CHAPTER 4

Biomass Pelletization Process

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Abstract

The production of energy by means of biomass has shown a clear trend towards the use of pellets due to their homogeneous size, which facilitates handling and feeding while also reducing costs associated with storage and transportation. The pellet quality depends on the properties of the feedstock and on the operative variables of the densification process. Quality parameters can be modified by adapting the process to the raw material to be pelletized. Whereas wood pellets from forestry residues already have successfully established technologies and markets, there is a need to develop the pelletization of agricultural biomass, which is periodically planted and harvested, and holds great energy potential, especially in rural areas.

Keywords: Pellet, manufacturing conditions, pelletization stages, biomass.

1 Introduction

In recent years, the production of thermal energy by means of biomass on a small scale has shown a clear trend towards densified biofuels (pellets) [1]. The homogeneous size facilitates an automatic or semi-automatic treatment and, thus, resolves the disadvantages of the traditional domestic use of biomass [2,3]. The use of densified biofuels also reduces the costs associated with handling, storage and transportation.

Despite the vast generation of agricultural and forestry residues, their utilization as fuel is still low in light of their energy potential. Some important factors that influence the level of energy usage of these residues are their low bulk density [4,5], local availability, the fact that they are dispersed over a relatively large area and a lack of information concerning fuel feeding, combustion and emission.
characteristics. This information is important for the design and efficient operation of combustion systems fully adapted to the biomass of each region.

The management of these residues is hampered by the costs associated with treatments needed for their proper removal [3]. Pelleting residual biomass would mean the conversion of a residue difficult to manage into an energy resource most adequate for use in the areas where each grove exists.

The final quality of pellets varies depending on the raw material properties and the manufacturing process [6] (Fig. 1). Although the inorganic and organic components of the different raw materials cannot be modified, certain variables dependent on the pelletization process can be controlled to optimize the production efficiency and enhance the quality of the finished product [5].

The aim of this chapter is to analyse the operative variables of the pelletization process that can be adapted to each type of biomass to improve the characteristics of the final pellets produced, according to the quality guidelines for biomass established by the European Standards EN14961-2 [7] and EN14961-6 [8].

2 The Pelletization Process

The biomass pelletization process consists of multiple steps including raw material pre-treatment, pelletization and post-treatment (Fig. 2).

2.1 Feedstock storage

An effective feedstock storage system is necessary so as to keep biomass away from impurities and offer adequate protection from rain and moisture in general. Rain may actually damage the feedstock by increasing its moisture content to such a high level that the drying process becomes unviable.

2.2 Removal of undesirable impurities

Raw material should be filtered before grinding to remove materials such as stones or metal fragments [9].

Many pellet plants are equipped with systems separating virgin biomass from inert materials such as stones and soil, or magnetic separators for metal impurity
removal. The presence of even the slightest amount of such materials in the final product is unacceptable. At the same time, they can cause serious damage to the mechanical equipment, i.e. in the hammer mill or in the pellet press.

2.3 Size reduction

The raw material must be reduced to a uniform size that is adequate for the pellet mill. The milled material going into the pellet mill has to be smaller than the die holes to prevent blocking of the holes. Therefore, materials should be ground to a size no bigger than the diameter of the pellet (~6 mm), producing a substance with a consistency similar to bread crumbs [10].

For pelleting, it is generally assumed that small particles with a large surface area will increase density and result in stronger pellets [11–13]. A narrow particle size distribution of the raw material also facilitates even moisture distribution during the drying stage. In a mixture of different sizes, small particles might become overly dried in the process and make self-bonding more difficult later on in the densification stage [14]. A mixture of particle sizes is considered beneficial, because this increases the durability of the pellets [15].

The size reduction equipment will vary depending on the characteristics of the raw materials. Chippers and shredders are used for raw materials with large diameters, while a hammer mill is more appropriate for chips or herbaceous raw materials.

In addition, the diameter of the raw material will influence the choice of equipment [16], chippers/shredders being adequate for raw materials with a diameter over 2.54 cm. Hammer mills are normally the most suitable for size reduction; however, there is a limitation on the size of the input material, which has to have a diameter of <2.54 cm to be processed.

Generally, chippers/shredders are used as a first step. Then, once the size of the chipped material has been reduced, the hammer mill is used as a finishing mill.
2.4 Material transportation

Once reduction has taken place, the material must be moved on to the next process. Screw conveyors are the most commonly used systems for transporting the material through the pelletization process because of the low cost involved.

Alternative options would include the use of a fan followed by a cyclone separator that separates air from the milled material. The air leaves the top of the cyclone, and the milled material is thrown to the outside edge of the cone and then falls out below [16].

2.5 Biomass drying

In pelletization techniques, the moisture percentage of the raw material should be between 10% and 20% to assure high-quality pellet production [16] (Fig. 3). However, the exact percentage to produce quality pellets is specific to each raw material [17].

Drying solid biofuels is a key factor, since wet raw materials result in low combustion temperatures, low energy efficiency and high emissions of hydrocarbons and particles [18]. In addition, it is very important to choose the right dryer, which may constitute the largest capital expenditure in a pellet production plant [16] and can dramatically increase the production cost per tonne [9,10].

Though fossil fuels can be used as the heat source of the dryers, they would increase pellet production costs while reducing the environmental friendly credentials of the biomass fuel pellets. Hence, the most common and cheapest solution is to generate heat by burning the pellets produced in situ, or the dried chips used for making the pellets. Yet, it is important to remember that the fly ash contained in the flue gas used in directly heated drum dryers remains in the dried sawdust, which leads to a higher ash content of the pellets and a certain degree of contamination by heavy metals [19].

Dryers can be classified depending on the medium used. According to Mujumdar [20], superheated steam dryers have some key advantages compared with air dryers – such as lumber or rotary dryers – because no oxidation or combustion reactions

![Figure 3: Influence of the moisture content of raw material in pellet production [16].](image-url)
are possible. Steam dryers have higher drying rates than air and gas dryers, and do not entail any danger of fire or explosions, while allowing toxic or valuable liquids to be separated in condensers [18]. These systems are more complex, however, and even minor steam leakage is devastating in terms of the energy efficiency of the steam dryer [21]. The most commonly used systems are the flue gas rotary dryers, which combine high inlet temperature with long residence time, and thus can result in pyrolysis and partial gasification [22].

2.6 Mixing and conditioning

Not all raw materials require mixing. Nevertheless, if necessary, mixers are used after the raw material has been milled and dried to: (1) get a more consistent material blend to be fed into the pellet mill when the raw material presents significant changes in moisture percentage, binding properties or material density [16] or (2) produce a homogeneous mixture of raw materials in the case of pellets made up of different raw materials.

Once the raw material has been mixed and its consistency is high enough, it may require the addition of other constituents able to increase the productivity of the pellet mill and enhance the final properties of the pellets produced.

Additives play a major role in wood pellet characteristics. They are a subject of major interest: as binding agents for the biomass raw material, they serve to improve pellet durability and physical quality, reduce the dust, improve pelleting efficiency and reduce energy costs.

A maximum content of 2% of additives is permitted in woody pellets [7]. No limitation exists for the non-woody pellets [8], though it is required to indicate the type and quantity used. To produce wood pellets with desired physical and thermal characteristics, the additive should be suited to the right biomass material. The most common additives are: (1) water, which is used if the moisture content of the mixed material is too low and (2) binders, which act as a glue between the particles if the lignin content of the material is not enough to hold a pellet together. Lignin is a natural, optimal binder of biomass, because it melts under the heat of the pellet mill [23]. If the lignin content of the biomass is low, it may be necessary to add other additives, however. One of the simplest binders is vegetable oil, which also aids the pellet process by reducing the frequency of blocked dies [16], but the most widely used substance overall is starch [24].

As concluded by Tarasov et al. [24] and summarized below, each additive will produce unique physical and thermal characteristics when used with different biomass materials:

- Lignosulphonate additives result in the best mechanical durability values for wood pellets but do not display high particle density. As they do not affect the calorific value of the wood pellets, they significantly increase sodium and sulphur content, and consequently increase emissions.
- Starch additives are the most widely used because they reduce the final moisture content more than lignosulphonate additives. However, too much starch
will make the final product extremely dry, which affects the mechanical durability of the wood pellets.

- Additives such as motor oil, corn starch, sodium carbonate, urea, vegetable oil and dolomite decrease the wood pellet particle density and contribute to the pellet process by reducing the frequency of blocked dies [16].

Corn starch and dolomite additives are the most effective in reducing the wood pellet particle density. All types of starch (native wheat starch, oxidized corn starch, native potato starch and oxidized potato starch) increase the mechanical durability of the wood pellets, the best results for mechanical durability being obtained by adding oxidized corn starch. Motor and vegetable oil additives increase the calorific value minimally, while corn starch and dolomite additives reduce the calorific values of wood pellets. Wheat starch is an additive that significantly reduces ash formation, but dolomite additive increases ash formation as well as the ash melting point in wood pellet combustion. Both corn starch and dolomite additives significantly increase carbon monoxide emissions.

Many pelletizing machines come with a built-in steam conditioning chamber [10]. Super-heated steam, at temperatures above 100°C, is used to soften the wood before it is compacted. Steam conditioning is not necessary, but it does make the raw material less abrasive to the pelletizing equipment and this helps reduce the maintenance costs [9].

2.7 Pellet production

Pellets are finally made by pellet mills, also known as pellet presses or extruders, which are available in a range of sizes. Generally, every 100 horsepower provides a capacity of approximately 1 ton of pellets per hour [10].

Pellets are created by using a great deal of pressure to force the raw material through holes in the die. The pellet mills are mainly formed by two elements: the die with the holes that act as the mould and the rollers that force the raw materials to go through the holes of the die.

As the pressure and friction increase, the temperature of the wood also increases. This allows the lignin to soften and the fibre to be reshaped into pellet form [9]. Simultaneously, the moisture content is reduced because of the higher temperature.

2.7.1 Types of pellet mills

According to the shape of the die, pellet mills can be classified as: (1) flat die pellet mills, which are used for small- to medium-scale pellet industries and (2) round die pellet mills, which are applied to medium- and large-scale pellet industries [16].

Flat die mills use a flat die with slots (Fig. 4). The powder is introduced into the top of the die and, as the die rotates, a roller presses the powder through the holes in the die. A cutter on the other side of the die cuts the exposed pellet free [25].

In the round/ring die, there are radial slots throughout the die. The die is positioned vertically, powder is fed into the centre of the die and spreaders evenly
distribute the powder. Two or more rollers then compress the powder through the die holes. Two cutters are used to cut the pellets free from the outside of the die [26].

In both cases, there has to be a rotary element, which can be the die or the rollers. In the case of flat dies, the rollers are the moving element, whereas the most common design of ring dies is where the die is powered and rotating, and the rollers move due to the friction and movement of the die.

The advantages and disadvantages of each type of pellet mill are summarized in Table 1.

2.7.2 Types of die
There are different die types that vary with regard to hole depth, hole pitch, hole width and die material [16].

- The depth of the hole is not related to the length of the pellet. It establishes the time the material is exposed to heat and pressure. Longer holes are recommended for materials with low lignin content to achieve better melting and, therefore, a harder, denser pellet.
- The pitch angle of the hole influences pellet compression, and it should be designed according to the feedstock.
- For biomass pellets, the most common diameters are 6 and 8 mm. These diameters, as well as the length of the pellets, are limited by the European Standards
Table 1: Advantages and disadvantages of flat and round pellet mills [16].

<table>
<thead>
<tr>
<th></th>
<th>Flat die</th>
<th>Round die</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Advantages</strong></td>
<td>Easier to clean</td>
<td>Lower costs of roller and die consumables</td>
</tr>
<tr>
<td></td>
<td>Quick access to the chamber</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Compact design</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Visibility of the pellets produced</td>
<td>Extra friction resulting in more heat and better quality of the pellets</td>
</tr>
<tr>
<td></td>
<td>Robust for problematic feedstock (wider tolerance)</td>
<td></td>
</tr>
<tr>
<td><strong>Disadvantages</strong></td>
<td>Possible uneven roller and die wearing</td>
<td>Extra friction resulting in more energy consumption</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Large size and weight</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Difficult access to rollers and dies</td>
</tr>
<tr>
<td></td>
<td>Slipping action of the rollers (can be solved by tapering the rollers)</td>
<td>Manual roller adjustment (can be solved by remote access)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>High costs</td>
</tr>
<tr>
<td></td>
<td></td>
<td>No visibility of the pellet process</td>
</tr>
</tbody>
</table>

[7,8] to assure that the pellets can be fed by the screw conveyors of standardized stoves and boilers without blocking the feeding systems. Experience has shown that thinner pellets allow a more uniform combustion rate than thicker ones, especially in small furnaces [11]. The length of the pellets affects the fuel feeding properties: the shorter the pellets, the easier to arrange for continuous flow [11].

- Pellet mill dies are made from several different types of metal. Dies must be resistant to abrasion, strong enough to handle the forces of pellet production and corrosion resistant without negatively affecting productivity. The materials most often used are carbon steel alloy, stainless steel alloy and high chrome alloy. Obviously, the most expensive materials ensure higher resistances and productivities.

These parameters have to be optimized in view of the particular feedstock to guarantee good productivity and to avoid blocking the dies. Blocked dies can be found when: (1) the raw material generates more resistant force while passing through the die than the force generated by the roller and/or (2) the die hole is corroded [16].

If the die gets blocked, the material has to be drilled out. To facilitate this process, it is best to work when the die is still warm, previous to the formation of hard pellets within the die holes.
2.8 Cooling and screening

Moisture resistance is an important pellet property. The pelleting process implies high temperatures, and attention must be paid to proper cooling and heat removal before the pellets leave a production plant, especially with regard to the storage stage [12,27]. If moisture content exceeds 20% of d.b., bacterial growth might occur [28], causing material degradation and self-heating, which in the worst case scenario might result in self-ignition [27]. In sum, the cooling process is critical for pellet strength and durability. When pellets leave the extruder, they are hot (90°C–95°C) and soft [10]; then, they are gradually air cooled, which allows the lignin to solidify and strengthen the pellets. In contrast to the drying process, cooling does not involve the addition of energy. There are three types of coolers: vertical, horizontal and continuous flow [9].

Once pellets have cooled, they pass over a vibrating screen to remove any fine material [10]. These ‘fines’ are augured back into the pelleting process to ensure that no raw material is wasted. Screening ensures that the fuel source is clean and as near to dust free as possible. Once screened, pellets are ready to be packaged for the desired end use [9].

3 European Guidelines

According to the quality parameters described in a previous chapter, and considering the specific characteristics of woody pellets from forestry residues and non-woody biomass from agricultural residues, the following European guidelines have been established (Tables 2–4).

3.1 European guidelines for woody pellets

The EN 14961-2 [7] defines three quality categories (A1, A2 and B) for woody pellets to guarantee their proper use and resistance (Table 2).

3.2 European guidelines for non-woody pellets or pellets from mixtures of biomasses

The EN 14961-6 [8] defines specific categories for straw, miscanthus and reed canary grass pellets (Table 3) in addition to two quality categories (A and B class pellets, produced from herbaceous and fruit biomass and blends and mixtures that can also include woody biomass) (Table 4). These guidelines are generally less restrictive than those established for woody pellets in EN 14961-2 [7].

4 State-of-the-Art of the Pelletization of Forestry and Agricultural Residues

Pelletizing technologies for the production of upgraded biomass fuels must be improved to lower costs and enhance fuel quality. Improvement may entail the
### Table 2: European normative guidelines for woody pellets [7].

<table>
<thead>
<tr>
<th>Units</th>
<th>A1</th>
<th>A2</th>
<th>B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diameter and length (D and L)</td>
<td>D06: D ≤ 6 ± 1 and 3.15 ≤ L ≤ 40</td>
<td>D08: D ≤ 8 ± 1 and 3.15 ≤ L ≤ 40</td>
<td></td>
</tr>
<tr>
<td>Moisture, M</td>
<td>M10: ≤ 10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ash, A</td>
<td>A0.7 ≤ 0.7 A1.5 ≤ 1.5 A3.0 ≤ 3.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mechanical durability, DU</td>
<td>DU97.5 ≥ 97.5 DU96.5 ≥ 96.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fines % as received</td>
<td></td>
<td></td>
<td>F1.0 ≤ 1.0</td>
</tr>
<tr>
<td>Additives % dry basis</td>
<td></td>
<td></td>
<td>≤2% (type and quantity to be specified)</td>
</tr>
<tr>
<td>Lower heating value as received, Q MJ/kg</td>
<td>Q16.5: 16.5 ≤ Q ≤ 19</td>
<td>Q16.3: 16.3 ≤ Q ≤ 19</td>
<td>Q16.0: 16.0 ≤ Q ≤ 19</td>
</tr>
<tr>
<td>Bulk density, BD kg/m³ as received</td>
<td>BD600 ≥ 600</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nitrogen, N % dry basis</td>
<td>N0.3 ≤ 0.3 N0.5 ≤ 0.5 N1.0 ≤ 1.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sulphur, S % dry basis</td>
<td>S0.03 ≤ 0.03 S0.04 ≤ 0.04</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chlorine, Cl % dry basis</td>
<td>C10.02 ≤ 0.02 C10.03 ≤ 0.03</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Table 3: European normative guidelines for straw, miscanthus and reed canary grass pellets [8].

<table>
<thead>
<tr>
<th>Units</th>
<th>Straw</th>
<th>Miscanthus</th>
<th>Reed canary grass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diameter and length, D and L</td>
<td>D06-10: D ± 1; 3.15 ≤ L ≤ 40</td>
<td>D12-25: D ± 1; 3.15 ≤ L ≤ 50</td>
<td></td>
</tr>
<tr>
<td>Moisture, M</td>
<td>M10 ≤ 10</td>
<td>M12 ≤ 12</td>
<td></td>
</tr>
<tr>
<td>Ash, A</td>
<td>A6.0 ≤ 6 A4.0 ≤ 4 A8.0 ≤ 8 A8.0+ &gt; 8</td>
<td>A6.0+ &gt; 8</td>
<td></td>
</tr>
<tr>
<td>Mechanical durability, DU</td>
<td>DU97.5 ≥ 97.5 DU96.5 ≥ 96.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fines % as received</td>
<td></td>
<td>F1.0 ≤ 1.0</td>
<td></td>
</tr>
<tr>
<td>Additives % dry basis</td>
<td></td>
<td>Type and quantity</td>
<td></td>
</tr>
<tr>
<td>Lower heating value as received, Q MJ/kg</td>
<td>Minimum value</td>
<td>Q14.5 ≥ 14.5</td>
<td></td>
</tr>
<tr>
<td>Bulk density, BD kg/m³ as received</td>
<td>BD600 ≥ 600</td>
<td>BD580 ≥ 580</td>
<td>BD550 ≥ 550</td>
</tr>
<tr>
<td>Nitrogen, N % dry basis</td>
<td>N0.7 ≤ 0.7 N0.5 ≤ 0.5 N2.0 ≤ 2.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sulphur, S % dry basis</td>
<td>S0.10 ≤ 0.10 S0.05 ≤ 0.05 S0.20 ≤ 0.20</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chlorine, Cl % dry basis</td>
<td>C10.10 ≤ 0.10 C10.8 ≤ 0.8 C10.10 ≤ 0.10</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
proper selection of matrices, testing and evaluation of bio-additives for quality improvement and reduction of operating costs, and development and testing of pre-treatment technologies for proper conditioning of the raw material. Moreover, future pellet production will have to cope with raw materials other than those most commonly used at present, i.e. wood shavings and sawdust. Due to steadily growing pellet markets in Europe and worldwide, the production of pellets from woodchips, forestry residues, short rotation coppice and different kinds of herbaceous biomass fuels will increase in the future, which makes respective R&D activities necessary [29].

As stated by Carroll and Finnan [30], the shortage of biomass from forestry production has increased the use of a wide range of alternative biomass feedstock to generate renewable energy [31]. This view is shared by Verma et al. [32,33], who state that ‘the limited availability of woody biomass for energetic purposes leads to the introduction of agro-forestry driven residues’. While an increasing proportion of the biomass needed for renewable energy is being imported from countries rich in woody biomass such as Sweden or Germany, agricultural residues and energy crops already play a large role in renewable energy generation [31] and are predicted to play a major part in the future energy crop mix [34].

The main problems with agricultural raw materials, in comparison to woody raw materials, are the higher ash content, the lower ash softening temperature and the higher risks of corrosion and fouling [35–37]. Additives can counteract these problems to some degree, but at the same time they increase the costs, and problems with high ash content would still remain. One way to increase the use of these
raw materials is to mix them with sawdust/shavings, and to adapt their proportions to the combustion conditions in the boiler (fluidized bed boiler, burner, etc.). Another problem with these materials is that the production costs may be high, especially for cultivated crops, requiring fertilizers, specialist machinery, etc. From a natural resource point of view, it is important that the net energy yield of using pellets as a fuel is as high as possible [38].

Most raw materials also have low bulk densities, resulting in high transport and storage costs. Pelletization affords benefits such as increased bulk density, therefore reducing transportation and storage costs and providing better material feeding with less dust formation [39], if we consider the factors that affect milling properties and the agglomerating character of the raw materials [11].

5 Conclusions

The pelletization process entails several stages that can be modified depending on the type of biomass used. These raw materials generally call for pre-treatment because of their origin and characteristics.

To determine the optimal pelletization conditions for each raw material, the densification process must first be tested under different conditions in terms of: compression force, moisture of the raw material, temperature of the pelletization and percentage of additives, when necessary. The pellets produced under the conditions analysed will have different values in view of their quality properties, and only those that fulfil the requirements established by the existing norms should be used as fuel.

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