

Integrated Solution of Valorization of Forest Residues

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Abstract

Portugal is giving an increasing focus to renewable energy. Bioenergy and the use of forest biomass is pointed out as having a big impact in the Portuguese economy.

This work aims to study an integrated system of valorization of forest residues. The first step was to analyze in detail the start-up of a new pellet production unit, the Omnipellets, owned by Grupo Martos, located near Leiria. It was found that drying the biomass is a crucial operation in the process, with a very high heat consumption. The success of this operation, to obtain a product with a moisture content between 8 and 12%, is based on a stabilized and efficient mode of operation of the furnace in conjunction with a mixing chamber. Some modifications were introduced in the process during the start-up to enhance safety and the efficiency of the full process.

An approach was developed and applied to optimize the use of available biomass sources, the BioPinch, that uses a similar method to the one used to minimize the contaminated hydrogen consumption. In this case the ash and moisture content were the two impurities considered in biomass from Grupo Martos.

The integration of a pellet plant with a cogeneration unit was also considered for a 4 MW furnace. It was possible to produce 218 kW of electricity and 1084 kg / h of steam. The heat integration is made by preheating the air that enters the mixing chamber and the hot waters for the greenhouses in Grupo Martos.

Keywords: biomass, cogeneration, pellets, valorization of forest residues.

1. Introduction

Portugal is a country with few energetic resources, which leads to a diversification of energy sources, such as the use of biomass.

Biomass is defined as the biodegradable fraction of products, residues and wastes from biologic origin from agriculture (including vegetable and animal substances), of forestry and related industries, including fisheries and aquaculture, as well as the biodegradable fraction of industrial and municipal residues [1].

It is a renewable energy, low-polluting and with a practically no emission of carbon dioxide (CO₂) (according with the natural cycle of neutral carbon). It presents low associated costs, exists in abundance and has a high energy potential.

The processing of biomass begins with its production in private forestry, energy crops or with the utilization of residues from agriculture crops. This is followed by the collection and transportation of the biomass, with on-site processing and nation-wide or world-wide distributed. This can also be done by collecting centres, such as biomass parks, or by loggers. The biomass processing consists in the following operations: separation, drying, chipping, briquetting, pelletizing and torrefaction. Processed biomass can then be applied in bio-products, such as wood industry and bio-refinery (paper production), and in bioenergy, where biomass is used as solid, liquid or gaseous biofuel.

- **Solid biofuel:** this is the most common use of biomass, being primarily composed by forestry and agriculture residues. The residues can be directly used for electric and thermal energy

production using the process of combustion, or it can be transformed in products such as briquettes, pellets and wood chips;

- **Liquid biofuel:** biomass is processed to acquire a liquid form, producing bioethanol, biomethanol and biodiesel;
- **Gaseous biofuel:** the most common forms are the wood gas or biogas, which are the result of wood gasification and anaerobic digestion processes.

In addition, biomass is the fourth major source of primary energy, after oil, coal and natural gas, with an availability higher than 10% in global offer [2]. However, the biomass originated from forestry faces some challenges such as water availability, lands to exploit, the use of fertilizers and techniques to control plagues, and the competition with the food industry, global and locally. Previous studies [3] show that Europe has a high potential for the exploitation of biomass for energy production that is not valued and it is an area that is important to develop and invest in, international, national and regionally.

Portugal presents a high potential in the use of renewable energies. Portugal's location, its territorial characteristics and natural resources promote the utilization of energy provided by biomass, sun, wind and water [4]. According to the *Instituto da Natureza da Conservação e das Florestas* [5] and the APEB [6], around 35% of Portuguese territory is occupied by forests, providing a higher economical value than other European forests. Despite Portugal's high forest area, this is not geographically distributed throughout the whole country, concentrating mainly in the interior North and Centre of Portugal, in areas

with difficult access which leads to an increase of the biomass recovery cost.

Nowadays, the solid fuel with the highest market increase internationally for the production of energy is the pellet [7]. Pellets are originated by biomass compression, usually pine sawdust, where the biomass lignin has the role of a binder of the organic matter [8]. These can have thermal applications, for heat or hot water production for domestic and/or industrial consumption, being burned in fireplace stoves and boilers. In order to standardize the pellets specifications in the European market, in 2011 it was introduced an European norm EN 14961-2 [9], with the parameters presented in Table 1. This norm is not a mandatory requirement, but only a guideline, in order to achieve a better use of this product.

Table 1 – The most important pellet parameters of ENplus [9].

Property	ENplus A1	ENplus A2	ENplus B
Length (mm)	$3.15 \leq L \leq 40$ ¹⁾		
NHV (MJ/kg)	$16.5 \leq Q \leq 19$	$16.3 \leq Q \leq 19$	$16.0 \leq Q \leq 19$
Mechanical Durability (%)	≥ 97.5 ⁴⁾		≥ 96.5 ⁴⁾
Fines (%)	≤ 1 ²⁾		
Ash Content (%)	≤ 0.7 ³⁾	≤ 1.5 ³⁾	≤ 3 ³⁾
Moisture Content (%)	≤ 10		
Bulk Density (kg/m ³)	≥ 600		

¹⁾ A maximum of 1 w-% of the pellets may be longer than 40mm, no pellets > 45mm allowed.

²⁾ As received.

³⁾ Dry basis.

⁴⁾ Deformation temperature, sample preparation at 815°C

2. Case Study

A study was conducted to a pellet production unit in its production start-up, which is coupled to Grupo Martos, a company dedicated to wood recovery industry. To this end, it was analyzed the production process as well as the startup phase and its problems and operating conditions.

2.1. Pellets Production

The raw material from the units within the Grupo Martos, or other suppliers, such as wood chips and/or sawdust, give input to the process and are fed to an eccentric sieve. Here, the oversized material is expelled from the process, and those which have lower particle size proceed to a grinding in a hammer mill, adding to the wet sawdust collected at the bottom of the screen and being stored in the green deposit.

Then it proceeds to the drying operation, since the raw material has moisture content between 40 and 50% and the product, for the production of

pellets, must provide levels between 8 and 12%. This operation is performed in a rotary dryer with three concentric bodies, wherein used as heat source hot gases from a biomass furnace of 4MW. In the drying line, between the furnace and the dryer, is a mixing chamber, responsible for temperature control and regulation of the flow of hot gases, and a battery fly ash separator.

Wet sawdust meets the hot gases and enters into the dryer, following their departure, there is a separation of wet gas of dry sawdust by gravity, which is transported to the dry deposit.

In order to reduce the particle size of sawdust and to obtain a more homogeneous product, it is subjected to another grinding in a hammer mill before being fed to the pellet mill. In here the sawdust is fed into the conditioner, where there is injection of water, and flows to the die where the material is deposited between it and the rollers, which exert pressure and force to compress the material, forming the pellets. As these are hot and malleable, they are cooled and then bagged.

2.2. Star-Up Analysis

The monitoring of pellet production start-up phase lasted about two months, with the presence of technicians of the furnace, the dryer and the press, together with the other workers from Omnipellets.

The biggest problem encountered in the start was the huge amount of product out of specification, as it was not with the desired moisture content, due to the stabilization problems of the operation of the furnace and dryer. Thus it was necessary to create an alternative that would make the product out of specification return to the process.

Using the data collected during this phase, the study proceeded to the operating conditions and the control variables of the drying process, with the following parameters into account:

- **Time** - The time of sample collection (min);
- **T_{sf}** – The outlet temperature of the furnace (°C);
- **ST1** – The inlet temperature of the dryer (°C);
- **H_E** – Moisture content of wet sawdust at the entrance of the dryer (%);
- **ST2** – The outlet temperature of the dryer (°C);
- **H_s** – Dry sawdust moisture content at the exit of the dryer (%);
- **VR6** – Rotation of the rotary valve 6, which wet sawdust dosed at the entrance of the dryer (%);
- **MS1** – Rotation of the drum dryer (%);
- **VA1** – Rotation of the centrifugal fan (%);
- **VM1** – Valve monitored the mixing chamber (%).

All these parameters are control variables of the drying process, as illustrated in Fig. 1, the H_s (red) is the main control variable. The orange variables can be considered secondary control variables as they

are not handled directly, but need to be controlled to achieve the desired H_s content. The black variables are the variables to be handled, either in manual or in automatic way.

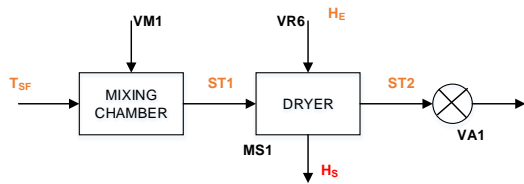


Fig. 1 – Drying line diagram with the variable to control.

In this study it was considered seven trials, which refer to the production of days with greater activity.

Looking at Fig. 2, referring to the first day of production, you can see that the furnace went out at 150 minutes, due to lower temperature T_{SF} and, as expected, consequently, it is visible increased H_s moisture content. At 350 minutes it had a new start again, where the furnace only stabilize H_s between 8 and 9% at 1600 minutes. It appears also to stop the furnace at around 2100 minutes, by the lower temperatures of $ST1$ and T_{SF} .

It is visible the difficulty in stabilizing the operation of the furnace by varying the temperature T_S , verifying the influence of the temperature $ST1$, where it has undergone several oscillations influencing the moisture content of the material at the exit of the dryer, although it has managed to stabilize the system in the range desired by the end of the test.

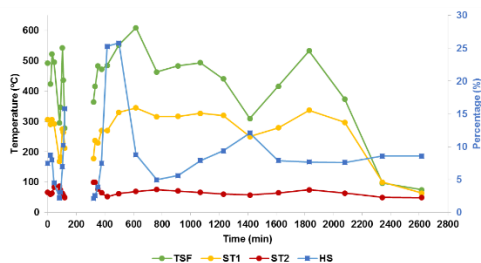


Fig. 2 – Graphical representation of the operating conditions of the drying line (T_{SF} , $ST1$ e $ST2$) and the moisture content at the exit from the dryer (H_s) over time, in trial T1.

In Fig. 3, as in the previous figure, it is apparent again that the furnace has been taken out. It also notes that the operating conditions $VA1$, $MS1$ and $VR6$ remain fairly constant, and it is not possible to verify a significant influence on the behavior of H_s over time. In this figure $ST2$ behavior is most evident, verifying that this has a more significant influence in the H_s in the first minutes. Between 600 and 1600 minutes, where $ST2$ increases it translates into decrease of the H_s . However, from the 1600 minutes the influence of $ST2$ is not as apparent in the humidity values, possibly because they have reached a balance between variables T_{SF} , $ST1$ and $ST2$.

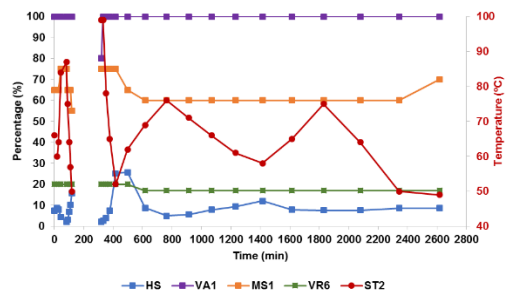


Fig. 3 – Graphic representation of the operative conditions of the dryer ($VR6$, $VA1$ e $MS1$), moisture content at the exit from the dryer (H_s) and the outlet temperature of the dryer ($ST2$) over time, in trial T1.

The trial T7 refers to the last day of production I attended. Looking at Fig. 4 it is visible that the stabilization of the output moisture content was achieved much more quickly than in the previous trial. In this test were only required 90 minutes to stabilize the temperature $ST1$, while the T_{SF} has been reduced.

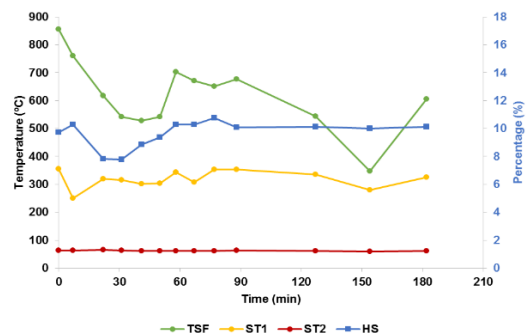


Fig. 4 – Graphical representation of the operating conditions of the drying line (T_{SF} , $ST1$ e $ST2$) and the moisture contents at the exit from the dryer (H_s) over time, in trial T7.

3. Proposals of Integration Scenarios

After that, a detailed analysis of all units of Grupo Martos was made to be able to characterize the products and by-products generated in all units of the Group, together with the associated energy consumption, in order to be able to carry out a first approach to new concepts Biomass Pinch (BioPinch), with data of production and consumption of Grupo Martos.

It also carried simulations in Aspen Plus® of various scenarios for energy optimization of Omnipellets production process, as well as the simulation of this process in a power generation unit.

3.1. Biomass Pinch

In order to minimize the consumption of resources in Grupo Martos resorted to an innovative approach, based on the methodology used to minimize hydrogen consumption contaminated with various impurities [10].

In order to obtain a graphical representation of minimizing consumption, the profiles are sketched from the impurity of the source and destination and aims to satisfy, according to their flow.

At the intersection of the two curves represented the resource and the need is known as Pinch Point, which means a minimum consumption of resource available like the methodology applied to the use of thermal energy [11].

The application of these methodologies is done iteratively, thereby performing up independent analyzes for every impurity, using an Excel spreadsheet.

Once this work is complete it is intended to apply this methodology to resources from biomass, appointed to this approach as the BioPinch (Pinch Biomass).

It was considered as available the resources provided by Martos and demand as the needs from the customers. The ash content and moisture content of the impurities were considered in this study, although for some products, these parameters are not part of the requirements imposed by customers. In such cases it was admitted a value based on the average contents.

This study was performed at two scenarios considering the situation of Grupo Martos before and after implementation of the pellet production unit. Showing only the case before implementation of the plant, relative to the ash content.

Analyzing Fig. 5 it can be seen that the level of the ash content for the need has been satisfied. It also observed the absence of BioPinch since the two curves do not intersect.

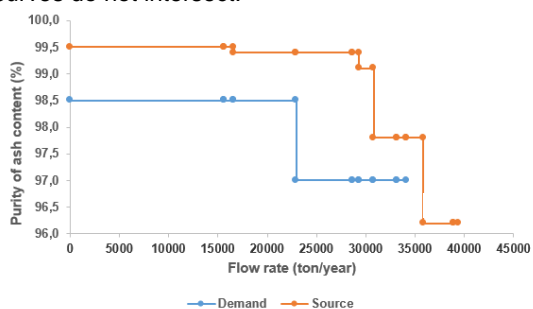


Fig. 5 – BioPinch representation regarding the purity of the ash content, before the implementation of Omnipellets.

As can be seen in Fig. 6, representing up to over curve puts in evidence the excess of the available resource. Here too there is the absence of BioPinch, since the graphical representation does not intersect the axis of ordinates.

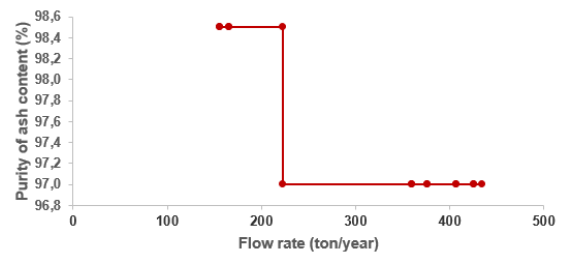


Fig. 6 – Graphical purity content of ash shortage representation between the resource and the need before the implementation of Omnipellets.

3.2. Integration Scenarios in the Basis Case Omnipellets

With the data collected during the start-up of pellets production and with the courtesy information from the suppliers (Table 2), it was possible to carry out a simulation of the drying process of Omnipellets, in the simulator Aspen Plus®. In order to study the thermal consumption and possible scenarios with and without energy integration, so as to satisfy thermal requirements within Grupo Martos. To be possible to reproduce operating conditions of T6 trial in simulator, was necessary to calculate heat losses to impose in the system.

Table 2 – Data for the simulation of Omnipellets plant in Aspen Plus® simulator.

F_M Biomass (UM)	22880
H_{Biomass} (%)	44
F_M Ar secondary + primary (UM)	160030
F_M Hot gases (UM)	182910
F_M Fresh Air (UM)	161161
H_{Air} (%)	0
F_M Wet Sawdust (UM)	91000
H_{Wet Sawdust} (%)	40
F_M Vaporized water (UM)	30420
H_{Dry Sawdust} (%)	10
F_M Dry Sawdust (UM)	60671
P (bara)	0,9

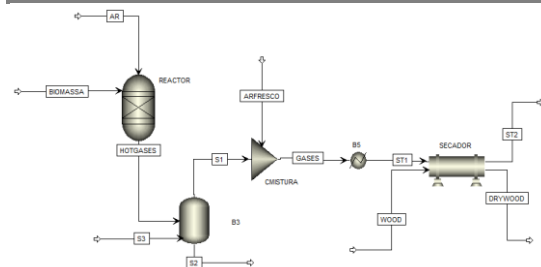


Fig. 7 – Basis case simulation obtained in Aspen Plus®.

The furnace energy use scenario has been designed to produce hot water for the greenhouses in Grupo Martos, discarding the need for biomass boiler. Thus, for the base case simulation it was added a heat exchanger between the furnace and the mixing chamber.

In this scenario, the production of hot water from the greenhouse with hot gases from the furnace is not a viable hypothesis, since the temperature at the exit of the dryer shows values below the dew point temperature. Since this simulation is fixed to the furnace outlet temperature and flow rate of fresh air into the mixing chamber, the latter should be set up to a certain limit, to increase the exit temperature in the chamber. However, the amount of heat that is required is very high and cannot be obtained by integration.

It was studied also the steam production scenario for the replacement of the water injected into the pelletizing operation, concluding that it is feasible to use the furnace exhaust gases at the required steam production because it does not significantly influence the operating conditions of the drying process defined in the initial simulation Omnipellets.

3.3. Integration Scenarios Case Basis with Electric and Steam Production

The procedure was also to study a possible integration of an electric power plant with a pellet production plant.

Again appealed to the Aspen Plus® simulator, starting the simulation based on an example available in the energy and cogeneration production program, using data relating to the *Central Termoeléctrica e Biomassa de Terras de Santa Maria* (CTBTSM), available in the works [12] [13], and the Omnipellets.

There were two possible scenarios: one which includes the power generation unit with a pellet production unit by pre-heating the water to the greenhouses; another same as above but with direct use of surplus steam to satisfy the thermal needs of the greenhouse.

Based on the example of a thermoelectric unit provided in the simulator Aspen Plus® and the data obtained from CTBTSM [13], continued with the simulation using as heat source hot gases resulting from the combustion furnace Omnipellets

The hot gases are input in a sequence of four heat exchangers, with water inlet at the end of that sequence, going through a reverse route of the gases. The water is heated by passing through each exchanger, passing the saturated steam off the penultimate resulting in superheated steam to the last exchanger output.

The superheated vapor pass through a turbine, where it defines a load loss, thus yielding electricity and steam at low pressure. This vapor is used to preheat the integration of the air fed to the mixing chamber and pre-heating of water in greenhouses.

It has been found that integration of electricity generation unit with a pellet may be feasible, since it

was obtained hot gases with temperatures within the case basis values.

However this integration requires further study on the actual losses in the mixing chamber and the flow ratio of fresh air/hot gases. The remaining thermal energy that was necessary to remove by condensation of steam (8.45 UP) can be used for heating the air fed to the mixing chamber (1.82 UP) and the pre-heating of 858 UM of hot water to greenhouses (5.2 UP). Only the remaining 1.43 UP, would be removed by use of an external cold utility. The option without energy integration, with exclusive production of electricity using a turbine with extraction to 0.5 bar, you could get 234 kW, because it allows the lowering of the turbine steam extraction temperature. In this case, the output vapor would be condensed by the use of an external utility, corresponding to 8.45 UP.

The second scenario is based on the first scenario but replacing the pre-heating of the greenhouses for the direct use of water vapor condensation in one of the three greenhouses. In this simulation it was concluded that it is possible to directly use the surplus steam condensation in one of the three greenhouses, decreasing the potency of biomass boiler. The condensate returns to the process after the compression pump 2 circulating in a closed circuit.

4. Conclusions

The goal of this work consisted in the study of an integrated solution of industrial resources valorization and forestry residues. Therefore, it was studied in detail the process of production of pellets, both in the assembling phase and in the start of a new unit of Grupo Martos, Omnipellets in Leiria.

After accounting the inputs, outputs and consumptions of the industrial complex, it was verified that the integration of the products originated in several units of the company is not enough to satisfy the amount needed for the production of pellets. In order to balance this fact the company can chose to expand its radius of feedstock collection and increase the capacity and/or the work schedule of the unit VRF, or increase its forestry exploitation.

With the application of the methodology of BioPinch to the resources of Grupo Martos, even though this evaluates the impurities independently, it was verified that the presence of humidity was the most important parameter to determine the minimum consumption. However this simplified approach is very incipient.

The process of production of pellets of Omnipellets is dependent of the drying operation and the furnace, and strongly dependent of the humidity of the feedstock, with the ideal values between 8 and 12% for the processed product.

The drying is achieved by the hot gases obtained from the biomass burning in the furnace. The success of the drying operation is based on the stable and efficient operation of the furnace, coupled with proper integration of the mixing chamber for obtaining the desired flow rate and the inlet temperature of the dryer.

From simulations carried out to integrate the base case with a thermoelectric power plant, similar to that CTBTSM, it was found that it is possible for this integration production electricity of 0,218 MW using a turbine and using a steam flow rate of 1084 kg/h.

In order to reduce the thermal needs of the Grupo Martos, it was simulated with success an integration of the turbine extraction steam to pre-heat the air chamber and mixing and the water used in greenhouses. Alternatively studied was the direct condensation of the steam (6.63 UP) in a group of three greenhouses, thus exploiting the enthalpy released.

5. Acknowledgements

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