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Experimental Investigation on Granular Insulator Charging

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Abstract. The paper investigates the electrostatic charging of the polypropylene granules using a double-wire corona discharge electrode configuration to analyze the impact of various parameters on the surface potential of insulating polypropylene granules. Various geometric parameters including the inter-wire spacing, applied voltage, charging height, and loading speed are examined. The uniformity and amplitude of the potential profile resulting from an inter-wire spacing of 80 mm, height of 20 mm, and low conveyor speed permit maximize the charging efficiency of the granular insulating materials.

Keywords: Corona discharge, electrostatic separation, polypropylene, surface potential, wire-to-plane electrode.

Eksperimentalna raziskava o nalaganju naboja v zrnatih izolatorjih

Prispevek obravnava elektrostatično nalaganje naboja na polipropilenske granule z uporabo dvožične elektrode s koronskim izpustom. Analizirali smo vpliv različnih geometrijskih parametrov na površinski potencial izolacijskih polipropilenskih granul: razmik med žicama, napetost, višino polnjenja in hitrost nalaganja. Enakomernost in velikost potencialnega profila, dosežena pri razmiku med žicama 80 mm, višini 20 mm in nizki hitrosti transportnega traku, omogočata največjo učinkovitost nalaganja naboja na zrnate izolacijske materiale.

1 INTRODUCTION

The corona discharge is an electric phenomenon which plays a crucial role in various fields of application. It is particularly common in high-voltage power lines, where the electric field is extremely high near the conductors [1, 2], importing the characteristics of the air around the conductive wire. This distinctive characteristic expands its range of applications to the air and gas treatment [3], ozone generation [4, 5], and electrostatic air filtration [6]. In addition, it enables the generation of ions and free radicals which accelerate complex chemical reactions [7]. It also allows for the treatment of material surfaces by enhancing the adhesion of inks, paints, and adhesives on substrates, such as plastic films or textiles [8, 9], eliminating the need for harsh chemical products. The corona discharge has another major application in electrostatic separation [10–13], where it facilitates the sorting of materials based on their electric properties, with a significant impact on recycling and mining operations [14].

The performance of the corona discharge relies on specific electrode configurations, such as point-plane, wire-plane, or plane-plane electrodes, which directly affects the nature and distribution of the discharges. In [15–19] extensive experimental research was conducted to characterize these configurations with the aim of improving the efficiency of the corona discharge [20–22]. [23, 24] increase the intensity of the current generated by the corona electrodes frequently utilized in practical applications such as the charging of insulating particles. [25, 26] analyze the current density on the surface of the plane electrode to optimize the overall performance. In [27], simple and cost-effective wire-plane electrodes are used out for their easy maintenance and low cost . In recent studies [28], one or more wires are added to these electrodes to ensure a homogeneous coverage over large surfaces, and thus enhancing the charging efficiency of polymer films. In [29], the impact of certain parameters is shown, such as the electrode geometry, distance between them, and operating states, on the charging efficiency of these films. However, the current research in the application of these configurations and parameters to granules, particularly in electrostatic separation processes, is limited and calls for a further investigation to meet the needs. The objective of our work is to investigate the effect the corona discharge

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produced by a new double wire electrode configuration on a non-uniform and non-homogeneous surface. The polypropylene (PP) granules are used in a corona discharge electrostatic belt separator [23]. This material is highly recommended in the research and industry, notably in the manufacture of electric cables, fibers and films. It represents between 35% and 40 % of the world's injection molding production [30–35]. Due to its low electric conductivity, less than 10^{-12} S/m, it remains a challenge in the electrostatic separation process, specifically in the triboelectric separation process, where it is more difficult to acquire a charge compared to other insulators, such as polystyrene (PS) [36].

To optimize and improve the electrostatic separation process applied to the granular waste, a new two-wire electrode configuration is implemented in a corona discharge belt electrostatic separator to maximize the separation efficiency and optimize the plastics recycling techniques.

The tests allow to analyze the impact of various parameters on the surface potential profile measured on the polypropylene (PP) granules from the industrial stream of the size from 2 mm to 10 mm. The used variation parameters are:

- The distance between the electrode wires: from 40 mm to 80 mm,
- The height between the electrode and the conveyor belt : from 20 mm to 40 mm,
- The applied voltage : from 12 kV to 18 kV,
- The speed from 0.05 m/s to 0.1167 m/s.

2 Materials and methods

The measurements are made on an experimental set-up (see Figure 1) consisting of two essential parts: one to load the material and the other to measure the surface potential profile of the granules.

The wire-plane electrode is powered by a high-voltage DC source of a positive polarity. The wires are made of tungsten of a diameter of 0.35 mm and a length of 300 mm attached to rigid supports. The electrode design allows the variation of both the inter-wire spacing and the height of the wire relative to the plane. The wires are initially positioned at a height of 20 mm from the plane. After exposing PP granules to an ionic shower, an electrostatic probe positioned at 3 mm above the granules measures their surface potential which is then converted into analogical signals and transferred to a computer for processing and analysis using an acquisition card. The experiments are realized at an ambient air, with the relative humidity ranging from 50% to 68% and the temperature varying between 20°C and 25°C.

3 Results and discussion

To evaluate the performance of the proposed configuration, two analyses are conducted.

3.1 Analysis of the current-voltage characteristic

3.1.1 The impact of the number of the wires : Two experiments are made on the electrode configuration: one with a single wire and the other with two wires spaced 80 mm apart. Figure 2 shows the voltage-current characteristic of both configurations. The results show that the current generated by the double-wire configuration is higher at the same voltage applied to both configurations. The increase is likely due to a better electric field distribution and higher charge emission efficiency.

3.1.2 The impact of the inter-wire distance: The double wire configuration having been previously proven, the impact is now analysed of changing the distance between the wires, i.e. 40 mm, 60 mm and 80 mm, on the current-voltage characteristic.

The results given in Figure 3 show that the increase in the inter-wire distance significantly affects the current generated. Using an inter-wire distance of 40 mm limits the current due to the shielding effect [21], where the electric fields of adjacent wires interfere with each other and limit the intensity.

By increasing the distance to 50%, the current generated increases, with the same result obtained at a doubled distance probably because the wires no longer interfere with each other and each of them behaves as an independent electric field generator, similar to that of a single wire.

3.1.3 The impact of the loading height (wire-plane distance): Figure 4 shows the current-voltage characteristics obtained at different heights between the wires and the plane, i.e. 20, 30 and 40 mm. The non-linearity of the curves shows that a rapid increase in current is obtained with the application of high voltages, reflecting the intensification of the corona effect when the voltage exceeds a certain level related to the dielectric strength of the air. Also, the voltage margins applied are no longer the same for the entire range of the heights studied. A comparison of the three characteristics shows that the current is inversely proportional to the height of the same applied voltage, this is likely due to the reduction in the electric field intensity as the distance between the wires and the plane increases. It should be noted that maintaining a small distance between the wire and the plane ensures a more efficient ionization.

3.2 Analysis of the surface potential profile on the polypropylene granules

An analysis of the potential profile measured on the surface of PP granules:

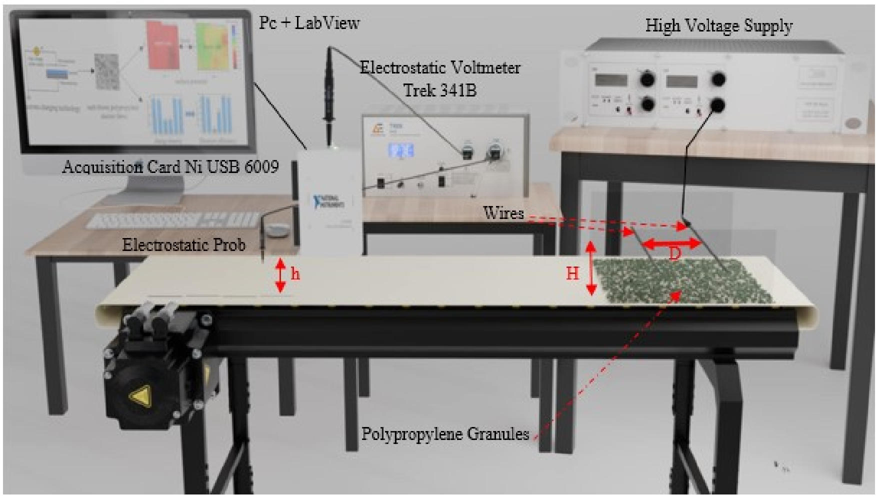

Figure 1. Experimental measurement setup.

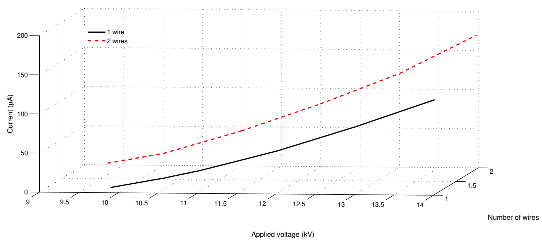

Figure 2. Impact of the number of the wires on the current-voltage characteristic.

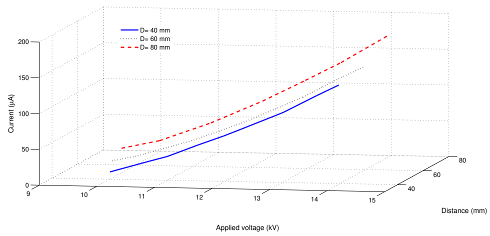

Figure 3. Impact of the distance between wires on the current-voltage characteristic.

3.2.1 The impact of the number of the wires: The impact of the wires number on the surface potential of the granules for a distance of 12 cm (-6 ;+6) is analysed. The surface is exposed to an electrode with a single wire and two wires spaced 80 mm from each other, at a voltage of 15 kV and a displacement speed of 0.0833 m/s. The potential profiles are shown in Figure 5.

In terms of the maximum potential, the double wire configuration offers a higher potential than the single-wire configuration. In the spatial analysis, the potential remains relatively stable for the two-wire configuration, with a decrease at the ends (˜± 6 cm) in comparison with the single-wire configuration.

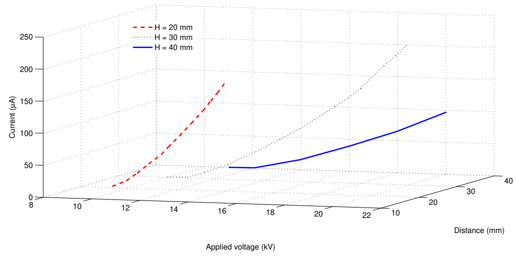

Figure 4. Impact of the distance between the electrode and plane 'H' on the current-voltage characteristic.

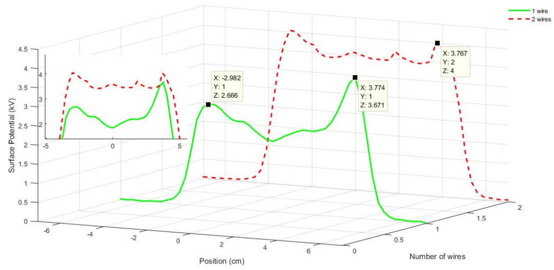

Figure 5. Impact of the number of the wires on the surface potential distribution of the polypropylene granules.

To assess the uniformity, the standard deviation (σ) is calculated using the formula developed by Karl Pearson in 1894 [37].

$$\sigma = \sqrt{\frac{1}{N}\sum(x_i - \bar{x})^2} \quad (1)$$

where: x_i is each individual value of the measured surface potential; $\bar{x}$ is the average of all these values and N is the total number of the measurements taken.

Applying 1 to the voltage profile shows that the two-wire configuration is more stable, with a standard deviation of 0.28 kV against 0.69 kV for the one-wire configuration, confirming a more uniform surface potential distribution maximizing the charging efficiency. The histogram in Figure 6 explains the difference and shows that the two-wire configuration guarantees a better electric field coverage and a more stable potential.

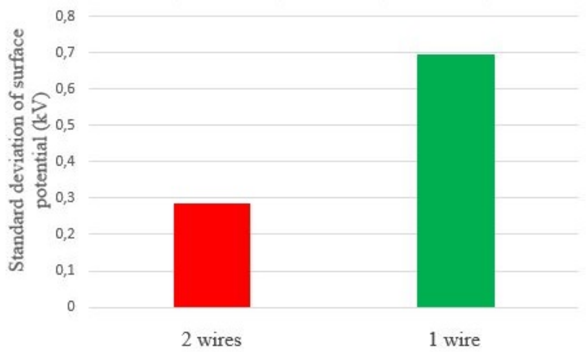

Figure 6. Histogram of the surface potential standard deviation for the two studied configurations.

3.2.2 Impact of the charging voltage: Based on our findings the double-wire configuration is used for our next tests. The impact of the applied voltage is analysed. The high-voltage DC generator is then set to 12, 15 and 18 kV DC, with the displacement speed maintained at 0.0833 m/s. Figure 7 shows the recorded voltage profiles. The curves display that the voltage significantly affects the distribution of the surface potentials which is rising from 3 kV to 4.9 kV obtained at the applied voltages of 12 and 18 kV respectively, an increase of 38%.

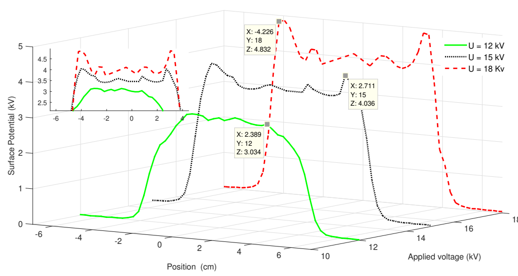

Figure 7. Influence of the discharge voltage on the surface potential distribution of polypropylene granules.

3.2.3 The impact of the inter-wire distance: Figure 8 shows the impact of inter-wire distance D (40 mm, 60 mm, 80 mm) on the surface potential distribution of the PP granules dynamically charged at a speed of 0.0833 m/s. To avoid the shielding effect, a voltage of 12 kV is used for the tests. The results show that the increase in wire spacing D significantly increases the surface potential. For D = 80 mm it is around 3 kV. For D = 40 mm, the potential drops to 2.1 kV, indicating a 40% decrease in the loading efficiency. Therefore, ensuring a more efficient loading of the granules, a wider spacing is recommended, so that the electric fields generated by each wire interfere less with each other.

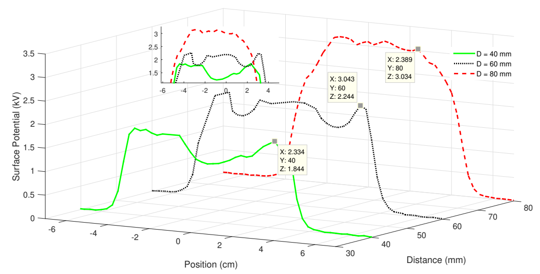

Figure 8. Impact of wire spacing D on the surface potential distribution of polypropylene granules.

It is worth noting that the spatial distribution shows a relative uniformity of the potential in the central region (from -4 cm to +4 cm) for any spacing. However, for D = 80 mm configuration it maintains higher potential values and a more homogeneous distribution. At the extremities (approx. $\pm$ 6 cm), the potential decreases rapidly, indicating a reduction in the electric field efficiency away from center.

3.2.4 Impact of the distance between the electrode and the plane: The impact is studied for distance between the wire electrode and the plane, i.e. 20 mm, 30 mm and 40 mm, on the surface potential distributions of dynamically charged PP granules. The results are given in Figure 9.

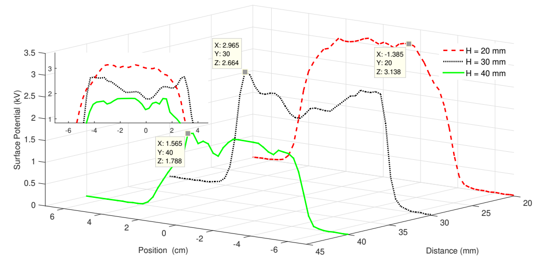

Figure 9. Surface potential distribution on the polypropylene granules dynamically charged by varying wire-to-plane spacing 'H'.

The measured surface potential profile is inversely proportional to the distance between the electrode and the plane. It is from 3 kV obtained of the height of 20 mm, to 13 and 40% of the heights 30 and 40 mm respectively, reflecting a reduced efficiency of the electric field at high distances. Thus the spatial distribution is similar to the one in previous tests.

3.2.5 Impact of the conveyor belt speed: Figure 10 shows the distribution of the surface potential on the

PP granules as function of the conveyor belt speed (v) for three values: 0.05 m/s , 0.0833 m/s and 0.01167 m **0.0833 m/s** at an 18 kV applied voltage, a wire-to-wire distance of 80 mm, and a 20 mm wire-to-plane height.

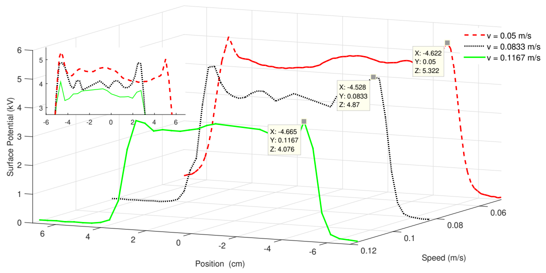

Figure 10. Impact of conveyor belt speed v on the surface potential distribution of the polypropylene granules.

It is shown that at a speed of 0.05 m/s, the surface potential is not only higher some 5.3 kV in the central zone, but also covers a wider area than at higher speeds. At this speed, the granules benefit from a longer exposure time to the electric field, enabling a better charge accumulation over a larger portion of the surface. On the other hand, for higher speeds (0.0833 m/s and 0.1167 m/s), the potential is slightly lower (around 4.8 kV and 4 kV respectively), representing a decrease in the maximum value (10% between each speed variation) and in the potential uniformity zone.

4 Conclusion

The paper investigates the impact of the electrogeometric parameters on charging the PP granules with a positive DC voltage corona discharge. The characteristics used to identify the impact of the studied parameters are the voltage-current characteristic and the surface potential profile measured during a series of tests. The first experiment shows that using of a double-wire configuration provides a higher current and a more uniform surface potential distribution.

Also the discharge voltage significantly affects the surface potential, showing a 38% increase with a 50% increase in the applied voltage. To avoid the shielding effect, a wire spacing of 80 mm is recommended to increase the surface potential by 40%.

At a wire-to-plane distance of 20 mm, the field increase in the space increases the potential at the surface of the PP granules. Using a low conveyor speed is highly recommanded to ensure a better potential distribution. Separating the PP granules from other insulating materials using a corona discharge with a double-wire electrode is also recommended.

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