Experimental Comparative Study of Different Tribocharging Devices for Triboelectric Separation of Insulating Particles

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Abstract -- **Several tribocharging devices are commonly used for charging insulating particles in order to separate granular plastic mixtures using vertical triboelectric separator. However, there is no comparative analyze of these devices when tribocharging is achieved in the same climatic conditions and using identical samples of insulating particles. The objective of this paper is to carry out an experimental study that compares several tribocharging devices build-up in the laboratory, which are: rotating cylinder, tribo-cyclone, static tribocharger, propeller-type and the fluidized bed. The study was performed using two granular samples of PVC and PEHD, having two different particle sizes of 1 mm and 2 mm. Experimental results showed that when tribo-charging pure samples of either PVC or PEHD tribo-cyclone is the most efficient. However, when mixed samples are processed the fluidized bed device gives best results of electric charge and separation efficiency.**

Index Terms-- **Tribocharging device, triboelectric separator, triboelectric charge.**

I. INTRODUCTION

Whenever two materials of different nature are subjected to either a simple contact or a friction test, electrical charges are generated and exchanged between them. This phenomenon has been known as the triboelectricity [1-4]. Triboelectricity is attributed to the electron transfer from one body to another [5-8]. However, in some specific cases (especially involving polymers), it's shown that the triboelectric charge created on the surfaces of particles may be the result of a ions transfer [9] or mass transfer [10]. In some systems, the three mechanisms of charge transfer can occur simultaneously [7].

The electrostatic separation methods such as corona discharge and electrostatic induction can separate mixtures of metals/insulators, whereas the triboelectrostatic method is specific for separating various mixtures of insulator/insulator particles [11-13]. Industrial applications of triboelectrostatic separation are numerous. The most important are the treatment of ash from coal power plants [14-17] and separation of granular plastic mixtures in the recycling [18-19].

In triboelectrostatic separation, the charged particles separate through an electric field by the particle–particle and particle–surface charging mechanisms. The charging method and charge density (nC/g) of the plastics have been reported by various researches. Many studies have been performed to analyze performance of triboelectric separators for sorting different types of insulating particles. There are currently several methods of triboelectric charging using rotating tubes [20-22], fluidized beds [23-28], a vibrating feeder [29-30], tribo-cyclones [31-32], fans [33-34], static charger, a honeycomb and a spiral tube charger. Many studies have been published on the subject. The objective of this paper is to perform a comparative experimental study of five tribocharging devices that are rotating cylinder, tribo-cyclone, static tribo-charger, propeller-type and the fluidized bed.

II. MATERIAL AND METHODS

The five tribocharging devices which are subject to a comparative study are described below:

a) Tribo-cyclone: a facility used for dust control in workshops has been modified to be used as triboelectric charging device (Figure 1). The particles to be tribo-charged are "blown" by the fan inside the cyclone, the inner wall being covered by a PVC layer, where they undergo continuous rubbing against the inner wall. In this case, the charge acquisition occurs upon contact of particles with the wall.

b) Fluidized bed: this process is the one most commonly used for the acquisition of triboelectric charge. The mixture of particles which is deposited on a sieve support is then brought into agitation by blowing air using a fan (Figure 2). The particles which are thus set in agitation in a fluidized bed acquire electrical charges of opposite signs due to collisions between them. In this case there is little charge acquired by collisions with the wall of the device.

c) Static Charger: plastic particles fall in vertical drop and slide into this device by gravity along the sloping Plexiglas walls, each one being inclined with an angle of 60° (Figure 3). The acquisition charge occurs as a result of "friction contact" between the granules and the walls.

d) Rotating tube: the particles of the granular mixture are introduced into an inclined PVC rotating tube, of 100 cm length and 10 cm in diameter, where they undergo many collisions of particle-particle and particle-wall types (figure 4). At the exit of the rotating tube, the granules of the mixed product acquire electric charges of opposite signs.

e) Propeller-type: The device consisted in a cylindrical chamber (diameter: 100 mm; length: 350 mm), made of Polyvinyl Chloride (PVC) (figure 5). At its lower end, the chamber is provided with a coaxial propeller, driven by a DC electric motor. This device entrains the granular materials into a helical motion that is expected to favor their triboelectric charging by granule-to-propeller, granule-to-cylinder wall, and granule-to-granule collisions. The sign and the magnitude of the charge of each granule are determined by the combined action of these three physical mechanisms.

The experimental study was performed using PVC and HDPE samples of two different average particle size (1 and 2 mm) as shown in figure 6.

In a first set of experiments, the estimation of the charge was carried out using pure samples containing 100 % PVC or 100% HDPE. The electric charge was measured using a sensitive electrometer (Keithley 6514) and a Faraday pail. The results were expressed in terms of the charge/mass ratio (nC/g).

The second set of experiments was performed with the free-fall separator, using mixed samples comprising 50 % of PVC and 50% of HDPE particles, for an applied voltage of ±35 kV. A schematic representation of the process in shown in figure7; the vertical plate electrodes (110 x 40 cm) were connected to two DC high voltage power supplies of opposite polarities (ISEG, 60 kV, 6 mA). After each separation experiment, triboelectric charge and separation efficiency were estimated.

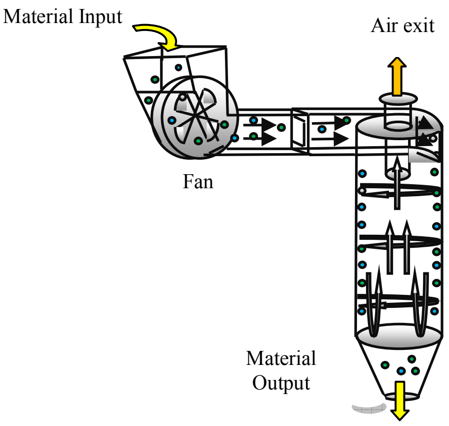

Fig. 1. Schematic representation of the tribo-cyclone tribocharger

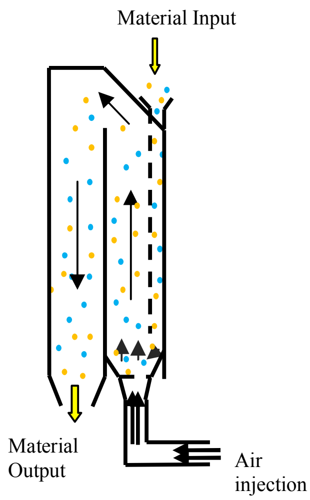

Fig. 2. Schematic representation of the fluidized bed

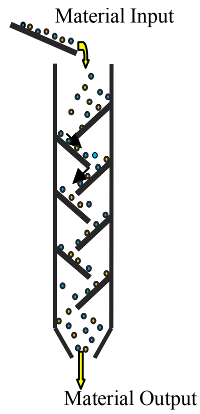

Fig. 3. Schematic representation of the static tribocharger

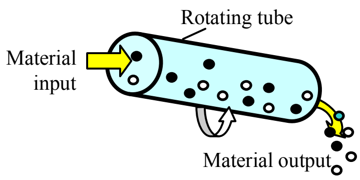

Fig. 4. Schematic representation of the rotating tube tribocharger

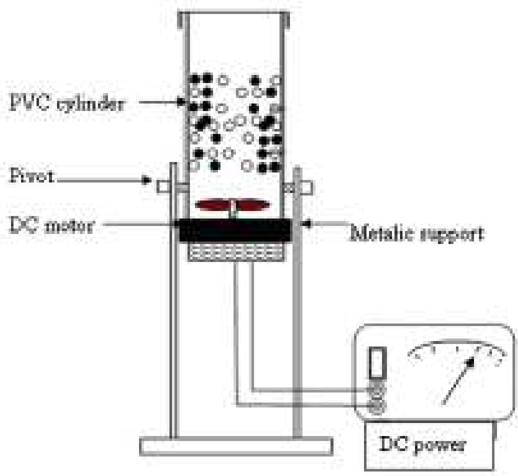

Fig. 5. Schematic representation of the propeller-type device

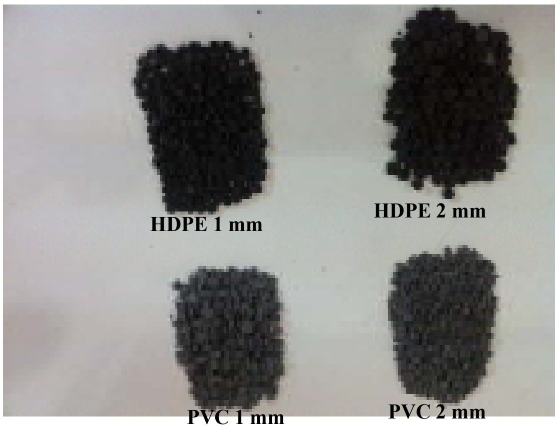

Fig. 6. Shape and size of PVC and HDPE particles

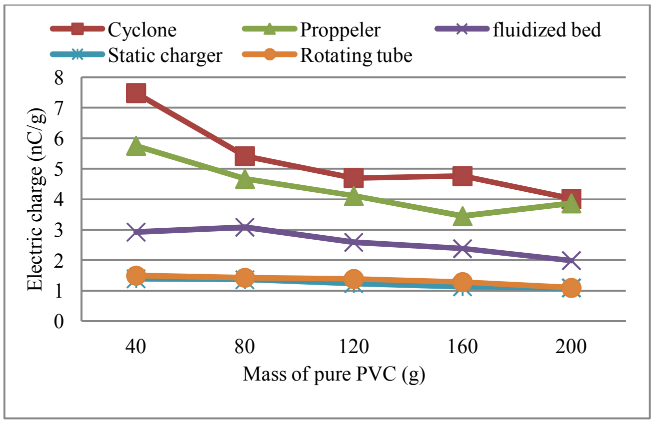

Fig. 8. Charge/mass of pure PVC particles using the different tribocharging devices

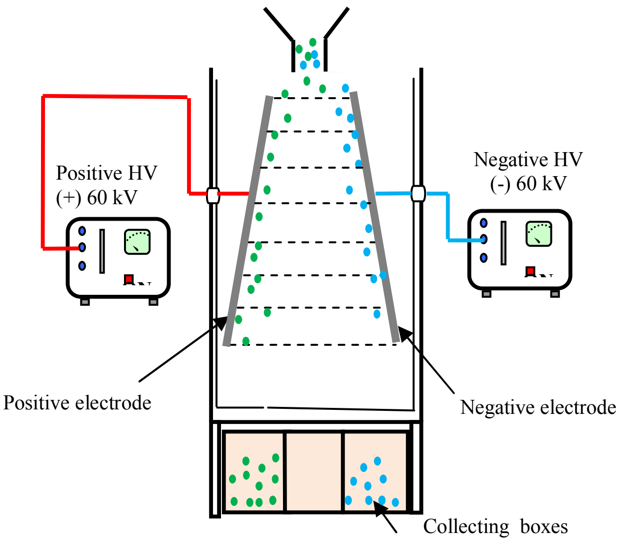

Fig. 7. Descriptive schematic of the free fall triboelectric separator

III. Results and Discussion

A. Ttriboelectric charge of pure samples

The results of the tribocharging experiments of pure PVC samples (granule size: 1 mm) are shown in figure 8. The charge/mass ratio decreases with the mass before stabilizing at a certain amount.

These experimental data show that the tribo-cyclone and the propeller are the two most effective charging devices, the charge/mass ratio attaining more than 7 nC/g for the former and getting close to 6 nC/g for the latter. The explanation is simple: the rubbing of the granules with the inside wall of the cyclone and the propeller is more energetic than in the other devices.

B. Triboelectric charge of mixed samples

The results of triboelectric charging of mixed samples are shown in figures 9 and 10. In all experiments, PVC granules acquire negative charge while HDPE granules acquire positive charge. There is no significant difference between the charge levels acquired by particles of average sizes 1 or 2 mm.

In spite that tribo-cyclone is the most efficient for charging particles of pure products, when charging mixed samples small amounts of electric charge were obtained. The dominant particle-wall type collisions occurring in the cyclone device charge similarly the two constituents of the mixture. In the fluidized bed device, the particle-to-particle collisions are largely predominant and give opposite charges to the granules. In the case of rotating tube and propeller systems both types of collisions occur, making the acquisition of charge less efficient but significantly better than the static charger and cyclone devices.

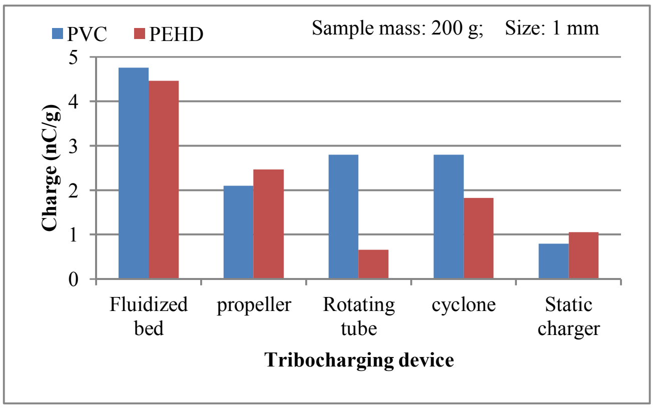

Fig. 9. Charge/mass of particles obtained after separation of PVC/HDPE mixed sample of size 1 mm, using the different tribocharging devices.

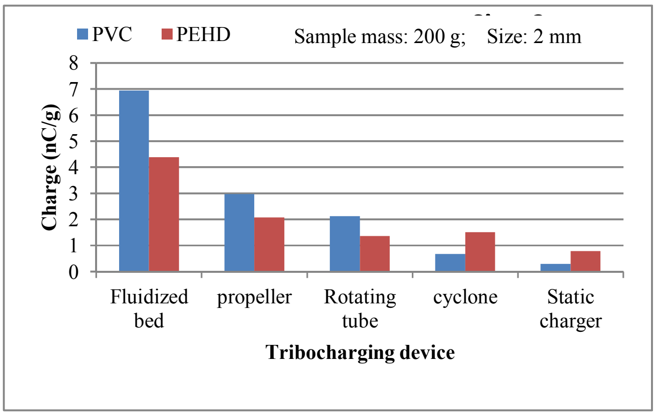

Fig. 10. Charge/mass of particles obtained after separation of PVC/HDPE mixed sample of size 2 mm, using the different tribocharging devices

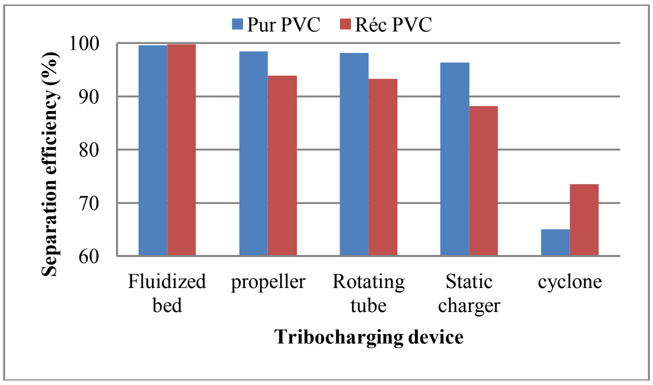

Fig. 11. Separation efficiency of triboelectric separation of a 200 g sample mass (50% PVC and 50% HDPE) using the different tribocharging devices. U= ± 35 kV

Obtained results of separation efficiency using a sample of 50% PVC and 50% HDPE particles, of granulometric size 1 mm, are represented in figure 11. The purity (Pur in %) is computed as the ratio between the mass of HDPE (or PVC) in its compartment on the total mass (HDPE + PVC) recovered in the same compartment. The recovery (Rec in %) is computed as the ratio between the recovered mass of HDPE (or PVC) in its compartment on the total mass of HDPE (or PVC) introduced in the separator.

It follows from above results that the tribo-cyclone device, whose inner wall has been covered with a PVC layer, is not recommended to use for tribo-electrostatic separation. One possibility would be to cover the inner wall with a material that is situated in the triboelectric series between the two plastics to be separated. The same comments are valid for the static tribocharger, for which also there are no collisions of particle-to-particle type, but separation efficiency is better than the tribo-cyclone because the walls are in Plexiglas. Indeed, the static charger was first build-up with PVC walls, results obtained with it were worse than those obtained with the tribo-cyclone. By comparing the three other devices, we note that the separation efficiency is substantially identical and imuch better compared with the previous two. However, the fluidized bed device is slightly more efficient compared to the propeller and rotating tube tribochargers.

IV. Conclusion

Triboelectrostatic separation is considered as an effective way for sorting different plastics in the recycling industry. The comparative study of five tribocharging devices shows that, for the granules of particle sizes comprised in the range of 1 to 2 mm (the sizes obtained after crushing of the plastic to be recycled):

a) The charge acquisition of granular mixtures for the triboelectrostatic separation is mainly a result of contacts between particles.

b) The tribo-cyclone device is more efficient in the case of pure granular products comprising a single type of material, due to energetic friction of the granules with the inner wall. Nevertheless, this system is much less effective for charging granular mixtures for triboelectric separation. The same is for the static charger.

c) Among the studied devices, the fluidized bed is the most effective for tribocharging mixtures of particles. The contribution of triboelectric charging by contact between particles is prevaling.

d) Devices using a rotary tube or a propeller are also effective for the charging of particle mixtures.

References

[1] W. R. Harper, *Contact and Frictional Electrification*, London: Oxford University Press, 1967.

[2] J. Lowell, "Contact electrification of metals," *J. Phys. D: Appl. Phys*, vol. 8, p. 53-63, 1975.

[3] L. B. Loeb, *Static Electrification*, Springer, Berlin, 1958.

[4] D. K. Davies, "Charge generation on dielectric surfaces," *J. Phys. D: Appl. Phys*., vol. 2 , p 1533-1537, 1969.

[5] E. G. Kelly, and D. J .Spottiswood, "The theory of electrostatic separation: a review," part II. *Particle Charging. Miner Eng*, vol. 2, p. 193-205, 1989.

[6] C. Pounder, "The Quest for a Charging Mechanism to the End of the 19th Century," *J. Electrostatics,* vol. 3, p. 389-394, 1977.

[7] G. S. P. Castle, "Contact Charging Between Insulators," *J. Electrostatics,* vol. 40-41, p. 13-20. (1997)

[8] S. Mazuda, M. Toragushi, T. Takahashi, and K. Haga, "Electrostatic beneficiation of coal, using a cyclone-tribocharger," *IEEE Trans.Ind. Appl*., vol. 19, p. 789-793, 1983.

[9] A. M. Gaudin, "The Principles of Electrical Processing with Particular Application to Electrostatic Separation" *Miner. Sci. Engng*., 3, 46-57. (1971)

[10] W. R. Salanek, A. Paton, and D. T. Clark, "Double mass transfer during polymer-polymer contacts," *J. Appl. Phys*., vol. 47, p. 144-147. 1976.

[11] E. G. Kelly, and D. J. Spottiswood, "The theory of electrostatic separations: a review," part I. Fundamentals, *Miner Eng*, vol. 2 p. 33–46, 1989.

[12] A. Tilmatine, S. Bendimerad, M. Younes, and L. Dascalescu, "Experimental analysis an d optimisation of a free-fall triboelectric separator of granular plastic particles," *International Journal of Sustainable Engineering*, Vol. 2, No. 3, p.p. 184–191, Sep. 2009.

[13] A. Tilmatine,S. Bendimered, F. Boukhoulda, K. Medles, and L. Dascalescu, "Electrostatic separators of particles. Application to plastic/metal, metal/metal and plastic/plastic mixtures," *Waste management*, Elsevier, 29, p.p. 228–232, 2009.

[14] P. Carbini, M. Carta, R. Ciccu, C. Del Fa, M. Ghiani, and G. Rossi, "Beneficiation methods for coal desulphurization," *64th Proc. CIC Coal Symp*, 1982.

[15] D. Gidaspow, D.T. Wasan, S. Saxena, Y.T. Shih, R. Gupta and A. Mukherjee, "Electrostatic Desulfurization of Coal in Fluidized Beds and Conveyers," *AIChE Symposium* (Series no.255), 83, 74-85. (1987).

[16] D. H. Finseth, T. Newby and R. Elstrodt, "Dry Electrostatic Separation of Fine Coal," *5th Int. Conf. Proc. and Util. of High Sulfur Coals*. Amsterdam: Elsevier Science Publishers. (1993).

[17] I. I. Inculet, R.M. Quigley, M. A. Bergougnou, J. D. Brown, and D. K. Faurschou,. "Electrostatic beneficiation of hat creek coal in the fluidized state," Canadian Inst. Mining and Metallurgy Bulletin, vol. 73, p. 51-61. (1980)

[18] V. Gente, F.L. Marca, F. Lucci and P. Massacci, "Electrical separation of plastics coming from special waste," *Waste Manag* 23, 951–958, 2003.

[19] R. D. Pascoe and B. O. Connell, "Development of a method for separation of PVC and PET using flame treatment and flotation," *Miner Eng*, vol. 16, p. 1205–1212, 2003.

[20] I.I. Inculet, G.S.P. Castle and J.D. Brown, "Electrostatic separation of plastics for recycling," Part Sci Technol, p.p. 1691–100, 1998.

[21] Y. Wu, G.S.P. Castle and I.I. Inculet, "Particle size analysis in the study of induction charging of granular materials," *J Electrost* 63, p.p. 189–202, 2005.

[22] A. Tilmatine, K. Medles, M. Younes, A. Bendaoud and L. Dascalescu, "Roll-type versus free-fall electrostatic separation of tribocharged plastic particles," IEEE/IAS Industry. Application Society. Volume 46, Issue: 4, pp: 1564 – 1569. 2010.

[23] M .Bilici, L. Dascalescu, C. Dragan, O. Fati, A. Iuga and A. Samuila, "Tribocharging and electrostatic separation of mixed granular solids in fluidized bed devices," *IEEE Trans. DEI*, vol. 18, p. 1476-1483, 2011.

[24] L. Calin, A. Mihalcioiu, A. Iuga and L. Dascalescu, "Fluidized bed device for plastic granules triboelectrification," *Part. Sci .& Technol*., vol. 25, p. 205-211, 2007.

[25] L .Calin L. Caliap, V. Neamtu , R. Morar, A. Iuga, A. Samuila, and L. Dascalescu, , "Tribocharging of granular plastic mixtures in view of electrostatic separation," *IEEE Trans. Ind. Appl*., vol. 44, p. 1045-1051, 2008.

[26] C. Dragan,O. Fati, M. Radu, L. Calin, A. Samuila, and L. Dascalescu, "Tribocharging of mixed granular plastics in a fluidized bed device," *IEEE Trans. Ind. Appl*., vol. 47, p. 1922 – 1928, 2011,

[27] F.S. Ali, I.I. Inculet and A. Tedoldi, "Charging of polymer powder inside a metallic fluidized bed," *J Electrost* 45, p.p. 199–211, 1999.

[28] A. Iuga, and al., "Tribocharging of plastics granulates in a fluidized bed device," *J Electrost* 63, p.p. 937–942, 2005.

[29] R. McCown, and F.B. Gross," Medium velocity impact triboelectrification experiments with JSC Mars-1 regolith stimulant, " *J Electrostat* 64, p.p. 187–193, 2006.

[30] Y. Higashiyama, Y. Ujiie, and K. Asano, "Triboelectrification of plastic particles on a vibrating feeder laminated with a plastic film," *J Electrostat* 42, p.p. 63–68, 1997.

[31] M.J. Pearse, and T.J. Hickey, "The separation of mixed plastics using a dry triboelectric technique," *Resour Conserv Recy* 3, p.p. 179–190, 1978.

[32] D.K. Yanar and B.A. Kwetkus, "Electrostatic separation of polymer powders," *J Electrostat* 35, p.p. 257–266, 1995.

[33] M. Miloudi, K. Medles, A. Tilmatine, M. Brahami and L .Dascalescu. "Optimisation of belt-type electrostatic separation of granular plastic mixtures tribocharged in a propeller-type device," Journal of Physics: Conference Series Volume 301 Number 1, 2011. 14 Apr 2011 – Electrostatics 2011 - 13th International Conference on Electrostatics in Bangor, UK at Bangor University.

[34] M. Miloudi, K. Medles, A. Tilmatine, M. Brahami and L. Dascalescu. "Modeling and Optimization of a Propeller-type Tribocharger for Granular Materials," *J. Electrostat.,* vol. 69, p.p. 631-637, 2011.