# Fuel Characterization of Pellet Chips

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**Abstract**

Small hardwood chips, known as pellet chips, were characterized and combusted in two different pellet burners, installed in a residential boiler specially designed for pellet combustion. The average particle mass was about 10 percent of the mass of an 8-mm pellet, with a similar surface-to-volume ratio. The bulk density of pellet chips was 160 to 170 kg m$^{-3}$ at 10 percent moisture content (about 25% to 35% of 8-mm pellet bulk densities). The combustion performance was good, with average $O_2$ and CO values (by volume) at 17.6 percent (SD, 0.6%) and 200 ppm (SD, 210 ppm), respectively, for the bottom-fed burner and 14.2 percent (SD, 1.1%) and 330 ppm (SD, 93 ppm), respectively, for the top-fed burner. Thus the study indicates that pellet chips produced with commercially available equipment can be used in ordinary pellet combustors, provided that the fuel feeding rates are increased and the moisture content well below 20 percent. More accurate market assessments will require the investigation of the performance of different types of combustion equipment with fuels of different qualities.

There is an increasing demand for biomass fuels in Sweden, particularly woody fuel pellets. It has been estimated that the amount of heat supplied by pellets could be increased by up to 6.45 TWh over the 2005 value (Ericsson and Börjesson 2008). This demand for high-quality fuel has resulted in a shortage of sawmill residues (e.g., saw dust), the traditional raw material for pellets (Junginger et al. 2008). Harvested tree components include stemwood, branches, needles, and stumps. Of these, stemwood biomass is generally considered to be the best for fuel pellet production and energy use, e.g., in small- and medium-scale heat production units. Significant quantities of roundwood (stemwood including bark) are therefore used for the production of fuel pellets. During the pelletizing process, the roundwood must be comminuted (chipped and ground) and dried to a state similar to that of dried saw dust or planer shavings before it can be compressed. The particle size distribution of the raw material for pelletizing, and thus the comminution method used, affects pellet quality and the efficiency of the production process (Arshadi et al. 2008, Bergström et al. 2008). In addition to combustion for heat production, such wood could potentially be used for gasification and could have nonfuel uses, such as fiber board manufacturing. In all of these applications, the particle size distribution of the raw material affects the processes involved and the quality of the output. Wood chips for fuel use, which traditionally vary widely in size, are now available with more well-defined size distributions. This has implications both for the use of wood chips as a fuel, as a gasification feedstock, and as an intermediate step in the manufacture of fuel pellets. While it is hard to obtain data on the wood chips that are actually used, the current European standard (Anonymous 2010a) gives an indication of their particle size distribution. According to the most stringent requirement (P16A), the mass of the coarse fraction (i.e., chips $\geq$16 mm long) should be below 3 percent of the total fresh weight (%, wt/wt); according to the least stringent criterion (P100), a coarse fraction ($\geq$200 mm) of 6 percent (wt/wt) can be tolerated. Some examples of particle size distributions have been reported in the literature (e.g., Fløjgaard Kristensen and Kofman 2000, Daugbjerg Jensen 2004, Hartmann et al. 2006).

Wood chips with more narrow size distributions are becoming available. At least one process has been commercialized that produces chips with much smaller and more uniform particle sizes, which reduces the need for grinding before pelletizing (Anonymous 2010b). Another

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process results in chips that could (after drying) conceivably be combusted in small- and medium-scale combustors designed for pellets or briquettes (Anonymous 2009a). Such wood chips, known as pellet chips, are thus a potentially important fuel.

Conventional chipping followed by grinding and pelletizing of the roundwood may not be the most cost-efficient way to prepare dried fuel; it may be more cost efficient to comminute the roundwood in such a way that the wood chips have combustion properties comparable to those of pellets. Dried wood chips with relatively uniform particle sizes could either be used locally as a fuel in less sensitive small- and medium-scale combustors (replacing pellets) or as raw materials for the production of upgraded fuels such as pellets or briquettes for use in more distant markets and in more sensitive combustors. An obstacle to the more widespread use of dried wood chips may be the lack of experience with this fuel.

There are rather few reports in the literature concerning the combustion of pellet chips as a fuel. The Danish consultant Agrotech (Pedersen 2009) performed combustion tests with pellet chips made using a disk chipper manufactured by PC Stål, Denmark. The chipper was equipped with a 30-mm sieve. The sieve determines the upper size of the chip particles, which were always below 45 mm. The resulting size distributions were determined for two batches (moisture contents [MC], 18.6% and 14.7% [wt/wt]). Seven burners were operated by different users, and some fuel feeding problems were encountered. However, apart from a size distribution measurement, no further physical characterization of the pellet chips was made, nor were quantitative measurements from the combustion tests reported. The basic shapes of wood chips have been described by authors including Hakkila (1989) and Beijbom and Nilsson (1979), and the dependence of their shapes on the operational parameters of the chipping process have been studied by Hartler (1986), Uhmeier (1995), Twaddle (1997), and Hellström (2008). Similar information is needed for pellet chips, and there is thus a remaining need for physical fuel characterization and for determining the fuel combustion properties.

Wood chips and pellets of similar composition and MC may nevertheless exhibit significant differences in terms of a range of properties of practical importance, including (1) fuel feeding properties, (2) combustion properties (fuel conversion, burn-out, etc.), (3) gaseous and particulate emissions, and (4) the operating parameters required for stable combustion. These properties need to be determined through combustion experiments, the results of which will depend on the type of combustor used. A variety of combustor types are often used in the small- and medium-scale combustion of dried fuels, including grates, pellet burners (top-fed, horizontally fed, or bottom-fed), horizontally fed stoker burners, and bottom-fed stoker combustors. This variety in combustion equipment generates a wide range of conditions related to fuel handling/feeding, combustion process, and optimization potential. To determine the generic properties of this fuel, both physical and thermochemical characterizations are needed, and more than one type of combustor should be used in the initial combustion experiments.

To maintain stable combustion, properties of the fuel, such as its chemical composition, structure, and MC, need to be within certain limits, as do certain operating parameters of the combustor, including the flows of fuel and air. The feeding properties of a fuel are determined by its particle size and shape distributions. These also affect its combustion properties (e.g., ignition, pyrolysis, burn-out, and emissions), so measurements of the particle size and shape distributions are important. All other things being equal, the lower bulk density of wood chips will result in a lower fuel feeding rate. Unless adjustments are made for this, the combustion power will be insufficient and the fuel-to-air ratio will be too low. Another possible feeding problem for wood chips is the formation of bridges that obstruct the fuel intake; this is more likely when fuels with a relatively high content of particles whose length exceeds 100 mm are used (Daugbjerg Jensen 2004). With smooth wood pellets, bridging is virtually nonexistent.

The objectives of this study were therefore to perform (1) a preliminary characterization of the physical properties of pellet chips and (2) a preliminary combustion test of pellet chips in ordinary residential pellet burners to determine the need for modifications.

## Materials and Methods

### Characteristics of the wood chips

Wood pellet chips from a commercial producer were characterized according to their MC and particle dimensions and used in feeding and combustion experiments. Trees from first thinnings in southern Sweden (diameter at breast height, mostly below 200 mm; maximum diameter, 270 mm) were felled and delimbed with a harvester in the winter of 2008 to 2009 and stored in piles until chipping in March 2010 (probably partly frozen at the time of chipping). The trees were mainly birch (*Betula pubescens*), with some aspen (*Populus tremula*). The wood chips used were prepared by Hakab Konsult AB of Ljusfallshammar, southern Sweden, using chipping equipment from PC Stål, Denmark, with double disks of 942-mm diameter and four knives. Since the chips used in this study were prepared for commercial rather than experimental purposes, relatively little was known about the origins of the roundwood used in their manufacture. The chipper was equipped with a sieve with a selectable hole diameter of 20, 30, or 40 mm. A 14-mm distance between knife and disk and the 30-mm sieve fitted were used. The sharpness of the knives was unknown. Shortly after the chipping, the batch studied (about 50 kg) was sampled and analyzed.

The MC (fresh weight basis) was determined after delivery according to standard SS187170-3. The size distributions of the wood chips were measured by sieving, using opening diameters of 45, 15, 5, 3, 2, and 1 mm; for opening diameters of 3 mm and above, the measurement procedure used was identical to that specified in Swedish standard SS 187174:2. For each size fraction, the average particle mass (fresh) was estimated by weighing a small sample (~0.5 to 20 g) and then manually counting the number of particles within the sample. Small samples (~0.5 to 20 g) of the 15- to 45-mm, 5- to 15-mm, and 3- to 5-mm size fractions were used to determine their particle dimensions. The length (along the direction of the grain), width, and thickness of the particles in each sample were measured manually. The average mass of the particles in each fraction was determined by selecting a subsample, measuring its mass, and then manually counting the number of particles within the subsample. The bulk density (kilograms per cubic meter) of the samples, based on their fresh weight, was estimated according to the standard SS18 71 78 (with minor modifications due to the small amount of material being tested).

To determine the risk of bridging when using wood chips, a procedure designed by Paulrud (2004) was used. Vertical funnels with apertures of different sizes were rested on a horizontal bottom plate and charged with a total of 2 liters of the fuel to be tested. The bottom plate was then removed and the passage of the material through the aperture was monitored to see whether an obstructing bridge formed. The experiment was performed five times with each combination of funnel size and chip type to reduce the influence of random disturbances. The funnels used had apertures of 60, 65, 70, and 75 mm, respectively.

## Feeding and combustion properties

For the combustion experiments, a bottom-fed pellet burner (Bequem 15 D, nomimal power 15 kW; Thermia Värme AB, Sweden) and a top-fed pellet burner (Janfire Flex-a, nominal power 18 kW; Janfire AB, Sweden) were used. These two burners very well represent the state-of-the-art technology for residential pellet burners that are installed in existing boilers to replace oil, wood log, and electricity heating. The burners were installed in a reference boiler (Combifire; VedSol AB, Sweden) that also is used in the national certification test system (P-marking) of residential pellet burners in Sweden.

The fuel feeding and combustion experiments are shown in Table 1. The fuel feeding rates were determined for the bottom-fed burner (dried fuel) and for the top-fed burner (dried fuel and fuel as received) for the 3- to 5-mm and 5- to 15-mm size fractions, respectively. The fuel was inserted directly into the inlet opening, where the external augers are fitted. Feeding tests were performed with both burners, using either the unsieved chips or one of the sieved, i.e., 3- to 5-mm and 5- to 15-mm, fractions. The fuel samples used had two levels of MC: 20 percent and 7 to 10 percent (some drying occurred between delivery and combustion tests). Reference experiments with standard softwood pellets of 8-mm diameter were also performed. The pellets were produced from sawmill residues at a plant at Härnösand, Sweden, owned by SCA (Svenska Cellulosa Aktiebolaget).

During each combustion test, the concentrations of $O_2$ and CO were monitored by a Testo 350XL instrument with standard electrochemical sensors.

*Table 1.—Survey of fuel feeding experiments and combustion experiments.*[a]

| Type of fuel | | Type of pellet burner | |
|---|---|---|---|
| Size fraction | MC (%) | Bottom-fed burner (maximum rate) | Top-fed burner (feeding test mode) |
| 3–5-mm chips | 20 | | F |
| | 7 | F | F/C |
| 5–15-mm chips | 20 | F/C | |
| | 7 | F/C | F/C |
| Mixed 3–5- and | 20 | | C |
| 5–15-mm chips | 7 | | C |
| Standard 8-mm pellets | 7–10 | F | F |

[a] MC = moisture content; F = fuel feeding experiment; C = combustion experiment.

Overall, six combustion experiments were performed with the different pellet chips assortments, as shown in Table 2. In total 5.6 kg of dry chips was combusted over 10 hours. Two tests with fuel of 20 percent MC (5 to 15 mm in the bottom-fed burner and 3 to 15 mm in the top-fed burner) showed that adequate combustion temperatures could only be maintained with a drier fuel. For the bottom-fed combustor, the mass flow of the 3- to 5-mm fraction was too low for acceptable combustion, and so only the 5- to 15-mm fraction was used. For the top-fed combustor, dried pellet chips of 3 to 15 mm were used, as were the 3- to 5-mm and 5- to 15-mm fractions. The large difference in fuel feeding rates made direct comparisons with pellets difficult, and previous measurements for pellet combustion in similar equipment were therefore used (Boman et al. 2011).

# Results

## Characteristics of the wood chips

The MC of the mixed hardwood chips, as delivered, was 26.3 percent. The size distribution of the undried chips was biased toward larger particles because the fine particles in this fuel tended to stick to other particles (Fig. 1).

The average masses (in grams) of individual fuel particles was 0.590 (SD, 0.36; $n = 32$) for the 15- to 45-mm fraction, 0.048 (SD, 0.04; $n = 24$) for the 5- to 15-mm fraction, and 0.007 ($n = 40$) for the 3- to 5-mm fraction (see Table 2 for particle dimensions). Most of the mass was accounted for by particles lighter than 0.1 g. For comparison, pellets with a diameter of 6 mm and a length of 36 mm have masses of around 0.6 g, while pellets with a diameter of 8 mm and a length of 36 mm have masses of about 1 g. The average bulk

*Table 2.—Average particle dimensions for the three major size fractions of the hardwood chips.*[a]

| Dimension | Particle size fraction (mm) | | |
|---|---|---|---|
| | 15–45 | 5–15 | 3–5 |
| Length | 41.2 (14.2) | 10.8 (4.5) | 7.9 (3.5) |
| Width | 11.3 (4.7) | 5.0 (1.5) | 2.7 (1.7) |
| Thickness | 5.3 (1.7) | 2.4 (1.1) | 1.1 (0.4) |

[a] Values are means (standard deviations) presented in millimeters. The 15- to 45-mm fraction accounted for only 1 percent of the total mass.

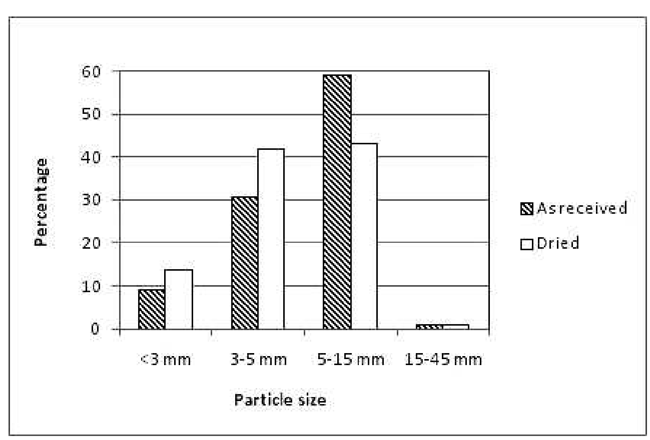


*Figure 1.—Size distribution of mixed hardwood pellet chips, expressed in terms of the percentage (by mass, of dried material at 105°C) of chips falling into different size categories.*

density of the fresh chips was 207 kg $m^{-3}$ (SD, 4 kg $m^{-3}$; $n = 5$) at 26 percent MC, which is a value commonly reported for partially dried chips.

The risk for bridge formation was higher than for wood pellets. For pellet chips the funnel openings required for unobstructed passage ranged from 60 mm (dried hardwood) to 75 mm (moist hardwood, 5 to 15 mm), while 60 mm is sufficient for 8-mm pellets.

## Feeding and combustion properties

Auger feeding of fuel material worked reasonably well after removal of the largest fuel particles (approximately 1% of the total mass of fuel). However, it was necessary to compensate for the reduced bulk density of the chips in order to maintain adequate combustion power. The measured fuel feeding rates are shown in Table 3. A 60-mm funnel opening was used with the dried hardwood chips; a 75-mm opening was used with moist hardwood chips with a size of 5 to 15 mm. The fuel with 7 percent MC could be fed with slightly higher mass flows.

For combustion of the 5- to 15-mm chips, the flue gas concentrations (by volume) of $O_2$ and CO (converted to 10% [vol/vol] $O_2$) were 17.6 percent and 199 ppm, respectively, for the bottom-fed burner and 14.2 percent and 328 ppm, respectively, for the top-fed burner (Table 4). The emission data are average values with standard deviations during a 15-minute period of constant and stable combustion at a 3- to 5-kW load. Combustion of stemwood pellets in small-scale appliances typically results in CO emissions of 50 to 200 ppm (at 10% $O_2$) during normal operation at nominal load (Johansson et al. 2004, Boman et al. 2011).

*Table 3.—Fuel feeding rates (kW) in the two residential pellet burners used.*

| Type of fuel | | Type of pellet burner | |
|---|---|---|---|
| Size fraction | MC (%)[a] | Bottom-fed burner (maximum rate) | Top-fed burner (feeding test mode) |
| 3–5-mm chips | 20 | | 17.1 |
| | 7 | 4.61 | 21.3 |
| 5–15-mm chips | 20 | | 18.2 |
| | 7 | 5.30 | 22.1 |
| Mixed 3–5- and | 20 | | |
| 5–15-mm chips | 7 | | |
| Standard 8-mm pellets | 7–10 | 21.1 | 72.2 |

[a] MC = moisture content.

*Table 4.—$O_2$ and CO concentrations in the flue gases during the combustion tests in the two different burners.*[a]

| Type of fuel | | Type of pellet burner | | | |
|---|---|---|---|---|---|
| | | Bottom-fed burner (maximum rate) | | Top-fed burner (feeding test mode) | |
| Size fraction | MC (%) | $O_2$ | CO | $O_2$ | CO |
| 3–5-mm chips | 20 | | | | |
| | 7 | | | 11.4 (0.8) | 460 (112) |
| 5–15-mm chips | 20 | 14.4 (0.7) | 2,220 (520) | | |
| | 7 | 17.6 (0.6) | 199 (211) | 14.2 (1.1) | 328 (93) |
| 3–15-mm chips | 20 | | | 12.3 (0.8) | 1,320 (270) |
| | 7 | | | 13.7 (0.7) | 1,010 (300) |
| Standard 8-mm pellets | 7–10 | | | | |

[a] Values are means (standard deviations) presented in percent by volume for $O_2$ and parts per million by volume for CO. CO values are corrected for an $O_2$ concentration of 10 percent. MC = moisture content.

## Discussion

The average fuel particle size of the studied pellet chips was smaller than that of the wood pellets used in the study, but their surface-to-volume ratio was similar. The particle size distribution agrees reasonably well with the result of Pedersen (2009). Only about 1 percent of the mass fraction of the studied pellet chips consisted of chips with a length in excess of 15 mm; for comparative purposes, the strictest European standard for wood chips (P16) requires that chips with a length in excess of 16 mm comprise no more than 3 percent of the total mass. The bulk density of the pellet chips was only about one-third to a quarter of typical wood fuel pellet bulk densities at 10 percent MC (ca. 550 to 700 kg $m^{-3}$; Anonymous 2010a). The relatively low bulk density of the pellet chips means that modifications to the fuel feeding system are needed in presently used wood pellet combustion systems to allow sufficient fuel mass flow. Another difference between the pellet chips and wood pellets was that the former were more prone to bridge formation, although this tendency was not severe.

Because pellets have a higher bulk density compared with pellet chips, they should be cheaper to transport, although limitations of the total weight of each truck (60 tonnes) mean that payloads are weight limited rather than volume limited. Maximum truck loads for bulk transport of pellets from two major manufacturers in northern Sweden are 36 to 39 tonnes and 38 to 42 tonnes, respectively. A typical payload for a chip-transporting truck is 135 $m^3$, resulting in a load of 24 tonnes (MC, 10%), about 65 percent of the load on a pellet truck. Assuming other costs are equal (driver's wages, fuel, capital, etc.) this gives an approximate relationship between the transportation costs of pellet chips and pellets of about 1.5.

Without the need for grinding and pelletizing, the costs for capital and electricity are reduced. A typical electricity consumption for pelletizing is 90 kWh per tonne of pellets, and a typical investment for grinding, pelletizing, and cooling is 1.2 million Euros (year 2004) for an annual capacity of 80,000 tonnes (Thek and Obernberger 2008). The trade-off between production costs and transportation costs means that pellets become increasingly competitive for larger production scales and more distant markets, while a process that requires less investment may be interesting for a risk-averse small-scale producer with a local market.

The CO emissions from combustion of pellet chips were reasonably low for dried material (MC, 7%). Considering the limited duration of the tests, the differences in combustion properties between the different qualities of dried chips cannot be regarded as significant.

The uncertainties about the raw material and chipping parameters and the limited ranges of variation for these factors mean that the results should be interpreted with caution. More details on tree species, season of harvest, and storage time would be useful, and so would more data on the operational parameters, such as the sharpness of the knives used in preparation of the chips. To optimize the quality of the wood pellet chips and facilitate the development of an efficient production process, further study of the influence of the type of raw material and the chipping parameters on the fuel and combustion properties of wood pellet chips will be required. The challenge is to identify the particle size and shape that enable a more ''optimal'' combustion of such small ''micro'' chips, herein called pellet chips. There is also a need to identify the type of equipment required and to identify the optimal operational parameters of the chipping process. Factors such as the tree species and the tree components (e.g., stemwood, branch wood, and stump wood) from which the chips are made, and the storage time and MC, would need to be tested systematically. The productivity of the chipping and pelletizing processes used to prepare fuels of different qualities should also be measured, as should the energy used by these processes. If finely comminuted wood chips are to be used in the production of pellets, it will be necessary to systematically compare different combinations of chipping and milling equipment in terms of their productivity, product quality, and energy consumption.

Sustained measurements would be needed to determine the optimum operational parameters and emissions. Our data indicate that when using pellet chips, it is necessary to increase the fuel feeding rate relative to that used with wood chips. Potential problems also include entrainment of small particles in the airflow, resulting in emissions of coarse particles. There is also a risk that the entrained fuel particles may not be completely combusted, leading to increased CO emissions and lower total efficiency. Design changes like lower air velocities at the grate should therefore facilitate more efficient combustion of finer material.

The economic viability of dried wood chip production needs to be assessed. Viability will involve a trade-off between process investment with economies of scale and transport costs. Because pellet chips are more expensive to transport than wood pellets, local customers are needed. However, the availability of a less expensive fuel than pellets might encourage consumers to switch from electric heating (used in about 9% of small residential buildings) or oil to forest fuels. The production of dried fuels can be used as a way to recover the 2 to 4 TWh of available waste heat (Anonymous 2009b), to use excess heat capacity in district heating systems from spring to autumn, and to increase electricity production in combined heat and power plants (Wahlund et al. 2002).

## Conclusions and Future Studies

On average, pellet chips were found to have around one-tenth of the mass and one-third to one-quarter of the bulk density of typical 8-mm woody fuel pellets. These differences were reflected in the need to use relatively high fuel feeding rates when combusting pellet chips. The combustion performance was good, with average $O_2$ and CO values (by volume) at 17.6 percent (SD, 0.6%) and 200 ppm (SD, 210 ppm), respectively, for the bottom-fed burner and 14.2 percent (SD, 1.1%) and 330 ppm (SD, 93 ppm), respectively, for the top-fed burner. Thus, the study indicates that pellet chips produced with commercially available equipment can be used in ordinary pellet combustors, provided that the fuel feeding rates are increased and the MC is well below 20 percent. In larger combustors, the difficulties are likely to be smaller because the combustion conditions will fluctuate less. The combustion tests also indicated that the use of wood chips in present residential pellet burners seems to be viable; for top-fed combustors, only software changes would be required.

The scope for using this kind of wood pellet chips in Sweden could be considerable because refined wood fuels account for around 0.65 TWh of district heating. It has been estimated that between 2005 and 2025, the use of pellets could increase to the point that they would account for 6.45 TWh, some of which could be supplied by pellet chips. To more accurately elucidate the properties of this fuel type and estimate the size of the potential markets, it will be necessary to study the performance of different types of combustion equipment with fuels of different qualities.

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