INCORPORATION OF INDUSTRIAL WASTES IN WOOD PELLETS

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ABSTRACT: The present work evaluates the incorporation of industrial wastes (Refuse Derived Fuel-RDF) into biomass for pellet production. Its influence on parameters such as pellet production, combustion and gas emissions was studied for up to 10% of residues incorporation. This approach also deals with the diverting of industrial waste from landfills. The main objectives were: increasing the heat value of the final product, diverting industrial residues with energy potential from landfill and assess the quality of different types of pellets with incorporation of industrial residues. Its implementation was carried out in three phases: selection and characterization of the different industrial residues, production of pellets from different mixtures of wastes and combustion tests. For this purpose a comprehensive characterization of the pellets, the gaseous emissions during combustion and the chemical characterization of the resulting ashes was carried out. The study has shown that the application of industrial residues is a promising route for their incorporation in pellets which should be balanced by the reduction of wastes for landfill. However a few problems were identified: higher difficulty in pelletizing and likely excessive wear of the pellet mill for some of the residues; combustion equipment requiring air supply adjustment and higher ash contents.

Keywords: Pellets, RDF, biomass

1 INTRODUCTION

Pellets are a source of renewable energy. It constitutes a flexible way to use wood residues (mostly sawdust) and reduce the greenhouse emissions that other energy sources produce. The continuous rise of electricity and fossil fuel prices, and their depletion, is a strong incentive on the demand of pellets as a heating fuel for both domestic and, increasingly, industrial applications. The former requires very high standards regarding their quality with strong emphasis in the ash content (below 1%); the easy of use is paramount to the consumer. However, those for large scale industrial applications require not so stringent standards. In addition the increasing demand for such fuels (due to the cost effectiveness and policies promoting the use of renewable sources) has opened the interest in using other forms of raw materials for pellet production.

One common route is the use of alternative sources as the sole raw material. That is the case of fast growing energy crops, like myschanthus or canary grass (Larsson *et al*, 2008); agriculture residues such as olive bagass or other food products (Gonzalez *et al*, 2004). Also, the use of municipal solid wastes in pellets has been a promising alternative for its energy valorization (Marsh *et al*, 2007). The other route includes some kind of blending in a wood based matrix of materials such as pruning ends bark and coal (Alzate *et al*, 2009), amongst others. In this approach, urban wastes and industrial residues may play an important role. Furthermore it may provide an alternative process for disposal of low toxicity wastes reducing the amount of landfill material and enhancing, in some cases, the heat value of the pellets produced. This contribution to the reduction of landfill material has been highlighted by Grammelis *et al* (2009). As far as the upstream industry is concerned, their wastes may be regarded as source of income.

Therefore the use of alternative sources as raw materials for pellet production is of growing interest. One key aspect is the composition of the fuel. Extensive analyses have been carried out by determining the elemental composition of the various fuels, mostly upstream the pelletizing process. The work by Grammelis *et al* (2009) on plastics and cellulose, hemicellulose and lignin and that by Obernberger *et al* (2006) on wood, bark, logging residues, straw and short rotation crops are examples. Although these authors did not use the materials in pellets, some of the resulting problems may be anticipated at this stage such as ashes, deposit formation.

The use of non traditional materials as fuels should anticipate a few challenges to the processing operation, although most of the work has been focused on biomass materials. Arshadia *et al* (2008) evaluated the influence of the raw material (sawdust moisture content, fractions of fresh pine, stored pine and spruce) upon the pellet production: energy consumption, durability, density, production rate. It was possible to conclude that the pellet quality improves with the level of stored sawdust and with reducing moisture. Both high pellet quality and reduced energy consumption can be achieved. Werther *et al* (2000) discussed the densification rate for agricultural residues. It was observed that the fibrous structure of the residues (straw as an example) prevent an adequate compression. This problem apparently could be prevented by pre-compaction as applied by Larsson *et al* (2008) to canary grass pellets. The authors analyzed the influence of moisture content upon the pellet properties (density) and durability. They found that by pre-compacting the raw material, the bulk density was brought up to 650 kg/m^3.

Finally a crucial issue is the combustion efficiency and resulting emissions. Various authors have addressed this problem either for a combustion process (Gonzalez *et al*, 2004) or for pyrolysis (Grammelis *et al*, 2009; Olsson *et al*, 2003) and gasification (Alzate *et al*, 2009). These authors found that the blending of different materials in single pellets improved the gasification when compared with biomass and coal taken separately. In general, various authors stated that the introduction of alternative raw materials should not prevent the utilization in existing equipments (Grammelis *et al*, 2009; Gonzalez *et al*, 2004; Olsson *et al*, 2003).

In summary, despite the promising use of other raw materials than sawdust, the work has been confined essentially to resources which do not differ greatly from sawdust. Therefore, it is possible to produce pellets of acceptable durability and that pose no major problems in existing combustion or gasification facilities. However, the use of industrial wastes should introduce additional difficulties both during their pelletization and in their subsequent utilization in combustion.

The use of local raw materials is crucial to the economics of the operation. According to Thek and Obernberger (2004) the raw materials may contribute to over 35% of the total production costs and transportation is a major component. In assessing the feasibility of residue incorporation in pellets, the local availability of both the raw materials and residues must be taken into the equation.

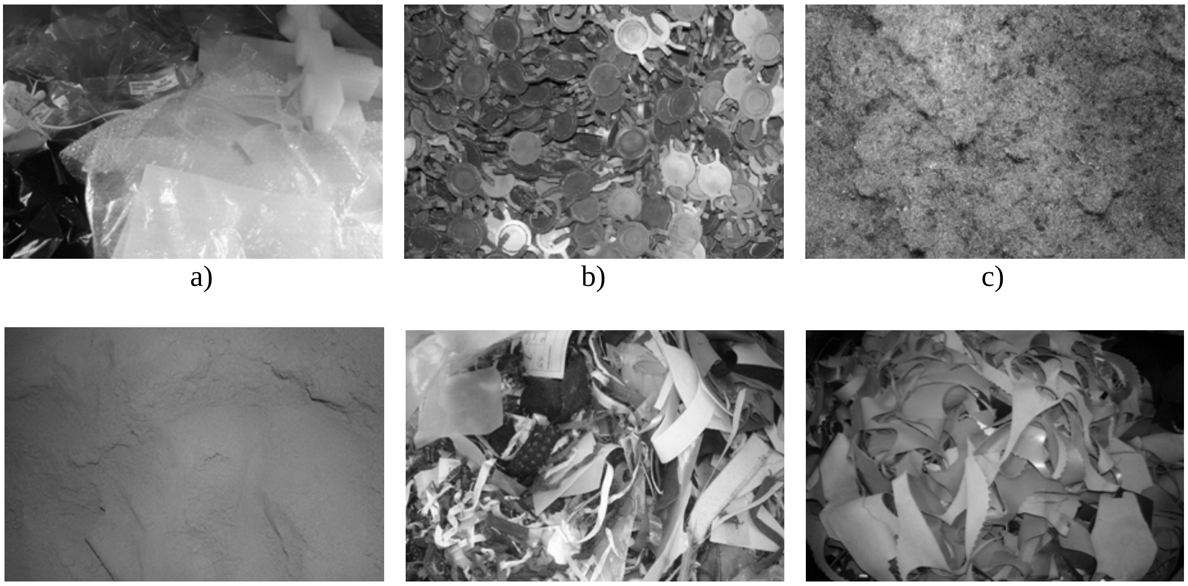
In the Northern region of Portugal, 420,000 ton/year of urban solid wastes are already channeled into an incineration plant with energy recovery. This represents approximately 27% of the total urban wastes generated. The scenario for industrial wastes is much bleaker and, at the same time, is open for opportunities. In a recent study, Castro (2009) estimated that the total amount of industrial residues is over 2.8 Mton/year. Their main source comes from key industrial sectors: textile, shoemaking, electronic components, wood processing, plastics and tire recycling. Together they represent nearly 60% of the region's GDP. Amongst those residues, approximately 800,000 ton/year can be used as an energy source.

The main goal of this project was to assess pellet production from a blend of industrial residues and biomass in an industrial plant at a pilot scale. The route envisaged for this is to incorporate the residues into a matrix of traditional raw material (pine sawdust). In this way it is expected that the processing operations should not deviate significantly from the traditional sawdust pellets and also the combustion could be performed efficiently in a wider range of combustion equipments.

2 EXPERIMENTAL DETAILS

2.1 Preparation

All the pellets were designed to incorporate up to 10% level of residues. These were selected by their relevance in the industrial pattern of the region: polymeric mould wastes (from the packaging industry), textile, shoemaking parts, painting dust (from the furniture industry), tire fluff and mould compound (electronic component industries). By using locally generated residues, the production costs should be reduced and could be integrated with local biomass resources from the forestry derived activities. Figure 1 shows each one of the residues before processing. However, for those with textile and tire fluff the incorporation levels were limited to 5% because of the power limitation of the pelletization unit. Sawdust from cutting pine wood logs was used as the matrix medium for all the compositions. Also, pellets made of 100% sawdust were used as a standard for comparison purposes. Pellets were produced in an axial 400 kg/hr small scale pelletization unit with 6 mm diameter holes. The mill was driven by a 3 phase, 15 kW motor.



a) b) c) d) e) f)

Figure 1 – Residues used as raw materials for pellet production. a) plastics; b) polymeric mould wastes; c) tire fluff; d) painting dust; e) textile parts; f) shoemaking parts.

The raw material preparation followed the steps depicted in Figure 2. The moisture content of the mixture (industrial residue + sawdust) varied between 14 and 18%. The grinding process of residue and sawdust were processed with a 4 mm opening sieve.

The various types of residues, go through a single treatment stage before pelletization. They are triturated in a knife mill, coupled with a 4 mm sieve. The moisture content at this stage was approximately 15%.

The sawdust had a high moisture content of approximately 50%. Once dried (down to 15%), the sawdust was crushed in a hammer mill with a 4 mm sieve. The moisture content was measured by weighting samples (on a scale with a resolution of 0.005 g) before and subsequent to being dried. An oven was used to dry the samples. Its temperature was controlled and set at 105±2ºC, according to standard CEN/TS 15414-3. Because of the small quantities involved, the sawdust drying was carried out by direct contact with air.

The sawdust and the grounded waste (weighted in appropriate quantities) were mixed in a rotating drum in order to obtain a homogeneous mixture. This was subsequently fed into the flat die pellet mill, and the 6 mm pellets were cooled by direct contact with air, for improving their mechanical consistency.

Sieving was the last step in the pellet production. The fine dust was removed from the pellets in order to assess their mechanical strength and increase their quality as they often yield an excessive level of particle emissions.

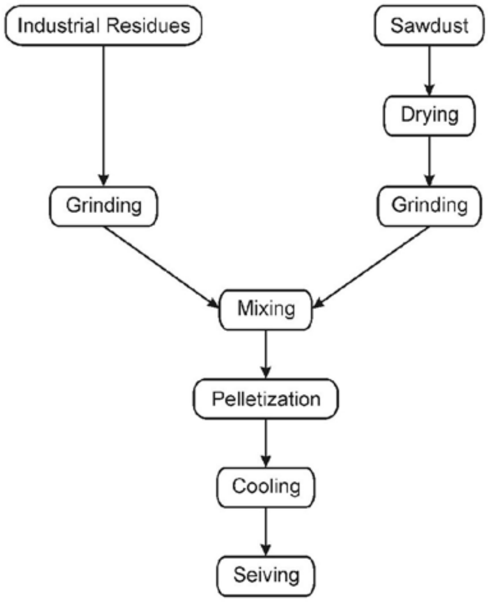


Figure 2 – Schematic representation of the pellet production process

2.2 Testing

The pellet combustion testing facility is depicted in Figure 3. Pellets, weighted in a digital scale (7) are fed into a 15 kW boiler (6). The thermal load is balanced through an air-water heat exchanger (4) by adjusting the water flow rate, which is measured by a rotameter (5). The exhaust gases are measured in the stack (1) by an orifice plate (3) and an isokinetic probe (2). A pump (8) and an expansion vessel (9) complete the cooling loop. All the combustion tests were carried out at a power level 3 (in 1 through 5 scale) for this particular boiler, and the data were recorded once the steady state was achieved.

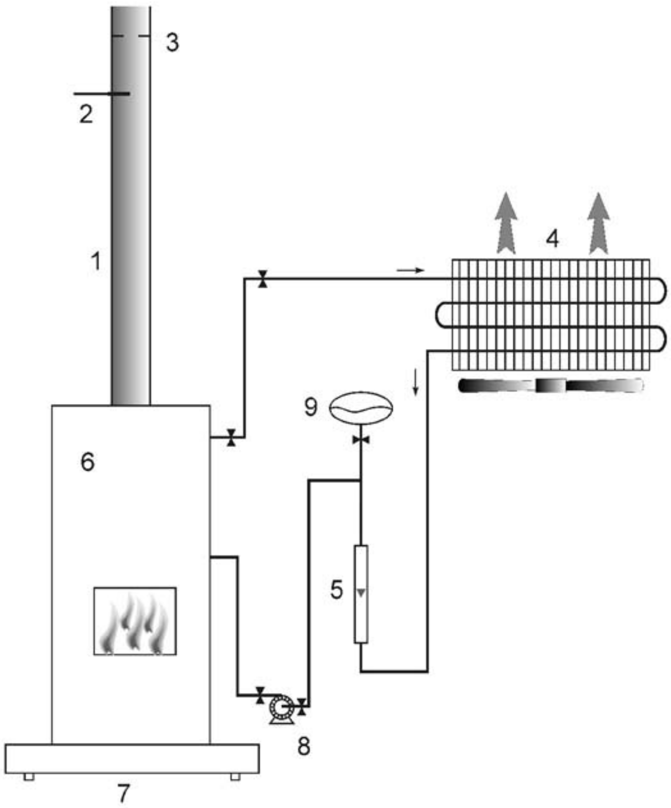


Figure 3 – Schematic representation of combustion testing facility

A Multi Gas Analyzer, model SIGNAL 9000MGA, was used for continuous monitoring of flue gas emissions: O_2, CO_2 and CO and NO_x (Figure 4). The analyzer is based on three well-established measurement techniques to enable measurement of four separate sample gases at any time.

For measuring O_2, the analyzer uses a dumb-bell paramagnetic sensor that is sensitive and linear. This sensor is heated to prevent condensation and to minimize drift. For measuring CO and CO_2, the analyzer applies an infra-red gas filter correlation technique using gas-filled optical filters for maximum selectivity; a single beam optical path increases tolerance to contamination. The NO_x analyzer uses the chemiluminescent method, which is based upon the chemiluminescent gas phase reaction between ozone and nitric oxide.

The analyzer has four independent ports to connect the span gases, for calibration. These consisted of a concentration of span gases in a nitrogen diluent, with the following concentrations: CO – 5000 ppm; O_2 – 20%, CO_2 – 10%, NO_x – 10000 ppm. The analyzer needs a continuous supply of purge gas – pure nitrogen – that is also used as a zero calibration gas.

Figure 4 –View of the SGNAL 9000MGA flue gas analyzer

The analyzer was connected to a computer for data acquisition and further processing via a 12 bits data acquisition board (NI PCI-MIO16E-4, 500 k sampling rate). This data acquisition board also integrates all the signals from the various thermocouples and the digital scale.

The gas sample was extracted from the final section of the stack by means of a vacuum pump. Upstream of the vacuum pump the sample was filtered and cooled in order to remove particles and moisture. Figure 5 shows a layout of the gas analyzer apparatus which includes: sample gas pipe system from the stack, vacuum pump, cooling system with chilled water, filters, span calibration gases, purge and zero gas supplies. For NO_x the analyzer has a dedicated heated probe to avoid condensation.

The heat value of each residue was measured by a calorimeter Leco AC500. This determines the heat value through the heat released to a volume of water. The CEN/TS 14918 standard was followed.

The elemental analysis was determined according to standard CEN/TS – 15104 by a LECO TruSpec Series. The composition in C, S and H is measured by infrared absorption and that of N by thermal conductivity. Other elements were measured by an X-ray fluorescence spectrometry technique. This was also employed to measure the ash composition.

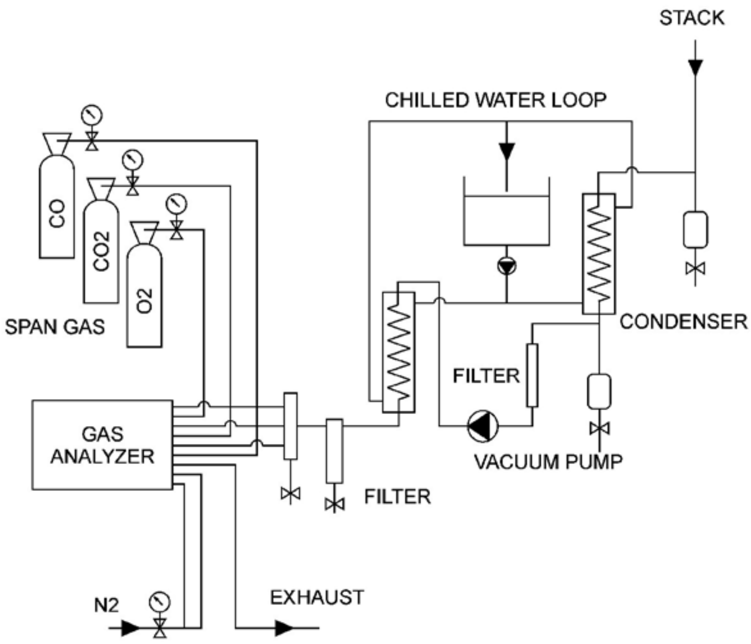


Figure 5 – Layout of the flue gas treatment facility for O_2, CO and CO_2

3 RESULTS AND DISCUSSION

3.1 Pellet Production

The production of pellets was made in batches between 13 and 30 kg. At the end of each batch, maize was used in order to lubricate the die and avoiding its obstruction for the following runs. It was observed that the addition of residues yielded an increase in the power consumption (observed in an ammeter) which in a few cases was a limiting factor. The production of the reference pellets (100% saw dust) posed no major problems and the product had a low content of fine dust (approximately 20%).

When residues are incorporated, the content of fine dust increases relatively to the reference pellets. The incorporation of mould compound and ink dust are the best as far as this parameter in concerned, where a 20% of fine dust was measured which means that their mechanical strength is similar to the 100% sawdust. Materials such as the shoemaking, textiles and tire fluff presented a very high level of fine dust, between 50 and 70%. This is due to their low stiffness and flexibility which prevents the particles to be rigidly bounded. In addition, pellets with textiles are highly dependent upon its source. The high flexibility of the tire fluff prevented its incorporation at the desired level, being limited to 5%. Small residues of rubber may also contribute to this behavior. Similar problems have also been identified with agricultural residues (Werther *et al*, 2000). For plastics, the high percentage of fines is due to the operating temperature of the extrusion process. It is expected that this may be below their melting temperature which prevents the efficient binding of the plastic with the saw dust (Marsh *et al*, 2007). When incorporating mould compound and plastics, the pellet mill was stretched to its maximum power capacity.

The absolute value for the fraction of fine dust should be taken with caution because of the limitation of the pellet mill. However, they may be used for comparison purposes between the various residues and also for comparison with reference pellets.

3.2 Characterization of Pellets

Table 1 summarizes the main physical characteristics of the pellets. It is observed that the addition of residues, even at low levels, reduces the density of the pellet, when compared with the 100% sawdust pellet. The value for these pellets is within the range expected for wood pellets (Larson *et al*, 2008). This behavior may be due to discontinuities in its structure. This is in agreement with the levels of fine dust in the product: denser pellets means lower amount of fine dust. However, tire fluff presented an exception. For this, it was observed that rubber residues were attached to the fibers and they should contribute to the average density of the pellets though the fiber structure inhibits a cohesive pellet.

Table 1 – Physical characteristics of the pellets

Parameters	**Results**						
	Sawdust	**10% Polymeric Mould**	**10% Painting Dust**	**10% Shoemaking residue**	**5% Textiles**	**10% Plastics**	**5% "Fluff"**
Moisture content (%)	5.1	6.2	7.6	9.5	14.2	9.6	10.3
Bulk Density (kg/m^3)	624	554	465	388	346	327	501
Ash content (%)	1.2	9.8	3.2	2.9	1.4	1.9	1.3
Low heat value (kJ/kg)	17100	15900	17400	17400	17400	19400	17500

The Moisture content is, for all types of pellets, within the desired value (under 15 %), which is the acceptable level for pellet combustion.

The low heat value of the pellets does not vary significantly with the introduction of such levels of residues, suggests that it may be compatible with the use of this pellets in domestic boilers. In fact, for most of the combinations tested, there is an improvement of the energy content. The most significant is the incorporation of plastics and tire fluff. It is also observed that the addition of mould compound reduces the final heat value. This may be due to the high levels of ashes. However, for industrial applications this enhancement can be decisive in the choice of the pellets, due to the large amount of the pellets used in medium and large scale units, yielding a reduction in fuel consumption.

The ash content in pellets with 10% of "Polymeric Mould Waste" was the highest, resulting in the formation of a large number of clusters, which can be a serious drawback for an efficient operation of domestic boilers, where ash is a major parameter in assessing the pellet grade. These pellets also show a high level of silica that may contribute to the formation of ash clusters. It should also be noted that three of the residues (tire fluff, textiles and plastics) do not induce a significant increase in the ash content.

3.3 Flue Gas Characterization

Table 2 summarizes the results obtained for the combustion flue gas characterization. Only data for CO, NO_x and heavy metals are presented here. The data is also corrected for 8% O_2. In general the introduction of residues in the pellet manufacture increases the amount of noxious gases and products.

Most of the pellets tested can comply with the legal limit regarding the heavy metals concentration. The exception refers to the incorporation of the tire fluff because some metallic residues are also present in the raw material. The cold separation by mechanical action of the rubber from the ply fabric and the metallic reinforcements is not 100% effective. A slight reduction of the incorporation levels in the pellets may render appropriate this route. Although this may sound discouraging, it must be stressed that the alternatives available for tire disposal are not easy to implement. For instance, the direct combustion of the residue is very complicated to conduct in a proper manner in a grate boiler. Therefore the incorporation, even in such small levels, may be an interesting method for the disposal of residues from the tire recycling operations. Also the levels of heavy metals with shoemaking residues are very close to the legal limit. This is not surprising because of the use of chromium in the manufacturing of leather products.

Table 2 – Composition of flue gases

Parameter	Measured concentration (mg/Nm^3)							Limits
	Sawdust	10% "Polymeric Mould"	10% Ink Painting	10% Shoemaking Residue	5% Textiles	5% Tire Fluff	10% Plastics	
Heavy metals								
Measurement	0.68	0.7	1.91	2.8	1.3	6.3	0.80	**8**
Corrected for 8% O_2	1.32	1.5	4.32	7.1	3.2	12.5	2.0	
CO								
Measurement	166	219	357	579	603	444	750	**1000**
Corrected for 8% O_2	360	508	845	1568	1780	888	2216	
NO_x (as NO_2)								
Measurement	115	100	265	395	144	181	113	**1500**
Corrected for 8% O_2	249	234	627	1069	425	362	334	

Regarding the CO levels, the pellets with the residues from the textile, plastics and shoemaking industries produced emissions above the legal limit, which suggests inefficient combustion. It should also be stressed that the boiler is a standard unit and no adjustments were possible to apply into the combustion parameters. Otherwise, better results could certainly be obtained. Nevertheless this is an important issue for their widespread application in combustion facilities that are non adjustable.

The NO_x levels are always below the legal limits though in some cases (shoemaking residues) close to the legal limit.

3.4 Chemical Characterization of the Ash Resulting from Pellet Combustion

Table 3 summarizes the chemical composition of the combustion ashes, carried out by an X-ray fluorescence spectrometry technique. Although the analysis was carried out for a much wider variety of compounds, the discussion is confined to chromium and silica.

Table 3 – Chemical composition of the combustion ashes

Parameters	**Results**						
	Sawdust	**10% Polymeric Mould**	**10% Ink Painting**	**10% Shoemaking Residue**	**5% Textiles**	**10% Plastics**	**5% "Fluff"**
Cr_2O_3 (%)	0.17	0.08	0.18	18.7	0.59	0.36	0.20
SiO_2 (%)	47.4	92.8	40.6	38.0	58.4	37.0	45.9

The data show that Chromium, formed as an oxide (Cr_2O_3), has a slight high level for pellets incorporating shoemaking residues. This is not entirely unexpected because it is used in the leather preparation. Because of the high toxicity associated with Chromium, further evaluation of the toxicological behavior is required in order to assess the possible hazards.

The silica (SiO_2) level in pellets with mould compound is a cause for concern as they run at approximately twice the levels observed with other pellets. Because it is a strongly abrasive agent, it can cause corrosion in the boiler.

CONCLUSIONS

The present work addresses the incorporation of industrial residues into wood based pellets. In this way, an alternative route for the disposal of such residues may be available with the added benefit of energy recovery. The criteria for the selection of such residues were based upon the industrial relevance and subsequent availability in the region. Six residues were selected. Tests were carried out at a laboratory facility that integrated all the required steps for pellet manufacture.

In this context the following conclusions can be drawn:

1. The production of pellets when residues are added, incurs in the penalty of an increase in energy consumption in the pellet mill. This is linked with increased difficulty in processing and, therefore, a higher rate of wear in the matrix and the pressing cylinders should be expected.
2. The structure of the residues has a strong influence in the quality of the final product. When they have a flexible structure, the resulting pellets exhibit poor mechanical properties because of their lack of stiffness. Consequently, the amount of fine dust is high, which can be as much as over 3 times that observed in the absence of residues. Also their bulk density is affected accordingly.
3. The level of ashes is higher in the presence of residues, though for some the increasing is small. The use of mould compound from the electronic industry has exhibited a very high level of ashes which is also associated with the reduction in the lower heat value of the fuel.
4. The combustion tests have shown an increase in the emission levels, when compared with 100% saw dust pellets. The NO_x levels are well within the legal limits. However, the CO concentration shows that combustion is poor with standard equipment. Clearly care should be taken in the selection of the combustion facility, which should enable control of the air supply to adjust to the fuel characteristics. The heavy metal content is well within the legal limits except for pellets incorporating tire fluff, although those made with shoemaking residues also show a high level.
5. This later characteristic is linked with the composition of combustion ashes. For the shoemaking residue the chromium level is high. Silica compounds are also present which may cause corrosion in the equipments.

In brief, the application of industrial residues has shown promising results for their incorporation in pellets. The evaluation has also to be balanced by the reduction of wastes for landfill, the most common route for their disposal. However, some issues are of concern and should require detailed analysis in any practical implementation: excessive wear of the pellet mill; appropriate combustion facilities in order to tune the air supply to the fuel characteristics; higher ash contents which (coupled with the previous item) may confine their application in medium-large scale industrial facilities.

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