Energy recovery from cork industrial waste: production and characterisation of cork pellets

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Abstract

The cork industry presents itself as one of the most entrepreneurial in the Portuguese industrial sector, contributing significantly to the increase of exports. However, it's an industry in which the use of raw materials is maximised leaving a large volume of waste. The cork industry has tried to take advantage of these residues, mainly through direct energy recovery, despite the technical and safety difficulties presented by the use of such low density material, which complicates and hinders its transportation for industrial uses outside the area in which it is produced. The densification process opens new doors for such use and also for its storage, because it produces better results when compared with other more common products, such as wood sawdust or even forest and agricultural waste. Thus, cork pellets emerge as a safer and more easily transportable alternative for energy recovery from cork dust and other granulated types of cork waste, which offer the prospects for wider use. The results demonstrate that cork pellets have higher calorific value when compared with other biomass pellets; typically, approximately 20 MJ/kg with 3% volume of ashes, which is equivalent to that obtained from the combustion of pellets produced from combined forest and agricultural waste with a bulk density of 750 kg/m^3, which offers real advantages in terms of logistics.
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1. Introduction

As economic and social evolution demands more energy, the lack of new sources of fossil fuels and the pollution that they cause, has led to a serious dilemma over environmental protection and economic development [1].

Since the world energy crisis of the 1970s, public and private decision makers have considered the possibility of achieving a transition from the current system based on fossil fuels to a more sustainable system based on clean energy. This new system is commonly referred to as renewable energy or green energy and might be the solution to the problem of the decline in the availability of fossil fuels, while reducing the emissions of greenhouse gases. This has now led to the development of some of these new energy forms with acceleration in their use over recent years [2].

Biomass is regarded as a source of energy that could play a key role in attaining the objectives set for Europe and Portugal with regard to the selection of new sources of energy, mainly for industrial use.

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Biomass could be one important energy source for two key sectors: electricity production and heating/cooling. The increased use of biomass is also an opportunity for reducing emissions of greenhouse gases, promoting regional development with the creation of new employment opportunities and reducing energy dependence on foreign countries [3].

The Portuguese government adopted the EU Strategy for the use of renewable energy following the dictates of Directive 2009/28/EC [4], transposed into Portuguese national legislation by Decree-Law no. 141/2010 [5], which stipulate that at least 31% of electrical power produced in Portugal, beyond 2020, should be generated from renewable sources [6]. Biomass has a very significant role in achieving this goal and several plants in operation by the end of 2012 will produce a total of 2,500 GWh of biomass-fuelled electric and thermal power [7].

The use of biomass waste contributes to the share of renewable sources for energy production, reduces imports of fossil fuels and reduces the risk of forest fires [8]. In this context, biomass as a renewable energy source seem to be a promising option for improving the environmental situation, as it has several positive effects and the increase of its use is part of the political agenda of many EU member states [9].

Consequently, the Portuguese governmental strategy has set ambitious targets for using biomass for power and heat generation, which has resulted in a potential need for large amounts of biomass in the country [10]. Given the limited availability of residual forest biomass associated with the increasing production of biomass pellets in Portugal [11], already one of the leading European producers [12], once this industry has used large quantities of raw materials from the forest [13], interest in alternative forms of biomass increases, especially the waste from some industrial utilisations of biomass, such as cotton, paper and cork.

Portugal is well-known throughout the world as a producer of cork. It has always been linked to this activity and has been, in recent decades, the largest producer and exporter of cork. It is estimated that the area occupied by the cork oak (*Quercus suber L.*) worldwide is very close to 2.2 million hectares. This is largely distributed around the Mediterranean zone, especially in areas with an Atlantic influence, such as southern Europe and North Africa. The Iberian Peninsula has 56% of the total area (Portugal 33% and Spain 23%), three countries in North Africa have 33% (Morocco, Algeria and Tunisia) and Italy and France have a combined area constituting the remaining 11% [14].

The cork industry sector, apart from a socio-economic secular component, contributes to the mitigation of climate change effects in the Mediterranean basin, while it helps to protect biodiversity, representing a model of sustainability between human activity and natural resources [15, 16].

Cork can be used as feedstock to replace other non-renewable materials, such as petroleum and its derivatives, which is now regarded as a luxury product and has applications ranging from textiles and footwear to nanotechnology. This proves that this forest-oriented industry, long ago abandoned the simple production of wine corks and champagne stoppers.

Forests in Portugal occupy about 39% of the total territory. Over the last two centuries the total area occupied by cork oak has increased significantly, reaching 23% of the total forested area [14].

Unlike what happens in clear up operations of forest areas occupied by other species, where waste is usually burned in situ and only occasionally used as fuel, the residues from clearing cork oak forests are usually collected and utilised, because of the high commercial value of cork and this helps to reduce the thermal load of the forest [17, 18].

Traditionally, the cork industry has found uses for several cork by-products, including thermal energy recovery from cork dust, for which there is many other viable applications. However, its low density and volatility, leads to some technical and safety difficulties in terms of its energy use and there have been many cases of serious accidents in cork factories due to explosions and fires [19-21].

In Portugal, there is great experience in the production of wood pellets, especially regarding the use of indigenous types of wood, such as several types of pine (*Pinus pinaster* and *Pinus pinea*), eucalyptus (*Eucalyptus globulus*) and poplar (*Populus sp.*) [22], among others but also regarding the use of products of lesser economic importance, such as wood scrub resulting from forest clearing, cistus (*Cistus ladanifer*), gorse (*Ulex europaeus*), broom (*Sarothamus scoparius*), fetus (*Pteridium aquilium*) and brushwood (*Rubus ulmifolius*) [23].

In light of this and considering all the knowledge acquired in the densification of other forest products, further research in this area seems to be very promising for identifying an alternative to the recovery of waste resulting from the cork industry, allowing easier reuse and even the creation of a viable commercial alternative as an energy resource.

No previous references for this type of reuse of cork waste have been found in specialised literature, which is a new contribution of this paper.

Thus, the aim of this study is to pelletize and characterise a product made from industrial cork waste, demonstrating the feasibility of obtaining a pellet with good physical and energetic characteristics, demonstrating the logistical advantages of this densification and offering the possibility of using this form of biomass in other locations outside the cork industry.

2. The production of pellets

Internationally, biomass pellets are currently the most traded bulk biomass solid commodity for energy purposes. In terms of volume sales, this is about 4 million tonnes, which makes these products comparable to the volume of trade in biodiesel and bioethanol [24]. In Portugal, important levels of production capacity of biomass pellets began in 2005 and the largest industrial units started operating in 2008. Currently, 1.2 million tonnes of annual production is split between large and small producers who explore different markets, including exclusive exportation by large producers and the supply of the domestic market by smaller producers [25].

Pellet production represents the possibility of using different types of biomass waste, which includes cork waste, by transforming them into a product with more homogeneous and uniform characteristics. This allows its use in the boilers of domestic or services buildings, such as schools and hospitals, similar to what already happens with the waste forms used as raw material in pellet production burned in advanced industrial boilers [26]. Large scale industrial applications can be considered, such as thermal or electric energy production, co-firing or co-gasification with coal [27]. Other industrial uses are also possible. For instance, gasification of cork pellets can produce syngas, which is very important for industry as raw material [28]. Gasification is considered a key factor for promoting biomass energy and bio-liquid fuels use, which recently attracted increasing attention due to the advantages of high conversion efficiency [29].

The production of biomass pellets is a sequence of steps that includes: pre-processing, drying, grinding, pelletizing, cooling, screening and bagging and is described briefly in this work. Fig. 1 shows schematically a standard biomass pellet production line.

"See Fig. 1 at the end of the manuscript".

The need for milling during pre-processing depends on the condition of the raw material to be used, i.e., it is often desirable to homogenize and mix the materials before pelletising. The same concept is applied to drying. This step is of fundamental importance for final product quality, because a raw material in which moisture content exceeds 15% becomes very difficult to pelletize properly. The greater or lesser need for drying of the materials before pelletising is a key factor for the amount of energy expended in the production of biomass pellets. In the case of cork waste, drying is usually not required because its characteristic is to present very low moisture content (10% to 15%).

In the next step, a hammer mill equipped with a 3.2 mm sieve reduces the dried cork waste to a usable size. The pelletising process is based on the extrusion of cork waste, or any other type of biomass, through the holes of a matrix. Sometimes, if the moisture content is too low, it may be necessary to add some water or vegetable oil to facilitate the extrusion process. This production process phase represents the largest share of electricity consumption in biomass pellet production and the main source of maintenance costs (up to 15% of annual maintenance costs) [30].

Cooling might also not be strictly necessary and represents low cost. Pellets are usually cooled immediately after pelletising, which helps to stabilise their form. Cooling systems often have one of two basic configurations of operation: horizontal or vertical airflow, the latter being the most widely used, which consists of a stream of air forced into contact with the pellets entering the pipe in counter-current direction.

Sifting is necessary to separate the residual fines of the finished pellets before bagging. The fines and other debris collected in the sieve are returned to the refiner and re-introduced to the pelletising process. If the fines content exceeds 3% of the total amount of sieved product, this indicates that a problem has occurred with the raw material (moisture content or dimension of the particles) or the pelletising process itself (matrix form, compressibility, process temperature), which would need to be corrected.

The final step of an industrial pellet production process is bagging the finished products; usually 15 kg bags for residential consumers, or 700–1,000 kg bags for large-scale users. The bagging system can be manual, semi-automatic or fully automatic, depending on the size of the plant and the quantities produced. Pellets can also be transported in bulk tankers, discharging pellets using a pneumatic conveyer system to a silo or hopper.

3. Materials and Methods

3.1. Industrial cork waste

Samples of cork granules were purchased from different cork companies in the area of Santa Maria da Feira (northern Portugal), in order to be representative of the waste produced in each of the industrial units (Fig. 2, 3 and 4).

"See Fig. 2 at the end of the manuscript".

"See Fig. 3 at the end of the manuscript".

"See Fig. 4 at the end of the manuscript".

This study aims to reproduce the conditions of an industrial environment, in order to simulate the production of cork pellets on a large scale and in accordance with the restrictions that might occur on an industrial production line. Thus, in addition to the characterisation of cork pellets, it also confirms the feasibility of using a conventional biomass pellet production line, which normally uses traditional raw materials, such as the sawdust of pine or other common woods.

Given the variation between the different types of waste produced by the cork industry, after samples were taken and laboratory tests and trials carried out, the waste was subsequently mixed, in order to create a product suitable for use on a large scale.

During tests, feedstock was introduced into the pelletising press and sufficient water added to raise the moisture content to a value capable of reducing the friction between the material and matrix. Another function of the added water is to allow the correct operation of the pelletising press without surge and vibration. However, this amount of water should not be too high in order to avoid producing poor quality pellets, which might easily disintegrate during transport and charging operations [31].

The optimal moisture content for industrial cork waste at the time of pelletizing is 15%, because it is necessary to lower the natural compressive strength of these materials [32] and counterbalance the evaporation induced by the high temperature inside the pelletizing press.

This evaporation occurs mainly for two main reasons:

• Cork has high resistance to friction due to its natural roughness [33, 34].

• The low permeability of the cork due to the high content of suberin [35].

Because there is a great use for all cork by-products, the resulting wastes are also different in their characteristics. However, using an all-in type mixture creates a final product with homogeneous characteristics, ensures a consistent raw material and emphasizes the feasibility of industrial production of cork waste pellets.

3.2. Preparation of material for pelletizing

Both the waste collection and sampling methods were conducted according to the direction of the draft standard FprEN 14778, Solid biofuels - Sampling [36].

The raw material needed to be pre-treated because the particle size of the obtained mixture was not homogeneous. Thus, in order to reduce all the material to a size less than 3 mm, a hammer mill was used (Fig. 5) with an incorporated sieve fed by a pneumatic transport system, simulating the industrial process.

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It is accepted that for pellet production the appropriate size of the particles of the raw material is 3.20 mm [30]. For cork pellet production Munch - Edelshtal PMR 420 press with a theoretical capacity of 1,000 kg/h was used, which processed about 5,000 kg of mixture of each sample (Fig. 6). Indeed an industrial scale production test was considered, processing 5,000 kg of cork waste, of which several samples were taken for laboratory analysis. With these amounts it was possible to stabilise the production and to achieve the optimal temperature for pellet production, because cork pellets reach their maximum durability when the matrix works at a temperature of 90 °C. Accordingly, the permanent production of this type of pellets successfully started in 2012, producing about 500,000 kg of cork pellets.

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Given the low moisture content of cork waste, typically about 6% to 8%, it was necessary to raise the moisture level of the raw material during pellet production up to 15%, as this is the ideal moisture content for pressing. Material with higher moisture content does not aggregate properly and with lower moisture content, there is an increased risk of fire inside the press.

This temperature, as indicated, yielded a final product with moisture content lower than 6% after being cooled at room temperature for 12 hours (Fig. 7).

"See Fig. 7 at the end of the manuscript".

However, it was found that unlike wood pellets, the cooling time of cork pellets is much less due to the particular thermal conductivity properties of the cork [33].

3.3. Moisture content

A method was used to determine the moisture content of the material, which consists of drying the material for a period of 24 hours, on a tray in an oven, at 105 °C. This method is described by the standard EN14774-2, Solid biofuels - Determination of moisture content - Oven dry method - Part 2: Total moisture - Simplified procedure [37]. The moisture content is obtained by weighing the material before and after the procedure and is described as a wet basis percentage.

3.4. Calorific value

The calorific value of cork pellets was analysed using an isothermal calorimeter bomb. The calculation of the Lower Heating Value (LHV) was subsequently calculated using the procedures specified by EN 14918, Solid biofuels - Determination of calorific value [38].

3.5. Ash content

The ash content was obtained according to the method suggested by EN 14775, Solid biofuels - Determination of ash content [39]. Thus, the samples were placed in an oven, the temperature of which is raised gradually to 250 °C (i.e., an increase of 5 °C/min). The temperature was maintained for 60 minutes and then increased again until it reached 550 °C, maintaining this temperature for a further 120 minutes. After this period, the ash content was obtained by the difference in weight percentage.

3.6. Density of cork pellets

The bulk density, measured according to EN 15103, Solid biofuels - Determination of bulk density [40], was determined using a scale with a precision of 1 g. A sample was placed into a container with a known volume and weighed, which gave the weight of the pellets by volume.

3.7. Durability of cork pellets

The durability of cork pellets was determined according to EN 15210-1, Solid biofuels - Determination of mechanical durability of pellets and briquettes - Part 1: Pellets [41]. A sample of 500 g of pellets was placed into a 50 rpm turntable box and 500 revolutions were performed. Thereafter, the pellets passed through a screen with openings of 3.15 mm in diameter. The durability is expressed as the percentage ratio of grain mass retained by the sieve in relation to the initial mass of the pellets.

4. Results and Discussion

From the performed tests it was found that the waste has low moisture content with a mean of 9%, which means that during the pelletising process, water must be added until a moisture content of 15% is attained, prior to enter the pressing chamber (Table 1).

"See Table 1 at the end of the manuscript".

Due to the high temperature resulting from friction between the raw material [42, 43], the rollers and the matrix, which ideally reaches 94 °C, this moisture is released, leaving the pelleted cork with a final moisture of less than 8%. It appears that the moisture of the finished product is always less than that of the raw material. This is because the production process occurs at higher temperatures than is usual for pellet production with other raw materials but also because of the properties of the cork itself, which has very small moisture content inside its particles [44].

The calorific value of the pellets was obtained and the results are presented in Table 2.

"See Table 2 at the end of the manuscript".

The results obtained show an increase of heating value (HV) when compared with the original raw material, except cork dust (particle size below 0.05 mm and a density lower than 60 kg/m^3) and always higher when compared with the HV of the mixture obtained from the set of residues [31]. Cork pellets have an HV superior to the mean HV of other pellets produced from conventional types of wood [45, 46].

The mean percentage of ash is in the range of 2.52% to 2.82% and these values are very similar to those obtained by other researchers for species of the same tree family [17]. For other types of waste pellet, such as agricultural waste, cork pellets have a lower percentage of ash (e.g., 5.27% for rye straw, 7.02% for wheat straw and 20.3% for rice husk) [47].

It is known that the density increases as the particle size decreases because the voids among the particles are smaller [30]. In this case, as the pellets are the result of a raw material formed by particles with different diameters (all-in type), this allows densities higher than 750 kg/m^3, i.e., more than the 100 kg/m^3 of conventional wood pellets (Table 3) [48].

"See Table 3 at the end of the manuscript".

The values obtained for cork pellet durability are between 92.3% and 97.5%, which are very close to the results obtained with pellets from forest and agricultural waste [49].

Due to the densification process, unlike the traditional direct combustion of this waste of industrial origin, it is possible to obtain an alternative product with advantages over its prior use, which presents an array of features that enhance its use as a biofuel, similar to that resulting from other forest waste (Table 4 and Table 5).

"See Table 4 at the end of the manuscript".

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Fig. 8 presents a comparison of wood pellets of pine and eucalyptus, forest waste pellets and cork pellets, regarding high heating value (HHV).

"See Fig. 8 at the end of the manuscript".

The analysed properties might vary in accordance with changes in the type of waste used, although the variability of the value, as verified, will not be very significant.

5. Conclusions

This paper presented an experimental investigation to produce cork pellets from cork industrial waste. The cork pellets emerge as a safer and more easily transportable alternative for energy recovery. The properties of pelletised cork waste showed that it is suitable for energy applications because of improvements in its homogeneity, moisture and physical characteristics that enable improved control over the combustion process. As a consequence of the high content of suberin present in the cork waste, there is no need to add binders or other additives for the production of pellets. Thus, with a set of characteristics similar to that of forest waste, together with higher bulk density, cork pellets acquire a transportation capacity that was not possible for cork waste, because of its low density, which allows new visions for its use outside of the cork industry for energy recovery or raw materials production, either in traditional form (direct combustion) or using alternative technologies (gasification), or even in co-firing with coal.

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Figure captions

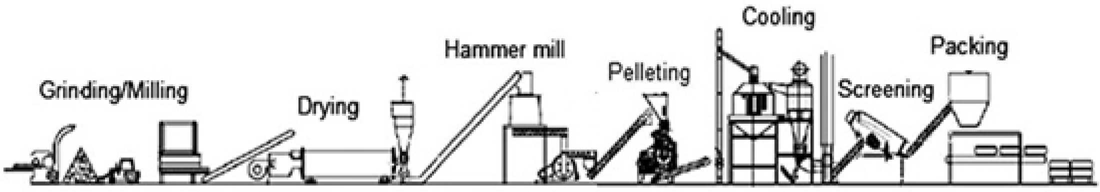

Fig. 1. Schematic layout of a typical biomass pellets plant (adapted from [24]).

Fig. 2. Granulated cork having a particle size exceeding 5 mm and a density of 90 kg/m^3.

Fig. 3. Granulated cork having a particle size greater than 2 mm and a density of 120 kg/m^3.

Fig. 4. Cork dust having a particle size smaller than 2 mm and a density of 60 kg/m^3.

Fig. 5. Hammer mill.

Fig. 6. Munch Edelshtal RMP 420 press.

Fig. 7. Cork pellets.

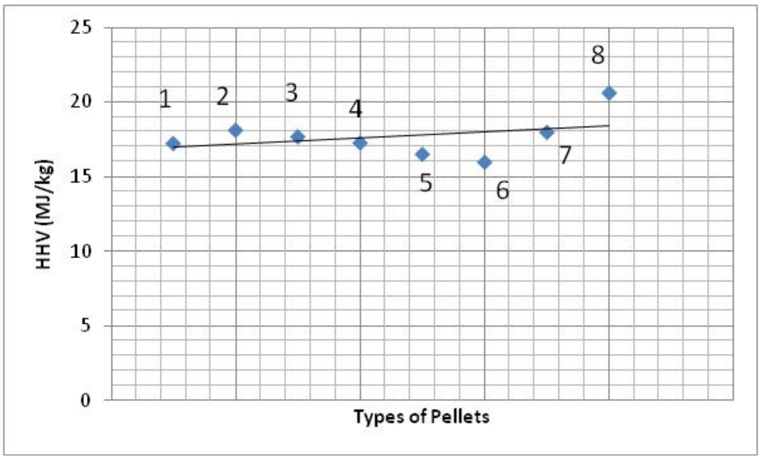

Fig. 8. Comparing HHV of wood pellets of pine and eucalyptus (1, 2, 3, 4 and 5), forest waste pellets (6 and 7) and cork pellets (8).

Tables

Table 1

Comparing moisture content: cork waste before entering the industrial process and cork pellets.

	Cork waste	Cork pellets
Moisture content (%)	9%	< 8%

Table 2

Net calorific value of cork pellet samples.

	Sample 1	Sample 2	Sample 3	Sample 4	Mean value
HHV (MJ/kg) *	19.37	20.25	21.16	21.78	20.64
LHV (MJ/kg) **	19.35	20.23	21.14	21.76	20.62

* High Heating Value ** Low Heating Value

Table 3

Comparing different densities: cork waste, cork pellets and conventional wood pellets.

	Cork waste (mean value)	Cork pellets	Wood pellets (ENPlus value [48])
Bulk density (kg/m^3)	± 100	± 750	> 650

Table 4

Summary of the physical characteristics of cork pellets.

Characteristic	Result	Unit
Low Heating Value	20.62	MJ/kg
Ashes	2.52 to 2.82	%
Moisture content	< 8	%
Bulk density	± 750	kg/m^3
Durability	92.3 to 97.5	%

Table 5

Summary of the physical characteristics of wood pellets (pine and eucalyptus) and pellets from forest waste.

Pellets	Wood (Pine and Eucalyptus) [46]				Forest waste [23]			
Characteristics	1	2	3	4	5	6	7	Unit
LHV	17.25	18.13	17.70	17.29	16.53	16.00	18.00	MJ/kg
Ashes	0.93	0.83	0.59	0.54	2.69	< 3		%
Moisture content	10.25	6.76	7.78	8.55	6.2	2.79	7.46	%
Bulk density				> 650				kg/m^3
Durability			94 to 98			92 to 96		%