Stefan Döring

Power from Pellets

Technology and Applications

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Preface

This book provides a brief description primarily relating to the wood pellet when employed as an energy source. It is intended to be of use to a large variety of readers: teachers as well as those taught, entrepreneurs and investors, financiers, operators, plant manufacturers, and other interested parties. With this in mind, this book initially presents the development of the pellet market with its trade flows and price developments, the potential of any specific biomass for pelletization, combustion characteristics, various quality requirements for the pellets, and legal restraints. Using these chapters as a foundation, the technology of pelletization is then described by way of examples. After that, the energy recovery from pellets is discussed. The conclusion contains a comprehensive representation of the available fire and explosion protection measures, the cost-effectiveness of pellets in comparison with fossil energy sources and a brief look at relevant research projects.

I would like to especially thank my publishers, Springer Verlag, who provided me the opportunity to write this book and to have it published. Further thanks are due to the other authors who supported me in creating this book and whom I value greatly, in particular professor Martin Kaltschmitt, Dr.-Ing., Mrs. Janet Witt, Dipl.-Ing, (UoAS), MSc, Mr. Stefan Schwing, Dipl.-Ing. from INBUREX Consulting GmbH, Mrs. Christiane Henning, MSc and Dipl.-Bus. Studies, and Mrs. Nadja Rensberg, Dipl.-Geogr.

Besides my co-authors mentioned, other specialists were involved in the book's conception and its revision. Thus, by way of example, my associates Alexander Hirsch, Arthur Pinnecker, Hubert Schillings, Wolfgang Schlaug, Roland Paul, and Christoph Roos must be mentioned here. Further thanks are due to Mr. Manfred Pfeifer and Mr. Jens Neumeister for their valuable support.

My sincere thanks to the companies and other sources mentioned in the respective chapters for providing and releasing the graphical material. Apart from those already mentioned, other specialists were involved in the work, whom I also wish to thank at this point. This book could not have been completed without their committed support.

This book was created parallel to my primary professional activity. All the relationships, facts, and numbers quoted were researched and presented to the best of our knowledge and belief and with great care. Nevertheless, the presence of errors and imperfections cannot be ruled out and I would therefore be very grateful for any specific and productive comments, which will be taken into consideration for a possible revised edition.

Leutesdorf, August 2010 Stefan Döring

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Contents

Chapter 1
Introduction

1.1 Political Aims and General Requirements of Power Economics

The provision of energy from regenerative energy sources, in general, and from biomass, in particular, is increasingly gaining importance in the political discussions about energy and the environment. Of all the regenerative energy sources, biomass is the most important option, by far. For example, in Germany around 75 % of the entire energy ultimately provided from renewable energy sources comes from biomass, and this proportion tends to be even higher worldwide. According to the ambitious aims of the Commission of European Communities, which have been adopted by many EU member states, among them also Germany, this proportion should even become distinctly greater in absolute terms. This applies especially with regard to fossil energy sources which must be increasingly managed with a view to taking more care to conserve resources.

In order to realize these political aims successfully in the marketplace—with extensive acceptance by the general public—innovative options for utilizing biomass must be increasingly developed and made available on the market. But this means that the problems and challenges still partly associated with utilizing biomass as an energy source must first be overcome. For example, the necessity to make the resource of biomass, which is available only to a limited extent, useable in the most efficient way possible, is such a challenge. Another, related task is to distinctly reduce the actual and/or potential environmental effects—meaning not only the potential effects on the climate but also and especially toxicologically relevant releases of substances which can affect the persons dealing with on-site biomass utilization. For these reasons, novel and innovative options for utilizing biomass can always be implemented only within the context of optimizing the entire supply chain—from biomass production via supply to utilization. In the course of this process the aim must be to to improve and to optimize the individual components of such a supply chain and their interaction also from the social point of view.

S. Döring, *Power from Pellets*, DOI: 10.1007/978-3-642-19962-2_1,

This also applies to providing heat with untreated wood which, due to the greatly fluctuating energy prices for fossil fuels and the apparent decrease in the security of supplies in the gas market (due to, among other things, the politically motivated interruptions of supply from Russia to the Ukraine) has become more and more significant in recent years and has, therefore, been marked by a noticeable expansion in the market. In addition, this development has been and is being supported by the administrative framework in Germany, but also in other European countries, since it also makes it possible to provide a noteworthy contribution to protecting the climate and creating added value in rural regions—as well as to improving the security of supplies.

With the increasing significance in the market of providing heat from biogenic solid fuels the associated negative effects have also gained significance in the political discussion relating to energy and the environment. This applies, on the one hand, to the sustained provision of the raw material—especially also against the background of the demand by the timber industry which has also increased noticeably in recent years—and, on the other hand, with respect to the emissions of, among other things, dusts and of odorous substances associated with the combustion of possibly toxicologically relevant wood in certain firing systems.

Against this background, the fact that wood pellets have increasingly become established for use in small firing systems definitely appears to present a very promising option which has to be taken seriously. Given this possibility, also established in Germany within the last two decades, a large number of the said challenges can be brought closer to an acceptable solution whilst exploiting the associated advantages. This applies particularly to the following aspects:

- Considering the supply chain in its entirety, wood pellets allow for a comparatively very efficient—and thus resource-conserving—provision of heat which, as a rule, adequately takes into account the applicable requirements for sustainability.
- The properties of wood pellets as a fuel are clearly defined by national and European standards. Furthermore, corresponding quality management concepts are available which help to maintain the quality demanded in the respective standards in a reliable and verifiable way. This has the advantage, on the one hand, that, as a result, national and international fuel markets can form which may have a stabilizing effect on prices and provide for a high degree of supply security. If, on the other hand the fuel properties are known and are being reliably maintained, the firing systems can be mechanically optimized in this respect by the manufacturers.
- As loose material, wood pellets enable the firing system to be operated fully automatically and thus to be optimized environmentally largely independently of any possibly inadequate behavior by its user. For this reason they achieve the lowest emission values and thus the best environmental grading in a comparison of the small firing systems for biogenic fuels (i.e. firewood, wood chips, wood pellets) currently available on the market.

Providing heat from wood pellets is thus marked by a large number of advantages in comparison with firewood or wood chips. To this is added the fact that the wood pellet supply chain is much more flexible in comparison with the other heat-generating options from biogenic solid fuels. This applies to, among other things, the raw material to be used. If the fuel specifications laid down are met, a certain proportion of the solid biomasses (e.g. straw) could in the future potentially also be mixed in if it can be verified by the appropriate R & D work that this has no negative effects on the combustion and on the associated release of substances. In addition, the wood pellet fuel can be used in a relatively simple manner in a large number of other energy markets due to its marketability and its familiar fuel characteristics . This applies to, among other things, its utilization in power plants in the medium and greater power range and to co-incineration in existing coal-fired power plants and combined heating and power plants in order to replace coal for reasons of climate protection and thus to avoid the associated climatic gas emissions of fossil origin.

Due to these advantages, a very dynamic wood pellet market has developed in recent years in Germany and in Europe—and partially also worldwide—of which it can be assumed that it will significantly expand also in the years to come and change further with the ever-increasing requirements for the pellet characteristics—driven by the rising demands for ever further reduction of the environmental effects of providing heat from biogenic solid fuels. At the same time, this market, too, will became increasingly internationalized.

1.2 Pellet Market Development

In this chapter, the development of the pellet market in Germany, in the EU and in selected overseas markets will be examined, taking into consideration the market parameters of production capacities and quantities, quantities consumed and the development of the wood pellet price. A following illustration of the trade flows is intended to show the size and formation of the pellet market. The individual parameters are represented for the period from 2001 to 2009.

The international pellet market has experienced an enormous growth in the last decade. A multiplicity of new players have entered the market and have already created a comprehensive pellet infrastructure including producers, dealers and consumers in many countries. The former niche market of the 1980s has matured to become a respectable industry at competitive level. During this process, characteristic market structures have formed which differ with regard to the pellet quality traded and with reference to the fields of application of the wood pellets; markets in which.

- wood pellets are used for generating electricity in power stations (called industrial pellet markets hereinafter),
- high-quality (as a rule certified) wood pellets are used primarily for generating heat in the lower range of power (called premium pellet market hereinafter),

– wood pellets are used both for generating heat and electricity (called mixed pellet markets hereinafter),
– no or only little local consumption is registered, only pellet production (called pellet export markets hereinafter).

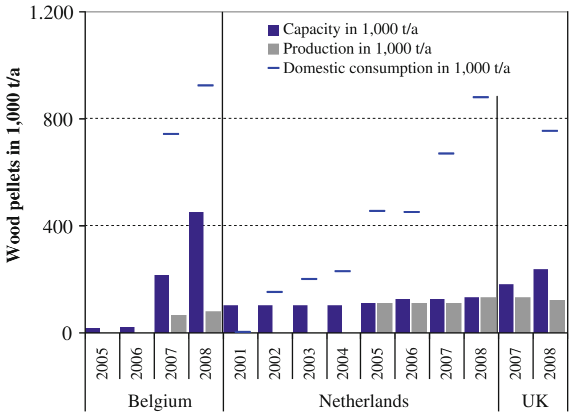
In the following section, the four market formations will be presented with the help of their typical representatives and their political and structural framework will be explained by way of examples in some countries.

1.2.1 International Markets

Industrial Pellet Markets

The industrial pellet markets in Europe include Belgium, the Netherlands and Great Britain. In these markets, wood pellets are used mainly for co-incineration in coal-fired power plants. Thus, in the Netherlands, e.g. more than 95 % of the total amount of wood pellets consumed is used in co-incineration (2008 status of 790.000 tons). In comparison with 2003, this is four times the amount of wood pellets previously used [1]. This positive development of the pellet use is attributable to a governmental promotion—the milieukwaliteit elektriciteitsproductie (MEP) program—a so-called feed-in system which was in force between 2003 and 2006 and offered a tariff of 6–7 €ct per kWh generated electricity from ligneous biomass bot. The longest term of the feed-in tariff contracts concluded in this period is 10 years, i.e. the promotion expires in 2012 or 2015, respectively. Correspondingly, a slow-down in the co-incineration of wood pellets in coal-fired power stations is expected at these times. The co-incineration of wood pellets is not promoted within the present incentive program stimuleringsregeling duurzame energie (SDE) for a sustained generation of electricity [2].

Fig. 1.1 Development of industrial wood pellet markets from 2001 to 2008



The Dutch wood pellet production is very low quantitatively (output level: 120,000 tons, production capacity: 130,000 tons in 2008), e.g. compared with the premium pellet market of Germany with a production of 1.5 million tons, and is also limited in perspective. This market is, therefore, dependent on high wood pellet imports. Limiting factors are mainly a scarcity of local forests and existing competition for the utilization of woody waste materials such as, e.g. the chipboard industry in Belgium and the Dutch milk industry [2]. The British wood pellet market is exhibiting a comparable development and size. Here, too, the market has developed slowly since its beginning in 2002 and is limited by the national occurrences of woody raw materials. Figure 1.1 shows the most important industrial pellet markets in summary.

Premium Pellet Markets

In the premium pellet markets, higher-quality wood pellets are primarily used for heat generation in single- and multi-family residences. Representatives of this group are Germany, Austria and Italy in Europe and the USA overseas. In comparison with the industrial pellet markets, significantly greater quantities of wood pellets are both produced and consumed in these markets.

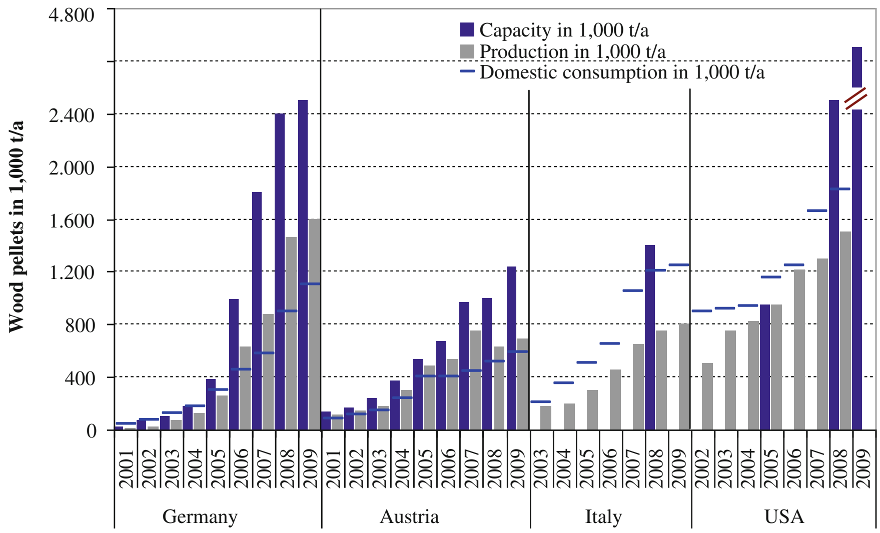


Fig. 1.2 Development of premium wood pellet markets from 2001 to 2008

One of the fastest growing markets in recent years has been the German wood pellet market. Promotional programs at federal and state level (e.g. the Market Incentive Program) and rising prices for fossil fuels have stimulated house owners into installing wood pellet heating systems. It has thus been possible for one of the largest wood pellet markets worldwide to form in Germany since the year 2000. The production capacity was 2.5 m tons in 2009, the production volume achieved being about 1.6 m tons. The consumption was 1.1 m tons [3]. Whilst the domestic demand had largely been covered by imports up to 2005, Germany can now meet the domestic need with its own production sites since 2007. In 2009, the production volume was clearly above the demand and about 30 % of the total volume produced was exported. Figure 1.2 provides an overview of the development of premium pellet markets.

Mixed Pellet Markets

Mixed pellet markets are characterized by a proportionate utilization of wood pellets both in power stations and for decentralized heat generation in heating systems in the relatively small and medium-sized power range. Representative markets are Denmark, Finland and Sweden, the latter market having the longest tradition in the production and utilization of wood pellets in Europe. Overall, the volumes of production and consumption of the mixed pellet markets are comparable with those of the premium pellet markets.

The Swedish wood pellet market evolved at the beginning of the 1980s and is today the largest wood pellet market in the world according to its figures of consumption. The emergence of the pellet industry was aided by the national framework of energy politics which, since the oil crisis in 1979, promoted alternative forms of energy sources indirectly by introducing, among other things, an energy tax and a CO_2 tax on fossil fuels. In Sweden, wood pellets are currently used both in unit type power stations and district heating power stations and for

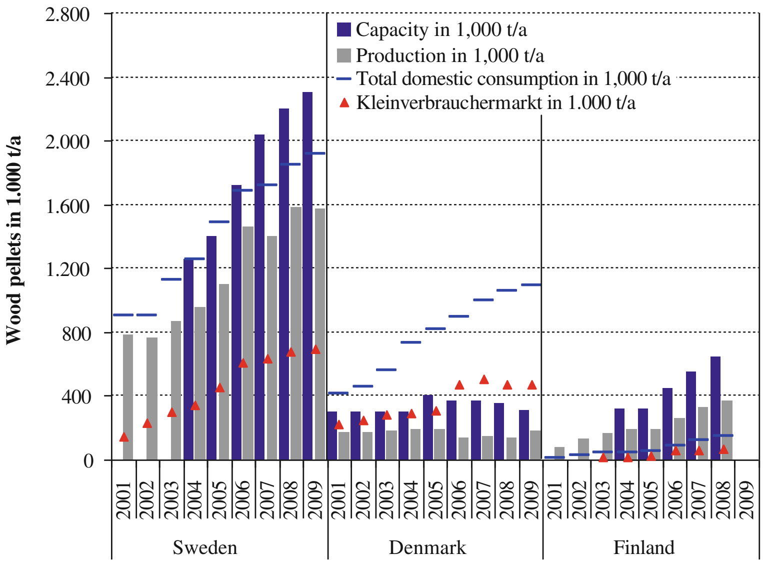


Fig. 1.3 Development of mixed wood pellet markets from 2001 to 2009

generating heat in private residences. This market began more strongly as an industrial pellet market but in the meantime a retail market has also formed which, however, still has the smaller market share (about 35 %) [2].

In 2009, Sweden had an installed wood pellet production capacity of 2.3 m tons with a production volume of 1.6 m tons which was used mainly inland. The export quota is currently about 5 %. The total consumption of wood pellets in the country is 1.9 m tons (695,000 tons in the retail market). To cover the domestic demand, Sweden mainly imports wood pellets from Canada, the Baltic states and Finland, but also from Poland and Russia. The Danish market, too, is dependent on high imports but its domestic consumption is half that of Sweden (1.1 m tons). Figure 1.3 shows the market data for Sweden, Denmark and Finland.

Export Markets

The largest export markets for covering the European demand for wood pellets are Russia and Poland, and Canada overseas. The Polish wood pellet market is still very young with comparably low production volumes but it exhibits strong rates of growth and untapped potentials. Poland has large reserves of forests and an associated distinct wood-processing industry which benefits the future development of this market for the wood pellet industry.

In Poland, the wood pellet production began in 2003. Since its market inception, a continuous expansion of capacities could be registered (40,000 tons in 2003, 640,000 tons in 2009). The wood pellets produced are mainly destined for export to Denmark, Sweden, Germany and Italy. It is only since last year that an increasing domestic consumption can be observed. The cause of this development is seen in the change in the energy politics of Poland, with an orientation towards obtaining energy from regenerative energy sources [4]. It remains to be seen to what extent biomass-type (district heating) power stations or co-incineration in coal-fired power stations will emerge in the next few years and thus vitalize the local wood pellet consumption.

In addition, Canada is presented as the currently largest exporter for the European wood pellet market. Canada supplies wood pellets mainly for use in power stations in the Netherlands, Denmark and Great Britain. Thus, the export quota of Canadian wood pellets to Europe increased from 35 % (appr. 150,000 tons in 2001) of the total production to 55 % (appr. 760,000 tons in 2009). In addition, Canada supplies the US market with wood pellets (23 % of the production volume in 2009) [5]. In 2009, about 1.4 m tons of wood pellets were produced with an installed production capacity of more than 2.0 m tons. According to opinions in the industry, production capacity and volume exhibit a great potential for growth in this market since there is still an unused potential for raw material (such as, e.g. an excess from sawmills, and due to the forest infestation by the mountain pine bug). Considering the as yet still restrained domestic demand, the volumes exported to the European market could increase correspondingly. The consumption of wood pellets in small firing systems is currently

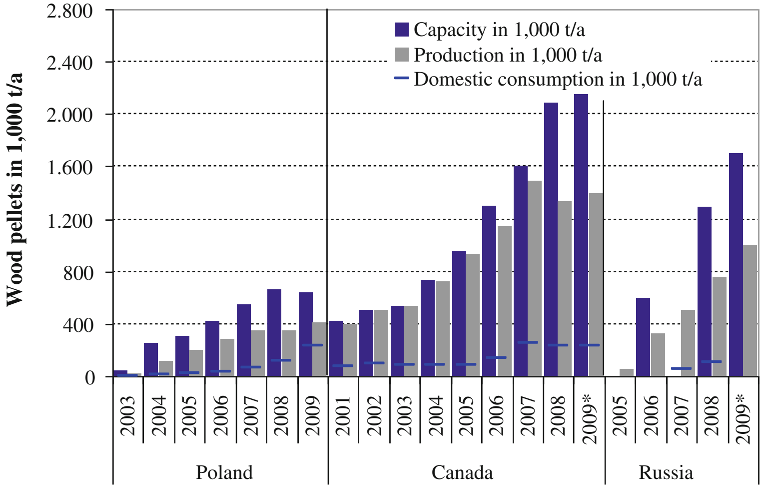


Fig. 1.4 Development of the wood pellet export market from 2001 to 2009, *estimated

about 230,000 tons. They have hitherto not been used in power stations but in the long term an expansion of co-incineration is expected. Thus, first legislation providing for a reduction in coal firing has been launched which can boost the use of wood pellets in the long term.

Figure 1.4 shows the development of the production capacities and volumes and the consumption in the major markets.

Overall Results

At present, more than 11–12 million tons of wood pellets are produced worldwide. A good 1/3 of which is destined for export, the countries of the European Union including the East-European countries and Russia exhibiting the highest volumes of pellet production and consumption (70–80 %). Outside of Europe, Canada and the US are currently representing significant wood pellet markets the growth potential of which is admitted to have very good chances in the years to come. In addition, the significance of some Asiatic countries (e.g. China, India, Japan) and of Brazil, Chile and Australia will probably increase in future.

The typical raw material for pellets for providing electricity and/or heat is wood. As well, agricultural residues such as straw or bagasse are also used to a small extent, primarily for the industrial pellet production.

The individual market parameters have been combined to provide a comparative representation of the development of the various pellet markets since 2001. It can be seen that the use of wood pellets and their production have continuously grown in the overall balance sheet for recent years (Fig. 1.5).

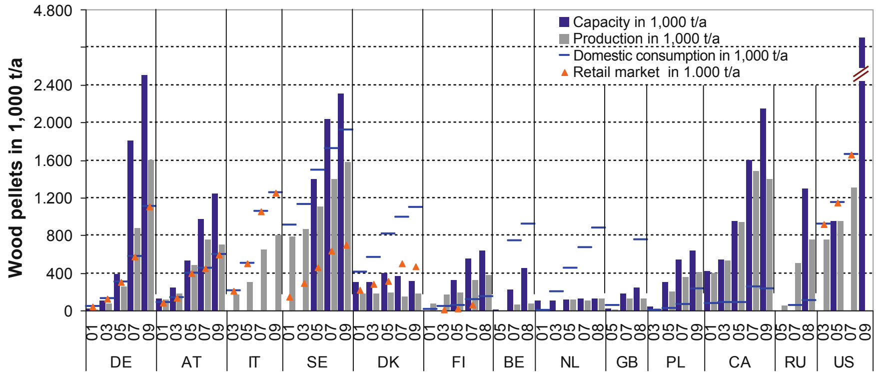


Fig. 1.5 Overview of the development of the wood pellet market in selected countries worldwide, from 2001 to 2009

1.2.2 Flows of Trade

To illustrate the import and export flows of wood pellets for the European market, Fig. 1.6 shows the global trade in wood pellets. The wood pellet trade takes place mainly within regional clusters. That is to say, the trade between individual countries occurs near their borders. For example, Poland, the Baltic states and Finland export to Sweden and Denmark. Considered worldwide, especially Canada and Russia are important pellet exporters for the European pellet market.

1.2.3 Price Movement

In general, two typical price segments can be distinguished: the retail markets and the industrial markets. Companies like ENDEX N.V. (Energy Derivates Exchange), FOEX Indexes Ltd. and Argus Media Ltd. publish industrial wood pellet prices. However, it is not possible to draw on a long history of these price indices and, on the other hand, the representation is still very fragmentary. Thus, have only been observing the prices since 2008 and FOEX have been doing so since 2007 (Published since September 2009). The prices collected by ENDEX are CIF prices of the ports of Amsterdam, Rotterdam, Antwerp (ARA), the most important ports for industrial pellets in Europe. The price survey is based on information from producers, dealers and power plant operators. FOEX collects a so-called PIX Pellet Nordic Index, taking into consideration the price information from industrial pellet dealers in the Scandinavian and Baltic countries [6]. In addition to these indices, national information on industrial pellet prices was used for comparison.

The price information for premium wood pellets is collected and published by national associations and also in the pellets@las project. For example, price

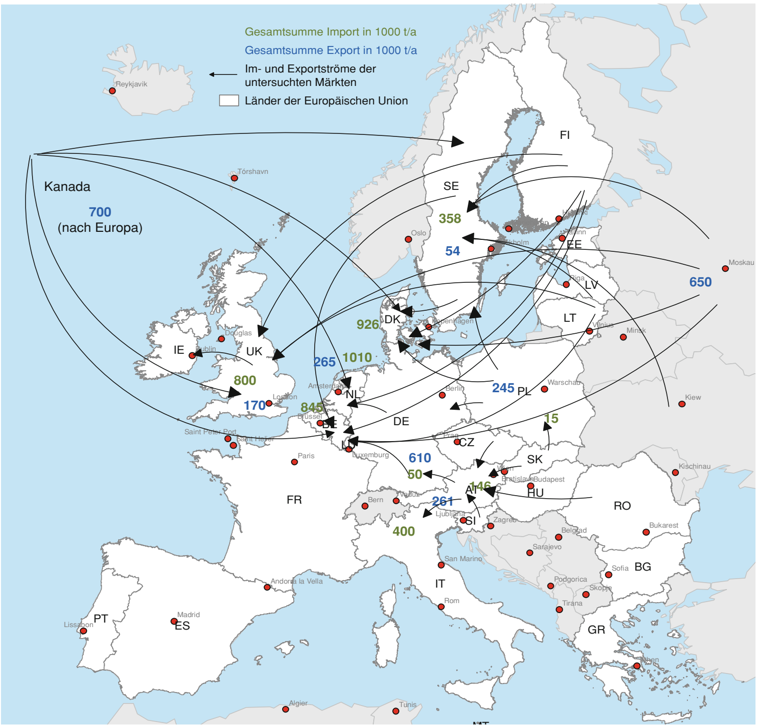


Fig. 1.6 Significant trade flows in the European pellet market in 2008

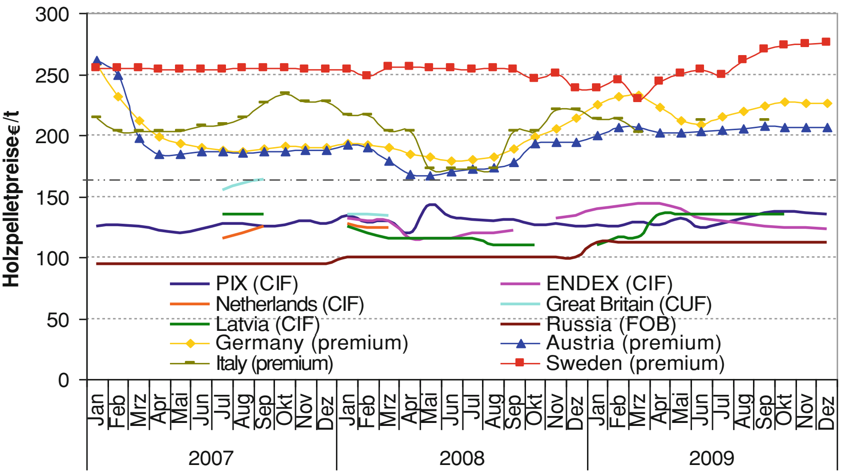


Fig. 1.7 Price movement for industrial and premium wood pellets from 2007 to 2009

movements are represented for the most important premium pellet markets and the mixed pellet market of Sweden. Overall, the industrial product shows a range of fluctuation of from 100 to 140 €/t and of between 170 and 270 €/t in the case of certified products (Fig. 1.7).

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Chapter 2
Biomass Types for Pellet Production

Biomass is the totality of organic substances occurring in a natural habitat, a distinction being made between phytological and zoological mass [1].

Biogenic fuels represent the proportion of the total quantity of biomass which can be used as energy sources to provide electricity, heat or engine fuels. Bio-energy sources can be subdivided into solid, liquid or gaseous by means of their state of aggregation. Of these, only the solid biogenic fuels are of relevance for the pellet production (with a water content which is as low as possible).

2.1 Classification

Figure 2.1 represents the wide variety of assortments of biogenic solid fuels accruing as residues, byproducts or waste products both in agricultural and

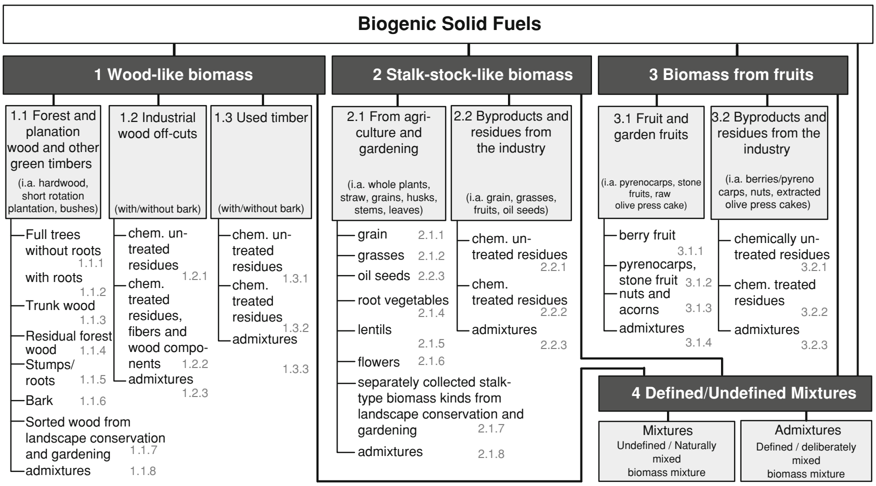

Fig. 2.1 Classification and specification of biogenic solid fuels to DIN EN 14961-

S. Döring, *Power from Pellets*, DOI: 10.1007/978-3-642-19962-2_2,

forestry-related production and in the further industrial processing or at the end of a utilization chain. Energy plants from agricultural cultivation (e.g. short rotation plantation, miscanthus, whole cereal plants, can represent additional potentials for pellet production. Following European standard DIN EN 14961-1, biogenic solid fuels are classified into wood or stalk-stock-like biomass, biomass from fruits and defined/undefined mixtures.

2.2 Raw Materials and Technical Potentials

In Central Europe, mainly chemically untreated barkless industrial wood offcuts which, for instance, accrue as offcuts in sawmills or as byproducts of the wood processing industry in the form of chips, wood dust or cut wood pieces, are being used for producing wood pellets. Newly felled wood (forest wood offcuts or also lower-quality log wood pieces—so-called calamities—e.g. from forests with storm damage or bark beetle infestation) is used to an as yet rather small extent as raw material for the wood pellet production since it requires a more elaborate production process due to, among other things, its higher water content and the amount of bark involved. The use of plantation timbers from the cultivation of fast-growing types of trees such as poplars or willows with multi-annual harvesting cycles (short-rotation plantation) is currently being prepared in many places but has hitherto been implemented only at a few sites. In the medium or long term, an increase in the use of newly felled timber in the pellet production is expected in order to exploit further contingents of biomass. It is also expected that the demand for biofuels will continue to grow and the availability of non-wood-like raw materials (e.g. straw, miscanthus) will progress so that their often significant but hitherto unused potentials can be put to further use.

However, any further development and the exploitation of additional biomass contingents for producing pellets may contribute to a shortage of the limited resources of natural biogenic raw materials available which would lead to numerous rivalries for utilization and further intensify existing rivalries. On the one hand, competitive fields can be developed with regard to the utilization of the land area and cultivation of biomass which has an effect on the supply and the available potential in raw material. On the other hand, the rivalries will intensify further with respect to the different technical options for utilization of the biogenic energy sources, particularly the material utilization of wood as such. To identify rivalries in the utilization of bioenergy, four levels can be distinguished in which the indicators are evident in varying degrees depending on the basic parameters (Fig. 2.2). Active indicators are, for example:

– Availability of a conversion technology at time x
– Options of biomass use/material flows for selected concepts of technology

– Area rivalries in biomass cultivation for the provision of electricity, heat and fuel
– Raw material prices for energy utilization in competition with food cultivation and the material utilization.

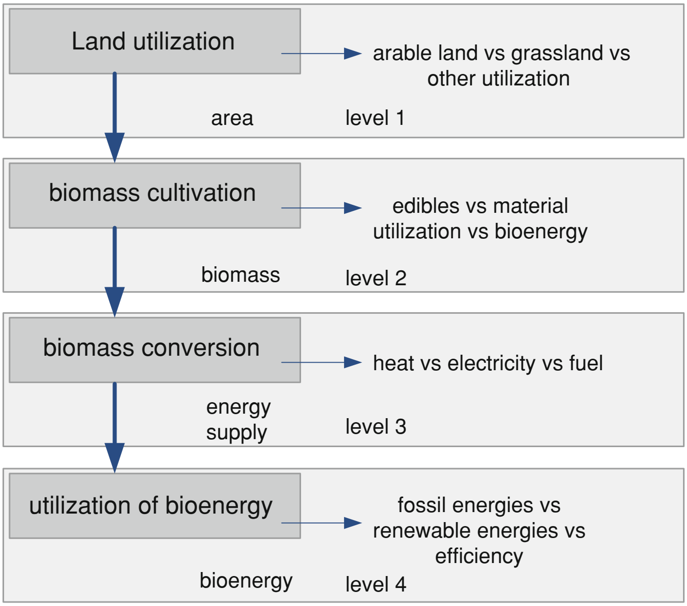

Fig. 2.2 Levels of utilization rivalries in the energy utilization of biomass

2.2.1 Methodical Approach

Following the results of the study "Sustainable Biomass Utilization Strategies in the European Context" [2], the relevant raw material potentials for the pellet production are derived for Germany and the EU countries. For the countries of Russia, Canada and the USA, the relevant biomass potentials are derived from existing studies of potentials [3–6].

The method for determining potentials is attributable to balancing material flows for determining the technically developable and energy-providing biomass potential, using the theoretical potential as a basis. The technical potential of raw material determined describes the proportion of the theoretical potential of the available biomass which, taking into consideration the given material utilization of biomass (food, feed and wood processing etc.) and structural and ecological restrictions (e.g. maintaining cycles of matter, areas claimed by biotope networks etc.) can be utilized with the available technologies.

The technical potential describes the proportion of the theoretical potential which can be utilized, taking into consideration current technical capabilities—i.e. available techniques of utilization, their efficiencies and with regard to the availability of sites [2].

With respect to the determination of technically available energy source potentials, only thermo-chemical conversion processes are considered in the biomass utilization of the raw material potentials considered and, accordingly, fuel-specific heating values are included. The basis for the determination of potentials are European and regional agricultural and forest and waste statistics, data by the FAO and numerous assumptions for the forward projection of the development [2]. Technical raw material potentials have been developed for the following biomass fractions:

- Forestry potentials
- Potential from felling = logwood + firewood + forest wood offcuts (harvest losses)
- Potential from unused growth = theoretical potential—felling
- Agricultural potential
- Potential from energy plant cultivation (short-cycle rotation plantation, miscanthus, whole wheat plants)
  - Potential from waste materials and byproducts
  - Industrial offcut potential from sawmills, wood composite, groundwood and pulp industry
  - Straw potential (grain straw, corn, rapeseed, sunflower straw)
  - Landscape conservation material.

2.2.2 Selecting Raw Materials

Due to the fact that the varied biogenic solid fuels have in some cases very different fuel characteristics, only the appropriate fuels can be used depending on their field of application. With regard to a qualitative use of the existing biomass types, it is possible to break these down into different input streams for pellet production—classified and specified according to European Standard DIN EN 14961-1 (Fig. 2.3). The potentials are subdivided into the following target markets:

- Wood pellets for the small-consumer market
- Wood pellets for the medium-sized and greater power range
- Other pellets, e.g. for use in the power station sector, partly also suitable in plants for agricultural fuels.

Figure 2.3 shows the import flows of the biomass potentials broken down into their qualitative fields of application. Wood offcuts represent a mixed fraction of woods from different tree components (including bark), like merchantable treetop wood, brushwood and short trunk segments.

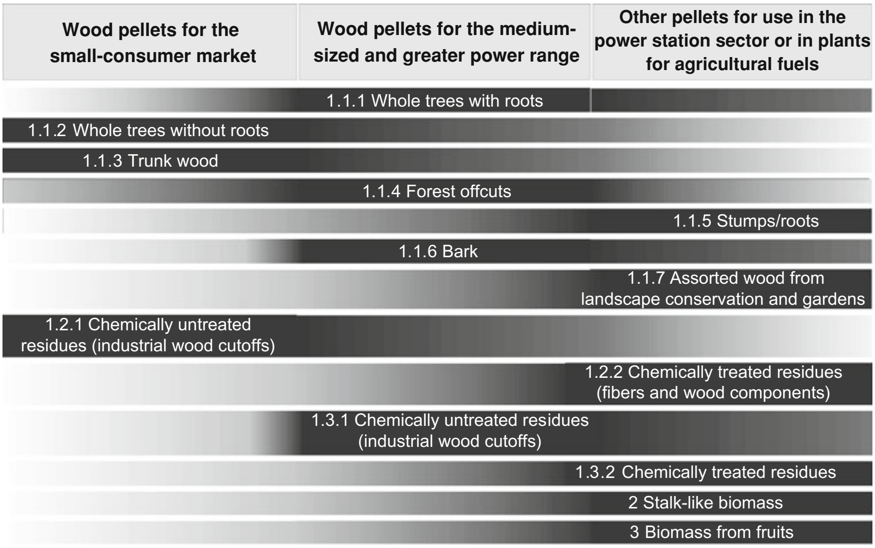

Fig. 2.3 Qualitative allocation of biogenic solid fuels (to DIN EN 14961-1) according to potential input flows for determining pellet potentials

Fractions not taken into consideration during the determination of potentials—stumps and roots, flowers, wild berries and garden fruit—do not appear as potential everywhere or are not available as such in the countries.

Due to the large number of different options for utilizing biomass, which will increase further in future—utilization rivalries—only 1/3 of the total technical forestry and agricultural fuel potential is taken into consideration for the fuel pellet production. The potential of industrial wood cutoffs is already being used most comprehensively today for the production of wood pellets and is, therefore, included with 50 % in the estimation of the wood pellet production potential.

2.2.3 Technical Potential

In the 28 EU countries, the technical potentials of raw materials for the pellet production varied between 500 and 750 TWh/a in 2010. This corresponds to a pellet production capacity of 100—150 million tons (Table 2.1). The greatest potentials for pellet production are largely found in the utilization of forest wood cutoffs and in the cultivation of energy plants for the production of wood pellets in the medium and higher power range or of other types of pellets (e.g. in the cultivation of whole grain plants).

With respect to the qualitative differentiation of the potentials according to fields of application, the potential for the production of pellets for use in small heating systems is currently about 200 TWh for the 28 EU countries. The pellet production

Table 2.1 Technical pellet production potentials for the 28 EU countries and Germany in 2010, derived from [2, 25]

		EU-28	Germany
Wood pellets for the small-consumer market	TWh/a	200	28–30
	Mio. t/a	40	5–6
Wood pellets for the medium-sized and greater power range	TWh/a	130–390	15–60
	Mio. t/a	25–80	3–12
Other pellet types	TWh/a	170	17–23
	Mio. t/a	35	3–5
Potential for pellet production (total)	TWh/a	500–750	60–110
	Mio. t/a	100–150	12–22
Pellet production plants	Number[a]	667–1 000	80–147

[a] with a production capacity of 150,000 t each

Table 2.2 Pellet production potentials for Russia, Canada and the US in 2010, derived from [3–6, 26]

		Canada	US	Russia
Forestry potential	TWh/a	0–80	170	250
Agricultural potential (energy crop cultivation)	TWh/a	400	630	400
Potential from remnants and byproducts	TWh/a	140	590	100
Potential for pellet production (total)	TWh/a	220–620	760–1,390	350–750
	Mio. t/a	44–125	150–280	70–150

potential for use in the medium-sized and higher power range was registering as continuous over the observation period and was between 130 and 390 TWh in 2010. The range of the potential can be explained by uncertainties and by the long-term high demand for biomass in the cultivation of energy plants. The technical potential for the production of other types of pellets is currently about 170 TWh.

The potential of raw materials available in Germany for the pellet production from agriculture and forestry and the wood processing industry including the chargeable assortment of unhewn timber is currently between 60 and 110 TWh (Table 2.2) according to moderate estimates. The greatest potentials of raw materials for pellet production are found in France,. Germany, Spain, Poland and Sweden (Fig. 2.4).

Taking into consideration regional studies of potential, significant potentials for use in the pellet production can be shown to exist in North America and Russia. Considering numerous options for utilizing biomass, the pellet produciton potential in North America ((USA and Canada) is between 1,000 and 2,000 TWh/a. In the US, considerable fuel potentials from industrial and agricultural remnants and byproducts are mainly found. Whereas Russia has a considerable forestry potential for use in the pellet production (Table 2.2).

In summary it is noted that the existing biomass potentials for pellet production in the EU, North America and Russia are hitherto not being fully tapped. In the long term, the potentials for pellet production are largely found in the field of

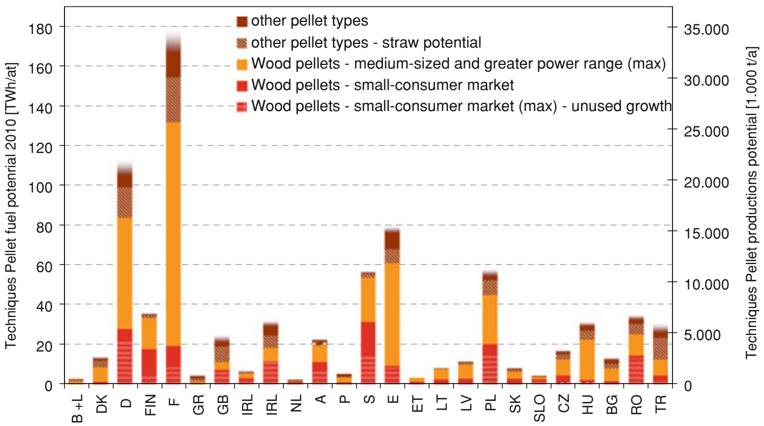

Fig. 2.4 Qualitative grading of the technical fuel potential for pellet production in 2010

utilization of forest wood cutoffs and of energy crop cultivation. Future prospects are that the potentials for pellet production will largely lie in the area of utilization of forest wood offcuts and of energy crop cultivation. In the long term, it its expected that the potential for production of wood pellets for the small-consumer market will drop slightly since, although the felling increases with increasing utilization of unhewn timber and thus the quota of wood cutoffs also increases, the potential from unused growth decreases. Furthermore, segments of wood cutoffs previously neglected in material utilization are increasingly put to other use due to the increasing competition for the utilization of low-cost timber quotas [7, 8]. The cultivation of energy crops, like the cultivation of short turnover plantations, can currently be considered only as an additional option for providing raw material for the pellet production. The basic conditions and stimuli for the agricultural cultivation of short turnover plantations must here be enhanced further in the short to medium term in order to be able to fulfill the current forecasts regarding the growth potential of the pellet market in Europe and world-wide with sustained quotas of raw material.

2.3 Characteristics of Raw Materials

2.3.1 Molecular and Elementary Structure

Knowledge of the chemical composition of biomass is of great significance for the assessment of the utilizability of the raw material for the pelletization and thermal utilization. In this context, a distinction can be made between the molecular structure of the biomass—which is mainly of relevance to the treatment of the raw

Table 2.3 Molecular structure of biogenic raw materials [9, 11, 10]

Components		Typical proportions and constituents
Fundamental substance:	Holocellulose	Cellulose (long-chain macromolecule) 20–55 % wood: 40–55 % Hemicellulose (short-chain, branched macromolecule) 10–40 % wood: 20–35 %
	Lignin	3-dimensional macromolecule 30–35 % softwood: 25–35 % hardwood: 18–32 %
Associated material;	Extracts	Fats, oils, resins, waxes proteins, starch, sugar, natural rubber dyes, tanning, bitter and odorous substances, camphor organic and inorganic acids, salts, minerals

material (e.g. for pelletization)—and the elementary structure, knowledge of which is of special value to understanding the thermal decomposition process.

With respect to the dry vegetable matter, biomass is composed of around 90 % carbon (C) and oxygen (O) and around 6 % hydrogen which are absorbed by the plant in the form of CO_2, O_2, H_2O or HCO_3. These three main components of the herbal substance are contained in all organic compounds (e.g. in lignin, cellulose, pectine, sugars, fats, starches snf proteins). The remaining parts of the dry substance serve to store the herbal nutrients. Up to 5 % of the dry matter can be associated with the important macronutrients (N, K, Ca and in lesser amounts P, Mg, S and Fe_1). In contrast, micronutrients only occur as trace elements in a concentration of between 0.001 and 0.03 % (Zn, Cu, B, Mn, Mo, Fe). Apart from a few exceptions, the nutrients are present uncombined in the phytomass (not combined with organic substances). The necessity and assignment of chlorine, silicon and sodium to plants has not yet been conclusively explained [1].

Considering the molecular structure of plants, solid types of biomass consist in about 95 % of the three biopolymers of cellulose, hemicellulose and lignin. The remaining proportion is composed of a multiplicity of associated materials, the so-called extracts (such as resins, fats, tanning agents, starch, sugar, proteins and minerals). The proportions of the chemical components related to dry matter vary in accordance with their specific type (Table 2.3).

Cellulose

Cellulose Cellulose, formed predominantly of linear glucose polymers, is the substance occurring most frequently in nature. It forms the structural substance of the plants and is the fundamental substance of the unlignified (non-woody) cell wall. Due to its high degree of crystallization, cellulose, inspite of having a relatively high number of hydrophilic groups, is not water soluble but acts hydroscopically (water-absorbing).Due to its molecular structure, cellulose imparts a high dimensional stability to the biomass, especially by providing tensile and flexural strength. In the case of wood and of most of the other biogenic raw materials, the tensile strength (cellulose content) is on average twice as high as the compressive strength (lignin content), resulting in the relatively high flexural strength of wood. Hardwoods form as a reaction to the tension-loaded side of the tree so-called tension wood which has particularly high strength.

Celluloses are used in the production of paper and insulating material from pulp and groundwood, and in the textile, cosmetics and food industry [9, 10].

Hemicelluloses

Hemicelluloses (also called polyoses) are polysaccharides with complex branching which support the plant multifunctionally, for example the supporting effect in the cellular membrane or as a backup, swelling and adhesive substance for cementing the cell walls. Hemicellulose always occurs as a substance associated with cellulose. Whereas in softwoods the fundamental building blocks of hemicellulose are represented by hexanes, in hardwoods it is the pentosanes which impart to them plastic properties (the wood becomes more flexible). Due to the amorphous molecular structure of hemicelluloses they easily absorb water but relinquish it only slowly and thus retard the drying out and dying back of the cellular tissue.

Hemicelluloses are obtained from agricultural products (e.g. corn cobs, oat spelts) and are used as, among other things, binding agent for activated coal or briquets, in the manufacture of paper (increasing its strength), in the food industry (thickening agent, jellification) [1, 9, 11].

Lignin

From the chemical point of view, lignin is described as a complex polymer chain of phenyl propane groups having thermoplastic properties. Lignin never occurs separately but always as a cellulose-associated substance. The reddish-brown substance lignin is the actual filling and lignifying substance of the plant which, due to its swelling effect (less than with cellulose) and cementing and stiffening effect is responsible for the compressive stability of the plant. Thus, a high lignin content ensures that the sprout of a plant will remain upright and can dry off even with a decreasing water pressure as is the case, for example, with the stalks of ripe cereal plants in the field. Wooden biomass types have much higher lignin contents than one year old plants (annual harvesting cycle) and can therefore also withstand high continuous stresses in spite of relatively low water contents. The lignin content also varies within a plant, depending on the type of biomass. Thus, the highest lignin values are typical of the lowest, highest and innermost parts of a trunk, of softwood branches, bark and compression wood1.[1] Being an organic substance, the natural lignin depletion begins with the harvesting of the plant/felling of the tree and can be accelerated by externnal factors (UV light, heat and moisture).

[1] Compression wood is the reaction wood formed in conifers on the pressure-loaded side (e.g. due to the main wind direction). Compression wood is heavier, harder and denser than the normal wood.

Lignin occurs in large quantities as a byproduct of the pulp industry and is now being used both synthetically and for energy purposes [1, 9, 11].

Extracts

The minor constituents, associated substances and extracts include more than 500 different compounds. In some cases, the inorganic components of the plants (K, Ca, Mg, Fe, Mn etc.) are listed separately as "ash" in the chemical allocation of the elementary constituents whilst the extract substances then contain only purely organic components [11]. They are then allocated to the minerals.

Although extractives partly constitute only minimal proportions of the molecular substance of plants they can determine significant characteristics of the raw material such as, e.g. [10]:

– resistivity against fungi and insects (tanning agents, terpenes, phenols)
– odour (e.g. fir tree, pine) and colour (e.g. walnut, Douglas fir)
– water-repellent (resins, waxes, fats, oils),
– impregnability (poorer with resin-containing woods)
– flammability (with resin-rich woods).

Whilst the timbers of the temperate zones have between 1 and 10 % extractives, between 2 and 30 % by weight can be found in tropical timbers. Their mass-related concentration is typically 3–7%. There are 2 different groups of extractives. On the one hand there are the primary minor components (e.g. starch, sugar, fats, fatty oils and protein).which are mainly deposited as storage substances in the fall in order to be available in spring for sprouting. This is why deciduous trees have a higher proportion of extractives than evergreens (with the exception of the larch). On the other hand, there is the multiplicity of secondary minor components which include, for example, heartwood substances, minerals, dyes and tanning agents, resins, essential oils, irritants and toxic substances. Apart from a few exceptions, heartwood has more metabolites than sapwood [1, 10, 11].

Resins, Turpentines

Resins serve to close wounds in plant tissue, cure in air and are hydrophobic. Conifers have high resin contents. Turpentines are liquid extractives which occur in conjunction with resins and are toxic [11]. Both substances are used commercially as solvents, resin size, odorants or as turpentine oil [10]. In the case of highly resinous conifers, the extracts can be collected by ("bleeding") the trees, i.e. scratching the bark.

Terpenes

Terpenes are of chemically similar structure to resins. They protect the plant from the penetration of bacteria and fungi. Terpenes are also hydrophobic and consist of slightly volatile compounds [10].

Tanning Agents and Waxes

Both of these substances are contained mainly in the bark of trees for the thermal, mechanical and chemical protection of the herbal tissue. They increase the rsistivity of the plant against external penetrators such as fungi and insects [10].

Fats, Starches

Fats can be detected in increased concentration mainly in conifers in winter. Starches, on the other hand, are stocked up typically in the growth phase of deciduous trees and partly converted into fats during the winter.

Minerals

Minerals contain a large number of the macro- and micronutrients of the plants (e.g. P, Mg. S, K, Si) which handle different metabolistic functions. For example, the silicic acid (Si) content has an influence on the resistance against insects (especially in tropical types of trees) [9].

Table 2.4 lists the organic components and inorganic substances (ash) of various biomasses referred to dry matter. In comparison with stalk-type biomass (annual plants), woody raw materials have much lower protein contents.

Table 2.4 Molecular components of various biomasses (no information on lacking mass fractions) [1]

Fuel	Cellulose	Hemicellulose	Lignin	Resins/Fats	Protein	Ash
Wood fuels (in % b.w.)						
Fir	42.3	22.5	28.6	2.3	–	1.2
Pine	41.9	21.5	29.5	3.2	–	1.3
Spruce	41.0	24.3	30.0	k.A.		k.A.
Ash tree	40.2	25.0	26.0	2.2	–	1.3
Beech	45.4	22.2	22.7	0.7	–	1.6
Birch	40.9	27.1	27.3	2.2	–	1.8
Poplar	48.4	18.2	21.6	2.4	–	1..3
Willow	42.9	21.9	24.7	2.0	–	1.2
Stalk-type fuels (in % dry matter)						
Wheat straw	38	29	15	–	4	6
Prairie grass	37	29	19	–	3	6
Miscanthus	43	24	19	–	3	2
Sorghum bicolor	23	14	11	–	k.A.	5
Tall fescue	25	25	14	–	13	11
Corn straw	38	26	19	–	5	6

Regarding the information on the molecular and elementary composition of various raw materials in this chapter, it should be pointed out that this can vary greatly both between the types of biomass and within one type and even when considering different parts of a plant (e.g. trunk wood, bark, needles, leaves, roots). There can also be fluctuations in the elementary composition within one period of vegetation or in the various development sections of a plant. Site-related factors such as climate, weather and ground or plant cultivation measures (e.g. fertilization) have an additional influence on the substance of the plant. In the case of biomasses having a short growth phase, especially, (e.g. straw and whole plants), generalizing conclusions regarding the content of elements can only be drawn to a limited extent from the type of biomass.

2.3.2 *Raw-Material Parameters for Influencing the Quality of Pellets*

According to their definition in prEN 14588, pellets represent a compressed biofuel of pulverized biomass which have been compacted with or without additives, have normally a cylindrical shape with a length of 5–40 mm, and have broken ends [12].

From a technical point of view, almost all biogenic solid fuels are suitable to be palletized. However, optimal successes in pelletization are only achieved if the raw material is relatively constant in its particle structure/grain size distribution, the water content and the chemical composition [13]. In this context, the molecular composition of the biomass has a decisive influence on the natural suitability of the raw material for pelletization, whereas the water content and the physical/mechanical properties of the raw material characterize the processing effort required and the storability of the biomass. For these reasons, the chemical effects of the molecular mass of the raw material on the palletizing process are shown in summary in Table 2.5 and then their influence on the pellet production process, in particular, is explained. In addition, the significance of the water and bark fraction of the raw material was listed as a quality parameter.

Basic Substance

Whereas cellulose is composed of 48 % carbon (52 % O, 6 % H), lignin has even 64 % carbon (30 % O, 6 % H). Due to their great heterogeneity it is not feasible to provide adequate information on the chemical composition of hemicelluloses.The unequal molecular composition of the raw materials affects the overall carbon content of the bioenergry source and thus its energy content referred to dry matter. In principle, it was found that the heating value for needlewood was about 2 % higher on average compared with that for leafwood. This rise, and also the heating value of the needlewood bark which is higher again by another 2 %. Is attributable to the higher lignin content of the needlewood and partially also to the higher content of extractives. Both groups of materials are characterized by the fact that their partial heating value of appr. 27.0 and 35.9 MJ/kg, respectively, is distinctly higher than that for cellulose (appr. 17.3 MJ/kg) or hemicelluloses (appr. 16.2 MJ/kg) [1].

Table 2.5 Selected raw material parameters for influencing the pellet quality and the production process [1, 11, 16–18, 21, 23, 27]

Parameter	Effects
Molecular composition	
Basic substance	Mass fractions of cellulose, hemicellulose and lignin affect the carbon content of the raw material and thus the energy content (heating value), referred to dry matter, of the pellets.
CelluloseCellulose	A large number of hydrophilic groups will influence the water absorption and water reduction of the raw material (drying characteristics)
Hemicellulose	The amorphous structure promotes the water absorption of the raw material but retards the release of water and thus the drying time of the raw material particles (drying energy expenditure)
	Swelling and adhesion function supports the pelletizability of the raw material
Lignin	Natural pressing aid (arching, adhesive effect), increases the mechanical strength of the pellets
	The hydrophobic structure increases the stability of the pellets with respect to (air) humidity after the curing of the ligning in the cooler; sealing of the pellet surface
	High lignin content of the raw material can be recognized from the external gloss of the pellets
	LigninLignin depletion starts at appr. 150 °C (loss/reduction of adhesive effect) and thus influences the choice of technical drying (temperature level) of the raw material.
Starch, sugar Albumens	Natural pressing aids/bonding agents, support the bonding power of the material to be pressed through their adhesion–stability, mechanical strength (abrasion) of the pellets
	Throughput of the press/energy expended is partially optimized due to the lubricating function (e.g. with potato starch, but can also be partially reduced, e.g. with molasses (sugar).
Fats, oils	Lubricating function affects throughput of the press/energy expended
	Decrease in stability/mechanical strength of the pellets
Resins, waxes	Hydrophobic structure also increases the stability of the pellets with respect to (air) humidity (s.a. ligning)
	Natural pressing aids, support the bonding power of the raw material particles and thus the mechanical strength (abrasion) of the pellets.
	Temperature level of the raw material drying system affects bonding forces/adhesion (high temperatures promote risk of self-ignition due to easily volatile components)
	Wax layer/sheathing of fibrous raw materials (e.g. in cereal) lowers pelletizability (and affects the choice of milling technology
Terpenes	Easily volatile, partially poisonous gases (storage)
Minerals	Inorganic components affect ash content and ash fusibility of the pellets

(continued)

Table 2.5 (continued)

Parameter	Effects
s.a. K, Ca, Na,, Mg, Si[a] etc.	Si increases the abrasion and wear of the presses (edge runner, dies) and conveying systems.
Selected components	
Water	Water contentWater content affects the fiber length in milling and the expenditure for drying The optimum water content of the chips has a decisive influence on the strength of the pellets with respect to abrasion. The water content of the raw material determines the requirement/expenditure for drying The water content of raw material and fuel affects the storability (growth of fungi, storage losses, risk of self-ignition) of the material, the fuel mass and its heating value. Adding water as a bonding agent in pelletization improves the sliding of material which is too dry, whereas adding hot steam is used more for the thermal activation of the bonding agents native to the raw material or added.
Bark	The high content of lignin and extractives (tanning agents) makes raw material more sensitive to temperature and pressure effects/ lubricating function optimizes throughput of the press/energy expended High proportion of minerals increases ash content.

Lignin

Since lignin hardens (dries) progressively in dead plants and thus loses its bonding capacity, the lignin can be activated/softened in the pelletization by supplying heat. With relatively fresh raw material, an increase in temperature can be achieved partly merely by means of the friction and pressure effects of the material to be pressed in the die. The activation of the lignin can be supported technically (e.g. in the case of older raw material stored for a longer time) by feeding hot water or hot steam into the conditioner [14]. Due to the hydrophobic (water-repelling) structure of the lignin, however, a speedy absorption of the water (water integration) is limited [15]. The addition of hot steam (small volume of water, high input of heat) will, therefore, probably have a better effect on the activation of the lignin than adding hot water.In addition, the dwell times of the mixture of materials to be pressed are limited.

The dimensional stability and mechanical strength of the pellets will be achieved only if the material to be pressed is cooled rapidly immediately after pelletization in order to then cure the previously softened lignin and any bonding aids possibly added (s.a. cooler [16–18].

The licensing of chemically extracted lignin (from the wood pulp industry) for use as pressing aid in pellet production is handled in different ways and depends on the nationally applicable standards and the legal framework conditions. In Germany, only untreated bonding agents from biomass from agriculture or forestry are permitted if the pellets in heating systems fall within the scope of the first BImSchV (Federal Immission Control Act Ordinance) [19, 20].

Starch, Sugar, Albumens

Adhesion supports bonding of the raw material particles in pressing. Adding pressing aids based on cereal and potato starches or molasses increases the natural concentration of the extractives in the material to be pressed (strengthening of the mechanical strength of the pellets) and improves the sliding/lubricating function of the material to be pressed [14]. However, molasses can also lead to a reduction in the throughput of the press [21].

Fats, Oils

The lubricating and sliding action of the extractives can lower the energy expended in the pressing process and, at the same time, increase the throughput rate of material through the press [21].

Waxes

Without any pretreatment, biomasses which have raw material surfaces sheathed in a layer of wax (e.g. cereal plants) tend to be less easily pelletizable compared with woody biomasses. It is possible to dissolve the wax layer, for example, by means of a double screw extruder which unravels the fibers of the raw material instead of milling it in cutting or hammer mills (typical procedure for wood). This process can be supported with a parallel water steam treatment. As a rule, fibrous pellets have higher mechanical strength and a lesser fine fraction than comparable straw pellets from chaff [16].

Resins

As a consequence of the increase in temperature in the press during the pelletization (pressure, friction), the resinous components of the raw material are softened and support the mechanical strength of the pellets due to their adhesion (similar effect to lignin) [16].

Terpenes

When wood is stored, the very volatile nature of the terpenes can result in outgassing which, together with CO and hexanal, can lead to harmful concentrations in enclosed storage spaces [22].

Minerals

Mineral contaminations (e.g. with sand, stones etc.) of the raw material during storage or transportation can increase the natural content of mineral substances [23].

Water Content

Too high a water content of the source material reduces the physical/mechanical properties of the pellets and especially their strength (abrasion). The pellets may become fissured and swell up due to the steam vented immediately after emergence from the press. This reduction in quality may occur also with an inhomogeneous water content of the raw material before pelletization [24].

Bark Fraction

The higher proportion of extractives and mineral contaminants reinforces the associated effects. In most cases, however, the relatively high proportion of lignin in the bark can produce an improvement in the throughput rate of the pellet press even with low rates of admixture [21]. However, the admixture of the bark fraction represents a decisive quality criterion for the use of wood pellets since bark has a significantly higher content of heavy metals and ash.

Apart from the criterion for exclusion of the bark fraction, the regional and weather-related location of growth of a tree can also cause a naturally increased concentration of elementary contents such as alkalis/alkaline earths, (e.g. K, Ca, Mg) and metals (e.g. Si, Fe, Zn, Cd, Pb) which cause the raw material of wood to be graded as critical to unusable since they can lead to technical problems when used in small heating systems. For this reason, the quality assurance of the raw material input makes use of rapid-test methods and laboratory analyses which analyze and log the essential wood characteristics in their delivered state. The frequency of these quality verifications is regulated contractually; in addition, retained samples of each delivery of raw material should be taken in the pellet plant.

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Chapter 3
Combustion Characteristics

3.1 Principles of Combustion

Combustion is understood to be the oxidation of a fuel with the release of energy. Carbon (C) and hydrogen (H) are oxidized in the presence of Oxygen (O) to form carbon dioxide (CO_2) and water (H_2O), respectively. Looked at from a chemical point of view, the oxidation of wood can be described by the following reaction equation:

$$CH_{1.44}O_{0.66} + 1.04\ O_2\ =\ >\ CO_2 + 0.72\ H_2O_{(steam)} + \ energy_{(heat)}$$

A complete oxidation of all oxidizable components is called a complete combustion. The excess air rate λ must then always be greater than or equal to one ($\lambda \geq 1$). In the case of incomplete combustion, i.e. with $\lambda \leq 1$, unoxidized or part-oxidized amount of fuel still remain after the end of the oxidation reaction which can then be oxidized further with the release of energy. The prerequisites for complete combustion are firstly a high combustion temperature, well mixed combustion air and combustible gases, a small amount of excess air and a sufficiently long stay of the fuel particles in the hot combustion zone.

The course of the oxidation of solid fuels can be split into a number of process phases which occur partly simultaneously and partly in succession. In Fig. 3.1, the combustion of wood is shown diagrammatically and will be described in the text which follows [1–6].

– As the biomass enters into the combustion chamber, the fuel begins to be heated up due to reflected-radiation from flame, firebed and combustion chamber walls.
– From about 100 °C onward, the fuel begins to dry out due to evaporation and removal of the water. In this process, the water is expelled both from the porous structure of the organic material and from the interior of the cells (at higher temperatures).
– Whilst the biomass is still drying in its interior, the pyrolytic decomposition begins at a surface temperature of about 200 °C with the dissociation of the macromolecules (i.e. cellulose, hemicellulose, lignin), the volatile components

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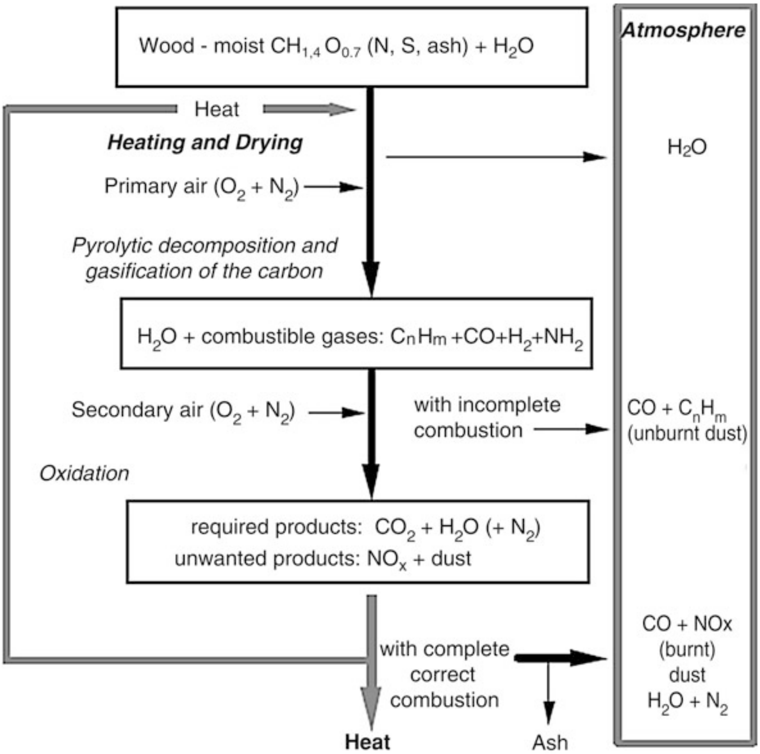

Fig. 3.1 Burning characteristics of wood (not showing the burning of the carbon with primary air, occurring in parallel with the burning out of gases) [14]

(CO, CH_4, H_2O_{steam}, etc.), tars and organic vapors/aromatics being transported to the surface of the wood and released, leaving solid carbon (charcoal).

– At about 500 °C, the solid carbon (about 15–20 % of the biomass) begins to become gasified with carbon dioxide, water vapor and oxygen to become carbon monoxide. At the same time, the volatile compounds (about 80–85 %) become mixed with the oxygen supplied, starting a homogeneous combustion reaction of the gases.
– The charcoal begins to oxidize at about 700 °C with a heterogeneous gas/solid reaction which is why this phase is much slower than the combustion of the gases in the combustion chamber. Depending on the fuel and heating system used, the temperatures in wood-burning systems rise up to 1,500 °C (2,000 °C max, but typically between 900 and 1,300 °C) in the main reaction zone during the 2-stage combustion and are about 600–700 °C at the end of the combustion chamber.
– The high temperatures in the combustion chamber are attributable to the exothermal oxidation reaction of the products formed during the pyrolytic

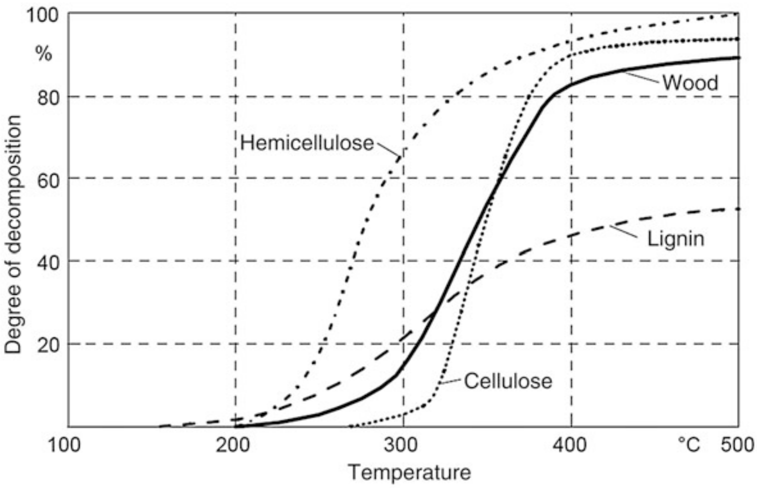

Fig. 3.2 Thermal decomposition of wood and its cellulose, hemicellulose and lignin components as a function of temperature [1]

decomposition with oxygen and promote the transfer of heat from the flames to the surrounding walls of the heating system (heat exchanger), leaving as essential components of the waste gas carbon dioxide (CO_2) and water vapor (H_2O_{steam}) and a small proportion of unburnt components in the ash.

The combustion processes described take place simultaneously in the various areas of the fuel as a function of the local temperatures. The speed of the reaction depends mainly on the size of the fuel parts and on the temperature in the furnace. In the case of automatically fed heating systems, the processes described take place in parallel at any given time since both new fuel is continuously supplied in the combustion chamber and there is already degassed fuel in the form of charcoal present and burning.

Attempting to reconstruct the thermochemical combustion process with respect to the thermal decomposition of the molecular structure of the biomass, the irreversible destruction of the first macromolecules begins with the fuel being heated within a temperature range of between 150 and 200 °C (Fig. 3.2). Depending on the rate of heating (K/min) and the raw material, vegetable matter is increasingly broken down until only solid carbon (charcoal) remains. The percentages by weight of the gaseous decomposition products (CO_2, H_2O, CH_4 etc.) released during this process are determined by the proportions of cellulose, hemicellulose and lignin specific to the raw material. After it has passed through a temperature range of about 320–340 °C, about 30 % loss in weight can already be registered in the case of wood, reaching a maximum release of gases and vapors (breaking down of volatile components, Fig. 3.3) at 400 °C and also of the breaking down of cellulose, which ends at about 450 °C. The biomass is marked by a weight loss of

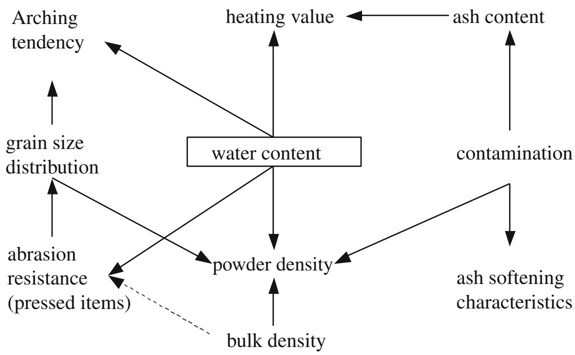

Fig. 3.3 Interactions of physical/mechanical fuel characteristics and chemical/material characteristics [1]

about 70 %. As the biomass is heated further, the remaining lignin is broken down up to a temperature of about 400 °C, followed by the oxidation (combustion) of the charcoal [1].

In biogenic solid fuels, the precise sequence of the thermochemical conversion process is influenced mainly by the fuel-specific characteristics. This applies especially to the processes which are the basis for the formation of pollutants. The thermal conversion process must, therefore, adequately account for the respective special features of the fuel used [1]. For this purpose, it is worthwhile to describe the fuel (i.e. the wood pellets) by means of qualitative features both with respect to its origin or type of raw material and to its fuel characteristics.

Table 3.1, therefore, shows not only the composition and features of biogenic solid fuels and a summary of their effects on the combustion process. The consideration of a holistic approach to the assessment of a supply concept should, however, include additional factors of downstream and upstream processes such as, e.g. the operating mode of the plant, the provision of the fuel (transportation, storage), and the ash utilization. For example, too high a water content in the fuel can cause not only losses in the efficiency of the heating system but also increased losses of substance during storage and promote fungal attacks on the fuel which can be associated with hazardous emissions.

From the parameters and quality features characterizing the fuel, information relating to the functionality of the combination of fuel and heating system and to the course of the thermochemical conversion process can be derived. The energy-source-specific and combustion-related characteristics influencing the energy content and the burning behavior of a fuel and the chemical composition affecting possible emissions and the ash characteristics. In contrast, the information on the physical/mechanical characteristics is of relevance for the selection and suitability of the combustion technology and for the storage and transportation [7], [8].

Table 3.1 Composition and qualitative characteristics of biomass pellets and their effects on combustion [1, 9–16, 24–26]

Parameter	Effects
Physical/mechanical fuel characteristics	
Number/shape of fuel pieces (dimensions,geometry)	Correlation with mechanical systems (conveyor systems) and types of hating systems; flammability, burnout time
Particle and fiber	Number/shape of pieces, grindability (selection and design of the milling system for structure processing the fuel for pelletization and feeding it into the combustion chamber)
Size distribution/fineness	Homogeneity of the fuel, pourability, tendency to arching, disturbance of the conveyor elements, operational continuity, burning characteristics, dust development, explosion risk
Wear resistance	Fineness (conveying characteristic, risk of segregation, dust development, transportation losses)
Storage density (bulk density/ stacking density)	Selection, dimensioning and complexities of storage, conveying and transport technology and of the storage containers
Gross density (particle density)	storage density, selection and dimensioning of the conveying systems; energy-source-specific characteristics (specific thermal conductivity, burnout time/degassing rate etc.)
Chemical/material fuel characteristics	
Water content	Fuel drying requirement; suitability for storage (growth of fungi, storage losses) of the fuel; risk of self-ignition; fuel mass, heating value, combustion temperature, burnout time
Heating/calorific value	Energy content of the fuel; Dimensioning of the heating system and of the storage location
Volatile components	thermal decomposition, combustion characteristics, ignitability of the fuel
Ash content	Particle emissions (dust), dimensioning of the heating system, ash generated/, risk of slagging; ash utilization and disposal; amount of cleaning required. ease of use
Ash softening character-istics	Tendency to precipitation and slagging, selection of heating system (e.g. grating design and cooling; operational safety and continuity, required maintenance.
Carbon (C)	Energy content of the fuel, air required for the combustion
Hydrogen (H)	
Oxygen (O)	Composition of the conversion products (product/waste gas) and of the ash
Nitrogen (N)	Waste gas emissions (NO_x, HCN, N_2O, H_3N)
Sulphur (S)	Waste gas emissions (SO_x, SO_2, SO_3/H_2SO_4) formation of aerosols (fine dust);increased risk of corrosion
Chlorine (Cl)	Slagging when interacting with alkali/alkaline earth metals
Phosphorus (P)	Incorporation of pollutants in the ash/ash utilization (fertilizer value)
Alkali/alkaline earth	Ash softening characteristics (ash softening temp. is lowered by K and Na, raised by Ca and Mg);
Metals (K, Ca, Mg, Na)	incorporation of pollutants in the ash (Ca, Mg); ash utilization (fertilizer value: Ca, K, Mg); high-temperature corrosion (K); fine-dust emissions/formation of aerosols K, Na)
Trace elements, esp.	Abrasion at conveyor systems;
Metals:	Ash softening characteristics (Si); quantity, quality and utilization of ash
(Fe, Zn, Al, Cd, Cu, Cr,Ni, Hg, Pb, Si, As)	Formation of aerosols (Zn, Pb); partially catalytic effect on PCDD/F formation

3.2 Physical/Mechanical Fuel Characteristics

The physical/mechanical characteristics mark the external features of the fuel which can also be described by parameters such as size distribution, percentage standard, tendency to form bridges, pouring and storage density. These features are determined to a large degree by the technologies employed for the provision of the raw material (harvesting) and for processing (in the case of pellets: milling, conditioning, pelletization) and can thus be adapted to the respective fuel requirements. The consistency of the fuel has a decisive influence on the handling of the fuel during transportation and storage [1, 9] (Fig. 3.4).

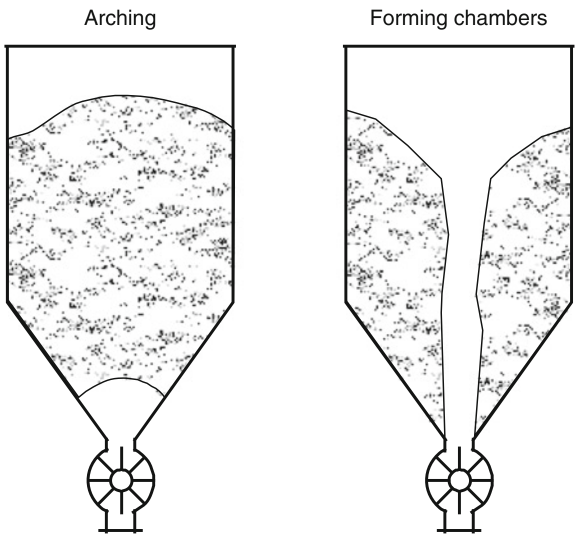

Fig. 3.4 Arch or chamber—phenomena of poor pourability of bulk materials

Lumpiness, Pellet Shape

As defined in prEN 14588, pellets normally have a cylindrical shape with a typical length of 5–40 mm and a diameter of <25 mm (DIN EN 14961-1) [1, 10]. Briquets are distinguished from pellets by their greater diameter (≥25 mm) and the predominantly stackable elongated shape [11], [12].

According to the European product standards prEN[1] 14961.2 (for wood pellets) and prEN 14961.6 (for non-wood pellets), pellets having a diameter of 6 or 8 mm are designated as fuel for use in heating systems in the small and medium-sized power range [12, 13]. In Germany and Austria, the 6 mm pellets have long become established whilst in Scandinavia and France, other pellet diameters are also used.

[1] According to prEN 14961-2, pellets for non-industrial utilization should have a minimum length 3.15 mm and maximally 40 mm, 1 % of the pellets being allowed to exceed this length limit up to a maximum of 45 mm.

Table 3.2 Guide values for a rough calculation of the percentage of fine material obtained according to the logistics and transport technology used [28]

Transport vehicle/Handling processes	Distance/unloading in	Increase in proportion of fine fraction by (range from–to)[a] (%)
Silo wagon	50 km	0.3–0.5
Truck with pneumatic unloading ramp	100 km	0.5–0.8
Truck w/o automatic unloading ramp	100 km	0.3–0.5
Bulk freight rail cars incl. loading and unloading	400 km	0.5–1.0
Inland marine transport incl. loading and unloading (1,000–5,000 t payload)		1.5–2.5
Seagoing marine transport incl. loading and unloading (up to 15,000 t payload)		1.5–3.5
Handling processes per 1 t of wood pellets:		
Automatic filling of trucks from tower silo storage		0.3–0.5
Handling, open space/store to truck		1.5–3.5
Handling, truck to train		0.5–1.5
Handling, truck to barge with temporary storage		1.5–3.5
Handling, truck to deep-sea vessel with temporary storage		1.5–3.5
Handling, train to deep-sea vessel		1.5–3.5

[a] Ranges depending on handling methods used

Size Distribution and Fine Fraction (Abrasion Resistance)

The distribution of pellet lengths and the fine fraction in the bulk material, and thus, apart from the mean particle length, also the proportions of individual magnitudes and, above all, the maximum length of the pellets, are of particular significance for the mechanical removal, conveyance and delivery systems of conversion plants [14]. The size/length distribution of the fuel was, therefore, defined as a quality characteristic in the standardization of pellets [12].

The fine fraction of a fuel is a measure of its abrasion resistance and provides information on the robustness of the fuel (i.e. dust development, decomposition and segregation) with respect to mechanical stresses such as, for example, during handling and transportation processes (Table 3.2).

The fractured ends of the pellets are the most important cause of an increased fine fraction which is why the abrasion resistance is correlated with the number of pellets per kg [15].

Arching Tendency (pourability)

During the removal of pellets (bulk material) from silos or storage containers unwanted cavities (so-called arches or chambers) can form. This means that the fuel no longer follows through and the conveyor system can thus not transport any fuel to the heating system. The tendency to arching of a fuel increases with increasing water content, with dumping height and with the increasing number of heterogeneous particles. The risk of arching is reduced by uniform particle sizes/pellet lengths and smooth surfaces [1, 9] (Fig. 3.5).

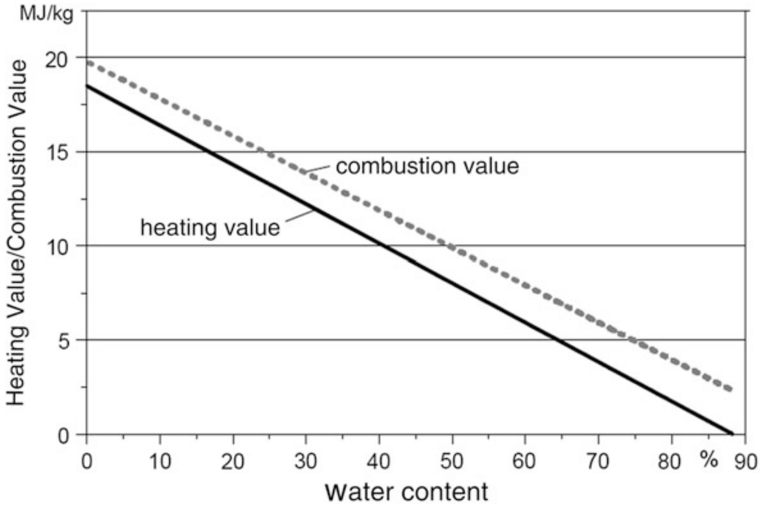

Fig. 3.5 Difference between heating value (net calorific value q_{net}) and combustion value (gross calorific value q_{gr}) with varying water contents of wood fuel [1]

Particle and Fiber Structure (grindability)

The particle and fiber structure of the raw material particles is of significance in pellets mainly when the fuel is ground up for use in power stations with dust burners, direct heating systems or fluidized bed combustion systems. Using fuel mills, (cutting or hammer mills), pellets are ground to a similar reduction ratio as the fossil fuel used (as a rule, coal) in order to thus provide for a parallel or common fuel feed into the combustion chamber. The grindability of the pellets is determined mainly by their water content and the mechanical strength of the fuel and by the fiber structure and the geometry of the pressed raw material particles. Attention should be paid to a maintaining a balance between good grindability and high storage density [5, 16].

Gross and Stored Density

The density of a solid fuel can be differentiated in accordance with various criteria as gross and stored density (bulk or stacked density). The gross density describes the actual material density of the fuel (Table 3.3). The bulk and stacked density of the fuel, which determine the storage and transport volume required, are also of relevance with respect to storage and transportation.

Table 3.3 Gross densities of completely dry wood ("kiln-dry density") [1]

Softwood (to 550 kg/m^3)		Hardwood (over 550 kg/m^3)	
Spruce	430 kg/m^3	Oak	670 kg/m^3
Fir	410 kg/m^3	Sycamore	500 kg/m^3
Pine	490 kg/m^3	Ash	670 kg/m^3
Douglas fir	470 kg/m^3	Beech	680 kg/m^3
Larch	550 kg/m^3	Birch	640 kg/m^3
Alder	490 kg/m^3	Hornbeam	750 kg/m^3
Lime	490 kg/m^3	Black pine	560 kg/m^3
Aspen	450 kg/m^3	Hazelnut	560 kg/m^3
Poplar	410 kg/m^3	Robinia	730 kg/m^3
Willow	520 kg/m^3	Elm	640 kg/m^3

In comparison with fossil energy sources, biogenic raw materials generally exhibit much lower gross or stored densities whilst the bulk density of wood pellets (650 kg/m^3) already reaches the lower limit of variation of coal (brown coal 500–600 kg/m^3, black coal 730–810 kg/m^3). However, the energy density (i.e. energy content/volume as a function of bulk density) will also always play an important role in a comparison of fuels. It is a decisive factor in the determination of the volume of fuel to be provided for generating a defined quantity of energy [1, 9, 16] (Table 3.4).

Table 3.4 Typical stored densities of biogenic solid fuels (poured or stacked) with a water conent of 15 % [1]

Wood fuels		Density in kg/m^3	Stalk-type fuels		Density in kg/m^3
Split logs	Beech	445	Round bales	straw	85
(stacked)	Spruce	305		Hay	100
Wood chips	Softwood	200	Square bales	Straw, miscanthus	140
	Hardwood	280		Hay	160
				Cereal plants	190
Bark	Needlewood	175	Chaff	Miscanthus	110
Sawdust		160		Cereal plants	150
Shavings		90	Grain		750
Pellets		650	Pellets		550

3.3 Chemical/Material Fuel Characteristics

The essential components of solid fuels are carbon (C), hydrogen (H) and oxygen (O) which determine the calorific value and thus the energy content of the (dry) fuel (Table 3.5). In comparison with bioenergy sources, biogenic fuels exhibit much higher oxygen contents and lower carbon contents.

Certain fuel properties of a biomass can only be determined, and thus indicate favorable or unfavorable combustion characteristics, by evaluating the specific laboratory analyses of the raw material. Laboratory results with measurement

Table 3.5 Contents of major elements in untreated solid biomass fuels compared with black and brown coal [1], [10]

Type of fuel/biomass	C	H	O	N	K	Ca	Mg	P	S	Cl
	In % of dry matter									
Needlewood (barkless)	51.0	6.3	42.0	0.10	0.04	0.09	0.015	0.006	<0.02	0.01
Leafwood (barkless)	49.0	6.2	44.0	0.10	0.08	0.12	0.02	0.01	0.02	0.01
Bark (needlewood)	52.0	5.9	38.0	0.50	0.20	0.50	0.10	0.04	0.03	0.02
Bark (leafwood)	52.0	5.8	38.0	0.30	0.20	1.50	0.05	0.04	0.03	0.02
Forest offcuts (needlewood)	51.0	6.0	40.0	0.50	0.20	0.50	0.08	0.05	<0.02	0.01
Forest offcuts (leafwood)	51.0	6.0	40.0	0.50	0.15	0.40	0.025	0.03	0.04	0.01
Spruce (with bark)	49.8	6.3	43.2	0.13	0.13	0.70	0.08	0.03	0.015	0.005
Beech (with bark)	47.9	6.2	45.2	0.22	0.15	0.29	0.04	0.04	0.015	0.006
Poplar (short rotation)	48.0	6.2	43.0	0.40	0.25	0.50	0.05	0.10	0.03	<0.01
Willow (short rotation)	48.0	6.1	43.0	0.50	0.25	0.50	0.05	0.08	0.05	0.03
Rye straw	46.6	6.0	42.1	0.55	1.68	0.36	0.06	0.15	0.085	0.40
Wheat straw	45.6	5.8	42.4	0.48	1.01	0.31	0.10	0.10	0.082	0.19
Triticale straw	43.9	5.9	43.8	0.42	1.05	0.31	0.05	0.08	0.056	0.27
Barley straw	47.5	5.8	41.4	0.46	1.38	0.49	0.07	0.21	0.089	0.40
Rapeseed straw	48.0	6.0	41.0	0.80	1.00	1.50	0.07	0.10	0.30	0.50
Corn straw	45.7	5.3	41.7	0.65					0.12	0.35
Sunflower straw	42.5	5.1	39.1	1.11	5.00	1.90	0.21	0.20	0.15	0.81
Hemp straw	46.1	5.9	42.5	0.74	1.54	1.34	0.20	0.25	0.10	0.20
Whole rye plants	48.0	5.8	40.9	1.14	1.11		0.07	0.28	0.11	0.34
Whole wheat plants	45.2	6.4	42.9	1.41	0.71	0.21	0.12	0.24	0.12	0.09
Whole triticale plants	44.0	6.0	44.6	1.08	0.90	0.19	0.09	0.22	0.18	0.14
Rye seeds	45.7	6.4	44.0	1.91	0.66		0.17	0.49	0.11	0.16
Wheat seeds	43.6	6.5	44.9	2.28	0.46	0.05	0.13	0.39	0.12	0.04
Triticale seeds	43.5	6.4	46.4	1.68	0.62	0.06	0.10	0.35	0.11	0.07
Rape seeds	60.0	7.1	23.0	3.80	0.84	0.50	0.26	0.73	0.10	0.07
Miscanthus	47.0	6.1	42.0	0.70	0.70	0.20	0.06	0.05	0.20	0.20
Grass (hay) mixed	46.0	5.9	40.0	1.3	1.50	0.35	0.17	1.50	0.20	0.70

results lying outside the specific range of characteristics of the biomass frequently indicate deliberate or unintentional contamination/admixture or atypical growth conditions (soil, climate, etc.). Thus, e.g., increased N, S or Cl contents can be an indication of chemical contamination by insecticides, glues, paints, wood preservatives or illegal compression aids.

The characteristics of solid fuels specific to energy sources summarized in the following text are primarily relevant for the thermo-chemical conversion and are greatly dependent on the elementary composition of the fuels under consideration.

3.3.1 Energy-Source-Specific Parameters

The energy-source-specific characteristics described in the following paragraphs are primarily related to the thermo-chemical conversion of a solid fuel and are greatly dependent on its elementary composition.

Water Content

In solid fuels, the quantity of water contained in the fuel is usually specified by its water content. The volume of water content is here referred to the total mass of the moist fuel [14]. The water content of pellets is determined by the conditions existing during the pelletization (water content of the material to be compressed) and pellet storage including length of storage. It is usually between 8 and 12 %. Since, as a rule, biological decomposition and conversion processes of biomasses are only triggered at water contents which are clearly above 16 %–associated with energy losses–there is no acute hazard in the case of pellets. Nevertheless, the tendency of the fuel to self-heating and self-ignition resulting from an increase in its water content should not be ignored [1].

A low water content is advantageous with respect to the thermochemical conversion since the utilizable energy content of a fuel with respect to its total mass drops with its water content (compare heating value vs. combustion value) [17]. There is a linear relationship between the water content and the heating value of a fuel. Figure 3.6 shows clearly that, for example, the heating value of wood (18.5 MJ/kg in this case) decreases linearly with increasing water content/increasing fuel moisture. With a water content of around 88 % or a fuel moisture of 730 %, it drops to zero. The water content of a biomass has a much greater influence on its energy content than does its type.

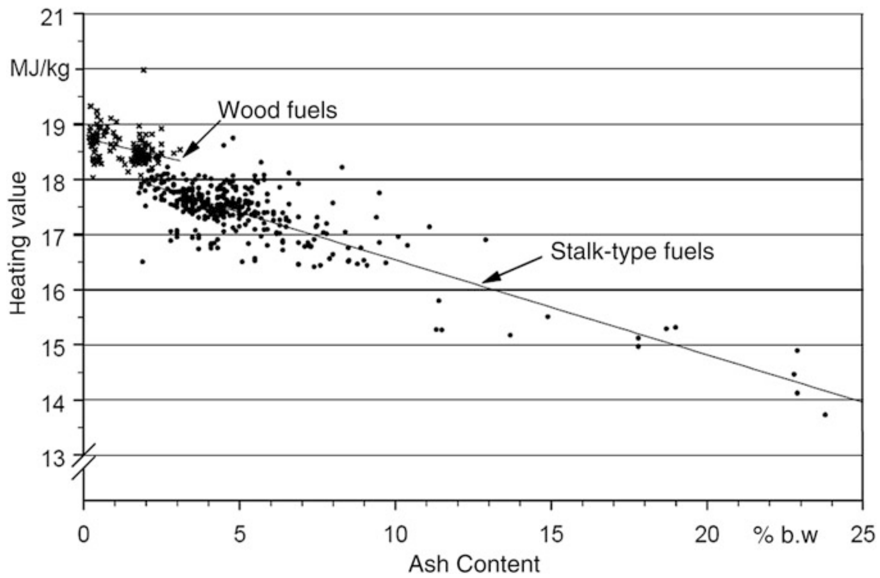

Fig. 3.6 Dependence of the heating value on the ash content, using different biogenic solid fuels as an example (referred to dry matter) [1]

Heating Value/Combustion Value

The heating value H_u (net calorific value qn_{et}) and the combustion value H_0 (gross calorific value q_{gr}) are used for designating the energy content of fuels in international standardization. The heating value is understood to be the amount of heat released with the complete oxidation of a fuel without taking into consideration the condensation heat of the water vapor present in the smoke (i.e. the gaseous water formed during the combustion is not accounted for). The combustion value specifies the amount of heat released with complete oxidation of a particular quantity of fuel, taking into consideration the reaction heat of the water vapor condensed in the smoke. In the case of solid and liquid fuels, the combustion value is referred to 1 kg of fuel and in the case of gaseous fuels it is referred to 1 m^3 of gas. Under standard conditions (0 °C, 1013.2 mbar). The difference between combustion value and heating value corresponds to the evaporation enthalpy of the corresponding water vapor at 25 °C (2442 kJ/kg) [9, 18].

In the following section, an approximation formula according to Kaltschmitt et al. ([1]) for calculating the heating value H_u, referred to dry matter, of biogenic solid fuels is specified (Eq. 3.1), the mean error of which corresponds to about 4 %.

$$H_{u_{(wf)}} = 34.8\ \mathrm{C} + 93.9\mathrm{H} + 10.5\mathrm{S} + 6.3\ \mathrm{N} - 10.8\mathrm{O} \quad (3.1)$$

Equation 3.2 has been derived for determining the combustion value F0. Its result is output in kJ/kg if the values for carbon (C), hydrogen (H) and nitrogen (N) are inserted in % mass from the elementary analysis of the dry biomass.

$$\mathrm{H_{o(wf)}} = 1.87\ \mathrm{C}^2 - 144\ \mathrm{C} - 2802\ \mathrm{H} + 63.8\ \mathrm{CH} + 129\ \mathrm{N} + 20147 \quad (3.2)$$

Accordingly, the heating value of dry biogenic solid fuels is determined mainly by the content of oxidizable elements (primarily carbon and hydrogen). In addition, energy is released by the oxidation of certain major nutrients (e.g. sulphur, nitrogen). Due to the mostly small concentration of such elements in biogenic solid fuels, this will scarcely influence the heating value in general. On the other hand, the oxygen content of the fuel will generally reduce its heating value since the oxidizable components in oxygen-containing compounds are already present in a higher state of oxidation and can often be oxidized further only with a restricted release of energy.

Equation 3.3 can be used for converting the heating value into the combustion value of the biomass. H_u is here the heating value of the biomass (in MJ/kg) with a certain water content (in %) and H_u(wf) is the heating value in a "water-free" (absolutely dry, anhydrous) state. The constant 2.443 is the result of the vaporization heat of the water in MJ/kg, referred to 25 °C [1].

$$\mathrm{H_u} = \frac{\mathrm{H_{u(wf)}}\ (100 - \mathrm{w}) - 2{,}443\, w}{100} \quad (3.3)$$

Since the heating value is influenced significantly by the water content of the biomass, the heating value of wood, for example, and thus also the amount of energy released during the thermochemical conversion, decreases linearly with an increasing water content (Fig. 3.6). The heating values of different biomass types should, therefore, always be specified in terms of the anhydrous mass [14]. The heating value of the biomass, referred to a dry substance, is correlated with the gross density of the material (Table 3.3 and 3.5)[19]. Compared with fossil solid fuels (i.e. coal), the heating value of biogenic solid fuels is less, wood fuels exhibiting a slightly higher heating value than stalk-type fuels (Fig. 3.7). The higher dry-matter heating value is due to the, on average, higher carbon content of bark compared with barkless wood but this advantage is frequently negated by the increased effort involved in drying this material.

Ash Content

The ash content of solid fuels affects both the emission of pollutants and the technical design and construction of of the combustion plant. In general, the risk of sintering/scorification (slagging) in the firebed is increased with an increased ash content of the fuel. For this reason, heating systems for burning such critical fuel fractions are in most cases equipped with water- or air-cooled grids, with movable grids or with automatic systems for ash removal from the combustion chamber. As a rule, an increased content of fuel ash will also lead to an increase in dust emissions and to the associated expenditure for dust removal. This is particularly relevant in the case of systems with a movable firebed which is increasingly subjected to mechanical influences. It is possible to see clear differences between wood and stalk-type substances with respect to their ash content. Whereas stalk-type biomass with an ash content of 5.2–12.2 % of the dry matter exhibits comparable behavior to fossil fuels, wood-type energy sources from the moderate zone are distinguished by contents of around ≤1 % of the dry matter. Due to the high proportion of inorganic components, the ash content of tropical timbers is above 5 % in some cases [1, 17]. Figure 3.7 shows the influence of the ash content on the heating value.

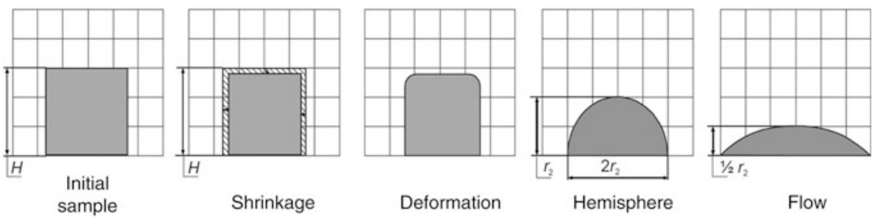

Fig. 3.7 Characterizing phases of the fusibility of the ash of a sample body acc. to standard test procedure prEN 15370 (initial shape at 550 °C, H = height of sample, r^2 = radius of sample) [1]

Table 3.6 Combustion characteristics of untreated solid fuels (average values referred to dry matter) [1, 10]

Fuel/Type ofbiomass	Heating,value in MJ/kg	Combustion value in MJ/kg	Ash content in %	Volatile components in %	Ash deformation[a]		
					DT[b] in °C	HT[b] in °C	FT[b] in °C
Needlewood (barkless)	19.1	20.5	0.3				
leafwood (barkless)	18.9	20.1	0.3				
Bark (needlewood)	19.2	20.4	1.5	77.2	1,440	1,460	1,490
Bark (leafwood)	19.0	20.0	1.5				
Forest offcuts (needlewood)	19.2	20.5	3.0				
Forest offcuts (leafwood)	18.7	19.7	5.0				
Spruce (with bark)	18.8	20.2	0.6	82.9	1,426		1,583
Beech (with bark)	18.4	19.7	0.5	84.0			
Poplar (short rotation)	18.4	19.8	2.0	81.2	1,335		1,475
Willow (short rotation)	18.4	19.9	2.0	80.3	1,283		1,490
Rye straw	17.4	18.5	4.8	76.4	1,002	1,147	1,188
Wheat straw	17.2	18.5	5.7	77.0	998	1,246	1,302
Triticale straw	17.1	18.3	5.9	75.2	911	1,125	1,167
Barley straw	17.5	18.5	4.8	77.3	980	1,113	1,173
Rapeseed straw	17.6	18.8	5.0	75.8	1,273		1,403
Corn straw	17.7	18.9	6.7	76.8	1,050	1,120	1,140
Sunflower straw	15.8	16.9	12.2	72.7	839	1,178	1,270
Hemp straw	17.0	18.2	4.8	81.4	1,336	1,420	1,456
Whole rye plants	17.7	19.0	4.2	79.1			
Whole wheat plants	17.1	18.7	4.1	77.6	977	1,155	1,207
Whole triticale plants	17.0	18.4	4.4	78.2	833	982	1,019
Rye seeds	17.1	18.4	2.0	80.9	710		810
Wheat seeds	17.0	18.4	2.7	80.0	687	887	933
Triticale seeds	16.9	18.2	2.1	81.0	730	795	840
Rape seeds	26.6	28.1	4.3	85.2			
Miscanthus	17.7	19.0	4.0	77.6	973	1,097	1,170
Grass (hay) mixed	17.1	18.0	7.0				

[a] DT deformation temperature, HT hemisphere temperature, FT flow temperature (acc. to CEN/TS 15370)

[b] Here: determination acc. to DIN 61 739, deviations from results acc. to new standard methods are possible

Ash Fusibility

In thermal processes such as combustion, physical changes of the ash occur in the firebed. Depending on the temperature, the ash becomes sintered and even fused. According to DIN 51731, or according to prEN 15370 for biogenic solid fuels, this deformation characteristic is described by means of the determination of defined temperatures for characterizing the melting process of a fuel sample (Fig. 3.8). The figure distinguishes between the shrinkage starting temperature (SST), the deformation temperature (DT), the hemisphere temperature (HT) and the flow temperature (FT).

The temperatures can be determined under oxidizing or reducing conditions based on the combustion process. The deformation of ash is dependent on the ash composition and thus mainly on the type of fuel. The lower the ash deformation temperature of the fuel or of the ash contained in it, respectively, the earlier the agglomeration and slagging will begin which leads to depositions and erosion in the combustion plant and the associated waste gas components. Whilst technically, temperatures of 1,300–1,400 °C are non-critical for most applications of wood, the corresponding temperatures are, as a rule, below 1,200 °C for stalk-type matter and even below 700 °C for cereal seeds [1, 17] (Table 3.6).

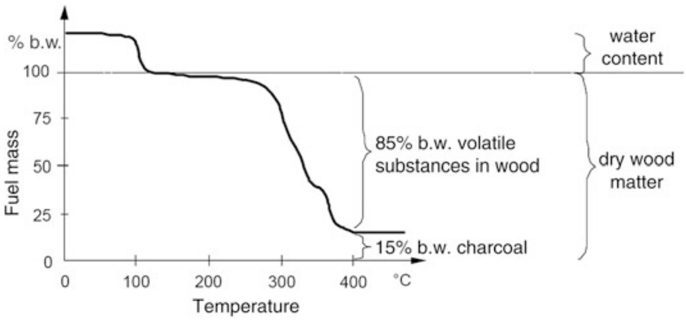

Fig. 3.8 Thermal behavior of biomass using moist wood as an example of the decrease in mass with temperature during heating without oxygen supply [1]

Volatile Components

Volatile components are gaseous compounds which escape under specified conditions when a fuel is heated. They largely consist of combustible gases and, to a certain extent, serve as a measure of the ignitability of the fuels in a combustion plant. With up to 83 % of the dry matter, biogenic solid fuels exhibit a high proportion of volatile components (Fig. 3.3).

Some extractives contained in biogenic fuel have especially volatile characteristics (e.g. terpenes, turpentines) and can partially outgas already at ambient temperatures during storage of the fuel. The risk is then that the gases will accumulate in hazardous concentrations in the storage space [20].

Charcoal

Charcoal is formed primarily from lignin since the biopolymers cellulose and hemicellulose are already largely destroyed at a temperature of 4,000 °C during the depletion of the macromolecular substance (Fig. 3.2).

3.3.2 Characteristics Influencing Combustion Products

The combustion products from the oxidation of biogenic solid fuels can be subdivided into airborne emissions and particle residues (ash), the quantities and concentration of which is determined both by the fuel of the combustion plant and by the operating mode. The latter can affect the efficiency of a combustion plant depending on the load requirements (full-load/partial-load operation) and the behavior of individual consumers (especially in the case of hand-charged installations).

The elementary analysis of a fuel (Table 3.1) is used for estimating the fuel-related emissions and residues. To estimate critical emissions from the combustion of biogenic solid fuels, the concentrations of relevant metabolites such as nitrogen (N), sulphur (S) and chlorine (Cl) and of some trace elements (i.e. mainly heavy metals and alkalies) is discussed.

Apart from the major products of the complete oxidation–carbon dioxide (CO_2) and water vapor (H_2O)–a number of other emissions are released in the combustion of biogenic fuels, the cause of which is presented in summary in Table 3.7 and the effect of which is shown in Table 3.5.

The gases listed in Table 3.7 are partially emissions hazardous to the environment and to health. Thus, particles represent a large proportion of the dust emissions in modern biomass combustion plants. Their size is between 0.001 and 100 μm. Particles from complete combustion consist of ash particles (e.g. CaO, Al_2O_3, SiO_2, JCl) and foreign substances (e.g. earth, sand, heavy metals). Particles from incomplete combustion are composed of the carbon-containing decomposition products (resulting from an incomplete burnout in most cases). From carbon synthesis products (e.g. soot) or from fuel particles which are dragged along directly from the firebed and are now found unburnt in the waste gas [14].

Wood combustion plants emit mainly particles having a size of ≤10 μm, i.e. particulate matter.[2] Depending on the ash content of the fuel, but especially depending on the form of fuel (pellet, briquet, NHS or firewood), the predominant

[2] The term "particulate matter" or "extra-fine particles" describes a complex mixture of solid and/or liquid organic and inorganic pollutants ejected into the air. The particles vary in size, composition and origin and are described by means of their particle size or aerodynamic diameter (PM means particulate matter) [21].

Table 3.7 Characterization of the elementary composition of waste gases from biomass combustion plants [1, 9, 14, 27]

Metabolites	Compounds	Cause
Water vapor	H_2O	Substances of complete combustion of the main fuel components (C, H, O)
Carbon dioxide[a]	CO_2	
Carbon monoxide	CO	Incomplete combustion
Hydrocarbons	C_nH_m	Incomplete combustion gaseous phase
Chlorine compounds[b]	HCl	High dependence on fuel content (e.g. with stalk-like biomass types, high-temperature corrosion
Dioxine, furane	Slight dependence on fuel, temperature-dependent, only relevant for chemically treated biogenic fuels (e.g. old growth)	
Sulphur compounds[c]	SO_2 SO_3	Depending on fuel content; in the combustion of the waste gas, SO2 is oxidized up to SO3
H_2SO_3	Below the dew point, SO_2 and SO_3 react with water vapor to become corrosive	
H_2SO_4	Sulphurous acid (H_2SO_3) or sulphuric acid (H_2SO_4)	
Nitric oxides	NO, NO_2 and N_2O	Compounds of molecular nitrogen of the combustion air and the nitrogen contained in the fuel
Particles	Ash,unburnt fuel,	Proportion of inorganic material in the fuel, incomplete combustion, soot (C) can also occur as byproduct of the combustion tar, soot

[a] In contrast to the combustion of fossil energy sources, biomass combustion is graded as CO_2 neutral since durng its thermal utilization only the amount of CO_2 is released which it has removed from the atmosphere during its growth
[b] 40–95 % of the fuel-related Cl compounds are bound up in the ash
[c] As a rule, there are appr. 99 % SO_2 and 1 % SO_3 present at the end of the combustion

part of the dust particles has a size of below 1 μm, also called aerosols.[3] Aerosols are easily respirable, can partly also enter the blood stream directly and can thus

[3] Aerosols are formed by the release of aerosol-forming components (relevant elements: K, Na, S, Cl, Zn, Pb) from the fuel and the subsequent formation of particles via nucleation of ash-forming vapors and by particle growth through condensation and agglomeration. The flue ash emissions from the complete combustion of biomass consist essentially of potassium sulphates, potassium chlorides and potassium carbonates (salts) [22].

become dispersed throughout the body of living beings. Over 90 % of the dust emissions from the combustion of wood pellets in small heating systems can be allocated to the aerosol fraction which is why–with a correspondingly high concentration of emission sources and continuous exposure–there can be a significant risk to health from particulate matter [23]. Further finding relating to the cause, propagation and effects of particulate matter are currently being worked out in various studies and research projects.

The composition and properties of the ash produced during the fuel conversion are mainly determined by the trace elements and alkaline and alkaline earth metals present in the fuel. The ash produced contains predominantly calcium (Ca), magnesium (Mg), potassium (K), phosphorus (P) and sodium (Na) and relatively small amounts of iron (Fe) and manganese (Mn).

Ash is the designation for the inorganic combustion residues of the organic fuel, i.e. the minerals. Ash consists mainly of oxides and carbonates from various metals (e.g. CaO, MgO, K_2O, P_2O, Na_2CO_3, $NaHCO_3$, SiO_2, Al_2O_3, Fe_2O_3). Thus, an increased concentration of silicon (Si), potassium (K) and sodium (Na) in the fuel is credited with a trend to lowering the ash deformation temperature whilst calcium (Ca) and magnesium (Mg) tend to raise the ash deformation temperature [22]. Since it not yet been possible to finally explain the mechanisms active in the interaction of dropping and rising ash melting temperatures, Eqs. 3.4 and 3.5 should only be utilized as an approximate estimation of the deformation temperature (DT) and flow temperature (FT) of a fuel. The elementary contents are here specified in % of the dry matter of fuel and the temperatures in °C [1].

$$\mathrm{DT} = 1172 - 53.9\,\mathrm{K} + 252.7\,\mathrm{Ca} - 788.4\,\mathrm{Mg} \tag{3.4}$$

$$\mathrm{FT} = 1369 - 43.4\,\mathrm{K} + 192.7\,\mathrm{Ca} - 698\,\mathrm{Mg} \tag{3.5}$$

Apart from the ash content and the deformation temperature, the fertilizing value of the ashes from the combustion of untreated biomass types, and thus their disposal or utilization options, can also be attributed to the concentration of the mineral components (such as P, Ca, Mg and K) of the biomass.

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Chapter 4
Legal Requirements for Using Wood Pellets for Providing Heat

The combustion characteristics of biogenic fuels can vary greatly depending on their growing- and site-related conditions. To achieve combustion which is as efficient and low in emissions as possible it is, therefore, necessary to match the fuel optimally to the heating system. Adherence to the legal requirements for emission limits must be guaranteed for any operating time. Providing as homogeneous a fuel quality as possible is an important prerequisite for achieving constant burn-off conditions. This can be achieved by providing production standards and certification systems based on these. Before a heating system is taken into operation, it is also necessary to find out how and where the residues from the combustion can be utilized or disposed of. The following sections will, therefore, deal with the administrative framework for using wood pellets in combustion plants in Germany.

4.1 Requirements for Emissions and Energy Efficiency

Federal Immission Control Act (BImSchV: Bundesimmissionsschutzverordnung)

In Germany, the use of pellets from biogenic raw materials is subject to the Federal Immission Control Act depending on the capacity of the combustion plant (e.g. up to 1 $MW_{NWL}$for pellets from untreated wood or up to 0.1 MW_{NWL} for straw pellets) or to the Technical Instructions on Air Quality Control (TA Luft) (up to 50 MW_{FWL}) Until the end of 2009, uniform emission limits applied to each power category for using untreated wood, independently of the type of fuel (Table 4.1). When the Amendment to the 1st BImSchV Act came into force in 2010,

– the minimum power category for limit requirements was lowered from 15 to 4 kW_{NWL},
– the dust and CO limits were progressively severely tightened,
– additional limits were set for NO_X and dioxine for straw and straw-like fuels.

S. Döring, *Power from Pellets*, DOI: 10.1007/978-3-642-19962-2_4,

Table 4.1 Emission limits for the combustion of wood pellets compared with other biogenic solid fuels in combustion plants of up to 1 MW [17, 18, 19]

Limits acc. to 1st BImSchV (Sept.2002) and TI Air (July 2002)[a]						Limits of the Amendment (valid from March 2010)[a]				
Fuel	NWL	Dust	CO	NO_X	Dioxine/ Furane	NWL	Dust	CO	NO_X[b]	Dioxine/ Furane
Untreated wood	≥15–50	150	4.000	–	–	≥4–500	100[c]/ 20[d]	1000[c]/400[d]	–	–
	>50–150		2.000							
	>150–500		1.000			>500		500[c]/400[d]	–	–
	>500–1.000		500							
Wood pellets	≥15–50	150	4.000	–	–	≥4–500	60[c]/20[d]	800[c]/400[d]	–	–
	>50–150		2.000							
	>150–500		1.000							
	>500–1.000		500			>500		500[c]/400[d]		
Straw, cereal (seeds, pellets, whole plants)[c]	≥15–100	150	4.000	–	–	≥4–		<100	100[c]/20[d]	1000[c]/400[d]/ 250[e,d]
	600[c]/500[d]	0.1[e]								
100–1.000[f]	40	200	400							

[a] All limit values are related to 13 % reference oxygen
[b] verified by manufacturer in a (single) type test
[c] Straw and similar plant material, cereal not intended for food (cereal seeds, plants, debris, husks and stalk residues) and pellets from the aforementioned fuels; permissible only in automatically charged combustion plants. To be used up to 48 months after announcement of the amended 1st BImSchV only in agricultural, forestry and horticultural enterprises and in enterprises of the commercial agrarian sector having experience in handling cereals, up to an NWL of 100 kW; plants from 100 kW FWL upward are subject to TI Air (limits with 11 % ref. oxygen were recalculated to 13$ using a factor of 1.25)
[d] For new systems (excepting single-room heating systems) and for existing systems, depending on the time of installation
– up to incl. 31st December 1994 from 1st January 2015
– from 1st January 1995 up to incl. 31st December 2004 from 1st January 2019
– from 1st January 2005 up to incl. 1st July 2009 1st January 2025
[e] for systems installed after 31/12/2914
[f] additional limit for volatile organic carbon compounds (total C): 40 mg/Nm3 (or 50 mg/Nm3 with 11 % ref. oxygen)

Table 4.2 Requirements of the “Blue Angel“ Label for wood pellet combustion plants [20] “Blue Angel“ limits /valid until 31/12/2010)[a]

Product[b]	NWL	Rational energy utilization				Emissions[e]		
	Efficiency	Aux. power required		Dust mg/m_N^3	CO mg/m_N^3	NO_X mg/m_N^3	C_{total} mg/m_N^3	
	kW	Nom. load	Part. load	Nom. load	Part. load		Nom. load	Part.load
Pellet furnaces	≤15[b]	≥90%	≥90%	25	180	400	10	15
Pellet boilers	≤50[c]	≥90%	≥88%	20	90	200	5	5

[a] other requirements for: dust content in waste gas at partial load, auxiliary power required at partial load and standby mode, el. power consumption of important plant components, water-related resistance, adjustment and operating instructions, services offered
[b] excl. use of wood pellets, preferably acc. to DINplus or to ÖNORM M7135 or DIN 51731
[c] with automatic ignition and combustion control
[d] with automatic ignition. Heat exchanger cleaning and power and combustion control
[e] of the thermal power generated
[f] referred to waste gas in its normal state (0 °C, 1013 mbar)

In the short to medium term, therefore, the fuel requirements/qualities and the combustion technologies must be matched even better in order to be able to meet the high legal requirements. The further tightening of the limits especially for stalk-type fuels from 2015 onward is therefore considered to be a technological challenge. It appears to be quite feasible, however, for the use of wood pellets with the plant technology currently on offer on the market.(at least for the test stand measurement for combustion plant licensing) and unproblematic for automatically charged wood pellet boilers.

"Blue Angel" Environmental Label

Pellet heating systems with particularly low emissions and high energy efficiency are awarded the "Blue Angel" environmental label by the German Institute for Quality Assurance and Labeling [Deutsches Institut für Gütesicherung und Kennzeichnung e.V. (RAL)]. The criteria are specified by the Federal German Office for the Environment, together with experts from science. RAL environmental label 111 has hitherto been awarded to 23 boilers of up to 15 kW by six manufacturers and RAL environmental label 112–54 boilers of up to 50 kW by 15 manufacturers (Autumn 2009 status). At the end of 2010, combustion plants were re-evaluated [1] (Table 4.2).

Air Quality Guideline

The "Guideline on Air Quality and Clean Air for Europe", in force since June 2008, is aimed at reducing the damaging effects of emissions of various pollutants such as SO_2, NO. NO_2, CO, benzol, particles (particulate matter[1] PM10, PM2.5) and lead, as well as ozone, on health and the environment. It specifies limit and target values for the various pollutants and defines uniform testing and measuring methods and alerting and information values in order to ensure that the public is informed adequately and in good time. For the first time, limit values are also listed for the respirable PM2.5 particles the concentration of which is to be lowered by 20 % compared with the values from 20110. The emissions of pollutants are considered with respect to area and independently of the question of originator.

In everyday life, the effects of the Guideline become apparent most clearly through the environmental zones in large cities. These were set up for assessing any transgression of the limit values for various pollutants, taken over from the predecessor guideline 1999/30/RG. For example, the following regulations apply since 2005 for the concentration of particulate matter PM_{10}:

50 µg/m^3must not be exceeded more than 35 times per calendar year.
The maximum allowable mean annual concentration is 20 µg/m^3

[1] The term "particulate matter" (PM) describes a complex mixture of solid and/or liquid organic and anorganic pollutants ejected into the air. They vary depending on size, composition and origin and are described by means of their particle size and aerodynamic diameter [2].

In Germany, these limits are monitored by the Lands of the Federal Republic. The new Air Quality Guideline has been replaced by a corresponding adaptation of the BImmSchG in 2010 and translated into German Law by a new legal ordinance [3].

Ecodesign Guideline

EU Guideline 2005/32/EG limits the environmental effects caused by the production, the use and the disposal of a product. The Ecodesign Guideline (Ecodesign GL) creates the foundation for evaluating and designing energy-operated products to meet environmental requirements, translated into national law in Germany by the “Energy-operated Products Guideline (EBPG—Energiebetriebene Produkte-Richtlinie). The Ecodesign GL is currently the basis for the development of executive measures for various product groups. on the basis of which a regulation for solid fuel combustion plants, among others, was to be passed in 2010 [4, 5]. The following were considered:

– Single-room heaters for heating and cooking in private residences up to 60 kW max, and
– Central heating boilers, subdivided into two power classes up to 50 and 500 kW.

Components preceding or following the heating systems, such as, e.g. fuel supply system, Control or buffer storage are not included in the investigation. The available combustion heating systems are currently checked and evaluated only with regard to their technical characteristics and innovation potentials, the way these are influenced by user behaviour and the market situation. It can be expected that there will also be requirements for the energy efficiency and emissions of combustion plants (e.g. NO_X). This could result in overlaps with the amended BImmSchV (Table 4.1) which must then be matched again to the new European regulation. However, the Ecodesign GL wil not be able to replace the national emission guidelines since it does not contain any regulations on plant operation including the emission limits and allowable solid fuels. It only relates to the commissioning of new systems (test stand examinations) and not to their operation [6].

Other Regulations

Apart from the above guidelines, there are a number of other guidelines for wood pellet heating systems which, for example, deal with the definition of pellet heating systems, set special requirements for their manufacture, define test stand measurements or refer to the identification of the systems, such as DIN 18894 (pellet furnaces), DIN EN 15270 (pellet burners), or DIN EN 14785-B1 (room heaters for wood pellets).

4.2 Removal of Ashes and Residues

Whereas the area of plant licensing and limitation of emissions is already being controlled comprehensively at a national and EU level, there are no consistent standards for the disposal/utilization of ash from biogenic fuels to the present day.

For this reason, reference is made only to Germany in the following sections whereas information relating to other EU countries can be found, for example, in [7].

Ashes are wastes in the sense of the German "Closed-Cycle Waste Management Act" (KrW-/AbfG - Kreislaufwirtschafts—und Abfallgesetz) since the main purpose of the operation of a wood burning system is the generation of energy and not the production of ash [8]. According to the principles of the closed-cycle economy, the recycling of wastes has precedence over their disposal [9]. For this reason, returning biomass ash to agricultural and forestry areas is an obvious choice in order to compensate at least partially for the requirement for nutrients produced by the removal of biomass. The benefit is due to the fertilizing effect of ashes mainly determined by the phosphor, calcium, magnesium and potassium contents. The concentration of which can vary greatly, however, depending on the type and origin of the biomass. It must also be considered that all plants will also accommodate heavy metals in small amounts as essential trace elements. In addition, heavy metals pass into or onto the plants by deposition and remain unburnt and concentrated in the ash when the biomass is utilized as an energy source [1]. Ashes from solid fuel combustion plants are distinguished by their location of occurrence as coarse and grate ash, cyclone ash (fine ash, flue ash) and filtered ash (extra-fine ash), the utilization of which differs in accordance with their heavy metal loading.

According to the German Fertilizing Act (DüngG—Düngegesetz) which came into force in 2009, fertilizers may be used or put into circulation commercially only if they correspond to a licensed fertilizer type (according to the Fertilizer Regulation (DüMV—Düngemittelverordnung) and are correctly marked. According to Para.1 of the DüMV, the fertilization must be *oriented in type, quantity and time towards the requirement of the plants and of the soil, taking into consideration the nutrients and organic substance available in the soil and the site and cultivation conditions* [10, 11]. In principle, only the "unburdened" ashes from the combustion chamber (coarse or grate ash) may be used from the combustion of untreated wood The use of cyclone ash is permissible only if it comes from a separator followed by an electric filter or fabric filter. The ash must be analysed and classified in a laboratory (especially for heavy metals). It can be used in its pure form as calcium or potassium fertilizer . Another possibility is to use it as an additive for the "carbonated calcium" type of fertilizer in mineral-type multi-material fertilizers or in organic-mineral fertilizers. The prerequisite is that limits for various heavy metals and the minimum nutrient contents specified for the respective type of fertilizer are adhered to [9]. The cases in which fertilization with wood ashes is permissible in forests are specified precisely in the Federal Forest Laws [12]

When the ashes from wood combustion plants are utilized privately in the garden, the Ground Protection Act (BBodSchG, BBodSchV) must be applied. The rule is then that a certain additional annual loading of the soil by heavy metals must not be exceeded. A mathematical analysis at the UMSICHT Fraunhofer Institute determined the maximum amount of deposited coarse ash from the combustion of untreated wood shavings with the relatively low annual quantity of

40 or 20 g/m^2 for wood pellet ashes. The quantities that can be deposited are reduced additionally by natural soil loading and immissions (e.g. from the air). Depositing the ashes in the garden is, therefore, not advisable, or only to a limited extent [13]. In practice, the ash produced is in most cases disposed of in the domestic waste.

For ashes which can not be deposited as fertilizer, other means of disposal must be found. If necessary, "weakly loaded" ashes can be used as building material aggregates (e.g. in the cement industry), or they must be eliminated in such a way that the wellbeing of the general public is not adversely affected. The possibility of depositing them on a disposal site is assessed in accordance with the extent to which the individual pollutants can be leached out acc. to Appendix B or D of the TI Community Waste or TI Waste, respectively. Accordingly, combustion chamber ashes can be usually deposited above ground whereas, as a rule, "strongly loaded" ashes (e.g. filtered dust particles), must be deposited below ground because of high TOC and eluate burdens [1].

4.3 Sustainability Requirements

The term sustainability can be traced back to the beginning of the 18th century where it describes the concept for a systematic and permanently caring cultivation of the forests. Since the end of the 20th century, sustaining management criteria are established for almost all branches of society, involving both economic, ecological, social components [14].

The Renewable Energy Directive (RED) is the European guideline 2009/28/EG for the utilization of energy from renewable sources. It names binding overall national goals and measures for utilizing renewable energy sources in the member states of the EU and regulates the reporting for the European Commission. For the first time, ecological sustainability criteria are defined which are intended to ensure that a minimum degree of THG savings is achieved when calculating the rate at which each individual country meets its target. Changes in land utilization due to the cultivation of energy plants for the production of biopropellant and liquid biofuels are accorded a particularly critical evaluation in this context.[2]

In the final analysis, the RED does not at present represent a suitable instrument for verifying sustainable pellet utilization since no binding demands are made on the participants in the procurement chain. There are recommendations for minimum conversion efficiencies for assisting regeneratively generated heating, cooling or electricity in plants with an installed power of >5 MWh. In addition, there should

[2] EU Guideline 2009/28/EG was translated into national law in 2009 as part of the Bioamss Power Sustainability Act (BioSt-NachV—Biomassestrom- Nachhaltigkeitsverordnung) for liquid biogenic fuels and the BiopropellantSustainability Act (Biokraft-NachV — Biokraftstoff-Nachhaltigkeitsverordnung), which are focussed on the use of liquid and gaseous energy sources for propellant production

be proofs of origin in electronic form per regeneratively generated MWh which ensure that the renewable energy source is traceable within the member states of the EU. Nevertheless, the RED offers the chance of orienting national assistance programmes selectively towards efficient, innovative application techniques since a conversion efficiency of at least $\geq$70 % is recommended for promoting industrially generated biogenic heating, cooling or electricity generation, whereas a system conversion efficiency of $\geq$85 % is suggested when using biomass in residential buildings [15]. This limit value should not represent any challenge for modern small pellet heating systems whilst the use of pellets purely for electricity generation in large industrial power plants would not be worthy of assistance.

In the meantime, the CEN/TC 383 and ISO/TC 248 Standardization Committees have devoted themselves to working out generally recognized and internationally binding sustainability criteria for biomass sources. Until then, the EC has decided at the beginning of 2020 not to specify any binding sustainability requirements for the use of solid and gaseous bioenergy sources for heat, cooling or electricity generation for the time being. Instead, the report contains non-obligatory recommendations for countries dependent on the import of biomass on how to ensure a sustainable procurement of biomass in the energy sector. These should also be included in order to unify the current national activities in the installation of verification systems [16].

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Chapter 5
Fuel Quality Requirements

Due to the natural site-related conditions and relatively short growth times, the fuel-specific characteristics of biogenic raw materials will never achieve a homogeneity comparable to that of fossil fuels. In the production of wood pellets, this natural disadvantage is counteracted in that the unhewn timber input from sawmills, the woodworking and -processing industry or in the form of wood offcuts is stored centrally as bulk shavings and is thus already mixed together a first time during storage and delivery. In the pelletizing process, additional conditioning measures (e.g. the addition of water or steam and/or of compression aids) can provide for the highest possible homogeneity of the wood pellets. It is thus possible for different fuel qualities to be produced in one and the same pellet factory. The quality of the final product must thus be agreed first with the pellet manufacturer so that the fuel requirements of the heating system and the demands of the customers can be met [11].

Towards the end of the 90s, national product standards for wood pellets, in which important fuel-specific characteristics are defined by means of threshold values (Fig. 5.1), were developed with the installation of the first pellet heating systems in Sweden, Germany and Austria. These product standards have been adopted or adapted by some European countries (e.g. DIN in Switzerland: SN 166000; SS 187120 in Norway: NS 3165) [8]. The regular checking and quality assurance is handled by certification programs such as "ÖNORM M7135 geprüft (tested)" or DINplus".[1] Today, both these Standards and Codes set almost identical quality requirements for wood pellets and have achieved a high degree of acceptance and market presence in Europe and beyond in the meantime (status as of October 2009: >150 certified plants, corresponding to about 30 % of all pellet plants in Europe) [5, 9, 12]. In other countries, the quality characteristics of wood pellets are presented

[1] The certification program "DINplus: Wood pellets for Use in Small Heating Systems" is an extension of "DIN 51731 geprüft (tested)" from 2004 and combines the most important product requirements of ÖNORM M7135 and DIN 51731. In Germany, the certificate is issued by DIN CERTCO. The requirements of DINplus have been adapted to match those of European Standard EN 14961-2, wood pellet class A1.

S. Döring, *Power from Pellets*, DOI: 10.1007/978-3-642-19962-2_5,

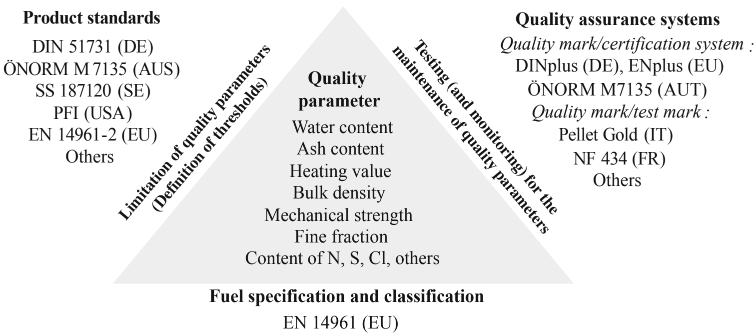

Fig. 5.1 Rules and standards differentiated by classification system, product standards and quality assurance systems for wood pellets, using selected examples

in the form of labels or test marks, e.g. "Pellet Gold" in Italy or "NF434″ in France. However, their testing and monitoring duties differ significantly from the established certification programs in Germany and Austria [7, 3, 1]. For this reason, many European manufacturers of automatically fed small heating systems or single room furnaces will now recommend or indicate the use of certified wood pellets as per DINplus or "ÖNORM M7135 geprüft (tested)". They are frequently even a prerequisite for guaranteeing a continuous, low-emission system operation.

In principle, internationally recognized quality standards provide a good opportunity for facilitating cross-boundary trade in a market expanding throughout the world and thus for enhancing the competitiveness of solid biogenic fuels. Furthermore, the confidence of customers in the respective fuel can be increased by greater market transparency and the entry of new players into the industry can be facilitated [13]. The European Commission, therefore, charged the Technical Committee (CEN/TC 335 Solid Biofuels) with the development of European standards for solid biogenic fuels. For about 10 years, numerous European experts from scientific institutions and industry in five working groups have in the meantime developed 28 product and quality standards, as well as test and terminology standards, which currently have the status of Preliminary European Standard (prEN or TS for Technical Specification) (Fig. 5.2). The first European standards (EN) have been available as full standards since the year 2010 [2, 10].

EN 14961 "Solid Biofuels—Fuel Specifications and Classes—Part 1: General Requirements" is the first one of this parcel of standards to come into force in Spring 2010. It lists for almost every solid biogenic fuel an identification of the origin of the raw material, a classification of the form of fuel and categorization of relevant quality parameters for the purpose of grading and comparison, including pellets [4]. Parts 2—7 of EN 14961 describe product standards for solid fuels for the non-industrial use of fuel. Further parts will be added in the years to follow.

In Part 2 of EN 14961, four quality classes for wood pellets are defined which partly differ in their usable raw materials, the permissible thresholds for the ash content, the heating value, the nitrogen and chlorine content and the ash fusibility.

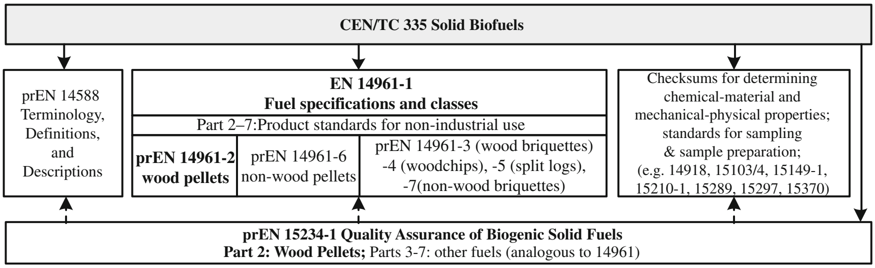

Fig. 5.2 Systematic arrangement of the EU Standards for biogenic solid fuels including specific regulations for wood pellets, status as of Spring 2010

Among other things, the Standard lists a multiplicity of thresholds for heavy metals, which exclude the use of chemically treated wood for pellet production (Classes A1 and A2), or limit it to minimal amounts of contamination (Class B). The Standard does not mention any concrete requirements for the ash fusibility of wood pellets but the available analysis values of ash deformation temperatures are to be documented. The fuel analyses must be performed in accordance with the latest European test standards [14].

The test standards for assessing the various quality characteristics were developed especially as part of the European standardization initiative TC 335 in order to be able to use uniform measuring and testing methods for determining the fuel-specific characteristics (e.g. water content prEN 14774, ash content prEN 14775, mechanical strength prEN 15210-1 or ash fusibility prEN 15370-1), for the first time throughout the EU [6].

Analogously to EN 14961, a multi-part standard EN 15234 is being developed for quality assurance for biogenic fuels along the entire provisioning chain. After coming into force (2011), prEN 15234-2, tailored for wood pellets, is intended to safeguard the quality of the pellets, from the provision of the raw material through the pellet production process and the transportation of the fuel up to the delivery to the end user. The specifications for a transparent documentation, e.g.:

– origin of the fuel,
– production parameters during the production of the fuel,
– all parties involved during the provision of the fuel and of the hand-over conditions.

are intended to reinforce customer confidence in the product and to contribute to the internal improvement of quality [15, 16].

With the introduction of the European group of standards, the ENplus certification system was developed 2009/10 for the requirements of the German and Austrian market. Based on prEN 14961-2, wood pellets are subdivided into three quality classes (A1, A2, B) and the specifications of prEN 14961-2 for quality assurance of the fuel along the provisioning chain for pellet producers and dealers are integrated into the manual. Within the framework of the new certification system, guarantees are thus provided not only for the quality of the product after

Table 5.1 Overview of international standards for premium pellets$_2$, Dy/Y films. To determine the fuel parameters, test methods are identified and used in some cases which restricts the comparability of the limit and analysis calues. All data provided without liability

Country			Germany		Austria		Switzerland	Italy
Standard/quality mark (QM)			Standard/QM	QM	Standard / QM	QM	QM	QM
Introduced since			1996	2004	1990 / 1997	2007	Valid till	2006
Last update				2007	2000	2009	2006	
Designation			Standard: DIN 51731 1) QM: DIN-tested	DINplus (valid till 2010, ref. to DIN 51731 + ÖNORM M 7135)	ÖNORM M 7135 / ÖNORM tested	Environment Mark EM 38	Swiss-pellets	Pellet Gold[1)]
Class			HP5	HP5 [4)]/ HP1 [5)]	HP 1			
Raw material			Untreated wood incl. bark	Untreated wood or bark	Untreated wood	Untreated wood and byproducts from the timber industry		Trunk wood, chem.untreated residues from the timber industry[7)]
Parameters		Unit						
Dimension								
Diameter	D	mm	10-Apr	4 D < 10	4 D < 10	4 D < 10	5–7	–
Length	L	mm	<50	5 × D[1)]	5 × D[1)]	5 × D	<50	–
Water content	W	%	12	10	10	10	10	10
Ash content	A	% (TM)	1.5	0.5[2)]	0.5[1)]	0.5[2)]	1.0	1
Heating value	H_U	MJ/kg	17.5–19.5 [2)]	18 [2)]	18[2)]	18[2)]	18	>16.9 [3)]
Mech. strength[1)]	DU	%	–	-97.7	(>97.7)	-97.7	–	(97.7)
Abrasion[1), 2)]		%	–	2.3 [6)]	2.3	2.3	4.5	2.3
Fine fraction[2)]	F	%	–	–	–	–	–	–
Pressing aids/additives	PHM	%	None	2[6)]	2[6)]	2	None	<2[4)]
Bulk density	BD	kg/m³	–	–	–	–	–	>600
Gross density		kg/dm³	1.0 –1.4	1.12	1.12[3)]	1.12	1.15–1.4	>1.15
Ash fusibility[3)]		°C	–	–	–	–	–	–
Nitrogen	N	%	0.3	0.3 [2)]	0.3 [2)]	0.3[2)]	0.3	0.3[3)]
Sulphur	S	%	0.08	0.04 [2)]	0.04[2)]	0.04[2)]	0.04	0.05[3)]
Chlorine	Cl	%	0.03	0.02[2)]	0.02[2)]	0.02[2)]	0.02	<0.03[3)]
Arsenic	As	mg/kg (TM)	0.8	<0.8	–	–	0.8	<0.8
Cadmium	Cd	mg/kg (TM)	0.5	<0,5	–	–	0.5	<0.5
Chromium	Cr	mg/kg (TM)	8	<8	–	8	8	<8
Copper	Cu	mg/kg (TM)	5	<5	–	5	5	<5
Lead	Pb	mg/kg (TM)	10	<10	–	–	10	<10
Mercury	Hg	mg/kg (TM)	0.05	<0.05	–	–	0.05	<0.05
Nickel	Ni	mg/kg (TM)	–	–	–	–	–	–
Zinc	Zn	mg/kg (TM)	100	<100	–	–	100	<100
Additional parameters			EOX [3)]: 3 mg/kg (TM)			EOX: 3 mg/kg (TM)	EOX: 3 mg/kg (TM)	Na <0.03 mg/kg TM, formaldehyde content, normative (mg/100 g)

Explanations

[1)]The standards examined use either mechanical strength or abrasion as a parameter since both can be derived from one another, the converted value is bracketed in the table

TM: dry matter

[3)] Def. ash fusion temperatures: SST = shrinkage starting temp., DT = deformation temp. (IT = initial deformation temp.); HT = hemisphere temp., FT = flow temp

Germany, Standard/QM: [1)] Also valid in CH as SN 166000; [2)] Water- and ash-free; [3)] Extractable organic bonded halogens

Germany, QM: [1)] Max 20 mass% = L to 7.5 × D; [2)] Water-free; [4)] DIN 51731; [5)] ÖNORM M 7134; [6)] Chem. unaltered products from primary agricultural and forestry biomasses

Austria, Standard/QM: [1)] Max 20 mass% = L to 7.5 × D; [2)] Water-free; [3)] Deviations of 0.02 allowed; [4)] Chem. unaltered products from primary agricultural and forestry biomasses

Austria, QM 2007: [1)] ≤70 % of raw material per year must be from sustainable forestry (PEFC/FSC or other recognized certification systems)

Switzerland: [1)] The pellet standard SN 166000 valid since 2001 in CH is identical with DIN 51731

Italy: [1)] Based on prEN 14961-2, PFI, DINplus and ÖNORM M 7135; [2)] lt. prEN 14961-1: 1.1.2.1; 1.1.2; [3)] Water-free; [4)] Type/fraction must

[2)]Normally <3.15 mm

Table 5.1 (Continued)

France		Sweden	Scandinavia	EU		USA	
QM	QM	Standard	QM	Standard/QM		Standard/QM	
No longer relevant	2009	1998	2005 2007	Standard valid from fall 2010; QM valid since 2010 (ref.to prEN 14961-2)		2008	
ITEBE	NF 434: "Marque NF Granulés biocombustibles"	SS 187120	Swan[2)] (Nordic Ecolabelling)	Standard: prEN 14961-2 (Mar 2010 status) QM: Enplus (marked A1 or A2); QM: DINplus (2010) only applies to A1		PFI Standard Specification for Residential/Commercial Densified Fuel/GZ: PFI QA/QC Program[4)]	
Extra	Bois premium	Group I	Class I + II	A1	A2	Super premium	Premium
	Wood	Unpolluted biomass	Trunk wood, chem.untreated residues from the timber industry[7)]	Trunk wood, chem.untreated residues from the timber industry[7)]	Whole trees without roots, trunk wood, forest remnants, bark, chem.untreated residues from the timber industry	Chemically untreated material	
6 ± 1	6 ± 1	–	class I: 6 ± 0,5 class II: 8 ± 0,5	6 ± 1 or 8 ± 1[1)]	6 ± 1 or 8 ± 1[1)]	6.35 to 7.25[1)]	6.35 to 7.25[1)]
10–30 [1)]	5 L 30	4 × D	5 × D	3.15 L 40[2)]	3.15 L 40[2)]	1 % > ~38.1[1)]	1 % > ~38.1[1)]
10	8	10	10	10	10	6	8
1.0	0.7	0,7	0.5	0.7	1.5	0.5	1
18	16.7[1)]	>16.9[2)]	17,1	16.5[3)] < Q < 19	16.3[3)] < Q < 19	[2)]	[2)]
97.7	97.5	–	97.5	97.5	97.5	97.5	97.5
(2.3)	(2.5)	–	(<2.5)	(<2.5)	(<2.5)	(<2.5)	(<2.5)
1	1[3)]	0.8	1.0	1[5)] (0.5[6)])	1[5)] (0.5[6)])	0.5	0.5
2[2)]	2[2)]	No limit value[3)]	2[6)]	2[4)]	2[4)]	[3)]	[3)]
650	650	600	I: 630 < BD ≤ 700 II: 700 < BD ≤ 780	600	600	~640 to ~737[1)]	~640 to ~737[1)]
1.15	–	–	–	–	–		
	–	IT to be specified	IT (SST) ≥ 1300 HT ≥ 1400	To be documented, with standard + QM: DINplus = informative, QM: ENplus = normative		To be documented	To be documented
0.3	0.3[4)]	–	0.3	0.3	0.5	–	–
<0.05	0.05[4)]	0.08[4)]	0.03	0.03	0.03	–	–
<0.03	0.03[4)]	0.03[4)]	0.02	0.02	0.02	0.0003[1)]	0.0003[1)]
<1	1	–	–	1.0	1.0	–	–
<0.5	0,5	–	–	0.5	0.5	–	–
<10	10	–	–	10	10	–	–
<10	10	–	–	10	10	–	–
<10	10	–	–	10	10	–	–
<0.05	0,05	–	–	0.1	0.1	–	–
<10	10	–	–	10	10	–	–
<100	100	–	–	100	100	–	–
			1200 kW max primary energy use/pellet production	The EN certification system plus A1 + A2 will be introduced first in DE & AT and applied in the EU in the coming years			
[1)]90 mass% must be within range [2)]Specify type	[1)]As delivered [2)]Type (mineral/organic) and fraction must be specified [3)]At plant exit [4)]Water-free	[1)]Also valid in NOR (NS 3165) and FIN [2)]As delivered [3)]Specify type and [4)]Water-free	[1)]Valid in NOR, FIN, DK, SE, ICE [2)]Fixed-term validity until 31.12.2012 [3)]Per EN 14961-1: 1.1.2.1; 1.1.2 [4)] Fresh wood: ≥70 % p.a. must be from forestry certified as sustainable [5)] Max 20 mass% = L to 7.5 × D [5)] Chem. untreated biomass	[1)] Optional, must be specified [2)]1 % max may be longer than 40 mm, max length = 45 mm [3)]Fresh [4)]Type and quantity to be specified [5)]Applies to loose pellets before loading ex plant, big bags before filling, sacks for delivery to end user [6)]Applies to sacks up to 20 kg before filling [7)]lt. prEN 14961-1: 1.1.3; 1.2.1 [8)]lt. prEN 14961-1: 1.1.1; 1.1.3, 1.1.4, 1.1.1. 6 u. 1.2.1		[1)]≤300 ppm (original value converted) [2)]Must be specified (BTU/pound) [3)]Must be specified [4)]Quality assurance/quality control (QA/QC) program, not applicable to overseas transportation	

Table 5.2 Overview of international standards for other wood and non-wood pellets. To determine the fuel parameters, different test methods are identified and used in some cases which resrict the comparability of the limit and analysis values

Country			Germany		Austria			
Standard/quality mark (QM)			Standard	QM		Standard		Standard
Introduced since			1996	1996		1990		2007
Last update						2000		
Designation			DIN 51731[1]	DIN 51731 tested		ÖNORM M 7135		ÖNORM C 4000
Class			HP4	HP5	Wood pellets 2	Bark pellets 1	Bark pellets 2	Miscanthus-pellets
Raw material			Untreated wood incl. adhering bark		Untreated wood	Untreated bark		Whole miscanthus plant acc. to prEN 14961-1
Parameters		Unit						
Dimension			Oct-40	10-Apr	10 D < 40	4 D < 10[4]	10 D < 40	D06: 6 ± 1[1] D08: 8 ± 1 D10: 10 ± 1
Diameter	D	mm						
Length	L	mm	<100	<50	4 × D[1]	5 × D[1]	4 × D[1]	D06: L 30[1] D08: L 35 D10: L 40
Water content	W	%	12	12	10	10	10	10
Ash content	A	% (TM)	1.5	1.5	0.5[2)3)]	6[2]	6[2]	A4.0: 4[1] A6.0: 6
Heating value	H_U	MJ/kg	17.5–19.5[2]	17.5–19.5[2]	18[2]	18[2]	18[2]	[2]
Mechan. strength	M	%	–	–	–	(>97.7)	–	97.5
Abrasion[1,2]		%	–	–	–	2.3	–	(<2.5)
Fine fraction	F	%	–	–	–	–	–	1
Pressing aids, additives	PHM	%	None	None	2	2	2	[3]
Bulk density	BD	kg/m³	–	–	–	–	–	580
Gross density		kg/dm³	1.0 – 1.4	1.0–1.4	1.0	1.12[4]	1.1	–
Ash fusibility		°C	–	–	–	–	–	>800
Nitrogen	N	%	0.3	0.3	0.3[2]	0.6[2]	0.6[2]	0.5
Sulphur	S	%	0.08	0.08	0.04[2]	0.08[2]	0.08[2]	0.05
Chlorine	Cl	%	0.03	0.03	0.02[2]	0.04[2]	0.04[2]	0.07
Arsenic	As	mg/kg (TM)	0.8	0.8	–	–	–	–
Cadmium	Cd	mg/kg (TM)	0.5	0.5	–	–	–	–
Chromium	Cr	mg/kg (TM)	8	8	–	–	–	–
Copper	Cu	mg/kg (TM)	5	5	–	–	–	–
Lead	Pb	mg/kg (TM)	10	10	–	–	–	–
Mercury	Hg	mg/kg (TM)	0.05	0.05	–	–	–	–
Nickel	Ni	mg/kg (TM)	–	–	–	–	–	–
Zinc	Zn	mg/kg (TM)	100	100	–	–	–	–
Additional parameters			EOX[3]: 3 mg/kg (TM)					

Explanations

TM: dry matter

1) The standards examined use either the mechanical strength or the abrasion as parameter since both can be derived directly from one another. The converted value is bracketed in the table

2) i.d.R. <3.15 mm

3) Characteristic ash fusion temperatures, SST: shrinkage starting temp. DT: deformation temp., HT: hemisphere temp. FT: flow temp

Germany:
1) Classified SN166000 in CH
2) Water- and ash-free
3) Extractable organically bound halogens

Austria (ÖNORM M 7135):
1) max% = L to 7.5 × D
2) Water-free
3) Up to 0.8 % if the untreated raw wood already has a higher ash content
4) Deviations of 0.02 allowed

Austria (ÖNORM C 4000):
1) Class to be specified
2) Heating value in delivered state informative
3) Type and quantity to be specified

Table 5.2 (Continued)

Sweden		France				EU				USA		Belarus
Standard		Quality mark				Standard/QM	Standard			Standard/QM		Industry standard
		2008				Publication planned for fall 2010	In development since 2005			2008		
1998												
SS 187120		NF 434: "Marque NF Granulés biocombustibles"				Standard: EN 14961-2 qm: EN B	prEN 14961-6 (Status June 2010)			PFI Standard Specification for Residential/Commercial Densified Fuel/PFI QA/QC Program[4]		TU RB
Group 2	Group 3	Bois standard	Bois industrial	Agro+	Agro	B	Straw	Miscanthus	Reed	Standard	Utility	
Unpolluted biomass						Forest and plantation wood, residues from the timber industry, used wood 7, 8				Chemically untreated material		
–	–	6 D 9 ± 1	6 D 16	6 D 8 ± 1	6 D 16 ± 1	6 ± 1 or 8 ± 1[1]	6 ± 1.8 ± 1 or 10 ± 1[1]			6.35 to 7.25[1]		9-Aug
5 × D	6 × D	5 L 30	5 L 50	10 L 30	10 L 30	3.15 L 40[2]	3.15 L 40[3]			1% > ~38.1[1]		30–50
10	12	10	15	11	15	10	10	10	12	10	8	12
1.5	1.5	1.5	3	5	7	3.5	6[9]	4[9]	8[9]	2	6	1.5
>16.9[2]	>16.9[2]	16.2[1]	15.2[1]	15.5[1]	14.7[1]	16.0[3] < Q < 19	Minimum heating value to be specified		14.5[3]	[2]	[2]	>16.9
–	–	95	95	95	92	96.5	97.5	97.5	96.5	97.5	97.5	–
–	–	(<5)	(<5)	(<5)	(<8)	(<3.5)	(<2.5)	(<2.5)	(<3.5)	(<2.5)	(<2.5)	–
1.5	1.5	2[3]	3[3]	2[3]	3[3]	1[5] (0.5[6])	1[5]	1[5]	1[5]	0.5	0.5	–
No limit value[3]		2[2]	3[2]	3[2]	3 %[2]	2[4]	[5]Example starch, cereal or potato flour, plant oils			[3]	[3]	–
500	500	650	650	650	650	600	650	650	650	~609 to ~737[1]	~609 to ~737[1]	500–650
–	–	–	–	–	–	–	–	–	–	–	–	–
IT to be specified		–	–	1000	800	To be specified, standard	[5]To be documented			[3]To be documented		–
0.3[5]	0.3[5]	0.3[4]	0.5[4]	1.5[4]	1.5[4]	1.0	0.7	0.5	1.0	–		–
0.08[5]	[4]	0.08[4]	0.08[4]	0.2[4]	0.2[4]	0.04	0.2	0.2	0.3	–	–	–
0.03[5]	[4]	0.05[4]	0.05[4]	0.2[4]	0.2[4]	0.03	0.1	0.08	0.1	0.0003[1]	0.0003[1]	–
–	–	1	1	1	1	1.0	1.0	1.0	1.0	–	–	–
–	–	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	–	–	–
–	–	10	10	10	10	10	50	50	50	–	–	–
–	–	10	10	40	40	10	20	20	20	–	–	–
–	–	10	10	10	10	10	10	10	10	–	–	–
–	–	0.05	0.05	0.1	0.1	0.1	0.1	0.1	0.1	–	–	–
–	–	10	10	15	15	10	10	10	10	–	–	–
–	–	100	100	60	60	100	60	60	60	–	–	–
						Ash-forming elements informative						

Sweden:
[1]Also applies in NOR (NS3165) and FIN
[2]On delivery
[3]Type and quantity to be specified
[4]To be specified
[5]Water-free

France:
[1]As delivered
[2] Type (mineral/organic) and quantity must be specified
[3]At plant exit
Fresh
[4] Water-free

EU:
[1]Optional, must be specified
[2]1 % max may be longer than 40 mm, max length <45 mm
[3]Type must be specified
[4]Type and quantity must be specified
[5]Applies to loose pellets before loading ex plant, big bags before filling, sacks for delivery to end user
[6]Applies to sacks up to 20 kg before filling
[7]Per prEN 14961-1: 1.1, 1.2, 1.3
[8]For QM: EN B raw-material input delimited, per prEN 14961-1
[9]Content to be specified

USA:
[1] Values converted
[2] Must be specified
[3] Type must be specified
[4] PFI quality assurance/quality control (QA/QC) program, not applicable to overseas transportation

production but until it is delivered to the end user. Apart from quality assurance, the integration of market monitoring is intended to provide opportunities for increasing the reliability of supplies. In addition, the use of raw materials from sustainable forestry for pellet production (PEFC- or FSC-certified) and documentation of their actual proportion and origin is encouraged. In the case of a proportion of >20 % of the import of raw materials or pellets from non-EU countries, the proof of sustainability must be provided mandatorily. The certification system was introduced in Germany and Austria in the Spring of 2010 and will be extended later to other EU countries [2].

In parallel with the development and market introduction of the European standards and certification systems, the "International Organisation for Standardisation" (ISO), by founding the Technical Committee "ISO/TC 238 Solid Biofuel" in 2007, is pursuing the aim of unifying the standards and test standards for biogenic solid fuels, valid in the EU and elsewhere, internationally in the coming years. The publication of the first bodies of rules was planned for 2011. It is expected that they will be based largely on the European CEN standards as to content and methods.

Table 5.1 provides an overview of international guidelines with specific quality requirements for premium pellets.[2] Other relevant quality standards and quality marks[3] for wood and non-wood pellets are listed in Table 5.2. These can be used depending on the fuel requirements of the heating system in the mesium or higher power range and partially also for industrial pellets.[4]

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[2] There is no official definition for the term of "**premium pellets**". As a rule, experts use this term for high-quality pellets produced from chemically untreated wood and not containing any or only marginal quantities of bark. They have a low ash content and high abrasion resistance. Premium pellets are suitable for use in automatically fed furnaces and in boilers in the lower to medium power range.

[3] **Quality marks** present logos or labels of quality assurance systems, which includes both certification and test programs or attestations.

[4] "**Industrial pellets**" have partly lower quality requirements compared with premium pellets and are used in relatively large heating systems or in power stations. Since systems in a higher power range have in most cases a more rugged fuel feed system, a more flexible control technology and, as a rule, are also equipped with exhaust gas conditioning components, any suboptimal combustion can be compensated for in a better way.

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Chapter 6
Pellet Production

Modern industrial pelletizing plants can process about 30,000–500,000 t/a. As a rule, these plants consist of several production lines with individual capacities of appr. 100,000–200,000 t/a per line.

The plant components of these production lines operating in parallel can be divided into two groups. On the one hand there are the central units which are used jointly by the respective lines, and then there are decentralized units available independently to the respective line.

Depending on the plant design, the central plant components include:

- Debarking
- Milling
- Wet storage and transportation systems
- Dryers
- Dry chip storage
- Pelletization
- Pellet storage and loading station
- Packing

From economic points of view, it is not worthwhile to design each line independently. The common plant components represent a compromise between a production capacity which has been secured to the greatest possible extent, and investment costs. Since the central units are plant components with long service lives, the risk of a failure of the total plant can be considered to be relatively low (Fig. 6.1).

6.1 Trunk Wood Yard and Trunk Wood Processing

In the past, wood shavings, as a byproduct from sawmills, were preferably used for producing pellets. However, the availability of wood shavings is falling world-wide whilst the demand for pellets is increasing at the same time, with the

S. Döring, *Power from Pellets*, DOI: 10.1007/978-3-642-19962-2_6,

Fig. 6.1 Pellet production, appr. 130,000 t/a incl. trunk wood processing

consequence that log wood, which can not be used in sawmills, is increasingly used as the raw material for producing wood pellets.

The size and type of construction of a timber yard essentially depends on the type of log wood to be processed, on the quality of the log wood (such as, e.g., range of lengths and diameters, curvature, remaining root and branch parts, growth deformities), on the type, volume and form of any wood offcuts and byproducts of the sawmill industry to be processed, on the geographic site and on the annual quantity processed and thus the annual output quantity. For producing wood pellets, industrial-quality wood in short lengths and with small diameters is predominantly used. The timber yard should provide sufficient flexibility with regard to log wood processing in order to take into account changing procurement criteria and thus to secure a long-term log wood supply.

From an economic point of view, continuous full utilization of the timber yard is desirable in order to keep the operating costs as low as possible. On the other hand, consideration must also be given to providing adequate reserves in the design of plant components for production peaks, waiting times, shortened working hours or continuous operation of the timber yard, in order to minimze production bottlenecks and to achieve a high degree of availability. It is especially in the industrial field that the timber yard has a special importance as the first process element in the pellet production, deciding over availability and profitability of the downstream processes. As well, operation in winter at extreme negative temperatures must be taken into consideration since the degree of debarking is then correspondingly lower.

The workflow diagram following represents an optimum for timber yard installations in the wood pellet industry. The design of the installation can be adapted, or have a different processing sequence, especially in the case of operations of a smaller order of magnitude. In the flow diagram following, the log passes through the following plant components:

- Dredger
- Chain conveyor
- Step feeder
- Rotary debarker
- Chain conveyor
- Metal detector
- Wood chipper.

Below the debarker, the bark falls onto a rail waste conveyor (also known as scraper chain conveyor). It can be optionally shredded in a bark mill and is conveyed into a bark box.

Above the debarking, the flow diagram shows the option of feeding in by dredger, via a chain conveyor or a vibration channel, short trunk wood which has already been debarked, or cut pieces from the sawmill for chipping these in the subsequent wood chipper.

At the beginning of the work in the pellet plant there is usually the input control of the log wood delivered. As a rule, there is a check in the form of a weight control by means of a weighbridge at the entrance to the plant. Since the moisture content in the log wood can vary, a moisture sample is taken from each load with a portable chainsaw. The moisture content in the wood shavings can be determined using a kiln. The water content can be determined more quickly using halogen scales. In the case of plant designs with single-trunk debarking, the input check can be automatic by calibrated measurement of material flow and integrated in the timber yard installations (Figs. 6.2 and 6.3).

To avoid multiple handling, the timber yard installations should be loaded straight from the truck, if possible, a brief unloading period being particularly important in this context. The receiving and storage deck of the timber yard installation should have a corresponding length. To minimize the unloading times, industrial undertakings in many cases use correspondingly large wheel loaders for unloading trucks. The structural design of the deck and its chain conveyors must take into account the high stresses to which they are exposed during the unloading

Fig. 6.2 Delivery of industrial wood and pre-delivery check [1]

process. To avoid production bottlenecks, optimum plant management will always require keeping a certain amount of log wood in reserve (Fig. 6.4).

6.1.1 Debarking

The wood pellet industry uses various debarking concepts which depend on production capacity, log wood dimensions and quality. Single-trunk debarking using debarking rotors is used for straight-stemmed log wood with a minimum length of 1.7 m, diameters from 100 mm and low volumes. The advantages of single-trunk debarking are comparatively low acquisition costs and a very good debarking result (Fig. 6.5).

To achieve greater debarking capacities, so-called rotary debarkers are used the capacity of which can be extended to an almost unlimited extent due to their modular construction. As it moves along, the bark is here broken open by shafts fitted with cams and is separated from the trunk wood. The use of rotary debarkers has been successful especially in the case of industrial-quality wood and offers sufficient flexibility in the procurement of log wood. The preceding sorting and allocating system must ensure reliable and undisturbed loading of the debarking

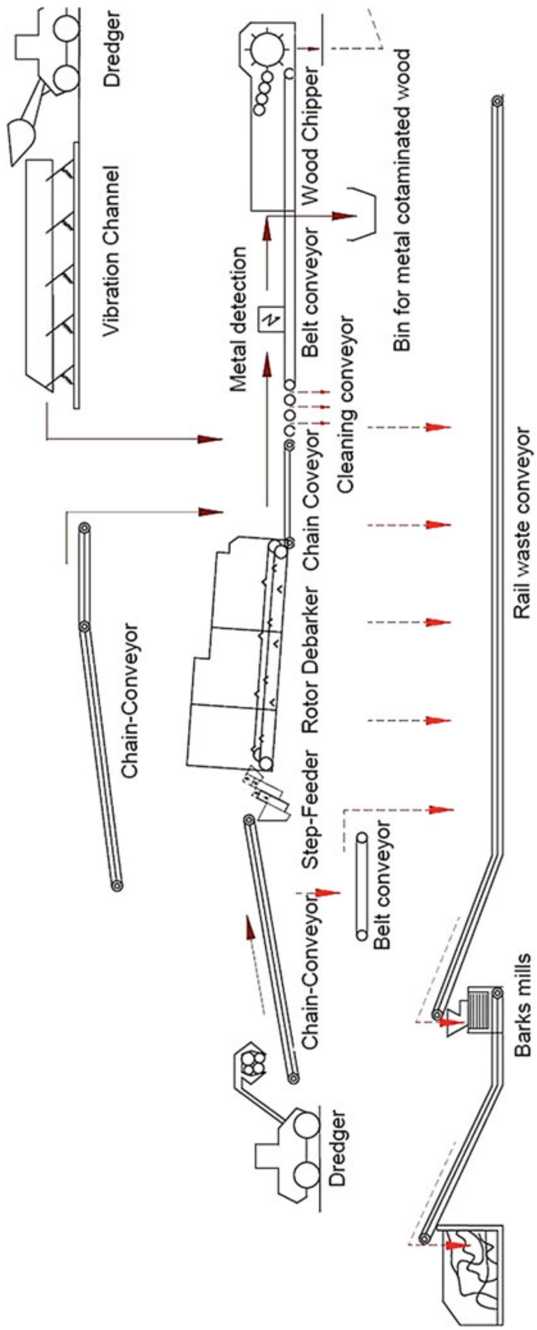
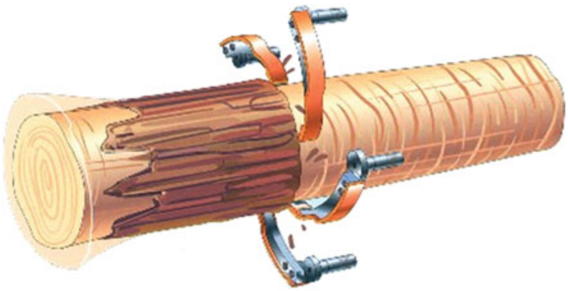


Fig. 6.3 Flow diagram for loading a capacity of 250,000 t/a [1]

Fig. 6.4 Dredger for loading timber yard installations [1]

Fig. 6.5 Schematic drawing of single-trunk debarking, Söderhamn Eriksson [1]



systems. Depending on the type of debarking used, the allocating system must feed the logwoods to the debarking station trunk by trunk or in small aligned bundles of logwood. Apart from the required capacity, the logwood dimensions also play a very decisive role in the design here, too.

To lock particulate matter such as, e.g., stones out of the process, cleaning sections in the form of roller conveyors can be used after the debarking systems. In most cases, the bark is used for producing energy and heat in pellet plants. This frequently requires milling of the bark, a process in which mainly hammer mills are used. The material is most efficiently transported by means of wide scraper chain conveyors and the design has to take into consideration the maximum amount of bark to be handled. At temperatures below 0 °C, caution is advised in the operation of the scraper. Attention must be paid to the fact that the bark can

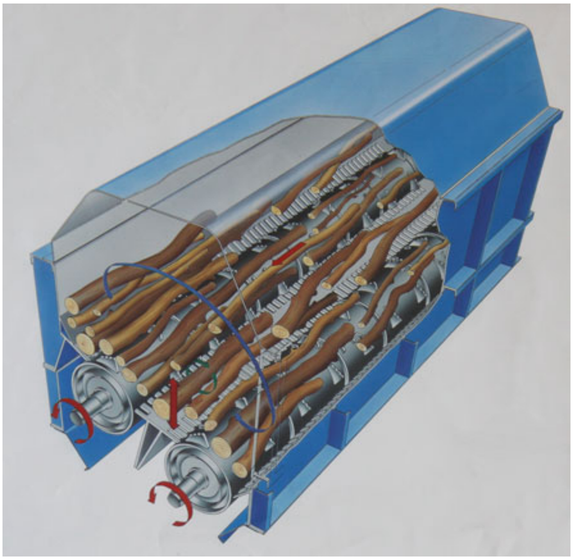


Fig. 6.6 Schematic drawing of a rotary debarker [1]

Fig. 6.7 Debarking using a rotary debarker in two lines [1]

freeze together in large volumes, or stick to the scraper conveyor, when water is used. The water is frequently added automatically in the debarker in order to optimize the degree of debarking. As a result, the bark can also freeze together in large volumes in the bark store (Figs. 6.6 and 6.7).

To avoid damage to the wood chipper due to relatively large steel parts, metal detector coils precede the chipper system. When metal is detected, the corresponding logs are sidetracked before they reach the chipper or must be removed by hand. Wood offcuts can be fed to the chipper conveyor belt inlet by vibratory conveyor.

The log wood is milled by using drum-type wood chippers, as a rule. Drum chippers have a good feed characteristic even with poor log wood qualities and produce relatively homogeneous source material for the wood pellets, in comparison with other variants. Depending on the type of chipper, the use of sieves or post-milling using, e.g., hammer mills, may be required.

Apart from the points listed above, the noise level in the timber yard plays an important role, particularly in an industrial area. In designing the timber yard, minimizing noise emission must be one of the aims and must be taken into consideration, as must be safety considerations.

As already mentioned, log wood is not the major material for pelletization. The production of wood pellets is mainly based on processing the byproducts from sawmills. Apart from wood shavings and sawdust, the byproducts also include wood chips and cut pieces. These must be similarly prepared for the pellet production by various different technical systems and method steps. The preparation has the aim of creating a wood chip which is geometrically as uniform as possible. The better the homogenization of the wet shavings, the simpler the tasks of the dryer and of the pelletization will be.

6.1.2 Trunk Wood Milling

In the sections to follow, the wood chipper and the hammer mill will be discussed in greater detail.

The chipping system forms the second step in the processing of the logwood. It has the task of milling debarked logwood and cut pieces into wood chips. The chipping system is the first milling stage in the pelletization process.and its core is the wood chipper. In the wood chipper, milling is done mainly by means of cutting tools. In the following chapters, three types of chipper will be explained in more detail. Depending on their function, these are disk-, drum- or screw-type chippers. As already mentioned, a metal detector should be installed upstream of the chipper. The housing of a chipper is of solid welded steel plate construction.

The drum chipper is used more frequently in the wood pellet production, the reason being that the quality of the wood chips is not subject to the same high demands as in the pulp industry. The drum chipper is also capable of chipping not only logwood but also long and short waste pieces and logwood endpieces. In addition, the drum chipper benefits from short knife changes, low space requirements and simple handling. Another advantage compared with the disk chipper is that it mills the logwood completely. Due to the way in which it works, the disk chipper will leave short remnants of logwood which, in turn, result in extra expenditure for equipment and conveyors. Moreover, there is no need to install any additional sieve before the drum hipper in order to remove slivers.

Fig. 6.8 Drum chipper with feed belt by Rudnick & Emmers [2]

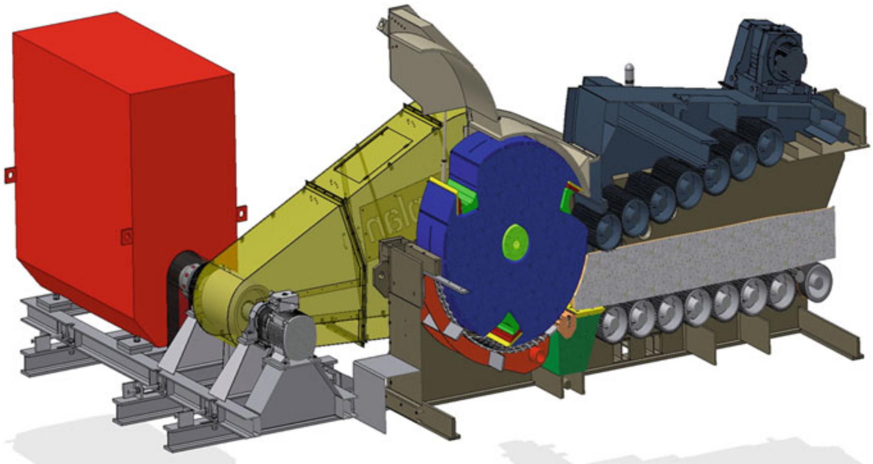


Fig. 6.9 Section through a drum chipper by Vecoplan, with motor, continuously arranged knives and feed rollers [3]

The drum chipper consists of a drum. A number of blades can be attached to the circumference of the drum. The cutting blades are arranged offset or continuous. The wood is supplied by surface-coated feed rollers at right angles to the drum axis the number of which varies in accordance with the chipper size. In addition, counter blades are also attached in order to simplify milling of short material (Figs. 6.8 and 6.9).

The size of the wood chips depends on the number of blades, the speed of rotation of the drum and on the feed rate. Good wood chips are only obtained with sharp blades. Blunt blades will break the fibres and increase the energy consumption. The service life of the blades should be at least 8 h (1 shift). It depends on the following parameters:

Fig. 6.10 Log wood and wood chips after use of a chipper

- Dampness of the wood
- Quality of the steel
- The angle at which the blade meets the wood
- Residual degree of soiling

The angle between the blade and the direction of the fibers varies in dependence on the required task since the height of the counterblade and the drum diameter are adapted to the respective task set. The decisive factor is that the chipping takes place across the direction of the fibers of the wood. This can not be guaranteed in the case of the end of a trunk or of short wood chips. The resultant excess lengths must be limited by the post-milling sieve. Large wood chippers have drum diameters of up to 2500 mm with drive powers of up to 800 kW (Fig. 6.10).

Disk chippers are not so frequent in the sawmill industry and are mainly used in the paper or pulp industry. In principle, they consist of a feeding device and a chipping element. The chipping element consists of a rotating cutter disk in which a number of blades are mounted. This number can vary depending on type and manufacturer. The angle between cutter disk and fiber direction is a constant -45^{o}. The material feed is arranged to be horizontal or at an incline of 45° depending on type and manufacturer. Large stationary installations in the US have a disk diameter of up to 3,000 mm with which a logwood diameter of up to 800 mm can be processed.

The logwood is fed to the cutter disk by one or more oppositely rotating profiled feed rollers. A counterblade ensures that a positive force is acting on the wood. The wood chips pass to the rear of the cutter disk through slots in the disk. At the rear there are casting shovels which cast the wood chip into the discharge chute. To ensure further milling of the wood chips, the entry to the discharge chute can be

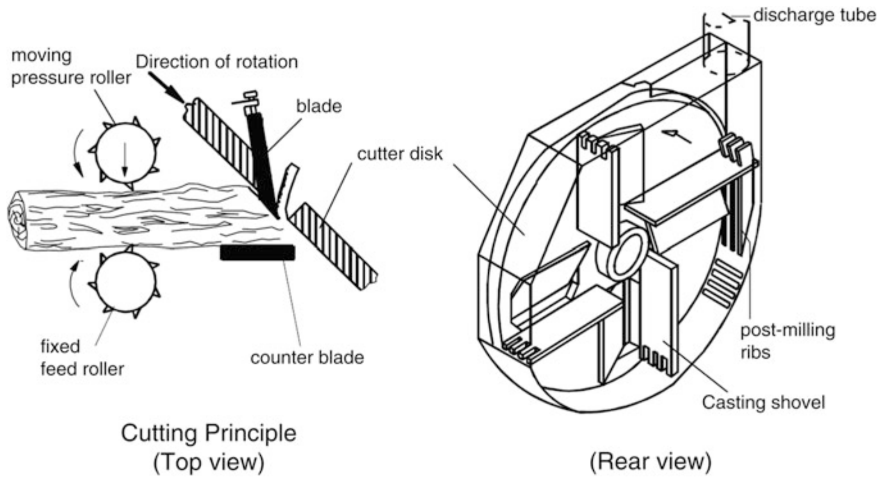


Fig. 6.11 Cutting principle and representation of the chipping element of a disk chipper with post-milling [11]

covered with impact ribs which additionally break up the wood chips with the aid of the casting shovels.

The length of the wood chips depends on the height by which the cutter blades protrude over the disk edge. The disk chipper must be preceded by a sifting unit since wood chips cannot be milled easily (Fig. 6.11).

The screw-type chipper is used for producing coarse wood chips of uniform size. The core of the screw chipper is a conically shaped screw with spiral turns. The chipping screw is in most cases installed horizontally in a tapered hopper. The outsides of the screw are sharpened to form a blade. There is no requirement for a feed system. The wood is fed axially to the screw shaft. The wood is gripped by the rotation of the screw, pulled in and cut. The wood chips are discharged by casting shovels which are mounted at the rear end of the screw. The size of the wood chips depends on the slope of the screw volutions (Fig. 6.12).

The debarking of the trunk wood and the chipper are followed by post-milling in a hammer mill, depending on the design of the chipper.

The hammer mill represents the third step in the processing of the logwoods. It is the task of the hammer mill to reduce the wood chips to wood shavings. The material is milled by striking tools. The wood chips should be free of impurities such as stones and metal. Impurities have a negative effect on the operation and increase the wear of the metal strikers. In addition, there may be sparks which must be avoided. The impurities can be separated out acceptably by appropriate heavy-material sluice gates at the mill inlet.

The hammer mill is of very rugged construction. Its core is a rotor at which a number of metal strikers are suspended pendulum-fashion. The metal strikers are hard-metal-coated and movable. Using replaceable sieve inserts ensures that the

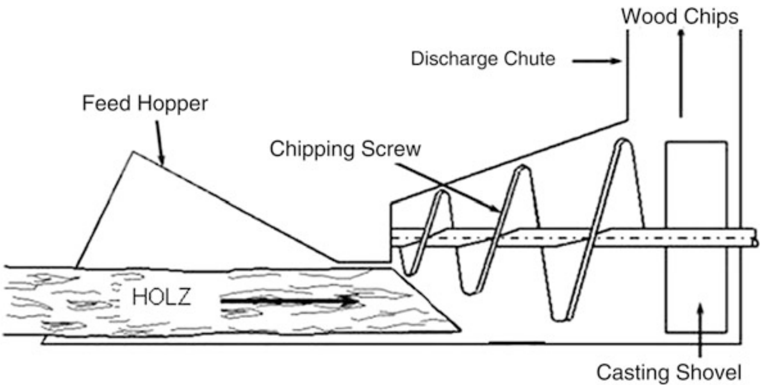


Fig. 6.12 Principle of construction of the screw chipper [11]

Fig. 6.13 Wet hammer mills by Rudnick & Enners [2]

desired particle size is not exceeded. The grain size of the raw material is determined by the diameters of the sieve holes. The drive motor is directly flange-mounted in most cases.

The movement of the rotor results in high peripheral speeds of the metal strikers. The wood chips bounce against the metal strikers and are broken up by the forces created by the large change in momentum. There is also a milling effect due to the friction and shearing work at the hole edges of the sieve inserts.

The width of the openings of the sieve holes determines the wood chip geometry, the throughput and the energy consumption. The capacity also decreases with increasing water content in the material to be ground. If the waater content rises in the material to be ground, the specific energy consumption also rises (Fig. 6.13).

6.2 Wet Shavings Store

The production of wood pellets at an industrial scale involves production methods which rely on a continuous supply of raw materials. To avoid bottlenecks in the supply, it is recommended to provide storage capacity for at least five working days.

In practice, however, much greater storage provision has been generally adopted. As a rule, raw materials are kept in reserve for several weeks, making it possible to overcome delivery shortfalls by suppliers. In this context, a plant shutdown because of a lack of raw materials can be considered to be the worst case scenario.

Greater storage capacity has further economic advantages. The extended planning periods allow the plant operator to respond appropriately to dynamic market situations. As a rule, these degrees of freedom provide for an improvement in the creation of value in continuous operation. A change of supplier during continuous operation without endangering the flow of production can be mentioned as an example. It is also possible to influence the qualities of the raw material. The increased investment costs are only slight in comparison with the potential savings.

Storage units have the task of supplying the production process continuously with raw materials or of temporarily storing the end products. For this purpose, roofed or non-roofed stockyards, storehouses, silos and similar storage facilities are used. Because of the necessity for "buffering" the mass and volume flows in continuous production, adequate dimensioning is of decisive importance for a smooth operation of the plant.

6.2.1 Outdoor Storage for Wet Wood Chips and Shavings

For cost reasons, storage of wet shavings on sealed surfaces without roofing has become accepted. When designing the outdoor storage facility, attention must be paid to the fact that the floor plate or floor covering is dimensioned such that the axle loads of commonly used trucks and wheel loader types can be accommodated. Depending on the design of the outdoor storage facility, storage heights of more than 6 m are normally available. For this reason, the boundary walls must be dimensioned accordingly if the area is to be used optimally. It must also be taken into consideration that during the transfer of the material pieces into and out of storage and their rearrangement, occasional collisions of the wheel loader shovel with the boundary walls are unavoidable. The lower region of the walls should, therefore, be made of corresponding reinforced concrete. The storage height has a corresponding influence on the foundations used for the boundary walls (Fig. 6.14).

Fig. 6.14 Open-air storage on sealed ground without boundary walls

The specifications regarding the drainage of the sealed surfaces and the treatment of the accruing water can vary depending on the relevant licensing authority. The detailed requirements must be settled individually by each plant operator.

These outdoor stores traditionally serve to keep wood chips for pellet production. However, current developments lead to the conclusion that in future wood-like substitute fuels such as, for example, remnants from the wheat production can be increasingly used.

The water content of the wood chips lies within a range of between 30 and 60 %. These values can vary upward or downward under extreme environmental conditions. Depending on the type of wood, water content and storage conditions, a temperature increase may occur in the interior of the pile when the storage times are relatively long. In particularly unfavorable circumstances, this heating effect can lead to spontaneous ignition. To reduce the potential hazard, wood chips, shavings and logwood should not be stored immediately adjacently to one another (Fig. 6.15).

As the length of storage time increases, so does the risk of the qualities of the raw materials deteriorating. Since the biomasses are a non-homogeneous natural raw material, different physical, chemical and biological processes will have a negative effect on the quality of the wood, the decomposition of the wood matrix due to bacteria and fungi being only one example of this. These processes are promoted by storage without weather protection. Storage in accordance with the "first-in-first-out" principle would, therefore, be the preferred method.

Fig. 6.15 Wet-chip store filled by scraper chain conveyor, weather protected [2]

Naturally, such an outdoor storage facility would be located in the immediate vicinity of the dryer. To guarantee undisturbed production, it is absolutely necessary that the individual process steps are located close together. An automatic conveyor with a corresponding storage unit are located upstream of the dryer.

6.2.2 Automated Indoor Storage

In order to charge the dryer continuously it is preceded by an indoor store, as a rule. The configuration of this plant component is governed by the given spatial situation. The floor space and the overall height of such storage units are limited depending on the design conception of the overall plant. Furthermore, the individual characteristics of the raw materials must be taken into consideration in the selection of the respective storage and transportation system. The following systems have been found to be successful in practical operation:

– Push-floor systems/pull-floor systems
– Stationary moving-floor system
– Loading/unloading conveyor or lifting/lowering conveyor
– Scraper floor systems
– Crane bunkers

Push-Floor/Pull-Floor (Walking-Floor) Systems

Push-floor systems are parallel rakes fitted with an hydraulic drive. Due to their gapless arrangement, this system is particularly suitable for bulk material and material pieces. Push-floor systems are relatively maintenance-free and save space. Special attention should be paid to the fact that the push-floor systems should be designed to be accessible to wheel loaders. Otherwise there may be problems in practical operation since inappropriate handling can lead to plant outages.

In general, there are two carrier systems:

– rake design
– ladder design

The guide rails on which the rakes or ladders move are cast into the floor plate as a result of which foundation-laying becomes correspondingly complex and costly. The guide rails act as guides for the rake-shaped carriers which are moved forward and back by two-way hydraulic cylinders.

The wedge-shaped geometry of the carriers ensures that the raw materials will be transported in the desired direction. The complete system consists of a number of rake-and-guide-rail combinations operating in parallel. Depending on the specific requirements and the design, the rakes can be moved up individually. To avoid arching, the store walls must be made correspondingly smooth and frictionless. Because of the complex foundations, the volume of concrete is included in the delivery schedule of the plant manufacturers, as a rule. Special concretes are used because of the abrasive wear. The design of the hydraulic system components depends directly on the weight and filling height of the raw materials. Apart of the possibility of valve control, each rake can also be driven by a separate hydraulic pump which has advantages especially from the point of view of energy consumption (Fig. 6.16).

Push/floor systems are suitable for transporting wet chips. However, using these systems with dry raw materials can be recommended only when they are closed and can not be traveled on, the reason being the extremely high dust loading with dry materials. Apart from the movement of the push-floor elements themselves, throwing the raw materials onto the push-floor and moving them to subsequent sections will promote the formation of dust. Although it is possible to counteract the dust formation by appropriate encapsulation of the installation, the expenditure is high. Moving in wheel loaders additionally represents a considerable explosion hazard. Critical dust particles can become ignited from hot engine components and exhaust sparks. For these reasons, alternative techniques are frequently used in the case of dry materials. The figure below diagrammatically shows a push-floor system (Fig. 6.17).

The stationary moving floor developed by Rudnick & Enners is related to the push-floor system. It provides a solution which is particularly interesting with respect to energy consumption, especially in the case of large capacity requirements (>150 Srm/h)

Fig. 6.16 Push-floor and hydraulic cylinders for chips, by Rudnick & Enners [2]

Loading and Unloading Conveyor/Lifting and Lowering Conveyor

Technically, loading and unloading conveyors are also called lifting and lowering conveyors. Using this conveyor system, storage boxes can be filled and unloaded automatically. In contrast to the push-floor system, no elaborate foundations are necessary. In the case of the loading and unloading conveyor, the floor of the store usually consists of a normal concrete surface since this area is not subjected to any special wear.

The loading and unloading conveyor is suspended under the roof. The walls and the roof must, therefore, be dimensioned in such a way that the static and dynamic loads can be absorbed. The system moves both vertically and horizontally in operation, a circumstance which must be taken into consideration in the dimensioning of the walls and of the connecting points.

The system consists of a conveyor unit which is moved by a hoisting device on steel cables via deflection rollers. Varying the speed enables the storage space to be filled or emptied uniformly. The figure below diagrammatically shows such a conveying system. The advantages of such a system are:

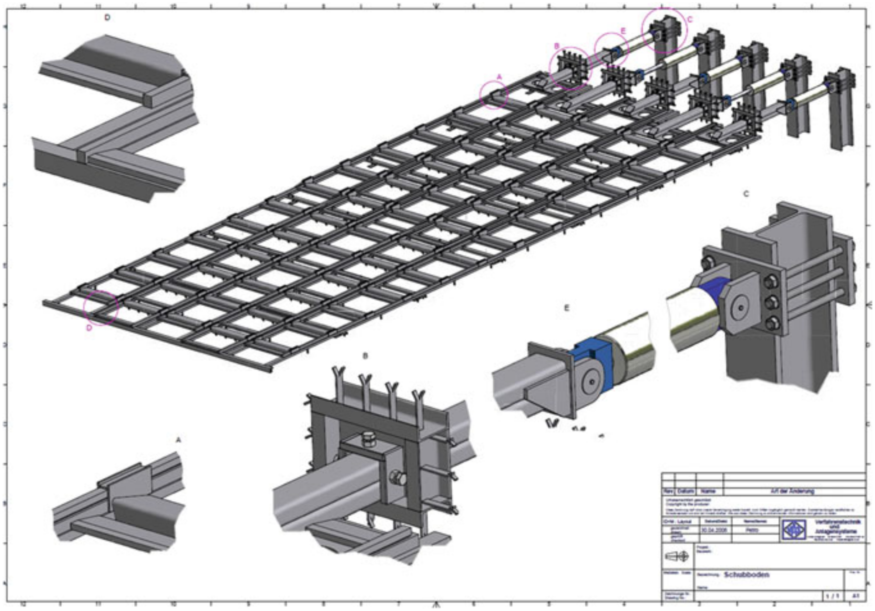


Fig. 6.17 Push-floor system by VAS [4]

– simple foundations
– fully automatic operation possible
– small numbers of staff required
– continuous mass and volume flow.

Because of the fully automatic system operation care must be taken to ensure that no persons can remain within the danger zone of the plant (Fig. 6.18).

The operation of the system can be described as follows:

1. The raw material is delivered by truck, wheel conveyor or scraper chain conveyor. The material can consist of various bulk materials such as, for example, sawdust, wood chips or agricultural materials.
2. The raw material is brought into the storage space by a wheel loader via a feed hopper. As an alternative, it can be fed in automatically by scrape chain conveyor or the like.
3. The material is transported by the horizontally and vertically movable loading and unloading conveyor either from one to another storage section, or discharged. The discharging is carried out by lowering the discharge unit, simultaneously operating the horizontal carriers. Special suspensions of the support cables provide for a vertical alignment of the conveyor system matching the filling level of the bunkers. Unequal removal from the bunkers enables the material to be mixed and thus to be homogenized. The control program is individually adapted to the respective raw material the discharge conveyor transferring the material to a scraper chain conveyor in this case

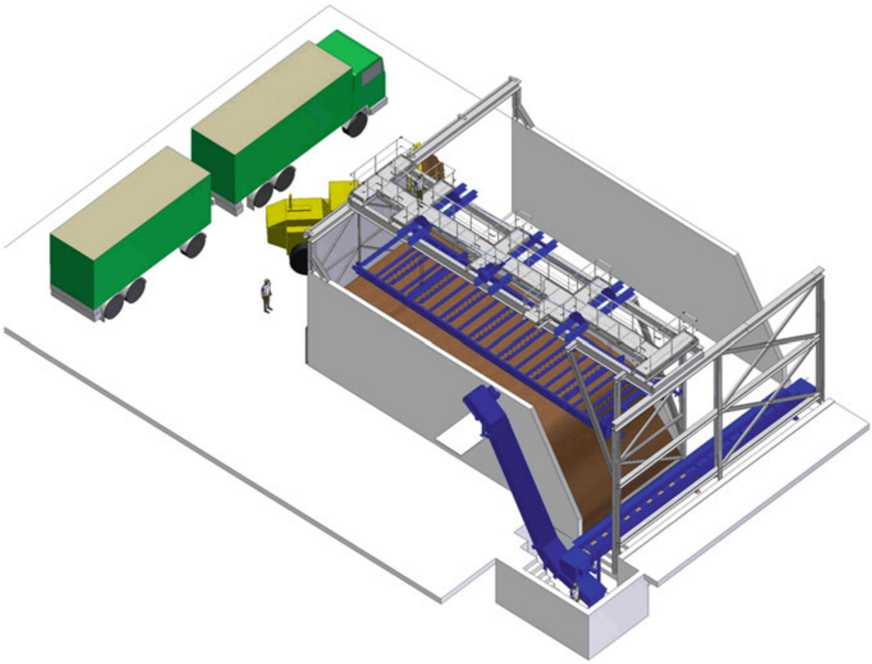


Fig. 6.18 Diagrammatic representation of a loading and unloading conveyor by Vecoplan [3]

Scraper Floor Systems and Scraper Chain Conveyors

Scraper floor systems consist of continuous chain lines driven by a pocket wheel on the load side. Between two uniformly driven chain lines, a carrier is located at regular intervals which transports the material to be conveyed in the discharge direction. Since these carriers "scrape" over the floor, the trivial name of scraper floor or scraper floor system has become established. The geometry of the carriers depends on the material to be conveyed and is appropriately adapted by the manufacturer. Scraper floor systems are driven by electric or hydraulic motors. In the past, mechanical ratchet systems were used in this application and are still being used in some cases. Because of the relatively complex foundations, the installation costs are relatively high, analogously to the push floor. Both these systems are used when crane installations and comparable conveyor systems cannot be applied because of a lack of headroom (Fig. 6.19).

Scraper chain conveyor s consist of a top run and a bottom run. As a rule, the raw material is carried along by the top run and cast off. The bottom run acts as empty belt and runs back. Scraper chain conveyors are not limited in their inclination. Inclinations of up to 90° can be implemented over short distances. Using this technology, overhead conveyors with inclinations of more than 90° are no rarity, either. These conveyor systems can be enclosed, as a result of which noise emissions are relatively low. Such installations are also almost dust-proof which is

Fig. 6.19 Scraper-floor construction by Holtec [1]

an advantage for work and explosion protection. The operating principle is analogous to that of the scraper-floor system.

Crane Installations

The crane installations are in most cases of the double-girder type with overhead trolley. The hoisting gear used is a rugged clutchless winch with, e.g., four single ropes. The cranes should have all the facilities necessary for smooth operation such as an automatic lowering mechanism and burying function. The gross load is detected by means of load-measuring bolts and weighing processor- All drives are controlled via frequency inverters, as a rule. The crane control used is an SPS, e.g. SIMATIC S7. Semi- and fully-automatic operation is optionally possible for loading, storing and mixing the material. Visual display by industrial PC using display software is fitted as standard as it is in all other systems.

Since this is a well-established technology, there is a large number of manufacturers on the market. This makes it possible to adapt this conveying system individually to the respective requirements. Critical raw materials can be lifted by high-grade clamshell cranes, the installation being protected against overloading by a sophisticated sensor technology. In modern crane installations, optimum filling of the clamshell buckets is ensured by an automatic lowering mechanism or "burying function". To be able to ensure a continuous mass and volume flow. The crane installation must be adequately dimensioned. The delivery rates must meet the requirements of the plant even with a relatively empty bunker and correspondingly long conveying distances.

Attention must be paid to the fact that crane installations are subject to an obligatory acceptance test in Germany. Before a crane (hoisting device) is taken into operation for the first time, an acceptance test according to BGG 905 (Berufsgenossenschaftliche Grundsätze—Principles of the Employer's Liability Insurance Association), is performed by an expert authorized by the Employer's Liability Insurance Association in Germany. This acceptance test extends from inspecting the documents available for a crane to checking all safety-related functions, safety margins and adjoining areas. A more detailed explanation in this context is available from BGV D 6 (Unfallverhütungsvorschrift Krane—Accident Prevention Regulations Cranes). The annual test should be carried out by a technically qualified person (BGV D 6 para.26). The operator of cranes is advised to train his crane drivers in accordance with the applicable principles of the Employer's Liability Insurance Associations (BGG 921).

6.3 Transport Systems for Wet Raw Material

The conveying equipment is responsible for the transportation of the mass flows and volume flows in the entire production sequence. It is thus an interface technology in which the operationally reliable presentation of the mass and volume flows between the plant components or appliances involved is of major importance.

As a sub-discipline of the power house, the conveying technology deals with the design of such systems. This is understood to include the design, dimensioning, project planning and implementation of such storage and transportation systems. In principle, conveying systems can be subdivided into:

- part-load conveyor (e.g., pallets)
- bulk-load conveyors (e.g., chips and pellets)
- dredgers
- hoisting gear

The complex applications have led to greatly differing approaches being taken. The consequential developments with respect to changed operating conditions have resulted in an abundance of different transport systems. For this reason, not all of the systems available in the market will be discussed in detail in the following sections. The systems presented serve as examples and are being used successfully in the wood pellet industry. Depending on application, systems not described here will also be used.

There will not be an overview of the conveyors of part-loads since these are only of a minor importance in the wood pellet production. They are only used in the packaging installations for the raw material. Here is a list of some systems, without any claim for completeness:

1. Belt conveyors (steel-belt conveyor, wire-mesh belt conveyor, cable-belt conveyor, tube-belt conveyor)
2. Bucket conveyors

3. Chain conveyors (scraper chain conveyor, drag chain conveyor, link conveyor, drag chain conveyors, carrying-……chain conveyor, swing tray conveyor, circular conveyors, pocket conveyor, loop conveyor, drag-loop conveyor)
4. Conveyors with screws (screw conveyor, screw-tube conveyor)
5. Vibrating conveyors (vibration conveyor, shaking chute, vibrating trough, vibrating tube)
6. Roller and ball conveyors (roller conveyor, wheel conveyor, screen roller conveyor, ball conveyor)
7. Accumulating conveyors
8. Gravity tubes and chutes
9. Conveyors with air/gas (pneumatic conveyor, pneumatic trough, air cushion conveyor, air table)
10. Hydraulic conveyors (hydraulic trough, hydraulic tube conveyor)

In the further subchapters, the most important conveying technologies will be presented.

6.3.1 Scraper and Drag Chain Conveyors

Scraper chain conveyors and drag chain conveyors are suitable for ascending and vertical transportation of sawdust and other types of bulk material. It is possible to overcome inclines of up to 90° over short distances. Inclines of more than 90° are also in use. (overhead conveyors). The scraper chain conveyor also produces relatively little noise and is almost dust-proof in its enclosed/encapsulated construction. Trough widths from 400 mm up to 2000 mm can be obtained as standard. Special designs such as, e.g., overhead conveyors (conveyors with over 90° ascent angle are not unusual can be technically achieved. The conveying systems can be manufactured both as open systems and as encapsulated, almost dust-proof systems.

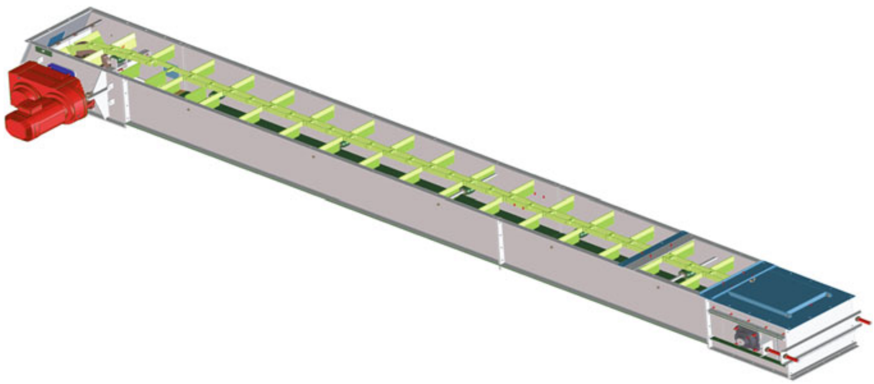


Fig. 6.20 Constructional drawing of a drag chain conveyor by Knoblinger [5]

Fig. 6.21 Scraper chain conveyor with chips, by Rudnick & Enners

The conveyor consists of a top run and a bottom run. In most cases, the material is discharged over the conveyor so that it is carried along by the top run. At the end of the conveyor it is transferred to the next unit. The bottom run returns empty (Figs. 6.20 and 6.21).

6.3.2 Conveyor Belt

Conveyor Belts belong to the group of ascending conveyors and are distinguished by high productivity coupled with a relatively low energy requirement. As a rule, conveyor belts are constructed to be stationary. However, more or less mobile systems are also being used in industry. These are special systems which had been designed for individual applications. Conveyor belt s have been used for decades in industry and mining because of their very high degree of operational reliability.

Conveyor belts cover great distances, especially in mining. At present, the longest conveyor belt in the world is being used in the West Sahara. From the mining town of Bou Craa, phosphate is being moved to the Atlantic coast over appr. 100km. Wood processing plants use mainly flat-belt, drag-chain or troughed conveyor belts for high infeed and delivery rates. Reinforced types are used as wood chipper feeding belts (Fig. 6.22).

Fig. 6.22 Conveyor belt for high chip capacities behind a push floor, by Rudnick & Enners

A pipe conveyor is a special form of the conveyor belt. This enclosed conveyor systems has individual advantages. Due to the enclosure, the raw material is transported in a dust- and emission-free way which considerably reduces the explosion hazard. Since the conveyor pipes are in most cases made of steel a high load capacity is achieved and, as a result, wide pylon spacing is possible. Since the routing can be optimally adapted to the spatial situation, many constructional options are available to the plant construction firm. The use of special belt coatings is a contributing factor in the cost-efficient transportation of bulk materials over relatively great distances, thus contributing to the increase in efficiency of this transport system. This system does not provide for steep ascending angles. The range extends from 0 to appr. 25°. This is sufficient in most cases, considering that a difference in height of more than 40 m can be overcome with a feed length of 100 m.

Since a pipe conveyor can be installed in existing plants without significantly affecting the production sequence. This alternative is increasingly being used. From the economic point of view, such a transport system might be worth-while.even from a feed length of 15 m onward. Widths of over 250 m are state of the art.

In the case of troughed and roller belts, the belt runs wholly or partially on rollers both traveling forward and on its return. The choice of transport belt profile depends on, among other things, the goods to be transported and any angle of inclination or gradient of the belt conveyor (Fig. 6.23).

Fig. 6.23 Pipe conveyor for bridging long distances, by Rudnick and Enners [2]

6.3.3 Screw Conveyor

Screw conveyors are excellently well suited for the dosage and uniform conveyance of bulk materials. In the wood industry, screw conveyors are primarily used for transporting sawdust and wood chips. Since screw conveyors are widely used in the industry, there are many different variants on the market. Special solutions such as explosion-protected versions are, therefore, state of the art and can be easily obtained. Delivery screws arranged directly underneath a product store have in some cases different gradients so that the screw conveyor is not overloaded.

In particular, screws are used for the dosed and uniform conveyance of chips, for example when chips having different degrees of moisture from two push floors are mixed. Screw conveyors are constructed as single- or two-shafted screw conveyors for horizontal and ascending conveyance. Multi-shafted screws are frequently used underneath chippers or under storage containers before pelleting machines (Fig. 6.24).

In the case of removal screws which are completely covered with material (e.g., removal from the maturation tank before pelleting), attention must be paid to the fact that the gradient of the screw is progressive in order to prevent overfilling.

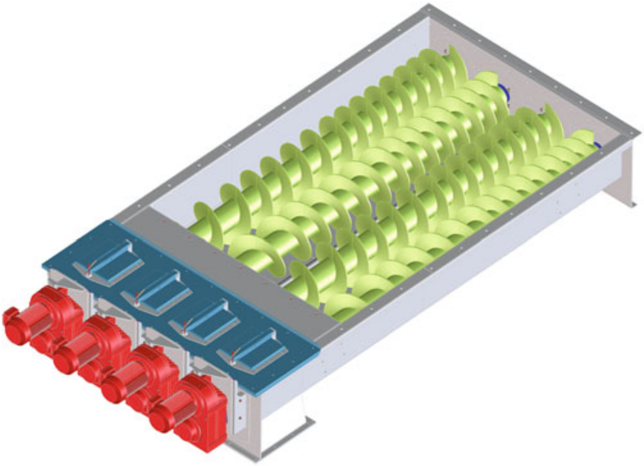


Fig. 6.24 Design of a screw floor under a small chip silo, by Knoblinger [5]

6.3.4 Vibratory Conveying Trough

Vibratory conveyors are used in the horizontal transportation of long and short pieces of waste timber, wood chips and sawdust. Because of the inherent natural frequency, combining it with the screening zone is an obvious choice. Drive is provided by unbalance motors or oscillating-armature drive.

In the case of a motor drive, two counter-rotating unbalance motors are used which generate the required linear vibration of the vibratory conveyor by superposition of the circular movement of the individual motors. The frequency is directly dependent on the speed of rotation, as a rule. This variant is very rugged and low in maintenance.

The oscillating armature (or magnetic piston) drive operates with a coil which causes an elastically mounted armature (piston) to oscillate due to alternating field strengths. The armature transfers its natural frequency to the material being transported. The advantage of this technology is that the conveying speed is continuously variable. The frequency can be influenced directly by adjusting the coil field. The higher system costs are a disadvantage.

Vibratory conveyors are well suited for use as a delivery device for push-floor systems. In this way, it is possible, for example, to ensure a uniform fuel supply in biomass power stations. Vibratory troughs "equalize" the product quantities, e.g., following a push floor, and have advantages compared with scraper chain conveyors, especially when they are arranged following a push floor (Fig. 6.25).

The Vibrotrough pictured above is provided with a crank drive. Due to its low frequency of <10 Hz and its high amplitude, this design is suitable for horizontal transportation at speeds of up to appr. 30 m/min with uniform distribution and dosing of the bulk material. Troughs using unbalance motors have a high

Fig. 6.25 Vibrotrough by Rudnick and Enners [2]

frequency of appr. 50–60 Hz and a low amplitude. In order to be able to achieve corresponding conveying capacities, these troughs are normally inclined in the direction of conveyance. Magnetic piston troughs are not used very much in biomass transportation.

Depending on their intended application, vibratory conveyors are also available, e.g., as heavy or extra-heavy models, models with amplified resonance, with inspection and maintenance flaps, spring mounted, blade guidance, reinforced rocker bars, reinforced vibrating elements, action monitoring, frequency inverter, emergency pull cord etc. Vibratory conveying troughs with sieving zones and sieving machines are also frequently used, as mentioned. An extra-heavy model with a wall thickness of at least 12 mm should be considered especially in the case of trunkwood being transported in front of chippers.

6.3.5 Bucket Conveyors

Bucket conveyors are amongst the oldest ascending conveyors for bulk material. The traditional bucket conveyor, also called elevator, is the preferred conveyor for use with steep inclinations or for vertical conveyance. This system, therefore, belongs to the family of ascending conveyors.

In a bucket conveyor, containers are attached at regular intervals to a duplicated or centrally located pulling mechanism. As a rule, the pulling mechanism is a sprocket chain or a belt and a distinction is, therefore, made between chain-type and belt-type bucket conveyors, depending on the pulling mechanism used. The containers are frequently designed to be V-shaped or U-shaped and can consist of steel or plastics. The respective material used depends directly on the material to be conveyed, plastics being the preferred material where there is an increased risk of explosions.

The bucket conveyor is filled from chutes. The material is conveyed upward by the rising strand. It is unloaded by being tipped off at the upper turning point and is transported further by a discharge chute. Bucket conveyors can be open or closed, the closed variants being almost dust-free. With respect to the dust loading, in particular, it is recommended to operate the bucket conveyor at a minimal negative pressure by connecting it to a suction system. Cycling is performed by two shafts, the drive being located on the upper shaft. The transport speed for pellets should not exceed 1 m/s to avoid the risk of the pellets being smashed when they are scooped out. Dry chips should also be transported maximally at this speed because of the explosion hazard.

The minimum bucket speed is determined by the material to be conveyed. The lighter this is, the slower the bucket speed can be. The centrifugal force must be sufficient to eject the material at the upper return roller. The lower the bucket speed, the lower the risk of damage to the material due to its transportation (friction and fractures at the return rollers) and the lower the conveying capacity in m^3/hr.

In agricultural engineering, delivery takes place in the downward shaft in most cases. If the material is delivered here, the following must be noted: the downward buckets produce suction. It is possible that more material will pass into the bucket elevator than it can accommodate. It is, therefore, necessary to ensure that the quantity continuously added is less than the maximum quantity to be transported. This can be accomplished by means of a slide or by feed proportioning using a conveyor. Delivered material in the downward shaft is channeled through the return roller where it is subjected to friction and wear, resulting in the material being ground down. If the material is delivered in the upward shaft, the following must be observed: The upward bucket produces a counterpressure which throws the material back again, particularly if it is very light in weight. This can greatly reduce the capacity of material conveyed. If lightweight material has to be delivered in the upward shaft, a stuffing screw is recommended. Any material introduced in the upward shaft is transported protectively which is mandatory for wood pellets. The belt of the bucket conveyor can move in only one direction as a

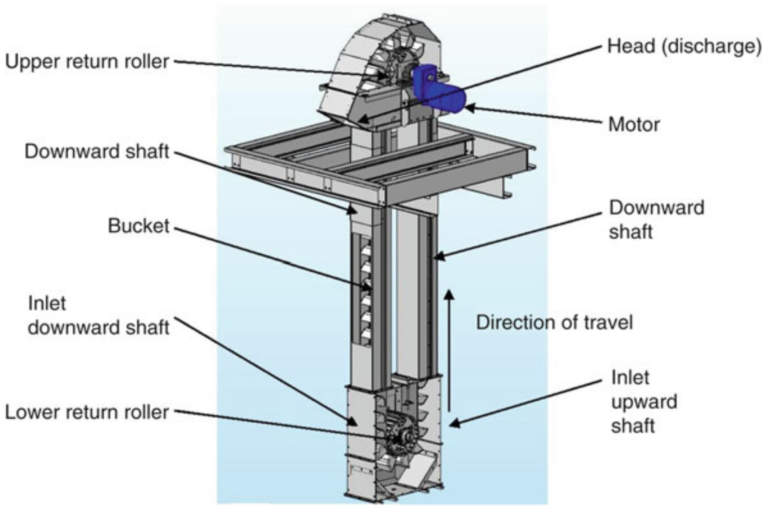


Fig. 6.26 3D view of a bucket elevator by Salamatec [6]

non-return lock is used. The bucket elevator should also be equipped with off-track monitors and speed monitors (Fig. 6.26).

Because of the high intrinsic weight of the individual components such as buckets and traction mechanisms, the drive powers required are correspondingly high. The conveyor height is thus limited for technical and economical reasons. However, this limited height is never attained for pellet installations. In practical operation, Bucket conveyors having a maximum conveyor height of 120 m are in use. As a rule, conveyor heights of 40 m are not exceeded in the pellet industry. The highest bucket conveyors are installed in front of pellet or dry-chip silos. A further disadvantage of bucket conveyors is the pit required in many cases. This must be protected expensively against water penetration.

6.4 Dryers

Considered technically, the dryer has a special task in the production of wood pellets. Financially, it represents one of the costliest plant components. From a technical point of view, intensive engineering is required here since type and design depend very greatly on the heat source. If the optimum variant in design and construction is not selected, this will have a lasting negative effect on the economic and technical situation of the pellet factory.

To ensure sustained good quality during pelletization and trouble-free operation, the existing raw material must be processed by means of drying systems. There are various technologies available in order to achieve the desired degree of dryness of the chips. In the following sections, two widely used systems, the belt dryer and the drum dryer, will be discussed in detail. Other options will then be mentioned briefly.

Firstly, two different terms must be explained which frequently lead to communication problems: There is wood moisture and the water content of the chip. 10 % water content does not mean 10 % moisture but 11.1 % moisture.

The wood moisture is specified with reference to the absolute dry weight. It is defined as the ratio of the mass of water in a given piece of wood (moist weight) to the mass of the completely dried wood (totally dry weight), see. (Eq. 6.1). The waterless mass of the wood is usually called the oven-dry mass since drying in a drying oven is the usual method for determining this.

$$u = \frac{m_F - m_T}{m_T} \times 100\,\% \tag{6.1}$$

u wood moisture
x water content
m_F moist weight
m_T totally dry weight

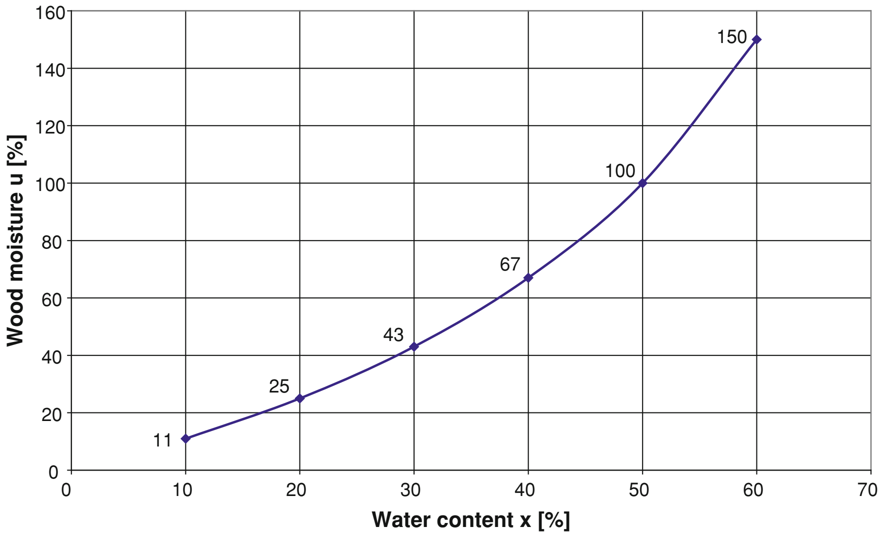


Fig. 6.27 Relationship between moisture and water content

The water content is referred to the wet weight. It is obtained from the difference between the real weight (moist weight) and the weight in the totally dry state divided by the moist weight (Eq. 6.2).

$$x = \frac{m_F - m_T}{m_F} \times 100\ \% \tag{6.2}$$

The relationship between moisture and water content is shown in the figure below (Fig. 6.27).

The water content affects the net calorific value (or heating value) of the wood chips and thus that of the pellets. Figure 6.28 illustrates the dependence of the heating value on moisture.

The moisture can be determined in different ways. The various options are shown in Fig. 6.29. Sawmills frequently use the method of electrical conductivity for which a large number of devices are available in the trade. In this method, two electrodes which measure the conductivity are hammered into the wood. The result of the measurement indicates the moisture. This method is quite inaccurate. A more accurate method is, in contrast, gravimetric determination where the wood is weighed in it present state (moist). It is then transferred into a drying chamber where it is dried for several hours at temperatures of between 100 and 120 °C until no further decrease in weight can be found. The weight is then measured again. Using the above formulae, the moisture or the water content can then be determined.

As an alternative to the drying oven operated at 100 and 120 °C, halogen hygrometers can be used. This method has evolved from infrared drying. The radiator technology is based on the halogen spotlight principle. Due to the compact type of construction of the spotlights, they attain their required operating

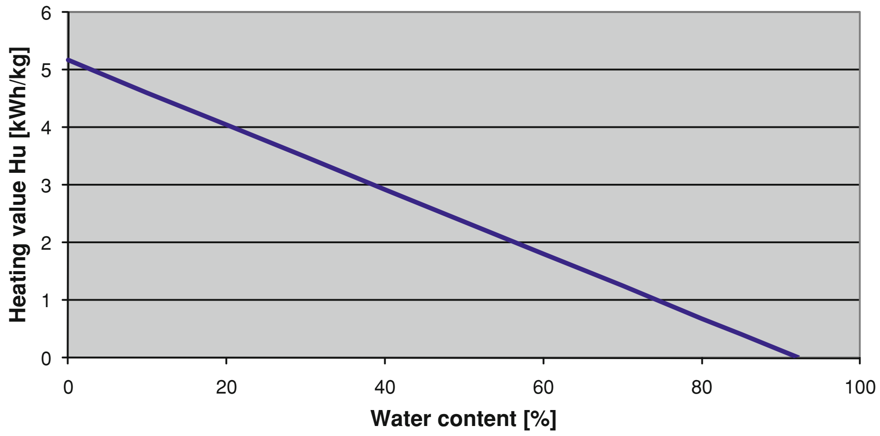


Fig. 6.28 Dependence of the heating value on water content (own measurements)

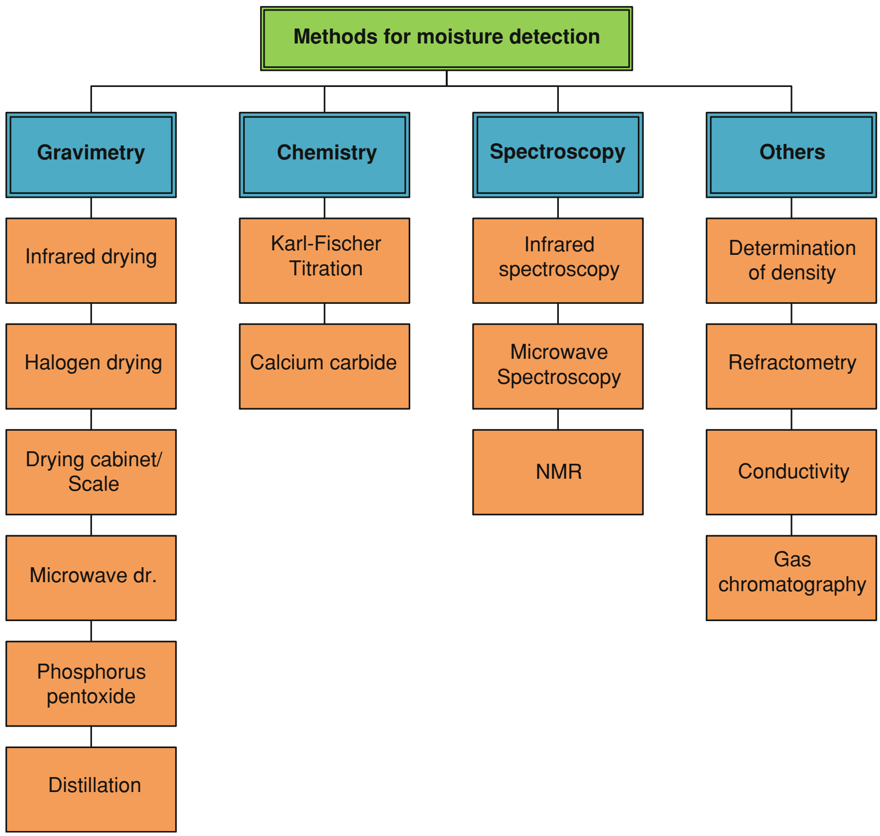


Fig. 6.29 Methods of measuring moisture

temperature very rapidly and can be regulated precisely. The result is normally a shorter measuring period compared with the conventional methods, and a better heat distribution over the sample. The uniform irradiation of heat on the sample, combined with the fine temperature control, leads to test results which can be repeated extremely well. Depending on the sample and the moisture content, accurate test results are available within 3–10 min. The disadvantage of the method is that, apart from water, other substances which are not distinguished from water in the result can also evaporate. Only a few ounces of sample material are needed. The method guarantees a reliable determination of moisture within a few minutes. In addition, the test results can be transmitted directly to a PC. This measuring technique is excellently well suited for checking the water content and for quality control in chips and the finished wood pellets. It is a combination of weighing technology and ultrafast halogen heating.

The water content influences the quality of the wood pellets to a high degree. The dryer must, therefore, be accorded great importance in the pelletization process. The required water content before pressing varies with the type of wood. In general, the optimum water content is about 10 %. It must be noted, however, that the chips lose water in the production process between dryer and pellet press. \this will be discussed in the sections following.

6.4.1 Belt Dryers

The belt dryer has its origin in the drying of grass in agriculture. It is preferably used when the heat is provided at a low energy level. A ratio of 90/70 °C or similar is a good ratio for the supply/return temperature at the heat exchangers of the dryer. Apart from warm and hot water, however, it is also possible to use steam or thermo-oil as the energy source. The sir temperature is limited to 120 °C in most cases. This has a corresponding effect on the maximum supply temperature of the heat exchangers for heating the air.

The operation of the dryer does not significantly differ from that of other drying systems. In principle, ambient air is sucked in and conducted through hat exchangers. A heating medium flows through the heat exchangers. The air is heated in the heat exchanger. Air temperatures of 90–110 °C after the heat exchangers are typical values for belt dryers. This heated air is very unsaturated and can thus absorb a great amount of moisture. The unsaturated air is sucked through the chips and the dryer belt. On its way through the chips, these release their moisture to the air. Below the belt, the air is cooled and almost saturated with moisture. It flows out into the open through the induced draft fan and the chimney stack.

The material is delivered through a small intermediate buffer to ensure that the spreading screws which have to distribute the chips on the belt can be reliably supplied with chips. The container does not need to be larger than 1 m^3 but this depends on the dryer's capacity. The chips are conveyed from the wet push floor into the intermediate buffer where the height of material is measured. The measurement values provide the control values for the upstream conveying equipment. At the outlet of the buffer, small discharge screws are arranged which transfer the wet chips to the spreading screws. Since the buffer must be suitable for wet chips having poor flow characteristics, attention should be paid to some constructional features. The buffer must not taper conically from top to bottom since this supports arching and can lead to no further material being discharged (interruption of the operation). To avoid further arching, a reel can be integrated in the container, As well, the buffer store should be heated in winter since wet chips can freeze which can also lead to interruptions.

N the belt dryer, the chips to be dried are uniformly distributed on a plastic or steel belt permeable to air. The material is uniformly distributed by means of a simple screw which is run filled to excess. The mass flows to be transferred to the screw are controlled by a level sensor. An alternative and more reliable way is using a recirculating screw. In this method, too much material is delivered to the first screw. The excess chips are transported back, and thus in a circle. The important factor is the uniform coverage of the belt, giving rise to a complete "carpet of chips". As soon as this carpet has a hole, i.e., places without chips, e.g., due to faulty product delivery, the heated air will attempt to follow the path of least resistance. Accordingly, less air will flow through the chips and, as a result, the efficiency of the drying will decrease. Apart from being an air-permeable conveying instrument, the belt with its covering layer of products is handling the task of a filter. The belt with its product layer must not deliver more dust into the stack, and thus into the environment, than is permissible under the licensing regulations. The belt is driven by smooth or ribbed drive rollers. The belt is diverted by guide rollers in accordance with the dryer design. The belt must be equipped with flexible sealing lips on its sides since otherwise false air and chips will bypass the belt into the stack on the sides of the belt. This would reduce the efficiency and would also lead to higher dust emissions.

At the end of the drying belt, the chips are collected in a screw feeder where the screw transfers the chips to the downstream conveying equipment. To obtain a chip which is as uniformly dry as possible, the chips have to hange their position since otherwise the top chips will always be dryer than the bottom ones because of the unsaturated air flowing through these, causing them to give off more moisture. There are various solutions for obtaining this homogenization. One variant is to arrange a spool in the approximate center of the dryer which turns the "chip carpet" over. A second variant is that the top chips are "milled off" by a screw conveyor at the end of the dryer and are transferred to the downstream conveying equipment. The bottom chips fall into a screw feeder and are distributed again on the "chip carpet" in about the center of the dryer uniformly by means of the spreading screw and pass as top layer through the further process. The height of both the spool in variation 1 and the screws in variation 2 can be adapted appropriately in accordance with the experience of the operating personnel. The thickness of the layer of chips is thus adjusted manually.

At the end of the belt there is also a cleaning brush which removes any adhering chips from the belt. The belt is also cleaned regularly with water jets under high

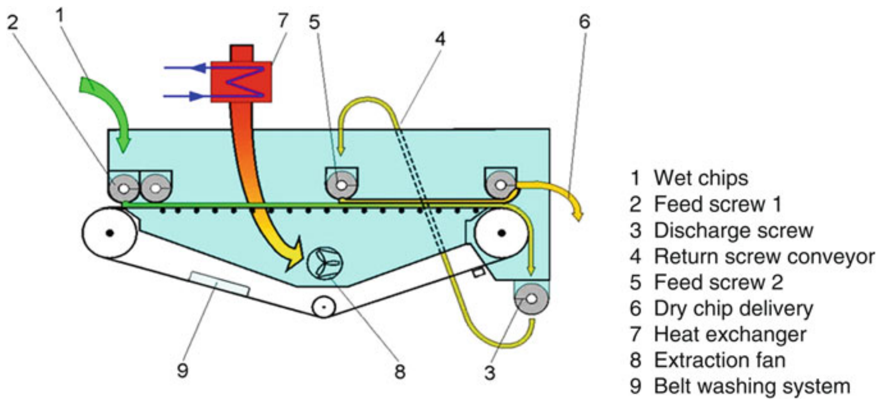


Fig. 6.30 Basic diagram of a belt dryer with return screw conveyor by SwissCombi [9]

pressure (up to 150 bar) from high-pressure nozzles mounted on the underside of the dryer. If the cleaning process by this belt washing system is not carried out, the belt will gradually become clogged with dirt, become more impermeable to air and thus increase the flow resistance for the latter. On the one hand, this will mean higher power consumption since the fan will have to work harder and, on the other hand, lower efficiency since less air will flow through the chips. If the belt is badly soiled, a solvent can be added to the water. The dirty water should be collected and disposed of in an environmentally compatible manner.

Figure 6.30 shows the basic diagram of a belt dryer with return screw conveyor.

As a rule, the radiator in which the ambient air is heated is arranged distributed over the length of the dryer above the dryer belt. If a low-temperature circuit and a high-temperature circuit are used, the low-temperature circuit is arranged before the high-temperature circuit in the direction of air flow.

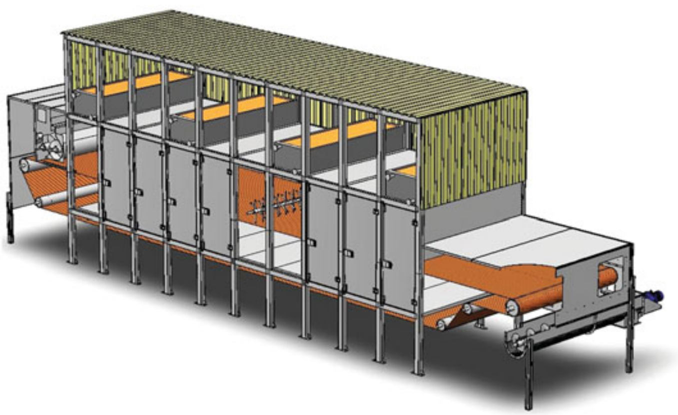


Fig. 6.31 3-D model of a belt dryer by Plant Engineering

The housing of belt dryers consists of a steel structure which is insulated in the temperature-stabilized areas. The steel structure is arranged into feed station, delivery station and preferably identical center sections (modular construction). The space underneath the dryer should be designed to be as accessible as possible since chips must be removed from there quite frequently. It is not necessary to provide the entire dryer with weather protection but this is recommended so that maintenance work can also be carried out under weather protection and the material is protected. The stack or stacks or waste air ducts are mounted on the steel structure.

Figure 6.31 shows an example of a belt dryer.

6.4.2 Drum Dryers

The first applications of drum dryers go back to the years around 1906. Similar to the belt dryer, the uniform distribution of the material during the entire drying process is also of greatest importance in the drum dryer. The manufacturers differ here in the type of installations by means of which the material is distributed as uniformly as possible. It is also of importance that the material is turned over with corresponding frequency and the drying air thus effectively reaches the surfaces of the material to be dried. These factors determine the efficiency of the dryer, among other things. To assess the thermal efficiency, it is possible to use the amount of energy needed per ton of water evaporation in MWh/t H_2O.

In contrast to the belt dryer, the drum dryer is used when higher throughputs are required and the heat energy is available in the form of flue gases or waste gases having higher temperatures.

Drum dryer s are divided into single-way drums and multi-way drums. In the single-way drum, the material and the flue gases pass through the dryer without being diverted. In multi-way dryers, the material and the drying gases are diverted at the end of the drum and pass into the second way after the turning chamber, where the mixture flows in the direction of the dryer entry again. Up to three channels are installed. In the pellet industry, single-way dryers are mostly used, offering advantages with respect to electrical energy consumption and uniform wood moisture at the dryer exit. Any fire fighting which may be required can be carried out more effectively in single-way dryers than in multi-way dryers.

An upstream power generating system or combustion chamber generates hot flue gas. This can be done by burning fossil or regenerative energy sources. The dryer for a pellet plant is heated in most cases by means of the flue gas from a fully automatic grate-fired furnace. The fuels used are, among others, ysrd bark produced in sawmills, and other timber byproducts. As an alternative to grate-fired furnaces, fully automatic burners for gas, oil or, more rarely, dust can be used. Depending on the fuels selected, different combustion chambers are used. The flue gases produced on the grate pass into the mixing chamber in front of the dryer.

To increase the efficiency of a drum dryer and to minimize the expenditure for cleaning the waste air, some of the waste air from the dryer is frequently conducted back into the dryer.(recirculating air). This occurs by the flue gas from the power generating system becoming mixed with the returning vapors in the mixing chamber to attain the air inlet temperature required for the drying process and then being sucked into the dryer. As an alternative to the recirculating air, fresh air can be added in the mixing chamber. The flue gases from the power generating system have a temperature of about 800–950 °C. It is cooled to a dryer inlet temperature of, for example, 400–450 °C by the return air which has a temperature of about 100–130 °C.

The mixing chamber is made of steel plate and is lined with brickwork or consists of heat-resistant material. In most cases, the chamber contains a closing cone which separates the power system from the dryer system with the aid of an hydraulic or pneumatic cylinder in the case of a shutdown of the plant or of an emergency.

Should a bark-fired furnace be used, an expensive hot-gas cylinder has to be installed for producing pellets having a low ash content (e.g. DIN pellets) in order to reduce the high amount of ashes produced in the furnace.

The flue gas mixture is sucked into the drying drum by means of a suction fan or induced-draft fan, using mainly high-power radial fans. The design takes into consideration the pneumatic system resistance of the dryer and of the waste air cleaning system which may be required.

The material to be dried is mostly introduced into the dryer through the gate for wet material above the flue gas duct. In most cases, the material to be dried is transported from storage silos or push floors into a bucket wheel gate by means of screws or scraper chain conveyors. The bucket wheel gate seals the atmosphere of the dryer against the environment so that no wrong, cold air passes into the dryer which would reduce its efficiency.

The drum consists essentially of a welded steel plate jacket. It is supported horizontally by ball races in roller stations. The thrust is absorbed by counter-rollers. The drum is driven, for example, via a large chain, a gear transmission unit and the drive motor. The material to be dried is repeatedly lifted up, intermixed and distributed over the entire drum or drying cross-section by the assemblies arranged in the dryer (lifting blades, cascades, star-shaped sprinkling assemblies, turning bars etc.). At the same time it is transported through the drum by the stream of hot gas/air. The material to be dried is dried uniformly in the dryer, independently of its grain size. The water contained in the chips is absorbed by the unsaturated flue gases by direct contact with these. The absorption of the water cools the flue gases and continues to saturate them with water. The water in the small chips evaporates more quickly than that in the larger chips. The light-weight, smaller chips are correspondingly transported more quickly through the dryer than the more inert larger chips. At the end of the drum where the chips have the desired water content the flue gases are correspondingly cooled down due to the water absorption.

After the chips have passed though the dryer with the flue gases, the mixture of flue gases and chips is separated in the downstream multicyclones. The chips leave the dryer through a bucket wheel gate and are fed into the main stream of material.

Fig. 6.32 Drum dryer for drying wood chips

After the cyclone, the flue gas is still slightly burdened with dust. Depending on the boundary conditions of the license at the respective site, further measures for dust removal may be needed. These can be, for example, textile or electrostatic filters.

The dried material is supplied to the further production processes or storage facilities by appropriate conveying systems such as drag chain conveyors.

As already mentioned, the process air stream and the material to be dried are conveyed through the entire drying process by means of a hot-gas fan. This is the greatest energy user in the plant. Some of the cold waste gas is fed to the mixing chamber at the dryer inlet via pipelines with return-air control valves in order to be mixed with the fresh hot gases to provide the required dryer inlet temperature. The remaining waste ga leaves the dryer through the subsequent stack.

The picture below shows a drum dryer for drying wood chips. The capacity of such a dryer extends from 10 up to more than 100 t/h of moist material in the product feeder. The basic circuit diagram of such a plant is shown in the next figure by way of an example (Fig. 6.32).

The wet chips are fed to the bucket wheel gate at the inlet to the dryer via a drag chain conveyor or a screw. The dryer is fed with the wet chips through the bucket wheel gate which separates the drying process from the ambient atmosphere. The chips are carried along by the flue gases. Light-weight chips are transported more quickly than the more inert, heavy chips. In the drum, the wood chips are distributed as uniformly as possible by the appropriate installed assemblies and turned regularly in order to achieve the highest efficiency possible. Following the dryer, the flue gas/chips mixture is conducted into a cyclone in which the dry chips are separated from the flue gas. The chips leave the cyclone on the floor through a bucket wheel gate which again seals the cyclone against the ambient conditions. The chips are supplied to the further production process or to the dry chips store by means of the appropriate conveying technology. The flue gases are transported further by the flue gas blower in accordance with the above description (Fig. 6.33).

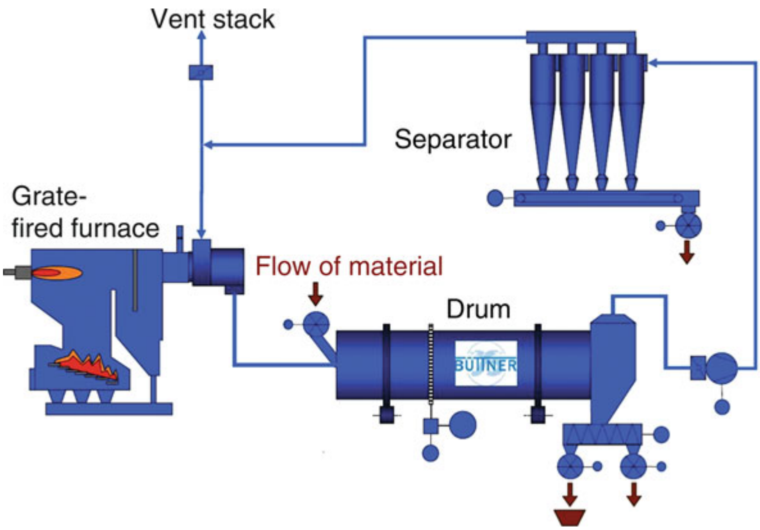


Fig. 6.33 PID for the drum dryer by Büttner [8]

Like the belt dryer, the efficiency of the drum dryer also depends on the amount of soiling of the components, among other things. This, in turn, depends significantly on the fuels used and on the prevailing operating temperatures. As soon as significant deposits can be seen, the dryer should be cleaned immediately. The cleaning interval for the drum dryer should be specified individually by the operator according to their operating experience and in dependence on various parameters such as, e.g., type of wood, heating, operating mode etc.

Apart from the drum dryers described here, indirectly heated drum dryers can be used. For the sake of completeness, the tubular dryer and the tubular drum dryer shall be mentioned here. These dryers are heated indirectly by means of steam, hot water or thermal oil and are predominantly used in connection with combined heat and power generation. In this application they are in direct competition with the belt dryer and may be more advantageous, depending on the application. According to present-day information, there is no known case of an application associated with a wood pellet production plant.

6.4.3 Control and Regulation

For monitoring and controlling the dryers, sensors and measuring instruments are installed at the appropriate locations. Examples are the measurement of moisture at the dryer exit, the waste air temperature and, in the case of the belt dryer, the differential pressure across the belt. The signals are processed in an SPS (stored program system) which is supplemented by a display on which the necessary data for operating and optimizing the plant can be clearly seen. It is worthwhile to display the trend lines of some values, especially for the later optimization of the dryer.

The SPS starts and stops the system automatically and responds appropriately to alarm messages. To provide for the safety of the personnel, it is recommended to arrange flashing light signals at a clearly visible place, in addition to installing a warning horn. These are used for signaling warning messages. The SPS also controls the heat supply for the dryer.

Since the dryer represents only one production unit in the entire pellet production process, the SPS of the dryer is in most cases connected to the control room of the entire plant by means of a data bus cable.

6.4.4 Parameters for Dryers

For the inquiry for and the comparison and later assessment of dryers, the corresponding parameters listed below should be queried or specified:

Chip intake flow	[kg/h]
Chip discharge flow	[kg/h]
Max. mechanical conveying capacity	[kg/h]
Input moisture	[%]
Output moisture	[%]
Evaporative capacity	[kg/h]
Type of wood	[% softwood, hardwood
Chip geometry	[mm]
Bulk weight	[kg/m^{3}tr.]
Type of heat source	
Capacity of the heat source	[kW]
Temperature level of the heat source	[^{0}C]
Dust emissions	[mg/Nm^3 $_{moist}$]
Plant altitude	[m above MSL]
Ambient air temperature profile	[°C]

The directly heated drum dryer requires data for the direct moisturization.

Waste timber, natural gas, heating oil

– Fuel	
– Fuel rate	[kg/h]
– Fuel geometry	[mm]
– Fine fraction	[%]
– Water content min./max	[%]
– Ash content	[%]
– Lower calorific value	[MJ/kg]

Using this information, specific parameters should be determined for a direct comparison of providers, including, among others:

– Thermal energy consumption	[MW/t water evaporation]
– Electrical energy consumption	[kW/t water evaporation]
– Specific effective dryer surface	[m^2/t water evaporation]
– Specific price	[€/t water evaporation]
– Specific price	[€/t steel]
– Specific price	[€/m^2 dryer surface]

Furthermore, an annual requirements curve should be determined for the thermal energy consumption. For this purpose, the mean diurnal temperatures for the last few years are obtained from the meteorological station nearest to the site. Availability of the humidities would also be very useful- The following criteria apply especially to low-temperature belt dryers. A reference year is selected or the mean value is formed from a number of years. The curve of the mean annual temperatures can look like that shown in Fig. 6.34. The temperature variation has a direct influence on the heat requirement of the dryer during the production of a constant amount of dry chips. This variation, which is opposite to that of the mean diurnal temperature, is shown together with the mean diurnal temperature in Fig. 6.35. The heat requirement is additionally increased in winter due to snow and ice formation in the chips. The diagrams are intended to illustrate that a dryer should not be designed for a mean annual temperature since reduced quantities of production in winter can not be compensated for by increased quantities of production in summer. If sufficient heat is available, the next point to be observed is the carrying capacity of the dryer. In the case of warm environmental conditions and relatively dry chips, this parameter will represent the next bottleneck.

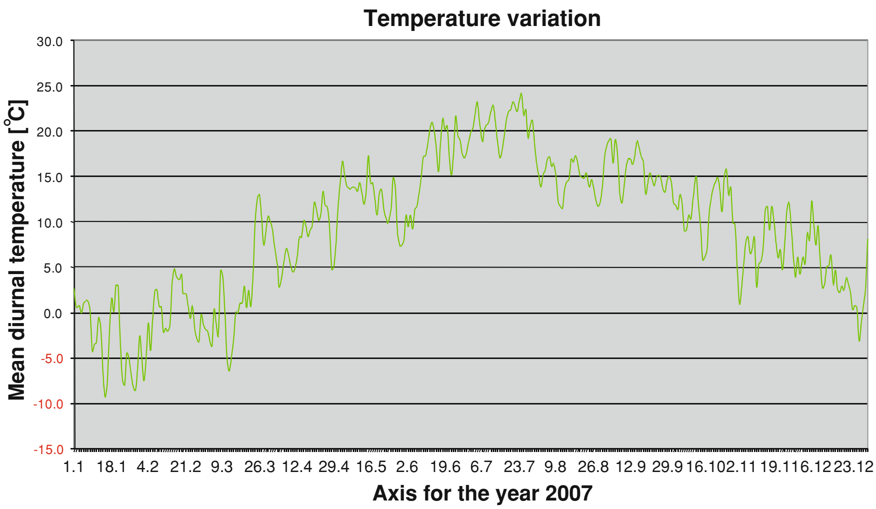


Fig. 6.34 Example of the variation of a mean annual temperature

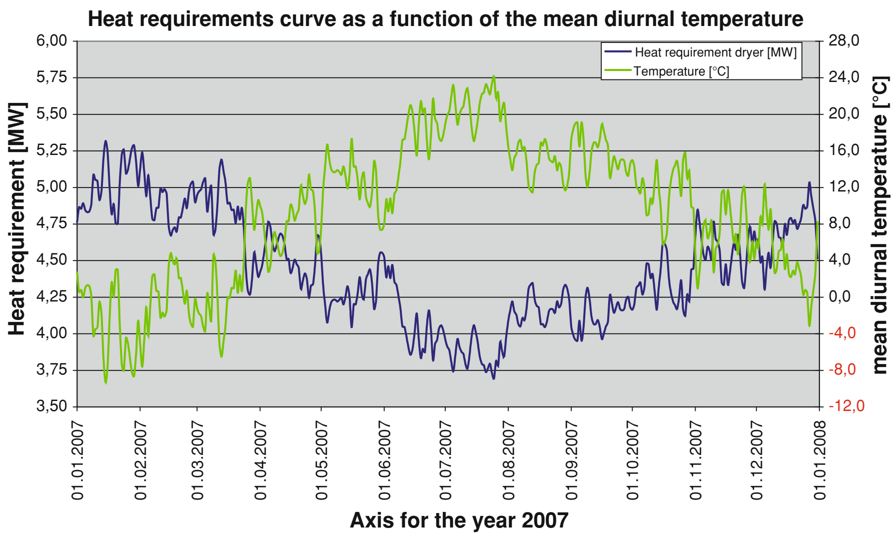


Fig. 6.35 Belt dryer for drying chips

6.5 Storage for Dry Shavings

6.5.1 Push Floor

The push floor has already been described in detail in previous chapters. This storage technology is suitable for wet shavings but only partially so for dry chips since the dust burden imposed on the environment is extremely high. Every movement of the push floor itself but especially the throwing onto the push floor and from the push floor onto following sections brings with it a high amount of dust loading.

The hall above the push floor must be constructed in such a way that no dry chips can become deposited. This applies to walls, ceiling, bearers and technical building equipment. Nevertheless, the risk of a dust explosion is extremely high compared with alternative storage structures. A further risk is presented by moving in with wheel loaders due to their exhausts which represent a further source of ignition. According to the current state of the art, storing dry shavings on push floors can only be recommended if this is a closed system which is not accessible by vehicle.

6.5.2 Silo

Dry-chip silo s are mainly constructed of monolithic reinforced concrete with integrated explosion holes, doors, hatches, viewing windows and recesses for technical equipment. The shavings silos must always meet the requirements of the latest legal regulations (Fire protection (Brandschutz) F90, Explosion protection (Explosionsschutz) VDI 3673). The shipment is completed by safety cage ladders, podiums, railings and extinguishing facilities (Fig. 6.36).

Dry chip silos should be equipped with the following accessories:

1. Railing of galvanized steel with handrail, kneerail and baseboard (screwed if possible),
2. Roof cover explosion flaps of galvanized steel plate, can be opened for inspection. with safety grating.
3. Wall explosion flaps of one frame of galvanized steel plate, cover plate of stainless steel with insulation,tested by the DMT Institute for Fire and Explosion Protection (DMT Institut für Brand- und Explosionsschutz,
4. Hatches and doors of galvanized steel plate, with double-walled insulation, in various sizes for inspection and maintenance, solid lever locks
5. Safety cage ladder of galvanized steel, with back protection, aecure crossovers to podiums and standing areas with safety device or as change-over ladder
6. Podiums of galvanized steel with non-slip flooring, with handrail, kneerail and baseboard
7. Extinguishing facility as dry line for water for non-hazardous, fast and safe fire fighting,
8. Staircases of galvanized steel,
9. Large-capacity motors for emergency space evacuation,
10. Level sensors
11. Possibly temperature sensors at various levels
12. Access doors for basement, sufficiently large

In the construction of round containers, metal casing is frequently used. A coordinated bracing system of the inner casing provides for precise circular

Fig. 6.36 Delivery screw, dry-chip silo

shapes. The casing is constructed with such stability that the inner and outer casing can be assembled in most cases without wall ties and spacer tubes which ensures the greatest possible degree of tightness from the start. In the case of special surface requirements, the inner casing is covered with non-woven fabric or plastic foil (Figs. 6.37 and 6.38).

The silos are in most cases assembled in the following stages:

– Professional laying of the floor reinforcement
– Installing various recesses for technical equipment
– Shuttering and concreting of the floor slab
– Compacting and stripping by vibrating beam, level or with a slope or hopper formation
– Installing the wall connection
– Erecting the outer and inner casing
– Professional installation of the wall reinforcement and various openings (pipe ducts, sliders,…),
– Completing the outer and inner casing,
– Concreting the wall and compacting with immersion vibrators triangular fillets if required.

Example of the assembly sequence when constructed with a ceiling:

– Installing a wall/ceiling sealing strip
– Stripping the inside of the wall
– Fitting the ceiling side shuttering
– Installing the ceiling shuttering
– Laying reinforcement
– Concreting, compacting and stripping,
– Any additional treatment required.

Fig. 6.37 Reinforced concrete shavings silo by Wolf System GmbH [7]

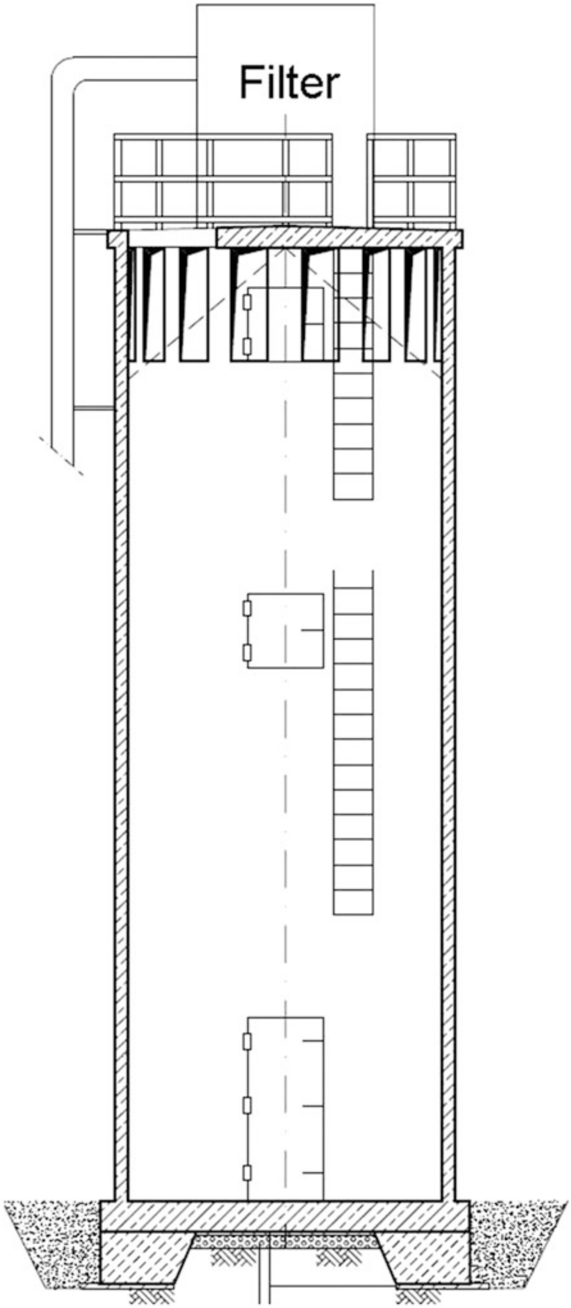


Fig. 6.38 Basic diagram of the reinforced concrete shavings silo by Wolf System GmbH [7]

6.6 Pelletization

In this chapter, the pelletizing process is first described in general terms before the most important units are discussed in greater detail. The pelletizing process essentially consists of the following units:

– Fe/Ne separator
– Air sifter
– Pulverizing hammer mill
– Additive silo and proportioning
– Mixer
– Homogenizing silo
– Mixer with addition of steam
– Pellet press
– Cooler
– Sieve
– Conveyor
– Pellet silo
– Loading

6.6.1 General Process Description

The rough description of the process following is intended only as an example. In some cases, a large number of adaptations to meet particular general conditions are required.

The raw material is transported by the appropriate conveyor, e.g., a craper chain conveyor, from the dry-chip store into the production section. The scraper chain conveyor starts on the floor of the dry-chip silo and rises up to under the roof of the pellet production hall. If the horizontal distance between silo and hall is too small so that the scraper chain conveyor would have to rise too steeply for transporting the chips, a bucket elevator must be used for reaching the necessary height.

The scraper chain conveyor delivers the chips to an Fe/Ne separator which separates iron from non-iron metals in order to protect the downstream hammer mill and prevent sparking. The material then passes into the feed hopper of the hammer mill. The hopper is required in order to be able to feed the hammer mill effectively and with a continuous mass flow if possible. The upstream process is readily "decoupled", i.e., fluctuations of material in the feed stream can be compensated for by the hopper. The controlled variable for the feed stream is determined by level detectors installed at the hopper (Fig. 6.39).

At the bottom of the feed hopper, discharge screws are arranged which feed the hammer mill. On their way to the hammer mill, the shavings pass through an air sifter which separates out heavy fractions such as rocks. This prevents any

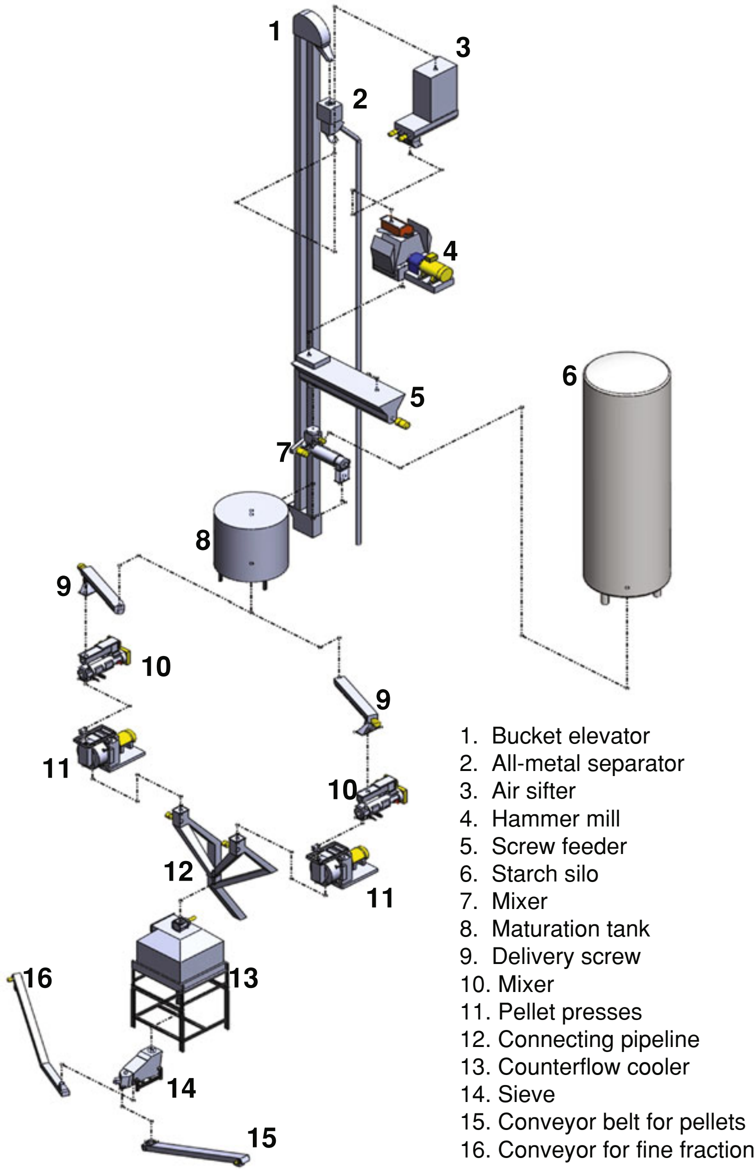


Fig. 6.39 Rough flow diagram for a plant with two presses; 8 to 10 t/h pellet production

sparking in the hammer mill when the metal hammers are grinding the rocks. Following the air sifter, the purified material is sucked through the hammer mill. The induced-draft (ID) suction fan is located behind the hammer mill.

In the hammer mill, the chips are crushed by means of the hardened flat-iron hammers which are mounted on a rotating shaft, until the material is forced through the sieve located on the periphery. The size of the holes of the sieve determines the fineness of the chips after the grinding process. The chips fall through a sealing-type rotary feeder into the following trough arranged underneath the hammer mill.

To accelerate the grinding process and the material throughput, suction is applied to the hammer mill as already described above. This is done by using a unit consisting of ID suction fan and filter. The filter is arranged behind the hammer mill on the same trough. Shavings which are sucked in with the conveying air are precipitated in the filter. The filter is cleaned pneumatically, as a result of which the shavings cleaned out fall into the trough. The shavings are transported out of the filter and the hammer mill to the downstream mixer by screws located in the trough.

In the mixer, starch can be added as binding agent, and water. The addition of water is dependent on the water content of the chips which is measured before or after the mixer. It is recommended to heat the water before apportioning it. Adding starch depends on the quality of the wood pellets which must be checked several times during a shift. It is the surface condition and the wear, in particular, which provide the plant operator with information on whether the proportion of starch and water should be changed. The starch silo is in most cases constructed as a polyester silo with pressure relief openings.

In most cases, the permitted height of construction is not sufficient for arranging the processes below one another. For this reason, the material mixed with water and additive is mostly conveyed vertically upward into the maturation tank by a bucket elevator. The chips should stay in this container for ten to fifteen minutes in order to become homogenized. In this time, the moisture can become homogenized in the individual chips and among the chips themselves and the starch can begin to swell.

On the floor of the maturation tanks, discharge screws are arranged. Frequently, there is one maturation tank provided for two presses. The discharge screws convey the raw material horizontally to the mixers which are arranged directly above the pellet presses. In the mixer, water or steam can be added if required. The addition of steam is dependent on the availability of steam and has the advantage that the chips and the binding agent are preheated and softened without greatly influencing the moisture content. The higher temperature is also of benefit to the binding characteristic of the starch. It leads to a greater proportion of the starch being subject to binding which optimizes the efficiency of the use of starch. The pellet quality can be optimized and the power consumption of the pressing process can be reduced and the throughput maximized (Fig. 6.40).

At the end of the mixer, the chips fall downward onto feed screws. These short screws feed the pellet press. The chips are introduced between the edge runners arranged in the press and are distributed as uniformly as possible by means of guide blades in order to achieve homogeneous loading.

The pellet press consists of a rotating die and rotatively mounted edge runners. The chips are forced through the minimal gap between edge runner and die as a

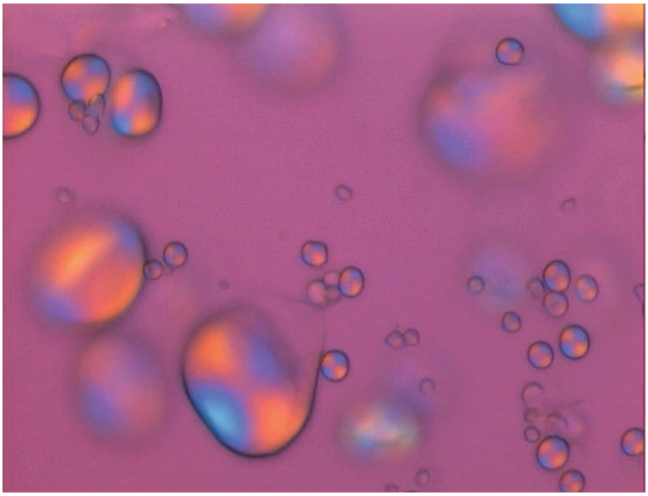


Fig. 6.40 Dissolved and undissolved starch grains in a wood pellet

result of which the only remaining escape route is through the press molding channels in the die. Edge runners and die are positioned with respect to one another in such a way that the edge runners almost touch the die. After emerging from the rotating die, the chips molded in the press molding channel are cut or broken to the desired length by knives fixed at the periphery. This process can only be set with limited accuracy. Below the press, a sampling point should be arranged for quality control (Fig. 6.41).

Fig. 6.41 Sampling directly below the presses

Fig. 6.42 Sampling directly below the pellet sieve

A further sampling point should be arranged below the sieve in front of the pellet store in order to be able to assess the quality of the pellets in the silo.

Following this, the pellets fall downward through a rotary feeder. The cooler is optimally arranged below the rotary feeder since the pellets, being 70–95 °C hot, are still unstable. If the licensed height of the hall is not sufficient, the pellets can be conveyed carefully upward into the cooler. The use of bucket elevators should be avoided here (Fig. 6.42).

In the counterflow cooler, the pellets are cooled to a temperature which is about 5 °C above the ambient temperature. Attention must be paid to design the cooler accordingly also for operation in summertime since the quality suffers considerably if the pellets are inadequately cooled. The cooled pellets are stable and solid. Cooling is carried out using ambient air which is sucked in from the outside, if possible. The air flows through the cooler in counterflow, i.e. against the direction of flow of the pellets from the bottom to the top. The air flowing through the cooler absorbs fine fractions and is cleaned by a downstream filter before being delivered zo the environment. The fine fraction is supplied to the production process.

If the sieve is arranged below the cooler, the pellets fall onto the sieve through pipelines. Otherwise, the pellets ae delivered onto the sieve by applying a gentle conveying technique. The sieve should output three fractions. Overlengths at the top where they are "cracked" by an appropriate device, standard wood pellets in the center and fine fractions in the lower deck. The "cracked" overlengths are fed to join the standard pellets and are transported by conveyor into the storage silos. This is done by pipe conveyors (belt), scraper chain conveyor, elevators etc. The fine fraction is returned into the dry-chip silo or into the production process in the case of low quantities.

Between the cooler and the sieve, or after the sieve, a continuous weigher should be arranged so that the quantities produced can be checked.

The pellet silos are in most cases made of sheet metal. Below the silos, sliders are arranged which fill the conveyors below. To achieve optimal emptying, several sliders are arranged along the axis of the conveyors. If automatic emptying of the residues is wanted, an automatic residue-emptying screw can be installed. The conveyor arranged below the silos transports the pellets to an elevator which, in turn, tips them into a loading silo.

There are various philosophies with respect to loading. The loading capacity, and thus the entire conveying technology, must match the respective requirements. Loading by ship necessitates greater capacity than truck loading. This correspondingly applies to rail loading. In every case, a sieve must be arranged below the loading silo in order to ensure that only a minimal quantity of fine fraction is loaded. The fine fraction is fed to the dry-chip silo. This can be done pneumatically or by mechanical conveyance, depending on the routing. The wood pellets are conveyed into a truck, a ship or a railcar.

If a weigher is arranged below the silo, a movable loading unit is recommended. This is also recommended if the silo is standing on load cells. As an alternative, the loading unit can be stationary, with the result that the truck must move under the loading bellows. The roofing must be adapted accordingly.

6.6.2 Plant Engineering

In the following sections, the plant technology described briefly before will be explained in greater detail.

Magnetic Separators

The magnetic separator has the task of protecting the downstream units, particularly the hammer mill and the presses, against the input of metal. The input of metal would destroy the systems, on the one hand, or at least speed up wear to an extreme extent and, on the other hand, represent a major risk of sparking which, in combination with dry shavings, would harbor an enormous risk of starting a plant fire. In the sections following, various systems will be presented.

Permanent-magnet systems are manufactured as ferrite, alnico or neodymium models depending on their intended tasks. Due to the performances required by the market, new systems and models are continuously being developed in conjunction with improved magnetic materials. For separating out ferrous foreign objects with a continuous flow of material on conveyor belts, in free fall, in vertically or diagonally arranged pipelines, under chutes and slideways etc., magnetic plates are arranged across the flow or alongside it, depending on application and task. This model of magnetic plates is provided with strong ceramic magnets which are constructed in such a way that a particularly strong and deep magnetic field is produced. The surfaces of the magnet which come into contact with the material flow are made of stainless steel (e.g., Material No. 1.4301) to protect the magnet. For assembly purposes, the magnetic plates are in most cases provided at the rear with a baseplate

Fig. 6.43 Principle and example of a tubular magnet by S + S [10]

including threaded holes. To provide for fast and thorough cleaning of iron soiling from the magnetic plates, the models can also be provided with a cleaning facility. This device can be provided for manual or pneumatic operation. Using a pneumatic facility is recommended when the magnetic plate is mounted at an inaccessible place.

In the construction of the conveying equipment which is combined with a magnetic system, particular attention must be paid to the selection of the machine elements to be used. It is not recommended to use magnetizable materials in the area of the magnetic system. The use of ferromagnetic materials has a negative influence on the operability of the de-ironing system which, e.g., leads to accumulations of iron particles at undesirable locations and impairs the performance of the de-ironing system. Examples of materials suitable for the manufacture of components are stainless steel (e.g. Material No. 1.4301), aluminum, brass and plastic.

The tubular magnet was developed especially for use in the conveyance of granulate material. It is possible to examine granulates with a grain size of up to 8–10 mm and a temperature of up to 80 °C in stationary or slow-flowing columns of material. If it is installed directly on the entry to a machine, the magnetic separator will separate ferromagnetic contaminants from the granulate shortly before this is processed. Cleaning is carried out by removing the magnetic rod system and then pulling the stainless steel sleeves from the magnetic cores. The deposited contaminants will drop off the rods and can be analysed. As an alternative, an automatic cleaning system can be installed (Fig. 6.43).

A large number of models is available. To illustrate the possible degree of automation, the tubular magnet is described in a further model. Magnets for free-fall application with pneumatically operated flap are used in pipelines for the thorough separation of ferrous metals from various bulk materials. In this type, separation is carried out with the aid of an electromagnetic field. Cleaning is done, for example, by a controller which removes the electromagnetic field as soon as a pneumatically operated hinged box is latched in the "Cleaning" position. In this electromagnetic model of the tubular magnet, the dimensions must be selected to

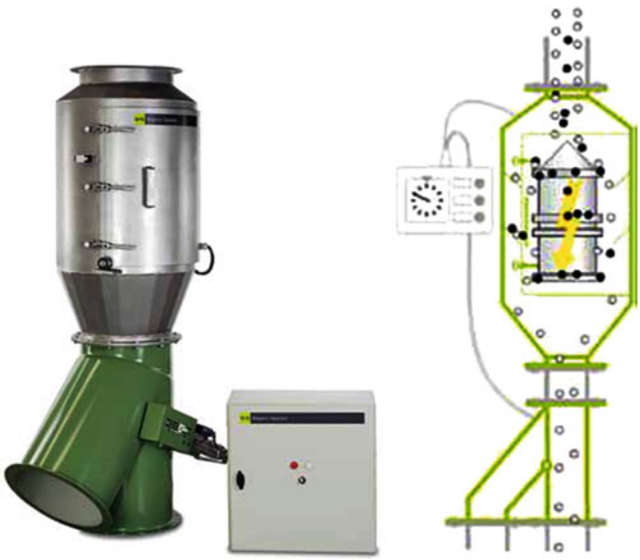


Fig. 6.44 Tubular magnet with pneumatically controlled flap by S + S [10]

be such that a sufficiently large free passage is guaranteed even with a contaminated magnetic core (Fig. 6.44).

The drum magnet is used for separating ferrous contaminants from bulk materials such as shavings and wood pellets. The material flow is conducted past the drum magnet. The ferrous contaminants are attracted and carried along by the rotating outer sheath, which is provided with guide ribs, until they have left the magnetic zone. They can then be either transferred or caught in a separate container. The system consists of strong ceramic magnets which are arranged appropriately for generating a strong magnetic field acting in depth. The rotating bearing journal is driven whereas the stationary axle journal is used for positioning the magnetic field. The magnetic field extends over 180° (Figs. 6.45 and 6.46).

The magnetic head roller is used for separating ferrous contaminants from shavings during their transport over conveyor belts. It replaces the drive roller at the discharge end of the conveyor belt. This magnetic head roller holds on to the ferrous contaminants and conveys them in the direction of the underside of the belt where they drop off as they leave the magnetic area of effectiveness of the head roller. The system consists of strong ceramic magnets. The disadvantage of this arrangement is that the iron will also carry shavings along with it.

Top-mounted magnets are in most cases provided with a strong permanent magnet of fully stabilized magnetic strontium/ferrite material. The discharging belt is driven by a slip-on gear type motor as a standard feature. The iron parts deposited are transported away continuously by the cycling flat belt. The rugged structure can also be equipped optionally with an hydraulic drive. Clamp-on

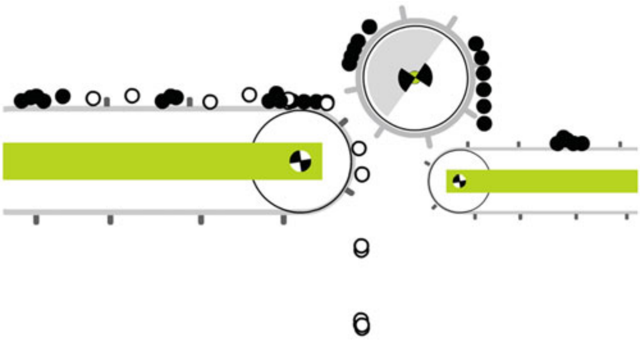


Fig. 6.45 Drum magnet with transfer of the separated components, by S + S [10]

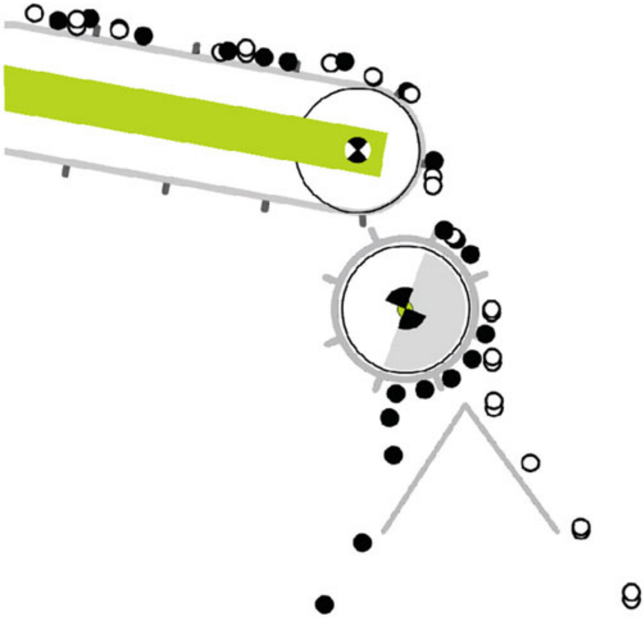


Fig. 6.46 Drum magnet, disposal of of separated components through a downpipe, by S + S [10]

protective plates on both sides prevent damage to persons or to the discharge belt. Using this technology, not many shavings or wood chips are deposited with the iron material (Fig. 6.47).

All-Metal Separators

All-Metal separators are mostly used in wood processing. Unlike magnetic separators, these also remove non-ferrous metals (aluminum, copper, stainless steel

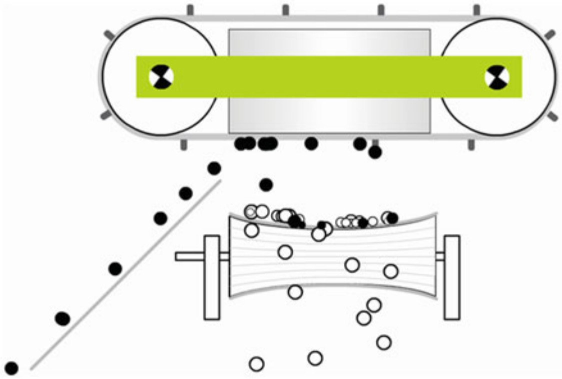


Fig. 6.47 Top-mounted magnet by S + S [10]

etc.) NF detection and selection is absolutely necessary especially in fuel lines of power stations and before wood chippers.

There are mainly two possible solutions available for the removal of NF particles.

1. Separation by Detection

The NF materials such as Cu, Al, are detected in the stream of material and separated operationally via a gateway. This approach is one of the most cost-effective means for NF separation. The disadvantage is that small fuel charges will be removed together with the detected NF materials, the advantage being the cost-effectiveness (Fig. 6.48).

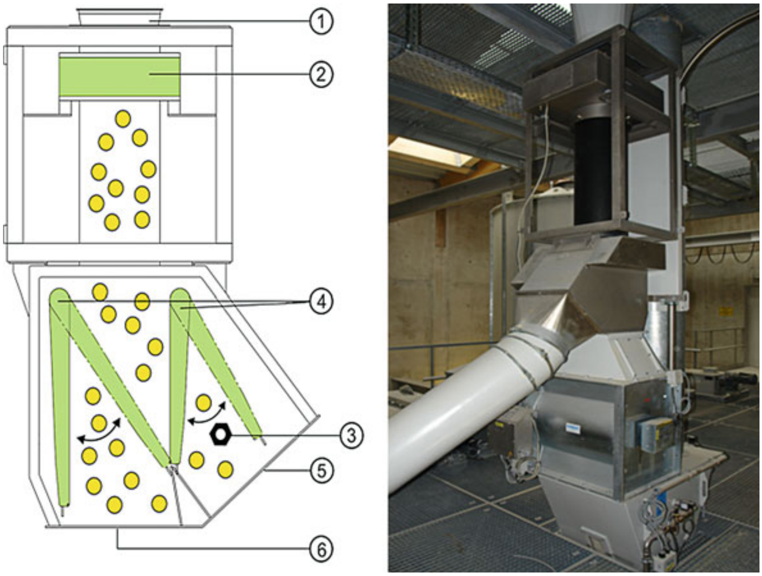


Fig. 6.48 *Left* Principle of operation: separation based on detection and elimination. *Right* Example of an application [10]

2. Separation by Induction Separator

Induction separators sort out metallic components such as aluminum. stainless steel or lead fully automatically from the stream of bulk material. This passes through a vibrating channel, optimally separated, into the detection range of the of the multi-channel metal detector. If there is a metal component within detection range, its position is detected accurately by the high-resolution metal detector coil. The precise portion of the metal is determined by the evaluation electronics which activate the correct nozzles of the blow-out system at the correct time and position- The metal part is thus directed into a separate discharge shaft without the rate of delivery being interrupted. There is a minimal loss of valued shavings.

Compared with eddy current separators, the induction separator has the following advantages:

– All types of metal are detected, both iron and non-iron metals and stainless steel.
– There is no need for an upstream magnetic separator.
– Compound materials of metal and wood (nail in a piece of wood, furniture fittings on old wood) can be reliably separated (Fig. 6.49).

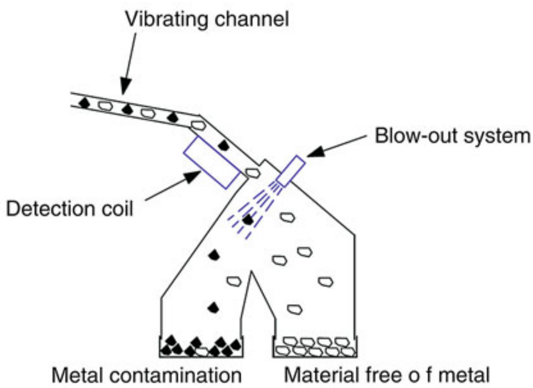


Fig. 6.49 Principle of induction separation and compressed-air separation

Air Separators

Like the Fe/Ne separator, the air separator also protects the downstream hammer mill against wear, sparking and destruction. by separating out heavy parts such as stones. In air separators, heavy parts and chips are separated mechanically in the air stream by means of their ratio of force of gravity and flow resistance. This is a sorting process utilizing the principle of separation by centrifugal force or by gravitational force. Fine chips follow the flow, coarse ones follow the force of gravity. Air separators are basically built in two versions. The stream of material is separated either by a vertical air stream or by a horizontal air stream. (counterflow sizer and crossflow sizer, resp.). The ascending tube separator, zig-zag separator etc. are the simplest form of an air separator but are scarcely used pelletization.

In contrast to the various forms of ascending tube separator, the air stream flows horizontally in the horizontal air separator. The solid particles fall into this air stream from the top. Depending on weight and air resistance, they are deflected by different amounts. Heavy or compact parts fall directly downward, others are swept along farther with the air stream. By adjusting the flap regulating the rate of air flow, and the deflection plate responsible for the degree of deflection, it is possible to determine how heavy the material is allowed to be which passes into hte hammer mill with the chips or which should follow the heavy material (Fig. 6.50).

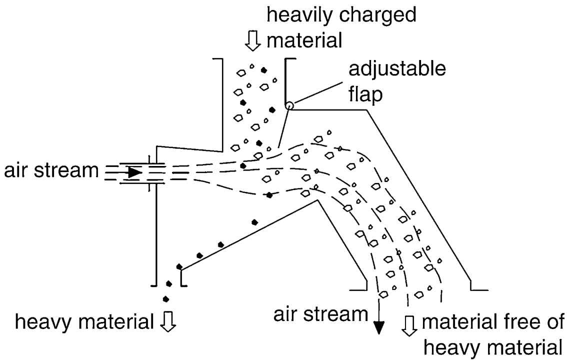


Fig. 6.50 Principle of an air separator preceding a hammer mill

Hammer Mill

A hammer mill (also called impact mill) is a grinding machine. It has the ask of crushing the chips quickly and with a varying degree of coarseness depending on application, especially also in the case of greatly heterogeneous mixtures of material. The material to be ground is crushed by the kinetic impact effect. In a metal housing, a rotor is turning at the outer periphery of which an application-related number of moving steel beaters are attached which can reach peripheral speeds of up to 120 m/s and more. When it enters into the beating circle of the rotor, the material to be crushed encounters the rotating beaters or hammers. The hammers also throw the pieces against the grinding wall where they are broken further due to the impact. Further crushing occurs in the lower area between rotor and grinding wall. The material to be crushed remains in the crushing zone until leaves the mill through the perforated sieve at the outer circumference of the mill. This sieve has the function of limiting the upper grain size. The maximum grain size can be adjusted by appropriately selecting the hole diameter of the sieve. The direction of rotor rotation can be changed (reversed) by grinding walls arranged on both sides. This provides the possibility of optimally utilizing the hammer heads in wear, a facility not provided by all manufacturers (Fig. 6.51).

In the pelletizing process, the hammer mill can be normally considered to be a type of policing hammer mill since, as a rule, the chips have already been crushed before they < are dried. For this reason, a pulverizing hammer mill is used here. It has the task of producing a geometrically homogeneous chip for the pellet press. The installed electrical power of the hammer mill is never made use of in most installations.

Fig. 6.51 Hammer mill with beaters

Proportioning of Additives or Size

Size is used for optimizing the binding characteristics during the pressing process in the die. The important factors are uniform proportioning of the size and avoiding "gulp-like" conveyance. Inserting it into an air stream is optimal. This can be done after the hammer mill when all chips are being conveyed pneumatically. The size can then be introduced into the airstream and is thus subjected to optimal mixing. Since the disadvantage of the high energy requirement for transporting the complete volume of chips pneumatically after the hammer mill is too great, this option is frequently not used. A further disadvantage is that the size may stick together in the filtering hose which separates the air from the chips.

A further possibility consists in proportioning shortly before the hammer mill which results in optimum mixing in the hammer mill. Here, too, the risk remains that the size can gum up the downstream filtering hose. This applies particularly in wet weather or with moist air. The explosion expert must also assess whether the addition of size increases the explosion hazard in the hammer mill. Nevertheless, some pelletizers have gained good experiences with this method.

Another option which is still well established and is taken into consideration in the further description of the pelletizing process is proportioning the size in the mixer following the hammer mill and preceding the maturation tank. The important factor is to select the screw feeder to be correspondingly small since only about 1 % of the volume of chips is added as size. Attention must also be paid to the size not being delivered "in gulps" even if there is a mixer. The mixer will be described in the section following.

Mixer

The mixer is a horizontal, cylindrical conveyor with a rotating shaft arranged centrally. On the shaft, mixing paddles are arranged. The water content is determined by moisture measurement and is used as control value for injecting water. The water should be introduced as finely dispersed as possible. As mentioned above, size is also added proportionally. The mixture is turned over by the paddles in order to obtain as homogeneous a mass flow as possible. The paddles can be adjusted individually with respect to position and angle. This affects the dwell time of the product in the mixer. The speed should also be adjustable.

There should be regular checks of the soiling of the mixer on its walls. For this purpose, correspondingly generous maintenance openings should be provided which should extend over the entire width of the mixing chamber. The mixers should also be made of rustproof stainless steel (Fig. 6.52).

Fig. 6.52 Mixer by Salmatec with adjustable paddles

Maturation Tank/Homogenizing Silo

The maturation tank has the task of providing the chips with sufficient time for the moisture in the chip to become homogenized and to become distributed as uniformly as possible among the chips themselves in order to be able to feed the pressing channel with as homogeneous a product as possible. This process optimizes the quality of the pellets. The dimensions of thetank should be such that chips have a dwell time of at least 1.5 min in the maturation tank before they are supplied to the mixer above the presses. Below the silo, delivery screws are arranged which feed the mixers. A similar tank can be arranged before the dry-chip hammer mills and has the task of feeding the hammer mills optimally and effectively (Fig. 6.53).

Fig. 6.53 Maturation Tank with Screw Delivery [5]

Pellet Press

In principle, there are two types of presses: presses with vertically acting ring die as used by most manufacturers and horizontally acting ring die as used by the company Amandus Kahl,, for example.

The die is driven by electric motors and V-belt. A press producing pellets at about 4–5 t/h has an installed power of about 450 kW. Depending on manufacturer, two to three edge runners are mounted inside the die. These are each mounted on a shaft and are not driven. The type of edge runner is also selected individually for each installation and frequently established by trials during commissioning. There are, e.g., perforated edge runners, diagonally-fluted and straight-fluted edge runners. The figure below shows perforated and straight-fluted edge runners after manufacture (Figs. 6.54 and 6.55).

The chips are delivered into the press area by screw feeders. Guide vanes ensure that the chips are fed in between the edge runners. The rotational movement of the die entrains the material in the direction of rotation and forces it through the gap between edge runner and die. The edge runners are adjusted in such a way that they almost touch the die. The chips must chose the path through the pressing channels of the die and thus leave the press (Fig. 6.56).

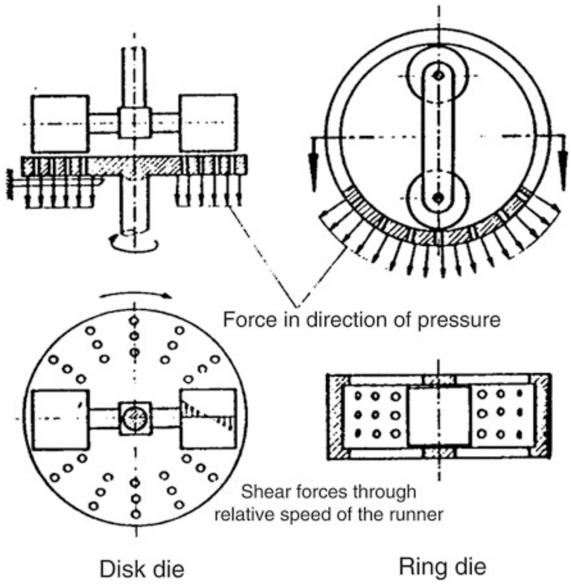


Fig. 6.54 Principle of operation of the flat-die and ring-die press [6]

Fig. 6.55 Top: Perforated edge runner; Bottom: straight-fluted edge runner, by Salmatec [6]

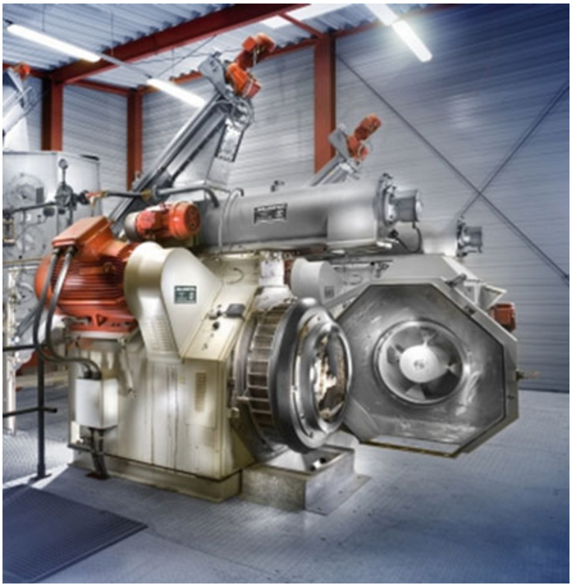


Fig. 6.56 Pellet press opened and ready for maintenance

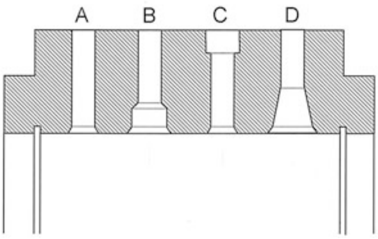


Fig. 6.57 Selection of dies, different die boreholes [6]

The pressing channel has a conical inlet before the chips receive their actual shape in the pressing channel. The inlet cone becomes worn in continuous operation and can be reworked, if necessary. After the inlet cone has become worn, the actual pressing channel becomes worn and thus shortened. The shape of the cone and the length of the pressing channel are dependent on the manufacturer and the wood used. Even the geographic origin of the wood is of significance. The pressing channel can thus be different in Scandinavia than it is in Russia, with the type of wood being the same (Figs. 6.57 and 6.58).

The choice of edge runner is also a science in itself and must be tested individually for each site. There are perforated, straight-fluted, diagonally-fluted, etc., edge runners.

With respect to equipment, an automatic lubricating system is important which only has to be connected to a grease tub. The auxiliary crane is also required for mounting and dismounting edge runners and matrices (Fig. 6.59).

Fig. 6.58 Adjusting the edge runner position

Fig. 6.59 Two presses with three edge runners each

Coolers

In the counterflow cooler, an air current flowing towards the product is used for cooling the pellets. The method of counterflow cooling avoids cold air from flowing directly onto the hot pellets. This prevents the surface structure from breaking up, thus ensuring that the quality will be high. The principle of counterflow cooling requires only small specific quantities of air (Fig. 6.60).

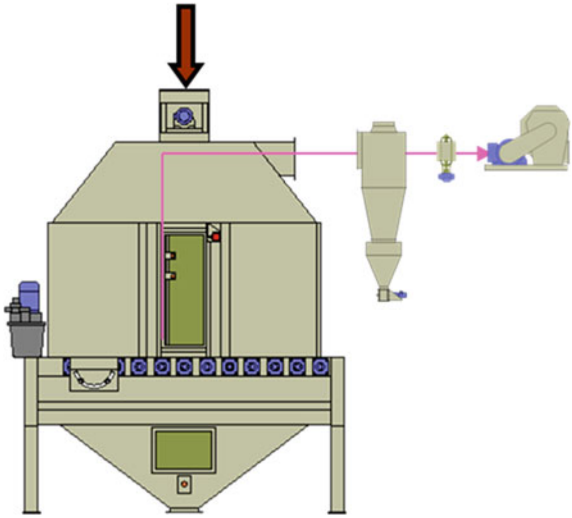


Fig. 6.60 Principle of the counterflow cooler, by Salmantec [6]

A rotary feeder regulates pellet feeding and at the same time seals the cooler for waste air toward the top. The pellet inflow is controlled by adjustable sensors which measure the filling height on the cooling surface. Below the feeder, a distributor provides for uniform distribution of the material on the cooling surface which represents the most important element of the counterflow cooler. It has the task of allowing the pellets to pass slowly downward whilst constant cold air is intended to flow through upward. Homogeneous air distribution in the cooler is necessary for the pellets to be cooled equally, thus ensuring the required quality. From the waste air, dust is removed by means of a cyclone separator or textile filter after the cooler before it is conducted outside by the fan.

The cooler must be designed geometrically in such a way that it is emptied completely and no clusters of the product are formed. The size of the cooler depends on the temperature of the pellets entering, the maximum ambient temperature possible. The specific heat capacity of the pellets and the expected water absorption of the cooling air.

During the cooling of the pellets, the temperature must be reduced to a safe value in order to guard against condensation. Above all, however, the hardness of the pellets is increased. This facilitates their later transportation and subsequent storage and reduces abrasive wear.

Screen

In the screen behind the cooler, three fractions are produced in order to convey the highest possible pellet quality into the silo. In the bottom deck, the fine fraction screened out is collected and then conveyed into the dry-chip silo or transported back into the production process at a suitable point. In the center deck, the high-quality pellets are collected and transferred to the conveyor equipment which transports them into the silos. The pellets with excess length remain in the top deck and can be cracked by a suitable cleat in order to reduce their length. The fine fraction produced during this process passes into the bottom screening deck and the cracked pellets are added to the good pellets (Fig. 6.61).

Fig. 6.61 Screen below the pellet cooler by Knoblinger [5]

Pellet Silos

In contrast to the dry-chip silos, Pellet silos can be made of sheet metal, and thus more cost-effectively. Sheet-metal silos are built up on site from the bottom up, i.e., beginning with the silo roof, continuing ring by ring underneath one another as the body of the silo grows upward.

Considering the foundation, it is of importance that a side projection of about one meter should be maintained. The silo should also be constructed with ventilation ducts at the bottom to provide for the option of cooling. A mobile fan can be installed at the corresponding pipe connections. The air is conducted upward through the pellets from the bottom. Furthermore, the temperature can be picked up optionally at various points in the silo and displayed. The floor of the silo consists of the foundation plate, into which the ventilation ducts and discharge hoppers of the silo are countersunk. The concrete plate is level in most cases. The silo can thus not be easily emptied of residues. This option is provided for by a residue-emptying screw. However, the screw can only be used when the silo is nearly empty and thus only very rarely. It remains to be checked whether manual emptying by "bobcat" or the like represents a viable alternative. Provision must be made for a corresponding opening in the silo wall and taken into consideration in the structural analysis. The gratings for the ventilation on the floor must also be accessible by vehicle (Fig. 6.62).

The conveyor equipment to the silo can rarely be accommodated structurally by the silo so that a corresponding additional steel structure is required. The filling conveyor above the silos can be intercepted at the silo.

Fig. 6.62 Sheet-metal silos for pellet storage with feed and discharge conveyor and loading station

The pellets leave the silo by automatic pushers arranged on the floor and pass to a conveyor which, for example, transports the pellets to a bucket elevator by which they are conveyed upward into a loading silo or directly into a truck, railcar or the like. As far as weighing is concerned, the loading silo can be equipped with weighing cells or scales can be installed.

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Chapter 7
Using Wood Pellets as an Energy Source

In the following chapter, after the storage of wood pellets, different combustion technologies will be discussed by means of which wood pellets can be burned. These can be grouped into small heating systems, medium-sized heating systems and large heating systems. In this context, small heating systems involve a power range of between 5 and 200 kW, medium-sized heating systems describes powers of up to 5,000 kW and large heating systems cover the range above 5,000 kW. Gasification is mentioned briefly. Since the traditional pyrolysis is not yet widely applied to wood pellets, this subject will not be discussed. The next subject to be discussed will be emissions and, finally, the possibility of co-incineration of wood pellets receives a mention.

7.1 Storage and Conveyance of Wood Pellets

Regarding the storage of wood pellets, a basic distinction must be made between systems intended for small heating systems and those for large heating systems. For small heating systems in households and small businesses and communes, a few systems for the storage and transportation of wood pellets have gained prominence in recent years, some of which will be presented in this chapter. In the larger combustion systems, silos are predominantly used for storage. These will not be discussed in any detail.

Pellets conforming to the DINplus standard have a maximum fine fraction of 1 % ex works. A further fine fraction is produced by the mechanical wear during transport and when they are blown into the pellet store. Depending on the type of store and conveying technology used, this can become segregated and accumulate in the lower region of the store. It is recommended, therefore, to empty and clean the store completely at regular intervals at times of low heat requirement.

The storage space must be adapted to the needs of the pellet supplier, to the junction to the boiler and the properties of the wood pellets (particularly to the fluidity and abrasion characteristics of the wood pellets), among other things.

S. Döring, *Power from Pellets*, DOI: 10.1007/978-3-642-19962-2_7,

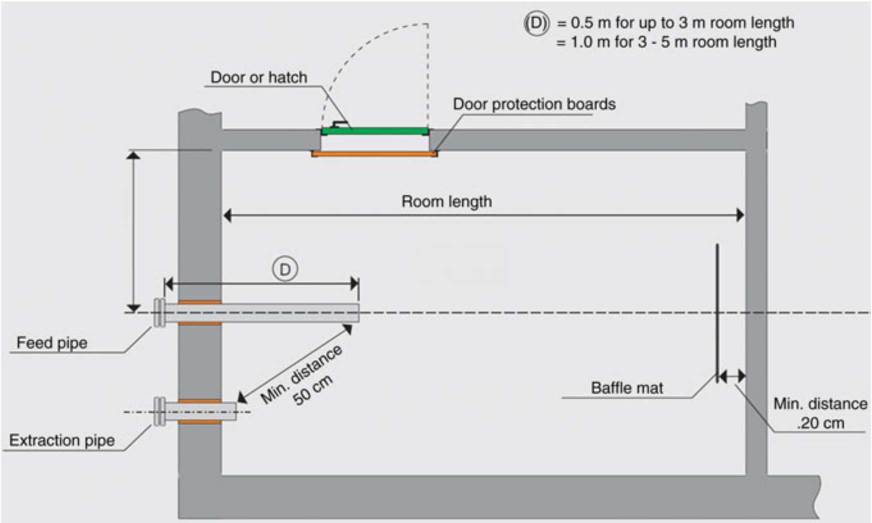

Fig. 7.1 Plan view of a pellet store

Delivery of the pellets using silo vehicles has now become standard practice. It should be possible to move the silo vehicle as closely as possible to the pellet store, keeping in mind the size of the vehicle. A road width of 3 m and a head room of 4 m are normally sufficient.

The pellet tank of the silo vehicle is joined to the appropriate connection pipe at the storage facility using a pneumatic hose. The pipe connection at the wall should be marked clearly and durably as "Feed Pipe". The coupling of the feed pipe is a Storz Type A coupling in most cases. The feed line is carried through into the pellet store and should be held in the pellet space by means of a hose clip after about 50 cm (s. Fig. 7.1). Even if it is not always possible, attention should be paid at the planning stage to the feed line having no bends, if possible. Bends increase the resistance, on the one hand, and especially the abrasion of the wood pellets. Furthermore, the storage facility should be arranged at the outer wall so that the pneumatic route of transportation is kept as short as possible. The feed pipe should be installed about 20 cm below the ceiling on the narrow side of the facility. For safety reasons, the metallic filling pipes must be grounded against electrostatic charging. The inside of the filling line must be smooth and finished without protruding edges (welding seams etc.). The extraction pipe for ventilation must also be marked clearly and durably. Coupling and diameter should correspond to those of the feed pipe. There should be a free-swinging baffle mat (deflection mat) installed in the direction of flight of the pellets and at the other end of the storage facility in order to absorb the energy of the pellets as gently as possible and to counteract increased abrasion and fractures. If the storage facility is of a wide construction, installation of two or more feed pipes is recommended so that the storage area is utilized optimally.

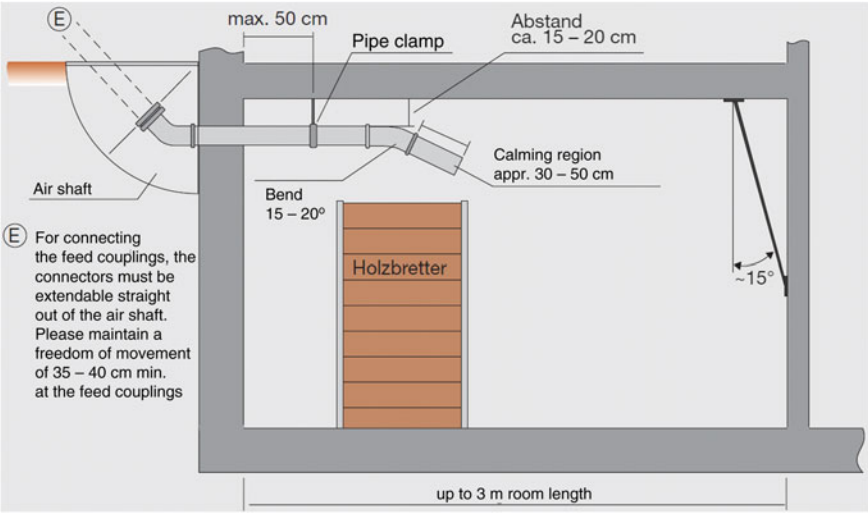

Fig. 7.2 Arrangement of feed pipe and baffle mat in a pellet store of up to 3 m in length

The storage capacity depends on the heat requirement of the object. As a rule of thumb for small systems, it should be possible to store 1- to 1.5-times the annual fuel requirement. The heat requirement, in turn, depends to a large extent on the year the house was built and its type of construction. It varies between a "passive house" requiring, e.g., 2,500 kWh/a and 500 kg wood pellets up to the standard old-style house needing, e.g., 50,000 kWh/a and 6,000 kg wood pellets per annum. The consumption is correspondingly affected by rebuilding work and additions and energy-saving measures such as roof insulation. An average family home needs about 4–5 t of wood pellets in a year.

Since the pellet store is often situated in the cellar, it is pointed out that wood pellets are hygroscopic (attract water). When they come into contact with moist walls and surfaces, the pellets swell up and can no longer be used, or only with difficulty. Normal air humidity does not affect the quality of the pellets.

The existing walls and the storage fittings to be installed must meet the static requirements of the store. Attention should be paid to the bulk density of the pellets of 650 kg/m^3, and a sloping floor must be appropriately supported.

To introduce the pellets into the store as gently as possible, it is recommended for the feed pipe to end in the storage space with a 30 cm-long tube inclined downward by 15–20°. The pellets leave the feed pipe in a downward-pointing arc and will then encounter the baffle mat which is also inclined downward by 15° and into the room (s. Fig. 7.2). It has been found in practice that the pellets are introduced quite gently using this arrangement. Naturally, the supplier must also pay attention to the appropriate injection pressure.

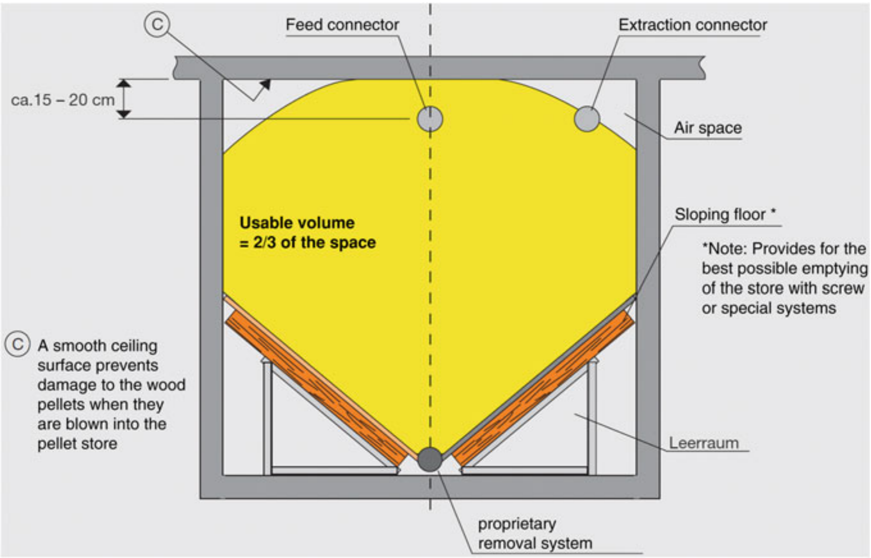

Fig. 7.3 Pellet store with sloping floor

Pellet stores which are longer than three meters should be filled using a straight feed pipe. The baffle mat should also be arranged to be straight and spaced about 20 cm away from the rear wall. Depending on the length of the store, two filling lines (one short and one long) should also be installed, as mentioned.

Concerning the conveyance of the wood pellets, a screw is frequently used which is located on the floor along the longitudinal axis of the storage space. So that all the pellets will reach the screw, if possible, the floor is in most cases constructed as a sloping floor. The inclination depends on the flow pattern of the pellets. An inclination of 45° has been found to be advantageous (Fig. 7.3). This amount of tilt ensures that the pellets slip down completely and are all supplied to the screw.

In order to keep the friction between pellet and surface as low as possible and thus to optimize the slipping characteristics, the surface of the sloping floor must be kept as smooth as possible. Smooth formwork panels or plywood panels have proved to be effective. If a removal screw is installed, it must be covered with a pressure relief plate. This prevents the weight of the pellets stored above it from pressing on it, causing considerable abrasion and especially blocking of the screw. The gap through which the screw is filled from the side should be about 7 cm.

Finally, it should be pointed out that attention has to be paid to fire and explosion aspects. For example, there should be no electrical installations in the store room. Furthermore, the boiler system should be shut down before the pellet feeding process begins. This subject should be discussed with the appropriate expert.

As an alternative to the screw conveyor with sloping floor, the following other systems, among others, are available:

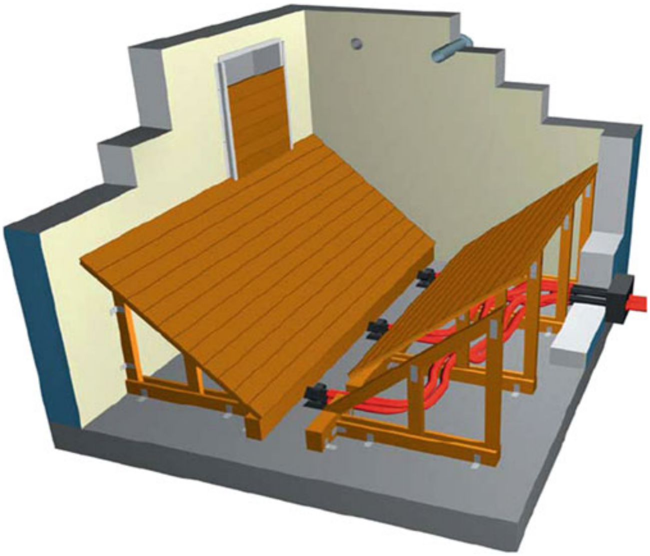

Fig. 7.4 Pellet store with sloping floor and pneumatic suction removal [1]

– Pellet store with sloping floor and pneumatic suction removal (Fig. 7.4),
– Pellet store without sloping floor and with pneumatic suction removal (Fig. 7.5),
– Storage container of flexible plastic in various shapes (Fig. 7.6),
– Underground plastic or concrete store (Figs. 7.7 and 7.8).

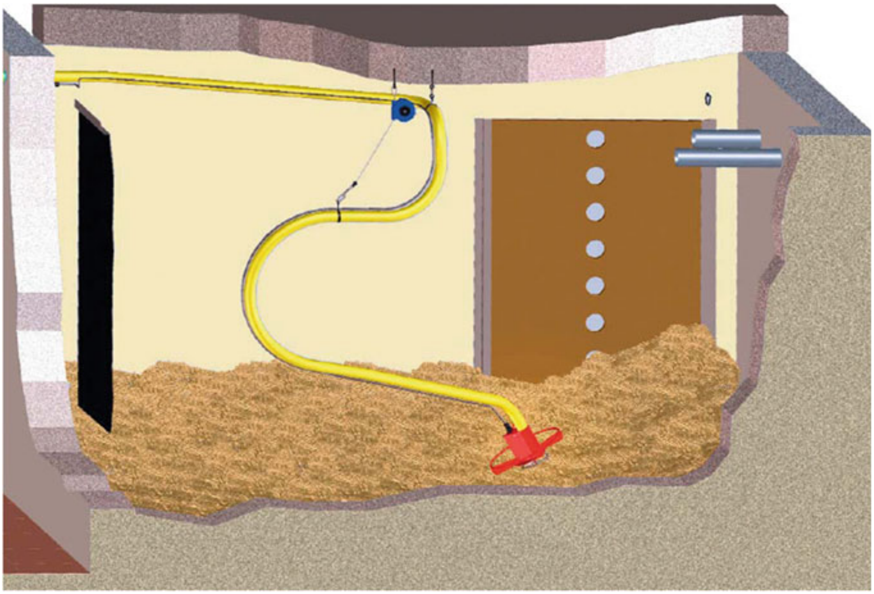

Fig. 7.5 Pellet store without sloping floor and pneumatic suction removal [1]

Fig. 7.6 Conical fabric silo [1]

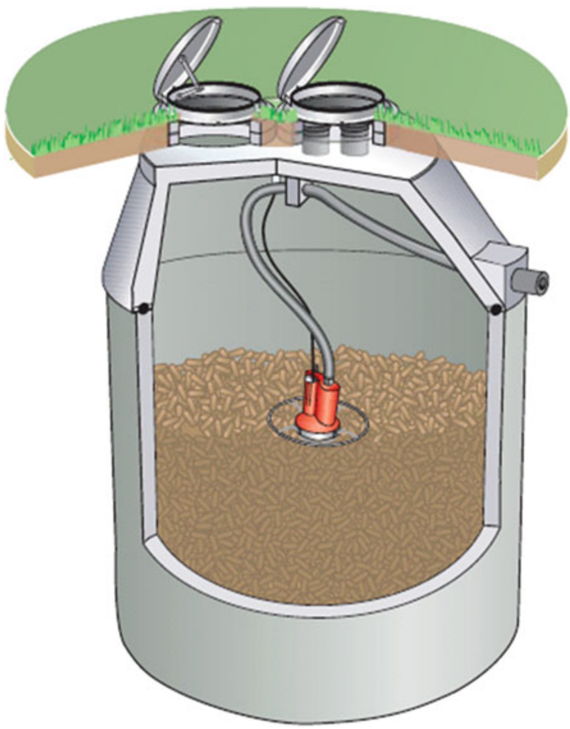

Fig. 7.7 Concrete silo as buried tank with pneumatic removal [1]

Fig. 7.8 Buried tank for external pellet storage [2]

The system using suction removal operates discontinuously so that attention should be paid to the fact that the daily supply container at the boiler has sufficient capacity. The suction system offers the user maximum freedom of planning since it is possible to overcome relatively long distances of up to 20 m with differences in height of up to about 5 m. It thus becomes possible to situate stores, e.g., in the ground outside the building.

7.2 Small Heating Systems

Small Heating Systems for pellet use are currently being offered by numerous manufacturers. The systems operate highly efficiently, with efficiencies of more than 90 % in some cases (according to manufacturer's information). They are available in various performance classes so that it is possible to adequately cover the range of energy requirements from energy-saving houses to houses with a higher energy demand up to storage and production halls. The system powers on offer are typically between 5 and 200 kW. Larger systems can also be obtained. The boilers are constructed as heating plant, as a rule. As an alternative, some manufacturers offer a model of the system as a stylish stove for the living room (Fig. 7.9).

Fig. 7.9 Fireplace pellet stove model Belina by Calimax

The predominant number of boilers is constructed as fully automatic systems, from feeding to cleaning. They are supplied with wood pellets from the pellet store or from the daily supply container directly at the boiler. The boiler shown in the figure below can be used, for example, in the power range of 4 to 48 kW. According to the manufacturer, the efficiency extends to up to 95 %. Ash is automatically removed from the combustion chamber by a ribbed grid of stainless steel. The pellets are metered in via a rotary feeder for burn-back protection and a feed screw. Ignition is performed by a ceramic heating element. The menu guidance is operator-friendly and the control system includes the possibility of taking into account solar and buffering technology. A special feature is the independent adaptation of the three-pass heating surfaces to the heat requirement (Fig. 7.10).

The pellets temporarily stored in the daily supply container or fed directly into the boiler pass into the combustion chamber of the boiler. The pellets can reach the pellet boiler in various ways, e.g., by means of screws or by a vacuum suction system. In general, there are three different types of pellet boilers (Fig. 7.11):

– Underfeed burner
– Drop shaft burner
– Retort burner

In the case of underfeed heating, the pellets pass via a screw arranged underneath the burner to the burning plate from below. The technology is distinguished by good combustion at full load even without a lambda sensor. The mostly double-walled pot consists of highly heat resistant stainless steel. The primary air is supplied over the floor directly under the fire. The secondary air is supplied in this burner above the flame over the shell of the pot. This takes place via numerous

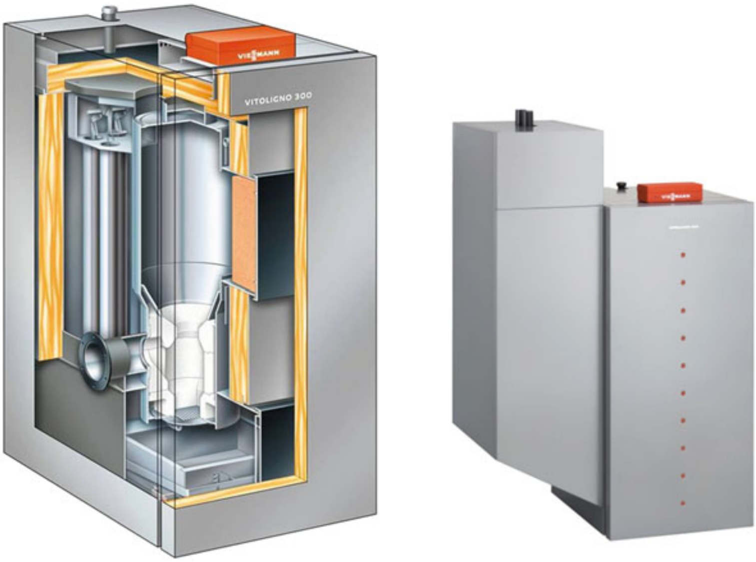

Fig. 7.10 Vitoligno 300-P wood pellet boiler model by Viessmann [3]

Fig. 7.11 Principle of the various pellet burners (Solarpraxis) [4]: *Left*—Underfeed burner, *Centre*—Drop shaft burner, *Right*—Retort burner with pellet side entry

small openings. A periodic rotary movement of the grate plate at the bottom of the pot ensures that the ash will fall through into the ash box provided. Due to the small fire bed, the combustion remains quite controllable and a high degree of burnout can be guaranteed. If the pellet quality is poor, however, slagging can occur on the grate plate which leads to an increased demand for cleaning of the plant.

For the drop shaft burner, the pellets are fed in via a screw above the burning plate and drop onto the burning plate from above.

The retort burner is characterized by the pellets being fed into the retort from the side (Fig. 7.12).

Fig. 7.12 Underfeed retort burner by KWB [5]

In spite of standardization, there are variations in the wood pellets in their length, their residual moisture, their ash content, and thus also their heating value. The control system must be capable of reacting to this appropriately. The stipulated performance depends on the required heat demand of the connected load. Many systems divide the combustion air into a primary and a secondary mass flow of air. The mass flows are either permanently set, can be controlled individually or jointly by blowers and/or may be monitored by air mass sensors. In this arrangement, the primary combustion air influences the combustion in the burning dish. It is introduced directly and is controlled in most cases via a combustion temperature sensor or a fire bed sensor. The temperature sensor ensures that the combustion chamber is thermally safe by preventing the combustion chamber temperatures from becoming too high. These can lead to damages in the combustion chamber materials and to damages in the downstream heat exchangers. In contrast to the primary combustion air, the secondary combustion air is not conducted directly into or under the flame but supplied above the combustion. In most cases, it is controlled by a lambda sensor sensitive to oxygen and thus provides for post-combustion in the flue gas and an almost complete burnout of the combustible components. Apart from the design characteristics of the boiler, control of the combustion is one of the most important criteria for the development of an efficient system. The control system must be adaptable to the different calorific values of the pellet batches and cover a wide load spectrum of the plant. Thus, plants of the latest generation achieve high degrees of modulation and ensure that the necessary heat requirement can always be covered. It is now possible to operate the plants in load cases of from 30 up to 100 %. These high modulation percentages are of importance since continuous starting and stopping of the boiler leads to an increased formation of harmful substances. Low combustion temperatures on

Fig. 7.13 Arrangement of the secondary-air nozzles in the post-combustion ring by KWB [5]

startup will lead to incomplete combustion. An increased release of carbon monoxide can also be expected in this case. Optimum combustion conditions will only occur when the system has reached its operating temperature (Fig. 7.13).

The burners ignite automatically by hot air blower or drier or glow-bar. As an alternative, larger boilers switch to maintaining fire. In the case of the latter, only as much fuel is fed in as is required for maintaining fire. Due to their lower power requirement, the development is moving away from the hot air igniters towards electronic ignition elements. A further advantage of electronic ignitions, apart from their low noise, is their low maintenance requirement.

The combustion chamber itself is made of fire-resistant materials such as, e.g., ceramics. Depending on the geometry of the combustion chamber, a part of the combustion heat remains stored there and thus improves the starting conditions when combustion is extinguished. The combustion itself can take place in a fire bowl.

Specially developed combustion systems such as the recirculation burners do not need any lambda sensors in some cases. A certain proportion of the flue gas is here recirculated into the combustion chamber, thus guaranteeing complete combustion. A well conducted combustion and low values of harmful substances, especially of carbon monoxide, to be expected as a result, should also be one of the most important criteria in the choice of a good pellet boiler.

For removing the ashes and kindling the fire, various grate technologies are used. These can be:

– comb grate
– tilting grate
– feed grate

– stepped grate
– lifting and lowering grate
– rotary grate
– lamellar grate

Apart from the heating performance of the boiler, other constructional influences on the design of the grate are also its cleaning characteristics, i.e. the quality of removal of any grate ashes or slag. The grate bars consist in most cases of high-temperature-resistant cast alloys having high chromium contents. Depending on the type of grate, the primary air introduced through the grate is also used for cooling the grate bars. A screw located underneath the grate can transport the ashes out of the combustion chamber into an appropriate storage container. Many systems dispense with this additional screw by arranging the ash box directly underneath the fire bowl. The storage containers are in most cases designed very generously so that they can be emptied at relatively long time intervals due to the small amounts of ashes produced. However, with very low ash contents of 0.5 %, the quantities are very small. The wood ashes produced are biologically degradable and can be used as garden fertilizer.

Following the combustion, the flue gases pass through the heat exchangers which then transfer the heat present in the flue gas to the water in the heating circulation system. The efficiency of the plant depends to a high degree on the quality of these heat exchangers. During the operation, parts of the flue ash carried along settle on the heat exchanger surfaces and, as a result, degrade the heat transfer. In consequence, less heat is delivered to the water to be heated. The waste gas temperatures rise and the system works more inefficiently. To reduce this degradation of the efficiency, the heat exchangers are equipped with self-cleaning systems in the present state of the art (Fig. 7.14).

The heat exchangers, constructed as tube bundles in most cases, can be regularly cleaned off to remove, e.g., adhering ashes. The tubes are arranged vertically due to the flue ash components. The cleaning systems, constructed as spiral springs in most cases, move up and down along the tubes. This purely mechanical cleaning provides for adequate cleaning. Any degradation of the efficiency through the soiling of the hat exchanger surfaces can thus be reduced. Once the flue gases have been conducted through up to three flues in the boiler past the heat exchanger surfaces they pass out of the boiler into the waste gas line provided above the roof. The heat exchanger surfaces in the boiler are designed taking into consideration avoiding dropping below the dew point. If the temperature drops below the dew point of certain flue gas components, acid components can lead to corrosion of the heat exchanger tubes or other boiler parts and thus cause damage to the boiler. For this reason, numerous manufacturers provide for the water to be preheated before entry into the boiler especially with low temperature heat distribution systems (Fig. 7.15).

In complete contrast to this, the condensing-type wood pellet boiler owes its life to these low return temperatures. The persistent effort by the manufacturers to achieve ever higher efficiencies led to the development of the first condensing-type

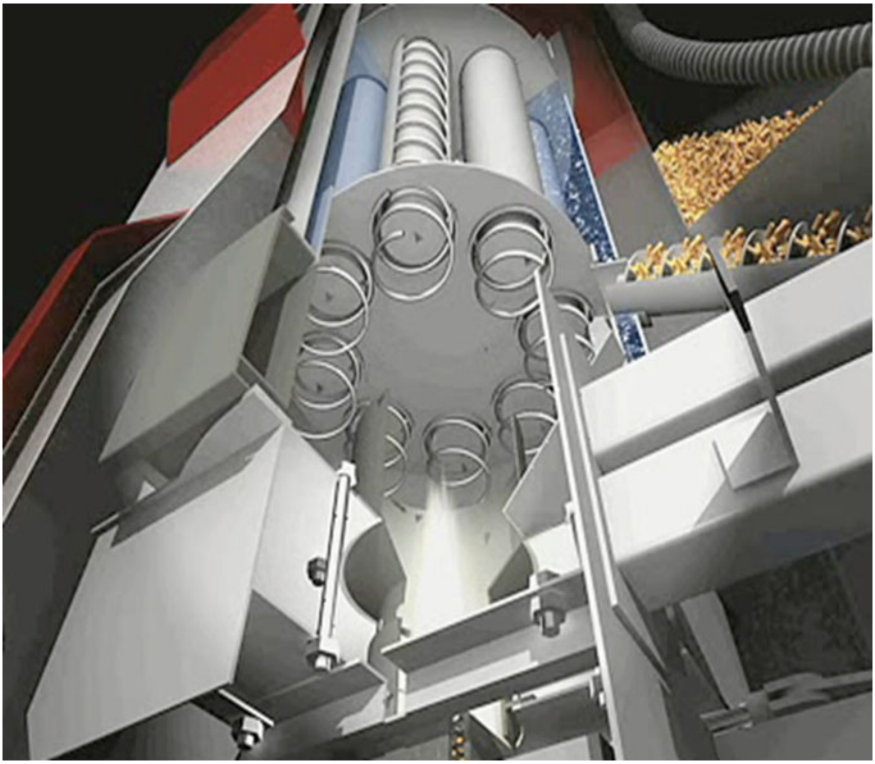

Fig. 7.14 Nessensohn pellet boiler during the deducting of the heat exchanger tubes by spiral springs moving up and down [6]

wood pellet boilers. As in the case of the condensing boiler for natural gas, the increase in efficiency is achieved by the additional utilization of the energy released during the condensation of water (evaporation heat) (Fig. 7.16).

In fuel, and thus in wood pellets, energy is tied up in a chemical form. Some of the energy is needed for the gasification of certain components such as the water, contained in the fuel or in the combustion air, into water vapor. To recover this energy, known as latent (hidden) energy, the flue gases have to be condensed. In a pellet condensing-type heating system, as in other condensing-type heating systems, too, this can be done only by having the lowest possible return temperatures in the heat distribution system. It is made possible by using panel heating systems such as, e.g., under-floor heating or wall heating. In these cases, return temperatures of less than 30 °C can be expected. The low return temperatures enable the flue gas temperature to be lowered to 30–40 °C. The water vapor contained in the flue gas can be condensed, the latent heat becomes usable and it is possible to achieve boiler efficiencies of over 100 %, based on the calorific value of the fuel. This means a leap in boiler efficiencies of 10–15 %. The condensate produced can be supplied to the internal domestic waste water loop as in the case of

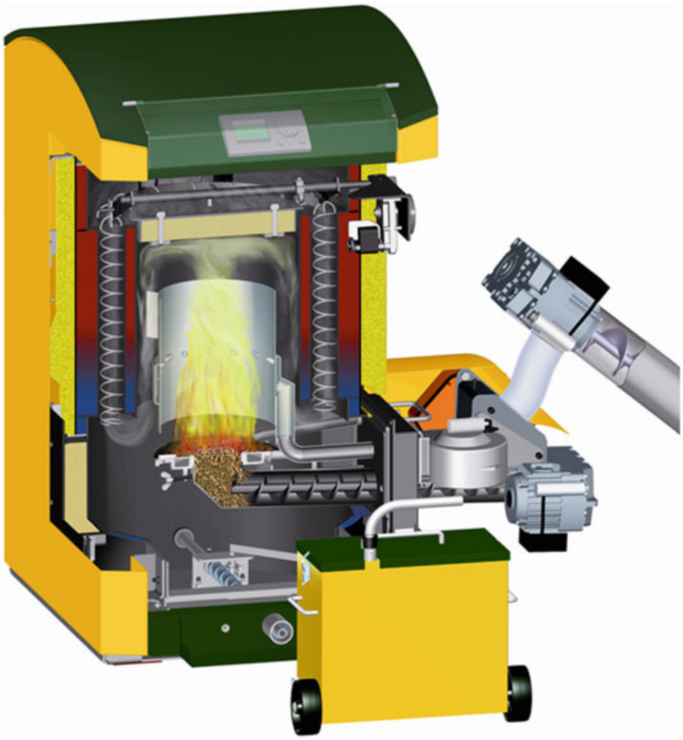

Fig. 7.15 Cross-section of the Easyfire pellet heating system by KWB [5]

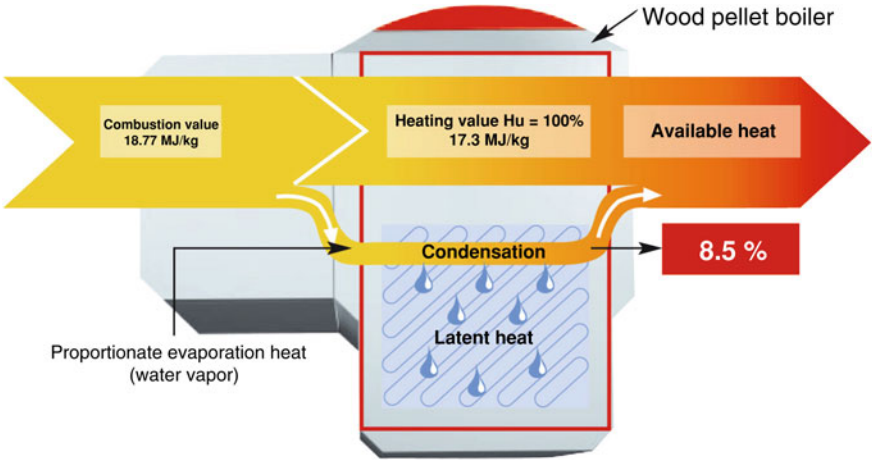

Fig. 7.16 Principle of the condensing-type wood pellet boiler according to [7]

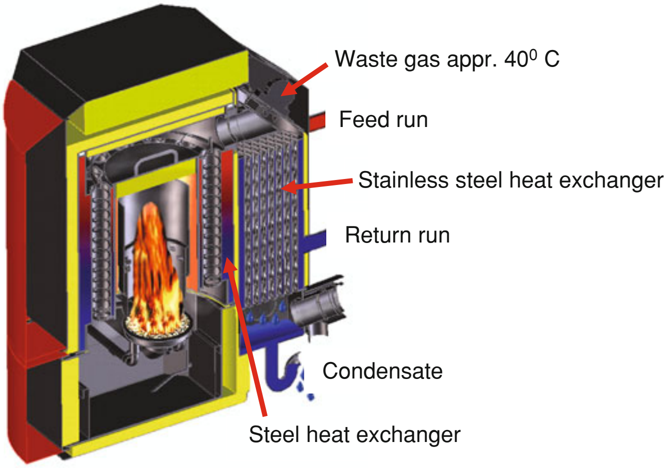

Fig. 7.17 Ökofen condensing-type wood pellet boiler [7]

the condensing boiler for natural gas. If the condensation is complete, there would be about 0.5 l condensate produced per kg of pellets. In practice, values of about 0.35 l/kg are achieved. From experience, the ph value of the condensate is about 4–6 and is thus comparable to the condensate when natural gas is used as the fuel.

In contrast to the domestic wood burners, the natural chimney flue is not sufficient for providing for low pressure in the boiler. For this reason, a low-pressure controller is used which controls the induced-draft blower in dependence on the low pressure required in the combustion chamber. It the low pressure is too low, e.g., due to a failure of the induced draft, the boiler control must stop the supply of fresh air automatically. Excess pressure in the boiler can lead to flue gases escaping. Combustion will slow down or become extinguished due the reduction in oxygen (Fig. 7.17).

To obtain a more uniform type of operation, the pellet boilers should be operated in combination with a heat reservoir. If buffer reservoirs are used, attention must be paid to the quality of the water, the proliferation of legionaires' bacteria representing one of the greatest risks at too low a temperature. The temperature in the reservoir should, therefore, be kept sufficiently high or should be increased at regular, limited intervals, respectively. This problem is known to the manufacturers, which is why they are offering special reservoir cleaning cycles, integrated in the controllers.

Pellet burners which are suitable for being installed in front of used oil-, gas- or wood-burning boilers represent a further interesting development (s. Fig. 7.18). Refitting can be carried out within power ranges of more than 60 kW, the prerequisite being that, apart from the constructional characteristics of the old system, a corresponding low pressure is generated by the chimney flue and the boiler temperature needs a minimum return temperature of about 50°C at about 70 °C.

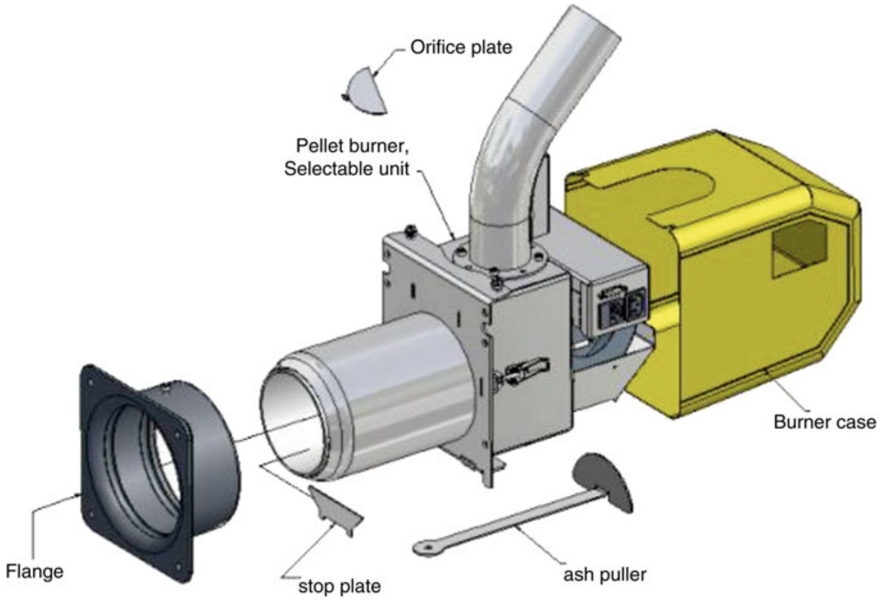

Fig. 7.18 Retrofit pellet burner by Pel-lets Innovative Heiztechnik GmbH [8]

The boiler must be cleaned manually in order to be able to guarantee an efficient heat transfer. This is specified by manufacturers as up to twice a month during the heating period. The amount of work required is assessed as amounting to a few minutes. The burner, which is a tunnel burner, achieves an efficiency of over 90 % using a fully automatic controller. The design largely dispenses with mechanically movable parts in order to keep the maintenance effort as low as possible. With this boiler, the fuel can be changed, using wood pellets, natural gas or heating oil depending on the burner installed in the boiler. Naturally, a boiler without burner can be procured, if necessary, and the burner can be correspondingly retrofitted.

Special boilers are constructed as a unit having three chambers located underneath one another. The upper two chambers are used for wood gasification as is known from the traditional gasification boilers. The third, lowermost chamber is provided with the respective burner at its front and clad with ceramics for an optimum quality of combustion. Both systems are separated from one another by a water jacket so that they have little effect on one another and, as a result, the boiler achieves a high efficiency when heated with individual fuels.

As an alternative to the pure pellet boiler, some manufacturers offer combinations which can burn split logs and wood pellets. The boilers have the advantage that a full-fledged operation of the system is possible with both types of fuel. This allows a higher degree of fuel flexibility to be achieved. The user can choose between manual split-log feeding or automatic pellet feeding. The pellets are here fed in automatically and burnt by gravity-fed fire techniques as described before.

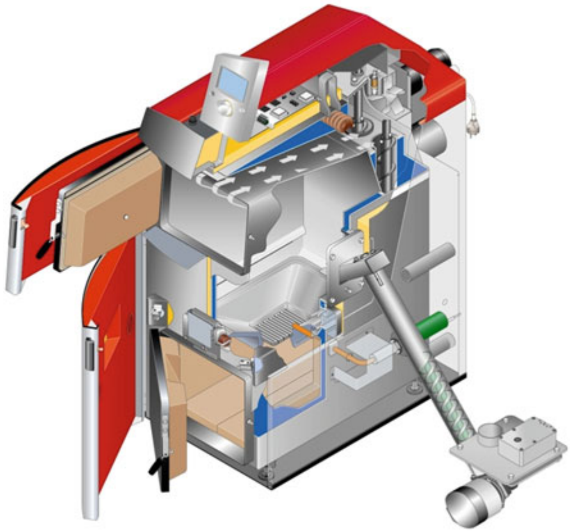

Fig. 7.19 Therminator II type split-log/pellets combination boiler with lambda sensor and speed-controlled blower by Solarfocus [9]

The combustion air needed in the different power ranges is mostly sucked in by a speed-controlled induced-draft blower. Some manufacturers even offer the boilers with lambda control to provide for an optimized combustion control. The primary air is conducted into the fire bed whilst the secondary air is added at the tips of the flames. This covers a further power range, reducing starting processes. Depending on the manufacturer, the boilers achieve efficiencies of up to just above 90 % according to manufacturers' information (Fig. 7.19).

This combination of pellet boiler and corresponding buffer reservoir makes the wood pellet boiler into an ideal partner for solar heat generation. Many suppliers provide for solar energy to be combined with the energy from wood. Intelligent controllers ensure that the yield from solar energy is as high as possible whilst simultaneously optimizing the boiler operation. The following figure thus shows how a pellet boiler is integrated into a solar heat generation circuit.

In the integration of the control system into the heating system, changing outside temperatures are taken into consideration as well as personal living habits. The pellet boiler is started only when the required heating energy can no longer be supplied completely by the solar system. This prevents/reduces any uneconomic burner startup. The decisive factor for the operation and the effective utilization of the solar energy is the control technology which should handled by one controller for both systems. Buffer reservoir and pellet boiler are one unit in the above illustration, which reduces the expenditure for installation. The system can be operated with and without solar module. If the proportion of solar coverage is to be increased, an additional buffer reservoir would have to be used as is already shown in the figure below (Fig. 7.20).

Depending on the system design, solar energy can save up to 30 % of the fuel consumption. The size of the solar system depends on how much is to be invested,

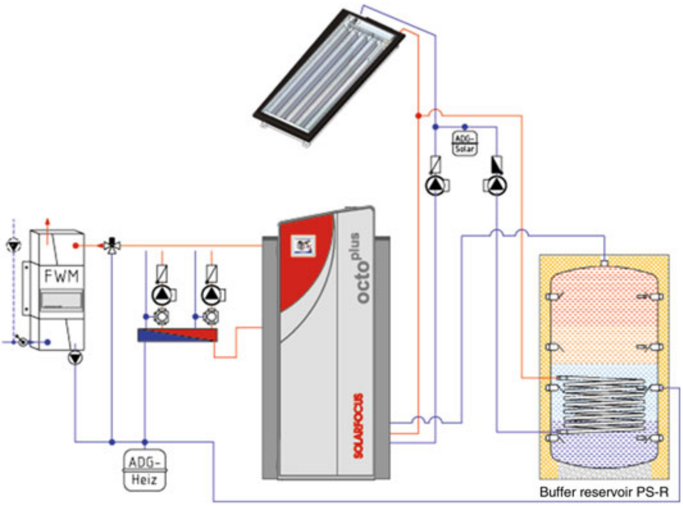

Fig. 7.20 Heating circuit with pellet boiler, solar technology and additional buffer reservoir by Solarfocus [9]

on the size of the available assembly space and how well the house is insulated. The area required for the collectors depends on the technology used. Vacuum collectors need less area than flat-plate collectors. The solar support for the heating system requires about 1.5 m^2 per person in the case of flat-plate collectors. To provide hot water, it would be 1.5 m^2 per person. When vacuum collectors are used, the areas are reduced to about 3 and 1 m^2 per person (Fig. 7.21).

In conclusion of the subject of small heating systems, the dust emissions will be discussed, a small proportion of which is contributed by wood-burning heating systems. However, the thresholds are becoming ever more exacting in this respect. Particulate matter (fine dust) consists of minute particles having a diameter of less than ten thousandth of a millimeter, corresponding to about one tenth of the diameter of a human hair. The particles, also called PM10, are largely released by combustion processes. The boilers themselves have reached a very high level with regard to the reduction of dust emissions. If the dust particles are not removed with the ashes, however, they will pass into the environmental air. The company Rüegg Cheminée AG has developed a particle filter especially designed for the conditions of a pellet boiler. This development thus meets the requirement for an amendment to the 1st Federal Immission Control Act (1. BImSchV) and the planned tightening of the emission values for particulate matter. The so-called Zumik®on particle separator can reduce the emission of particulate matter from wood-fired heating systems distinctly and contributes to air pollution control. It is suitable for retrofitting.

The technology applied differs significantly from mechanical filtration. A high voltage of up to 20,000 V is applied to a thin electrode in the centre of the flue gas pipe. This produces charged particles, so-called charge carriers and gas ions, in the flue gas flow. The gas ions become attached to the fine-dust particles

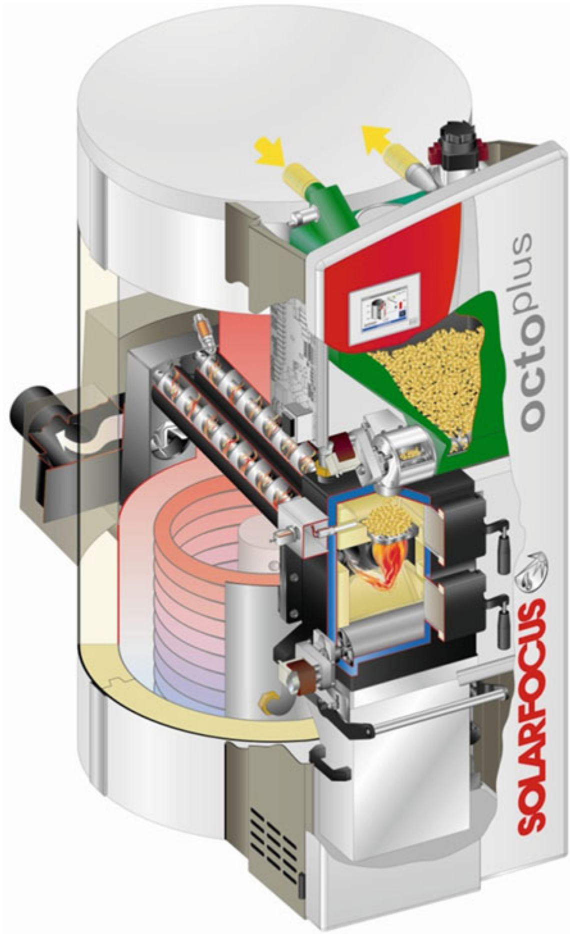

Fig. 7.21 Pellet boiler by Solarfocus with integrated buffer reservoir [9]

which causes these to become charged up. Due to the electrostatic forces, the particles charged in this way are moved towards the inner wall of the flue gas pipe where they are deposited. The charge of the particles is neutralized during the process of deposition. Nevertheless, the particles continue to adhere to the flue gas pipe due to their mechanical interlocking. The layer of dust building up in this manner can be cleaned off safely and easily by the chimney sweep using conventional cleaning techniques. The system is cooled and kept clean by means of a minimal air supply (5 m^3/h max) which leads to increased operational reliability and a longer service life.

The unit consists essentially of three components:

1. The filter insert with electrode and thermosensor is mounted as a complete unit on the flue gas line, the electrode being inserted into the center of the flue gas pipe through a defined opening.

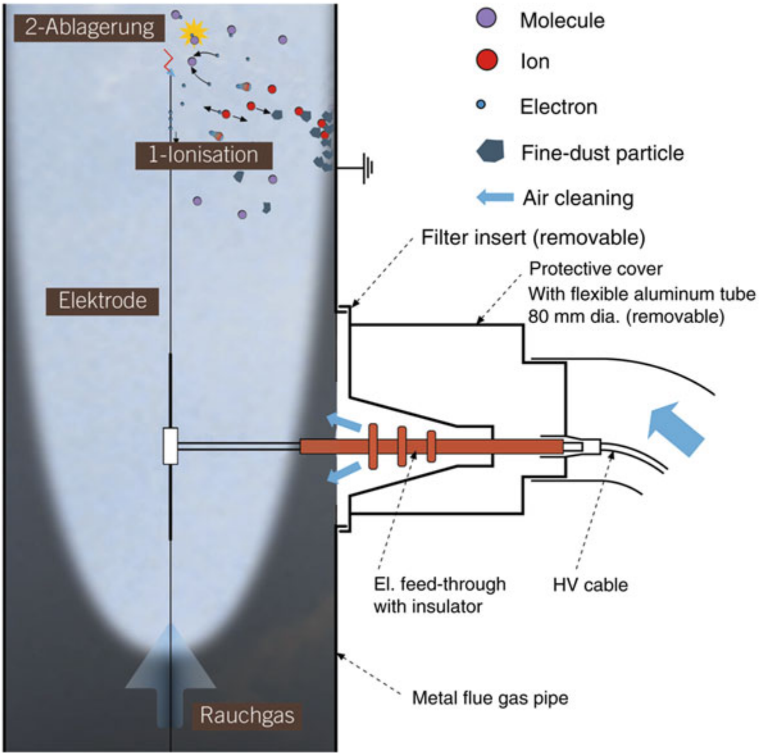

Fig. 7.22 Built-in particle separator in the flue gas pipe, by Rüegg Cheminée AG [10]

2. The feed line is responsible for the cables and, in certain applications, for carrying the cleaning-air.
3. The control unit supplies the electrode with the optimum high voltage for the system and switches the system on or off at the appropriate flue gas temperature.

The particle separator is suitable for automatic wood-fired heating systems (pellets, wood logs or shavings) with a lower power than 70 kW and flue gas pipe diameters of from 150 to 400 mm. According to manufacture's information, systems equipped with particle separators achieved separation effects of 60–90 % in practice (Fig. 7.22).

Although the particle separator can be retrofitted as a secondary measure, the following prerequisites must be considered for its installation:

– The flue gas pipe after the filter insert must be ceramic or of metal.
– The adapter tube around the electrode must be made of metal.
– The separation length after the filter must be at least 2 m.
– Flue gas pipe diameter = 150 to 400 mm.

  – Access to the filter in its built-in state must be guaranteed.
  – Cleaning air supply must always be guaranteed (~5 m^3/h)

– Flue gas temperatures <400°C
– Heating power <35 kW for wood logs, up to 70 kW max. for pellet and shavings systems.
– 230 V mains connection.

The particle separator is suitable both for hand-charged log-fired heating systems and for automatically charged pellet- and chip-fired heating systems. Apart from the technology described here, other manufacturers, including boiler manufacturers, are offering alternative options for reducing dust: (Fig. 7.23)

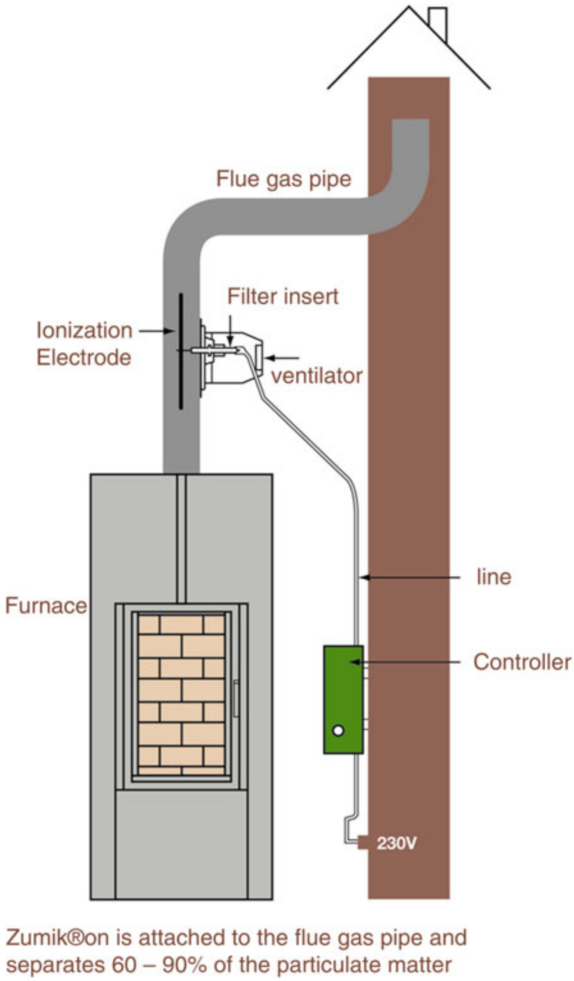

Fig. 7.23 Installation diagram for the particle filter by Rüegg Cheminée AG [8, 10]

7.3 Medium-Sized Heating Systems

This chapter deals especially with pellet heating systems in the 0.2 to 5 MW power range. This range is used in heating relatively large objects such as halls used commercially and industrially. These systems can also be applied to supplying industrial production plants with process heat. In contrast to pure hall heating, supplying process heat provides a higher annual rate of utilization.

It is also possible to have a combination of heating and process heat supply. Here, too, the pellet heating system represents a competitive alternative to the fuel–oil- and natural-gas-fired heating systems previously used. Most of the systems described can burn not only wood pellets but also dry wood chips. Proven heating systems include:

- Rotary firing systems
- Nozzle-grate firing systems
- Underfeed firing systems
- Feed grate firing systems
- Cyclone firing systems
- Feed grate with combustion tray
- Other systems and combinations of these.

In the sections following, the rotary firing systems, nozzle-grate firing systems and underfeed firing systems will be described in grater detail. The feed grate firing system is the one known best and is not used only for wood pellets. Its field of application extends from the medium-sized heating system for wood pellets and wood chips through waste wood up to heavy refuse incineration plants.

In the rotary firing system, a feed screw conducts the wood fuel continuously onto a moving grate on which the fuel is gasified with a lambda-controlled primary-air supply. The gasification takes place with a lack of air. Rising combustion gases are mixed with atomized secondary air with an imparted angular momentum using rotary blowers, ensuring perfect mixing with the combustion gases. The system is used within a power range of from about 100 to 600 kW for dry fuel (Fig. 7.24).

The nozzle grate, as employed by the company Weiss Kessel and eminently suitable for wood pellets, is formed by a water-cooled screw with mounted cast ring elements, extending longitudinally through the combustion chamber. Due to the slow rotational movement of the nozzle grate, the fuel fed in is stoked with a simultaneous injection of primary air and ash is removed continuously. The result is a relatively quiet combustion. Since the primary air is not used here at the same time as cooling air for the nozzle grate, extensive possibilities for adjusting the fuel mixture are available. This optimal stirring of the fuel/air mixture ensures that the system adheres to the applicable emission limits and stays below them.

The system consists of the following components:

- Combustion chamber
- Feed screw

Fig. 7.24 Pellet firing system according to the rotary firing system principle. Type Pyrot by KÖB/ Viessmann [11]

– Nozzle grate
– Graduated air supply
– Separation of combustion air zones matching the temporal and local combustion sequence
– Large fire and burnout space to meet the requirements, with long dwell time of the combustion products in an area of optimum temperature.
– Inspection hole
– Maintenance/cleaning door
– Continuous ash removal by ash screw

In its arrangement with combustion in the fire tube, the boiler is available with a power of between 840 and 2,000 kW. The power can be increased to 3,150 kW with a firing system built underneath and two nozzle grates.

The power is controlled continuously at between 40 and 100 % load. The negative combustion chamber pressure is maintained as is usual by an induced-draft fan controlled by a frequency converter. The fuel/air ratio is corrected via the O^2 controller and the combustion chamber temperature. The firing system is connected to the boiler. The Turbocrat boiler is constructed as a horizontally mounted three-pass boiler unit with fire duct, reversing chamber, protective jacket with floors and welded-in flue tubes. A deposition of flue ash in the flue tubes is counteracted by the high flue gas velocity. The automatic compressed-air impulse cleaning facility for the flue gas tubes in operation reduces the manual cleaning intervals of the boiler flues and thus also shutdown periods. The firing system as originally developed for fuels having a low ash softening temperature and high calorific (heating) value. The boiler was used initially in the furniture industry for burning chipboard residues and

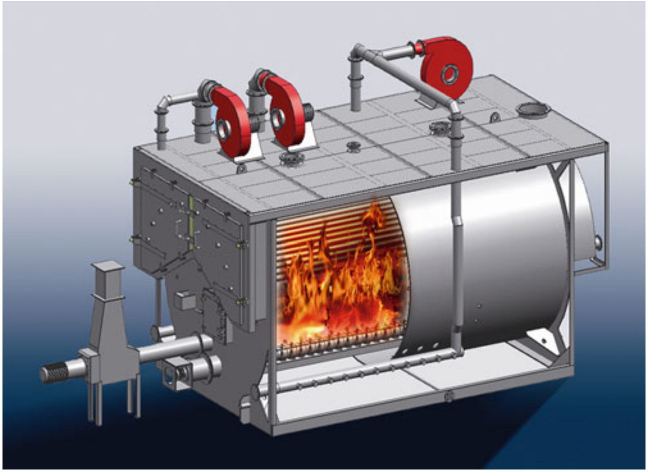

Fig. 7.25 Nozzle grate boiler by Weiss Kessel [12]

a mixture of grinding swarf and shavings. Today, the boiler is suitable for burning wood chips in accordance with DIN 51 731. However, its flexibility also allows for the admixture of wood chips and digestates. It is also possible to use lignite or peat sticks. Fuels which do not meet the requirements of the German Federal Immission Control Ordinance (Bundesimmissionsschutzverordnung—BimSchV) require tests in the individual case and adaptation work on there flue gas side (Fig. 7.25).

The system is built as a containerized module by the company of Mann Naturenergie (s. Fig. 7.26). In an upper container, the wood pellets are stored which pass by way of a feed screw into the fuel feeder of the firing system/boiler unit located in the lower container. In the container of the example quoted below, a Weiss firing system with a power of 880 kW is installed. One such system is in operation in the Hohenlohe Hospital in Öhringen. The system attains a total weight of about 80 tons completely filled.

As a further example, a boiler installation with underfeed firing system will be discussed. The fuel is supplied to the installation (see figure below) via a feed screw. As primary air is supplied, combustion starts in the fire tray provided for this purpose. The further combustion takes place in the combustion chamber in which secondary air, also provided for post-combustion, is also supplied. A burnout grate provides for a good burnout before the ash is automatically disposed of. The grate ashes removed are collected in the container provided for them and can be discharged at a later time. A bricked-up arch isolates the combustion chamber from the downstream hot water or steam generator. The heat contained in the flue gas is transferred to the water or steam operating medium by means of a three-pass heat exchanger. The heat exchanger and the combustion chamber can be accessed via the common front door. The exhaust fan installed ensures that the flue gases will escape and that the necessary negative pressure is maintained within the installation (Fig. 7.27).

Fig. 7.26 880 kW pellet boiler by Weiss in a container, supplied by Mann Naturenergie GmbH & Co. KG, Langenbach [13]

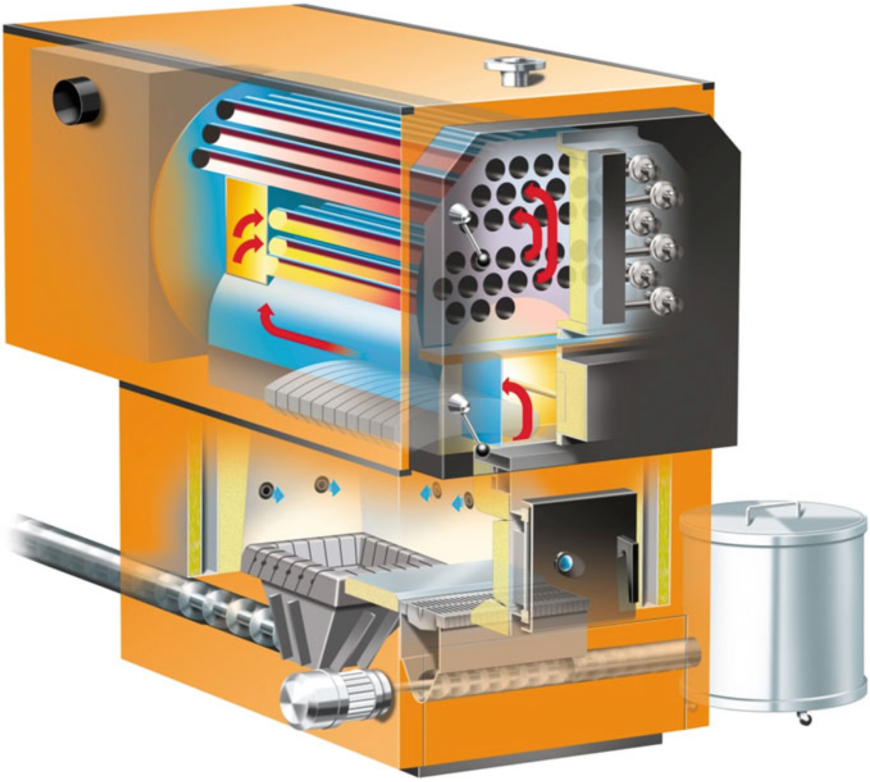

Fig. 7.27 UTSP type underfeed grate firing system for wood pellets from 180 to 900 kW power by SCHMID Holzfeuerungen [14]

In the case of the feed grate, the material to be burnt is delivered from the rear end of the firing system or from the head end. The grate rods are constructed to overlap one another which minimizes the amount of material falling through the grate. The grate is also designed in such a way that the primary air can be distributed cleanly and uniformly in various zones and, as a result, a quiet undisturbed gasification zone is produced. In larger installations, the grate is divided into different zones, mostly three (sintering trolley). The sintering trolleys are driven hydraulically in most cases, the intervals of motion being adapted automatically to the performance. An electrical drive can be used as an alternative. With respect to the bricking up of the combustion chamber, the same applies as before. The secondary air supplied in the combustion chamber and to the burnout flue provides for a graduated combustion for an optimum burnout and a reduction in the NOx value in the flue gases. The ash is transported slowly by the feed grate to the end of the grate where it is supplied to the automatic ash removal system. Underneath the grate, undergrade ash removal is used, depending on supplier and application. The parts which fall through the grate are supplied to an ash screw and, together with the remaining ash, are supplied directly into an ash container. The grate-fired furnace is the most flexible alternative in this power range and is used in the higher range of power.

The figure below represents a pellet boiler based on the feed grate by the Kohlbach company. The plant can be used in a power range of between 1,000 and 6,000 kW. As and alternative to wood pellets, wood chips of G50 quality, having a maximum water content of 20 %, can be used. Due to the high calorific value of the wood pellets, the grate loading is 912 kW/m^2 and the combustion chamber loading is 341 kW/m^2. These values result in a correspondingly short feed grate, the grate not being driven hydraulically but electrically in this case (Figs. 7.28 and 7.29).

Fig. 7.28 Pellet boiler based on a 1,000 kW feed grate firing system with adjoining pellet silo by Kohlbach, Austria [15]

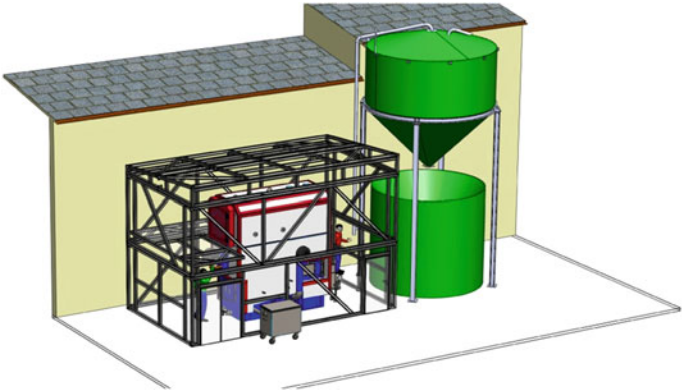

Fig. 7.29 Pellet boiler based on a 1,000 kW feed grate firing system with adjoining pellet silo by Kohlbach, Austria [15]

7.4 Large Heating Systems

In the series of large heating systems, it is mainly the technologies of grate firing, fluidized-bed firing and dust firing for solid fuels which are being used. Grate-fired systems are mostly used in smaller power classes than fluidized-bed systems. When wood pellets and untreated wood are used, the emission limits to be observed are restricted to nitrogen oxides (NOx), carbon monoxide (CO) and dust. The formation of CO and NOx is counteracted by so-called primary measures when it occurs. These measures can be the recirculation of flue gas and thus reduction in the combustion temperature, the grading of the combustion process (in the case of dust firing systems) or even the introduction of additives. Additives are generally used with fuels containing chlorine, sulphur or heavy metals. They can be dispensed with in the case of untreated wood, as a rule. Using these primary measures, the legal regulations for gaseous emissions can be observed. To observe the regulations on dust emissions, multicyclones and fabric or electric filters are additionally used.

Grate-fired systems

The grate-fired system was discussed briefly in the preceding chapter. The fuel is brought onto the grate by feed screws, flaps, gates or the like and burns there on the back of the grate bars. Grates can be constructed in different ways. There is, for instance, the flat grate with a horizontal arrangement, the sloping grate, the stepped grate, the walking grate, the oscillating grate, roller grate (e.g., rubbish combustion) etc. Grates for fuels rich in heating value are water-cooled in order to minimize the wear of the grate surfaces whereas grates for low-calorie fuels are air-cooled.

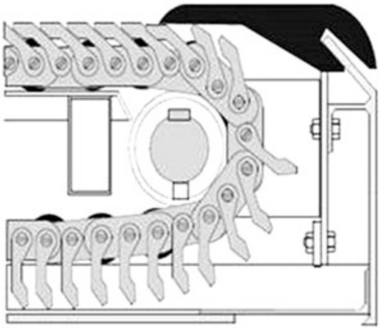

Fig. 7.30 Rear end of a walking shingle grate (folding grate) [18]

The grate bars must be close enough together that, although the fuel can not fall through, the ash can fall downward. Furthermore, the primary combustion air is provided from below through the grate bars. The closer the bars are together, the greater the resistance to the combustion air. The cooling by the combustion air along the two bar sides and at the bar end is decisive for the life of the grate bars. In the case of high-calorie fuels, such as wood pellets, the surface of the bars which is cooled by air, must be constructed to be as large as possible. In the case of the grate, the cross-section necessary for the combustion air (free grate area), the cooling of the grate bars, the layer height and grain size of the fuel and the negative pressure required in the combustion chamber must be harmonically matched to one another. The delivery of the fuel onto the grate must be such that a uniform distribution on the grate is ensured. Otherwise, the air distribution is affected by the different counterpressure which is reflected by the pattern of the fire and thus by the efficiency and the wear.

The walking grate is often used in combination with spreader feeding. The grate bars can be arranged in the direction of travel or transversely to the direction of travel of the grate (folding or shingle grate). The grate bars are arranged to be interlocked and are driven by chains on the sides, similar to a wide scraper chain conveyor. In the top run, the fuel is delivered and combustion takes place. In the bottom run, the grate bars in the folding grate fold vertically downward which promotes cleaning and cooling. Problems which are not expected with pellets exist in the case of fuels which stick to the grate and prevent folding in the bottom run (Fig. 7.30).

The stepped grate from the figure below is used frequently. Each second row of the grate is moved forward and back by hydraulic drives which transports the fuel downward and stokes the fire. The fuel is subjected to three method steps on the grate. After the fuel has been delivered it is first dried. This is done by preheated air and mainly by the combustion gases which are conducted under control over the freshly delivered fuel fraction. Following this, the gaseous components are expelled and ignited and combustion takes place. In the last zone burnout occurs until the ash falls into the ash removal system at the end of the grate (Fig. 7.31).

Fig. 7.31 Stepped grate

In the oscillating grate, the supporting substructure is formed by steam pipes of the water-steam cycle. The grate bars are hooked in alongside the pipes and form the combustion surface. An electric motor which is connected to the supporting pendulum of the grate via an eccentric shaft imparts an oscillating movement of a few millimeters to the grate. This technology is used frequently in straw-fired heating systems.

In direct firing systems, the air acts as the means of conveyance. Wood pellets must be pulverized before they are blown in. The pellets are frequently ground up in such a way that the same grain size is produced as that of the chips before they were palletized. This grain size is in most cases a decisive parameter for the burners and must be considered already in the production process of the pellets. This parameter is often agreed contractually. The hammer mill preceding the pellet presses influences the grain size of the shavings with its sieve insert. It is, therefore, of significance for the pellet production that this sieve has a perforation which reduces the size of the shavings before pelletization in such a way that the fuel specification demanded by the customer is met. After they have been blown in, the wood particles burn in the air. The larger particles pass onto the grate and burn out.

Fig. 7.32 Grate bars of a stepped grate, side view [16]

Depending on the blowing-in and on the grain size, the grate may be occupied unevenly as a result of which leaked air may be introduced. A comparative advantage is provided by the simple possibility of controlling the quantity of fuel (Fig. 7.32).

Fluidized-bed firing system

Apart from the combustion, drying and cooling of solids are further fields of application for fluidized beds. Fluidized-bed firing systems cover the range of capacity of grate-fired systems and beyond. Whereas a grate-fired system is designed for a limited spectrum of fuels, the fluidized-bed exhibits greater flexibility. Different fuels having a high proportion of ballast can be burnt at the same time. Other advantages of the fluidized-bed are lower NOx emissions due to lower combustion chamber temperatures and a lower specific boiler volume per MW system heat output.

In principle, a distinction is made between a stationary fluidized-bed and a circulating fluidized-bed. The latter has the advantages of better heat transfer coefficients, more homogeneous fuel distribution, more effective fuel conversion and faster load acceptance rates. However, it requires higher investments, justifying the expenditure for large-sized systems.

In the fluidized-bed firing system, an inert material, mostly ash and/or sand, is placed as carrier material on a nozzle floor of metallic or ceramic materials. The height of the layer is determined by the permissible backpressure. The combustion

Fig. 7.33 Nozzle floor of a fluidized-bed firing system [16]

air pressed through the nozzle floor stirs up the bed and keeps it in a state of suspension.

In the circulating fluidized-bed, the material of the bed is entrained by the nozzle air. It stretches out over the entire reactor height and is carried out of it. This is achieved by having higher incoming flow rates than in the case of the stationary fluidized-bed. Following the first pass, the bed material is separated from the flue gas in the cyclone and supplied to the fluidized-bed again. The high flow rates as well as the higher dwell times of the fuel within the combustion chamber lead to a higher throughput of material and an increased burnout. It must be noted that the circulating fluidized-bed sets higher demands with respect to the grain sizes to be adhered to than the stationary fluidized-bed, with a correspondingly increased processing expenditure (Fig. 7.33).

One disadvantage of the fluidized-bed firing system which has already been addressed is that higher demands are made on the grain size of the fuel. Only small particles can be used. Excessive sizes, stones and other foreign bodies accumulate on the nozzle floor. This can produce a non-uniform air distribution and thus unequal bed temperatures, with the possible result of the plant having to be shut down and emptied. For this reason, appropriate safety measures for separating excess lengths and extraneous materials must be integrated along the path of the fuel from fuel bunker to boiler entry (Fig. 7.34).

Fig. 7.34 Circulating fluidized-bed firing system by Metso Power [16]

Spreader feeding

The so-called spreader feeding is a further firing system technology. Similar to the circulating-type fluidized-bed, it makes higher demands on the processing of the fuels than does, e.g., grate firing. From the processing system, the fuels are transported into a number of feed hoppers from where the fuel is supplied to the spinner wheels via several feed screws and rotary feeders. In contrast to grate firing and fluidized-bed firing, it is possible with spreader feeding to deliver different fuel fractions separately into the combustion chamber via the spinner wheels

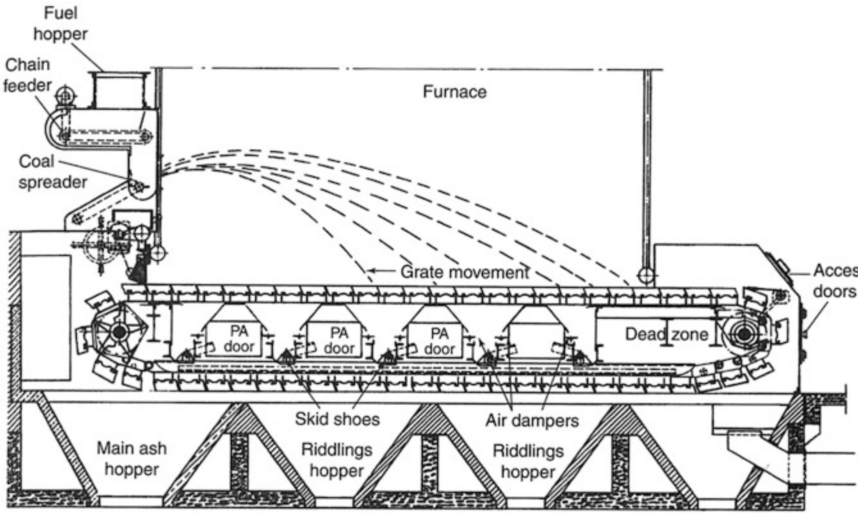

Fig. 7.35 Spreader feeding with walking grate [16]

which throw the fuel into the combustion chamber. The number of spinner wheels depends primarily on the plant size. Due to this type of delivery, the firebed is relatively flat and can thus respond quickly to load changes. Given relatively small particles, the fuel is dried already in the airborne phase, resulting in quicker degassing and ignition of the fuel on the grate. The grate loading can thus be increased to up to 50 % in comparison with grate firing. The combustion spreads out over the entire grate area. Apart from the set trajectories of the spinner wheels, the delivery of primary air underneath the grate and corresponding secondary-air volumes for post-combustion and recirculating flue gas volumes are important criteria for controlling the fire. Similar to the fluidized bed, the combustion chamber temperatures are below 1,000°C, virtually avoiding slagging. The grate provides for a controlled movement of the fuel and stokes the combustion. It also removes the ash. The fuel moves in the opposite direction to that of delivery (Fig. 7.35).

7.5 Co-Incineration of Wood Pellets

Not all of the systems described before provide for the exclusive combustion of wood pellets. Whilst small heating systems are mostly designed to be used purely with wood pellets, this specialization to a single type of fuel diminishes with increasing plant size. Many systems providing for the co-incineration of wood pellets with wood shavings or alternatively both are available already among medium-sized heating systems. The co-incineration of pellets, or generally of biomass, in existing combined brown-coal- or black-coal-fired heat and power plants (large heating systems) is one of the options for reducing the CO_2 emissions. After overcoming initial obstacles, problems of logistics, storage and fuel processing have been defused by the power stations which are already using wood pellets. Among others, the following problems occurred:

– Slagging,
– Corrosion phenomena at the superheater,
– Accelerated deactivation of the catalyzers,
– Use of the ashes in the cement and concrete industry.

The above problems were found to be negligible with a co-incineration of 5–10 % wood pellets.

The largest quantities of pellets are co-ignited today, and will be presumably in the future, in large heating systems, the motivation being the savings in CO_2 when burning wood pellets in comparison with, e.g., coal. In the context of national emission trading, wood is considered to be CO_2-neutral. If the operator and his plant are subject to emission trading, he will thus save volumes of CO_2 certificates to be presented. The use of pellets has to be considered economically, therefore, not only with respect to the costs of other fuels such as coal but also including the saving in CO_2, depending on application. From a technical point of view, there is nothing in the industry and energy supplies that argues against the co-ignition of wood pellets in large heating systems. From the point of view of emission trading it must even be welcomed since plants for generating heat and power are obliged to participate in emission trading above a thermal output of 20 MW and thus the obligation to supply CO_2 certificates could be lessened by the use of biogenic fuels. It remains to be seen whether national emission trading will continue to contribute to an increase in the proportion of co-ignition of pellets in large heating systems in the future.

Large quantities of pellets are co-ignited in pulverized-coal firing systems. This technology can be found in plants producing more than 100 t/h up to over 2,000 t/h steam. There are individual plants (some of them as pilot project) with lower capacities down to a few t/h steam. The pulverized-coal firing system thus follows on from the maximum power capacity of the grate-fired heating system. Apart from being able to implement larger steam generators, the background to the development of this firing technology is formed by its good control characteristics and the possibility of using coals unsuitable for grates.

The fuel is ground into dust in coal pulverizers, blown into tubular burners and burnt predominantly or exclusively in a suspended state. For the burnout, cooling-off and discharging of the ash, a walking-type or feed grate is integrated additionally or partially. The combustion chamber is constructed in such a way that the combustion temperature is either below or above the ash fusion temperature. In the case of the latter, the bed ash or slag is discharged in a liquid state (slag-tap furnace). Due to the high temperatures, more nitric oxides are produced, the maintenance costs are higher due to wear and the construction is more expensive.

The pulverized coal is conveyed to the burners by blowers using hot air or recycled flue gas. Flue gas is used when the hot air is not sufficient for predrying the fuels or air can lead to a self-ignition of the fuel due to too high an oxygen content. The pulverizers (mills) are grouped into roller, impact, beater and gravity mills.

Before they are blown in, the pellets are pulverized like the coal, The specification of the power station operator must, therefore, be adhered to. This is based on the grain size of the pellets after pulverization. The grain size then corresponds approximately to the grain size after the hammer mill, which are arranged before the presses in the production process. The sieve of the hammer mill must, therefore, be matched to the desired grain size, if necessary.

Co-incineration is currently carried out mainly in Belgium, the Netherlands and Great Britain due to the CO_2 mechanisms described above.

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Chapter 8
Protection Against Fire and Explosions

Wood pellets are alternative energy sources which can be produced in consistent quality and are easily transported. They can be converted into other forms of energy by combustion, both industrially and in the private domain. The pellets are made from shavings containing a not inconsiderable proportion of fine fractions and organic binding agents.

Under suitable circumstances, the energy contained in the pellets can be released already during the production process which results in unwanted fire and explosion events. An Internet search using the keywords "explosion" and "wood pellets" will supply sufficient examples of such events.

Apart from human lives, this also endangers material assets and the environment so that the manufacture of wood pellets must include measures for the protection against fire and explosions.

8.1 Requirements of the Guidelines

In the last decade of the 20th century, explosion prevention and protection have been regulated anew by two fundamental guidelines in Europe and thus in the member states.

Guideline 94/9/EG [1] (implemented in the Explosion Prevention Ordinance in Germany [2]) is directed mainly at manufacturers of devices and protective systems. The aim is the introduction of safe devices and components of which the plants are ultimately composed. As a basic requirement, the devices must be designed in such a way that explosions which can lead to a dangerous situation can be stopped and/or the effective range of the explosion can be limited to a sufficiently safe degree. The proof that the basic safety objectives of Guideline 94/9/EG [1] are being met must be provided as part of a risk assessment. Compliance with the safety objectives is subsequently certified by the manufacturer.

S. Döring, *Power from Pellets*, DOI: 10.1007/978-3-642-19962-2_8,

To guarantee the free traffic of goods within Europe, the requirements of Guideline 94/9/EG [1]represent maximum requirements, i.e. no member country may set higher demands for devices or protective systems.

As part of their duty of care towards their employees, the employers must guarantee safe working conditions. With regard to explosion hazards, these requirements are stated in concrete terms in Guideline 1999/92/EG [3] and in its German version in the Occupational Safety Ordinance [4]. The employer has to identify potential explosion hazards as part of a risk assessment, evaluate them and provide the necessary countermeasures. The results of the risk assessment must be described in an explosion protection document. This document must be available both for new plants and for existing ones.

In contrast to Guideline 94/9/EG [1], Guideline 1999/92/EG [3] defines only minimum requirements so that each member country can set more extensive requirements regarding occupational safety. The result is that explosion protection is not controlled uniformly even though the intentions were different.

8.2 Formulation of the Protection Concept

Due to their organic substance and a relative grain size of less than 500 μm, the volumes of wood dust and binding agents occurring in wood pellet production must be graded as potentially explosive. The explosion control concept required as a result has the aim of breaking through the so-called triangle of fire of fuel, air and ignition source (Fig. 8.1).

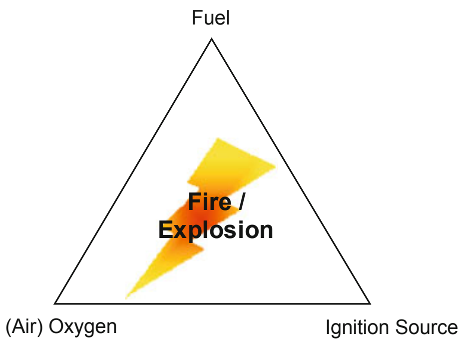

Fig. 8.1 Triangle of hazards of explosion protection

This is possible by applying the following principles:

– Primary explosion protection: The occurrence of potentially explosive mixtures is avoided with sufficient reliability. This can be done, e.g., by displacing the oxygen from the system which, however, is not economic in wood pellet plants because of their high throughputs.

– Secondary explosion protection: The occurrence of potentially explosive mixtures is permitted. Depending on the probability of the occurrence of such mixtures, requirements are set for the avoidance of effective ignition sources. In this context, the 13 ignition sources from DIN EN 1127-1 [5] and/or TRBS 2152-3 [6], respectively, must be discussed. This principle of protection is predominantly applied in wood pellet plants since ignition sources can be avoided in most cases due to the relative lack of combustibility of the wood and binding agent dusts.
– Tertiary explosion protection: The occurrence of potentially explosive mixtures and the simultaneous occurrence of effective ignition sources is permitted. There will be an explosion but the effects and dimensions of the explosion will be limited. This principle of protection is typically applied to special plant components such as hammer mills or silo cells.

The principles of protection mentioned above are suitable for ensuring the required safety both individually and in combination. In this context, it is of importance that attention be paid to the interaction between the selected concept of protection and the operating characteristics of the plant. Safety concepts which interfere permanently with the operating characteristics will not be accepted in the long run. If technical measures are not maintained appropriately, they are valueless. This will even increase the risk since reliance is placed on a safety which is only imaginary. Every technical safety concept must, therefore, be underpinned by organisational measures. This includes maintenance instructions, operating instructions for the behaviour in certain situations (No Smoking signs, Permission to light fires) and training sessions in which the employees are acquainted with how to handle the potential hazards and are informed about the countermeasures installed.

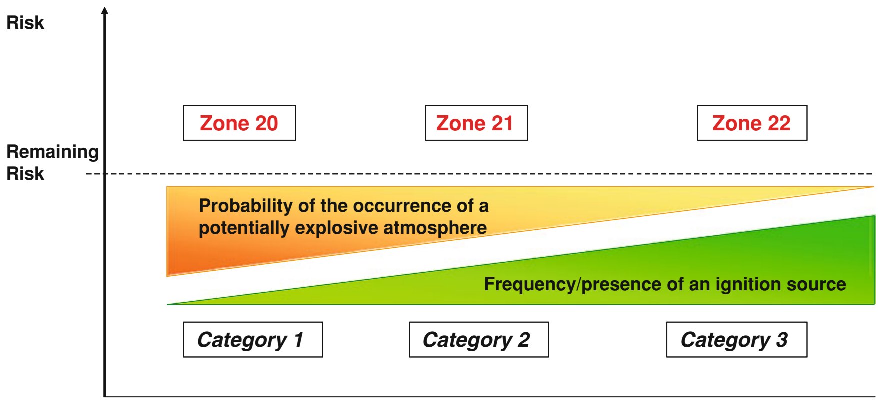

Fig. 8.2 Relationship between Zone and CategoryCategory

The required safety concepts do not have the aim of achieving a zero risk but of limiting the remaining risk of fire and explosion to a socially acceptable residual risk.

The probabilities of the occurrence of potentially explosive mixtures are here placed in relation to the probability of the occurrence of effective ignition sources (Fig. 8.2).

Production plants for wood pellets can be generally grouped into three areas with respect to fire and explosion hazards:

– Area in front of the dryer: The material is still moist and coarse here so that mainly a fire hazard can be expected here. Residues of material which accumulate outside the plant can dry and can thus be combustible. The risk of explosion is rather negligible, however, even with dried material.
– Area from the dryer to the pellet presses: The material is dried here to a residual moisture of appr. 10 % and milled to a median value of appr. 3–4 mm for the pressing. Explosion hazards are, therefore, predominant in this area. Depending on the specific boundary conditions, however, fire hazards must also be taken into consideration (e.g. deposits on cable supports or motors).
– Area after the presses: Due to the abrasion or fracture of pellets, a greater distribution of grain sizes must be expected here so that the risks of fire or explosion must be evaluated to be equal. However the risk of explosion can be dominant due to sievings leading to a separation and accumulation of fine fractions. In the area of the presses, the fire hazard dominates because of the high energy input.

Working out suitable safety measures requires knowledge of the physical/chemical material properties of the wood types and binding agents. These are described in the form of characteristic safety numbers (STK). The characteristic numbers are not pure material constants. Instead, dust exhibits the following dependence on the process parameters:

– Temperature: At a higher temperature, the entire system is at a higher energy level and less energy is needed for the propagation and maintenance of an explosion.
– Grain size: Increased fineness results in a more advantageous volume/surface ratio for the propagation of an explosion (Fig. 8.3).
– Moisture: Maintaining an explosion requires less evaporation of water ballast in the case of dry materials (Fig. 8.4).

In addition, the characteristic numbers also depend on the measuring method used. In order to obtain good comparability, the characteristic numbers are determined using standardized measuring methods. The tests for determining the characteristic numbers are optimized with the aim that the characteristic numbers describing the ignitability of a substance assume minimum values and the characteristic numbers describing the effects of explosions assume maximum values. This provides a conservative set of characteristic numbers with which the test-related deviations will not have a negative effect. Due to the above influencing

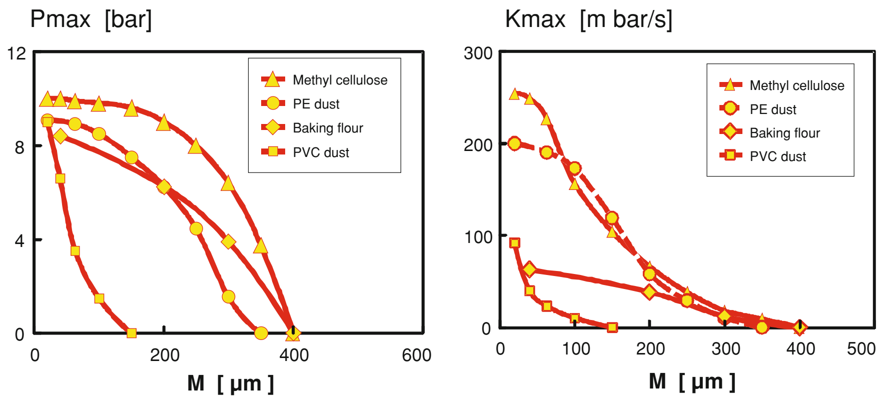

Fig. 8.3 Explosion characteristics as a function of median value/2/

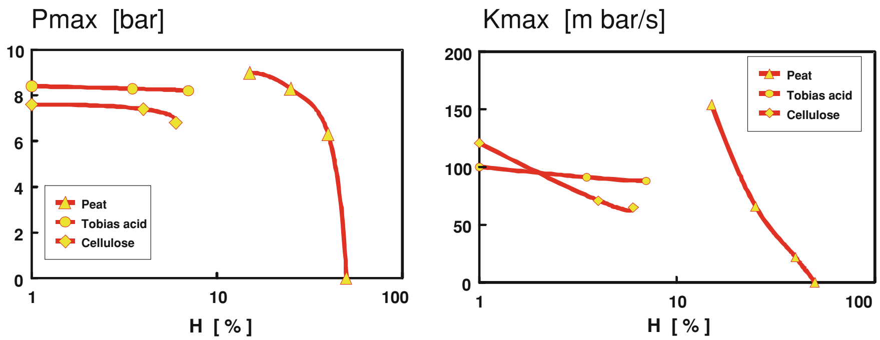

Fig. 8.4 Explosion characteristics as a function of water content/2/

factors, it is only possible in rare cases to calculate safety-related characteristic numbers from other chemical/physical quantities in an inherently consistent way.

Apart from the raw wood materials (wood chips, shavings), native starch is used with the usual moisture content of the product for bonding the fine fractions. The bonding agent used may also be lignin. The precise consistency of the products can be subject to fluctuations since they are products of nature. As a rule, therefore, the safety-related characteristics are estimated conservatively from values obtained from literature. The following values can be obtained from [7] Table 8.1:

Table 8.1 Safety-related characteristics of the raw materials used in the production of wood pellets

Sample	Wood	Lignin	Native starch
Combustibility index	≤5	≤5	≤3
Smoldering temperature	>275 °C	k.G.b. 450 °C	k.G.b. 450 °C
Self-ignition temperature	180 °C	n.i	n.ii
For 400 ml	>30 g/m^3	>15 g/m^3	>30 g/m^3
Lower explosion limit	5–10 kg/m^3	n.i	n.i
Upper explosion limit	>10 mJ	>10 mJ	>10 mJ
Min. ignition energy	>300 °C	>450 °C	>380 °C
Ignition temperature	9 barÜ	8,7 barÜ	10 barÜ
Max. excess explosion pressure			
Dust constant C_D	200 barm/s	208 barm/s	156 barm/s
Dust class	1	2	1

n.i. no information available

8.3 Occurrence of Explosive Atmospheres: Zoning

The safety characteristics show that in the production of wood pellets, substances are used which are potentially explosive. It is, therefore, necessary to evaluate, both for the interior and the exterior of the plants, the probability with which potentially explosive atmospheres will occur (Table 8.2).

Table 8.2 Definition of Zones

Zone	Potentially explosive atmosphere in the form of a cloud of combustible dust contained in the air
20	Continuously present over long periods, or frequently
21	Can form occasionally in normal operation
22	Does not occur normally in normal operation, or only for short periods.

For this purpose, the relevant body of rules, the German Ordinance on Operational Safety (BetrSichV [4], DIN EN 1127-1 [5]) defines the following zones:

The definitions can be interpreted as follows:

- **Zone 20** identifies regions in which potentially explosive dust/air mixtures must be assumed to be present continuously. Apart from processes in which this is actually the case, this also includes processes in which potentially explosive dust/air mixtures occur regularly repetitively over a long period of time (e.g. during a process step lasting several hours) or in short intervals.
- In **Zone 21**, a potentially explosive atmosphere may occasionally occur in normal operation (including start-up and shut-down). However, this occurs at irregular intervals or with reduced probability so that it does not necessarily have to be expected every time.

– In **Zone 22**, potentially explosive dust/air mixtures will not occur in normal operation; only fault-related conditions need to be considered. However, if corresponding faults occur too frequently or such faults are present for too long (e.g. an undetected fault, or inefficient countermeasures are enacted during a fault), higher-level grading is required.
– Layers, deposits and accumulations of combustible dust, lave to be taken into consideration in the zoning like any other cause which can lead to a hazardous atmosphere being formed,

8.3.1 Zoning for Installation Sites

Due to the fact that the installations are designed with adequate dust tightness of the equipment, encapsulated conveyor systems, no openings in normal operation and adequate dimensioning of the aspiration, together with fundamental cleaning measures, dust deposits are normally reduced in the installation site, i.e. outside the equipment. The grading criteria according to DIN 50079-10-2 [8] for Zone 22 are thus met.

General zoning can be dispensed with if the higher-level cleaning requirements represented below are implemented:

– Regular checks, and, if necessary, cleaning, logged for each shift must be guaranteed.
– There must be no recognizable footprints visible on the floor.
– There must be no closed dust blankets which cover paint and structure of equipment or plant components.

However, the periphery of 1 m around open plant facilities must be allocated to Zone 22.

The cleaning devices to be used should be explosion-protected, mobile or stationary vacuum cleaners. Large accumulations of material, e.g. after a manual cleaning out of presses, should be eliminated using a broom and shovel. Blowing it away with compressed air is not permitted in principle. On the one hand, dust clouds are formed which can also be locally potentially explosive and, on the other hand, the dust is distributed very finely and can become a fire hazard in the case of dust accumulating e.g. on cable trays.

The operator is obliged to ensure, by means of suitable organisational measures (operating instruction with regular control by superiors) that the measures taken are adhered to.

In outdoor installations, dedusting due to weather conditions is a factor so that initially unzoned grading of the outdoor installation must be assumed.

This, therefore, results in the basic zonal allocations for the listed areas in dependence on the criteria presented (Table 8.3).

Table 8.3 Zoning for Installation Sites

Area/criterion	BetrSichV zone
Within buildings	
+ Basic cleaning requirements are implemented	22
+ Increased cleaning requirements are met	Unzoned
+ Within a radius of 1 m around operationally openable facilities	22
Outdoor installations (weather-induced dedusting)	Unzoned

8.3.2 Zoning for Plant Areas in Contact with the Product

The zoning of the interior of the plant components must take into account the grain size distribution and the moisture of the wood parts handled.

- Silo: To standardize the production, silos are used as buffers or stores. The resultant zone is dependent on the grain size of the material stored.
- Dryer: Inside the dryer, the moisture decreases to about 10 % so that an explosion hazard can be expected within the dryer.
- Conveying routes: It is necessary here to distinguish between fine fractions of the material transported and between conveying speeds. A high content of fine fractions and a high conveying speed will often lead to potentially explosive atmospheres whereas a low content of fine fractions and low conveying speeds will rarely lead to potentially explosive atmospheres.
- Hammer mills: The zoning is determined by the moisture content of the material. When material having a moisture of more than 35 % is milled, no zoning is necessary. When milling in the dry chip range, the occurrence of potentially explosive atmospheres must always be expected.
- Filter: Zoning depends on the material to be filtered. Separators for vacuuming pellet routes should be graded at a lower level than separators following dry milling.
- Presses: This is where the conditioned chips are pressed into pellets. The fine fraction is reduced by the pressing.
- Cooler: This is where the fresh, pressed pellets are cooled. The only fine fraction to be expected is pellets scrap and abraded particles.

As an example, the following zoning is obtained for the sample installation presented in the previous chapter:

Zoning as the central element in hazard assessment should always be matched to the individual case, using guides and technical rules and standards as a source of information (Table 8.4).

Table 8.4 Exemplary zoning for wood pellet plants

Apparatus	Reason	Zone
Silo and buffer tank	Few fine fractions	20
Dry chips	High fine fraction component	20
Dry, milled chips	Low fine fraction component, scrap and abraded particles	22
Pellets belt dryer	Quiet bed of material, some risk of fire	22
Conveyor slow-running	Low fine fraction component, e.g. pellets	22
	Medium fine fraction component, e.g. dry chips	21
	High fine fraction component, e.g. ground material	21
Fast-running	Low fine fraction component, e.g. pellets	22
	Medium fine fraction component, e.g. dry chips	21
	High fine fraction component, e.g. ground material	20
Hammer mill		
Wet milling	Due to the moisture there is only a risk of fire	n.d.p.e.a.
Dry milling	Formation of relevant fine fractions operationally possible	20
Filter		
Pellet vacuuming	Only scrap and abraded particles to be considered as fine fractions	21/22
Fine fraction vacuuming	Fine fractions are separated and accumulated	20/22
Presses	Binding of fine fractions by water vapour in conditioner, pressing of the material into compact pellets, noting abrasion. Occasionally, dust clouds will form.	21
Cooler	Delivery of compact pellets with low fine dust fraction; high cooling air throughput; a potentially explosive dust/air mixture can be expected in he short term only in exceptional cases	22

n.d.p.e.a: no dangerous potentially explosive atmosphere

8.4 Avoiding Ignition Sources

Since the 1st of July 2003, only those devices and protection systems which meet the requirements of Guideline 94/9/EG [1] may be sold in Europe.

This guideline creates a link between the occurrence of potentially explosive mixtures and the occurrence of effective ignition sources in order to stay below the accepted margin of risk.

As a rule, the operator is obliged to use equipment corresponding to Guideline 94/9/EG in his installations. However, according to Appendix IV B of the BetrSichV the operator can also commission devices which have not been verified to meet Guideline 94/9/EG.

In these (individual) cases, however, the plant operator is obliged to perform his own risk analysis and thus to ensure that all necessary measures have been taken to keep the risk of explosion below the acceptable margin of risk. As a result he himself becomes the manufacturer of his plant.

Suitable equipment is selected by linking the zone (operator's area of responsibility) with the category (manufacturer's area of responsibility) (Table 8.5).

Table 8.5 Relationship between category and zone

Category	Equipment safety	Safety guaranteed	General requirement for equipment	Applicable in zone
1	Very high	Even with rare	Ignition sources occurring	20
		Equipment faults	Very rarely must be avoided	21
				22
2	High	Even with frequent	Ignition sources occurring	21
		Equipment faults	Rarely must be avoided	22
3	Normal	In normal operation	Ignition sources occurring	22
			Continuously or frequently	
			Must be avoided	

8.5 Technical Measures for Avoiding Effective Ignition Sources

Since it is not possible to avoid potentially explosive atmospheres in the installations, measures must be taken to prevent ignition. According to the requirements of DIN EN 1127-1 [5] and TRBS 2162-3 [6], thirteen possible ignition sources must be considered in this context. These ignition sources will be defined briefly below.

1. Electrical equipment. Apart from the formation of hot surfaces due to overheating which can contribute to causing ignition, there is also a risk of ignition due to electrical sparks which can occur, e.g. during the opening and closing of electric circuits (switching on light) or due to loose contacts.

2. Hot surfaces. Apart from trivial hot surfaces such as heaters, drying cabinets or heating coils, hot surfaces can be created by friction. Mechanical energy is here transformed into heat (e.g. clutches, brakes, shaft feedthroughs, bearings). Apart from the actual ignition of a potentially explosive atmosphere, layers of dust or other combustible solids an also be heated to the extent that they become effective ignition sources.

3. Static electricity. Depending on the process and the characteristics of the material involved, electrostatic discharges may occur both with insulating materials and with conductive materials in an insulated position. The incendivity (ignition efficiency) of the specific form of discharge (spark discharge, corona discharge, brush discharge, propagating brush discharge, cone discharge) depends on the ignitability of the potentially explosive mixture.

4. Mechanical sparks. From solid materials, particles can be detached by processes of friction, impact or wear which can assume an increased temperature due to the injection of energy during the process of detachment. This can be increased even further by oxidation processes (e.g. iron). On the one hand, it is possible for suitable fuel/air mixtures to be ignited by these sparks and, on the other hand, pockets of embers can be produced in deposited dust accumulations which, in turn, act as ignition source.

5. Chemical reaction (Self-ignition, decomposition). If the rate of heat production in a dust pile is greater than the rate of heat loss to the environment. An exothermal reaction can act as an effective ignition source. Apart from the thermal balance, the volume/surface ratio of the reaction system, the ambient temperature and the dwell time have an influence on the temperature increase and thus on the effectiveness of the ignition source. Apart from the temperature increase per se, pockets of embers or fires arising as a result must also be taken into consideration.

6. Open flames and hot gases (smoking, welding, cutting). Combustion reaction results in temperatures of over 1000 °C. Apart from hot gases, dust flames or sooty flames will also produce glowing particles of solids which could act to ignite a potentially explosive atmosphere. Welding and cutting also produce sparks which are effective ignition sources.

7. Lightning strike. Because of their high energy density, bolts of lightning must always be considered to be effective ignition sources. Furthermore, incendive sparks can be created by the currents flowing in the area of the lightning strike.

8. Electrical equalizing currents. Equalizing currents in conductive electrical installations can flow as return currents in power generating systems or as a consequence of body or ground contact in the case of faults in electrical installations or also due to magnetic induction. If these relevant plant parts are separated, joined or bridged, a potentially explosive atmosphere can be ignited by the electrical spark or arc.

9. Ultrasound. When ultrasound is used, the energy is absorbed by the substance thus irradiated which can heat up to such an extent that an ignition may occur.

10. Electromagnetic waves (frequencies from $3*10^{11}$ to $3*10^{15}$ Hz). Radiation in this spectral range can become an ignition source of a potentially explosive atmosphere, especially when focussed, or trigger a fire on solid surfaces, The power density especially of laser beams may still be sufficient for ignition even over great distances.

11. High-frequency radiation (frequencies from 10^4 to $3*10^{12}$ Hz). Systems delivering such high-frequency energy are, e.g., radio transmitter masts or high-frequency generators for heating, drying or also welding. Conductive parts in such a field of radiation act as receivers and may ignite a potentially explosive atmosphere, given the right circumstances.

12. Ionising radiation. Ionising radiation generated by X-rays or radioactive substances can ignite a potentially explosive atmosphere due to energy absorption. However, the radiation source itself may also heat up to such an extent that it can be considered to be an ignition source.

13. Adiabatic compression. The temperatures occurring here can be so high that they can act as ignition source for potentially explosive mixtures. During the abrupt pressure relief of high-pressure gases, shock waves will form in pipelines. At fixtures and bends, especially high temperatures will then occur. However, this ignition source forms a subordinate role for the dusts handled.

For installations producing wood pellets, the ignition sources can be classified in three different groups:

Table 8.6 Trivial ignition sources

Ignition source	Measure
Electric equipment	Avoided by selecting the devices in accordance with the category required
Open flames and hot gases (smoking, welding, cutting)	Avoided by obtaining a hot work permit
Lightning strike	Avoided by lightning arrester
Electrical equalizing currents	Avoided by potential equalization
Ultrasound	Avoided by selecting the devices in accordance with the category required
Electromagnetic waves (frequencies from $3*10^{11}$ to $3*10^{15}$ Hz)	
High-frequency radiation (frequencies from 10^{4} to $3*10^{12}$ Hz)	
Ionising radiation	
Adiabatic compression	Not relevant to wood pellet plants, as a rule.

Trivial Ignition Sources

These ignition sources can be avoided easily by using suitable equipment and organisational measures:

Significant Ignition Sources

These ignition sources are typical for plants producing wood pellets. Due to special equipment requirements, these require more detailed considerations as shown in the following sections (Table 8.6).

Mechanical sparks and hot surfaces can act as ignition sources due to frictional and grinding processes if the relative speed is more than 1 m/s in the case of a moving built-in part.

This relative speed is typically exceeded in the case of elevators, ventilators and mills.

Depending on the category required, the occurrence of relevant ignition sources can be avoided even at higher relative speeds by applying the principle of "Safe Construction" according to DIN EN 13463 Part 1 [9] together with Part 5. In this context, the following aspects must be taken into consideration, in particular:

- External bearings, if possible
- Suitable combinations of materials, i.e. no use of light metals or hard materials
- Rugged design of built-in internal structures, suitable for utilization complying with regulations
- Adequate wall space between moving and stationary components
- Regular inspection and maintenance especially of the shaft feedthroughs and built-in fixtures.

Table 8.7 Significant ignition sources

Ignition source	Measure
Hot surfaces	Avoided by selecting the devices in accordance with the category required
Mechanical sparks	Avoided by selecting the devices in accordance with the category required

Applying the "Safe Construction" design feature, Category 2 devices (safe even with frequent faults, useable aximally in Zone 21) can be built. To achieve Category 3 (safe even with very rare faults, useable in Zone 20), his principle of protection can not be applied as the only measure in the case of high-speed equipment such as levators or hammer mills. Safe plant design then requires supplementary constructional explosion protection.

In the end, applying the design measures represented above makes it possible to provide the proof of category required for the respective zone, taking into account the specific feature of high-speed equipment (Table 8.7).

Process-induced Ignition Sources

These ignition sources are created by the process, e.g. in the case of pneumatic conveyors or during the pressing of the pellets (Table 8.8).

Table 8.8 Process-induced ignition sources

Ignition source	Measure
Static electricity	Avoided by adequate grounding
Chemical reaction (self-ignition, decomposition)	Avoided by preventative measures

Chemical reactions can become effective ignition sources in the form of self-ignition processes. Where the dry chips are stored in silos, self-ignition processes must be avoided by limiting the storage temperature and time.

Self-ignition processes in the dryer can be avoided by limiting the drying temperature, regular inspection intervals and running it empty and introducing a cooling phase before prolonged stoppages.

Smouldering fires are largely avoided by limiting the surface temperatures of the electrical and non-electrical resources at the plant installation site.

However, within the plant, processes are being carried out which require more extensive measures for avoiding smouldering fires.

– Conveying into congested conveying paths (e.g. screws, drag chain conveyors)

If a conveying path becomes clogged, the energy of motion of the transporting elements is converted into heat energy. This may lead to smouldering fires. Clogging is detected by using blocking detectors and shutters and the feeding conveyors must be switched off.

Table 8.9 Identification of equipment according to 94/9/EG/16/

Zone	Non-electrical ID	Electrical ID	Test required
20	Ex II 1 D Indicates maximum Surface temperature Test number/test station	Ex II 1 D IP 6X Indicates maximum Surface temperature Test number/test station	Type test Statement of compliance Manufacturer
21	Ex II 2 D Indicates maximum Surface temperature	Ex II 2 D IP 6X Indicates maximum Surface temperature Test number/test station	Statement of compliance Manufacturer Results of the hazard analysis in the documentation Testing depends on type of Ignition protection Type test for electrical Equipment only
22	Ex II 3 D Indicates maximum Surface temperature	Ex II 3 D IP 5X Indicates maximum Surface temperature	Statement of compliance Manufacturer Results of the hazard analysis in the documentation

– Hammer mills and associated removal of the products.

If foreign particles are introduced into the mill, the foreign particle can become heated up to the extent that it will form a hot spot in the further production sequence. The grinding area will, therefore, have to be preceded by a magnetic separator and one for heavy materials.This reduces the probability of introducing foreign particles into the hammer mill but does not completely eliminate it (e.g. breaking off of a hammer). The mill exit for material must, therefore, be equipped with a spark detection and extinction system.

Clogging of the mill can be detected by a storage and internal temperature monitor.

– Pellet presses, pellet cooler and associated discharge air systems.

In the area of the presses there is an increased risk of fires being started or of overheated glowing particles being produced. The cooler exit for material and the area of cooler discharge air must, therefore, be monitored by a spark detection and extinction system.Clogging of the presses is monitored by monitoring the temperature of the edge runners.Using spark detection arrangements as the only protective measure against explosions is not sufficient since they have not been tested as a preventative measure in the sense of Guideline 94/9/EG [1]. However, as preventative measures, they are the link to fire protection (Table 8.9).

According to Guideline 94/9/EG [1], the equipment used must be identified as follows:

8.6 Controlling Explosions

It is not always that all ignition sources can be avoided reliably enough by applying preventative measures. In spite of comprehensive inspection, maintenance and monitoring measures, it is not possible to eliminate hot surfaces due to grinding and frictional processes on high-speed mechanical units such as, e.g., in hammer mills, with absolute certainty. In central; aspiration filters, too, an immission of ignition sources can not always be reliably ruled out due to the multiplicity of existing extraction points.

Constructional protective measures are also projected when installations exhibit a particularly high potential for damage (e.g. large blocks of silos) or if there are more extensive interests in proction. Thus, the availability of installations can be increased by limiting the effects of flames and/or pressure in the case of an explosion since the explosion only relates to a defined and especially designed area.

In principle, the occurrence of potentially explosive mixtures and the simultaneous occurrence of effective ignition sources is permissible where constructional protective measures are in place. There will be an explosion but the effect and the propagation of the explosion are being confined. Possible measures can be differentiated as follows

– Pressure-resistant construction: The installation is designed to withstand the maximum positive explosion pressure.
– Shock-pressure-resistant construction. The installation is designed to withstand a reduced maximum positive explosion pressure and equipped with pressure relief facilities. Deformation of the plant components is permissible but uncontrolled fracturing is not.
– Explosion suppression. The start of an explosion is detected by active sensors and an extinguishing agent is introduced into the installation in order to terminate the reaction.
– Explosion-related decoupling. A flash-over of an explosion from one plant section to another is prevented by using active (e.g. extinguishing barrier) or passive (e.g. explosion guard valve) actuators.

The basis for applying constructional measures is an overall system analysis taking into consideration the intended purpose of use and intended substances. At the same time it is necessary to take into consideration that, having one remaining effective ignition source as a starting point (e.g. from a hammer mill), it is not the entire installation considered which must be produced using the constructional measures but that the area affected by a potential explosion can be delimited. Accordingly, the following aspects must be processed for the "constructional explosion protection" concept of protection:

– Specifying the area to be protected,
– Dimensioning the size of the relief facility or of the suppression of an explosion, respectively,
– Guaranteeing the strength of the devices,
– Selecting the decoupling device.

It depends on the individual case whether first the size of the area to be relieved or of the explosion suppression is to be dimensioned or first the strength of the area to be protected is to be specified. The area available for pressure relief may be limited, e.g. on a silo roof. In this case, the strength of the container must be varied in such a way that the installable relief area is large enough. Otherwise, the strength of rectangular containers (filters, mill end containers) may be limited. The size of the relief area must then be varied such that the reduced maximum positive explosion pressure does not exceed the achievable strength of the protected volume. However, the specific boundary conditions from the applicable standards must always be adhered to.

The "constructional explosion protection" principle of protection is only properly effective if the explosion can actually be controlled by the pressure relief area or the explosion suppression arrangement in conjunction with an adequate container strength. This is why there must not be an uncontrolled fracture or failure of the container. Possible consequential damage can be caused by secondary explosions due to dust deposits or fires in the installation area or also the endangering of persons.

The harmonized EN 14450 Standard [10] is used to provide proof of strength. There are three available alternatives:

– Construction according to EN 1445 [11]
– Pressure test as type test
– Explosion test as type test.

These three verification procedures always include a pressure test which must be performed. for each device.

This can be performed as hydrostatic test or as air pressure test and the required pressure must be present for at least 3 min. The test pressure must correspond to 0.9 times the design pressure, permanent deformations not being permissible then.

If a pressure test cannot be carried out for technical and/or safety reasons, the quality of the equipment must be verified by:

– Proof of the Material Certificates to EN 10204 [12]
– Pressure test as type test
– Explosion test as type test.

However, this alternative proof must be considered to be an exception and should not be considered as primary proof for a constructional explosion protection concept.

8.6.1 Dimensioning of the Pressure Relief Area

In order to limit the effects of an explosion to a defined degree, a pressure relief area must be provided. If due to the starting explosion the pressure in the container exceeds a threshold value, i.e. the triggering pressure of the relief facility, the area opens up and the further expansion of the explosion propels the mixture outward through the relief opening. This relates both to burnt substances and unburnt substances so that the combustion reaction will also take place externally. As a result, a pressure build-up accompanied by flames will also be observed in the environment which is why this area must be identified as a hazardous area.

The relief area is dimensioned in accordance with the harmonized EN 14491 [13] which triggers the assumption of compliance according to Guideline RL 9 4/9/EG [1]. When other approaches to dimensioning are applied (e.g. NFPA 68 [14] or VDI 3673 [15]), the proof that the aims of protection according to 94/9/EG [1] have been met, must be provided separately and in writing.

The calculation equations derived empirically are based on the pressure relief of a single container filled with an optimal dust/air mixture in a turbulent state.

If the actual process parameters deviate from this in the individual case, the relief area may be over- or under-dimensioned if the equations from EN 14491 [13] are applied. For example, in the case of the product being fed tangentially into a silo, not the entire silo volume will be filled with an optimal dust/air mixture. In these cases, it is possible to deviate from the stipulated calculations to EN 14491 [13] and the dimensioning of the smaller relief area must be based on published or experimental data which have been determined using representative pressure relief trials.

In principle, the design of the protective measure of "pressure relief" should take into consideration the following aspects:

- Early relief of burnt gases,
- Positioning of the pressure relief areas close to potential ignition sources,
- Avoiding dams and obstacles between possible ignition sources and the pressure relief areas (avoiding turbulences),
- Avoiding elongated structures (lateral instead of front-end relief),
- Avoiding blockages, e.g. due to buckling filter support cages.
- As in the EN 24460 Standard [10], too, adequate user information is demanded in the EN 14491 Standard [13].

8.6.2 Suppression of Explosions

As in the case of explosion suppression, too, an initial explosion is allowed in the suppression of explosions (Fig. 8.5). This is detected by means of detectors, typically flame or pressure detectors, and signalled to an evaluating unit. This processes the signal recorded and is able to distinguish between normal fluctuations and the start of an explosion in the case of pressure fluctuations in the process. If the criterion of an explosion is met, the extinguishing agent is blown into the protected container. This is done within a few dozen milliseconds. The pressure in the container will rise up to a previously defined reduced positive explosion pressure when the reaction to the explosion is terminated by blowing in the extinguishing agent. Due to the complexity of the suppression of explosions, the entire system consisting of type and positioning of the detectors, type of control center and type, quantity and position of the extinguishing agent injection means must be designed by the manufacturer of the suppression system.

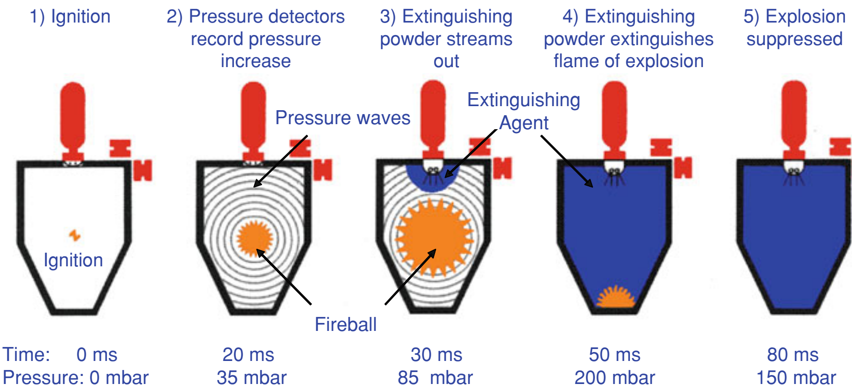

Fig. 8.5 Basic diagram Suppression of explosions. Source: Company literature

8.6.3 Selection of the Decoupling Facilities

Decoupling measures for explosions are necessary for two reasons. On the one hand, the risk assessment defines the area constructed to be pressure surge resistant. Propagation of the explosion beyond this area must be avoided. In this arrangement, the area constructed to be pressure surge resistant is decoupled from the area not constructed to be pressure surge resistant.

On the other hand, decoupling measures must also be provided between a number of interlinked units constructed to be pressure surge resistant In this respect, two effects are of relevance:

- Explosions are always accompanied by the propagation of a flame front and of a pressure front, the blast wave spreading faster than the flame front, as a rule. The blast wave will thus enter the connected container sooner, leading to e “pre-compression” of the potentially explosive mixture in the second container. The higher primary pressure on entry of the flame front will result in a higher positive explosion pressure since the positive explosion pressure is proportional to the primary pressure in the system.
- A beginning explosion proceeds comparatively slowly. Thus, a correspondingly long period is available for relief areas to open up or a suppression action to be triggered. Where containers are coupled, turbulence is generated during the transition from one container to the next. This will lead to the flame surface, and thus the front of the reaction, becoming enlarged. The explosion can, therefore, enter the connected container as a flame jet, the reaction then proceeding much faster there and the reaction time in the relief facility then not being sufficient for relieving the explosion. The pressure buildup is uninterrupted and the positive explosion pressure exceeds the dimensioned strength value.

Possible systems for decoupling are described in TRBS 2162 Part 4 [6], DIN EN 1127-1 [5] and in DIN EN 14089 [16], the latter also containing test procedures and quality requirements for these systems.

There is a distinction between passive and active systems. The passive systems are systems which operate without external interaction (e.g. a drive controlled via a sensor). Examples of passive systems are, i.a.:

– Rotary feeders,
– Timed feeder
– Material buffer
– Check valves.

Active systems always need explosion detection. This can be provided by optical infrared detection (flame detector) or pressure detection. Optical detectors can be faster than pressure detectors and can already detect an explosion in its initial stages and a flame can be located accurately (e.g. when entering into a pipeline). However, they can easily become soiled and thus blind.

Pressure detection can be static or dynamic. Static pressure detectors can be triggered by mechanical effects or vibrations which is why they are used in pairs at an angle of 90° from one another. Dybanic detectors analyse the pressure variation occurring and are thus able to differentiate between an explosion and normal operational pressure fluctuations.

The active systems include

– Quick-shutoff elements such as quick opening valves and quick-acting bellows-type pinch valves
– Extinguishing barriers.

The risk assessment includes whether a particular protective system is suitable for its planned application. The analysis must include, for example, if

– the pressure detectors are suitable for driving active extinguishing systems in processes with high and irregular pressure fluctuations,
– the decoupling of extraction lines bz means of simple check valves also functions reliably with the loads of material to be expected,
– the rotary feeders are suitable also for highly abrasive material.

Due to the complexity of the decoupling relative to explosion protection, the suitability of the protection system for its planned application must be confirmed by a system certificate by the manufacturer.

8.7 Organizational Measures

In comparison with earlier rules and regulations, the Betriebssicherheitsverordnung—BetrSichV (Industrial Safety Act) allows employers a greater margin in designing their plants for safety by reinforcing their own operational

Table 8.10 Requirements for Implementing Organizational Measures

Subject	Measures
Identification	Marking areas at risk from explosion with warning signs at their approaches
	Prohibiting ignition sources such as, e.g., smoking and the use of open fires and light (notes, identification).
Instruction of the	Instructing the personnel for activities in areas at risk from explosion
Employees	Handling combustible substances
	In case of combustible liquids—measures for accepting and eliminating leakages
	In case of combustible dusts—measures for eliminating dust deposits
	Behavior in case of alarm, evacuation, emergency stop etc.
	Further training of technical staff in sessions on special subjects of explosion protection
Operating	Written working and operating instructions to BetrSichV
Instructions	Work release system for working in areas at risk from explosion
Coordination	Requirements for the coordination of and agreement on the protective measures to be taken.
	Including neighboring installations and current operations.
	Different working groups from different employers endangering one another.
Surveillance	Inspection rounds concerning the leak-tightness of the installation
Prohibition of	Access to the installations is to be allowed only for authorized persons
Unauthorized entry	Third parties have to report to the registration office of the respective installation.
Fire Protection	Providing for escape and rescuing of employees
Tests	Determining the type, range and periods of tests required according to BetrSichV paras. 14 and 15.
	Specifying persons persons for testing or trying out resources before commissioning and repeated at intervals of at least 3 years by a competent person (e.g. electrician for electrical systems, locksmith) with regard to the use of devices in areas at risk from explosions.
	The following tests are required:
	Electrical installations
	Test for grounding
	Potential equalization
	Lightning protection
	Construction and state of non-electrical resources
	The tests have to be recorded and stored at least until the next test

responsibility. Apart from the selection of resources (technical measures), the organizational measures must be accorded considerable significance.

Organizational measures must be taken whenever explosion protection cannot be guaranteed and maintained at the places of work. Since, as a rule, it is primarily people who are active in plants and these can cause risks and hazards in cases of human errors, it has been found that a safe working environment can be created and maintained in particular only by involving the employees. The organizational measures must, therefore, also take into consideration possible interactions between explosion prevention measures and operational procedures. In practice, a combination of technical and organizational explosion prevention measures has, therefore, been found to be successful which ensures that the employees can handle the work handed to them without putting their health and safety or that of others at risk (Table 8.10).

The following aspects must be taken into account in explosion protection:

The legal requirements for organizational measures with respect to operating instructions, testing of resources and Competent Persons can be outlined as follows:

Formulation of Operating Instructions

Plants in which explosion hazards are present must produce for their employees binding operating instructions relating to the hazards to be expected and the protective measures to be taken. The operating instruction must contain the work-station-related hazards for persons and the environment and indicate the protective measures to be taken or to be adhered to in a comprehensible language in such a manner that the employees can comply with them.

The operating instructions must show clearly what explosion hazards exist and where, what movable appliances are allowed to be used and what special personal protective gear must be worn, if necessary.

The work permit system represents a focal point in this context. Under certain circumstances, it is unavoidable in areas at risk from explosions that hazardous work such as welding, cutting or burning has to be carried out. In these cases, legislation demands a special duty of care. A written work permit system which obliges all parties involved to assess hazards in writing and to take all necessary protective measures before, during and after the performance of the activities has been found to be worthwhile.

Testing Appliances and Resources

The test obligations of paragraph 10 represent a central regulation of the Industrial Safety Act (Betriebssicherheitsverordnung—BetrSichV). The employer is obliged to ensure that appliances, the safety of which depends on the assembly conditions,

– are checked for their correct assembly and installation and for their safe operation
– after their assembly, and
– before their initial operation.

Apart from that he has to check at regular intervals appliances which are subject to damaging influences.

The test periods have to be determined by the employer himself as part of the hazard assessment according to para. 3 of the BetrSichV. The results of the tests acc. to para 10 must be recorded. The recordings must be available at any time for presentation to the responsible regulatory authority in order to ensure an efficient implementation of the Industrial Safety Act (BetrSichV).

The required tests for installations in areas subject to explosions according to para. 14 with regard to assembly, installation, conditions of mounting and reliable operation, design testing to Appendix 4, No. 3.8 and the repetitive tests to para. 15 of the BetrSichV have been firmed up further with TRBS 1201 Part 1 [17].

Devices which are used in areas subject to explosions must be tested by a qualified person according to para. 14 before they are taken into operation and repeatedly thereafter according to para. 15 of the BetrSichV.

Qualified Persons

The testing of the installations and devices requires qualified persons, according to TRBS 1203 [18].

Guaranteeing that the qualified personnel is adequately trained is the responsibility of the operator. Employees of external companies and service companies having the appropriate qualifications may also be called upon. However, the operator is always obliged to guarantee the technical aptitude of the employee used (e.g. via corresponding written agreements with the outside company).

Companies are obliged to nominate qualified persons in the sense of paras. 14 and 15 of he BetrSichV.

When selecting the personnel, the company must pay ascertain that they have the necessary knowledge regarding the process technology, the engineering and electrical technology including control technology and, due to their long years of experience in industrial processing processes, have practical, previously practiced knowledge of the process dynamics involved.

Apart from their professional qualifications, employees who are to become active as qualified persons must have sufficient knowledge in the field of explosion protection.

Nominating and announcing the qualified persons must take be carried out by management after the employees affected have qualified as required.

In Germany, qualified persons are defined in three grades, whereas in the rest of Europe, they are only known as "Competent Persons". In the Austrian interpretation of Guideline RL 1999/92/EG [10], a supplementary constructional explosion protection is demanded for all containers containing combustible dust. In the French interpretation, this supplementary protection is demanded for silo complexes larger than 5,000 m^3. The Belgian and the Dutch versions of the European Guideline set concrete requirements for performing the zoning.

8.8 Fire Prevention Measures

According to the building laws, plants for producing wood pellets are special buildings and are characterized by a specific purpose-designed architecture subject to the intended use. The preferred construction is flexible (steel or reinforced concrete) which facilitates the installation of plant equipment. The personnel/area ratio is typically small, the users are familiar with the locality, healthy and capable of walking.

To obtain the building permit, a fire prevention concept has to be submitted together with the building application. For special buildings for industrial and commercial purposes, the fire prevention measures are based on the Industrial Building Guideline (IndBauRL—Industriebaurichtlinie) [19] which specifies the qualitative preventative aims of the building code quantitatively. In its widest sense, the building code is aimed at neighborhood protection. It is necessary to ensure, therefore, that in the case of a fire in one unit, it does not have any negative effects on others (neighbors). In this context, burning out of one's own burning section is permissible.

Thus, following the principle of fire retardation by compartmentalization, maximally permissible sizes of fire sections and requirements for the support structure and selection of building materials are set in the IndBauRL [19]. This results in a minimalistic fire prevention concept which, however, is adequate for obtaining a building permit since the protective aims according to the building laws are met.

Carrying out an analysis of utilization is not necessarily required for the concept of fire prevention according to the building laws. The fire loads are assessed only with regard to their contribution to the amount of heat released, the ignition and the burnout rate are not included.

From the Hazardous Materials Act [20] and from the Industrial Safety Act [4], demands are made of the operator for protecting their employees against fire. This relates especially to the hazards presented by the materials handled and by the equipment used which must be taken into consideration. The hazards must be assessed with respect to the aim of protecting persons (escape and rescue).

As an economic unit, the company is interested in maintaining the value chain over a long period. In this context, the question regarding the value of the machines, source materials and finished products for the continued existence of the company must be answered with respect to a suitable fire prevention concept. As a rule, complex machines are single products which may take a long time to replace. Once the new machine has been delivered it must be integrated into the production process, validated and checked out. It is only then that customers can be supplied again with products.

It is necessary to find out whether the failure of a key item of machinery will cause the entire production on site to come to a standstill.

Special attention must also be paid to changes in use. Inadequate management of change will cause company departments to perform changes which have not been authorized. For example, this may relate to extensions to existing buildings or to buildings previously sufficiently spaced apart growing together due to roofing provided for the temporary storage and handling of products or utilization as installation space for technical systems such as filters or ventilation systems.

To be able to use a plant successfully over a long period, a comprehensive study of fire prevention must be created which assesses the assumptions made in the fields of building law, industrial safety and asset protection and combines them to form an overall concept

In doing so, the following questions must be answered:

– What aims of protection are to be achieved?
– Apart from the permit according to the building laws, is the protection of machines also of significance?
– How is a fire ignited and propagated?
– In the area of dryers, hammer mills or presses, a large amount of energy is fed into the product
– What damage can be expected in case of a fire?
– The extent of damage to a small return conveyor should generally be assessed at a lower level than a fire in a dry chip silo.
– By what means can fires and their hazards be countered effectively? E.g., to fight a fire manually with water presents problems because of the large silo dimensions.

In working out the overall concept, care must be taken that measures which are taken voluntarily for asset protection reasons, e.g. fire alarm system, are not used to ease the burden of building law requirements. There is a risk that in a case of change of use, the plant protection system is dismantled together with the plant, thus eliminating the basis for the easement.

The following precautionary fire prevention measures can be mentioned:

– Ensuring that the operating rooms are clean
– Not permitting any deposits on cable trays
– Introducing Hot Work Permits.

Apart from the phenomenon of pure self-ignition, hot spots may form and smoldering fires spread due to ignition sources being fed in externally. These smoldering fires are initiated by hot particles, e.g. overheated material from dryers, presses or mills, being fed in. There are spark detectors or CO monitors available for monitoring the operating conditions.

Defensive Safeguards

There is no possible complete protection against smoldering fires even with the precautionary technical measures presented, although the risk remaining after the precautionary preventative measures is generally accepted. Due to the high damage potential, additional defensive measures must, therefore, be provided.

Therefore, spark detection and extinguishing systems are additionally installed as a fire prevention measure in wood pellet plants. The following mounting locations have been found to be successful as fire prevention measure in plants for producing wood pellets:

– after the dryer exits in each case,
– in the material exit of the dry-chip mill,
– in the material exit of the pellet presses in each case,
– in the material exits and aspiration passages of the pellet coolers in each case.

In the case of a silo fire, the traditional extinguishing agents will not have the desired effect since water will flow down in channels within the bulk material without necessarily extinguishing the seat of the fire and foam covers the surface of the bulk material, impeding the free draft of the fumes. This lowers the available amount of oxygen and the fumes (carbon monoxide in most cases) are able to accumulate underneath the foam cover due to the incomplete combustion.

If the silo is opened without proper control, oxygen may be supplied so that the smoldering fire can change into an open fire. In addition, dust can be stirred up by the use of extinguishing jets which ignites on the hot surface and can be caused to explode.

In selecting the defensive measures it must be taken into consideration that, in principle, a silo fire is a slow process (taking days and weeks rather than hours) and thus leaves sufficient time for preparing and carrying out effective countermeasures.

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Chapter 9
Profitability of Pellet Boilers

Using biomass for heating has increased greatly in recent years. More and more consumers are becoming interested in this climatically friendly type of heating thanks to the increased ease of handling, the system reliability and the improved environmental characteristics. It is especially the wood pellet plants which have attained a high degree of publicity by now.

This chapter describes the economic comparison between pellet heating systems and the most widely used alternative systems based on natural gas and heating oil.

9.1 Fuel Prices

Compared to fossil energy sources, pellets represent a competitive alternative. This is based on the lower fuel costs possible today. In addition, the development of costs for oil and gas has been very volatile in recent years. The price for heating oil had thus reached a record level of over 90 ct/l in the summer of 2008. Since the prices for natural gas are still coupled to the oil price in many instances, the development is similar here. It can be observed, however, that many providers are detaching themselves from their dependence on the oil price.

Before considering the actual profitability, Fig. 9.1 shows the development of the energy prices for pellets, natural gas and heating oil. The basis for the data are consumer prices for purchasing 3,000 l of heating oil, 33,540 kWh of gas, 6 t of pellets (incl. VAT and other costs). The reference quantity for the energy content is the lower calorific value. The diagram illustrates the advantages of pellets with reference to the specific fuel price at the possible specified quantities ordered for a single-family detached house or two-family semidetached house. The pellet prices between May 2009 and May 2010 are shown in Fig. 9.2. Between these 12 months, the price fluctuated between 204 and 230 €/t by about 11 % (based on 230 €/t). In the equivalent of heating oil, the price would be approximately between 41.6 and 46.9 ct/l of heating oil.

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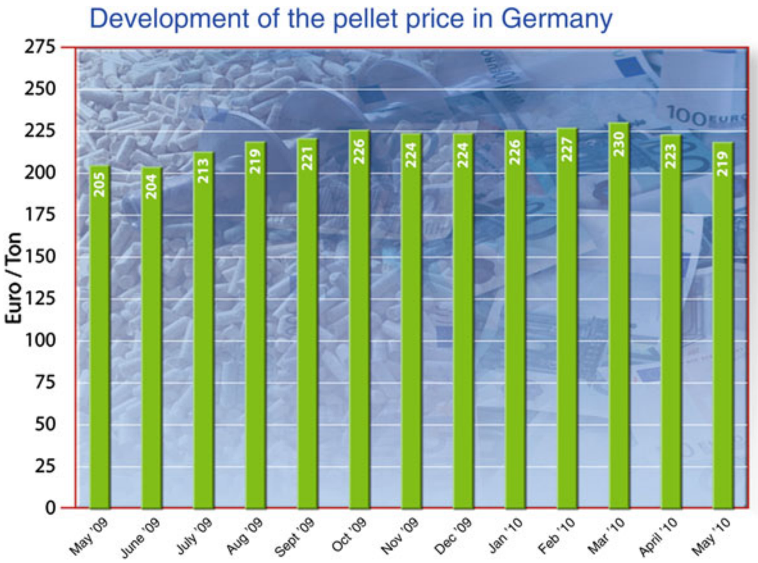

Fig. 9.1 Development of energy prices in Germany between 2005 and 2011 [1]

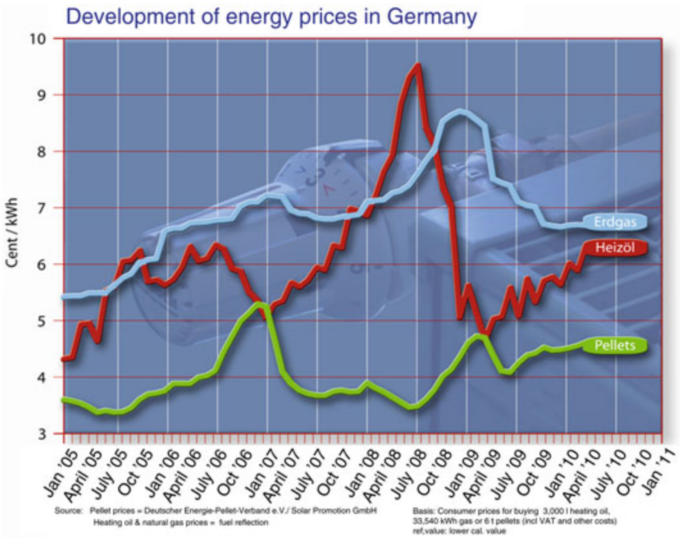

Fig. 9.2 Development of pellet prices in Germany [1]

As with all other heating systems, too, the individual design must be considered in pellet heating systems. The market offers everything from space heaters with water heating system to central heating systems for several housing units.

In addition, there are many respectable offers for combined pellet/solar heating systems. With these, the pellet heating system can in most cases remain completely shut down in summer since the tap water can be heated by the solar system alone. Pellet boilers should always be combined with a hot water tank, which increases the investment. But it minimizes the number of starts and the system runs longer at its optimum operating point since the tank acts as a buffer between the heating network and the boiler. With respect to the gas prices, it must be noted that the gas market is liberalized and it is, therefore, currently difficult to establish a representative price. If an inquiry is spread among numerous providers, gas prices are obtained which differ by up 100 %.

9.2 Economic Comparison of Various Heating Systems

In the example following (s, Table 9.1), a heating system for a single- or two-family house (depending on the type of construction) having an annual heat requirement (Item 1) of 20,000 kW/a is examined. The specific consumption has been assumed to be 80 kWh/m^2. In contrast, a passive house consumes up to 15 kWh/m^2 and KfW-60 houses attain 60 kWh/m^2 (KfW = kreditanstalt für wiederaufbau − Reconstruction Loan Corporation). The annual efficiency (Item 2) of pellet heating systems is based on the practical experience of some pellet heating plant owners. The fuel energy needed (Item 3) is obtained as the quotient of heat requirement and annual efficiency. The heating value (net calorific value) (Item 4) reproduces the energy content of the fuel and is required for determining the quantity of fuel needed. The fuel price (Item 5) represents a snapshot of the market prices. The data are based on consumer prices for the purchases of 3,000 l of heating oil, 33,540 kWh of gas and 5 t of pellets, respectively (including VAT and other costs). The reference value for the energy content is the lower heating value . The fuel demand (Item 6) is the quotient of fuel energy (Item 3) and heating value (Item 4), additionally taking into consideration a factor for correcting the units.

The investment costs (Item 7) include all the costs for the installation of the heating system. This does not include the radiators and the heat distribution system. The costs do include the boiler and peripheral equipment, the fuel store and transportation system, the chimney and the assembly and commissioning of the system. In 2009, these costs could be reduced by possible subsidies, a well-known subsidy having been the the MAP program (Marktanreizprogramm—market incentive program) for pellet heating systems. However, this program was cancelled in May 2010 and is no longer available to builders. Pellet boilers must, therefore, hold their ground next to the competing systems.

The capital costs (Item 8) are composed of depreciation and interest rates. After the fuel costs, these have the greatest influence on the profitability of the system. The depreciation was calculated linearly over 20 years for the following example. The interest was calculated dynamically for each year. The total interest rates were

Table 9.1 Comparison of the profitability of heating systems, based on wood pellets, heating oil and natural gas

Item	Parameter	Unit	Pellets	Heating oil	Natural gas
1.	Heat demand	kWh/a	20,000	20,000	20,000
2.	Annual efficiency	%	83	88	90
3.	Fuel energy	kWh/a	24,096	22,727	22,222
4.	Heating value Hu	kWh/kg	4.9		
		kWh/l		9.97	
		kWh/m^3			10
5.	Fuel price	€/t	223		
		€/l		0.63	
		€/m^3			0.66
		€/MWh	45.51	73.19	66.00
6.	Fuel demand	t/a	4.92		
		l/a		2,280	
		m^3/a			2,222
7.	Investment	€	13,000	9,100	8,300
8.	Capital costs, 20 years	€	923	693	632
9.	Fuel costs	€/a	1,097	1,436	1,467
10.	Misc. operating costs	€/a	160	85	65
11.	Total costs	€/a	2,180	2,214	2,164
12.	Specific costs	€/MWh	108.98	110.71	108.18

divided by the depreciation period in order to obtain an average interest rate. Depreciation plus average interest equal capital costs. With respect to the interest rate, the pellet boiler was rated as 4 % and the natural gas and heating oil boiler as 5 % since it can be assumed that low-interest loans can be claimed from the KfW when regenerative energy is used. It may be possible to obtain a lower interest rate which is a considerable advantage for the pellet heating system.

The fuel costs (9) are the product of fuel price (5) and fuel requirement (6). The miscellaneous costs include chimney sweeping, electricity consumption and emission measurements. The higher degree of soiling by solid fuels reveals the disadvantage of pellet heating. The specific costs (12) show the costs per MWh thermal unit in Euros and are the indicator for assessing the profitability of the various heating systems.

As a result, it can be registered on the one hand, that the wood pellet is much more advantageous with respect to fuel price (5) than heating oil or natural gas. Using the fuel price for pellets of 45.51 €/MWh as a basis, the costs for heating oil are higher by about 39 % and those for natural gas by about 45 %. This must be compared with the higher capital and operating costs for the pellet boiler which almost cancel this advantage. In the case of the specific cost there is almost equality between the natural gas boiler with 108.18 €/MWh and the pellet boiler with 108.98 €/MWh. In the case of the assumed annual heat consumption of 20,000 kWh and 20 MWh, respectively, a saving of 16 €/year is obtained for natural gas. Compared with the heating oil boiler which closes with 110.71 €/MWh the pellet boiler costs are lower by 1.6 %. If the decimal places are also taken into consideration, savings of around 34 €/year can be obtained.

If the interest rate for natural oil and natural gas heaters levels out at 5 % and that for pellet heaters drops to 3.5 %, the pellet boiler will become cheaper than the natural gas and heating oil boiler. Such a difference in interest rate can be considered to be realistic.

It remains to be noted that the profitability of the heating systems is primarily dependent on the fuel prices, the purchase price and the interest rate for credit. Each case can thus be calculated individually.

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Chapter 10
Research and Development

Large-scale production of wood pellets started in Germany in 2001. As far as the author knows, the first industrial plant for producing wood pellets in Germany was that by the Westwälder Holzpellets GmbH in Langenbach in the Westerwald forest. It was erected on the initiative of the partner and managing director Markus Mann on company premises next to a combined biomass heat and power plant, the heat of which was used for drying the chips.

In this chapter, technical aspects and biomass potentials will be discussed. It is worth mentioning, therefore, that the development in the fields of marketing and education began in this plant. Training courses en masse for heating companies, chimney sweeps, presentations etc. as carried out in those days by the company are no longer needed today and are, therefore, no longer a part of the subject of development. Nevertheless, this pioneering spirit has been a decisive influence on the speed of the proliferation of the use of wood pellets as an energy source.

The evolution and improvement of the efficiency of pellet boilers is progressing enormously. These highly developed boilers with their excellent efficiency make correspondingly high demands on the fuel. The situation in Germany, Austria, Italy etc. cannot be compared with e.g. the Scandinavian market where wood pellets were used long before the first pellet producer began operations in Germany. The pellet boilers are of such rugged quality that the demand for pellet quality is low compared with the German market.

Knowledge of the following basic parameters represents an essential basis for the production of high-quality wood pellets. Firstly, the pelletizer must know the characteristic properties of the raw material so that he can appropriately adjust the individual process components for preparing the raw material. On the other hand, the quality requirements of the final product or of the consumer, respectively, determine the necessary conditioning measures and press parameters during the production process (e.g. the use of binding agents, dimensions of the wood pellets). Lastly, however, fuel handling and fuel conditions (moisture, storage time etc.) during pellet transportation and storage and the structural design and operability of the heating system itself also influence the successful use of the fuel.

S. Döring, *Power from Pellets*, DOI: 10.1007/978-3-642-19962-2_10,

In practice, the interaction of these various types of components represents a great challenge since several partially competing elements acting within the fuel supply chain can influence the pellet quality and the (further) development of optimized heating systems is based on standardized fuel characteristics.

Although the industry is increasingly aware of the need for providing a closed fuel quality assurance system for the ultimate customer, one or the other damage case shows that there is a further need for research and qualification and optimization measures in the pellet production, the fuel and heating system standardisation, the provision of verifiable measuring and testing methods, the pellet storage and the reduction of the emission of pollutants from the combustion. Some of the most important "construction sites" will be described below.

10.1 Optimizing the Pellet Production

Wood pellets are currently being produced largely from woody biomass, only a small proportion of which consists of bark, independently of whether the pellets are intended for the premium pellet market or for the industrial pellet market. In particular, bark is separated from the raw material before pelletization since the dies cannot withstand the abrasiveness of the bark and the production costs, therefore, become uneconomical due to the increased wear. Considering the limited availability of high-quality technical raw material potentials for pellet production, appropriate direction of the flow of material within the pellet market appears to be increasingly necessary in order to be able to service both the efficient use of wood pellets in the small consumer market and the growing demand for industrial pellets for the power station sector. The flow of material can be controlled both politically (e.g. raw material restrictions or stimuli for using alternative biomasses for power stations as in the UK or Poland) and financially (e.g. distinct price difference between agropellets and premium wood pellets. However, it must be actively supported by the pelletizers and fuel dealers in order to inform potential customers professionally about the advantages and disadvantages of different pellet qualities.

In future, the flexible production of pellets of different raw material and end product qualities will require planners, plant manufacturers and pelletizers to have much more extensive knowledge of the characterizing properties of the raw materials and the inclusion of binding agents or additives in the pelletizing process. This should also include consideration of the admixture of liquid additives and additives dissolved in steam which can contribute both to the enhancement of the fuel quality and to the optimization of the process. In addition, the enzymatic extraction of the biogenic raw material for activating new bridge linkages offers an additional option for developing the pelletization process further. However, using novel raw material processing and conditioning measures requires the provision of technical plant components which, e.g. guarantee as homogeneous as possible an admixture of alternative additives (apart from powdery pressing aids) and cause minimal wear and maintenance breaks even in the case where partly harder raw materials are used (hardwoods).

Similarly, the selective mixing of different qualities of raw materials may present a possibility for compensating for unfavourable pelletizing and combustion characteristics in the medium term and at the same time enable new cost-effective and/or regional raw material potentials to be tapped.

The continuous analysis and evaluation of cost saving potentials during the pellet production can also contribute to a lowering and securing of as constant as possible a pellet price level. The planning of new pellet plants should include especially the use of sustainable, preferably regional occurrences of raw materials. The individual concept of the site with it dimensions and long-term existence must always be considered also as a contribution to the regional creation of value.

The following key aspects of research and development are thus of relevance to the optimisation of the pellet production process in the short to medium term:

- Characterisation of the properties of biogenic raw materials for pelletization, including agricultural and forestry-related biomass and industrial remnants, storage conditions and aging processes.
- Determination of the world-wide potential of raw materials also in developing countries and evaluation of the logistics concepts for tapping the markets for raw materials,
- Provision of effective and most flexible raw material processing methods possible for milling and drying stalk-type material and biomass from fruits for the pellet production.
- Investigations relating to the admixture of additives for optimising the physical/mechanical fuel characteristics of non-wood pellets or mixed pellets (e.g. for increasing the fuel durability) and for compensating for adverse chemical/material fuel characteristics (e.g. for reducing particle emissions or for improving the ash fusibility),
- Improvement of the technical possibilities for admixing binding agents and aggregates; optimisation of the conditioning parameters such as the use of water/steam, time and energy expenditure).
- Method-related development of the pressing method, taking into consideration the most flexible raw-material-specific adaptations possible (reduction of the energy used, minimizing the maintenance and repair times/costs, optimisation of dies and edge runner design, more wear-resistant materials).
- Analysis and description of variable fuel characteristics during pellet storage and transportation.
- Optimisation of the measuring methods and test standards for fuel-specific analysis, verifiability of the examination results.
- Development of the product standards and quality assurance measures for wood and non-wood pellets according to application technology and performance class.

10.2 Optimizing the Capacity of Wood Pellets for Their Use as an Energy Source

In parallel with the optimization and further development of the pellet production, technical maturation of the combustion systems is required which—in spite of the necessity for large cost reductions in the manufacture of the plant in order to increase competitiveness in comparison with fossil heating systems—guarantee the use of pellets having higher pollutant contents in the ashes and in the emission. Using corrosion-resistant materials, air- or water-cooled grids and inexpensive secondary measures for reducing pollutants in the exhaust gases are already being developed. Process = optimized control elements which can control both the fuel supply and the air supply in the combustion space individually and automatically should also be developed further. This also includes, for instance, the standardized installation of long-lasting lambda probes in small heating systems, synchronization of the fuel delivery into the combustion space in accordance with the current load requirement profile (heat requirement), the fuel temperature and waste gas emissions (CO/TOC content) and the total effectiveness of the combustion system (efficiency). Furthermore, standardization of the structural design of the fuel supply (including fuel screws) in the pellet boilers/furnaces and of the combustion chamber could entail an increasing homogenization of the pellet qualities.

However, various investigations conducted in practice have also shown that, apart from the pellet combustion site, hydraulic linkage of the plant into the existing line network also offers great potentials for optimization. In addition, it is possible to achieve a reduction of partial-load states by installing buffer stores and combining the pellet heating system with a solar heating-type tap water heater.

On the exhaust gas side, the installation of baffles in the flue is extended further. The emission of particulate matter by pellet plants are already being analyzed today in several research projects (e.g. at the TFZ. The Hamburg–Harburg TU and the DBFZ) with regard to their origin composition and mechanism of action on humans. It is expected that the current scientific studies and continuing practical investigations will result in pointing to effective measures for avoiding or reducing the presence of particulate matter.

Apart from the research activities already being conducted, there is a further need for optimizing the possible applications of pellets as energy sources with regard to

- Fuel supply and ash removal into and out of the combustion chamber, respectively,
- Combustion chamber design of the boiler and furnace for optimizing the fuel burnout, the reduction of pollutant emissions and the effective heat transfer
- The availability of small and medium-sized heating systems licensable in DE for using stalk-type or mixed pellets (wood pus stalks or other biomass)
- Provision of effective particle separators

- Optimization of the annual efficiency of the heating system including heat insulation and recovery measures and of the combination of pellet and solar systems
- Lowering the production costs of the heating system and of the technical plant components for fuel conveyance and waste gas conditioning
- Using pellets in plants for coupled power and heat generation (e.g. Stirling plants)
- Fixing sustainability criteria for assessing the use of pellets for providing energy
- Torrefaction/carbonization of various biomasses with subsequent pelletization for use in coal-fired power stations.

Against the background of the above-mentioned numerous research aspects it remains to be hoped that the optimization of the pellet energy source will advance further in the coming years and the research funds needed for this will be provided in sufficient amounts by industry, small and medium-sized businesses and the public authorities. As long as the economic competitiveness of pellets for generating power and heat cannot be secured compared with fossil fuels it will be the political and legal framework (e.g. target quotas for using biomass or the arrangement of the Renewable Energy Law or of the Renewable Energy Heat Law) which determines the growth of the national and international markets. For the players in the industry and for potential investors, this means that any greater utilization of the existing pellet production capacities is possible only with a framework with long-term stability and incentive programs and the current pellet production quantities will continue to be available as substitutes for fossil fuels. However, the medium- and long-term development of the pellet market will also urgently require, apart from stable framework conditions, the mobilization of additional raw material potentials (e.g. the use of forest wood off-cuts, energy plants, straw) for safeguarding the production capacities.

Appendix
Physical Quantities and Their Conversion Formulae

Conversion of the Most Important fps Units into the SI System [1]

Length	1 ft = 1/3yd = 12 in	1 ft = 0.3048 m; 1 mi = 1609.34 m
Area	1 ft^2 = 144 in^2	1 ft^2 = 0.092903 $_m2$
Volume	1 ft^3 = 1728 in^3 = 6.22882 gal (UK)	1 ft^3 = 0.0283169 $_m3$
	1 gal (US) = 0.83268 gal (UK)	1 bu (US) = 35.2393 l; 1 bbl (US) = 115.627 l
Velocity	1 ft/s	1 ft/s = 0.3048 m/s
	1 knot = 1.150785 mile/h = 1.6877 ft/s	
Acceleration	1 ft/s^2	1 ft/s^2 = 0.3048 m/s^2
Mass	1 lb = cwt/112; 1 sh tn = 2000 lb	1 lb = 0.453592 kg
	1 slug = 32.174 lb; 1 ln tn = 2240 lb	1 slug = 14.5939 kg
Force	1 lbf	1 lbf = 4.44822 N
	1 pdl = 0.031081 lbf	1 pdl = 0.138255 N
Work	1 ft lb = 0.323832 cal_{IT}	1 ft lb = 1.35582 J
	1 btu = 252 cal_{IT} = 778.21 ft lb	1 btu = 1.05506 kJ
Pressure	1 lb/ft^2 = $6.9444 \cdot 10^{-3}$ lb/in^2	1 lb/ft^2 = 47.88 N/m^2
	1 lb/in^2 = 0.068046 atm	1 lb/in^2 = 6894.76 N/m^2
	1 atm = 29.92 in Hg = 33.90 ft water	1 atm = 1.01325 bar
Density	1 lb/ft^3 = $5.78704 \cdot 10^{-4}$ lb/in^3	1 lb/ft^3 = 16.0185 kg/m^3
	1 lb/gal = 6.22882 lb/ft^3	1 lb/gal = 99.7633 kg/m^3
Temperature	32 °F = 0 °C; 212 °F = 100 °C	1 degF = 0.5556 °C
Power	1 ft lb/s = $1.8182 \cdot 10^3$ hp = $1.28505 \cdot 10^{-3}$ btu/s	1 ft lb/s = 1.35582 W

(continued)

S. Döring, *Power from Pellets*, DOI: 10.1007/978-3-642-19962-2,

(continued)

Length	1 ft = 1/3yd = 12 in	1 ft = 0.3048 m; 1 mi = 1609.34 m
Specific heat capacity	1 btu/(lb degF)	1 btu/(lb degF) = 4.1868 kJ/(kg·K)
Thermal conductivity	1 btu/(ft h degF)	1 btu/(ft h degF) = 1.7306 W/(m·K)
Heat transfer/transmission coefficient	1 btu/(ft^2 h degF)	1 btu/(ft^2 h degF) = 5.6778 W/(m2·K)

Important Units of Mechanics [1]

Unit	Symbol	Physical or technical quantity	Description by basic units
Kilogram	kg	Mass	
Kilogram per second	kg/s	Mass flow	
Kilogram times square meter	kg × m^2	2nd degree mass moment of inertia	
Kilogram per cubic meter	kg/m^3	Density	
Cubic meter per kilogram	m^3/kg	Specific volume	
Square meter per second	m^2/s	Kinematic viscosity	
Newton	N	Force	1 N = 1 kg × m/s^2
Pascal	Pa	Pressure	1 Pa = lkg/(m × s^2)
Joule	J	Work, energy	1 J = 1 kg × m^2/s^2
Watt	W	Power	1 W = 1 kg × m^2/s^3
Newton meter	N × m	Moment of force	1 N × m = 1 kg × m^2/s^2
Newton per square meter	N/m^2	Tension	1 N/m^2 = 1 kg/(m × s^2)
Pascal second	Pa × s	Dynamic viscosity	1 Pa × s = 1 kg/(m × s)
Joules per cubic meter	J/rn^3	Energy density	1 J/m^3 = lkg/(m × s^2)
Ton	t	Mass	1 t = 1 × 10^3 kg
Gram	g	Mass	1 g = 1 × 10^{-3}kg

Important Units of Thermodynamics [1]

Unit a)	Symbol	Physical or technical quantity	Description by basic units
Kelvin	K	Thermodynamic temperature, temperature difference	
Square meters per second	m^2/s	Thermal conductivity	
Joule	J	Quantity of heat	1 J = 1 kg × m^2/s^2
Watt	W	Heat flow (rate)	1 W = 1 kg × m^2/s^3
Joule per kilogram	J/kg	Specific internal energy	1 J/kg = 1 m^2/s^2
Joule per Kelvin	J/K	Heat capacity	1 J/K = 1 kg × m2/(s^2 × K)
Joule je kilogramm und Kelvin	J/(kg × K)	Specific heat capacity	1 J/(kg × K) = 1 m^2/(s^2 × K)
Watt per square meter	W/m^2	Heat flow density	1 W/m^2 = 1 kg/s3
Watt per square meter and Kelvin	W/(m^2 × K)	Heat transfer coefficient	1 W/(m^2 × K) = 1 kg/(s^3 × K)
Watt per meter and Kelvin	W/(m × K)	Thermal conductivity	1 W/(m × K) = 1 kg × m/(s^3 × K)
Kelvin per Watt	K/W	Thermal resistance	1 K/W = 1 K × s^3/(kg × m^2)
Degrees Celsius	°C	Celsius temperature, centigrade	1 °C = 1 K

Heat Quantity Q

Heat is the energy which can be exchanged between the system and the environment without performing work. This refers to the kinetic energy of the molecules. These molecules are always moving except when they are at absolute zero temperature. The greater this kinetic energy, the higher the temperature. The temperature can be changed by adding or removing heat.

$$Q = m \times c_p \times \Delta T$$

Heat Transmission Coefficient k for Various Substances and Materials

From	Via	To	W/(m^2K)
Water	Cast iron	Air/flue gas	10…11
Water	Steel	Air/flue gas	11…24
Water	Copper, brass	Air/flue gas	14…30
Water	Cast iron	Water	280…300
Water	Steel	Water	290…350
Water	Copper, brass	Water	350…400
Air/flue gas	Cast iron	Air/flue gas	3…10
Air/flue gas	Steel	Air/flue gas	11…15
Air/flue gas	Copper, brass	Air/flue gas	9…17

(continued)

(continued)

From	Via	To	W/(m^2K)
Air/flue gas	Fire bricks	Air/flue gas	6…7
Steam	Cast iron	Air/flue gas	7…11
Steam	Steel	Air/flue gas	11…30
Steam	Copper, brass	Air/flue gas	14…21
Steam	Cast iron	Water	815…1050
Steam	Steel	Water	930…1400
Steam	Copper, brass	Water	1150…29001

All values are guide values

Heating Values and Energy Equivalents of Various Fuels

Fuel	Heating value (kWh/kg)	Coal equivalent	Tonne oil equivalent
Hard coal	8.218	1.009	0.707
Coke	7.967	0.979	0.685
Brown coal briquettes	5.583	0.686	0.480
Heating oil EL	11.863	1.457	1.020
Heating oil S	11.398	1.400	0.980
Gasoline	12.096	1.486	1.040
Natural gas H	8.816 kWh/m^3	1.083	0.758
Town gas	4.443 kWh/m^3	0.546	0.382
Electr. power		0.123	0.086

All values are guide values

General Conversion Factors for Quantities of Wood

	T_{adry}	sm	stm	bm^3
1 t_{atro}	1.0	1.3–2..5	2.9	4.86
1 sm	0.4–0.75	1.0	1.4	2.43
1 stm	0.3	0.7	1.0	1.70
1 bm^3	0.2	0.41	0.59	1.0

All values are guide values

Abbreviations: adry = absolutely dry (0% water content), sm = solid cubic meter: 1 m^3 solid wood, stm = stacked cubic meter: 1 m^3 stacked wood including air spaces, bm^3 = bulk cubic meters: cubic meters of piled wood parts (e.g. wood chips)

Combustion Data of the Beech and Fir/Pine Tree with 18 % Water Content

		Beech	Fir/pine
Wood chips bulk density	kg/Sm^3	280	182
Heating oil equivalent	l/t	408	4.17t
Energy	MJ/t	14.700	15.000
	kWh/t	4.083	4.167

All values are guide values

Volumetric Weights of Various Wood Types with 15 % Water Content

Unit	Solid wood sm/kg (solid meters)	Split logs stacked stm/kg (stacked cubic meters)	Wood chips bm^3/kg (bulk cubic meters)
Beech	716	445	295
Oak	702	436	289
Fir tree	472	304	194
Pine tree	527	340	217

All values are guide values

Manufacturers of Pellet Boilers

Company	Location	Power Range in kW
Arca Heizsysteme e.K	D—91207 Lauf a.d.P.	4,5–15
BIOKOMPAKT Heiztechnik GmbH	A—4391 Waldhausen	45–130
Biomasse-Zentrum-Saar-Mosel	D—66679 Britten	2–40
Biotech Energietechnik GmbH	A—5101 Bergheim	9–200
Biotherm Pelletheizungen	D—35630 Ehringhausen	14,9 and 23
Brötje GmbH	D—26180 Rastede	4–24
Buderus/Bosch Thermotechnik GmbH	D—35576 Wetzlar	2,4–32,2
Calimax Energietechnik GmbH	A—6844 Altach	1,8–12
CARL CAPITO Heiztechnik GmbH	D—57290 Neunkirchen	4,4–30
Eder Tech GmbH	A—5733 Bramberg	4,3–30
ETA Heiztechnik GmbH	A—4716 Hofkirchen	7–90
Ferro Wärmetechnik GmbH	D—91126 Schwabach	3,9–950
Fröhling Ges.m.b.H	A—4710 Grieskirchen	15–100
Georg Fischer GmbH & Co.KG	D—89312 Günzburg	10–30
Gilles Energie und Umwelttechnik GmbH	A—4810 Gmunden	12,5–153
GMH-Umwelt GmbH	D—86573 Obergriesbach	15–50
Hargassner GmbH	A—4952 Wenig/Innkreis	9–200
HDG Bavaria GmbH	D—84323 Massing	4,5–200
Herz Armaturen Ges.m.b.H	A—82722 Sebersdorf	4,8–60
Hoval GmbH	D—85609 Dornbach	10–160
Janfire GmbH	D 18513 Wendisch Baggendorf	4–600

(continued)

(continued)

Company	Location	Power Range in kW
Junkers / Bosch Thermotechnik GmbH	D—73249 Wernau (Neckar)	9–35
KWB Deutschland Kraft und Wärme aus Biomasse GmbH	D—48653 Coesfeld	10–300
Liebi LNC AG	CH—3753 Oey-Diemtigen	4,3–75
Lindner und Sommerauer SL-Technik GmbH	A—5120 St. Pantaleon	2,4–23,5
MHG Heiztechnik GmbH	D—21244 Buchholz	4–27
Oertli-Rohleder GmbH	D—71696 Möglingen	12–25
ÖkoFen Heiztechnik GmbH	D—86866 Mickhausen	8–224
Olymp—OEM Werke GmbH	A—6430 Ötztal-Bhf	3–45
Paradigma Deutschland GmbH	D—76307 Karlsbad	10–56
Paul Künzel GmbH & Co.	D—25497 Prisdorf	10–20
Pel-lets Innovative Heiztechnik GmbH	D—28757 Bremen	10–60
Pelletswärme MB GmbH	D—18513 Wendisch	4–23,7
Perhofer Gesellschaft m.b.H.	A—8190 Birkenfeld	15 and 30
RAPIDO GF Wärmetechnik GmbH	D—41748 Viersen	4,3–26
Rennergy Systems AG	D—87474 Buchenberg	9–200
SBS—Heizkessel GmbH	D—48268 Greven	10–28
SHT Heiztechnik aus Salzburg GmbH	A—5101 Salzburg-Bergheim	2,3–11,9
SOLARFOCUS GmbH	A—4451 St. Ulrich	3,9–14
SOLARvent Biomasse-Heizsysteme GmbH	D—63743 Aschaffenburg	4–54
Sonnig-Solar GmbH	D—91732 Merkendorf	4–30
Strebelwerk Ges.m.b.H.	A—270 Wiener Neustadt	3–500
Vaillant GmbH	D—42859 Remscheid	13, 20, 30
Viessmann Werke GmbH & Co KG	D—35108 Allendorf	4–42.000
Wagner & Co. GmbH Solartechnik	D—35091 Cölbe	10–45
Windhager Zentralheizung GmbH	D—86405 Meitingen	2,9–78
Wolf GmbH	D—84048 Mainburg	2,4–35
ZWS GmbH	D—47506 Neukirchen-Vluyn	4–45

Table without claim for completeness

Suppliers of Wood Pellets

Company	Location (Germany)
AGRAVIS Raiffeisen AG	Münster
Ante-holz GmbH	Bromskirchen-Somplar
BayWa AG	München
Biomasseprodukte	Feldkirchen
Enviva Pellets GmbH & CO.KG	Vilsbiburg
GEE Energiy GmbH & Co. KG	Hamburg
German Pellets GmbH	Wismar
Gregor Ziegler GmbH	Plößberg
Hans Engelke Energie OHG	Berlin
Hofgut Mauer Humus & Bioenergie GmbH	Münchingen
HOLZ- ENERGIEZENTRUM WÜRTTEMBERG	Obersteinenberg
Hubert Heitmann e.K.	Büchen
Juwi GmbH	Wörrstadt
Kleeschulte GmbH & Co. KG	Büren
Ley Mineralöl GmbH	Konstanz
Albert Ludwig Brennstoffe e.K.	Blaustein
Maier Korduletsch Energie GmbH	Vilshofen
PowerPellets Vertriebs GmbH & Co.KG	Olsberg
Raab Pelltec GmbH	Eiselfing
Raiffeisen Waren-Zentrale Rhein-Main eG	Köln
Rheinbraun Brennstoff GmbH	Frechen
SCHARR QÄRME GmbH & Co. KG	Stuttgart
Schellinger KG	Weingarten
StegMühle von Berg GmbH & Co. KG	Oberstetten/Niederstetten
VIS NOVA Trading GmbH	Bremen
WAGNER GmbH Brennstoffe.Containerdienst	Grünstadt
Westerwälder Holzpellets GmbH	Langenbach
WPG Westfälische Propan-GmbH	Detmold
ZG Raiffeisen eG	Karlsruhe

Table without claim for completeness

Producers of Wood Pellets in Germany

Company	Location	Capacity t/a
BSVG Biostoffverwertungsgesellschaft Klix GmbH	Großdubrau	10,000
EPC GmbH European Pellet Company	Torgau	150,000
MH Bioenergie Stackelitz GmbH	Stackelitz	3,000
HOWEE Holzwertstoffe Eberswalde GmbH	Eberswalde	50,000
Holzkontor und Pelletierwerk Schwedt GmbH	Schwedt/Oder	100,000
FNG Fehrbellin Naturholz GmbH	Fehrbellin	40,000
BEN BioEnergie Niedersachsen GmbH	Buchholz i. d. N.	43,000
German Pellets GmbH	Wismar	605,000
Holzindustrie Schlitz GmbH & Co KG	Schlitz	kA

(continued)

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Company	Location	Capacity t/a
Gebr. Hosenfeld GmbH & Co. KG	Hosenfeld	40,000
Naturholzzentrum Hardegsen	Hardegsen	kA
Tangermünder Holzpelletwerke GmbH	Tangermünde	100,000
Woodox Management GmbH	Düsseldorf	180,000
Pelltec GmbH	Sonsbeck	6,000
STAWAG Stadtwerke Aachen AG	Aachen	40,000
Westpellets GmbH & Co. KG	Titz Ameln	4,000
WEAG & Mohr GmbH & Co. KG	Trier	15,000
Sägewerk Assenmacher	Ormont	6,000
Juwi Bio GmbH	Wörrstadt	8,000
Energiepellets Oberhonnefeld GmbH	Oberhonnefeld Gierend	30,000
Westerwälder Holzpellets GmbH	Langenbach	40,000
Sorpetaler Fensterbau GmbH & Co, KG	Sundern- Hagen	1,000
Baust Holzbetriebs-GmbH	Eslohe-Bremke	10,000
Ante-holz GmbH	Bromskirchen	40,000
IWO-Pellet Rhein.Main GmbH	Offenbach	25,000
Holzwerk Grasellenbach Monnheimer GmbH& Co. KG	Grasellenbach	10,000
Süd-Energie Bioplus GmbH	Monsheim	8,000
Bio-Energie Mudau GmbH & Co. KG	Mudau	30,000
BioPell GmbH	Empfingen	50,000
Emil Steidle GmbH & Co. KG	Sigmaringen	30,000
Sonnen—Pellets Krauchenwies GmbH & Co. KG	Krauchenwies	40,000
Trocknungsgesellschaft Bopfingen und Umgebung	Bopfingen	10,000
Allspan GmbH Spanverarbeitung	Karlsruhe	3,000
Naturholzzentrum Kehl	Kehl	kA
Bioenergie Sonnen Pellet GmbH	Buchenbach	60,000
Haas Holzprodukte GmbH	Galkenberg	12,000
Glechner Pellet-Produktions GmbH	Simbach a. Inn	15,000
Binderholz Deutschland GmbH	Kösching	150,000
IN-Energie GmbH & Co. Betreiber KG	Großmehring / Interpark	30,000
Anton Heggenstaller GmbH	Kühbach-Unterbernbach	120,000
Holzwerke Pröbstl GmbH	Fuchstal-Asch	60,000
FireStixx Hartleitner GmbH & Co. KG	Ziertheim	10,000
Horst Römer Leimholz	Emskirchen	8,000
Trocknungsgenossenschaft Weißenburg eG	Ellingen	6,000
JuraPellets GmbH & Co. KG	Ursensollen	2,000
Holz Schiller GmbH	Regen	30,000
Enviva Pellets GmbH & Co. KG	Straubing	120,000
EVS GmbH & Co. KG	Hengersberg	90,000
FP Franken-Pellets GmbH & Co. KG	Stadtsteinach	15,000
Tröger—Der Einrichter	Arzberg	5,000
Gregor Ziegler GmbH	Plößberg	30,000
Theodor Herbert GmbH & Co. KG	Motten	7,000

Table without claim for completeness

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Index

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