyclone-separator solid particles are separated from the air and gas flow and circulated back to the furnace. Since the burning fuel circulates between the furnace and separator, the term used for this combustion technology is the *circulating fluidized bed*.

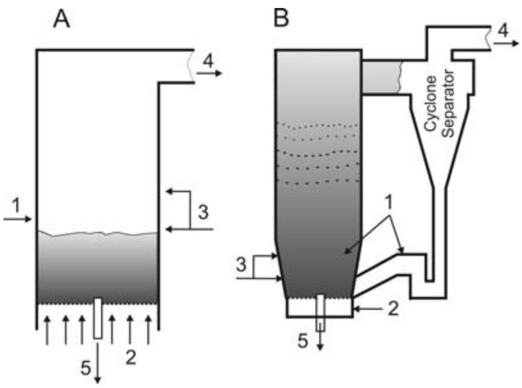


Figure 4.9. Schematic diagram of furnaces with bubbling (A) and circulating (B) fluidized beds

1 – fuel; 2 – primary air; 3 – secondary air; 4 – flue gas; 5 – bottom ash.

Both the bubbling and circulating fluidized beds are good for burning biofuels, peat and waste. For oil shale and coal the circulating fluidized bed suits better.

One of the advantages of fluidized bed technology is the possibility to burn different low quality fuels reducing at the same time emission of hazardous air pollutants. In fluidized bed the temperature is relatively low (about 850 °C) and therefore no ash melting and furnace slagging is likely to happen. Also, nitrogen emissions decrease at this temperature and in a sulphur-rich fuel, the sulphur can be bound with adding a sorbent (lime) in the ash.

A granulometrically uniform fuel is generally required for fluidized bed combustors. For burning biofuels and peat, the bubbling fluidized bed is formed from an inert material: usually quartz-sand. When activating a fluidized bed, the bed material is heated up to the temperature of 600 °C using gas or liquid fuel start-up burners. After that the main fuel fed into the bed will ignite, the temperature in the bed will rise and the start-up burners used for fluidized bed activating will be switched off.

There are some options for feeding the fuel into the bubbling fluidized bed:

- feeding fuel via a vertical duct onto the fluidized bed;
- the fuel is thrown over the cross-section of combustion chamber by spreader-stoker;
- feeding fuel into the fluidized bed through a horizontal channel either by pneumatic or screw conveyer.

Unlike grate furnaces which have difficulties at low capacities, a bubbling fluidized bed furnace with a sand bed can operate efficiently in a wide range of capacities. Due to accumulated heat of the sand bed the boiler can stay even with no load for a short time.

An example of the practical implementation of fluidized bed technology is shown in Figure 4.10. The Finnish Putkimaa OY fluidized bed boiler is a vertical firetube boiler with fluidized bed at the bottom of the firetube. Such a compact design allows building even an exceptionally small fluidized bed boiler from 1 MW on. Medium and large scale fluidized bed boilers have typically a parallel to furnace chamber vertical flue gas duct with water-tube heating surfaces.

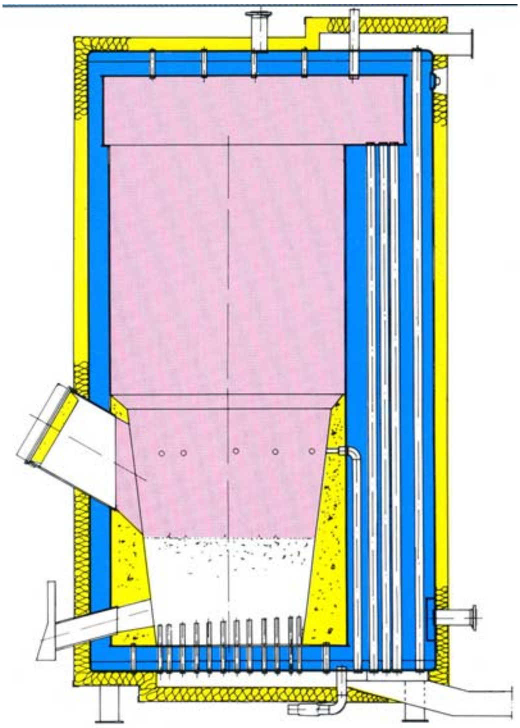


Figure 4.10. The PML type fluidized bed gas tube boiler of the 1 – 5 MW capacity (Putkimaa OY, Finland)

4.2.3. Fuel gasification

The biomass gasification principles have been known since the end of the 18th century [52], but in the beginning this technology was used only for supplying gas to the gas lanterns. During World War II the biomass gasification equipment was used for generating gas for engines of vehicles, i.e. for substitution of liquid motor fuels. Also in the seventies and eighties of the twentieth century the biomass gasification was considered an alternative for replacing diesel oil or gasoline the prices of which had risen, but in addition, the gasification equipment for energy generation emerged.

The gasification of a solid fuel with low quality and low calorific value is implemented for three reasons [53]:

- to use a solid fuel with low quality in the industry, in particular chemical industry;
- to produce clean fuel for specific needs;
- to convert a simple boiler to burning fuels of troublesome properties.

In the DH boiler plants gasification technology was introduced comparatively lately, for instance in Finland about twenty years ago. Due to the high cost of equipment, the biomass gasifiers have not been used very widely. According to several experts, the most prospective field for the implementation of gasification reactors is evidently gasification of biofuels for the CHP plants based on internal combustion engines [54].

In the fixed bed biomass gasifiers (see Figure 4.11) the fuel is fed from the top and the generated gases flow either in reverse to the fuel flow (so-called updraft or counter-current system) or in the same direction (so-called downdraft or co-current system).

In the case of updraft system the gases contain soot, ash and pyrolysis products, such as tar, but at the same time this technological method allows gasifying of low quality fuels, i.e., those with high moisture and ash content [54]. The generated gas can be burned, but the gas ducts must be regularly (about once a week) cleaned. After cooling and cleaning, the gas would be so clean that it could be used even as a fuel for internal combustion engines.

The downdraft gasifiers give the tar-free hot gas, but it must still be cleaned from the soot and ash. At the same time, this method of gasification presumes that the fuel is relatively dry and almost ash free.

The capacities of fixed bed gasifiers[5] are mostly over 1 MW and reach up to about

[5] The capacity of a gasifier is defined by the energy content of the fuel fed into the unit

10 MW (downdraft system) or 20 MW (updraft system). For higher capacities (about 7 – 100 MW), the fluidized bed gasification technology is implemented.

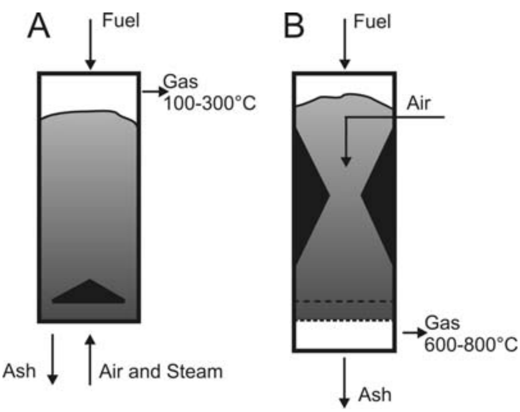


Figure 4.11. Schematic diagram of updraft (A) and downdraft (B) gasifiers

In Figure 4.12 the principal scheme of the Novel gasifier (Condens OY, Finland) is presented. The reactor capacity is 1 – 10 MW, fuel particle size 0 – 50 mm (woodchips, sawdust, bark or waste) and the range of fuel moisture content is 0 – 60 % [55].

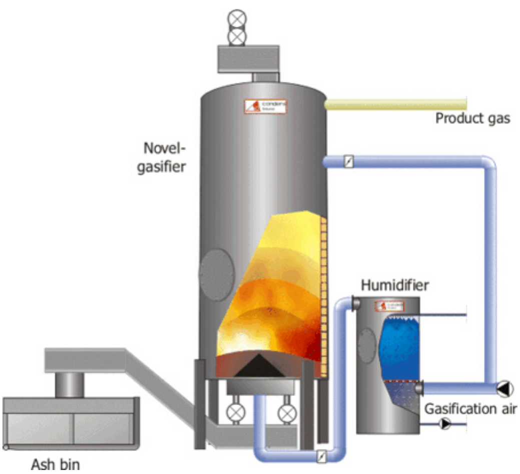


Figure 4.12. The Novel 1 – 10 MW gasifier of Finnish Condens OY

4.2.4. Straw combustion

For burning straw boilers of special construction are required where the peculiarities of this fuel type have been taken into account. Herewith the Danish experience on the use of straw as a fuel is referred [44].

Since straw is a residue of grain growing, it suits for heating farms. One of the simplest options is burning whole straw bales in the batch-fired boilers ([44] and Figure 4.13). It is a cyclic process: first a straw bale is fed into the furnace through the open furnace door by a tractor; then the door is closed and fuel ignited. The combustion air is blown into the combustion zone from the top.

Due to the cyclic burning, combustion air control is rather complicated and high combustion efficiency can not be achieved.

When the straw bales are shredded before feeding into the furnace, the fuel can be fed automatically and this makes adjusting the combustion regime easier (see Figure 4.15). Besides Denmark, such boilers have been put successfully into operation in Lithuania and Latvia.

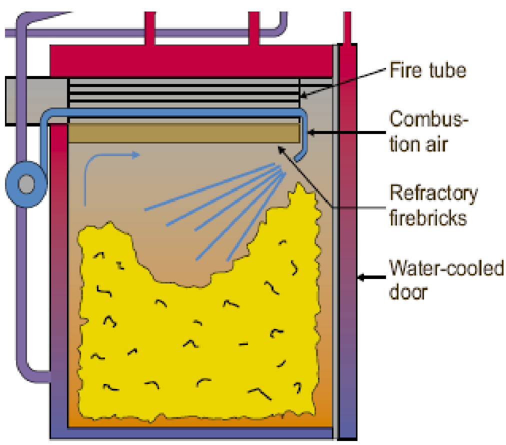


Figure 4.13. The combustion principle of the batch-fired boiler for straw bales [44]

In addition to the technological features, the efficiency of straw fired boilers depends also on the load and capacity of the unit. For example, the efficiency of the above boiler for the cyclic combustion of straw is about 10 % lower than that of the boiler with the automatic feeding of shredded straw while the efficiency increases with the load for both boilers.

The straw bales can also be fed into the furnace in series without shredding. The schematic diagram of such a "cigar-type" combustion method is given in Figure 4.14.

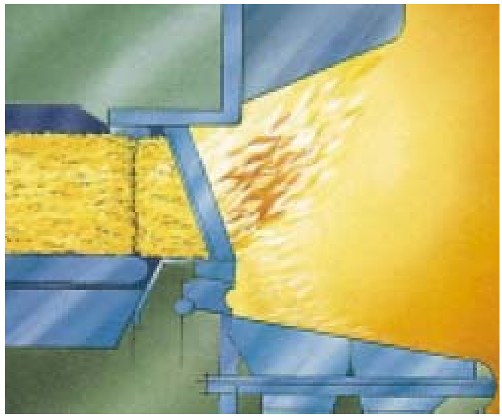


Figure 4.14. „Cigar-type" combustion method with the successive feeding of straw bales [44]

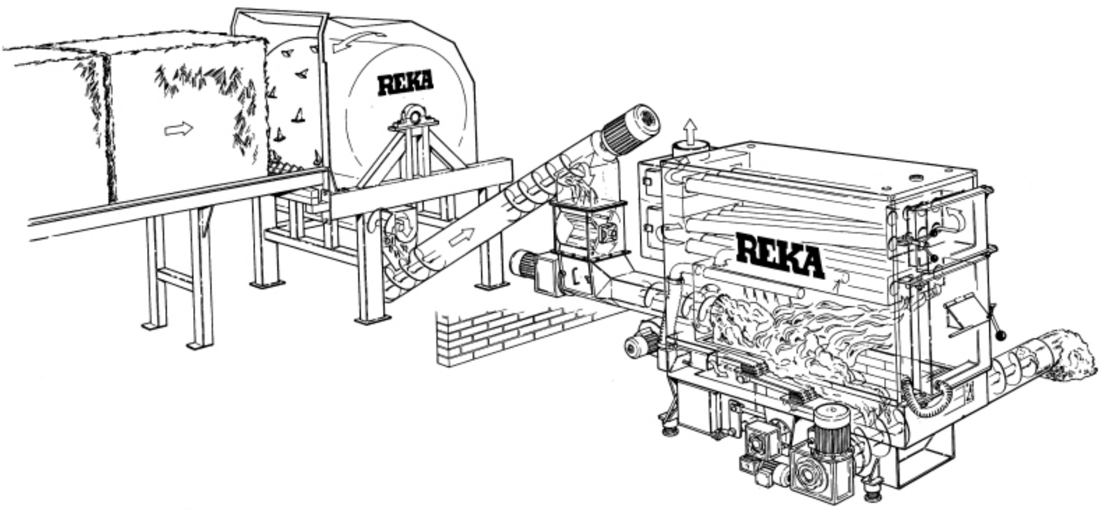


Figure 4.15. Automatic straw combustion system with the straw bale shredding unit [44]

4.2.5. Combustion of pellets and solid fuel burners

The pellets are a high quality homogeneous fuel the shipping, storage, conveyance and even combustion of which can be automatically controlled as easily as the respective operations of light fuel oil burning.

The pellet combustion system (see Figure 4.16) consists of the following main parts:

- fuel storage or tank;
- conveyor for delivering the fuel from the storage to the pellet burner;
- pellet burner;
- boiler.

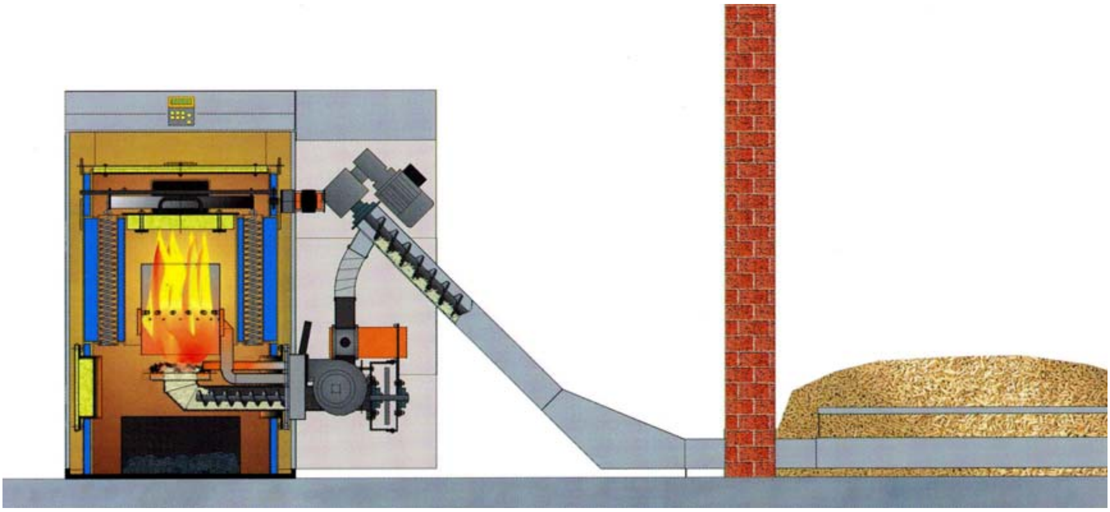


Figure 4.16. Principle scheme of the pellet combustion system [56]

The delivery of pellets from the storage to the boiler can be arranged easily by a screw conveyor from which the pellets drop into the screw feeder of the burner. Usually volatiles released at the burner inlet burn in the boiler combustion chamber.

A special pellet boiler integrated with a burner and feeding system can be used. Another alternative is replacing an oil or gas burner with a pellet burner. The pellet burner can be connected to the boiler via a maintenance manhole.

Wood pellets are dry volatile-rich fuel, the ignition is not difficult and the combustion process can be easily automated. This proves that the replacement of light fuel oil by pellets causes practically no loss of handling comfort. However, when burning the pellets, the ash must be removed from time to time, but once or twice a week is a sufficient frequency for that.

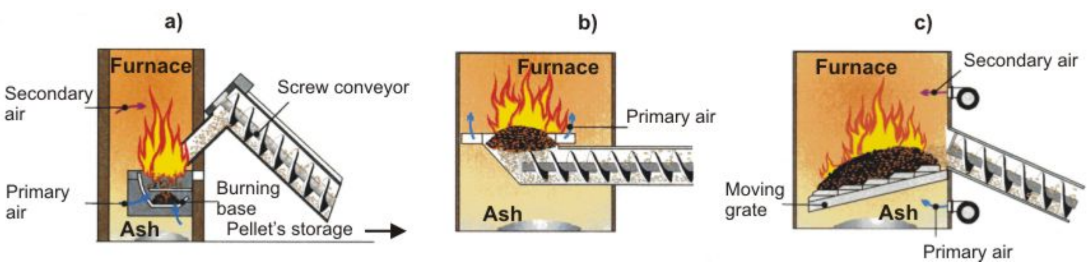


Figure 4.17. Technological solutions for the pellet feeding and combustion systems

Figure 4.18. The EcoTec 300 kW pellet burner (Sweden)

Besides pellets, some other fuels, for example woodchips and even sod peat, might be combusted in the burners similar to pellet ones (see Figure 4.19). As a rule, the fuel burned in such burners must be homogeneous and relatively dry.

Figure 4.19. The water cooled burning head of the Arimax BioJet burner 60 – 500 kW (Finland)

1 – ceramic burning chamber; 2 – cast iron step grate; 3 – water-cooled casing

At Tallinn University of Technology two modifications of burners have been developed and prepared for manufacturing (see Figure 4.20). One of the burners is designed for burning dry fuel and the other for wet fuel. Sod peat and woodchips are the most appropriate fuels for the burners. The maximum recommended moisture content is 35 %. When burning the fuels with higher moisture content, the capacity lowers significantly (in particular for the sod peat), combustion becomes unstable and losses increase rapidly.

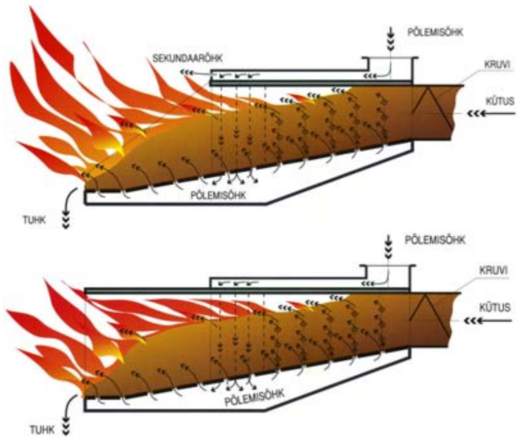


Figure 4.20. Burner layouts for dry (upper) and moist (lower) fuels developed at Tallinn University of Technology

Figure 4.21. Solid fuel burner of Tallinn University of Technology with a 240 kW universal boiler

4.2.6. Boiler conversion for burning other fuels

In the descriptions of the above combustion technologies mainly the processes in furnaces have been treated but only little attention has been paid to boilers, i.e., the heat exchange surfaces via which the combustion heat is transferred to the water. In new biofuel fired plants the furnace and heating surfaces make an inseparable integrity. From the point of view of combustion technology and emission level such a complex solution is usually preferred compared to the partial or complete reconstruction of the existing plants.

There are several options for boiler conversion to biofuels or peat in fossil fuel boiler plants:

- adjusting of coal fired boilers for burning biofuels or peat;
- building a pre-furnace to the existing fossil fuel boiler;
- building a grate or fluidized bed system into the existing boiler;
- replacement of the oil or gas burner with solid fuel burner;
- installing a fully new biofuel boiler in place of some dismounted boiler or using free space in the boiler house.

Readjustment of coal fired boilers to burn biofuels and peat of much higher volatile content and lower calorific value usually cannot give a satisfactory result and this alteration of coal fired boilers can be only an emergency solution for a short period.

Replacement of an old boiler with a new biofuel one gives practically as good result as building a new boiler plant, but may be less expensive, because the premises, pipelines and electrical installations of the existing boiler plant can be used. However, adjustment of the new storages and fuel conveyors with the complex of earlier boiler plant is somewhat more complicated than building a new boiler plant.

As the capacity of solid fuel burners usually does not exceed some hundreds of kilowatts, this solution can be used only for the readjustment of lower capacity local heating boilers and smaller DH boilers (see section 4.2.4). This solution is also suitable for boilers in small family houses.

A pre-furnace can be built to a boiler of almost any type, but it should be considered that the boiler heating surfaces could be easily cleaned from fly ash. This should be taken into account especially when equipping the firetube boilers with a pre-furnace, because it may obstruct the access to horizontal fire tubes and make regular cleaning complicated.

The flue gases from the combustion of biofuels and peat inevitably contain fly ash and for reducing its deposition on the heating surfaces and making their cleaning easier, the heating surfaces with vertical gas-tubes would be a good solution.

4.2.7. Small boilers

The distinction of small boilers according to their size is in general conventional and here the boilers primarily used for heating single family houses are considered small boilers (see also Table 4.2). However, the typical technical solutions for small boilers could be applicable for covering a relatively wide capacity range.

Here the attention is focused on the types of equipment for burning billets and refined woodfuels. In general, small boilers are designed for burning the higher quality and upgraded fuels.

4.2.7.1. Top fired boilers

Most of the older boilers for heating single family houses, the so-called top fired boilers, were preliminarily built for burning hard coal and coke, i.e., the fuels with low volatile content. A thick layer of coal could be put on the grate where it burns glowing, almost without a flame. Most of the released heat is radiated to the furnace walls. The demand for secondary air is insignificant. Also no big heat recovery surface is required for the utilization of the heat of flue gases, because the heat exchange takes mostly place in the combustion chamber.

In the top fired furnaces for the fuels with high volatile content (fuelwood, wood or peat briquettes and sod peat) sufficient space is left above the fuel bed for burning volatiles and the secondary air is also channelled there (see Figure 4.22). Heat is mostly released from the flame in the upper part of the furnace and due to the higher temperature of flue gases discharged from the furnace the heat recovery surface (convective heat transfer surface) must be bigger than that for burning volatile-poor fuels (coals).

The main disadvantage of the top fired furnace for burning log wood is the need for frequent fuel adding. All the fuel in the furnace is in the combustion zone and the combustion rate can be influenced only slightly with the primary air control. The control of the inflow of both primary air and secondary air is inaccurate and reaching the high combustion efficiency is a challenge. In order to avoid frequent adding of wood, usually a boiler with higher capacity than the maximum consumer's load is selected and connected to the accumulator tank.

4.2.7.2. Bottom fired boilers

Compared to the top fired boiler, the so-called bottom fired boiler (see Figure 4.23) provides a much longer combustion cycle, because from the capacious fuel hopper the fuel keeps dropping onto the grate constantly. Only a part of fuel loaded in the fuel hopper is involved in the combustion at a time.

With dropping downward the fuel keeps drying and is heated up. Near the grate the fuel is gasified (volatiles are released) and the char that is remained on the grate continues burning. For the combustion of gasified part of fuel (volatiles) in the space next to the combustion chamber the conditions are created where the volatiles are ignited and burnt. Therefore, the secondary air must be injected and sufficiently high temperature provided in this space. For providing the latter requirement, one or several walls of the secondary combustion chamber are covered with the ceramic lining.

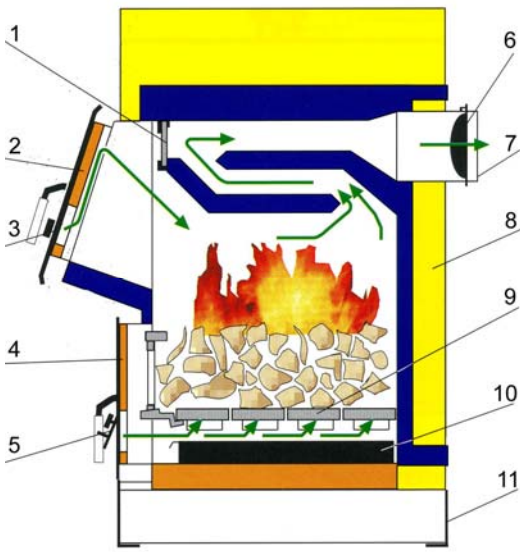


Figure 4.22. A top fired boiler from Eder Ltd (Austria)

1 – removable fire screen; 2 – refill hatch; 3 – secondary air valve; 4 – lower (ash) hatch; 5 – primary air valve; 6 – rotary valve; 7 – flue gas duct 8 – insulation; 9 – grate; 10 – ash pan; 11 – base

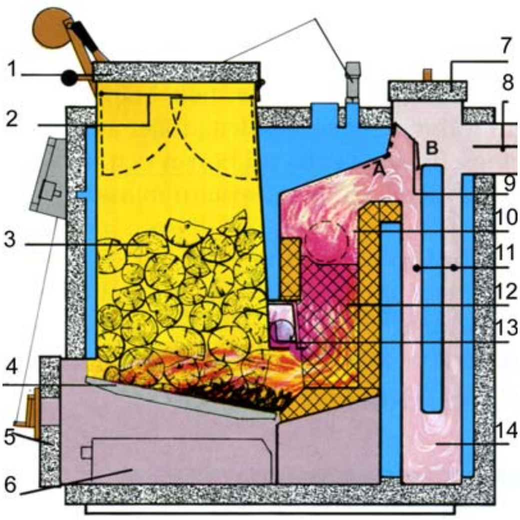


Figure 4.23. The Arimax bottom fired boiler, Högfors Lämpö OY, Finland

1 – refill hatch; 2 – fire screens; 3 – fuel hopper; 4 – grate; 5 – lower maintenance hatch with the primary air valve; 6 – ash pan; 7 – cleaning hatch; 8 – rotary valve; 9 – valve for ignition; 10 – combustion chamber; 11 – flue gas ducts; 12 – ceramic lining; 13 – secondary air; 14 – site for the cleaning hatch in the boiler surface

The working cycle of a bottom fired boiler can last rather long, often from five to eight hours. When fuelling with log wood or wood briquettes, the fuel in the fuel hopper will burn out faster than when fuelling with peat briquettes or sod peat. It is not necessary to add the fuel to the bottom fired boiler so often as to the top fired boiler, but at the same time the billets and briquettes have to be drier and of the uniform size.

The combustion rate can be controlled with the primary air valve either manually or automatically with the combustion air controller. The automatic controller regulates the air supply under the grate so that the water temperature in the boiler remains at the required level.

In the bottom fired boiler the combustion efficiency depends highly on the shares of primary air and secondary air, but the right proportion is not easy to keep. In order to keep high boiler efficiency, the boiler is recommended to be connected to the system via the accumulator tank, so that the system would not be operated in the low efficiency regime, which rises the carbon monoxide content in flue gases inadvisably high.

4.2.7.3. Reverse fired boilers

As a result of further development of bottom fired boilers, the so-called reverse fired boiler was invented (see Figure 4.24 and Figure 4.25) where usually the ceramic or metalloceramic grate is used for stabilizing the combustion.

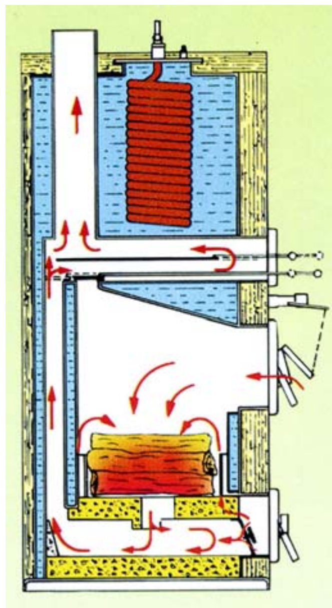
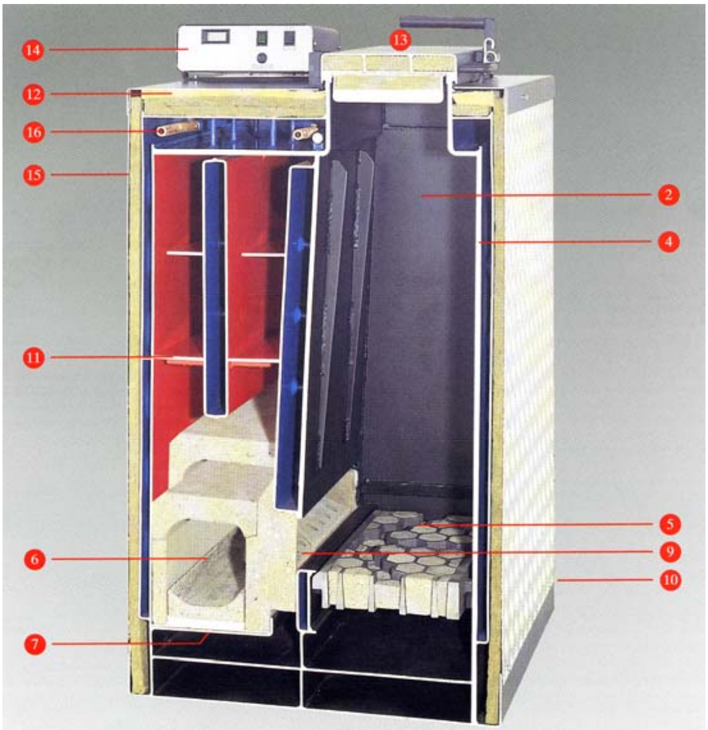


Figure 4.24. The reverse fired boiler EXONOM A25 BX MILJÖ made by the Swedish company EURONOM where a spiral heat exchanger is installed in the water volume

A heat resistant grate with the high operating temperature provides excellent combustion conditions also in case of varying boiler load. The boiler efficiency remains high and the content of hazardous emissions in the discharged flue gases is low.

The requirements to the grate are very high: it must be temperature and shock resistant during the boiler lifetime while logs may fall on the grate when filling the firebox. Naturally, such a grate is expensive.



1, 3, 8, 13 – fuel refill and maintenance hatches; 2 – fuel chamber with the expanding lower part; 4 – cooling wall of the chamber; 5 – ceramic grate; 6 – ceramic secondary combustion chamber; 7 – air distribution and control system below the secondary combustion chamber; 9 – flue gas outlets; 10 – control valve of flue gas temperature (in the rear of the boiler); 11 – flue gas flow directors; 12 – insulation; 14 – control panel; 15, 17 – outer wall; 16 – heat exchanger

Figure 4.25. Reverse fired boiler DRAGON of the Austrian GRIM GmbH

Several different fuels can be burned in the DRAGON boiler (see Figure 4.25). Hatch 1 is used for refilling with wood when log wood is fuelled, for woodchips hatch 13 is used. The width of the fuel chamber allows feeding with 0.5 to 1 m long logs and the capacity of boilers remains in the range 15 to 70 kW.

4.2.7.4. Dual and universal boilers

A wood fired boiler can be rebuilt into universal boiler in several ways. One of the simplest options is installing electric heaters in the water volume of the boiler, which will be switched on as soon as the temperature of boiler water drops below a given minimum temperature. Since the electric heaters and their control automatics are not expensive, this could be a possible option at designing any small boiler.

Another option is using replaceable furnace doors. The door or maintenance hatch of a top fired or bottom fired boiler can be replaced with the one, which has a hole fitting for the connection to a liquid fuel burner. In this case with some simple readjustment, a wood fired boiler can be converted into a liquid fuel boiler, or vice versa.

Also, such technical solutions are possible where the oil burner can operate independently from the wood firing part of the boiler and the burner is switched on automatically when the wood in the furnace has burned out and the water temperature is falling. Sometimes two totally separated furnaces with the combustion chambers and flue gas tracts are constructed in the common water-jacket of the boiler. These boilers are called dual boilers (see Figure 4.26).

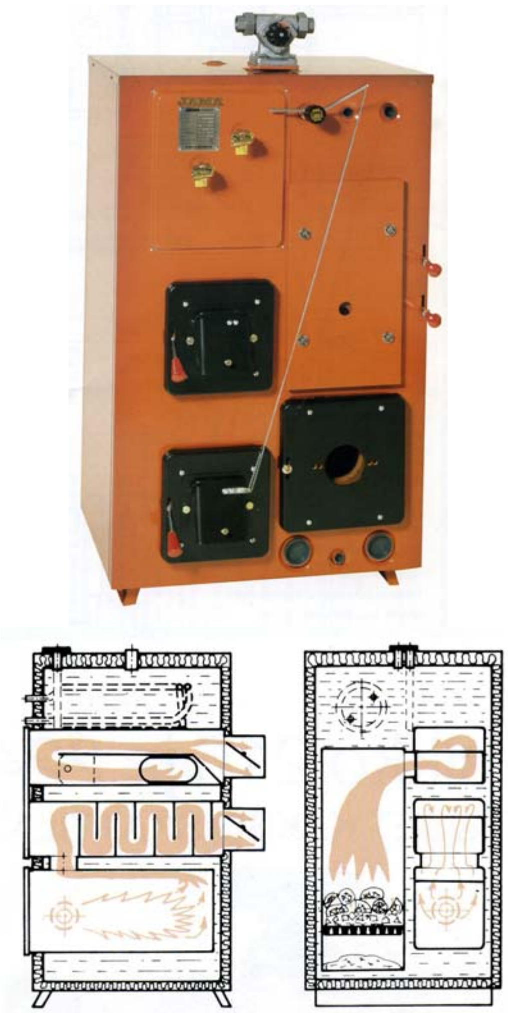


Figure 4.26. Dual boiler Jämä Kaksikko, JÄMÄTEK Oy, Finland

Above: the front view, below on the left: the cross-section of oil firing section and on the right: the cross-section of top fired solid fuel section.

4.2.7.5. Pellet boilers and fireplaces

Pellets are well suitable for heating single family houses and besides boilers they can also be used in fireplaces. The above described pellet combustion methods (see section 4.2.4) can be implemented both in family house boilers and bigger ones.

In the following figures (see Figure 4.27 and Figure 4.28) a common method for using the pellet burner with a small boiler is given. Since the pellet burner (see Figure 4.29) can also be adjusted to the light fuel oil boiler, there will be no need for the boiler replacement when switching from fuel oil to pellets. It will be only necessary to replace the liquid fuel oil burner with the pellet burner.

Figure 4.27. The Malle 20 kW boiler (AS Viljandi Metall, Estonia) with the pellet burner Iwabo VillaS and pellet feeding system

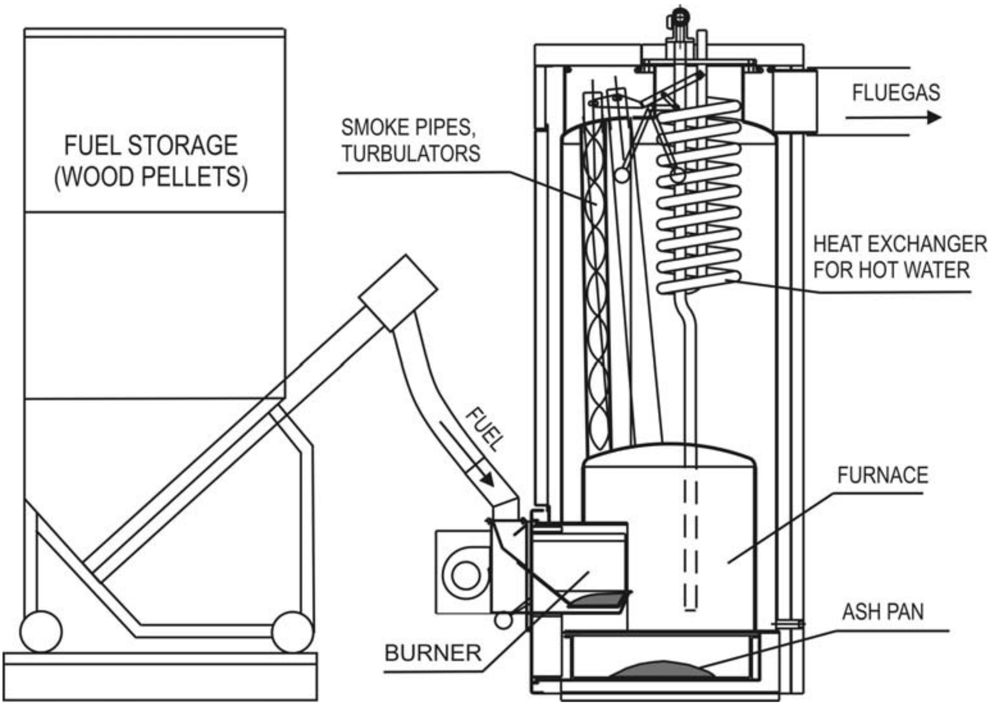


Figure 4.28. The small boiler Pelle with the pellet container, feeder and burner Iwabo VillaS developed at Tallinn University of Technology

Figure 4.29. Two views of the pellet burner Iwabo VillaS

5. FUEL STORAGES AND CONVEYORS

5.1. General requirements for the storage of solid biofuels

In this chapter mainly the storages and conveyors for woodchips, milled peat, sod peat and combustible biological waste (household waste) will be treated. Less attention will be paid on the storage of log wood and fuel pellets, as these fuels are mostly used in smaller local heating facilities of the capacity below 300 kW. The pellets are a fuel of uniform (homogeneous) consistence and the layout of the combustion equipment given in other chapters give a good description of their storage and combustion options (see Figure 4.16).

The pellets are also widely used in big combustion plants in some countries (e.g., Sweden), but in most cases the fuel is pulverized before feeding into the pulverized firing furnace and the fuel preparation does not differ much from the respective preparation of fossil fuels.

A typical biofuel fired boiler plant is designed with a solid fuel boiler in the centre. Such a boiler plant of 1 to 10 MW in general consists of the following key devices:

- fuel storage;
- fuel handling equipment;
- fuel bin;
- boiler feeder system (for feeding fuel into the furnace);
- combustion unit – boiler,
- flue gas cleaning equipment,
- ash handling system.

In order to determine the required capacity of a new boiler plant, the annual heat demand of the connected heating system must be known. Also the daily and yearly variation in heat demand must be known (see section 7.2, load curve). According to the above, the required fuel stock in the storage is defined.

The amount of fuel stored at the boiler plant and thus the capacity of the fuel storage depend on several factors, including also the type of agreement with the fuel supplier. In general the 5 day fuel stock is considered a minimum reserve for the maximum heat load. Such a reserve provides fluent operation of the boiler plant on weekends and holidays for the extreme weather conditions. For providing fire safety, it is not recommended to store fuel in the heaps higher than 8 meters.

In the woodchips storage there is a constant danger of breathing in the allergy dust or micro-organisms. Therefore the storage must be well ventilated and it is not recommended to work in the storage alone.

The bulk volume of different biofuels varies significantly and it must be considered when designing the storage spaces. Figure 5.1 gives the bulk volumes of several solid fuels, which would give the same amount of heat for the complete combustion that the light fuel oil does, i.e. the volume of light fuel oil has been taken for a basis of the comparison.

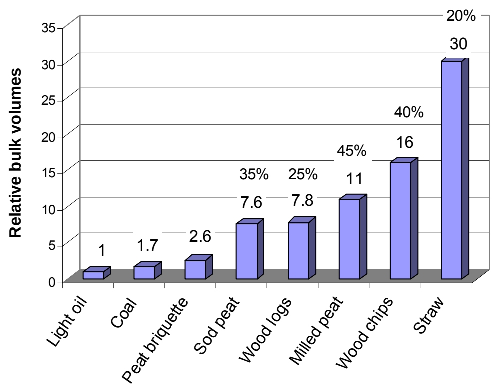


Figure 5.1. Relative bulk volumes of fuel (mean moisture content also shown)

While the storage and feeder systems for woodchips, sod peat and milled peat differ a little and mainly in the conveyor construction, the properties of straw as a fuel differ so much that special conditions are required for the storage and a special technological solution must be developed for feeding this fuel into the furnace.

The biofuel storage must meet the following basic requirements:

- must protect the fuel from weather impacts, surface and ground water;
- storage should be mechanized, for higher capacities also automated;
- vehicles delivering the fuel must have access to unload directly in the storage or mechanized reception unit.

The main failures in the operation of biofuel fired boiler plants occur when conveying fuel from the storage to the boiler feeder system. Therefore, the delivery system from the storage to the boiler is of significant importance. The boiler plant will fail to operate when some link in the fuel delivery chain breaks down. In the storages (woodchips) of biofuel boiler plants a fuel crusher is used very often before feeding the fuel into the boiler. The crusher has to crush mainly the frozen fuel.

5.2. Storage types

The storages can be provisionally divided as follows:

- an interim storage (fuel storage) with the capacity of about five day fuel stock and
- terminal with the storage capacity of maximum one day fuel stock and for the automated fuel supply to the boiler.

The fuel interim storage and terminal are usually located in one building, for example in a metal storage facility with a concrete floor (see Figure 5.2). The interim storage may also be located separately. For woodchips also a concrete or asphalt paved open square may be used as an interim storage facility, but in this case the fuel remains unprotected from weather impacts.

Figure 5.2. Fuel storage – an interim storage, photo by Ü. Kask

In higher capacity automated boiler plants the crane with automatic detector is used for filling the terminal (see Figure 5.4). In smaller boiler plants the fuel is transported from the interim storage to the terminal by a bulldozer or frontal loader (see Figure 5.3).

Figure 5.3. Frontal loader, photo by Ü. Kask

A mechanized storage for the sod peat is a particular complex of fuel receiving and unloading devices with appropriate structures. The storages can be either hall-type or bunker-type.

Bunkers can be at least partially drive-in facilities and for the accessibility one wall or roof of the bunker has to be designed so that it can be opened. The trucks are also unloaded from the delivery bay or a supplementary receiving device is used. In the first case a truck is driven on the delivery bay or elevated ground and tips the fuel to the bunker from the top. This modification is used mainly when it is a side-tipped vehicle. In the second case the vehicle can be tipped backward or has a conveyor for unloading the truck body. The third option is unloading the vehicle from the ground level into the underground bunker or conveyance of the fuel dumped on the ground to a ground-level bunker with an auxiliary conveyor.

In general the bunker has to have vertical walls or it can expand downwards. If not, evidently an arch of fuel could be formed above the device unloading the bunker. In order to avoid moisture freezing on the bunker walls and bottom, the circumference of the bunker is covered with waterproof (greasy) plywood. For the clean and dry sod peat (less than 5 % of the particles finer than 20 mm, moisture content below 33 %) the danger of arching is insignificant and therefore the storage could also be funnel shaped. The walls of such a storage outside the boiler plant must be thermally insulated and should have some heating. The size of this storage is limited and the stock has also to be limited to the amount of an order (for example 1 day instead of 3 days).

5.3. Fuel handling equipment

As mentioned above, bulldozers or front loader-tractors or cranes with automatic detector are used for filling the terminal with fuel. The front loaders are used when the interim storage is located in the same building with the terminal or further away. The crane can be used only when the interim storage and terminal are located in the same building. Sometimes the fuel is fed directly into the furnace with a crane.

Grab crane (see Figure 5.4). The crane is a vehicle of high efficiency that can be well used also for delivering low quality fuel. It is essential to use grapple forks. For grapples without forks it is difficult to fill the shovel. For large boiler plants a grab crane is a relatively inexpensive solution, for very small boiler plants it is too expensive device.

Figure 5.4. Grab crane, photo by Ü. Kask

The structure of the fuel terminal includes also the bunker discharge equipment. The principal requirements to this equipment in the storage are the following:

- they must provide the necessary productivity and enable productivity control;
- the discharge opening must not be clogged;
- the unloaded bunker must resist to the dynamic blow from the fuel falling in;
- the fuel flow must stop instantaneously when the discharger is halted;
- the bunker floor must be completely emptied;
- the discharger and bunker construction must exclude fuel arching;
- the construction must be fireproof;
- spilling and dusting must be excluded;
- wear and tear must be considered when selecting materials.

The most widely used spread devices for unloading the bunker are the following:

- push elements (push floor);
- chain scraper;
- fixed shaft screw;
- screw bottom; can be a radially rotating and transversal screw;
- hydraulic rotor.

Next we shall consider some most common terminal discharge devices.

Hydraulic pushers or push floor (see Figure 5.5). In the bottom of the bunker triangular shaped pushers are fixed on the bearing beams running the length of the bunker. The system of beams and pushers is pushed and pulled by the hydraulic cylinders (see Figure 5.6). The pusher shape and the reciprocal movement of neighbouring pushers provide a guided fuel flow. For a low fuel layer, the fuel flow is partially pushed and pulled. In order to reduce this movement, some special designs of the bunker bottom have been developed. The discharge opening for fuel unloading must run over the whole bunker bottom width and the conveyor must provide discharging of all the fuel pushed there. The discharger is used for unloading rectangular flat bottom bunkers.

The benefits of push-floor bunkers are the following:

- bunker floor can be located on the ground;
- reliable and simple design, stones and stumps does not disturb normal operation of the bunker;
- height of the fuel pile may reach 10 m;
- equipment to be maintained (hydraulics) remain outside the fuel storage area.

Disadvantages of the push-floor bunker:

- relatively high power demand;
- the bunker cannot be emptied completely and uniformly;
- stricter requirements to the building structure resistance and stability.

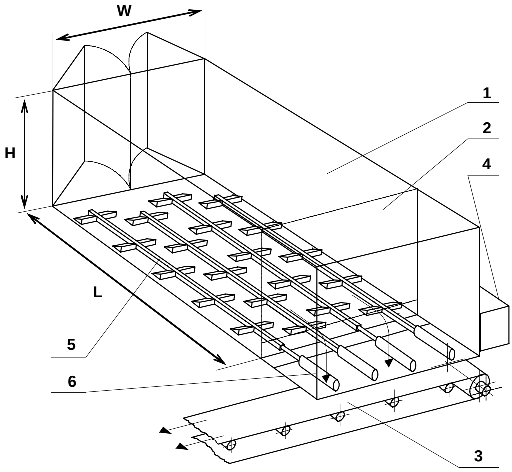


Figure 5.5. Solid fuel bunker with pushers

1 – bunker; 2 – front wall of the bunker; 3 – belt conveyor; 4 – power pack; 5 – push element (pusher); 6 – hydraulic cylinder

Figure 5.6. Hydraulic cylinders driving the push floor elements (Saxlund)

Chain scraper (see Figure 5.7). In narrower bunkers two chains are attached on the sprockets and four in wider ones. Between the chains one or two rows of scraper bars made of flat steel or angle steel bars are fixed. The drive to run the chains is located in the outlet end of the bunker and the upper chain is the pulling chain. Since the velocities are very low ranging between 1 to 25 cm/s, the ratchet gear run by the hydro- or electric drive is used and sometimes it can also be driven by the hydromotor. The scraper runs only in one direction. It can be used for unloading the rectangular flat bottom bunkers. The benefits of the chain scraper are:

- the process of fuel unloading from the bunker runs smoothly and is easily controllable;
- the power demand is lower than that of push-floor discharges;
- bunker can be completely emptied.

Disadvantages of the chain scraper:

- more complicated design and therefore lower reliability than that of push-floor discharges;
- the bunker must have empty space under the bottom to locate the backward moving lower chain;
- the bunker width and height of the fuel pile are limited (height up to 5 m).

Screw conveyors (see Figure 5.8). The screw conveyors can be those of the moving and fixed shaft. The first can be divided into the conveyors with radially rotating and transversal screws. The conveyors with transversal screws are used in the bunkers with rectangular flat bottoms. Such screw moves backward and forward along the bunker bottom pushing the fuel out of the bunker into the conveyor mounted perpendicular under one bunker end. The conveyors with radially rotating screw are used in the bunkers with conical or flat circular bottoms. The rotating screw delivers the fuel to the outlet in the centre of the bunker bottom where the fuel falls into the next conveyor. One or several screw conveyors with the fixed shaft can be mounted in the bunker bottom. In the first case the bunker becomes narrower downwards and its field of application is limited. The bunker of this shape can only be used for the screened and dry sod peat.

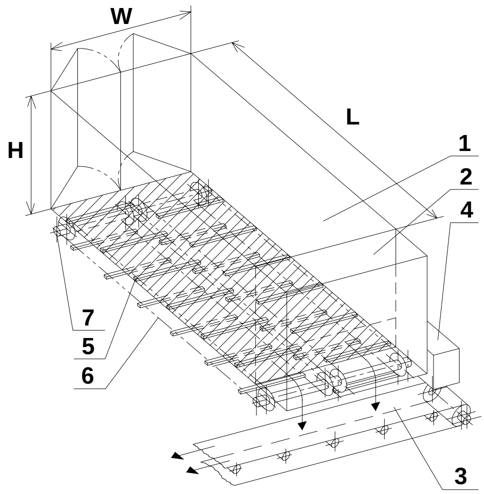
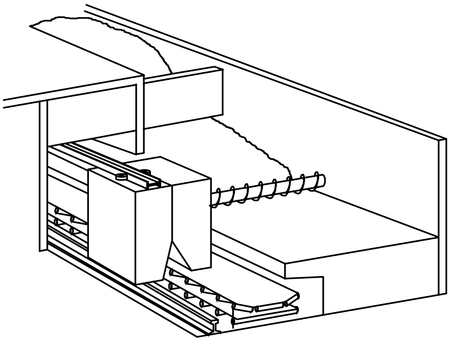


Figure 5.7. Solid fuel bunker with the chain scraper bottom, above photo by Ü. Kask

1 – bunker; 2 – front wall of the bunker; 3 – belt conveyor; 4 – power pack or electric drive; 5 – scraper; 6 – chain; 7 – idler a)



b)

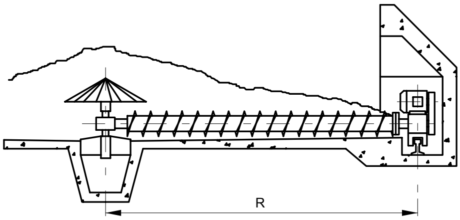
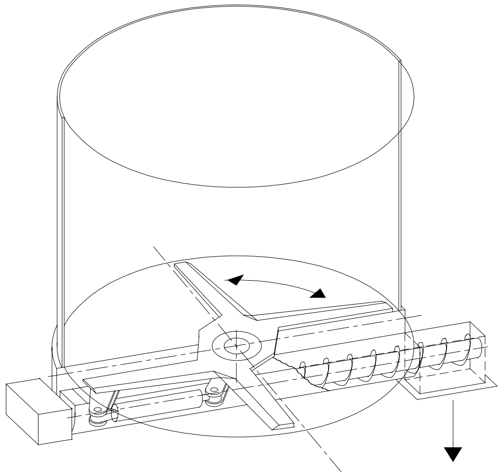


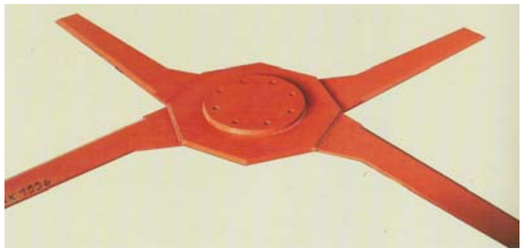
Figure 5.8. Screw conveyors in the bunker bottom

a) bottom with transversal screw;

b) bottom with radially rotating screw.



A. Bunker



B. Rotor

Figure 5.9. Bunker with the hydro rotor (Saxlund)

The main benefits of screw conveyors are:

- long length is possible;
- uniform productivity;
- precise productivity control.

Disadvantages of screw conveyors:

- heavy wear and tear;
- sensitive to the metal, stones, tree branches, stumps, etc.;
- high starting torque;
- crushes the material to be transported (significant for the sod peat).

Hydro rotor (see Figure 5.9). In the bottom of a cylindrical silo there is a multiblade rotor, which rotates in reciprocal directions driven by hydraulic cylinders fixed under the bottom of the silo. The profiled rotor blades push the fuel into the outlets in the silo bottom above a conveyor. The hydro rotors are used for unloading fuel from the cylindrical silos with the diameter up to 10 m and height 25 m.

When considering the benefits and disadvantages of storage discharge equipment, they must be adjusted to different fuels in different ways. In the tables (see Table 5.1 and Table 5.2) the suitability of various storage discharge equipment and also conveyors to the sod peat and woodchips has been evaluated. The latter is often used as a reserve fuel in the peat fired boilers. The data is derived from the following source [51].

Table 5.1. Suitability of the storage discharge equipment for solid fuels

Device	Sod peat	Woodchips
Chain scraper	++	+++
Push-floor	+++	+++
Flat bottom with screw conveyors	++	+++
Chain scraper	+	++
Hydro rotor	+	+++

+ suits with limitations
++ suits
+++ suits well

Table 5.2. Conveyor suitability for solid fuels

Device	Sod peat	Woodchips
Screw conveyor	+	++
Belt conveyor	+++	+++
Elevator	+	+++
Chain scraper	+++	+++

+ suits with limitations
++ suits
+++ suits well

6. MITIGATION OF ENVIRONMENTAL IMPACTS FROM BIOFUEL BOILER PLANTS

Although a biofuel boiler plant is considered environmentally friendly, any technology has some impact on both the natural environment and residents in the region. The direct impact of biofuel boiler plants on the surrounding environment could be summed up as follows:

- gaseous and solid emissions to the atmosphere;
- ash to be handled;
- noise;
- fuel transport with heavy-duty vehicles.

The possible noise and unfavourable impact of heavy-duty vehicles traffic can be mitigated with the right selection of the site for the boiler plant and appropriate planning. In order to fight against solid and gaseous emissions, much more attention must be paid on the promotion of combustion and gas cleaning technologies, which should create potential for meeting the increasingly stringent environmental requirements.

6.1. Solid and gaseous emissions

Solid emissions from the boilers burning any solid fuel can be provisionally divided into bottom ash and fly ash. The ash from burning biofuels falls to the bottom of the furnace where it is collected and transported usually by a screw conveyor or a chain scraper conveyor to the collection hopper. The fly ash is the fraction of ash particles carried by flue gases to the stack via the boiler flue gas tract.

The total of gaseous emissions depends directly on the ash content of the burned fuel. In general the ash content of woodchips and sawdust pellets remains below 1 %. The ash content of clean woodchips (debarked) can remain below 0.3 %. When a lower quality raw material is used (it contains plenty of bark, probably polluted with soil), the ash content can be higher (even over 5 %).

The typical ash content of peat is 4 – 6 %, which is quantitatively about 10 times higher than that of the clean wood fuel. The ash content of straw remains within the range of 3 – 5 %.

Besides the quantities, the ash content must be considered also for the ash storage and handling.

The hazardous gaseous emissions are first of all sulphur emissions (SO_2), nitrogen emissions (NOx[6]), carbon monoxide (CO), unburned hydrocarbons and carbon dioxide (CO_2).

The carbon dioxide emissions should be treated separately, because its increased content in the atmosphere is a reason for the global warming or climate change. During the growth of biomass the amount of carbon dioxide absorbed from the atmosphere as a result of photosynthesis equals its emission back to the atmosphere as a result of combustion. Besides, it is worth of noting that CO_2 released from the decay of biomass in the nature is emitted back to the atmosphere. If the biomass is burned in the amount of its increment, the carbon dioxide released from the biomass combustion to the atmosphere does not influence its content in the atmosphere and according to international agreements this carbon dioxide is not taken into account as a greenhouse gas.

The concentration of carbon monoxide and unburned hydrocarbons in flue gases depend practically only on the combustion conditions and appropriate uniform distribution of the combustion air.

The sulphur and nitrogen emissions depend both on their content in the fuel and combustion process. In most of the biofuels and peat, the content of nitrogen

[6] The symbol NOx is used for nitrogen oxides NO and NO_2, but nitrogen can be found in the emissions in the form of laughing gas (N_2O).

and sulphur is not high and capturing of these compounds in the flue gases of biofuel combustion plants is not often implemented.

6.2. Standards for the limitation of pollutant emissions

The objective of the Directive 2001/80/EC on the limitation of emissions of certain pollutants into the air from large combustion plants is to reduce the emission of pollutants into the atmosphere significantly and for this purpose the limiting values are set to certain pollutants. A large combustion plant in the context of this directive is a combustion unit with the thermal capacity of at least 50 MW independent of the type of used fuel.

In the Directive biomass means products consisting of any whole or part of a vegitable matter from forestry or agriculture, which can be used as a fuel. Additionally, the following waste used as a fuel can be considered as biomass as well:

- vegetable waste from agriculture and forestry;
- vegetable waste from the wood processing industry if the generated heat is recovered;
- fresh organic fibrous waste of pulp and paper industry if it is burned on-site and the generated heat is recovered;
- cork waste;
- wood waste, primarily the construction and demolition wood waste, excluding the residues that may contain halogenic organic compounds or heavy metals due to the wood impregnation with the protection systems or surface coating.

The limit value of pollutant emission per unit volume of gases discharged from the combustion unit into the ambient air is the permitted limit of pollutant emission per one normal cubic meter (at the temperature of 273 K and pressure 101.3 kPa) for the dry flue gas. For solid fuels, including the biomass, the limit values in flue gases are given at the 6 % oxygen content by volume.

In Estonia the limit values for the pollutant emissions from large combustion plants have been fixed with the Regulation No 112 of the Minister of Environment in order to provide both the observance of total emissions and local air quality.

The new and existing combustion plants are considered separately in order to exploit the working resource of earlier built plants without bigger environmental investments.

Table 6.1. Limit values of sulphur dioxide emissions for the existing solid fuel combustion plants

Thermal capacity of combustion unit, P, MW	Emission limit value, mg/Nm^3
50 ≤ P ≤ 100	2000
100 < P ≤ 500	2000 … 400*
P > 500	400

* – linear reduction according to the increase of heating capacity.

Table 6.2. Limit values of sulphur dioxide emissions for new biofuel combustion plants

Thermal capacity of combustion unit, P, MW	Emission limit value, mg/Nm^3
P > 100	200

Table 6.3. Limit values of nitrogen dioxide emissions for the existing combustion plants firing solid fuel

Thermal capacity of combustion unit, P, MW	Emission limit value, mg/Nm^3
$50 \le P \le 500$	600
P > 500, up to 12.31.2015	500
P > 500, from 01.01.2016	200 (450*)

* – for a combustion unit that is run less than 1500 hours a year (five year average).

Table 6.4. Limit values of nitrogen dioxide emissions for the new biofuel combustion plants

Thermal capacity of combustion unit, P, MW	Emission limit value, mg/Nm^3
$50 \le P \le 100$	400
$100 < P \le 300$	200
P > 300	200

Table 6.5. Limit values for solid particle emissions for the existing solid fuel combustion units

Thermal capacity of combustion unit P, MW	Emission limit value, mg/Nm^3
$50 \le P < 500$	100
$P \ge 500$	50

Table 6.6. Limit values for solid particles emissions for the new solid fuel combustion units

Thermal capacity of combustion unit, P, MW	Emission limit value, mg/Nm^3
$50 \le P \le 100$	50
P > 100	30

Note: in the tables the provisional term "existing" involves besides the presently operating plants also units, which received the building licence by November 27, 2002 at the latest and the combustion plants commissioned by November 27, 2003 at the latest, the term "new" covers the combustion plants that have received the building licence after November 27, 2002 or have been commissioned after November 27, 2003.

In general, in the EU the emissions from smaller combustion plants (< 50 MW) are not directly regulated by legal acts. In several countries the respective requirements have been imposed, but the profound comparison of the requirements is complicated since the terms applied to the limit values and those of respective measurements differ. For example in Austria, the country that has been a pioneer in imposing environmental requirements, the emission limits have been established based on the energy content of the fuel as fed into the boiler.

Table 6.7. Emission limits for wood fired boilers in Austria

Type of boiler	Emission limits, mg/MJ			
	CO	NO_x	OGC[7]	Particles
Manual feeding	1100	150	80	60
Automatic feeding	500	150	40	60

[7] organic gaseous compounds

The limit values per energy content of the fuel fed into the boiler cannot be compared with the pollutant content in flue gases without considering the peculiarities of the combustion process. For example, the value 1100 mg of CO per MJ corresponds to about 1700 mg/Nm^3 or 1400 ppm at the oxygen content of 13 %. At the same combustion conditions about 230 mg/Nm^3 or 110 ppm would correspond to the limit value of 150 mg/MJ and about 120 mg/Nm^3 to the hydrocarbon content of 80 mg/MJ.

In some countries special voluntary environmental standards have been introduced, e.g., the „Blauer Engel" in Germany and the ecological label („The Swan") in the Nordic countries.

In some countries the performance of small boilers is assessed based on the Best Available Practice (BAT) principle. Such a principle has been applied in Finland, Great Britain and Denmark.

Table 6.8. Voluntary environmental standard „The Swan" for solid fuel boilers in the Nordic Countries (mg/m^3)

Boiler capacity	CO	OGC	Particles
< 100 kW	1000* (2000**)	70	70
100 – 300 kW	500* (1000**)	50	70

Note: at the 10 % O_2 content in flue gas.

* – automatic fuel feeding

** – manual fuel feeding

With the environmental problems becoming more actual, coordinating of the requirements on small boiler equipment, including the biomass fired boilers has started also. The CEN European Committee for Standardization has established with the standard EN 303-5 requirements to solid fuel boilers with the nominal output capacity up to 300 kW.

Table 6.9. Emission limits (g/m^3, for the 10 % O_2 content) to the boilers with the capacity to 300 kW (according to the standard EN 303-5)

Nominal capacity,	**Manual fuel feeding**			**Automatic fuel feeding**		
kW	**< 50**	**50 – 150**	**150 – 300**	**< 50**	**50 – 150**	**150 – 300**
CO						
Class 1	25.00	12.5	12.5	15.0	12.5	12.5
Class 2	8.00	5.0	2.0	5.0	4.5	2.0
Class 3	5.00	2.5	1.2	12.5	2.5	1.2
OGC						
Class 1	2.00	1.50	1.50	1.75	1.25	1.25
Class 2	0.30	0.20	0.20	0.20	0.15	0.15
Class 3	0.15	0.10	0.10	0.10	0.08	0.08
Solid particles						
Class 1	0.20	0.20	0.20	0.20	0.20	0.20
Class 2	0.18	0.18	0.18	0.18	0.18	0.18
Class 3	0.15	0.15	0.15	0.15	0.15	0.15

Table 6.10. Emission limits based on the Best Available Technology for small (< 50 kW) wood firing units in Finland

Unit capacity, kW	NO_x		SO_2	
	mg/MJ	mg/m³	mg/MJ	mg/m³
1 – 5	100 – 130	250 – 325		
5 – 10	50 – 100	125 – 50		
10 – 50	20 – 50	50 – 125		
1 – 50			100 – 150	250 – 375

There is no directive in the EU that has made the EN 303-5 requirements compulsory. Nevertheless, the standard has been approved by the CEN[8], the standardization organisations of the CEN member states are obligated to accept the standard as a national standard. The standard EN 303-5 is a common basis for boiler manufacturing in all countries of the EU. The CEN Technical Committee (CEN/TC 295) has also developed standards for small (< 50 kW) household heating equipment and furnaces – EN 13229:2001, EN 13240: 2000, EN 12815: 2001 and EN 12809:2001.

6.3. Capturing of solid particles in flue gases

The flue gas must be cleaned to the required level in order to reduce the ash content in the gas discharged through the stack. The ash content in flue gas is defined by emission standards.

For separating the fly ash from flue gas different types of devices and methods are available: multicyclones, bag filters, electrostatic precipitators and also scrubbers. A new trend in cleaning the flue gas from the fly ash and improving energy efficiency of biofuel boilers is flue gas cooling, which would include condensation of water vapour from the gas and capturing of solid particles.

All listed devices have some advantages and disadvantages and therefore their application for cleaning a certain boiler flue gas depends on several circumstances, including the boiler size (capacity).

To provide high efficiency of cleaning equipment, the unit must be correctly selected and calculated. In the calculations for the cyclone and electrostatic precipitator, the gas flow rate through the unit is defined according to the size of ash particles.

The main application factors of gas cleaning equipment are shown in Table 6.11.

Table 6.11. Performance indicators of gas cleaning equipment

Unit	Ash content in gas, mg/Nm³	Application temperature, °C
Multicyclone	150 – 500	< 500
Bag filter	10 – 50	< 150
Electrostatic precipitator	99.9%*	< 300
Scrubber	50 – 100	< 70 – 80

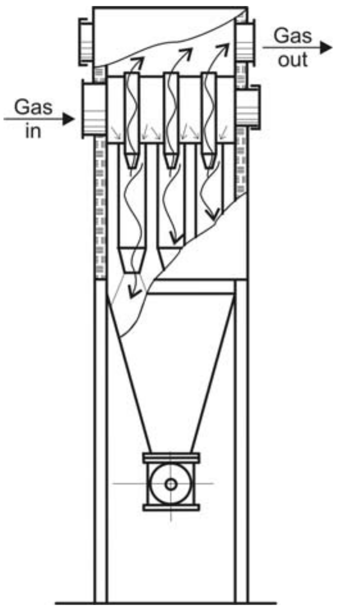
* The performance of electrostatic precipitator is characterized by its cleaning efficiency.

6.3.1. Multicyclones

The cyclone is a unit where solid particles are separated from the gas flow by the centrifugal forces in a vertical tube.

[8] European Committee for Standardization

The multicyclone (see Figure 6.1) consists of several conventional or direct flow cyclones that are connected to the device with a common collector and hopper. Smaller size of the plant and lower resistance of the gas duct can be obtained with the use of a multicyclone.



Producer Justsen Energiteknik A/S (Denmark)

Type JU-EM

Efficiency 80 – 90 % (depending on the ash coarseness)

The ash content in flue gases is 150 – 300 mg/Nm^3 (depending on the fuel quality)

Figure 6.1. Multicyclone

The fly ash from wood burning contains relatively big particles and therefore they can be easily separated in multicyclones. In multicyclones the ash content of flue gas can be reduced to the level of ~150 mg/Nm^3. The multicyclone is relatively inexpensive, of simple design and does not require special maintenance. Therefore, multicyclones are quite widely used in boiler plants. Important is also the fact that the multicyclone is not especially sensitive to temperature.

6.3.2. Bag filters

In bag filters (see Figure 6.2) the solid particles in the gas flow are captured with fine fabrics or porous ceramics.

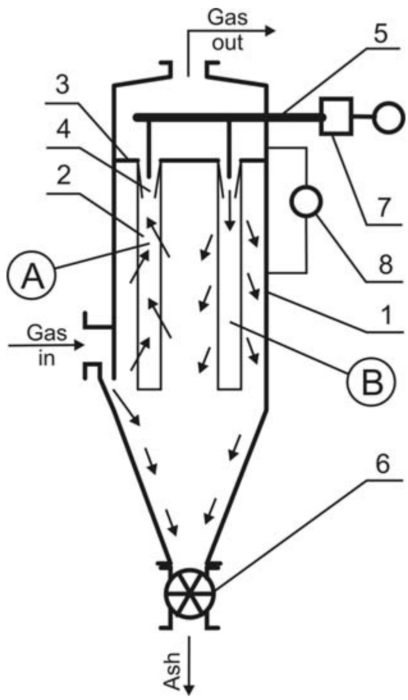


Figure 6.2. Bag filter with pulse jet cleaning

A – filtration, B – regeneration; 1 – body; 2 – filter element; 3 – Venturi plate; 4 – Venturi; 5 – compressed air collector; 6 – rotary valve; 7 – solenoid valve; 8 – pressure gauge.

The bag filters are significantly more effective flue gas cleaning units than multicyclones, providing the flue gas ash content of 10 – 50 mg/Nm^3. As a rule, the working temperature of bag filters does not exceed ~180 °C. The most frequently used material for the filters is polyester fabric. The teflon fabric has essentially better chemical resistance and temperature tolerance, but compared to the polyester fabric it is tens of times more expensive.

In order to prevent spreading of sparks into the filter, a cyclone or settling chamber is installed in front of the filter. The bag filter requires regular regeneration/cleaning to provide the filter high efficiency and low resistance. The most common bag filter cleaning methods are: mechanical shaking, cleaning with the reversed gas flow and pulse cleaning. Also some combined cleaning methods are used: for example, mechanical shaking follows the reversed gas flow.

Due to the possible exposure to ignition, the bag filter must be protected from high temperatures and high oxygen content in flue gases. Usually an automatic protection system is used to channel the gas past the filter.

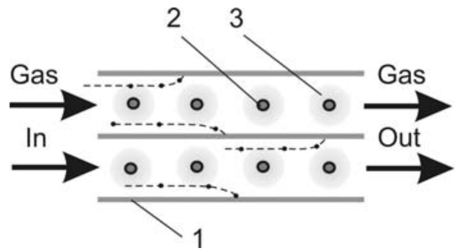
In biofuel combustion equipment the bag filters are not so often used as multicyclones. In the larger plants bag filters are used as secondary units after multicyclones.

6.3.3. Electrostatic precipitators

In the electrostatic precipitators (see Figure 6.3) the gas to be cleaned flows through the electric field and the solid particles are precipitated on the electrodes.

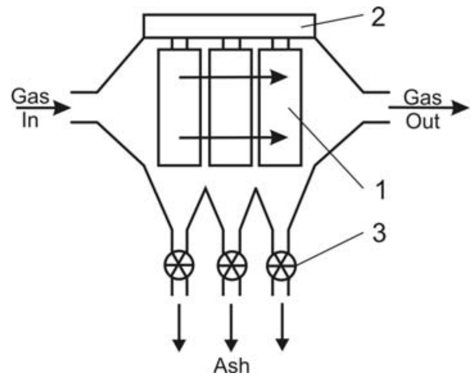
Operation principle. The precipitator electrodes have DC high-voltage supply while the energized corona electrode is usually negative. High voltage between the electrodes creates a corona discharge and most of the gas between the electrodes is negatively ionized. The negative ions move to the precipitating electrodes under the impact of the electric field. The ions moving towards the precipitating electrodes collide with solid particles in the dusty gas and are absorbed at the latter surface. As a result, the dusty particle will be charged negatively and start to move towards the precipitating electrodes. The electrodes are cleaned from the deposited material by shaking them regularly.

The electrostatic precipitator is an efficient, but relatively expensive gas cleaning unit. This is why their application in small biofuel units is limited.



A. Performance principle

1 – precipitating electrode; 2 – corona electrode; 3 – ion field or corona



B. Longitudinal section

1 – precipitating electrodes; 2 – high-voltage units and electrode shakers; 3 – rotary valve

Figure 6.3. Electrostatic precipitators

6.3.4. Flue gas condensation

With the flue gas condensation (or more precisely condensation of water vapour from flue gases) two objectives can be obtained: firstly, the ash particle content in the flue gas will be reduced to the level comparable with the efficiency of a bag filter, and secondly, the energy efficiency will increase on account of the heat released by condensation.

The flue gas in the biofuel boiler contains water vapour for two reasons: the reaction of hydrogen in the fuel with the air oxygen in the combustion process gives water vapour and the moisture in the fuel (the usual moisture content of woodchips is 35 – 55%) is also converted to water vapour.

The water vapour content in flue gas is of interest, because it is the non-utilized energy released by condensation (see also 4.1.3). Theoretically the released condensation energy equals the evaporation heat of water plus the heat from cooling. When the flue gas is cooled under dew point, the water vapour starts to condensate. To the lower temperature the flue gas is cooled, the more water vapour is condensed and heat gained. For cooling the flue gas, the return water from the district heating system is used (see Figure 6.4 [57]).

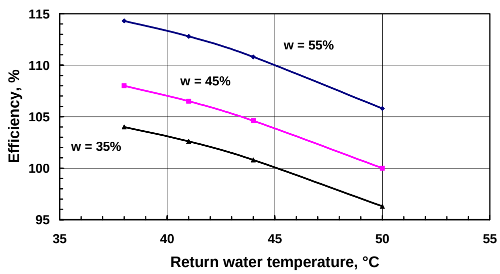


Figure 6.4. Impact of flue gas condensation on the boiler plant efficiency

The flue gas cooler is the first unit in the boiler plant that the return water passes.

The residual of flue gas condensation is the condensate that consists of water, which includes smaller amounts of dust particles and organic matter from incomplete fuel combustion. In the condensate also heavy metals, chlorine, and sulphur can be found. The pH (alkality) of condensate may vary in a wide range depending on the system structure, but usually it remains within the limits of pH 6-7. The heavy metals, first of all cadmium can be found in the solid part and they are insoluble in water. Therefore the condensate must be pre-treated before discharging it into the nature. The treatment is usually filtration of solid particles and neutralisation of water to the level that corresponds to the respective environmental requirements [22].

To avoid the transfer of water drops into the flue gas tract and stack, an efficient spray catcher is used after the flue gas cooler. In small boiler plants where the flue gas is condensed, a reasonable solution for reducing the corrosion risk is to use corrosion resistant materials in the flue gas tract and stack construction.

6.4. Ash handling and utilization

6.4.1. Ash handling

As mentioned above, the ash content of woodchips and wood pellets is mostly ~1 % that of cereal straw 3 – 5 % and peat fuel 4 – 6 %. This part of non-combustible mineral matter becomes ashes in the combustion process and has to be removed from the boiler unit.

Ash handling can be either a dry or wet process and respectively dry or wet handling systems are used.

For the dry ash handling the boiler and flue gas tract have to be equipped with special devices for ash disposal to provide the air-tightness of the system (rotary valves, cone discharger valves). The Figure 6.5 shows an rotary valve from the Saxlund company.

Figure 6.5. Rotary valve (Saxlund)

The ash is further transported by a screw or drag chain conveyor (see Figure 6.6) to the collection hopper. For larger boiler plants also pneumatic transport is used.

Figure 6.6. Drag chain conveyor (Saxlund)

In the wet ash handling system, as a rule, no special devices are needed for providing the air-tightness of the system, because the suction of false air into the boiler is excluded by water locks. A disadvantage of wet ash handling is heavy wet ash in the ash container and corrosion.

The frequency of container discharge depends on the fuel flow and container capacity, once or twice a month during the heating period can be considered reasonable. Figure 6.7 shows some solutions of ash containers for a biofuel boiler plant.

6.4.2. Ash utilization

The wood ash contains nutrients vital for the plants, e.g., potassium, magnesium and phosphor. Therefore, wood ashes can be used for forest fertilizing in case the content of some component is not too high and does not exceed environmental standards.

A. Ash container with a screw conveyor

B. Container under the ash hopper. Between the hopper and container an air-lock can be seen.

Figure 6.7. Ash containers, photo by Ü. Kask

From the wood or straw combustion also heavy metals concentrate in the ashes. However, when returning ashes either to the growing site of the forest crop or field crop in reasonable quantities, the situation does not differ much from that where the felling waste is left in swaths in the cutting area or straw in the field. Still, wood ashes must be utilized in the forest areas and straw ashes in agricultural lands.

The peat ash is not suitable for fertilizing forest and field crops due to its chemical composition and therefore the use of peat ash is limited. This ash can be used as a basement material in road construction for example. If the ash could not be used, it has to be stored according to the requirements. Utilization of peat ash must be in accordance with the local legislation.

There is a certain relation between the combustion quality and content of polyaromatic hydrocarbons (PAH) in the ash. Therefore, simultaneously with the fixing the heavy metal content also the content of unburned carbon in the ash must be determined. When the content of residual carbon in the ash remains below 5 %, the PAH can be determined every second year, but when the content of unburned carbon exceeds 5 %, the PAH analysis must be made every year [22].

6.5. Cleaning of boiler heating surfaces from deposits

The furnace and heating surfaces of a running biofuel boiler will be covered with ash and soot at the flue gas side with time. The deposition of solid combustion residue is called gas side fouling of heating surface. Also, fouling of heating surfaces at the water side occurs and this is called inside fouling.

Gas side fouling of heating surfaces in a solid fuel boiler is essentially more intensive than that in gas or light fuel oil fired boilers. Due to fouling, the gas in the boiler is cooled less efficiently and both the efficiency and heat capacity of the boiler decrease. The gas side deposits of biofuel boiler are in general friable or sintered to some extent and quite loosely attached to the heating surface. The behaviour of the deposit depends on the temperature regime of the boiler heating surface and on fuel combustion regime.

In order to keep the thermal capacity of the boiler possibly high, the heating surfaces must be regularly cleaned. The cleaning depends on the fouling intensity and selected cleaning method.

The methods used for cleaning biofuel boilers are: pneumatic cleaning, vibration cleaning, and acoustic cleaning methods. Also cleaning with a steam jet or water jet is known, but these methods are used for hardly removable deposits and thus they are of no interest as cleaning methods for biofuel boilers.

Pneumatic cleaning. In the boiler gas tracts the compressed-air nozzles or blowers equipped with nozzles are mounted. For expanding the cleaning range, the blower is given both linear and rotary motion. In between the blowing sessions the blowers are pulled out of the gas tract. Cleaning is performed while the boiler is running. The cleaning process is fully automated. For this method compressed air is needed for cleaning.

Vibration cleaning. The heating surfaces are shaken with mechanical vibrators (shakers). The vibrating movement of tubes is transferred to the deposit on the tube surface that will be influenced by the inertial force of the deposit. The relationship between the deposit strength and inertial force defines the probable removal rate of fouling. This method is used for cleaning platen heating surfaces.

Spring hammer cleaning. A mechanical shock with a hammer on the heating surface shakes the surface and as a result the surface is released from deposits. The frequency of shocks – from some minutes to several tens of minutes – is chosen based on the intensity of fouling. This method is used for cleaning platen heating surfaces from soft unbound deposits.

Acoustic cleaning. The cleaning device (Nirafon, Primasonic) removes particles from the heating surfaces by an acoustic pressure shock. The pressure shock is repeated until the required cleaning results have been achieved.

For small boilers simple cleaning methods are used. In the boiler manual usually cleaning of heating surfaces and furnace is foreseen using the accessories (scoop and brush) included in the boiler set.

7. PLANNING OF HEAT SUPPLY SYSTEMS USING SOLID BIOFUELS

7.1. Determining the heat demand

When planning the heat supply in district and local heating systems, the proper determination of heat demand is of definite importance – the whole system has to be dimensioned based on the demand. The heat demand depends on many factors, the most essential of which are the following:

- heated area and/or volume of buildings;
- purpose of the use of buildings;
- operation time;
- ventilation characteristics and operation time;
- consumption peculiarities of hot tap water;
- technical condition of the heat supply system;
- consumption habits.

It is expedient to divide the users into groups for estimation of demand depending on the user behaviour. The user groups to be analysed separately could be the following:

- residential houses;
- office buildings;
- stores;
- schools and kindergartens;
- hospitals;
- hotels, etc.

The industrial enterprises where the process heat is needed will not be covered in this survey. As a rule, the users of each group have certain peculiarities in heat consumption that must be taken into account. While the demand for space heating of the typical consumers of these groups does not necessarily differ much, the difference in hot tap water demand is considerable. Certainly, differences emerge also from the ventilation system behaviour and performance.

The heat demand can be established in several ways. Regarding consumers connected to the district heating (DH) system to which the heat has been supplied for many years already with their actual heat consumption being measured, the heat demand of previous years can be taken for the basis. It is recommended to use the data of the last three years at least. Thereby, the consumption for heating should be normalized with using the degree days of the respective years. At the same time, the data on a very long period is not expedient to use either, because in this case the heat supply could be significantly influenced (reduced, as a rule) due to the renovation/insulation work made in the building in the meantime.

It must be underlined that when estimating the future demand based on the earlier consumption level, evident decrease of heat load in the future has certainly to be taken into account. The reason for the reduction can be additional thermal insulation of buildings, more flexible control of heat consumption, introduction of energy saving appliances and changes in the consumption habits, etc. The rising prices (both heat and water) and for example installation of water meters in each flat can also reduce consumption.

Initially declared demand of consumers and present boiler capacity cannot be taken as a basis for determination of future heat demand. Particularly, in the countries of transition economies the experience of last years has shown that both the production and transmission capacities in DH systems are oversized due to the significant decrease of consumption.

In order to estimate the heat demand correctly, possible accession of new consumers must certainly be considered too. The respective information should be available in the detailed plans of the district, if these have been developed by local authorities. The situation is even better when a development plan of energy supply is available.

For the consumers who are going to be connected to the DH system in the near future, the project documentation related to heat supply can be used for establishing the heat demand in case of a new building. When the new consumer is the one who has used the local heating before, the data on the earlier consumption can be used. For the consumers who are going to be connected to the system later, the demand could be estimated more simply based on the volume of buildings, number of inhabitants, etc.

In some regions it should be considered that some consumers may disconnect from the DH system. Such a case may occur if local authorities do not regulate heat supply, or if there is no zoning option anticipated for heat supply in the national legislation. Transfer to the local heating that is endangering the present district heating system is more extensive in the regions where the DH quality level is low, price relatively high, but at the same time a natural gas distribution pipeline is located nearby. In this case the DH company should cooperate closely with local authorities in order to find the solutions that would satisfy both individual consumers and the whole region.

Residential houses and office buildings need heat both for space heating and for hot tap water preparation while the energy used for ventilation is mostly considered as a part of space heating.

The energy demand for hot tap water preparation is defined via the number of residents of dwelling, daily estimated hot tap water demand per capita and temperatures of cold and hot tap water. In most cases the hot tap water temperature has to be increased for about 50 degrees, for example from 5 °C to the temperature of 55 °C.

The daily hot water demand depends much on the consumption habits of residents, but then the method of defining the hot water consumption is also very significant. The Estonian experience shows that after introducing the individual metering of hot household water and arranging the payment based on metering data, the average consumption decreases significantly, sometimes even 2 to 3 times.

Although the hot tap water is not used uniformly throughout the day, the thermal capacity for water heating is usually calculated based on the daily average consumption. Since only about one fifth of the energy for space heating is required for preparation of hot tap water, the required boiler capacity might be calculated without taking into account the peak load for water heating.

In order to calculate the energy cost for space heating either the total number of degree days of the considered period or difference between the average outdoor temperature and designed indoor temperature are used while these two methods do not differ essentially.

In order to determine the maximum thermal capacity for space heating, usually the fixed outdoor temperature for space heating calculations in the region[9] is used. For instance, the temperature for Estonia is –19 … –23 °C, for Stockholm –18 °C, for the northern part of Finland and Sweden even –29 … –32 °C. The lower the temperature used in calculations is, the higher heating capacity is required.

The heating capacity found in this way along with the capacity needed for hot tap water production is still not the capacity required for heat production in the boiler plant, but it gives the total heat demand at end consumers. For calculating the total boiler capacity, the losses in the heat pipelines must be taken into account; for

[9] The fixed outdoor temperature for space heating calculations is usually the average temperature of the coldest five day period in the region.

calculating the fuel demand also boiler efficiencies must be considered.

7.2. Load duration curve

As mentioned above, the heat load fluctuates – throughout the year and during a day. Therefore, determination of the load change time series is a complicated task. For the simplification it is recommended to use a special graph – the heat load curve (or load duration curve). The construction of the load duration curve is particularly expedient in case there is more than one boiler in the boiler plant. For building the curve, the data on the boiler(s) load in regular intervals (the recommended interval is an hour) has to be used. With arranging the data on load in the decreasing sequence and putting the values to the graph where the horizontal axis shows the hours during a year (8760) and vertical axis the load (in power units). As a result, we shall get the desired graph, which shows the load duration during a year. The area under the curve line in the graph shows the total of heat output (in energy units) produced during this period. The shape of load curve can differ significantly depending on the climate of the site, characteristics of the heat demand and several other factors.

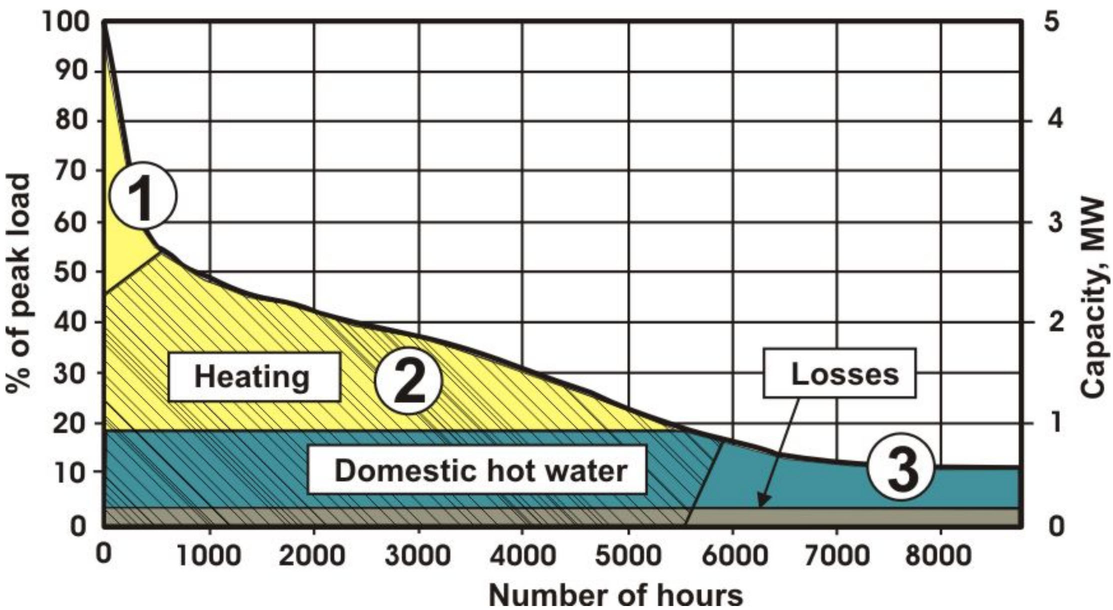


Figure 7.1. Typical load duration curve of DH boiler plant

The degree day used in heat supply calculations expresses the difference of 1 °C between the mean designed indoor temperature of a building (the so-called equilibrium temperature) and daily (the 24-hour period) mean outdoor temperature. For example, if the daily mean outdoor temperature is 2 °C, the number of degree days of the 24 hour period (1 day) is 16 (18 – 2 = 16, here the equilibrium temperature has been taken 18 °C). So far, there is no common practice between countries in the use of degree days in analysing the heat supply. For example, there are differences in the use of mean designed indoor temperature, there are also differences in calculation methods. Therefore, the data of different countries cannot always be compared, but it does not hinder the use of degree days for analysing the changes in heat demand, for example in the districts supplied by one boiler plant. For this purpose the so-called normalisation of heat consumption in different years could be recommended. The normalisation factor should be calculated by dividing the total of the degree days for each year with the number of long-term annual average of degree days. Comparison of normalised annual heat consumption allows analysing whether the differences were caused by weather conditions or by applied saving measures.

7.3. Boiler selection

Since the biomass boilers are relatively expensive, before making the investment decision the boiler should be selected in such a way that its annual utilisation time would be possibly long. In the following some general principles and criteria for the boiler selection are given.

Using the load duration curve the behaviour of annual heat load can be analysed. It can be seen that for covering the winter peak about 8 – 15 % of the annual heat demand must be produced. In the typical DH system the summer energy consumption makes also about 10 % of the annual demand. These are the peculiarities that must be considered when selecting boilers.

Several other factors have to be taken into account too. It is necessary to consider that a biomass boiler cannot operate on very low load, because then the boiler efficiency will decrease significantly. The high efficiency and low emission rate can be achieved with a stable operating load. Investment costs for biomass boilers are significantly higher than for fossil fuel boilers, but the biofuel price is significantly lower. Therefore, the biomass fired boiler should have the utilisation time at least 3000 – 5000 hours a year depending on the climate zone. For example, considering the climate conditions and fuel prices in Estonia, for the sake of economic feasibility the utilisation time should be higher than 4000 h a year[10].

For the most of solid fuel boilers the lowest running load is about 30 % of the rated capacity. The above shows that the capacity of biofuel boiler should be chosen by 40 – 50 % lower than the peak load. As a conclusion – the biofuel fired boilers should be operated for covering the base load. The base load is of uniform behaviour and provides a reasonably long running time at the rated capacity. The boiler with the capacity of about 50 – 60 % of the maximum heat load usually allows producing 80 – 90 % of the annual heat demand.

For covering the peak load, it is expedient to choose oil or gas fired boiler with capacity about 50 – 60 % of the peak load. In case the load is low in summer (demand of hot household water only), the same boiler could be used too, excluding thus the use of biomass fired boiler at a low load.

It should be noted that the boilers for burning refined wood fuels (pellets, briquettes) can be controlled better and in a wider range. Therefore, the capacity of a pellet boiler can be chosen as 65 – 70 % of peak load and in this case the production makes 90 – 95 % of the annual energy demand. The use of a pellet boiler for covering the peak load could also be considered.

In small and medium scale biomass fired boiler plants often three boilers are used: a biomass fired boiler for the base load and two light fuel oil boilers, one of which covers the peak and low summer load, and the other is a reserve boiler.

As a rule, the capacity of a reserve boiler should be equal to the capacity of the biggest boiler. In most cases some old boiler, which can still be operated, but has low efficiency can be used as a reserve boiler.

[10] The boiler utilization time is calculated dividing the annual heat output by the nominal capacity of the boiler

Possible implementation of heat accumulation (hot water tank) can also be considered when choosing the boiler capacity. This option can be considered in particular if there are big demand variations during a day. Heat could be accumulated during a low demand period and the accumulated heat can be used in the hours of high load. This would allow reduction of the peak boiler capacity. Heat accumulator can also be foreseen if installation of a solar water heater is planned. Naturally the expediency of such a solution depends on the climate zone/latitude of the site.

7.4. Infrastructure of boiler plant

The biomass fired boiler plant requires more space than the boiler plant of the same capacity firing oil or gas. In addition, space for a biofuel storage and for fuel transport vehicles is needed.

When biofuel is introduced in an existing boiler plant, in most cases the boilers can be fitted in the plant building, but some additional space is needed for the fuel storage and handling. When planning the solution for space, also the need for ash handling and disposal, and regular boiler cleaning must be considered.

When building a biofuel boiler plant, the site must be carefully chosen. Besides to the technical and spatial aspects, attention must be paid also to the environmental restrictions. Both fire safety and environmental restrictions are of definite importance, in particular when the boiler plant has to be located in the densely inhabited area. At the same time, the practice of several countries shows that such solutions are possible. However, the concrete conditions depend on the building legislation of the country and respective legal acts of local municipality, which must be precisely followed when choosing the site. No universal guidelines can be given for environmental requirements, but local requirements must be satisfied, including distribution of the pollutant emissions, height of the stack, noise level, etc.

The restrictions to the possible site of biomass storage may often be decisive for the selection of the site for the boiler plant. When selecting the site for a large boiler plant, the requirements related to the transport must certainly be taken into account: access space for the trucks with the required size must be provided. These problems can be solved with less efforts in case of building a new boiler plant. For the boiler plants with the capacity below 1 MW the amounts of biofuel are so small that there are no specific requirements to the transport.

In case of building a biomass boiler plant, the following approximate estimation of the size of the territory could be taken for the basis (see Table 7.1).

Table 7.1. Tentative size of the territory for biomass boiler plants [58]

Capacity, MW	Territory, m^2
2	2500
5	3000
10	7000

The need of space for the boiler house itself depends mainly on the boiler size. The space required for a reserve boiler must not be neglected either. When the heat analysis shows possible growth of the load in the future, some additional space could be reserved for the future extension if possible.

Chapter 5 deals in detail with fuel storages.

7.5. Fuel

When biomass is used, the choice has to be made mainly between non-refined (e.g., woodchips) and refined (pellets) fuels. The properties of pellets (also wood briquettes) and chips differ quite significantly (see section 2.2). In the local circumstances, availability and price of the fuel may turn out to be more important than considering fuel properties. Table 7.2 gives some factors that should be considered when selecting between the pellets and woodchips.

Table 7.2. Aspects of wood fuel use

	Pluses	Minuses
Woodchips	• a local fuel as a rule • promotes local employment • less expensive than pellets	• bigger investment • requires larger storage • non-uniform quality • use is more labour consuming
Wood pellets	• higher quality • smaller storage • use is less labour consuming	• more expensive than woodchips • does not support local employment

An option of using both woodchips and pellets in the same boiler plant could be considered also.

In addition to technological considerations, also a fuel market and resource survey should be carried out for selecting the fuel. For the woodchips it is certainly necessary to establish how many woodchip producers are active in the surrounding area (e.g., in the area of up to 100 km radius). At the same time, attention must be paid on the type and properties of available woodchips, particularly the moisture content. Also the size of woodchips producer company, supply reliability and company's development perspectives must be considered in order to avoid supply interruptions in the future. The possibility to conclude a long-term supply contract should be investigated. Since the development perspectives are directly linked to the development of forestry in the respective region, it would be useful to find out the planned felling volume in the surrounding forests when building a large scale boiler plant.

A long-term agreement on fuel supply with the desired quality and favourable price is one of the key factors for the project success. It is particularly important when woodchips are used. The analysis of biofuel projects shows that the issues related to the woodchips quality and security of supply are often the reasons for failure. The normal operation of the boiler plant is impeded if fuel supply is irregular (random deliveries), but very often fuel properties differ from the required and agreed quality class and it has been the most serious problem. Already in the planning stage of the woodchips fired boiler plant the main properties (moisture content, particle size, etc.) of the fuel have to be agreed with the suppliers. The negotiations with suppliers should be rather detailed and the contract details have to be understood by both parties in a similar way. It is especially important when concluding the agreement on fuel properties (see also section 2.5 in which the quality certificates and classes of solid biofuels are described). Also the supply schedules and size of the trucks should be agreed. For the success of the project it would be useful to conclude a preliminary supply agreement fixing the most important terms.

From the point of view of security of supply, agreements with several suppliers would be essential but in case of a single supplier the woodchips quality can be determined more easily. In case of single supplier, possible conflict situations could be avoided in a more simple way as well.

The price risk should also be remembered. Considering the general trend of fuel and energy price development, the prices of biofuels will grow also. Thus, there are several factors the influence of which may differ by countries. Regional factors have quite strong impact on prices of wood fuel which is mainly a fuel of local origin. Wood pellets (and briquettes) are traded in the international markets and the price level in the neighbouring countries influences the prices of these fuels as well. However, taxation of fossil fuels (particularly taxation of CO_2 emission) will increase the competitiveness of biofuels. The economic feasibility is certainly influenced by the subsidies for biofuels available in several countries. Therefore, most of decisions can be made only considering the country-specific aspects.

7.6. Fuel storage

The type of fuel, security of supply, the premises available, size of fuel trucks, etc. are the main factors influencing the size (volume) of fuel storage. If the storage can be established in the existing building, it will be usually less expensive to match the fuel supply schedules with the storage capacity, instead of building a new storage facility. When building a new storage facility, the consideration that the minimum storage capacity should be at least 50 % higher than that of fuel truck should be taken for the basis. Evidently, the fact that the supply gap of at least a couple of days could be survived with the available fuel stock – for example weekends, holidays, etc., has to be taken into consideration.

In a smaller pellet fired boiler plant also the construction of a pellet tank can be considered to satisfy the need for the whole year. In summer time fuel could be bought for heating season in this case. This could be expedient in case where the pellet prices in summer are lower than in winter. In the pellet storages the fire safety requirements must be extremely strictly followed and at the same time probability of pellet moistening must be avoided.

7.7. Economic evaluation and analysis of biofuel projects

7.7.1. Revenues and expenses of a DH utility

The revenues of a DH company are generated from the heat (sometimes electricity) sales and they must cover the costs of the company completely. The costs include:

- fuel cost, while both the cost of biofuels and fossil fuels must be taken into account;
- capital (investment) costs, i.e., repayment of loans and loan interests;
- operating costs, i.e., day-to-day expenses incurred in running the business;
- maintenance costs, including the cost of planned maintenance and that related to troubleshooting;
- profit.

The profit can be understood and treated differently – in many countries the profit is a financial source used for investments, technology upgrading, mitigation of environmental impact and improvement of labour conditions. The owner’s profit from the power company’s activities, i.e., dividends from the shares, may be either allowed or prohibited.

In some countries (e.g., in Denmark) the DH companies are usually owned by local authorities and earning the profit for owner is forbidden. In other countries (e.g., in Estonia) most of DH companies are privately owned and the owners’ interest in earning reasonable profit provides better management.

While planning future investments the most complicated item is forecasting the price changes, because the reimbursement of planned investments depends highly on the fuel prices at the repayment period. The prices on fossil fuels are mainly developed in the international fuel market and for the biofuels also, the international trade is increasingly influencing their prices.

The fuel prices are more and more influenced by environmental taxes, but it concerns mainly fossil fuels and improves the competitiveness of biofuels.

The investments made, repayment of loans and interests make the capital cost. For calculating the capital cost, the interest rate, length and terms of repayment and the plant lifetime have to be also considered. The source of financing is not important at the investment appraisal, i.e., from the point of view of project appraisal, it is not important whether the project is financed from the owner's equity or by a bank loan (see 7.7.2).

For the evaluation of the economic feasibility of investments it is useful to consider the costs separately as fixed and variable costs. The fixed costs include costs that do not depend on the heat output (i.e., equipment loading), and are approximately proportional to the plant capacity. The fixed costs include, for example the capital cost and salaries of employees. Since the heat loss in DH pipelines does not depend on the amount of supplied heat, the heat loss in pipelines can also be considered as the fixed costs.

The variable costs are formed mainly of fuel costs, but a part of operating and maintenance costs can also be the variable cost.

7.7.2. Evaluation of the return on investment

For the evaluation of the return on investment several methods can be used, incl.:

- method of payback time, while difference is made between the simple payback time and so-called discounted payback time;
- the Net Present Value method (NPV);
- the Internal Rate of Return (IRR), etc.

When making investment analysis, the change in the value of money over time must be considered, i.e., a certain amount of money (e.g., one million EUR) today and after 10 years are not of the same value. The change in the value of money over time must not be related to the inflation, but first of all to the circumstances that the idle money does not produce new (additional) value, but the money invested in business produces additional value.

The actual value of capital (money) in a certain moment of time when the calculation is made is called its present value or discounted value and conversion of the value of respective future payments to the present moment – discounting. The rate of change in the value of money is indicated by the discount rate, which shows the change of value in percents in a year.

The payback time is the time needed to break even the investment cost in the course of normal operation. Two alternatives are used for expression of the payback time: simple payback time (non-discounted) and discounted payback time.

It is very convenient to calculate the simple payback time when the annual revenues (difference between income and cost) are equal. The simple payback time is defined by the formula

$$T = \frac{I_0}{a},$$

where T – simple payback time,

I_0 – amount of investment,

a – difference between annual revenues and costs.

The given formula allows a very simple calculation and does not require knowing the interest rate or any other loan terms. Simple payback method is usually implemented for the pre-evaluation of project feasibility. If the simple payback time is longer than the project manager and bank want it to be, some changes should be made in the project that would shorten the payback time.

The simple payback time shows the payback time with zero interest rate, i.e., the value of money is not discounted. The actual repayments include also loan interests and are therefore bigger and the actual payback time (discounted payback time) is longer than the simple one.

Usually the payback time should be less than 5 – 7 years, which in practice is always shorter than the lifetime of the equipment. Since the lifetime of biofuel fired plant is more than 15 years usually, the payback time does not take into account the feasibility of the boiler plant during the total operating period. In order to compensate this disadvantage and for a more detailed appraisal of the project and investment several other methods are used in addition. The above are the reasons why many banks require indicating the payback time, Net Present Value and Internal Rate of Return in the loan application.

The Net Present Value shows what is the profit earned during the project period. The bigger the Net Present Value is (NPV[11]), the more profit the boiler plant built within this project will earn during its lifetime. The negative NPV shows that the project is not profitable.

The NPV value depends highly on the loan interest rate (discount rate). Since the loan interest rate may change throughout the years, the Internal Rate of Return (IRR[12]) should also be calculated. The value of IRR is expressed in percents and it shows the maximum loan percent that would still provide profit for the project during its lifetime. If the calculated IRR value is higher than the present and expected loan interests, it refers to the positive NPV value and the project is profitable.

Presently, in many countries the loan interests are the lowest in history. The long term upholding of the low level of loan interest rate is considered to be unlikely and it is recommended to evaluate the feasibility of projects for a higher loan interest rate.

7.8. Planning peculiarities of biofuels based local heating

Both in district heating and local heating the heat source is selected based on the load and load duration curve (see Figure 7.1). In the local heating systems the heat load is mostly lower than in DH networks. Therefore, the required capacity of boilers (heat sources) is lower and installation of more than one boiler is neither technically nor economically feasible.

If biofuels are intended to be implemented in local heating, a biofuel boiler should be designed to cover the total load during a year. Considering the typical load duration curve and lack of a peak load boiler, the utilization time of a biofuel boiler in the local heating system would make half of the time for a biofuel boiler run on the base load in a DH network.

In order to exclude the need for complicated and expensive equipment in the local heating system, refined or high-quality biofuels are considered to be the most suitable fuel. The use of pellets is especially convenient, because the automation level for this fuel could be practically the same as for liquid and gaseous fuels.

Sometimes, the lack of peak load boiler is attempted to be compensated with the installation of electrical heating elements – either in the biofuel boiler or anywhere else in the heating system. A short term peak load could be covered with electricity. The electric heating elements could also be used as additional heaters in single family houses where the biofuel boiler could be shut down in case of residents’ longer absence (for example skiing holidays in winter) while the heating water temperature could be maintained on the minimum level using electricity.

[11] abbreviation NPV (*net present value*) shows also the standard MS EXCEL function used for calculation of the value

[12] abbreviation IRR (*internal rate of return*) shows also the standard MS EXCEL function used for calculation of the value

8. SOME EXPERIENCE IN BUILDING AND EXPLOITATION OF BIOFUEL BOILER PLANTS

In this chapter some experience in the implementation of biofuels in the Baltic countries is described while the specific examples come from Estonia. Wood has been used as a main fuel for heating buildings for a very long time already. The use of wood as a boiler fuel has been also known for about 100 years already, at first for fuelling the boilers producing steam for steam engines.

In the seventies of the last century the sawmilling and forest industries started to develop rapidly while the wood residues were utilized in the boiler plants. Some wood waste fired boilers that were put into operation then are still running today.

The wide-scale boiler conversion of coal and oil fired boilers to wood and peat started in about 1993 – 1994. In the Baltic countries the main reasons for this change were considered to be the rapid rise of the price of these fuels and solvency problems of the people in the period of immense political and economic changes. The programme of the rapid and wide-scale introduction of biofuels at the renovation of boiler plants was started with the support of the World Bank, EBRD and in particular the loans provided by the Swedish government via the NUTEK (presently STEM) accompanied with the technical advice given by the specialists from the Nordic countries. Denmark has also provided grants as irrecoverable assistance. The first new generation biofuel power plant in Estonia is a present from Denmark (1993).

8.1. Some observations on the statistics

In the period between 1993 and 2003 the use of biomass and peat has been significantly increased as boiler fuels. According to the Estonian Statistical Office (see Table 8.1 [59]), the heat production increased 3.5 times against 1993 while the production growth was mainly based on wood fuels.

Table 8.1. Main statistical data on the wood fuels and peat fired boilers in Estonia [59]

Factor	Unit	1993	1995	1998	2003
Number of boilers		609	1080	815	903
Capacity	MW	712	1366	865	856
Produced heat	GWh	527	1191	1456	1941
Consumed fuel	TJ	2790	6144	7099	8719

In Estonian DH boiler plants, industrial enterprises and local heating facilities over 900 biofuel and peat fired boilers with the total capacity about 850 MW were used in 2003. In 2003 almost 2 TWh of heat was produced in peat and biofuel boilers making thus over 30 % of the total heat output. At the same time it is noteworthy that the share of liquid fuels has dropped to 22.5 % and coal is practically not used any more (the share is about 0.01 %).

It is expedient to treat the boilers fired with wood fuels and peat together, because mostly both fuels can be burned in the same furnace. When peat is planned to be the main fuel, after a rainy summer due to the lack of peat, woodchips have often been burned in such furnaces. However, in statistics the boiler is considered either a peat boiler or a wood fuel boiler according to which fuel was mostly used in the respective year. Therefore in the statistics the same boiler can be considered a peat boiler in one year and in some other year a wood fired boiler.

Several interesting trends can be outlined based on the statistics (see Table 8.1). For example, the number of boilers rose rapidly in the beginning of the period of boiler conversion to peat and wood fuel, then it decreased and later started to grow again, but the growth was slower. The total number of boilers reached the maximum 1080 in 1995. At the same time the average boiler capacity changed to some extent too (see Figure 8.1), although the variation of capacity has remained in relatively narrow limits at the level of about 1 MW.

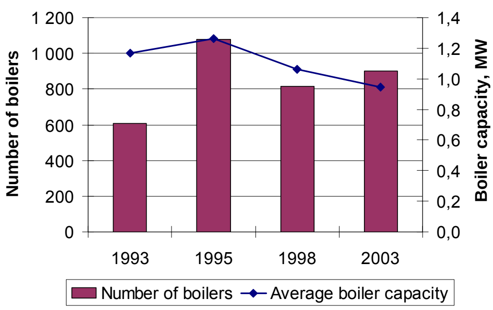


Figure 8.1. Change in the number of biofuel and peat boilers

Unlike the number of boilers and total capacity, the heat output has increased constantly since 1993 (see Figure 8.2). Hence a direct conclusion can be drawn that the boiler loading has constantly improved. The proof to this change is the diagram showing the change of utilisation time (see Figure 8.3) calculated also on statistics (see Table 8.1). As explained before (see section 7.3), the longer utilisation time of boilers refers to their economically more feasible exploitation.

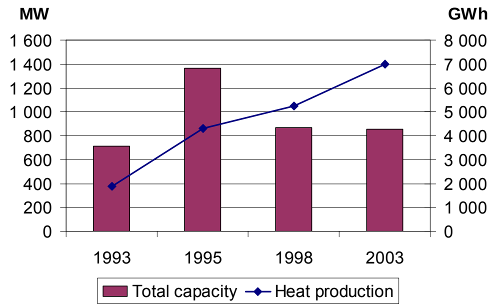


Figure 8.2. Development of total capacity and heat production of the wood and peat fired boilers

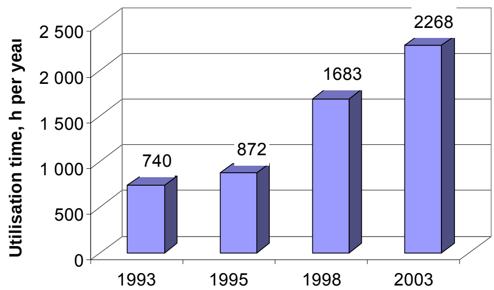


Figure 8.3. Change of the annual utilisation time of wood and peat fired boilers

The average annual efficiency of boilers (see Figure 8.4) can be calculated based on the statistics (Table 8.1). The calculated efficiency values can be compared with the results of measurements made in the TUT[13] Department of Thermal Engineering during several years, which show that in the optimal combustion regimes the actually measured efficiency of most of the biofuel boilers reaches 85 – 87 %.

[13] Tallinn University of Technology

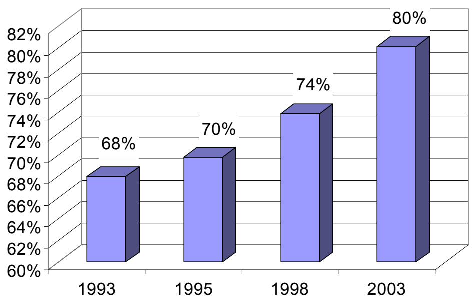


Figure 8.4. The average annual efficiency of wood and peat fired boilers according to statistics

However, it must be noted that in boiler plants the amount of fuel and energy content in the fuel is determined in a simplified way. Besides, in several cases the boilers have no heat meters and both the energy content of used fuel and heat output are estimated. Although the accuracy of the efficiency calculated according to the statistics is not that high as experimentally determined results, the statistical data allow expressing the growth of efficiency of the equipment throughout the years and its increase to 80 % level in 2003 can be considered reliable.

As the rapid decrease in the boiler number after 1995 shows, several biofuel projects appeared to be failures. The most frequent reasons for boiler failure were incorrect planning, building and exploitation errors, for example:

- failures in supplying sufficient amounts of fuel with acceptable quality, fuel supply was delayed and the boiler was shut down due to the lack of fuel;
- incorrect selection of biofuel boiler capacity, i.e., much higher heat demand than earlier was taken for the basis of boiler selection and when the actual heat loads appeared to be much lower, the solutions proved to be inapt;
- primitive and very cheap technology was used, which was not reliable and did not satisfy the expectations;
- insufficient skills of the staff, sometimes also unwillingness or lack of motivation for learning to use the new equipment;
- temporarily lower price and convenience in handling of competitive fossil fuels (natural gas, shale oil).

In the middle of the nineties of the last century several heat suppliers to small towns in the rural areas went bankrupt due to being burdened with loans and lacking management expertise. Planning and building errors played a certain role also. For example, when the pre-furnace for burning wood or sod peat was installed in front of the firetube-boiler designed for burning natural gas, cleaning of flue gas tubes turned out to be extremely inconvenient and time consuming.

The reliability of first Estonian made pre-furnaces was low, the furnace lining collapsed, the grate components were burnt out quickly, etc. In many boiler plants no attention was paid to the fuel quality. In some cases attempts were made to burn wet and almost 2 m long thick logs in the furnaces designed for coal combustion. Such oversights and inappropriate fuel damaged the image of wood fuels seriously.

Reduction in the number of boilers and shutdown of some boiler plants can partially be explained by social changes. Due to the rapid depression in agriculture, people in rural areas lost their jobs and income. In rural settlements the inhabitants of multi-storeyed houses who were former workers of agricultural enterprises (collective or state farms) could not pay the bills for heating and hot tap water. The heat companies run into chronic debts due to the unpaid bills and they, in turn, could not repay their loans and for the supply of the fuel. The residents started to install individual heat sources in their houses or even flats that worsened still further the economic situation of heat producers, because the number of end users in DH networks decreased and the heat price for the remained users had to grow inevitably.

The trends were similar in all the Baltic countries almost at the same time.

In the beginning of the new millennium the intermediate recession has been overcome and the total number of wood and peat fired boilers is growing again. The use of wood fuels and peat has been fostered by the price rise of fossil fuels and electricity, but the investment climate has also improved and prospects for investment support have expanded too. For funding boiler conversion to biofuels, the so-called joint implementation projects can be used, in the framework of which the industrial countries (e.g., Finland, Denmark, et al.) who have not managed to reduce their CO_2 emissions, support funding of greenhouse gas reduction projects in other countries, including Estonia.

The economic feasibility of the wood waste use is well expressed by the fact that most of sawmills and wood processing plants, and practically all the companies who export their products, have built waste (bark, sawdust) based boiler plants to supply heat for wood drying kilns.

8.2. Some examples of successful biofuel projects

Both in the Baltic countries and North-West Russia three different technical solutions have been considered for planning implementation of biofuel projects:

- readjustment of present coal fired boilers to burning wood fuels or peat;
- conversion of fossil fuel boilers to burning wood fuels and peat;
- installation of new complex biofuel boilers in place of fossil fuel boilers or building a new separate boiler plant fired by biofuel.

In the period of the rapid increase of fuel prices, burning of less expensive fuels has been tested in several coal fired boilers. As a rule, it is only an emergency solution. When burning volatile-rich and moist wood or peat fuels in the coal furnaces, the temperature of combustion chamber remained low and due to the incomplete combustion, the heat loss increased rapidly. In addition to the high combustion loss and low efficiency, fouling of heating surfaces and stack created problems too.

Although satisfactory results can be reached by the skilful control of combustion process in coal fired boilers [60], this kind of combustion has not been successful anywhere for a long time.

For boiler conversion from fossil fuels to biofuels two alternatives can be considered:

- fitting a grate for the combustion of biofuels in the furnace;
- building a separate pre-furnace in front of the boiler.

A grate can be fitted in the furnace when the furnace volume is big enough. This is a good solution for the widely used Russian made DKVR boilers (see Figure 8.5).

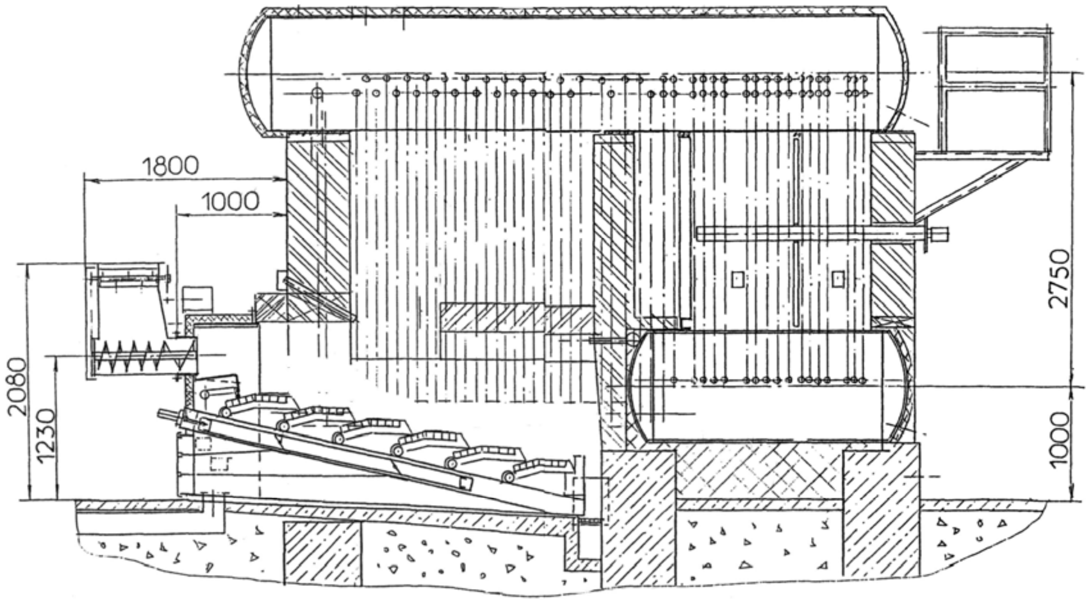


Figure 8.5. Grate for combustion of woodchips and milled peat installed in the furnace of earlier heavy fuel oil fired DKVR-4-13- type boiler

As we can see in the figure, a part of the grate remains stuck out in front of the furnace of DKVR-type boiler. In this chapter some biofuel projects with a similar technical solution have been considered closer (sections 8.2.4 and 8.2.5).

A pre-furnace can be built in front of practically any boiler. Thereby the standard solutions for pre-furnaces are applicable and the boiler does not need major reconstruction. Mostly the existing furnace space in boilers is used for post-combustion of volatile-rich gases escaping from the pre-furnace and for this purpose additional air (secondary air) must be injected into the furnace. The systems with pre-furnace have also been treated in the following examples: for example in sections 8.2.2 and 8.2.3.

It is essential for the boiler reconstruction project that the technical condition of the boiler would provide its operation after conversion to biofuel sufficiently long. When reconstructing an old boiler, it may happen that the boiler will depreciate earlier than the pre-furnace built in front of it or the built-in grate. Therefore it sounds logical that up to the middle nineties of the previous century the existing boilers were widely reconstructed, but later also replacement of old boilers appeared to be expedient, i.e. installation of a new complex biofuel boiler.

When installing the biofuel boilers, local companies usually prefer to install new equipment in the existing boiler house replacing an old boiler. This allows significant cost saving compared to building a totally new boiler house. The cost savings might be achieved using individual technical design and skilful combination of old and new equipment. The big foreign boiler producers and their local daughter companies prefer usually to build a new boiler plant using the turnkey solutions that have been developed based on their long-term experience.

In the first stage of searching data on biofuel projects, we collected information about 20 implemented projects with sending out questionnaires. Based on the replies that we got, we selected 10 projects where the boiler capacities remained within 4 – 8 MW for a more profound analysis. We selected five projects where the existing fossil fuel boiler was reconstructed and five where a new complex boiler unit was installed. Next we visited the selected sites, learned about the equipment, communicated with the management of the boiler plant, boiler operators and other service staff of the plant and in some cases also with fuel suppliers.

Owing to the complaisance of the staff, in most cases we could also become acquainted with the technical documentation of the plant, use the operation and maintenance data for previous years and take photos.

Next we give an overview of the selected successful conversion to biofuel projects carried out in the period of 1993 – 2003, thus the longest operation and maintenance experience dates back 12 years (see section 8.2.1) and even for the newest considered projects the boilers have been operated at least one year (see sections 8.2.8 and 8.2.9).

In delivering the operation and maintenance experience we took the observations of the staff of boiler plants and replies to our questionnaire for the basis. Naturally, first of all the staff recalls difficulties and problems, the solutions of which allowed them acquiring experience. Hence the list of errors and problems must not be considered as a list of failures. All the considered biofuel projects have been successful and the staff of these boiler plants is highly content and happy that they can produce less expensive heat based on domestic renewables than earlier with fossil fuels.

If data available, we have tried to present also observations related to the period of preparing the project and building the boiler plant.

8.2.1. Tehnika Boiler Plant in Türi

Principal data on the project of conversion to biofuel:

Commissioning date: 1993.

Boiler plant:
OÜ Terme Tehnika boiler plant in Türi.

Equipment supplier:
Vølund Energy Systems A/S, Denmark.

Boiler unit:
4 MW complex boiler unit Danstoker, pre-furnace with an uncooled mechanical inclined grate, vertical firetube boiler.

Fuel:
woodchips, waste of felling and wood processing industry, bark, sawdust, sod peat with the moisture content of 35 – 55 %.

Fuel storage:
closed storage equipped with automatic grab crane.

Fuel handling equipment:
fuel from terminal being loaded directly to the furnace by hydraulic pusher.

Boiler cleaning, ash handling and other devices:
dry ash removal by screw conveyors, multicyclone inside the boilerhouse, old brick stack.

The 4 MW boiler installed in the OÜ Terme Tehnika Boiler Plant was the first new generation biofuel boiler in Estonia. At the same time it was the first international project after Estonia regained independence, which provided stable heat supply to the DH network of a small town.

Initially the Danish government planned financial aid to Estonia for buying heavy fuel oil for heating. Since the energy crisis in Estonia was only a short-term problem, the Danish government decided to use the money allocated for the aid for building a boiler plant fired with a domestic fuel. It took in total 7 months to reach from the decision making to the commissioning of boiler plant.

Boiler unit

A complex Danstoker boiler unit was installed in place of the old boiler, which was based only on heavy fuel oil. Since the vertical firetube boiler unit was taller than the height of the boiler plant, the roof had to be demounted and later raised higher to install the boiler (see Figure 8.6).

Figure 8.6. Assembly of the complex biofuel boiler unit in Tehnika Boiler Plant in Türi, photo by V. Vares

Though the Danish company used a thoroughly tested technical solution, an electronic flame sensor was additionally installed on the Türi boiler in order to avoid the possible explosion danger that could emerge due to the incorrect use of the equipment[14].

[14] In Latvia there was an explosion in the furnace during the start-up period of a similar boiler, because the primary air fan was switched on erraneously after the flame was extinct in the furnace.

The flow sheet on the control panel of the biofuel boiler (see Figure 8.7) gives a general impression on the location of the boiler, its auxiliary equipment and sensors.

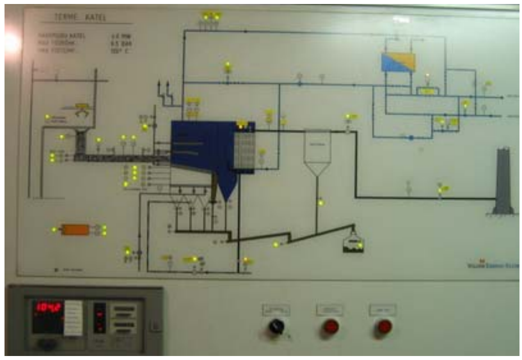


Figure 8.7. View of the control panel of biofuel boiler in Tehnika Boiler Plant, photo by Ü. Kask

For monitoring the processes in the furnace the boiler has a sufficient number of inspection holes. This enables the service personnel to monitor the process on the grate and in the furnace and control the boiler performance. It was noticed that a lot of ash accumulated on the arch above the grate in one working day. The fuel combustion zone is mostly located in the central part of the grate where the ends of grate bars melt. Each year the grate bars have been replaced in a way that the bars with burning traces would be relocated in the places with lower load and the less damaged bars in the centre of the grate where the load is higher. Due to the replacement, only a few bars have been replaced with new ones.

The operators have made a noticeable observation during boiler start-up. Twice as much time is needed for reaching the nominal load if the grate was covered by ash than with the clean grate, i.e., up to 8 hours instead of usual 3 – 4 hours. In case of a low quality fuel (first of all of extremely fine particle size, but also fouled with earth) the air gaps in the grate were clogged. When burning the demolition waste and laminated wood waste, ash melted on the arch and formed solid deposits in the convective part of the boiler (see Figure 8.8). To clean the arch from deposits the so-called thermo shock was used.

Figure 8.8. Hardened ash deposits from the curved arch, photo by Ü. Kask

After eight years of operation the furnace lining needed repair and in the course of repair the old lining was demolished to a certain limit and then new concrete lining placed again. The cast iron plates on both sides of the grate were strongly worn out in the upper cold zone. They were replaced with the plates from the lower zone.

In summer when the consumption load is low, in the convective section of the boiler the gases reach the dew point. After 15 years of operation it was considered necessary to inspect the metal in the convective section thoroughly, because there are some doubts that it cannot resist for a long time. The surface of flue gas tubes was earlier cleaned by brushes, but after this method didn't help any more the cleaning is now carried out by a milling cutter. After milling the oxide-film could be removed from the tube surface as well.

There is a reason to believe that the excess fouling of flue gas tubes could be avoided with the implementation of other cleaning methods, for example, regular acoustic cleaning that does not require boiler shutdown and would exclude developing of a thick deposit layer, which has to be removed, but during the brushing and milling process also the protective oxide layer is constantly removed.

Although the control system of the boiler plant has operated without failure for a long time, in 2005 the boiler plant's control computer failed, but it could be restarted using back-up software.

<u>Fuel handling equipment</u>

The fuel handling system has caused no noteworthy problems. Its throughput corresponds to boiler capacity and the system worked properly also in case of any full load.

<u>Fuel storage and equipment</u>

The fuel storage (see Figure 8.9 and Figure 8.10) has been built in such a way, that a crane performs all the operations, including loading the storage with fuel and all other fuel handling operations.

Figure 8.9. Fuel storage of Tehnika Boiler Plant in Türi, photo by Ü. Kask

Figure 8.10. Computer controlled grab crane has distributed fuel uniformly over the storage area, photo by Ü. Kask

The grab crane (made in Denmark) in the storage is computer controlled and operates in the coordinate system. The storage equipment is sensitive to the fuel properties and can be considered quite demanding for the local conditions. When long chunks (e.g., pieces of board) occur in the fuel, the crane may be switched off. Some specialists of the boiler plant have upgraded the system. The grab crane cables are replaced twice a year and greased with Teflon paste that has given the best results. In winter the fuel freezes for about 30 cm at the walls. Since the fuel at the walls cannot be handled then, later fungi may start to develop there.

<u>Fuel</u>

In the last years the fuel quality and security of supply have become most acute problems. The capacity of the closed storage allows fuelling the boiler run at full capacity for less than three days.

Up to now we have succeeded to supply the wood fuel with different properties only while for reaching the moisture level acceptable to feeding into the furnace (35 – 55 %), the fuels with different moisture content have had to be mixed, for example the wet bark has been mixed with plywood residues. The moisture content of the fuel as received has varied in the range of 15 – 65 %.

For preparing the wood fuel a hammer mill is used in the boiler plant. The wood crushed with the hammer mill is loose (see Figure 8.11) and it is difficult to feed the loose fuel to the furnace – the pushers move under the fuel layer without pushing it onto the grate (height of the furnace door is 10 cm and that of the push bar 5 cm). The same problem occurs in the other boiler plant of the company (Vabriku Boiler Plant, see section 8.2.5).

Figure 8.11. Woodchips crushed with the hammer mill, photo by Ü. Kask

As an additional fuel, peat can be used in the Danstoker boiler, but this is not the case in the other similar boiler plant of the company (Vabriku Boiler Plant, see section 8.2.5), because the mineral part of peat ash reacts with the material of furnace lining and cracks the lining.

<u>Gas cleaning, ash handling and ash disposal equipment, stacks</u>

Cleaning of multicyclone is considered extremely important (cleaning is done with a brush fixed to the electric drill). When huge amounts of small-particle fuel are burned, the 12 mm slots of multicyclone will be clogged. In the ash handling equipment no ash glowing is practically possible, except due to wrong combustion regime: for example insufficient air flow, incorrect ratio of primary and secondary air, due to variations in the fuel quality the amount of combustion air has not been adjusted to the acceptable level.

In order to avoid vibration, the radial bearings of ash conveyor were replaced with the radial/axial bearings. The removed ash is used by local farmers as a fertilizer.

The brick stack built at the same time with the boiler plant and used earlier for heavy fuel oil boilers is in some points heavily crumbling (see Figure 8.12) and needs repair. In winters of the last 5 – 6 years when it has been cold outside icicles have been formed on the stack. The water condensed out from flue gases penetrates between the stack bricks outside and freezes. The stack is designed for oil fired boilers with the total capacity of ~25 MW, but today the total capacity of the boiler plant rarely exceeds 4 – 5 MW.

Figure 8.12. Brick crumbs at the foot of crumbling stack, photo by Ü. Kask

8.2.2. Aardla Boiler Plant in Tartu

Principal data on the project of conversion to biofuel:

<u>Commissioning date</u>: 1994.

<u>Boiler plant</u>:
Aardla Boiler Plant of AS Eraküte, Tartu.

<u>Equipment supplier</u>:
KMW Energi AB, Sweden.

<u>Boiler unit</u>:
The DKVR-type steam boiler from 1988 for the combustion of fossil fuels was equipped with the TRF–type furnace with an uncooled mechanical inclined grate made by KMW Energi; estimated capacity after reconstruction 6 MW.

<u>Fuel</u>:
woodchips, waste of felling and wood processing industry, bark, sawdust with the moisture content of 35 – 55 %.

<u>Fuel storage</u>:
double section closed storage, the one section being equipped with moving push bars; fuel feeding with a grab crane and tractor.

<u>Fuel handling equipment</u>:
chain scrapers, fuel from terminal being loaded directly to the pre-furnace by screw conveyor.

<u>Boiler cleaning, ash handling and other devices</u>:
acoustic soot blowers, dry ash removal by screw conveyors, multicyclone outside, old brick stack

The conversion to biofuel project in Aardla Boiler Plant in Tartu was funded by the loan of Swedish government within the NUTEK Environmentally Adapted Energy Systems programme in the Baltic States and Eastern-Europe. In the framework of this programme the Swedish government financed the work of project consultants separately. In all the NUTEK programme projects also the Swedish consulting company ÅF Energikonsult Syd participated financed by the Swedish government.

<u>Boiler unit</u>

In Aardla Boiler Plant in Tartu a pre-furnace to the existing heavy fuel oil fired boiler was built for burning biofuels. During about 11 years of operation the following problems could be observed: low durability of the pre-furnace lining, ash melting and slag formation on the grate, fouling of heating surfaces, including the economizer and air preheater, problems related to the cleaning of heating surfaces and control of the air/fuel ratio, erosion and corrosion of heating surfaces, etc.

The most significant problem in the pre-furnace is low resistance of grates. The initially installed grates lasted only 4 years and during this period 4 bars in the grate were replaced. Five years after the pre-furnace was put into operation (1999), practically the whole grate has been replaced. Today the cast iron grate bars made in the Tartu Foundry and Mechanical Plant are used (see Figure 8.13), because the price of original grate bars exceeds that of the bars produced in Tartu 6 times. Hence, using the original grate bars would have meant average additional expenses of 50,000 EEK (about 3,200 EUR) per year. Unfortunately the cast iron grate bars of Tartu Foundry do not contain chromium, their quality is extremely irregular and the grate bars must be replaced each summer (see Figure 8.14 and Figure 8.15).

Figure 8.13. New grate bars of Tartu Foundry, photo by Ü. Kask

Figure 8.14. A grate bar after a year in the boiler, photo by Ü. Kask

Figure 8.15. A grate bar with the burnt front end, photo by Ü. Kask

The lining in the pre-heater is repaired to some extent each year. A noteworthy incident happened in January 1995 when 3.5 months after the start-up the roof of the fire pass connecting the pre-furnace with furnace collapsed (see Figure 8.16).

The calculations made by KMW Energi AB showed that after the boiler reconstruction the output capacity of the unit should be 6.0 MW. In order to reach the capacity, the temperature in the pre-furnace was raised to 1200 °C, but the material of the lining could not resist this temperature. Besides the fly ash started to melt in the gas tract and this resulted in slagging of heating surfaces (the same problem has been identified in Kuressaare also, see section 8.2.6).

Figure 8.16. Fire pass between the pre-furnace and boiler, photo by Ü. Kask

In order to avoid such accidents, the specialists of the boiler plant changed the combustion technology. Tertiary air channels were added and via these channels the air was conducted from the secondary air fan to the fire pass immediately in front of the boiler (see Figure 8.16).

Figure 8.17. Far end of the tertiary air channel, photo by Ü. Kask

As a result of renovation, the flame became stable in the furnace and boiler capacity increased to 7 MW without any need to keep the temperature in the pre-heater high. Since now the combustion process does not end in the pre-furnace, but a part of generated gas (volatiles) burns completely in the boiler (DKVR) furnace, the lining in the pre-furnace and grates resist the temperature also better (the temperature in the region around the grates is lower). Also the slagging of fire pass is excluded, because the temperature in the pre-furnace does not exceed 1000 °C.

In 2004 a tertiary air fan and CO sensor were added. These improvements were necessary because of big variations in the fuel quality, especially in the moisture content. For a dry fuel the secondary air supply had to be reduced and the share of tertiary air increased, but both secondary and tertiary air were supplied from the same fan. Now with the changes applied, it is easier to control the optimal combustion regime and gain the maximum efficiency. Earlier dry fuel did not burn completely on the grate and from both mechanically and chemically incomplete burning the loss was significant. From 2005 the combustion process is controlled automatically by the signal from the CO sensor (up to then it was manually controlled).

Once the boiler has been closed because of emergency situation that occurred due to corrosion on the outer surface of all front wall pipes. For excluding corrosion the boiler inlet water temperature is kept above 70 °C, earlier it was 55 °C. The inspection made after the boiler had been run for a year stated that no corrosion had been observed on the tubes outer surface.

In 2004 the economizer was reconstructed, its heating surface expanded and, as a result, the boiler capacity of up to 9 MW was obtained with high quality fuel.

Fuel storage and handling system, problems with fuels

For stocking the fuel a double section closed storage was built where one section was equipped with hydraulic pushers. The fuel is fed with a grab crane and tractor (see Figure 8.18). The conveyors for delivering the fuel from the storage to the boiler plant could not be built because of the DH pipelines (see Figure 8.19) that obstructed the direct construction route. The insulation of pipeline was renewed after reconstruction.

Figure 8.18. Fuel handling with a grab crane in the fuel storage of Aardla Boiler Plant, photo by Ü. Kask

Figure 8.19. DH pipes obstructed the route planned for the conveyors from the storage to the boiler plant, photo by Ü. Kask

Technologically the most acute problems are variation of fuel quality and impurities in the fuel (see Figure 8.20).

Figure 8.20. Stones removed from the fuel, photo by Ü. Kask

The following is an example of how much the fuel quality may differ. Throughout the years the boiler plant has received different types of wood fuels, including these of varying lump size – woodchips, sawdust, bark, residues from the veneer and plywood mills and different forms of shavings and cutter chips. The capacity of the storage facility with two sections (two naves, each with hydraulic pushers) is 140+90 m^3. When one day two truckfuls of woodchips with the moisture content of 50 %, two loads of waste veneer with the moisture content of 26 % and one truckful with the bark of the moisture content of 60 % is supplied to the plant, the boiler will be adjusted to the average moisture content of 46.5 %. The next day one truckful of woodchips will arrive with the moisture content of 55 %, the other 35 % and instead of the bark the waste veneer of the moisture content of 26 % will be supplied. Now the operator has to readjust the boiler to the total moisture content of 35.5 %.

In practice such a readjustment has to be made after the arrival of each truckful. The receiver of the fuel who is responsible for preparing or mixing the loads of fuel cannot guess what kind of fuel will arrive in the next truck. That is the reason why the boiler can run in the optimal regime only for a short period and therefore the average efficiency of the whole boiler unit decreases.

Boiler cleaning, ash handling and other devices

For removing deposits from the boiler convective surfaces, acoustic cleaning units were installed in 1998. These units provide satisfactory performance. The economizer is equipped with compressed air soot blowers that were earlier used also in the boiler convective pass.

When the boiler is operated at the maximum load, after each four months it has to be shut down while the furnace and convective surfaces have to be cleaned mechanically, which takes in maximum five days.

The housings of original screw conveyors for ash handling were replaced already a year after the start-up (1995). Their diameter was significantly enlarged and design improved. The original conveyors proved to be inappropriate for Aardla Boiler Plant and created problems. After installing new housings the bearings of conveyors have needed replacement only once.

No failure has been observed in the multicyclone for discharging flue gases. The brick stack has been repaired twice since 1994, however there is no need for rebuilding.

8.2.3. Võrusoo Boiler Plant in Võru

Principal data on the project of conversion to biofuel:

Commissioning date: 1994.

Boiler plant:
Võrusoo Boiler Plant, AS Võru Soojus, Võru.

Equipment supplier:
Järnforsen Energy Systems AB, Sweden.

Boiler unit:
the DE-25-14 -type steam boiler from 1988 was equipped with a pre-furnace with an uncooled travelling grate made by Järnforsen. During the boiler reconstruction a heavy fuel oil burner was installed for covering the peak load. The estimated capacity after reconstruction was 7 MW for woodchips and 4.5 MW for heavy fuel oil making the total of 7+4.5 MW.

Fuel:
woodchips, waste of felling and wood processing industry, bark, sawdust with the moisture content of 35 – 55 %.

Fuel storage:
double section closed storage; one section being equipped with the hydraulic pushers on the floor; fuel supply with a tractor.

Fuel handling equipment:
chain scrapers, fuel from terminal is feeded to the pre-furnace by hydraulic pusher.

Boiler cleaning, ash handling and other devices:
dry ash removal by screw conveyors, multicyclone outside, steam soot blowers inside the boiler, old brick stack.

The conversion to biofuel project in Võrusoo Boiler Plant was also financed by a loan of the Swedish government within the Environmentally Adapted Energy Systems programme in the Baltic States and Eastern-Europe.

Boiler unit

The series of DE-type steam boilers has been developed in Russia to replace the aged series of DKVR-type boilers. The manufacturing of DE-type boilers started in the eighties of the last century. The throughput of DE-25-14-type boiler is to 25 tons of steam an hour at the steam pressure of 14 bars. In this boiler there is no capacious furnace for the installation of grate, because the boiler was originally foreseen for burning only gas and fuel oils. For the conversion of DE-type boiler to burning biofuels, a separate pre-furnace must be built in front of the boiler (see Figure 8.21 and Figure 8.22).

Figure 8.21. The DE-type boilers in Võrusoo Boiler Plant, rear view, photo by Ü. Kask

Figure 8.22. Pre-furnace installed in Võrusoo Boiler Plant, photo by Ü. Kask

The first known attempt to convert a DE-type boiler to burning biofuels was made in Birzhai, Lithuania also within the Swedish Environmentally Adapted Energy Systems Programme where a smaller version of the boiler series (DE-15-14) was equipped with a pre-furnace in the beginning of 1994 and the project proved to be successful.

For the conversion of DE-type boilers to burning biofuels, it is expedient to lower the heat load on heating surfaces. Besides it must be taken into consideration that removal of deposits from the convective surfaces is quite a troublesome procedure.

In Võrusoo Boiler Plant three similar DE-25-14-type boilers were installed at the time when the users heat demand had decreased rapidly and the total capacity of boiler plant exceeded the demand for three times. In such a situation the use of standby heavy fuel oil boilers for peak load covering would have been highly complicated. Thus two options remained for covering the peak load:

- to install an additional heavy fuel oil fired peak load boiler of acceptable capacity (i.e., smaller) or
- to reconstruct the boiler converted to biofuel burning so that a heavy fuel oil burner could be built in its side wall.

The consultants from the Swedish Consulting Firm ÅF Energikonsult Syd recommended testing the second solution and so a 4.5 MW liquid fuel burner was installed on right side of the boiler. It was foreseen for starting at peak loads and should operate in parallel with the pre-furnace (see Figure 8.23). Unfortunately the staff of boiler plant could not implement this elegant idea in full scale.

Figure 8.23. Site on the boiler side for the installation of a fuel oil burner, photo by Ü. Kask

In the course of testing heavy fuel oil was burned in the additional burner and neither faults in the combustion technology nor extended fouling of heating surfaces were observed. The later boiler operation proved that solid deposits were formed on heating surfaces by burning cheaper shale oil. The properties of the deposits differed from those of heavy fuel oil, which could not be removed with the usual steam blowers and the staff gave up the implementation of additional burner.

In the first year after the boiler reconstruction the staff had problems with the adjustment of combustion regimes and establishing the right ratio of primary and secondary air, but later the required knowledge and skills were acquired.

In case of burning predominantly bark, slagging problems have been encountered both in the pre-furnace and on boiler heating surfaces. In the pre-furnace big and extremely solid slag chunks have been formed that had to be removed with hammer drills. In case of bark combustion, the boiler heating surfaces have been covered with loose deposits, but sometimes even with a glassy slag layer the removal of which is very difficult without damaging the tube metal. By burning bark the lining damages due to slagging have been observed in other boiler plants in Estonia too.

Fuel handling equipment

For fuel handling drag chain conveyors are used. The fuel is fed from the intermediate bin to the pre-furnace by a hydraulic pusher. These units have caused no serious technical problems and their efficiency satisfies the boiler needs. Minor problems have occurred in case of the frozen fuel or fuel with non-standard lump size.

Figure 8.24. Fuel in the storage section equipped with hydraulic pushers in Võrusoo Boiler Plant, photo by Ü. Kask

Fuel storage

For the fuel a double section closed storage where one section is equipped with hydraulic pushers and fuel is fed with a tractor (Figure 8.24) has been built.

In the first years after boiler plant refurbishment the fuel was pushed to the section with a push-floor with a small tractor, but its capacity was insufficient and it needed frequent repair due to overload. The problem was solved with purchasing a more powerful tractor.

Fuel

In the last years fuel quality and its availability has been the most significant problem. Since there is no open storage on the territory of the boiler plant and the capacity of the closed storage provides fuel supply to the boiler run at full load for less than three days, there have been cases where the load of the wood fuel boiler has been lowered due to the lack of fuel.

The fuel quality in the surroundings of Võrusoo Boiler Plant is also influenced by the circumstances that fuel suppliers use unpaved areas for intermediate storage facilities. The fuel is polluted both by the natural (earth, sand) and artificial soils (gravel, crushed stone). Often fuel contains impurities like metal pieces and they might fall into the fuel feeding system or into ash conveyors (see Figure 8.25).

Figure 8.25. Some examples of metal pieces collected from fuel and ash, photo by Ü. Kask

Gas cleaning, ash handling and soot removal equipment, stacks

Flue gases from the biofuel boiler were conducted through the multicyclone to the existing brick stack (see Figure 6.7) where also flue gases from the heavy fuel boilers are discharged.

Removing the ash from between the tubes of the convective tube bank section between the drums is a time and labour consuming process. The steam soot blowers operate well, but most of the ash removed from the heating surfaces with blowers remains in the gas tract where it must be taken out manually from time to time.

8.2.4. Männimäe Boiler Plant in Viljandi

Principal data on the project of conversion to biofuel:

Commissioning date: 1995.

Boiler plant:
Männimäe Boiler Plant, AS ESRO.

Equipment supplier:
HOTAB, Sweden.

Boiler unit:
A moving inclined grate has been installed in the furnace of earlier heavy fuel oil fired DKVR 10-13-type steam boiler; estimated capacity of the reconstructed boiler is 6 MW.

Fuel:
woodchips, waste of felling and wood processing industry, bark, sawdust with the moisture content of 35 – 55 %.

Fuel storage:
double section closed storage; one section being equipped with hydraulic pushers; fuel feeding with a tractor; possibility for fuel moistening

Fuel handling equipment:
chain scrapers, fuel from terminal being loaded directly to the pre-furnace by hydraulic pusher.

Boiler cleaning, ash handling and other devices:
acoustic soot blowers installed in convective part of boiler, dry ash removal, multicyclone inside the boilerhouse, old brick stack.

The conversion to biofuel project in Männimäe Boiler Plant in Viljandi is another project that was funded by the loan provided by the Swedish government within the Environmentally Adapted Energy Systems Programme in the Baltic States and Eastern Europe. While most of the considered boiler plants were municipal property in the period of boiler conversion to biofuel combustion[15], AS ESRO was one of the first privatized DH companies in Estonia.

Boiler unit

As it was explained above (see for example Figure 8.5), the DKVR-type boilers have capacious combustion

[15] Presently all the Estonian DH companies are operating according to the same legislation, their shares belonging either to the local government, national or foreign investors.

chambers and this enables installing the grate in the furnace (see Figure 8.26).

Figure 8.26. Front view of the reconstructed DKVR-type boiler, photo by Ü. Kask

After the boiler conversion to biofuel combustion, the boiler started to operate as a steam boiler. In 2002 it was reconstructed into a hot-water boiler that increased the capacity almost by 2 MW. For high quality biofuel combustion, the boiler has reached the constant capacity of 8 MW.

The operation of biofuel boiler and of the whole boiler plant is computer controlled (see Figure 8.27). This allows monitoring of many operation parameters of the boiler and the boiler plant on the screen.

As in Aardla Boiler Plant (see section 8.2.2), grate bars of Tartu Foundry and Mechanical Plant have been used in Männimäe Boiler Plant and similarly, the front edges of the bars get rapidly damaged (see Figure 8.15).

The first technical solution has undergone several modifications. For example, the location of a deformed control valve for fuel feed has been changed.

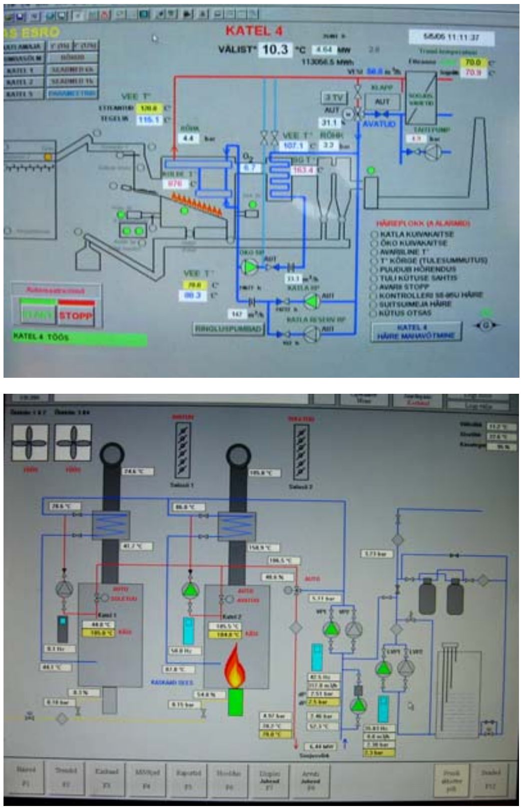


Figure 8.27. Biofuel boiler and the whole boiler plant is computer controlled, photo by Ü. Kask

The fuel quality has had a strong impact on the furnace performance all the time. In order to improve the combustion conditions of moist fuel, an arch was built on the upper section of grate (the fuel drying zone). Unfortunately, it did not improve very much the furnace performance. The furnace temperature often falls and fuel does not burn evenly on the grate, or to be more precise, the fuel burns quicker in one end of the grate than in the other and a part of the grate might stay uncovered with fuel. This is also the main reason why the grate bars become damaged rapidly. The problems related to the adjustment of combustion process in the furnace become also apparent from the fact that CO content in after-boiler flue gas cannot be kept below the permitted level (1000 ppm) constantly.

The grate has also been damaged by the ash softening or sintering on the grate, and here the reason could be either the fuel being very dry or polluted with mineral debris. The boiler plant uses also dry waste from the nearby wood processing plant as a fuel that should be moistened or mixed with moist fuel. Unfortunately neither moistening of dry fuel nor its mixing gives the fuel a homogeneous moisture content, and operational faults keep repeating from time to time. At the end of heating period, i.e. in spring, the grate bars are already heavily damaged and then the incompletely burned glowing particles brought about by inadequate combustion process may pass through the cyclone ash glowing under the cyclone and can be observed.

After each 2 – 3 months the boiler has to be shut down for cleaning it from ashes and deposits. There has been no need to replace the tubes of heating surfaces throughout the whole period of biofuel combustion (~10 years), but the brickwork of furnace arch has had to be renewed. The new arch was laid with a smaller radius than the previous one. The furnace lining above the grate surface has collapsed once (lasted for 6 years) and the lining directly next to the grates is worn out.

<u>Fuel handling equipment</u>

No significant problems have been observed with the fuel handling equipment. Their capacity satisfies the boiler demand and they perform reliably. The chains of fuel conveyor lasted almost nine years and were replaced for getting slack, not because of damages.

<u>Fuel storage and storage equipment</u>

A limited fuel stock (for a couple of days) is stored in a double section closed storage where one section is equipped with hydraulically driven push bars/ladders and fuel is fed with a tractor (see Figure 8.28). Since a plant producing wooden doors/windows is located nearby and the fuel supplied from the plant is dry (ca 20 % moisture content), a moistening option is available in the storage, because the furnace is foreseen for burning moist fuel.

Figure 8.28. Fuel handling in the fuel storage of Männimäe Boiler Plant, photo by Ü. Kask

The hydraulic cylinders for driving the push bars along the storage bottom lasted about 6 – 7 years. Up to the year 2005 the welded seams of all hydraulic cylinders have been repaired for 2 – 3 times. Once a poured concrete support has broken too (see Figure 8.29).

Figure 8.29. Welded ending part of hydraulic cylinder, photo Ü. Kask

In the storage the pusher bindings were broken in several places in the first years of operation, besides, the push bars were worn rounded at the edges and could not provide reliable forwarding of sawdust and bark in summer. Therefore, the attachment points had to be strengthened and metal layer welded on the front edges of the push bars. Waste veneer and long strips of bark in the fuel have been the cause of its uneven dropping on drag chain conveyor.

Fuel

In recent years the biggest problems for the company have been fuel quality and availability. There is no open storage in the territory of the boiler plant and the capacity of closed storage allows a three-day supply for the boiler operated at full capacity.

The moisture content of the fuel as received varies in the range of 20 – 65 %. Problems rise when the moisture content of the fuel exceeds 50 %.

In summer when the load of the boiler plant is only 1.5 – 2.5 MW, often only sawdust and bark are fired. In winter this kind of fuel does not allow reaching the nominal capacity and incompletely burned glowing particles reach the multicyclone. A similar problem has been observed also for example in Haapsalu and Keila Boiler Plants (see sections 8.2.7 and 8.2.8).

In 2004 a lot of fuel made from aspen wood with a 45 – 48 % moisture content was supplied to Männimäe Boiler Plant and using this fuel it was not possible to control the combustion process in the furnace. As a result, burning tended to die out here and there on the grate. This experience shows that the fuel from aspen should be drier than that made from other species of wood.

Gas cleaning, ash handling and soot removal equipment, stacks

Two acoustic cleaning devices are used for cleaning the boiler heating surfaces. The noise from their operation has not disturbed the staff of the boiler plant. For dry fuels the operation of these acoustic cleaning devices is satisfactory, but when burning moist fuel constantly, the acoustic soot blowers are of no help and the boiler convective surfaces get rapidly fouled. In 2004 for the first time hardened ash lumps were found in the economizer. These lumps had to be chopped out. No other acoustic cleaning and soot blowers have been installed in the economizer.

The brick stack was to be repaired and its metal construction replaced in 2005.

8.2.5. Vabriku Boiler Plant in Türi

Principal data on the project of conversion to biofuel:

Commissioning date: 1998.

Boiler plant:
Vabriku Boiler Plant, OÜ Terme in Türi.

Equipment supplier:
AS Tamult, Estonia; Saxlund, Sweden.

Boiler unit:
a moving inclined grate was installed in the furnace of a DKVR 10-13-type heavy fuel oil steam boiler (from 1981) that was rebuilt into a hot-water boiler. The estimated capacity of the converted boiler is 4 MW.

Fuel:
woodchips, waste of felling and wood processing industry, bark, sawdust with the moisture content of 35 – 55 %.

Fuel storage:
a closed storage equipped with a computer controlled grab crane.

Fuel handling equipment:
chain scrapers, fuel from intermediate hopper is fed to the furnace by hydraulic pusher.

Boiler cleaning, ash handling and other devices:
dry ash removal by screw conveyors, multicyclone inside the boilerhouse, old brick stack.

The boiler conversion to biofuel in Vabriku Boiler Plant in Türi is another project that was financed with the loan provided by the Swedish government within the

Environmentally Adapted Energy Systems Programme in the Baltic Countries and Eastern-Europe. For the owner of the boiler plant (OÜ Terme) it was already the second biofuel project. In Tehnika Boiler Plant of the same company (see section 8.2.1) burning of biofuels proved to be economically feasible and based on the gained experience it was considered expedient to carry out a similar project also in the Vabriku Boiler Plant (see Figure 8.30).

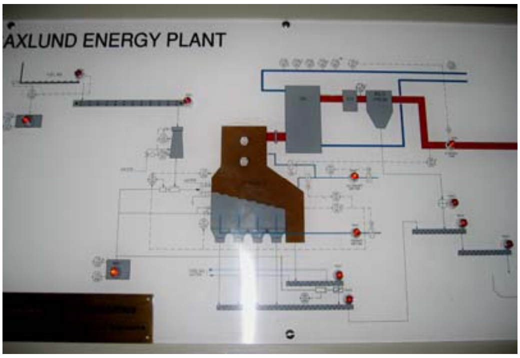


Figure 8.30. Poster with the scheme of Vabriku Boiler Plant in Türi, photo by Ü. Kask

Boiler unit

In Vabriku Boiler plant a decision was made not to install a new boiler unit, but to reconstruct the DKVR-type boiler that was in good condition (see also 8.2.4 and Figure 8.5).

For the reconstruction a Swedish Saxlund grate was used. This grate had proved itself in several Estonian boiler plants, incl. the boiler house of AS Tamult, the main equipment supplier and designer of the reconstruction.

OÜ Terme had a good chance to compare the performance of two biofuel boilers with different technical solutions in its two boiler plants. In the furnace of DKVR-type boiler in Vabriku Boiler Plant higher temperatures can be observed than in the furnace of Vølund boiler (see section 8.2.1). These circumstances allow burning moist logging residue and stumps in the reconstructed boiler, although at the same time slagging of the grate is intensive.

Strong ash deposits are formed on the tubes inlet of convective part of DKVR-type boiler. The same problem could be observed in the DKVR boiler of Männimäe Boiler Plant in Viljandi (see section 8.2.4).

After reconstruction of the boiler the full project capacity was not reached at once, but only about the half of it. Only after the very curvy air channels with high aerodynamic resistance have been replaced by new ones, the nominal capacity of 4 MW was obtained.

There has been an incident in Vabriku Boiler Plant where, due to a power failure, the boiler halted and got overheated, and the damaged temperature sensors had to be replaced. Fortunately, the accumulated heat of the furnace and its lining did not heat the boiler water up to the intensive evaporation and dangerous increase of pressure.

Fuel handling equipment

No significant problems have been observed with the fuel handling equipment. The capacity of the fuel handling equipment corresponds to the boiler capacity and no failures have been.

Fuel storage and storage equipment

No significant faults have occurred in the fuel pushers on the storage floor. The storage conveyors can serve the boiler adequately for any load. A tractor is used for moving the fuel to the storage (see Figure 8.31).

Figure 8.31. Tractor adapted for fuel moving, photo by Ü. Kask

Fuel

In both Tehnika Boiler Plant and Vabriku Boiler Plant of OÜ Terme there have been problems with the security of fuel supply and quality. However, the equipment of Vabriku Boiler Plant is not excessively sensitive to the fuel quality. The attempts to fire peat were not successful and therefore the permanent use of peat as a reserve fuel must be excluded.

Gas cleaning, ash handling and soot removal equipment, stacks

The screw conveyor for hot ash removal, made from thin sheet metal, had to be replaced after a couple of years of operation. Before the replacement special hatches for the removal of mechanical impurities were made into the conveyor wall for avoiding the break-up of screw conveyor, but it was not sufficient and the new conveyor was made of thicker and stronger sheet metal. A comparison could be drawn with the screw conveyor operating under similar conditions in Tehnika Boiler Plant of OÜ Terme, which has been properly operated already 14 years.

The device designed for cleaning the heating surfaces from deposits was not installed and up to the present time mechanical cleaning is used.

The injection of tertiary air into the furnace was foreseen, but as tertiary air did not enhance the combustion and increased the oxygen content in the economizer zone, it was switched off.

The flue gas temperature at the boiler outlet has been at the required level (~170 °C) that excludes water vapour condensation on the boiler stack walls.

8.2.6. Kuressaare

Principal data on the project of conversion to biofuel:

Commissioning date:
1st stage 1998;
2nd stage 2002.

Boiler plant:
Kalevi Boiler Plant of AS Kuressaare Soojus.

Equipment supplier:
1st stage Saxlund, Sweden;
2nd stage AS Tamult, Estonia.

Boiler unit:
1st stage – a 5 MW Danish Danstoker boiler and pre-furnace with the moving inclined grate was installed; also a device for condensing water vapour from flue gases was installed;
2nd stage – a moving inclined grate was installed in the furnace of heavy fuel oil fired steam DKVR 10-13-type boiler (boiler from the year1983). Besides, the boiler was rebuilt into a hot-water boiler. The estimated capacity of the converted boiler is 6 MW.

Fuel:
woodchips, logging residue, residue from wood processing industry, bark, sawdust with the moisture content of 35 – 55 %.

Fuel storage:
a sheltered storage where one end is open and another end is accommodated with hydraulic pushers; fuel is supplied with a manned crane and tractor. In addition, a large open storage for biofuels is used.

Fuel handling equipment:
fuel for both boilers is transported from storage to boiler house by common chain scrapers; from intermediate hopper to the furnace fuel is fed by hydraulic pusher.

Boiler cleaning, ash handling and other devices:
1st stage – acoustic sootblowers, wet ash removal by chain scrapers, multi-cyclone inside the boilerhouse, old brick stack common to both boilers, flue gas condensation (gives 5 % extra boiler capacity);
2nd stage – dry ash removal by screw conveyors and chain scrapers, common flue gas condenser and new steel stack replacing old brick stack for both boilers has been installed in 2005.

In the same boiler plant 2 biofuel fired boiler units have been put into operation with a five year interval. In the 1st stage the project (1988) was financed by the loan provided by the Swedish government within the Environmentally Adapted Energy Systems Programme in the Baltic countries and Eastern-Europe.

Since the first stage of the biofuel project proved to be successful and a part of the base load had to be constantly covered with an economically less favourable fuel (heavy fuel oil), a decision was made to reconstruct one more boiler and fund it by a commercial loan.

The fuel storages built in the 1st stage proved to be sufficient and fuel conveyors so efficient that it could serve the second biofuel boiler too. Since, based on the performance of the first boiler an intentional decision was made about building another biofuel boiler, the technical manager of the boiler plant recorded all the faults and troubles during the first year of operation very carefully. The following is a short survey of the data.

In May 1998 the boiler unit was halted due to the lack of fuel and this shutdown period was used for welding work and inspection of the unit. Some cracks were found in the furnace lining, leaks via the bearings of the mixer of wet ash handling system and deflection of a metal beam in the ash channel in the end section of furnace grate.

In September 1998 the bolts of fuel pusher loosened and spring washers were added for retightening them. Some problems were observed in cleaning the fuel conveyors, but these problems have remained unsolved up to now. For cleaning the conveyor it had to be backspaced, but it could be done only by turning the cooling fan blade of the electric motor.

In October 1998 a lot of melted ash and damaged lining were found in the furnaces.

In November 1998 the float of wet ash handling system needed repair. The valves for control of primary air inlet were replaced by another type of sliding valves.

In December 1998 during the inspection the boiler pressure-relief valves did not work.

In January 1999 rising of the furnace grate was noticed and to avoid it, the guide bars were installed. The fuel spreader (a rotating cylinder with fins that levels the fuel layer in the storage before feeding it to the conveyor) had shifted axially, because of the missing stopper.

In February 1999 the metallic cross beams of fuel pushers (so-called ladders) on the storage floor were broken loose from the guide bar at the welding seams.

The same problems with the fuel storage repeated in **March 1999**: the attachment of hydraulic cylinder broke at the welding seam. Approximately at the same time bearings of the mixer of ash handling system were broken too due to the failure of ash screw (dry ash conveyor) protective switch. Since there was no opportunity to perform service of the flame and underpressure sensors, the service platforms were built by the DH company at their own cost.

Boiler unit

Compared to any other project described above in the 1st reconstruction stage of Kuressaare Kalevi Boiler Plant a significant technical improvement was made – a condensing unit for condensing water vapour from flue gases (so-called flue gas condenser) was installed that increased the boiler output capacity for about 5 %.

In the pre-furnace and boiler built in the 1st stage no automatic control of combustion regimes was available that would have simplified burning of biofuels with varying quality (type, moisture content, lump size). Originally there was no flue gas recirculation system in the boiler unit and it was built a year later by the owner. As it was explained above (see section 4.1.2), the temperature of flue gases escaping the furnace can be controlled with the recirculation of flue gases and thus overheating of furnace lining can be avoided. In the cylindrical horizontal section of furnace (so-called secondary combustion chamber) the lining has collapsed since it was once exposed to a high temperature for a long time. Unfortunately the temperature in this region could not be correctly monitored, because the temperature sensor was installed incorrectly (a design error).

In 2004 after 6 years of operation it turned out that the wall thickness of Danstoker boiler tubes in the surroundings of water inlet was in some places less than 1mm. The tubes lost their shape and water leakages emerged. Evidently mixing of DH return water with the boiler water was not adjusted and the temperature of inlet water was too low that induced acid dew point corrosion (called as low temperature corrosion) of tube metal in the flue gas side. Frequent cleaning of tubes with brushes breaks the oxide film on the flue gas side and shortens the lifetime of tubes. One reason for the tube wear could also be erosion due to the mineral particles in the ash.

During the 2nd stage of the project a heating arch of fireclay bricks was built along half of the grate to the DKVR-type boiler in order to improve drying conditions of the fuel. In spite of the reconstruction of DKVR boiler, the fuel as wet as that burned in the uncooled pre-furnace of Danstoker boiler could not be combusted in the DKVR boiler. From time to time some water tubes in the boiler have been replaced and this must be done in the future too.

Some grate bars both in the pre-furnace of Danstoker boiler and DKVR boiler have had to be replaced, besides the location of grate bars has been interchanged in both boilers, some grate bars have been repaired by welding additional metal on them.

Fuel handling equipment

In the 1st stage after putting the Danstoker boiler into operation the deficiencies in the fuel handling equipment were removed immediately in the first year, for example the fuel feed screw in front of the boiler were replaced with a hydraulic pusher. Up to now the problems related to uncomfortable cleaning procedures of drag chain conveyor and elimination of cloggings that first appeared already in September 1998 have not been solved yet.

When in 2002 the adjacent DKVR-type boiler in the same boiler plant was converted to firing biofuels, a horizontal drag chain conveyor for delivering the fuel to the feed hopper in front of the boiler was added to the fuel handling system. The intermediate bin was also changed. Later a test firing of reed was carried out in this boiler and it showed that the stalky reed does not fall well from the intermediate bin on the conveyor. The same problem reoccurred with the mixture of reed and woodchips. The reed needs to be chopped into 7 – 10 cm long chips that would evidently provide falling of both the reed and mixed fuel on the conveyor.

Fuel storage, storage equipment

After removing the errors and faults that were detected in the first year of operation no serious operation faults have been identified. After seven years of operation the concrete floor under the push bars in the fuel storage has worn out. Some additional cross beams have been welded to the hydraulically driven push bars and the attachments of push bars have been welded anew from time to time. The maintenance and repair of grab crane has caused a lot of problems (see Figure 8.32). The grab crane was ordered from an Estonian company and the first crane lasted for 5 years owing to the constant maintenance and repair. Although the storage and storage equipment were originally designed to serve a 5 MW boiler, they could later supply fuel to two boilers with the total capacity of 10 – 11 MW.

Figure 8.32. Manned bridge crane with grabber, photo by Ü. Kask

Fuel

Quality. In the open storage of the boiler plant the snow content in the fuel is in some winter too high. The snow occurs often in the fuel during transportation or loading in intermediate storages. Frequently the moisture content in the fuel exceeds even 55 %. This happens in snowy periods and at the time of snow melting, but sometimes the moisture level is high due to the fuel content (big amounts of woodchips from small twigs and/or needles, bark). If the amount of spruce bark is big in the fuel, fuel loading from the storage to the drag chain conveyor is disturbed and conveyance to the boiler is disturbed, because long stringy bands of bark curl around the fuel spreader and the latter cannot operate properly (the fuel layer in the storage does not spread on the drag chain conveyor uniformly). All types of fuel should be ground to the particle size foreseen according to the design.

Another problem of fuel quality is pollution with soil (mud and sand), often big pieces of debris (metal and stones) can be found in the fuel.

In the open fuel storage in some cases self-ignition of wet wood fuel with high bark content has occurred. As the experience showed some years ago, the energy density of high fuel piles (5 – 6 m) may reduce for 50 % during three to four months. One summer the company stockpiled a lot of bark and stored it in an open storage. It became evident during the heating period that the specific fuel consumption increased for 50 %. Wet biofuels (in particular with the moisture content higher than 50 %) should not be stockpiled in high piles and the piles should be mixed from time to time in order to homogenize the fuel moisture content through the whole pile.

Availability of fuel. In warm winters (the earth is not frozen) the forest machines have no access to the cutting areas and the company's mobile wood chipper cannot be used in the forest. So, the only option is to chip roundwood in the storage areas. However, without a wood chipper fuel stocking would be still more disturbed, because Kuressaare is located on an island and a part of fuel is transported by trucks from the mainland. In some cases the fuel has not arrived from the mainland for several days. The availability of wood fuel can be seasonably difficult all over the country, or in the Baltic countries altogether.

Gas cleaning, ash handling and soot removal equipment, stacks

In spite of an acoustic soot blower, one section of flue gas tubes of Danstoker hot-water boiler has to be cleaned manually with brushes every two months. The tube bank of convective surfaces in the DKVR boiler has to be cleaned from the gas-side deposits only twice a year. Cleaning is a time and labour consuming procedure, because the fly ash and soot have deposited between densely located tubes. No slagging of heating surfaces has been observed.

The existing brick stacks have been used for discharging flue gases of sulphur-rich fuels (heavy fuel oil, shale oil) to the atmosphere for a long time. Presently, one of the stacks was used for the flue gases of both biofuel boilers and liquid fuel fired peak load boilers and the result is crumbling of the stack. When moist fuels are combusted, a dew point is formed in the stack, water vapour in the flue gases condenses and reacts with the sulphur compounds deposited there earlier. The formed sulphuric acid crumbles the stack (traces of crumbling can be found both on the inner and outer surface of the stack).

The climate conditions support crumbling of the stack. For example the condensed water on the inner surface of stack penetrates between the stones and/or in the stones and freezes there on a frosty day (traces of crumbling can be seen on the outer surface of stack).

The screw conveyor for ash removal from the DKVR-type boiler built in the 2nd stage had to be replaced after a year of operation because of its wear. That is a proof to the fact that the ash contains too much mineral debris. The screw conveyor was decided to be replaced by a drag chain conveyor and this conveyor has lasted longer. The dry ash is discharged to a water bath for avoiding dusting in the ash room.

8.2.7. Haapsalu Boiler Plant

Principal data on the project of conversion to biofuel:

Commissioning date: 2001.

Boiler plant:
Haapsalu Boiler Plant, AS Eraküte.

Equipment supplier:
Saxlund, Sweden; AS Tamult, Estonia.

Boiler unit:
Pre-furnace with the mechanical inclined grate and 7 MW Danstoker boiler.

Fuel:
woodchips, waste of felling and wood processing industry, bark, sawdust with the moisture content of 35 – 55 %

Fuel storage:
double section closed storage facility where one section is equipped with hydraulic pushers; fuel handling with a tractor; possibility for fuel moistening in the storage.

Fuel handling equipment:
chain scrapers, belt- and screw conveyors.

Boiler cleaning, ash handling and other devices:
dry ash removal by chain scrapers and screw conveyors, multicyclone inside the boilerhouse, old brick stack.

AS Eraküte is a subsidiary of the French capital based concern DALKIA who has acquired several DH companies in Estonia. The biofuel project in Haapsalu Boiler Plant (see Figure 8.33) was financed by the commercial loan guaranteed by the holding company.

Boiler unit

The boiler unit has worked without any failure and when the fuel with the designed quality is used it can reach the nominal capacity easily while about 10 % overloading of the boiler is possible. The capacity range has been selected successfully and it satisfies the heat demand of DH network.

Figure 8.33. View of Haapsalu Boiler Plant after reconstruction, photo by Ü. Kask

Some problems related to ash melting and sintering emerged in the boiler when very dry waste of plywood and furniture industry (moisture content about 10 – 15 %) was burned. Since the boiler is designed for firing much moister fuel (30 – 55 %), a water pipe punched with holes has been installed for moistening the fuel transported from the storage by drag chain conveyor and according to the agreement the cost of the loss of calorific value due to fuel wetting is covered by the supplier. In summer when the average load of the boiler does not exceed 2 MW, also dry not moistened fuel (shavings) can be fired. When the bark to be combusted is too wet (moisture content over 55 %), the nominal capacity of the boiler cannot be reached.

For the average load (3 MW) Haapsalu boiler can reach the nominal capacity in less than 2 hours. In the biofuel boiler of Keila Boiler Plant with the same technical solution (see section 8.2.8) it takes 4 hours. The boiler load can be increased faster in Haapsalu Boiler Plant owing to the ceramic arch built in the furnace, which Keila boiler does not have (the boiler units installed in these two boiler plants are of the same type and produced by the same company).

The grate of Haapsalu boiler has three moving grate steps while in Keila there are only two of them. This difference can also be a reason why the boiler load can be better controlled and moister fuel fired in Haapsalu boiler.

Similar to Kuressaare (see section 8.2.6), the temperature sensor of Danstoker-type boiler for controlling the furnace process was originally installed in the wrong place (displayed lower temperatures) in Haapsalu too. In Kuressaare the TUT[16] specialists recorded for the actual lining temperature even up to 1200 °C and therefore the lining melted.

It would be expedient to make inspection holes for monitoring the ash deposition on the arch crown. A more suitable configuration should be found for the arch crown in order to reduce the ash amount.

Fuel handling equipment

No significant problems have been observed with the fuel handling equipment. Their capacity satisfies the boiler demand and they have performed reliably.

Fuel storage, storage equipment

Since the territory of boiler plant is small and there is no sufficient space available, a small storage was built that needs frequent filling. The full stock in the storage facility provides the fuel for two days and this makes the smooth logistic management especially important (see Figure 8.34).

[16] TUT – Tallinn University of Technology

Figure 8.34. Fuel handling in the storage of Haapsalu Boiler Plant, photo by Ü. Kask

Figure 8.35. Some examples of debris and uncrushed wood screened out from the fuel, photo by Ü. Kask

Fuel

As in all other boiler plants, the most acute problem in the last years has been the fuel quality and availability here also. There is no open storage area in the territory of boiler plant and the capacity of closed storage facility provides the fuel supply to the boiler running at full capacity for less than two days. The present fuel supplier has stockpiled fuel in open areas near Haapsalu town and there have been no problems with the fuel transport from these places to the boiler plant.

Unfortunately, there are no big wood reserves and big wood processing plants nearby Haapsalu. Also logging residue cannot be fired, because there are no big cutting areas in the neighbourhood and therefore the forest residue is not collected. The fuel supplied from far away suppliers includes the share of haulage cost, which is constantly increasing.

The low quality of fuel can be proved by the photo where we can see the debris screened out from the fuel (see Figure 8.35).

Gas cleaning, ash and soot removal equipment, stacks

When the fuel or mixture of fuels used for firing is not of required quality, the optimal combustion regime cannot be maintained and unburned fuel particles occur in the multicyclone, the metal of multicyclone may be heated up to some hundred centigrades and glowing ashes may reach even the ash conveyors. The metal hatches of multicyclone and concrete covers of conveyor channels cannot resist high temperatures (see Figure 8.36).

Figure 8.36. Multicyclone foundation and concrete channel cover, photo by Ü. Kask

No problems have emerged with the acoustic blower for cleaning the heating surfaces of hot-water boiler and the noise it makes. No complaints have been received from the residents in the neighbourhood about the boiler plant.

8.2.8. Keila Boiler Plant

Principal data on the project of conversion to biofuel:

Commissioning date: 2003.

Boiler plant:
Keila Boiler Plant, AS Eraküte.

Equipment supplier:
Saxlund, Sweden and AS Tamult, Estonia.

Boiler unit:
Pre-furnace without cooling and with the mechanical inclined grate, 7 MW Danstoker boiler.

Fuel:
woodchips, waste of felling and wood processing industry, bark, sawdust with the moisture content of 35 – 55 %.

Fuel storage:
closed storage facility equipped with a computer controlled grab crane

Fuel handling equipment:
chain scraper, belt conveyor, screw conveyor.

Boiler cleaning, ash handling and other devices:
wet and dry ash removal, multicyclone inside the boilerhouse, old brick stack.

The biofuel implementation project in Keila Boiler Plant was financed by the commercial loan guaranteed by the holding company DALKIA. The decision about biofuel implementation was made after the previous project of AS Eraküte in Haapsalu Boiler Plant (see section 8.2.7) proved to be both technically and economically successful.

In the course of reconstruction of Keila Boiler Plant all the equipment in the plant were replaced, a biofuel boiler with a pre-furnace (see Figure 8.37) was installed along with the storage equipment, the peak load and reserve shale oil boilers. The building of boiler plant was refurbished. Later the owners reached to the conclusion that it would have been expedient to install the flue gas condenser at once. After the reconstruction completed installation of the condenser would be related to more costs, because no space was originally foreseen for this condenser.

Figure 8.37. Pre-furnace in Keila Boiler Plant, photo by Ü. Kask

Boiler unit

The boiler unit has operated without failures when the fuel with required quality has been used and can reach the nominal capacity easily. For the fuel moisture content below 45 % the boiler can be overloaded for about 10 %. No problems have occurred in the control of combustion regimes.

Originally the temperature sensor in the horizontal gas duct between the furnace and boiler was installed incorrectly, but after replacing the sensor started to meter adequately the mean temperature of gas flow that must be kept below 1000 °C with the control of combustion regime.

In the water inlet region of boiler some boiler tubes were discovered to be seriously damaged while the wall thickness was decreased from 4 mm to 2 mm in some places. For the Danstoker boilers the boiler manufacturer recommends to keep the water inlet temperature at the level of 108 °C or above it. When burning moist fuel, the metal of heating surfaces starts to corrode dangerously in the very low temperature range. Although Keila Boiler Plant has failed to maintain the water temperature at boiler inlet at the level recommended by the producer, it should be kept at least at about 85-90 °C.

The water temperature at boiler inlet is controlled by a mixing pump, which adds higher temperature water discharged from the boiler to the boiler feeding water. Two possible reasons are suggested that could lower the boiler feeding water temperature to an extremely low level:

- mixing takes place in the location too close to the boiler or
- error of temperature sensor.

In the used waste fuel the content of mineral debris is too high and thus erosion could have also had impact on the decrease of wall thickness.

Ash sintering on the grate is a result of burning dry fuel (waste veneer). Sometimes the thickness of fuel layer on the grate is uneven and therefore it burns better at the grate edges.

Fuel handling equipment

No significant problems have been observed with the fuel handling equipment. Their capacity satisfies the boiler demand.

Fuel storage, storage equipment

In spite of the fact that the tender and technical specification were prepared by experienced foreign consultants, several significant parameters were not specified or evaluated incorrectly in the design stage of storage facility. The handling throughput of computer controlled grab crane was selected 80 m^3/h and capacity of grabber system 5 m^3, but to this day it has been replaced with half a smaller grabber unit of the capacity of 2,5 m^3 and lower throughput. Originally an unsuitable electric motor was chosen for driving the grab crane – after one minute of work it should have been cooled down for five minutes and the motor burnt out. The grabber was made in the Estonian company AS Eesti Kraanavabrik (see Figure 8.38).

Figure 8.38. Estonian made bridge crane with grabber, photo by Ü. Kask

The producer of grab crane has not entirely recognized his faults, although many problems have emerged in the crane performance. Once in 2005 the overload protection did not switch on and as a result the cable was broken and the grabber fell on the fuel pile. The representative specialist of equipment manufacturer had misadjusted the overload protection after having installed the weight sensor. One more disadvantage of grab crane is that it cannot pick up the fuel at the walls and in the corners (see Figure 8.39). The wet fuel stocked in high piles may self-ignite, also mould fungi may develop there. Unfortunately, in the storage trench using of some other equipment (for instance tractor) would be extremely complicated and expensive.

Figure 8.39. Fuel piled at walls, photo by Ü. Kask

The storage solution with a grab crane could have been made significantly better if local conditions would have been considered and suitable and reliable equipment would have been chosen. The timely maintenance of grab crane and other storage equipment has proved to be very significant and in spite of drawbacks in configuration it has helped to exclude more serious emergency situations.

Fuel

The main problems of the heat supplier are the fuel quality and availability. There is no open storage facility in the territory of boiler plant and the capacity of the closed storage provides fuel supply to the boiler run at full capacity for up to three days.

There was a period when once also the construction and demolition waste was burned and problems related to slagging of the grate and lining arouse, i.e., solid deposits were formed (see Figure 8.40), erosion and fouling of heating surfaces appeared. The tests for burning waste fuel have been ended, because the solution of emerging problems would cost more than the plant could economize by buying less expensive fuel.

Figure 8.40. A piece of deposit removed from the furnace, photo by Ü. Kask

Gas cleaning, ash and soot removal equipment, stacks

When the optimal combustion regime cannot be maintained by burning some fuel or fuel mixture, unburned fuel particles occur in the multicyclone (the temperature of multicyclone metal can raise up to two hundred centigrades (see Figure 8.41) and move from there on even to ash conveyors where they are burnt out.

Figure 8.41. Multicyclone and ash conveyor, photo by Ü. Kask

8.2.9. Peetri Boiler Plant in Paide

Principal data on the project of conversion to biofuel:

Commissioning date: 2003.

Boiler plant:
Peetri Boiler Plant, OÜ Pogi in Paide.

Equipment supplier:
Wärtsilä OY, Finland.

Boiler unit:
8 MW Wärtsilä patented uncooled bottom fed BioGrate pre-furnace with a conic grate (see Figure 4.6) and hot-water boiler.

Fuel:
woodchips, waste of felling and wood processing industry, bark, sawdust with the moisture content of 35 – 55 %.

Fuel storage:
push-floor intermediate storage opened on one side and heated push-floor main storage, in addition an open storage is used; fuel supply in the storage with a tractor.

Fuel handling equipment:
chain scrapers, fuel is fed to the furnace from the bottom using an screw feeder.

Boiler cleaning, ash handling and other devices:
wet ash removal with chain scrapers and screw conveyors, multicyclone inside the boilerhouse, new steel stack.

The new fuel boiler plant in Paide (see Figure 8.42 and Figure 8.43) was one of the first in Estonia that was financed from the joint implementation project based on the Kyoto Protocol. According to this scheme, the amount of CO_2 emissions reduced during the reporting period is accounted as reduction of greenhouse gas emissions in Finland. As compensation, the Finnish state covers the investment cost partially. All the equipment to the boiler plant was supplied by the Finnish company Wärtsilä.

OÜ Pogi is a private company who has leased Peetri Boiler Plant from the Paide Municipality and operated it for a long time. Due to the short-term leasing agreement, OÜ Pogi could not guarantee the loan that was necessary for the refurbishment of municipal boiler plant. The biofuel could be introduced owing to the fact that OÜ Pogi bought a neighbouring plot and built a new boiler plant on it. At the same time the newly built boiler house was also a guarantee for the bank loan required for co-financing.

Figure 8.42. Peetri Boiler Plant in Paide, photo by Ü. Kask

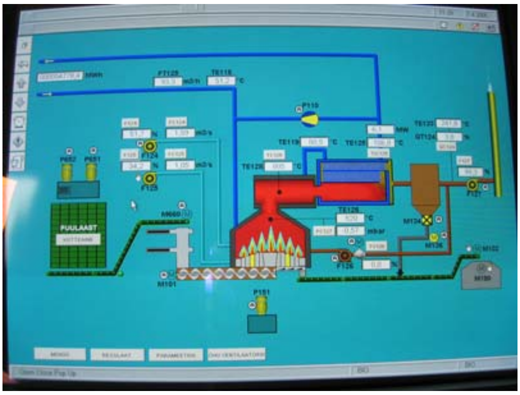


Figure 8.43. Scheme of Peetri Boiler Plant with the operation parameters displayed on the server screen, photo by Ü. Kask

Since the heat supplied from this biofuel boiler plant proved to be significantly cheaper than that based on the fuel oil, a device for condensing water vapour from flue gases was decided to be built that would increase the capacity of biofuel boiler for about 2 MW and increase the share of wood fuels in heat supply of the town from the present 70 – 76 % to about 90 %. The flue gas condenser should be ready to 2005.

The construction period of the boiler plant stretched over a longer period than planned and lasted over 1.5 years in total. It enabled avoiding the mistakes usually made in a hurry. The boiler is designed to work unmanned, but in practice several disturbances in fuel supply exist and the fuel quality varies in a wide range and that is why an operator has been on duty for 24 hours a day up to now.

The scrupulous and effective work of employees is motivated by a bonus system, which has fully justified itself.

Boiler unit

The operation of all boiler equipments and combustion regime is computer controlled and human intervention is needed only infrequently for eliminating more serious faults. For example, some cases of clogging and temperature rise have occurred due to slagging in the gas flue gas duct behind the furnace, which start the fire extinction system in the furnace and the fire will be extinguished. Sometimes the socket of temperature sensor is covered with ash and then the fire extinction system does not switch on. In normal conditions the system must be started when the temperature in the flue gas duct between the furnace and boiler rises over 950 °C and at 1050 °C the boiler is shut down. When the fuel is drier than permitted, the temperature will rise to the level mentioned above but the fire extinction system has excluded the risks of using dry fuel up to now.

The horizontally located boiler must be regularly cleaned after 6 – 8 weeks. The boiler is directly connected to the municipal DH network, but according to the plans, the boiler will be disconnected from the DH network with a plate heat exchanger that would improve the reliability of the system.

The performance of this BioGrate pre-furnace has been treated above (see section 4.2.1.2 and Figure 4.6). In this furnace fuels with highly varying quality and moisture content can be successfully burned and therefore this type of furnace can be considered one of the best technical solutions for burning such fuels.

Fuel handling system

A peat conveyor was originally selected for the fuel conveyor and it did not deliver woodchips and sawdust well. After installing a frequency converter, the conveyor worked equally well with all types of fuels.

Large chunks, stones and several types of metal pieces in the fuel reach often the feed auger (in front of the boiler), which is equipped with a coupler and reversing option and this protects the auger from breaking. For removing the inappropriate lumps the feeders have been halted from time to time.

In conclusion, no significant technical problems have been there with the fuel handling system and their handling throughput satisfies the boiler demand.

Fuel storage and storage equipment

From the fuel storage, which is an intermediate storage with fuel pushers open on one side that can accommodate the weekly fuel stock (see Figure 5.2), the fuel can be supplied to the main storage by conveyors and a tractor loader. The storage equipment can feed the boiler at all loads. The fuel stock in the main storage can supply enough fuel to run the boiler at nominal load only for one day. The bottom of main storage is heated with the return water from the DH network (see Figure 5.3). This solution proved to be good already in the first winter. The fuel is not stuck in the corners of storage either.

Fuel

Highly diversified fuel from sawdust to stumps is supplied by several suppliers located within a 100 km radius of the boiler plant.

Several impurities of unknown origin have been found in the fuel that lower the ash melting temperature in the combustion process and cause slagging of the grate and furnace walls. The fuel is often polluted with soil and sand that also has impact on the processes in the furnace and ash behaviour. Cleaning of the furnace grate is a time and money consuming process.

The key problem as everywhere else is the constantly lowering fuel quality and rising price.

Gas cleaning, ash and soot removal equipment, stacks

The boiler has no acoustic cleaning device for cleaning heating surfaces, but in the near future it is planned to be installed.

At all the boiler loads all different fuels can be burnt completely on the grate and thus no unburned particles reach the multicyclone and both the multicyclon and ash conveyors are not overheated.

In the wet ash handling system the floats indicating water level have been replaced, because due to the damaged floats, the boiler load lowers automatically.

8.3. Conclusions about the experience gained from the use of biofuels in Estonia

8.3.1. Boiler loading and specific fuel consumption

As shown above (see section 7.7.2), in order to reach economic feasibility the expensive biofuel boilers must be maximum loaded, i.e. the boilers should operate at the base load. The following graph (see Figure 8.44) shows the calculated utilization time of the boilers in Estonian boiler plants in 2004.

A very long utilization time (in Haapsalu and Keila even over 6000 hours per year) shows excellent performance without practically any failures during the whole year. As a comparison a typical duration of heating period in Estonia could be given, which is 5300 h. The long utilization time refers also to fast payback of the investments.

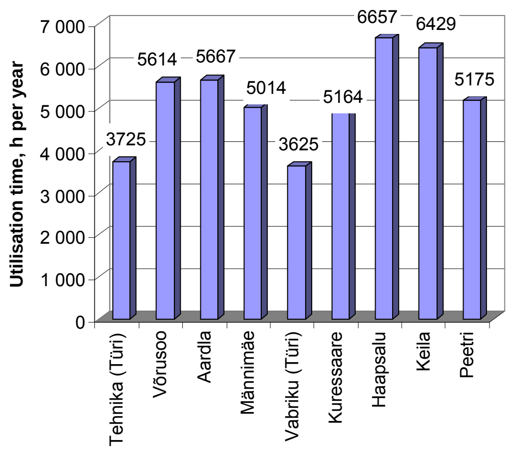


Figure 8.44. Calculated utilisation time of biofuel boilers in 2004

The incredibly long utilization time of the considered biofuel boilers was a pleasant surprise to the authors of this Manual too. This excellent result could be reached owing to the following factors:

- in Haapsalu and Keila health centres and spas are among the heat consumers and their high heat demand in summer time allows prolongation of the period when biofuel boilers carry base load;
- biofuel boilers have been successfully implemented outside the main heating period, i.e., for heating hot domestic water in summer;
- smooth performance of the equipment during a long period and small number of emergency standstills;
- stable fuel supply.

Besides all the reasons listed above, it should be underlined that all the considered boiler plants were well managed and the staff was well motivated.

In two boiler plants of OÜ Terme in Türi the boiler utilization time was somewhat shorter (less than 4000 hours a year). Thereby, the load demand has decreased in the Türi town and in the small DH networks the biofuel boilers cannot be used for covering the base load only. In the beginning and end of heating season (i.e., in autumn and spring) the boilers must be run partially loaded.

When comparing the calculated utilization time with the statistical average of biofuel boilers in Estonia (see Figure 8.3), we can see up to threefold difference. Hence, in many cases the enterprises where biofuel boilers are used have any reason to analyze their work critically and learn from the experience of successful boiler plants.

In all the considered boiler plants the account of the use of biofuels is kept in loose cubic meters of the received fuel. No possibilities for weighing the received fuel loads, no laboratories for on-site determining of fuel moisture content exist in boiler plants and therefore, the energy content of received fuels cannot be calculated via fuel weight.

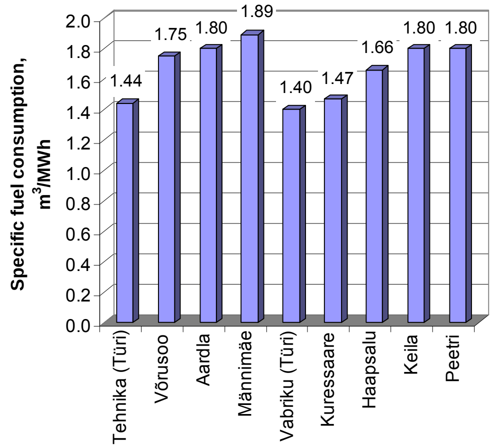


Figure 8.45. Specific fuel consumption in 2004

For different fuels the specific fuel consumption rate per one MWh heat output reflects the fuel quality indirectly. According to experts, the expected efficiency of considered biofuel boilers should not differ significantly. The specific fuel consumption of biofuel boilers given in the Figure 8.45 vary in the range of 1.4 and 1.9 m^3/MWh. While in both Türi boiler plants and in the Kuressaare boiler plant the fuel of higher than medium quality (specific fuel consumption rates 1.4, 1.44 and 1.47 m^3/MWh, respectively) is used, for example in Männimäe Boiler Plant the fuels with much lower energy density and presumably lower quality or lower bulk density are used.

8.3.2. Risks related to the implementation of biofuels

According to the questionnaires filled by boiler plant managers, the favourable factors for the implementation of biofuels include:

- long-term tradition and know-how on utilization of wood fuels for energy production;
- availability of natural forest resources and other biofuels;

- developed forest and wood processing industry that provides stable fuel supply;
- introduction of biofuel production and utilization decreases unemployment in rural areas;
- growing demand for biofuels as environmentally friendly fuels and
- continuous rise in fossil fuel prices along with increasing environmental taxes and charges.

In most of biofuel boilers peat can also be combusted. It allows a flexible following of changes in the fuel market. To the present time, straw has not been widely used as a fuel. Besides, there is a lot of unused agricultural land where energy forests or energy crops could be grown. Thus, there is no fear that the biofuel resources would be exhausted in the future.

Although decreasing of unemployment was mentioned as a resource for promoting the use of biofuels, unfortunately the unemployed people are often of low qualification and reliability in rural regions.

There are often no people with the initiative in rural areas who could be able to prepare loan or grant applications for biofuel projects and carry out the projects. High loan loads of local municipalities can also stand on the way of getting loans from credit organisations.

Several factors can be listed among the risks that mostly relate to either influences of market economy or environmental restrictions:

- competition in the raw material market for biofuels will be come stronger;
- potential investments will go elsewhere where their payback time is shorter;
- increase in the price of petrol and diesel oil make the production of biofuels more expensive, but at the same time it could be an incentive for starting the production of liquid biofuels;
- in the fuel market the prices of biofuels change in the same direction with fossil fuel prices;
- due to the high price level in the international markets the substantial demand for upgraded biofuels will rise the price on biofuels in the countries where biofuels are produced;
- constant increase of labour costs;
- continuously more rigorous restrictions on nature and environmental protection (for example, formation of the so-called Natura areas);
- the projects of growing energy forests and agricultural energy crops cannot be launched due to economic policies.

Although a number of risks has been listed, it all is based on the improved consciousness of people and willingness to foresee and take into account all the aspects related to the future of biofuels in their projects. Presently the conviction is growing that there are significantly less risks in the use of biofuels as domestic fuels than in the use of fossil fuels.

8.3.3. Conclusions and recommendations

The analysis of a 12 year experience in the use of biofuel allows drawing several conclusions and giving recommendations for the future. In summarizing we followed mostly the examples from Estonia, but also some examples of successful biofuel projects from Latvia, Lithuania and North-West Russia were taken into account.

1. The simplified technical solutions of biofuel boiler plants do not provide stable performance of boiler plants and as a result turn out to be more expensive than some modern and already tested technological solutions that require higher investment costs. Therefore, any technical simplification for cutting costs is dangerous and non-recommended.

2. Conversion of fossil fuel boilers to biofuels may give a satisfactory result. At the same time any reconstruction requires very profound knowledge of boilers and an individual solution must be prepared for each boiler plant, which may rise the cost to the same level as that of buying new complex units. As a rule, the reconstructed boilers are more sensitive to the fuel quality variation than a new complex plant. In conclusion, we recommend preferring new complex solutions if the investment levels of these two options are similar.

3. The investments for building biofuel boiler plants are quite substantial. The projects pay pack the better, the more efficiently the biofuel equipment can be loaded. Hence, the plant should work on the base load and the existing or new oil or gas fired boilers should be used for covering peak loads.

4. The quality of biofuels may vary in a wide range, but a combustion unit is usually foreseen for burning the fuel of certain moisture content and quality. Combustion of fuels, which are not suitable for burning in a certain boiler (even for a short time) may cause serious faults in the unit performance – for example, slagging of grate or heating surfaces, unburned particles reaching the multicyclone, etc. If possible, the use of fuels with variable quality should be avoided, although the problems could be mitigated with mixing the fuels or moistening a dry fuel.

5. According to the Estonian experience, Wärtsilä BioGrate boilers and boilers based on fluidized bed technology fit better for combustions of fuels with variable fuel properties.

6. The use of biofuels is a great challenge for the staff, both in management and fuel supply point of view. It also sets demands to the skills and motivation of boiler operators and technical personnel. In most cases, boiler operators tend to overestimate their skills. So, changing experience with specialists from other boiler plants and participation in training courses are equally important. The responsibilities of biofuel boiler operators are much more complicated than the service personnel of gas and oil fired boilers has to face. Therefore, additional motivation and remuneration of the staff of biofuel boiler plant is indispensable.

7. In case the biofuel fired and a sulphur rich fuel fired boilers use the same exhaust gas ducts and stack, dangerous corrosion damages of the gas ducts and stack may emerge when moist biofuel is burned. Such so-called low-temperature corrosion phenomena may also occur on some low temperature heating surfaces of the biofuel boiler that was earlier heavy fuel oil fired one. In conclusion, it is recommended to equip the biofuel boiler with a separate stack and exhaust gas duct. Furthermore, the temperature of boiler inlet water should be kept at the required (i.e., sufficiently high) level.

8. In the Baltic countries as well as in Poland and Russia financial support is available for funding the biofuel projects by the countries, which cannot meet the Kyoto requirements on the reduction of greenhouse gas emissions otherwise.

9. APPENDICES

9.1. Units

Table 9.1. Conversion of energy units

	toe	**MWh**	**GJ**	**Gcal**
toe	1	11.630	41.868	10.0
MWh	0.08598	1	3.6	0.86
GJ	0.02388	0.2778	1	0.2388
Gcal	0.1	1.1630	4.1868	1

Table 9.2. Prefixes

k	= kilo	= 10^3	= 1 000
M	= mega	= 10^6	= 1 000 000
G	= giga	= 10^9	= 1 000 000 000
T	= tera	= 10^{12}	= 1 000 000 000 000
P	= peta	= 10^{15}	= 1 000 000 000 000 000

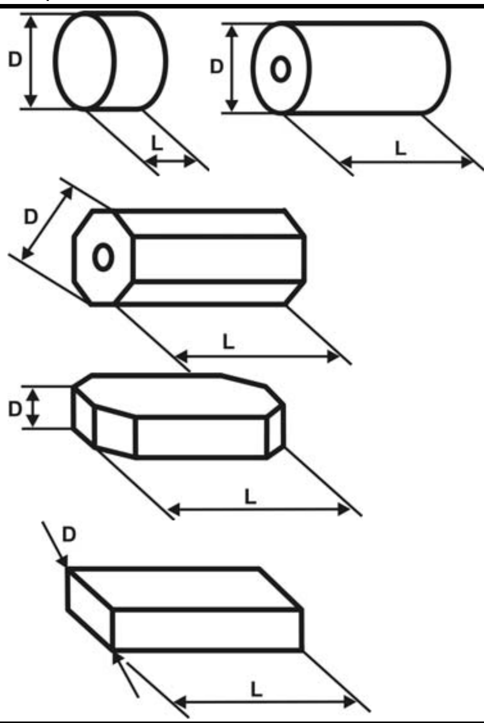
9.2. Specification of properties of biomass and peat fuels

Table 9.3. Specification of properties for wood chips [16]

	Master table			
	Origin:		Woody biomass	
	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 ≤ 16 mm	< 1 mm	max 1 %[a] > 45 mm, all < 85 mm
	P45	3.15 mm ≤ 45 mm	< 1 mm	max 1 %[a] > 63 mm
	P63	3.15 mm ≤ 63 mm	< 1 mm	max 1 %[a] > 100 mm
	P100	3.15 mm ≤ 100 mm	< 1 mm	max 1 %[a] > 200 mm
	Moisture, weight % as received, M_{ar}			
	M20	≤ 20 %	Dried	
	M30	≤ 30 %	Suitable for storage	
	M40	≤ 40 %	Limited for storage	
	M55	≤ 55 %		
	M65	≤ 65 %		
	Ash, weight % in dry matter, A_d			
	A0.7	≤ 0.7 %		
	A1.5	≤ 1.5 %		
	A3.0	≤ 3.0 %		
	A6.0	≤ 6.0 %		
	A10.0	≤ 10.0 %		
	Nitrogen, weight % of dry bases, N_d			
	N0.5		Nitrogen is normative only for chemically treated biomass	
	N1.0			
	N3.0			
	N3.0+			
Informative	Net calorific value $q_{net,ar}$ (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)		Recommended to be stated as a category Cl0.03, Cl0.07, Cl0.10 and Cl0.10+ (if Cl > 0.1 % the actual value to be stated)	

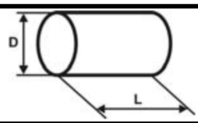
[a] – The numerical values for dimension refer to the particle sizes passing through the mentioned round hole sieve size (3.15 mm, 16 mm, 45 mm, 63 mm and 100 mm). Dimensions of actual particles may differ from those values, especially the length of the particle.

Table 9.4. Specification of properties for briquettes [16]

	Master table		
	Origin:		Woody biomass Herbaceous biomass Peat Blends and mixtures
	Traded form:		Briquette
Normative	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)	
	Moisture, weight % as received, M_{ar}		
	M10	≤ 10 %	
	M15	≤ 15 %	
	M20	≤ 20 %	
	Ash, weight % of dry bases, A_d		
	A0.7	≤ 0.7 %	
	A1.5	≤ 1.5 %	
	A3.0	≤ 3.0 %	
	A6.0	≤ 6.0 %	
	A10.0	≤ 10.0 %	
	Sulphur, weight % of dry bases, S_d		
	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)	

<table>
<tr><td rowspan="15"></td><td colspan="3">Particle density, kg/dm^3</td></tr>
<tr><td>DE0.8</td><td>0.80 – 0.99</td><td rowspan="4"></td></tr>
<tr><td>DE1.0</td><td>1.00 – 1.09</td></tr>
<tr><td>DE1.1</td><td>1.10 – 0.99</td></tr>
<tr><td>DE1.2</td><td>≥ 1.20</td></tr>
<tr><td colspan="3">Additives, weight % of pressing mass</td></tr>
<tr><td colspan="3">Type and content of pressing aids, slagging inhibitors or any other additives have to be stated</td></tr>
<tr><td colspan="3">Nitrogen, weight % of dry bases, N_d, %</td></tr>
<tr><td>N0.3</td><td>≤ 0.3 %</td><td rowspan="5">Nitrogen is normative only for chemically treated biomass</td></tr>
<tr><td>N0.5</td><td>≤ 0.5 %</td></tr>
<tr><td>N1.0</td><td>≤ 1.0 %</td></tr>
<tr><td>N3.0</td><td>≤ 3,0 %</td></tr>
<tr><td>N3.0+</td><td>> 3.0 % (actual value to be stated)</td></tr>
<tr><td colspan="3"></td></tr>
<tr><td colspan="3"></td></tr>
<tr><td rowspan="3">Informative</td><td colspan="2">Net calorific value $q_{net,ar}$ (MJ/kg as received) or energy density, E_{ar} (kWh/m^3 loose)</td><td>Recommended to be specified when retailed</td></tr>
<tr><td colspan="2">Bulk density as received, (kg/m^3 loose)</td><td>Recommended to be stated if traded by volume basis</td></tr>
<tr><td colspan="2">Chlorine, Cl (weight % of dry basis)</td><td>Recommended to be stated as a category Cl0.03, Cl0.07, Cl0.10 and Cl0.10+ (if Cl > 0.1 % the actual value to be stated)</td></tr>
</table>

Table 9.5. Specification of properties for pellets [16]

	Master table		
	Origin:		Woody biomass Herbaceous biomass Fruit biomass Blends and mixtures
	Traded form:		Pellets
Normative	Dimensions, mm		
	Diameter (D) and length (L). Maximum 20 % of the pellets may have a length of 7.5 x·D		
	D06	≤ 6 mm ±0.5 mm and L ≤ 5 x D	
	D08	≤ 8 mm ±0.5 mm and L ≤ 4 x D	
	D10	≤ 10 mm ±0.5 mm and L ≤ 4 x D	
	D12	≤ 12 mm ±1.0 mm and L ≤ 4 x D	
	D25	≤ 25 mm ±1.0 mm and L ≤ 4 x D	
	Moisture, weight % as received, M_{ar}		
	M10	≤ 10 %	
	M15	≤ 15 %	
	M20	≤ 20 %	
	Ash, weight % of dry bases, A_d		
	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, weight % of dry bases, S_d		
	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 % (actual value to be stated)	
	Mechanical durability, weight % of pellets after testing, DU		
	DU97.5	≥ 97.5 %	
	DU95.0	≥ 95.0 %	
	DU90.0	≥ 90.0 %	
	Amount of fines (weight %, < 3.15 mm) after production at factory gate		
	F1.0	≤ 1.0 %	At the last possible place in the production site
	F2.0	≤ 2.0 %	
	F2.0+	> 2.0 % (actual value to be stated)	
	Additives, weight % of pressing mass		
	Type and content of pressing aids, slagging inhibitors or any other additives have to be stated		
	Nitrogen, weight % of dry bases, N_d, %		
	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 $q_{net,ar}$ (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
	Chlorine, Cl (weight % of dry basis)		Recommended to be stated as a category Cl0.03, Cl0.07, Cl0.10 and Cl0.10+ (if Cl > 0.1 % the actual value to be stated)

Table 9.6. Specification of properties for bark [16]

	Master table		
	Origin:		Woody biomass
	Traded form:		Bark
Normative	Moisture, weight % as received, M_{ar}		
	M40	≤ 40 %	
	M50	≤ 50 %	
	M60	≤ 65 %	
	M70	≤ 70 %	
	Ash, weight % of dry bases, A_d		
	A0.7	≤ 0.7 %	
	A1.5	≤ 1.5 %	
	A3.0	≤ 3.0 %	
	A6.0	≤ 6.0 %	
	A12.0	≤ 12.0 %	
	Nitrogen, weight % of dry bases. N_d		
	N0.5	N0.5	Nitrogen is normative only for chemically treated biomass
	N1.0	N1.0	
	N3.0	N3.0	
	N3.0+	N3.0+ (actual value to be stated)	
Informative	Net calorific value, $q_{net,ar}$ (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_d weight % of dry bases		Recommended to be stated as a category Cl0.03. Cl0.07. Cl0.10 and Cl0.10+ (if Cl > 0.1 % the actual value to be stated)

Table 9.7. Specification of properties for log woods [16]

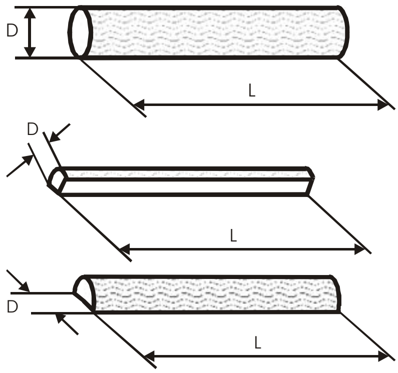
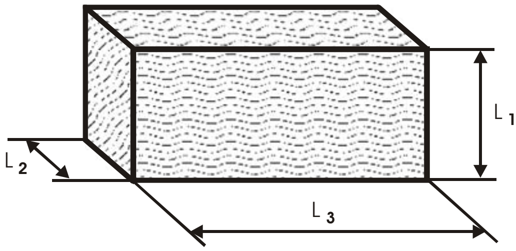
	Master table		
	Origin:		Woody biomass
	Traded form:		Log woods
Normative	Dimensions, mm		
	Length L and thickness D (maximum diameter of a single chop)		
	P200-	L < 200 mm and D < 20 (ignition wood)	
	P200	L = 200 ± 20 and 40 mm ≤ D ≤ 150 mm	
	P250	L = 250 ± 20 and 40 mm ≤ D ≤ 150 mm	
	P330	L = 330 ± 20 and 40 mm ≤ D ≤ 160 mm	
	P500	L = 500 ± 40 and 60 mm ≤ D ≤ 250 mm	
	P1000	L = 1000 ± 50 and 60 mm ≤ D ≤ 350 mm	
	P1000+	L > 1000 mm, actual value for L has to be stated and D has to be stated	
	Moisture, weight % as received, M_{ar}		
	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 $E_{net,ar}$ (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
			Mixtured: split and round wood as a mixture
	The cut-off surface		To be stated if the cut-off surface of log woods are even and smooth or ends of log woods are uneven (use of chainsaw is considered to be smooth or even)
	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

Table 9.8. Specification of properties for straw bales [16]

	Master table	
	Origin:	Cereal crop straw Grass straw Oil seed crops stalks and leaves
	Traded form:	Big bales

Normative

Dimensions, mm: height L_1, width L_2 and length L_3



	Height L_1	Width L_2	Length L_3
P1	1 300	1 200	2 200
P2	1 300	1 200	2 400
P3	600 – 900	1 200	2 400
P4	1 300	1 200	1 100 – 2 750

Bale density, kg/m^3		
BD130	≤ 130	
BD150	≤ 150	
BD165	≤ 165	
BD165+	> 165	
Moisture, weight % as received, M_{ar}		
M16	≤ 16 %	No part over 23 %
M16+	≤ 16 %	Parts over 23 % acceptable
M23	≤ 23 %	No parts over 30 %
M23+	≤ 23 %	One or more parts over 30 %
M30	≤ 30 %	No part over 35 %
M30+	≤ 30 %	One or more parts over 35 %
Ash, weight % of dry bases, A_d, %		
A05	≤ 0.7 %	
A10	≤ 1.5 %	
A10+	≤ 3.0 %	
Species of biomass		
Has to be stated		

Informative

Net calorific value, $q_{net,ar}$ (MJ/kg as received) or energy density, E_{ar} (kWh/m^3 loose)	Recommended to be stated
Particle size or structure	It is recommended to declare production methods that influence the size of straw particles. That is, for instance, whether the crop has been trashed by rotation or oscillation or whether it has been chopped

Table 9.9. Specification of properties for sawdust [16]

<table>
<tr><td rowspan="3"></td><td colspan="2">Master table</td><td></td></tr>
<tr><td colspan="2">Origin:</td><td>Woody biomass</td></tr>
<tr><td colspan="2">Traded form:</td><td>Sawdust</td></tr>
<tr><td rowspan="16">Normative</td><td colspan="3">Moisture, weight % as received, M_{ar}</td></tr>
<tr><td>M20</td><td>≤ 20 %</td><td>Dried</td></tr>
<tr><td>M30</td><td>≤ 30 %</td><td>Suitable for storage</td></tr>
<tr><td>M35</td><td>≤ 35 %</td><td>Limited for storage</td></tr>
<tr><td>M55</td><td>≤ 55 %</td><td></td></tr>
<tr><td>M65</td><td>≤ 65 %</td><td></td></tr>
<tr><td colspan="3">Ash, weight % of dry bases, A_d, %</td></tr>
<tr><td>A0.7</td><td>≤ 0.7 %</td><td rowspan="4"></td></tr>
<tr><td>A1.5</td><td>≤ 1.5 %</td></tr>
<tr><td>A3.0</td><td>≤ 3.0 %</td></tr>
<tr><td>A6.0</td><td>≤ 6.0 %</td></tr>
<tr><td colspan="3">Nitrogen, weight % of dry bases, N_d, %</td></tr>
<tr><td>N0.5</td><td>N0.5</td><td rowspan="4">Nitrogen is normative only for chemically treated biomass</td></tr>
<tr><td>N1.0</td><td>N1.0</td></tr>
<tr><td>N3.0</td><td>N3.0</td></tr>
<tr><td>N3.0+</td><td>N3.0+ (actual value to be stated)</td></tr>
<tr><td rowspan="3">Informative</td><td colspan="2">Net calorific value, $q_{net,ar}$ (MJ/kg as received) or energy density, E_{ar} (kWh/m^3 loose)</td><td>Recommended to be specified</td></tr>
<tr><td colspan="2">Bulk density as received, (kg/m^3 loose)</td><td>Recommended to be stated if traded by volume basis in categories BD200, BD300, BD350</td></tr>
<tr><td colspan="2">Chlorine, Cl_d weight % of dry bases</td><td>Recommended to be stated as a category Cl0.03. Cl0.07. Cl0.10 and Cl0.10+
(if Cl > 0.1 % the actual value to be stated)</td></tr>
<tr><td colspan="4">NB! Particle size for sawdust is considered to be homogenous. Particle size distribution could be specified if required</td></tr>
</table>

9.3. Tables of widely used data

Table 9.10. Fuelwood net calorific value $q_{net,ar}$, MWh/t (if average calorific value of dry ash free matter 19.2 MJ/kg)

Moisture, M_{ar}, %	Net calorific value $q_{net,ar}$, MWh/t, according to ash content A_{ar}				
	1 %	2 %	3 %	4 %	5 %
25	3.79	3.75	3.71	3.67	3.63
26	3.73	3.69	3.65	3.61	3.57
27	3.67	3.63	3.59	3.55	3.52
28	3.61	3.57	3.54	3.50	3.46
29	3.55	3.51	3.48	3.44	3.40
30	3.49	3.46	3.42	3.38	3.34
31	3.43	3.40	3.36	3.32	3.29
32	3.37	3.34	3.30	3.26	3.23
33	3.31	3.28	3.24	3.21	3.17
34	3.25	3.22	3.18	3.15	3.11
35	3.19	3.16	3.13	3.09	3.06
36	3.14	3.10	3.07	3.03	3.00
37	3.08	3.04	3.01	2.97	2.94
38	3.02	2.98	2.95	2.92	2.88
39	2.96	2.92	2.89	2.86	2.83
40	2.90	2.86	2.83	2.80	2.77
41	2.84	2.81	2.77	2.74	2.71
42	2.78	2.75	2.72	2.68	2.65
43	2.72	2.69	2.66	2.63	2.60
44	2.66	2.63	2.60	2.57	2.54
45	2.60	2.57	2.54	2.51	2.48
46	2.54	2.51	2.48	2.45	2.42
47	2.48	2.45	2.42	2.40	2.37
48	2.42	2.39	2.36	2.34	2.31
49	2.36	2.33	2.31	2.28	2.25
50	2.30	2.27	2.25	2.22	2.19
51	2.24	2.22	2.19	2.16	2.14
52	2.18	2.16	2.13	2.11	2.08
53	2.12	2.10	2.07	2.05	2.02
54	2.06	2.04	2.01	1.99	1.96
55	2.00	1.98	1.96	1.93	1.91
56	1.94	1.92	1.90	1.87	1.85
57	1.88	1.86	1.84	1.82	1.79

Moisture, M_{ar}, %	Net calorific value $q_{net,ar}$, MWh/t, according to ash content A_{ar}				
	1 %	2 %	3 %	4 %	5 %
58	1.82	1.80	1.78	1.76	1.73
59	1.76	1.74	1.72	1.70	1.68
60	1.71	1.68	1.66	1.64	1.62
61	1.65	1.62	1.60	1.58	1.56
62	1.59	1.57	1.55	1.53	1.51
63	1.53	1.51	1.49	1.47	1.45
64	1.47	1.45	1.43	1.41	1.39
65	1.41	1.39	1.37	1.35	1.33
66	1.35	1.33	1.31	1.29	1.28
67	1.29	1.27	1.25	1.24	1.22
68	1.23	1.21	1.19	1.18	1.16
69	1.17	1.15	1.14	1.12	1.10
70	1.11	1.09	1.08	1.06	1.05

Table 9.11. Typical properties of log woods seasoned in the storage [41]

Wood species	Wood density, kg/m^3 solid	Bulk density, kg/m^3 stacked	Net calorific value $q_{net,ar}$, MJ/kg	Energy density E_{ar}, kWh/m^3 stacked
Birch	680	485	13.6	1 800
Spruce	490	340	13.7	1 295
Pine	550	385	13.6	1 450
Alder	570	400	13.3	1 470
Aspen	540	380	12.9	1 360

Table 9.12. Swedish classification for pellets SS 187120 [6]

Property	Unit	Group 1	Group 2	Group 3
Diameter (D) and length (L) at producer storage	mm	L < 4 x D	L < 5 x D	L < 5 x D
Bulk density as received, D_{ar}	kg/m^3	$D_{ar} \geq 600$	$D_{ar} \geq 500$	$D_{ar} \geq 500$
Amount of fines (< 3 mm), weight basis, F	%	F ≤ 0.8	F ≤ 1.5	F ≤ 1.5
Net calorific value as received, $q_{net,ar}$	MJ/kg	$q_{net,ar} \geq 16.9$	$q_{net,ar} \geq 16.9$	$q_{net,ar} \geq 15.1$
	kWh/kg	$q_{net,ar} \geq 4.7$	$q_{net,ar} \geq 4.7$	$q_{net,ar} \geq 4.2$

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