Experimental Study of a New Inclined Plane Electro-Separator

Hafidha RERIBALLAH[1], Wessim AKSA[1], Mohamed Fodil BOUKHOULDA[1], Seddik TOUHAMI[1], Karim MEDLES[2], Amar TILMATINE[3]

[1]Electrostatics and High Voltage Research Unit IRECOM,
University Djillali Liabes of Sidi Bel-Abbès, Algeria
[2]PPRIME Institute, University of Poitiers – IUT, Angouleme, France
[3]Applications of Plasma, Electrostatics and Electromagnetic Compatibility Research Unit APELEC,
University Djillali Liabès of Sidi Bel-Abbès, Algeria

E-mail: ghriballah9193@gmail.com

Abstract - The efficiency of tribo-electrostatic separation of millimeter granular mixture is higher, however the electrostatic separation of particles bigger than 10mm is less efficient due to the strong gravitational force exerted on the particles is higher.. The principal objective of this work is the realisation and optimisation of a new inclined plane electrostatic separation installation. This installation was used to separate a granular plastic mixture of big size. The preliminary experiments were carried out to determine the influence of some parameters on the installation. With the help of these results, it was possible to model the separator produced by the design of experiments methodology, using MODDE 5.0 software, which allowed us to separate granular mixtures with maximum recoveries and high purity greater than 90%.

Keywords - Tribo-electrostatic separation ; Big particle ; Inclined plane ; Modelling.

I. INTRODUCTION

Electrostatic separation technologies have been widely employed for the recycling of industrial waste [1-4]. And has been a very efficient solution for removing conducting contaminants in order to obtain pure plastic products [5-7]. These technologies represent the most significant class for the selective sorting of solid materials by electrical forces acting on charged or polarized particles [8, 9]. The treatment of granular insulating mixtures in electrostatic separators requires tribo-electric charging. The latter is the most practical physical mechanism for charging the plastic granular materials [10, 11]. Some of the tribo-charging devices used include Propeller-type tribocharging device ,vibrating feeders, rotary cylinders and fluidized beds [12-17].

Several studies have been carried out on triboelectrostatic separators of different electrode configurations but are always limited to millimetre granular size mixtures [18-20]. The free-fall electrostatic separator with two plane electrodes is one of the most widely used installations in the electrostatic sorting of granular millimetre mixtures [21, 22]. However, the process of separation of large particles is less efficient because the gravitational force exerted on the particles is stronger and causes problems in which the electrostatic force that attracts the particles is weaker and therefore the separation process fails.

The application of electrostatic separation of big particles in the industry is more economical but requires more developed installations.

The objective of this article is the realization and experimental analysis of a new configuration of the electrostatic separator. A parallelepipedal, closed and inclined shape through which the particles slide. This new inclined plane configuration has the particularity to separate big size particles and to give the particles a good trajectory for a better separation Cross Type

II. DESCRIPTION OF THE EXPERIMENTAL INSTALLATION

The installation realized in this study is a new generation of the classical free-fall separator designed for the separation of a mixture of big size particles. The installation includes in its design a PMMA enclosure (parallelepiped enclosure) attached to an insulating support, having two movable axes, which can form angles ranging from 0° to 45° from the horizontal.Tthe device consists of two aluminium electrodes (height : 450 mm; width: 150 mm) attached to plexiglass insulating plates (height : 500 mm; width : 150 mm). The distance between electrodes is adjustable from 150 mm to 200 mm. These electrodes are powered by two high voltage sources with opposite polarity. The charged binary mixture slides on the wall and separates under the influence of electrostatic, friction and gravitational forces. A collector has been used for product recovery, it consists of three compartments (length: 900 mm; width: 200 mm; depth: 100 mm) (Figs. 1 and 2).

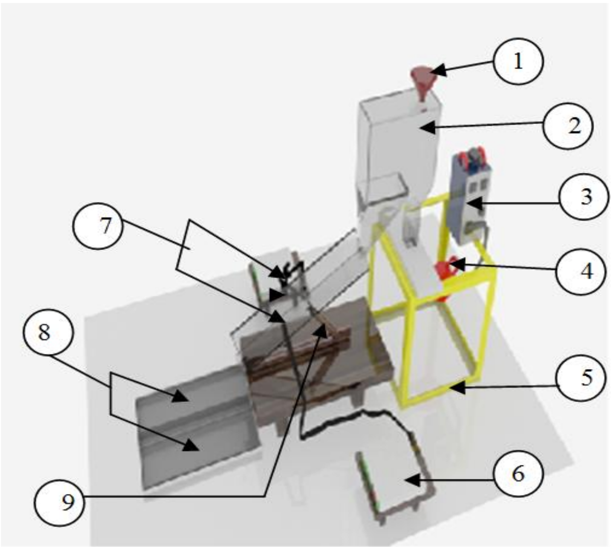

Fig. 1. Schematic representation of the inclined plane installation.

1: Funnel ; 2 : Fluidization chamber ;
3 : Adjustable generator ; 4 air Blower ; 5 : Metal support ;6 : High Voltage generators ; 7 : Electrodes ; 8 : Collection trays ; 9 : Insulating support.

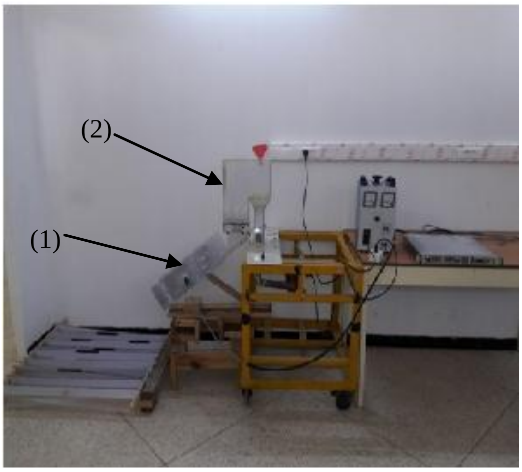

Fig. 2. Photograph of the inclined plane installation.

1: charging part ; 2: separation part.

This inclined plane installation is combined with a triboelectric charger, the latter is realized from a fluidization chamber, which consists of transparent Plexiglas walls with dimensions (150×150×130 (mm)). The use of a blower has permitted to furnish the fluidization air with a variable flow rate in the chamber, the repetitive collisions between the particles ensure their loading by opposite signs.

In the second part of the device the granules are subjected to the action of gravitational forces expressed by (1), coulombian (2) and friction with the wall expressed by (3) :

$$\vec{F}_g = m \times g \times \sin \mathrm{i} \quad (1)$$

with : F_g : Gravitational force (N).
m : Mass particle (g).
g : Gravity 9.80(N/M)
i: The angle of inclination (°).

$$\vec{F}_e = Q \times E \quad (2)$$

with : F_e: Electric field force (N)
Q : The granular particle charge (C).
E : The electric field (V/m).

$$\vec{F}_f = \vec{F}_N \times \mu \quad (3)$$

with : F_f : Force of Friction of the particle (N)
F_N : Component of the application force, normal to the contact surface (N).
μ : Coefficient of friction which depends on the nature of the surface.

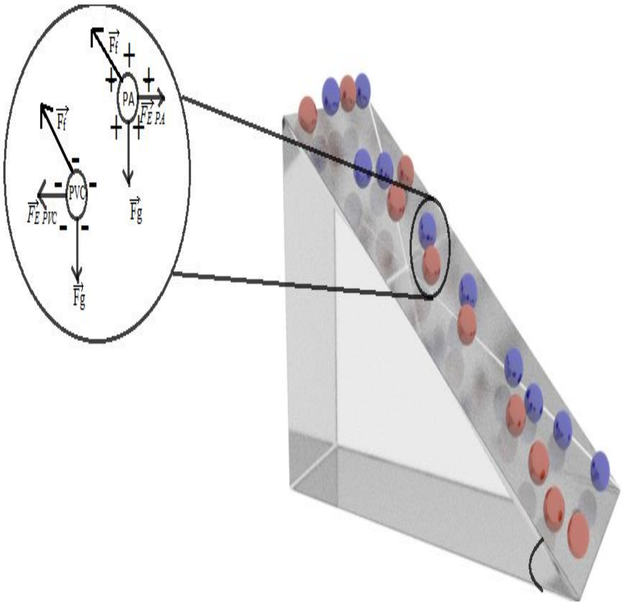

Fig. 3. Description of the forces acting on the particles in the separator.

III. MATERIALS AND METHOD

The granular particles used during the experiments are Polyamide (PA) and Acrylonitrile Butadiene Styrene (ABS) whose particle size for both materials is greater than 10 mm .

The construction of the installation allowed the adjustment of several parameters to determine the influence of each of them on the separation efficiency. After the binary mixture has been fluidized bed charged and separated by the inclined plane device (40 g for each material), its charge and mass are measured in the three separate compartments: ABS, PA and mixed.

The adjustment parameters offered by this separator are :

- The voltage applied *U* (kV).
- The distance between the two electrodes *d* (cm).
- The angle of inclination of the electrodes *i* (°).

TABLE I. Parametric study carried out

	Variation in control factors		
	***Voltage applied* (kV)**	***Distance between electrode* (cm)**	***Angle of inclination* (°)**
Test 1(U)	[5 – 25] kV	17,5 cm	30°
Test 2 (*D*)	20 kV	[15 – 20] cm	30°
Test 3 (*i*)	20 kV	20 cm	[20 – 40]°

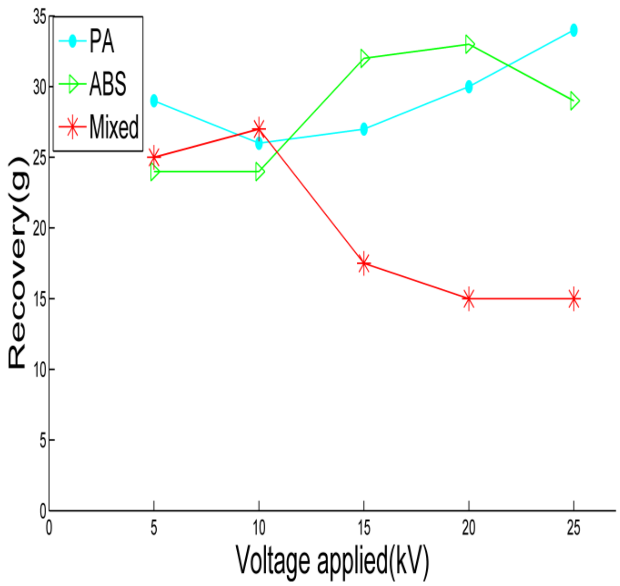

Fig. 4. Variation of the recovered mass as function of the applied voltage for PA, ABS and Mixed product.

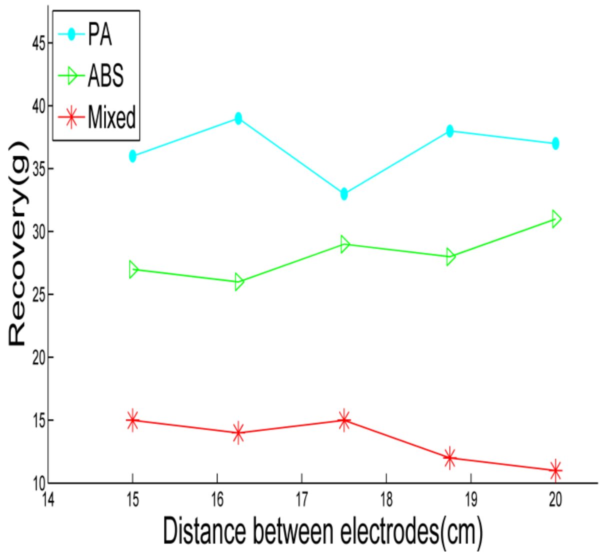

Fig. 5. Variation of the recovered mass as function of the inter-electrodes distance for PA, ABS and Mixed product.

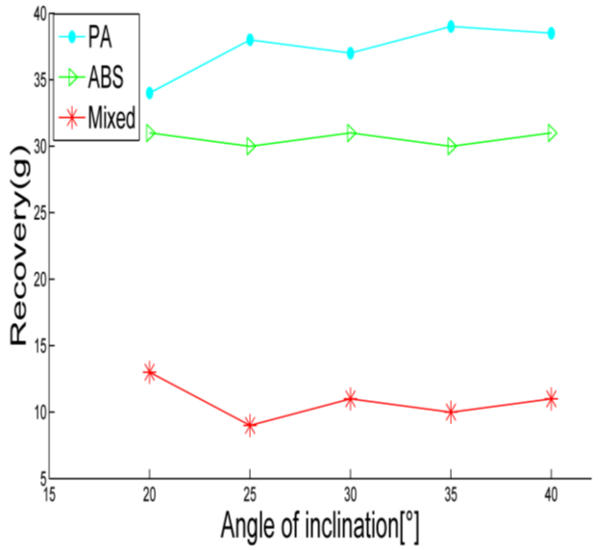

Fig 6. Variation of the recovered mass as function of the inclination angle for PA, ABS and Mixed product.

After the preliminary tests we have defined the limits of the experimental space.

TABLE II. limit of the Experimental Domain

Factors	**Min**	**Max**
U [kV]	15	25
D [cm]	16.25	20
i [°]	25	35

The other variables of the system are kept constant : the time of particle charging 1 min; the mass of the granular product m_{ABS} = 40 g, m_{PA} = 40 g the relative humidity of the air HR = 50± 2% the ambient temperature T = 20± 2°C

When the objective is the modeling and optimization of a process, the experimental design methodology [23] recommends the use of a composite factorial experimental design and the adoption of a quadratic model. We used the software mode 5.0 (Umetrics, Sweden) [22], to calculates the coefficients of the mathematical model, draws the response contours, and identifies the best adjustments of the parameters for optimizing the process. Moreover, the program calculates two statistical criteria: the goodness of fit R^2 and the goodness of prediction Q^2.

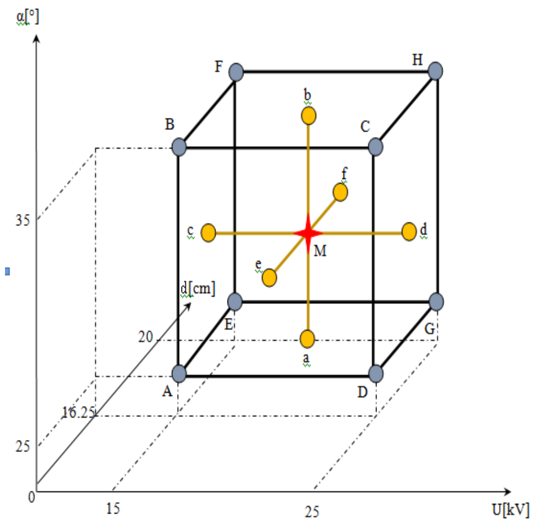

Fig. 7. Graphical representation of the 17 experimental points of the composite design.

IV. RESULTS AND DISCUSSION

The results of the 17 experiments given by the mode 5.0 software are presented in Table III.

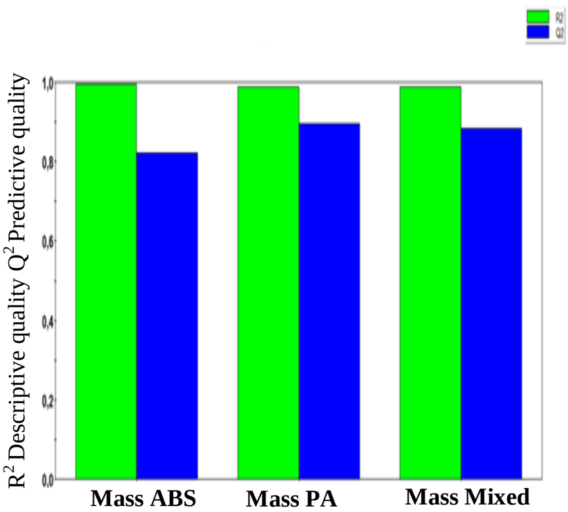

Fig. 8. Representation of the coefficients R^2 and Q^2 for the three responses.

TABLE III. Mass to recover ABS, PA and mixed products collected in the three compartments

test	U (kV)	d (cm)	I (°)	ABS (g)	PA (g)	Mixed (g)
1	15	16.25	25	36.6	40	8.7
2	25	16.25	25	33.6	36.4	10.5
3	15	20	25	41.9	36	5.2
4	25	20	25	40.1	32	3.6
5	15	16.25	35	27	35	5.9
6	25	16.25	35	30.1	35.6	11
7	15	20	35	35.6	34	5
8	25	20	35	37.8	33.8	4.6
9	15	18.125	30	33	33.3	9.3
10	25	18.125	30	34	31.8	11.4
11	20	16.25	30	38.2	31.8	9.7
12	20	20	30	36.8	30	7.9
13	20	18.125	25	35.8	34.2	9.5
14	20	18.125	35	30.8	33	9.2
15	20	18.125	30	32.6	31	11.2
16	20	18.125	30	32.4	31.2	12
17	20	18.125	30	32.3	31	11.4

Fig 8 represents the coefficients of the descriptive quality of the model: R^2, and the predictive quality of the model: Q^2 for the three responses.

The mathematical models of the responses:ABS, PA and mixed : m_{ABS} (R^2 = 99,4 %, Q^2 = 82,2 %), m_{PA} (R^2 = 98,8 %, Q^2 = 89,6 %)et m_{mixde} (R^2 = 98,8 %, Q^2 = 88,4 %), computed with MODDE 5.0, were :

$$m_{ABS} = 32.64 + 2.79\ d - 2.13i + 0.79\ Ui + 0.44\ di + 0.66\ U^2 + 0.58\ d^2 + 0.61i^2 \qquad (4)$$

$$m_{PA} = 31.1 - 0.75\ U - 1.06\ d - 0.55\ I + 0.66\ Ui + 0.47di + 0.82\ U^2 + 0.57\ d^2 + 1.3\ i^2 \qquad (5)$$

$$m_{mixte} = 11.35 + 0.54\ U - 1.83\ d - 0.71\ Ud + 0.36\ Ui - 0.85\ U^2 - 0.89\ d^2 - 1.25\ i^2 \qquad (6)$$

According to Figs 9 and 10, the inclination and distance have a great influence on the recovery of either ABS or PA masses because the increase in distance for the ABS product is proportional with the recovered mass and inversely proportional for the recovery of PA product and with regard to the inclination it is inversely proportional for the recovery of ABS or PA product, unlike the voltage which has an insignificant influence on the ABS and PA product. Compared to the mass of the mixed (Fig. 11) the most significant factor is the distance because it is inversely proportional to the mass recovered but the other factors have a small influence on the mass recovered.

The best recovery of the ABS mass is obtained by low values of inclination and high values of distance (Fig. 12). The decrease in the angle of inclination decelerates the particles in their movements due to the low gravitational force generated, which increases their stays in the area of separation. The increased distance allows ABS particles with a significant charge to avoid collision with electrodes of opposite polarity.

The best recovery of PA is obtained by low values of inclination and low values of distance (Fig. 13). The PA charge is less important, its separation requires an intense electrostatic field, this is possible by reducing the distance between . electrodes.

According to MODDE 5.0 software, the table (3) shows the mass of ABS, PA ,mixed recovered as a function of the voltage values ,distance, inclination and the overall optimum of the process presented in this table are respectively : M_{ABS} = 36.34 g, M_{PA} = 39.86 g et M_{mixte} = 6 g, correspond to the following optimal values : U = 21.99 kV, i = 28.83° et D = 18.32 cm.

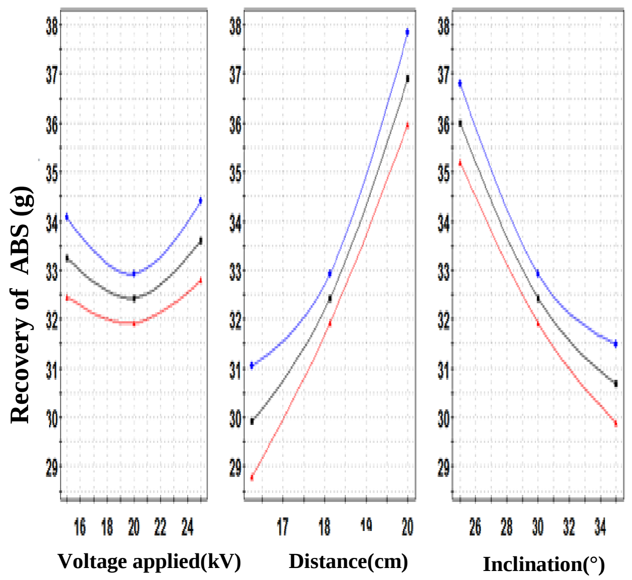

Fig. 9. Variation predicted by MODDE 5.0 software for ABS recovery [g] according to the voltage applied in [kV], distance in [cm] and angle of inclination in [°].

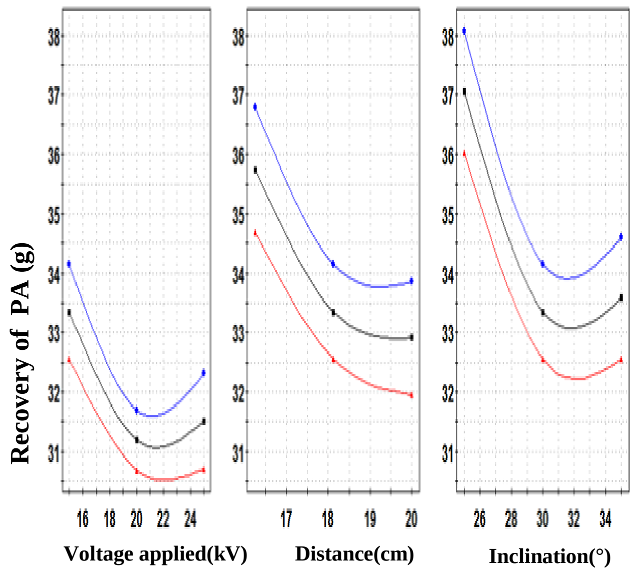

Fig 10. Variation predicted by MODDE 5.0 software for the recovery [g] of PA according to the voltage applied in [kV], the distance in [cm] and the angle of inclination in [°].

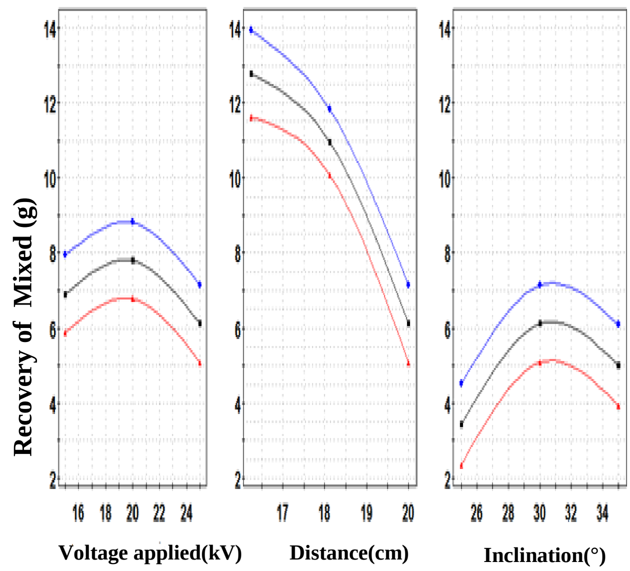

Fig 11. Variation predicted by the MODDE 5.0 software for the mass [g] of the mixed according to the voltage applied in [kV], the distance in [cm] and the angle of inclination in [°].

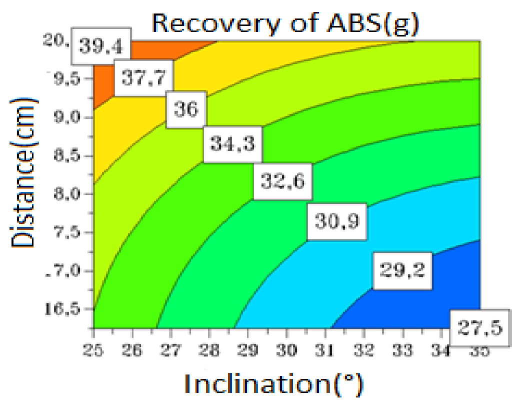

Fig. 12. Iso responses contours for ABS [g].

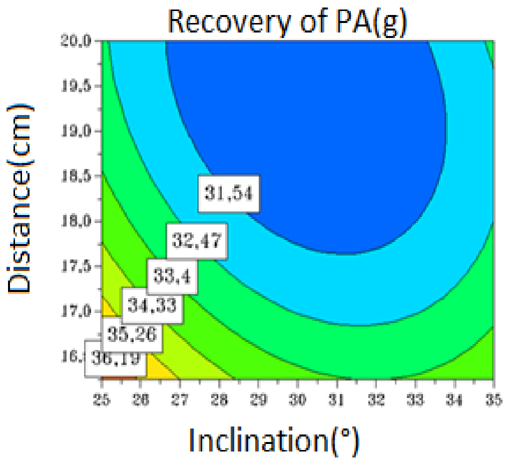

Fig. 13. Iso responses contours for PA [g].

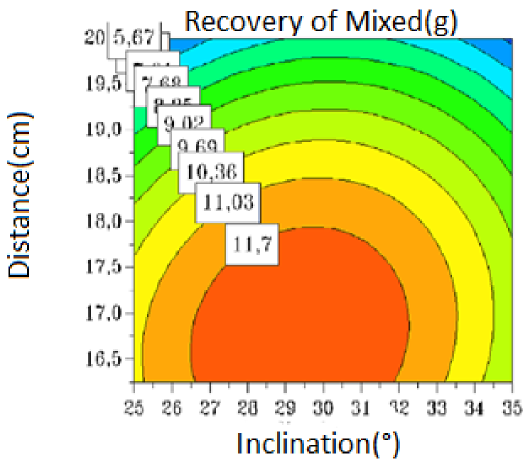

Fig. 14. Iso responses contours for mixed [g].

V. CONCLUSION

The start-up of this new configuration, which consists of a charging part and a separating part, has proven its efficiency in the selective sorting of big size binary mixtures of insulating materials.

The yield of the new inclined plane tribo-electrostatic separator is related to several controllable factors including: the voltage applied to the electrode system, the inclination of the electrodes and the distance between them. Distance and inclination have a great influence on mass recovery.

The low values of the angle of inclination allowed the gravitational force to be reduced and consequently the separation yield to be increased.

The experimental study using the experimental design method allowed us to model and optimize the separation process. This study proposed the following optimal values of the factors: U = 21.99 kV, i= 28.83° and D = 18.32 cm.

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