DRY FRACTIONATION OF PLANT MATERIAL POWDERS USING AN ELECTROSTATIC CORONA SEPARATOR: A MODEL STUDY

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In a dry bioreffinery scheme, the separation of plant materials into fractions of interest compound is a crucial step. In recent years, electrostatic separation of agri-resources has sparked a growing interest for its potential but optimization efforts remain to be done especially in case of fine powders. The present work is an experimental investigation of factors, which influence the separation process of plant biomass powders in a custom built corona electrostatic separator with view to optimization. Three particle size classes of cork, semolina and wood powders have been characterized in term of charge decay curves and their behavior on the device have been studied. Separation tests of a blend constituted of 1g of wood powder and 1g of semolina have also been conducted with very promising results.

1. Introduction

Plant materials are structurally organized in a multilayer composite containing different tissues (epidermis, parenchyma, sclerenchyma and vessels), each of which is composed of different macromolecules (carbohydrates, proteins, lignin, , lipids, polyphenols…) and ash. As a result, they are excellent sources of raw materials for many applications as biofuels, green chemicals (surfactant, resin,) or biomaterials (fiber). In a plant biorefinery scheme, the first step consists of the separation of agri-resources materials into its major compounds, that is most of the time achieved by expensive chemical processes (pulping, hydrolysis, solvent extraction, steam and ammonia explosion, etc…). These processes induce a degradation of the native functionalities of the compounds [1] and are known to have a significant environmental impact since they are highly energy and water/solvent consuming. Dry fractionation processes, inspired by wheat and durum milling could be seen as an interesting alternative [2]. They usually combine different unit operations of pretreatment, grinding and physical separation to gradually destructure and fractionate the plant materials at tissue (100 micrometers) or cellular scale (10 micrometers) [3]. Among all the separation processes, the electrostatic separation emerged as an eco-friendly technology since it allows the preparation of enriched fractions in compounds of interest (proteins, cellulose, hemicelluloses or phenolics) from biomass particles ranging between 10 and 500 micrometers [4]. In an electrical separator, particles are first charged either by triboelectric charging, or by conductive induction or by ionic cloud and then sorted in a high voltage electrical field. Originally, the electrostatic separators have been developed for the polymer, mining and mineral processing industries and the existing industrial devices are not directly transposable to the agri-ressources separation since the particles obtained in a dry biorefinery scheme are smaller and/or lighter. In the scientific literature, two devices, based on two different principles, are mainly used for the electrostatic separation of plant materials. The first one, inspired of the industrial free fall electrostatic separator demonstrated its potentials for many raw materials as wheat bran [5], gluten and starch mixture [6] , oilseed cake [7], rice straw [8] but presents a weak flexibility. The second (belt-corona separator), akin to a corona drum separator have been used for the removing of fibers in different substrates: corn flour [9], oilseed cake [10], peeling and gluten mixture [11] for relatively coarse particles (d50 >1 mm). Assuming that devices based on each of these principles lead to different separations, a custom-built belt-corona separator has been designed and an experimental investigation of factors influencing the separation process of plant biomass powders with view to optimization has been conducted. In this study, three plant model powders, in term of composition, have been selected and characterized with charge decay curves and particle size. In a second time, separation tests have been carried out with a blend of two of these materials to evaluate the efficiency of the process and the interaction of the different powders during the separation process.

2. Materials and methods

Particles are deposited on a grounded conveyor by a vibration hopper. They could be charged either by corona discharge, induction or contact electrification. By contact to the ground conveyor, the conducting particles lose their charge quickly while the poor- or non conducting particles that lose their charge more slowly, are attracted onto the rotor surface by the image force of their surface charge [12]. Thus, the ratio of the electrical forces to the gravity force mainly governs the separation of the particles and the efficiency of the system is related to the mass of a particle, its shape and its nature (composition). The corona discharge and the rotor electrode in the custom built separator are powered by a high voltage generator between -60kV and + 60 kV. The speed of the conveyor and the rotor electrode, the distance between the conveyor and the rotor electrode (d_e) are adjustable. Thus the charge of the particles, the contact time between the particles and the conveyor, and the norm of the electrical field could be managed.

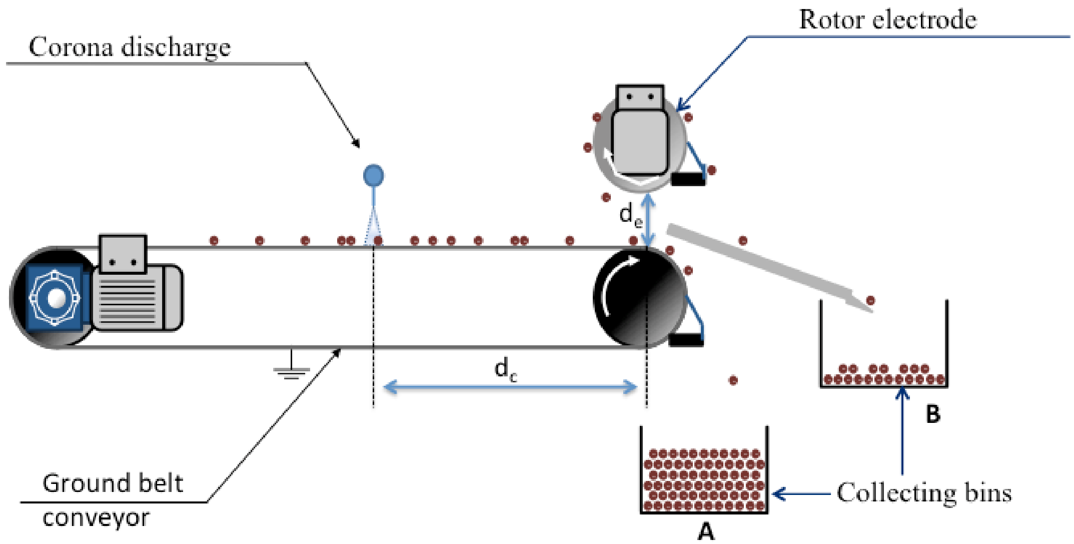

Fig 1: Custom built corona belt separator

In a theoretical point and in first approximation, we assume that a particle could be attracted by the rotor electrode if the electric attraction force $\mathrm{Fe} = \mathrm{k}.\frac{q_a \cdot q_b}{d^2}$ is higher than the weight of the particle $\mathrm{P} = \mathrm{m.g}$ with k being the dielectric constant of the material, q_a the charge of the particle (a priori related to the surface of the particle), q_b the charge of the rotor electrode, m the mass of the particle and g the acceleration due to gravity. Thus, we can presume that the ratio $\frac{S_{50}}{m_{50}}$ could be related to the ability of a powder to be attracted by the rotor electrode.
Three different materials have been selected for this study : cork powder, pine wood powder and durum semolina. Semolina is mainly composed of gluten and starch, wood of lignocellulose and cork of lignocellulose and suberin. They also have very contrasted densities and present a homogeneous structure at the scale of the particle sizes considered in this study. Thus they could be viewed as model powders for the understanding of the mechanisms occurring in the separation process of plant materials. Three classes of calibrated particle sizes have been prepared by milling and sieving for each material. The particle size distribution of each class has been measured by laser diffraction. The median size and the ratio $\frac{S_{50}}{m}$ have been determined and are reported in table 2. The different classes have been defined as having some recovery classes between materials and as having a similar magnitude ratio $\frac{S_{50}}{m_{50}}$ with S_{50} and m_{50} being respectively the surface and the mass of a particle of diameter d_{50}. In table 2, the lower and upper boundaries of the classes are the mesh size of the sieve used for the preparation of the classes.
It can be noticed that for most classes, especially for the coarser one, the median particle size is higher than the upper bound. This could be related to the elongated shape of the cork and wood particles. For each classe of materials, decay charge curves have been built. In the case, the high voltage of the corona discharge was set to 20 kV, the distance between the corona separator and the conveyor have been set to 4 cm. The speed of the rotor electrode and of the conveyor was respectively set to 90 tr.min-1 and to 4,10 m/min and the position of the corona discharge was modified in order to manage the contact time between the particles and the ground conveyor. The charge of the particle was measured in a Faraday cage at the conveyor outlet, in three replicates

of 0,5 g of powders. The charge is expressed as □C/g since the attraction of the powder by the rotor electrode is a function $\frac{q_a}{m}$.

Table 1 : The different particle size classes for cork, wood and durum semolina

		Spreading of the class (□m)	D_{50} (□m)	S_{50}/m_{50} (m^2/g)
Cork	Class 1	1400<O<2000	1900	$9,5*10^{-3}$
	Class 2	560<O<900	955	$1,9*10^{-2}$
	Class 3	315<O<450	490	$3,7*10^{-2}$
Wood	Class 1	560<O<900	921	$3,8*10^{-3}$
	Class 2	315<O<450	535	$6,6*10^{-3}$
	Class 3	100<O<200	254	$1,4*10^{-2}$
Durum semolin	Class 1	315<O<450	407	$9,7*10^{-3}$
	Class 2	200<O<300	330	$1,2*10^{-2}$
	Class 3	100<O<200	173	$2,3*10^{-2}$

The different materials have been tested on the separator in two different configurations with 2g of each class. The parameters of each configuration are summarized in the table 2. The powder recovery in bin A (powder not attracted by the rotor electrode) et B (powder attracted by the rotor electrode) was weighted to determine the efficiency of the process. In a second time a blend composed of 1g of wood powder (class 1) and 1g of cork powder (class 1) was separated. The mass of each material in each collecting bins (A and B) have been determined by sieving with a mesh size of 560 □m.

Table 2: Configurations for the separation test

	Configuration 1	Configuration 2
Voltage of the corona electrode	0 kV	-20 kV
Position of the corona electrode (distance from outlet)	/	1000 mm
Voltage of the rotor electrode	-20 kV	+ 20 kV
Distance between the rotor electrode and the conveyor (d_e)	25 mm	40 mm

3. Results and Discussion

3.1 charge decay curves

Figure 2 shows the charge decay curves obtained for cork (a), semolina (b) and wood (c) for the three particle size classes used in this study. Cork and wood powder appear to be rather electrically insulating. For cork powder, decay curve have been fitted by exponential law (fig 2 a) with regression coefficients R^2 >0.85 for all cork classes. The half-discharge times have been determined from the fits and are respectively equal to 54, 81 and 76 seconds for class 1, 2 and 3. For wood powder (fig 2b), the charge curve decay cannot be fitted by an exponential law but by a linear regression (R^2> 0,87) probably due to the low number of measure points especially during the first second following the charge of the particles. The half-discharge times (132, 126 and 123 seconds for class 1,2 and 3) are probably not representative since a physical law of charge decay is not observed. When charging particles, the charges are deposited at their surface. Smallest particles developing highest surface, it seems logical to measure greater maximal charge for class 3 than for class 1. However, for both cork and wood powders, the maximum charge values are obtained for class 1. In addition the charge decay is faster for class 1 than for class 2 and 3 while the ground contact surface of the powder would be smaller. These observations could be related to the difficulty to realize a monolayer of particle during the deposit for fine powders. Indeed if particles are organized in multilayers, only particles at the top would be able to be charged and particles of lower layers will have a screening effect during the discharge phase as illustrated in fig 2d. Thus a particular attention must be paid to the feeding of the conveyor belt.

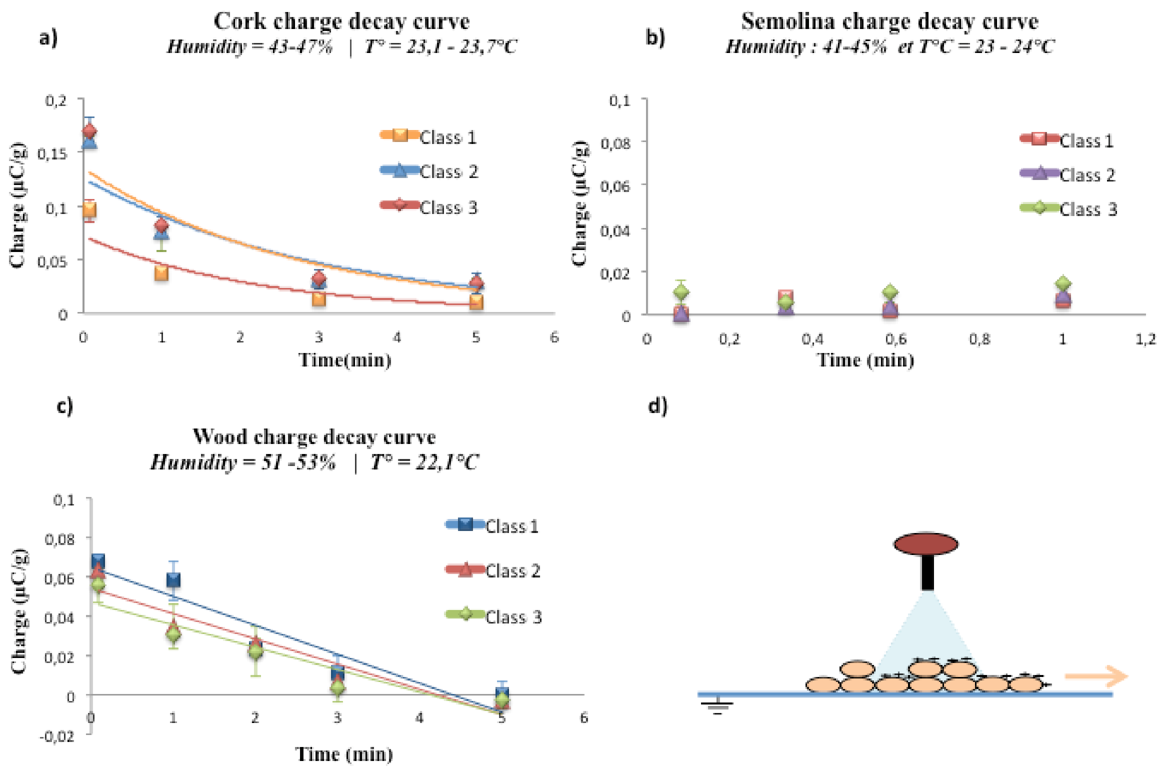

Figure 2 : Charge decay curves for cork (a), semolina (b) and wood (c) powders. Schematic representation of the charge of particles in case of a multilayer deposit (d)

In contrast with cork and wood powders, semolina behaves like a conductor since the charge measured is more than 10 times lower and do not vary with time. When contacting the ground conveyor, particles of semolina lose their charge almost instantly. Only the residual charge value is measured in the Faraday cage (fig 2b) and no effect of particle size is observed.

In all cases, charge values and discharge times seem to be coherent with requirements for separation on the device since the speed of the conveyor is 4,10 m/min (for a total length of 2 m). Thus, by playing with the position of the corona electrode, it is possible to modulate the residual charge of the particles in the separation area (proximity of the rotor electrode).

3.2 Behavior of pure materials on the corona separator

The behavior of pure materials has been studied on the separator without (configuration 1) and with (configuration 2) charge of particle by the corona electrode prior to the separation. In the first case, when the particles arrive in the electrical field, they may be attracted to the rotor electrode by induction effect. In the second case, we assume that the charge of particles played a leading role in the attraction by the rotor. The losses reported in table 3 correspond to particles, which are first attracted, then pushed after contact with the rotor electrode and fell outside of the collecting bins.

In table 3, we notice that induction effects are important for class 1 and 2 of cork and wood powders and to a lesser extent for class 3 of cork. For these classes of materials, the shape factor is more important (see table 1) and may be responsible for the attraction, particles acting as electrical dipoles in the area of the electrical field. Class 1 of semolina seems to be less sensitive to induction effect. For class 2 and 3, the induction effects are notable but because of their high conductivity, particles change of electrical polarity by contact to the rotor electrode and are instantly repulsed.

In configuration 2, particles are charged prior to the separation. However, particles of semolina have already lost their charge when they reach the area of the electrical field. The attraction of a part of the powder is only due to the induction effects described above. The variation in the proportion of powder attracted between the configuration 1 and 2 have to be related to the difference of d_e in both configurations. In configuration 2, the corona electrode is positioned at 1 m of the outlet of the conveyor. According to decay curves (fig 2 a and b), the most charged powder for a time of 15 s, is the class 1 of cork for which the 90 % of the powder is attracted (Bin B + Loss) by the rotor electrode. Similarly, when they reach the separation area, the class 2 of wood and the class 3 of cork have approximately the same charge (0.55 □C/g) whereas the percentage of attracted powder is 50% and 70 % respectively. This percentage reaches 75 % for the class 3 of wood for which the charge measured is lower. This could not be related to difference of mass between particles, wood particles being heavier. Thus more complex mechanisms are involved in the separation and complementary work must be conducted.

Table A	Cork					
	Configuration 1(without Corona)			*Configuration 2(with Corona)*		
	Bin A (%)	Bin B (%)	Loss (%)	Bin A (%)	Bin B (%)	Loss (%)
Class 1	10	90	0	10	85	5
Class 2	25	75	0	70	30	0
Class 3	30	60	10	50	40	10
Table B	Wood					
	Configuration 1(without Corona)			*Configuration 2(with Corona)*		
	Bin A (%)	Bin B (%)	Loss (%)	Bin A (%)	Bin B (%)	Loss (%)
Class 1	5	95	0	45	45	10
Class 2	20	75	5	30	55	15
Class 3	65	25	10	25	55	20
Table C	Semolina					
	Configuration 1(without Corona)			*Configuration 2(with Corona)*		
	Bin A (%)	Bin B (%)	Loss (%)	Bin A (%)	Bin B (%)	Loss (%)
Class 1	70	15	15	50	15	35
Class 2	55	20	25	25	35	40
Class 3	45	20	35	60	30	10

Table 3 : Behavior of cork (3.a), wood (3.b) and semolina (3.c) powders on the corona separator

3.3 Separation of a wood-semolina blend

Table 4, shows the results obtained for the separation of a blend constituted of 1 g of semolina (class 1) and 1 g of wood powder (class 1). Interestingly, no losses are observed for this blend in comparison to 10 % and 35 % for wood and semolina individually. Similarly, the repartition of semolina and wood powders are totally different from those observed above, highlighting the occurence of interactions between powders during the separation process. Nevertheless, results obtained are promising since 80% of the semolina is recovered in bin A and 90 % of the wood powder in bin B.

Table 4 : Yields and compositions of materials recovered in each bin during the separation of blend wood/semolina

Bin A(%)		**Bin B(%)**		**Loss (%)**
45%		55%		0%
Wood (%)	Semolina (%)	Wood (%)	Semolina (%)	
5%	40%	45%	10%	

4. Conclusion

In order to understand the mechanisms occurring during the electrostatic separation of plant materials powders, three classes of different particle sizes for three different plant materials (semolina, cork and wood powders) have been characterized in term of charge decay curves. These curves shown that the charge of the powder highly varies according to the composition and the size of the particles, semolina behaving as a conductor whereas cork and wood powder acting more as insulating materials. The behavior of three different plant materials have been studied on a custom built corona electrostatic separator for the different particle sizes. Results highlighted that the charge of the powders is not the only factor governing the separation process and more complex phenomena are also involved. This has been confirmed during the separation of a blend composed of 50% of semolina and 50% of wood for which the efficiency of the separation is higher than for each product individually. Based on this preliminary study, complementary work will be conducted on a complex plant material finely ground. The study will be focused on optimization of conditions of separation using a specific experimental design.

5. References

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