A tribo-electrostatic separation process of micronized particles using rotating disks immersed in a fluidized bed: modeling and optimization

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Abstract - The tribo-electrostatic separation of mixtures of micronized particles from plastic waste remains a major challenge for researchers. Indeed, the aerodynamic forces acting on such particles often outweigh the gravitational and electrostatic forces. A patent application has been filed for a new separator model produced and tested at the University of Sidi Bel-Abbes. The device comprises two parallel rotating discs, arranged vertically and connected to two DC high voltage power supplies of opposite polarities. The experimental study, carried out with a mixture of micronized particles of white PVC and gray PVC, having an average size of 50 µm, aims to assess the influence of the various factors (intensity of the electric field, speed of rotation of the discs and fluidization air flow) on the triboelectric charge acquired by the particles and on the efficiency of the separation. A face-centered composite experimental design was developed. The results obtained showed that among all the factors studied, the intensity of the electric field has the most significant influence. The best separation was obtained for an electric field of 3.9 kV/cm and a disc rotation speed of 100 rpm.

Keywords -Electrostatic forces, Tribo-electrostatic separation, High Voltage, Micronized particles.

I. INTRODUCTION

Conventional carry select adder performs better in terms of speed. The delay of our proposed design increases lightly because of logic circuit sharing sacrifices the length of parallel path.

However, the proposed area-efficient carry select adder retains partial parallel computation architecture as the conventional carry select adder Electrostatic separation is a generic term given to an important class of industrial waste treatment technologies, widely used for sorting granular mixtures due to electric forces working on the charged granules or polarized, it becomes more and more a global concern because of increasing the waste of electrical and electronic equipment [1]. Separation of mixed granular materials at using electric power is one of the oldest applications of electrostatics [2, 3]. Electrostatic separation, which has been widely used in the mining industry [4, 5], is a very promising technology for the treatment of granular waste, produced by example of electrical cables or printed circuits [6, 7]. Besides, nowadays powders and micronized particles are widely used as raw materials, or intermediate products, or even as final product. When the powder is set in motion in any industrial process, the surfaces of particles become tribo-electrically charged and various phenomena occur, such as adhesion to the walls of particles charged in the pipes of pneumatic transport or in fluidized beds with electrostatic forces [8,9].

On the other hand, these electrostatic forces can be used to control the movement of charged particles. So many applications electrostatics involving micronized particles have been developed, such as dusting, precipitation and separation [10].Nowadays, good yields in terms of recovery and purity often more than 90% are currently obtained for electrostatic separators of mixtures granular with millimeter particles [11, 12].

Despite continuous research efforts to improve the performance of different types of electrostatic separators [13, 14], the application of this technology in the industry always encounters major difficulties:

the processes of separation of granular mixtures from microparticles, micrometers powders and powders products remain problematic and are not as effective due to the aerodynamic force that can outperform the electrostatic force. In fact, this constraint causes problems to maintain trajectories desired for recovery of high purity products. The electrostatic separation process depends on a multitude of factors. In such application, the list of factors influencing the process includes the electric field, speed of rotating disks and flow rate of mixture particles [15-18] and so on…. Thus, it's not simple to determine with precision the optimal values of the process factors. An experimental procedure for optimizing the extraction process was employed using a home-made experimental set-up, comprising a tribo-electrostatic separator device. The installation consists of two metal disks rotating at a given speed, connected to two high-voltage DC power supplies of opposite polarity. These two rotating electrodes are immersed in a fluidized bed which contains the mixture of particles to be separated. The peculiarity of this device is that tribo- electric charging and separation operations occur simultaneously in the same area, and that two rotating disks are used instead of two fixed vertical electrodes as is the case with the conventional separator.

The object of this paper is to present an experimental optimization of a new tribo-electrostatic separator. Three "one-factor-at-a-time" experiments, corresponding to three controllable factors, followed by a factorial design were performed based on a two steps strategy: fixing the variation domain of the input variables and searching the optimum set point.

II. Materials and methods

The mixture of particles is deposited on an insulating sieve inside the separation chamber measuring 21 cm x 22,5 cm x 18 cm, made with transparent PMMA (plexiglass) walls. The air is injected by a blower with a power of 750 W and variable flow rate by means of a variable frequency drive. The fluidized bed schematically shown in Figure 3 is characterized by a cross-section of 21 cm x 22.5 cm and a height of 10 cm from the PVC screen on which the product is deposited. This sieve, distributing the air uniformly in the fluidized bed, is made of 0.1 mm average mesh size. The initial mass of product in the fluidized bed was 600 g. The electrostatic effects of triboelectric charging within the fluidized bed are due to particle-particle and particle-wall collisions, which result in the triboelectrification of the mixture of micronized materials. The electric field is generated between the two rotating electrodes. These steel discs of 22 cm in diameter and 4 mm thickness are separated by a variable interval of 4 to 12 cm and immersed 3 cm into the fluidized bed.

The powder product used for this study consists of two different types of PVC supplied by an industrial manufacturer of PVC plastic pipes, CHIALI Group, Sidi Bel-Abbes, Algeria. "White PVC" (WPVC) is a pure virgin polymer, while "grey PVC" (GPVC) contains a small percentage of carbon. The surface properties are modified and therefore the two types of PVC are charged differently by the triboelectric effect. The powdered material was obtained by grinding the PVC pipes to be recycled. A fine-mesh sieve was used to recover the finest particles with an average size of 50 µm (Fig. 1). The experiments were carried out on samples with a total mass of 600 g, consisting of 50% WPVC and 50% GPVC.

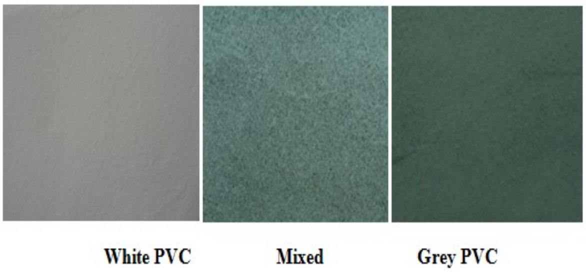

Fig. 1. Aspect of the particles used in the experiments.

In each experiment, the blower is switched on and the materials are pre-charged into the fluidized bed. Then the rotation of the rotating discs is started, and the separation process starts as soon as the high-voltage power supply is switched on. The process is stopped as soon as the purity of the separated products starts to decrease. This degradation of operation is observed when the product remaining in the fluidized bed becomes less than about 100 g.

The mass of the product collected in each collection compartment was weighed using a 0.1 g precision electronic balance. For each experiment two tests were carried out and the mean value was used to draw the curves. The experimental study was carried out considering three factors: the electric field E (kV/cm), the flow rate of air injection R (l/min) and the disk rotation speed V (rpm). The tests were carried out at ambient temperature (19°C to 24°C), with relative air humidity ranging from 40 to 60%.

III. DESIGN OF THE MASS OF PARTICLES RECOVERED EXPERIMENTS

Design of methodology for experiments is useful for screening, optimization and robustness testing. Screening experiments are designed to identify the variation of the mass of recovered particles depending to the three factors of treatment namely the electric field intensity (E), the flow rate of air injection R (l/min) and the disk rotation speed V (rpm), in order to determine a mathematical model of the mass of recovered particles by using a dedicated modeling software MODDE 5.0 [19]. The responses chosen in this case: mass of recovered white PVC particles (RWPVC) and mass of recovered grey PVC particles (RGPVC).

The following "one-factor-at-a-time" experiments define the intervals of study for the various factors were chosen according to the responses obtained from the preliminary tests (Figures 2, 3 and 4).

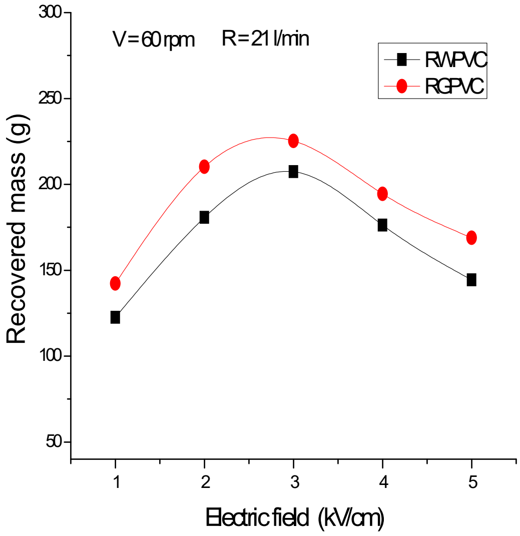

Fig. 2. Variation of the collected mass of white PVC and grey PVC as a function of the electric field at a constant values (V = 60 rpm, R = 21 l/min).

The recovery rate of the two PVC products increases with the electric field up to 3 kV / cm, and decreases for the higher values of the field (Fig. 2). This is explained by the fact, the electrical force becomes greater and a large quantity of product is quickly collected on the two discs, which ends up completely covering the electrodes. Thus, the decrease in separation efficiency.

Based on these results, we opted for $E_{max} = 2$ kV / cm and $E_{min} = 4$ kV / cm for the limits of the electric field variation interval.

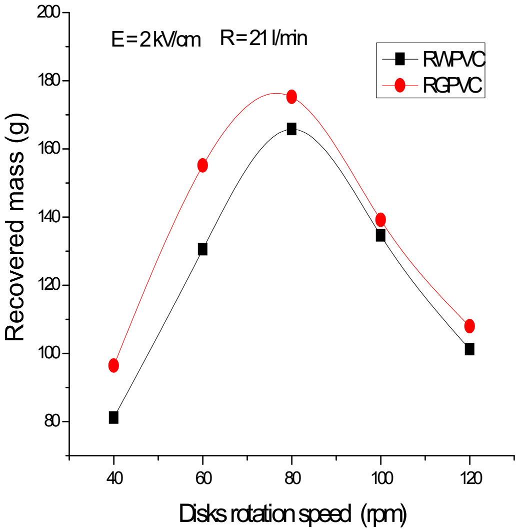

Fig. 3. Collected mass of white PVC and grey PVC as a function of the electric field at a constant values (E = 2 kV/cm, R = 21. l/min).

In addition to the electrical imaging force that causes the particles to attach to the disk, there is another mechanical force to consider: the centrifugal force, which is proportional to the rotational speed of disks "*n*". As the centrifugal force increases, the centrifugal force causes the particles to detach and the separation efficiency to decrease. On the other hand, for reduced values of speed n, the granules have enough time to rapidly cover the entire disc surface causing the attachment of particles of opposite electrical charge, thus decreasing the recovery rate.

According to the results shown in Figure 3, the speed variation range was chosen as follows: nmin = 60 rpm and nmax = 100 rpm. This is explained by the fact, the electrical force becomes greater and a large quantity of product is quickly collected on the two discs, which ends up completely covering the electrodes. Thus, the decrease in separation efficiency.Based on these results, we opted for E_{max} = 2 kV / cm and E_{min} = 4 kV / cm for the limits of the electric field variation interval.

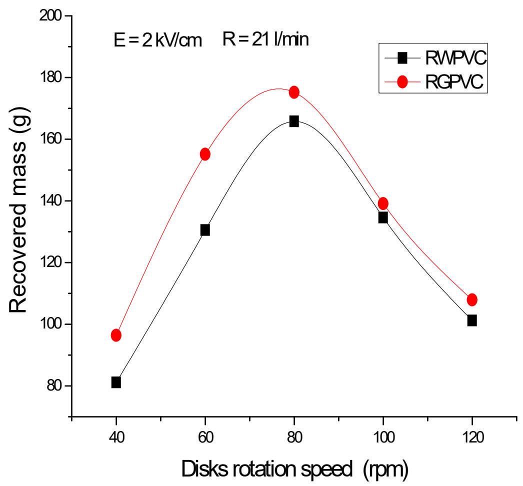

Fig. 4. Collected mass of white PVC and grey PVC as a function of the electric field at a constant values (E = 2 kV/cm, R = 21 l/min).

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According to the results shown in Figure 4, the speed variation range was chosen as follows : n_{min} = 60 rpm and n_{max} = 100 rpm.

The variation in recovery as a function of air flow is shown in Figure 5, which shows that it is not necessary to increase the fluidization rate too much. Indeed, when the air flow rate increases, the particles acquire a higher triboelectric charge and the phenomenon of attraction between the two types of PVC on the disc will cause a decrease in separation efficiency. Therefore, when the disc is completely covered with one type of PVC causing the formation of a layer about 1 mm thickness, the other type of PVC will begin to attach to it. The limits of the variation range for this factor are Rmin = 24 l/min and Rmax = 29 l/min.

So, the results of the experiment are given in Table 1.

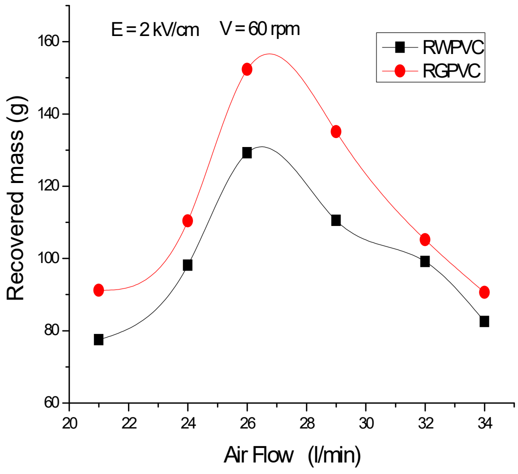


Fig. 5. Collected mass of white PVC and grey PVC as a function of the air flow at a constant values (E = 2 kV/cm, V = 60 rpm).

Table 1. Results of recuperation white and grey PVC experience extract according to variation in treatment values.

Ex p No	E (kV/cm)	V (tr/min)	R (l/min)	R WPVC (g)	R GPVC (g)
1	2	60	24	235,788	238,622
2	4	60	24	246,614	252,038
3	2	100	24	234,67	230,562
4	4	100	24	245,862	248,654
5	2	60	29	235,362	234,596
6	4	60	29	250,494	248,604
7	2	100	29	238,728	241,812
8	4	100	29	251,27	261,756
9	2	80	26,5	231,52	233,944
10	4	80	26,5	245,21	249,98
11	3	60	26,5	243,8	246,1
12	3	100	26,5	243,05	248,2
13	3	80	24	244,23	247,1
14	3	80	29	248,5	251,2
15	3	80	26,5	242,52	246,944
16	3	80	26,5	242,1	246,1
17	3	80	26,5	244	242

The predictive qualities of the models are satisfactory for all recovered mass of particles since the coefficient values Q2 and R2 close to 100%, (R2 = 0.99, Q2 = 0.916 for RWPVC and R2 = 0.978, Q2 = 0.956 for RGPVC) lead to a validated mathematical models (Fig. 6).

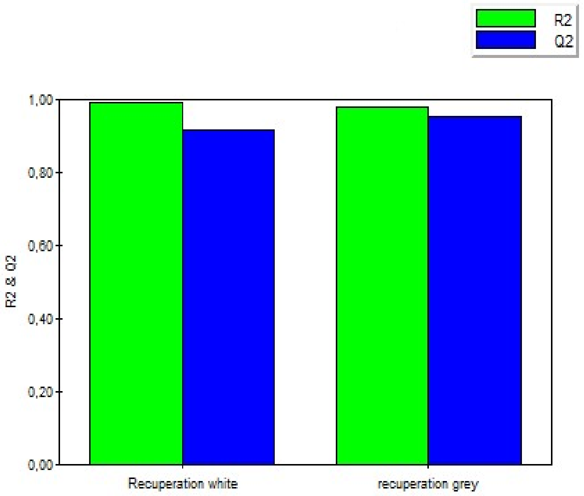
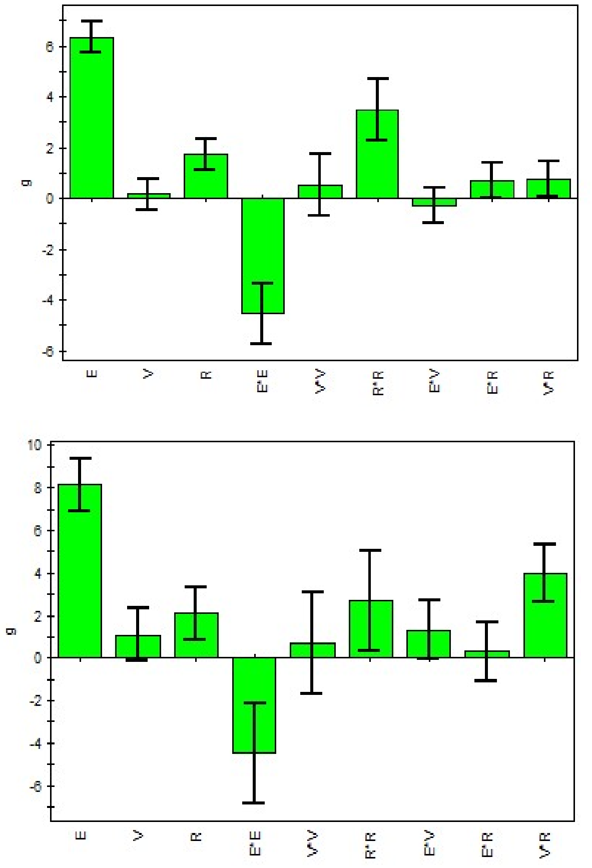


Fig. 6. Representation of descriptive quality and predictive quality of mathematical model for RWPVC and RGPVC.

According to the mathematical model obtained, the mass of the recovered particles should be higher by increasing both the electric field E and the flow rate R for all, the most significant factor being E. Moreover, the interaction between the pulses number and the capacitor value are not significant.

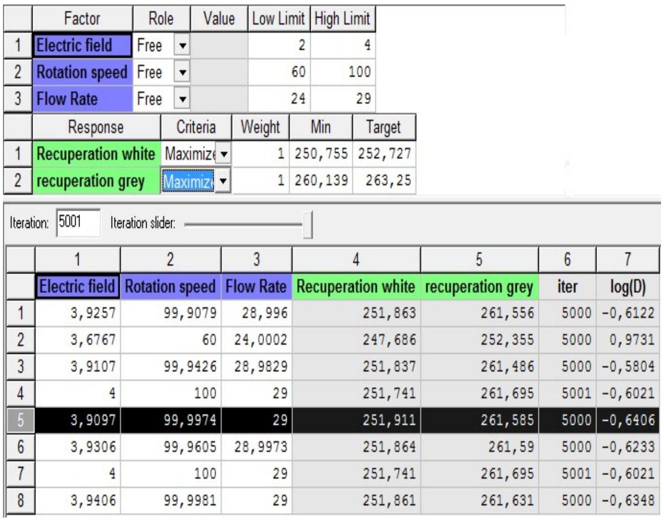


a)

b)

Fig. 7. RGPVC Plotted coefficients of the obtained model of recovered mass : a) RWPVC, b) RGPVC.

In addition, the software offers the possibility to identify the optimal values of the factors which should give the highest amount of recovered mass. According to this model, the optimum of the process (i.e., the greatest amount of recovered mass of white and grey PVC) should be obtained as shown in figure.8



	Factor	Role	Value	Low Limit	High Limit
1	Electric field	Free ▾		2	4
2	Rotation speed	Free ▾		60	100
3	Flow Rate	Free ▾		24	29

	Response	Criteria	Weight	Min	Target
1	Recuperation white	Maximiz ▾	1	250,755	252,727
2	recuperation grey	Maximiz ▾	1	260,139	263,25

Iteration: 5001 Iteration slider:

	1	2	3	4	5	6	7
	Electric field	Rotation speed	Flow Rate	Recuperation white	recuperation grey	iter	log(D)
1	3,9257	99,9079	28,996	251,863	261,556	5000	-0,6122
2	3,6767	60	24,0002	247,686	252,355	5000	0,9731
3	3,9107	99,9426	28,9829	251,837	261,486	5000	-0,5804
4	4	100	29	251,741	261,695	5001	-0,6021
5	3,9097	99,9974	29	251,911	261,585	5000	-0,6406
6	3,9306	99,9605	28,9973	251,864	261,59	5000	-0,6233
7	4	100	29	251,741	261,695	5001	-0,6021
8	3,9406	99,9981	29	251,861	261,631	5000	-0,6348

Fig. 8. Optimal values of the factors proposed by MODDE 5.0 for recovered mass.

According to this model, the optimum of the process should be obtained:

E = 3.09 kV/cm, V = 100 rpm and R = 29 l/min corresponding to RWPVC = 251.911 g and RGPVC= 261.586 g (Fig. 8).

IV. CONCLUSIONS

At present, there are several separators based on electrostatic phenomena. However, the difference in separation processes seems to be a determining point. The tri-electrostatic separator with feluidized bed proves the height of its heel compared to the other separators; this separator has recycled with success the micronized products.

The results obtained in this paper show that the electric field applied to the rotating disks was the most significant factor in the separation process. The separation rate attends 86 % of the introduced mass for optimal values.

Finally, Tribocharging of granular plastic mixtures in fluidized beds is a multi-factorial process. Indeed, a study of this phenomenon is essential for such a separator.

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