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Impact of Geometric, Electrical and Environmental Parameters on Particle Micromanipulation using Progressive Waves

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Abstrac: Particle micromanipulation using traveling waves is an essential field based on the interaction of several factors. Among the main elements that influence this technique are the geometry of the traveling wave conveyor (two-phase or three-phase), the intensity of the electric field and the environmental conditions. The aim of this study is to analyze and optimize the geometric, electrical and environmental parameters that affect particle micromanipulation using traveling waves. By gaining a deeper understanding of these parameters and their interactions, the work aims to improve the efficiency and accuracy of this technique. This includes optimizing the geometry of the support, identifying the most effective electrode design to generate a dynamic electric field that allows the particles to be moved accurately. Controlling the electric field by adjusting the multiphase voltages applied to the electrodes to create an optimal electric field suitable for various micromanipulation applications. Stabilization of environmental conditions, assessing the impact of humidity on the micromanipulation process.

Keywords :*Waste electrical and electronic equipment, Environmental conditions, traveling waves, two-phase, three-phase voltage, humidity.*

1. Introduction:

Waste electrical and electronic equipment is growing rapidly around the world and has become one of the main types of solid waste. The proper treatment and disposal of WEEE is essential for the development of a circular economy. As improper treatment of WEEE can lead to serious pollution, environmentally friendly recycling has been strongly encouraged by laws and regulations in recent years (Lu *et al*., 2018).

In the context of electronic board recycling, it can be used to separate different components or materials according to their electrical characteristics. The efficiency of the separation depends on the ability to control the triboelectric charge of the particles (Mimouni, 2024).

Travelling wave transporters or electric curtains are generally used to move micronized insulating particles (Atten *et al.* ,2009), (Duff,2013), (García-Sanchez et al. ,2006), (Kawamoto *et al.*, 2006, 2011,2015), (Masuda et al., 1987), (Yang *et al*. ,2009). They consist of parallel electrodes separated by a small gap of around 1 mm and powered by a polyphase voltage.

The resulting dielectrophoretic and Coulomb forces cause the particles to move (Biris et al ,2013), (Calle et al ,2004), (Landis *et al*., 2002), (Lean et al ,2005), (Mazumder *et al* ,2013), (Mimouni *et al*.,2017), (Tilmatine et al ,2018), (Zouaghi *et al* 2019).

Insulating particles can be transported under the effect of an electric field generated by a traveling wave carrier (COP) or a stationary wave carrier (COS). The difference between the two types of carrier lies in the number of interposed phases, which play a very important role in the electric field.

The aim of this work is to improve recycling techniques for waste electrical and electronic equipment (WEEE), the management of which has become a crucial issue on a global scale due to its environmental impact. The work has a dual theoretical and practical perspective.

From a theoretical point of view, it contributes to the advancement of knowledge in particle micromanipulation by means of progressive electric fields, a central field for the treatment of materials in the context of WEEE management. The transport

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mechanisms of insulating particles in an electric field, generated by progressive or stationary wave carriers, are being explored in depth. By optimizing the geometry of the electrodes, as well as the control of the electric field and the environmental conditions, this work provides a better understanding of the influence of the various parameters on the efficiency of particle micromanipulation.

In practical terms, the study is of direct interest to the recycling sector. In particular, in the context of separating components on electronic boards, the technique studied could offer a more precise and efficient method for handling and separating materials according to their electrical properties. This would contribute to improving recycling processes, reducing the pollution caused by the inadequate treatment of electronic waste and promoting economic efficiency.

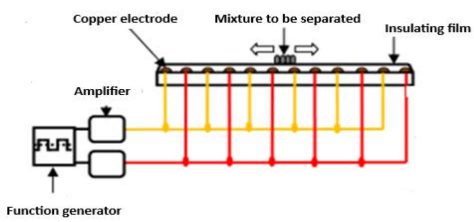
2. Equipment and method

The equipment needed for the research work carried out in this chapter on the transport of particles and their separation by progressive wave theory is:

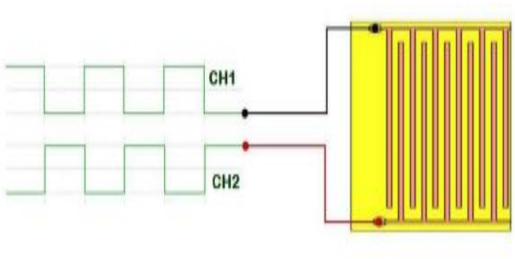
- Two function generators.
- Three high-voltage amplifiers.
- Three-phase traveling wave transporters
- BNC cables.
- 1 mg precision scale.
- Four-channel oscilloscope.
- Sieve shaker
- Ambient humidity meter
- Two conveyors, one three-phase and the other two-phase

3. Two-phase conveyor

The two-phase conveyor, on which copper electrodes 100 mm wide and 126 mm long are placed, is separated by a gap equal to 1 mm. The descriptive diagram in figure (01.a) shows the conveyor's connections to the power supply, while the signals applied to the electrodes are shown in figure (01.b).



a) Descriptive diagram of the two-stage conveyor.

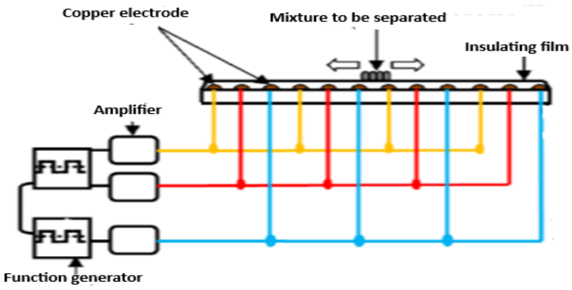


b) Shapes of the signal applied to the electrodes.

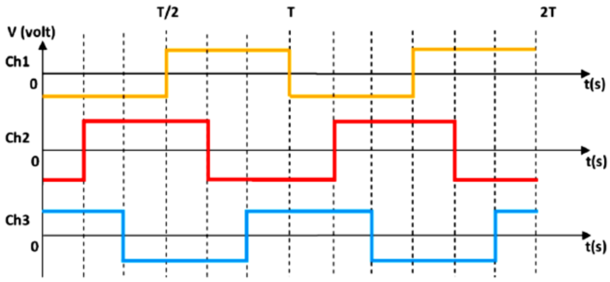
Figure (01) Descriptive diagram of a two-phase conveyor with the arrangement of the two signals applied to the electrodes.

4. Three-phase conveyor

The three-phase conveyor, on which copper electrodes 100 mm wide and 126 mm long are drawn, is separated by a gap equal to 2 mm. The descriptive diagram in Figure (02. a) shows the conveyor's connections to the power supply system, while the signals applied to the electrodes are shown in Figure (02.b).



a) Descriptive diagram of the three-phase conveyor.



b) Shapes of the signal applied to the electrodes.

Figure (02): Descriptive diagram of a three-phase conveyor with the arrangement of the three signals applied to the electrodes

5. Mistral used

The experiments were carried out with the granular mixture obtained from the electronic board of a cathode ray tube television, crushed and ground after sieving with a 1 mm sieve. Figure 03 shows the mixture when used in all the following tests.

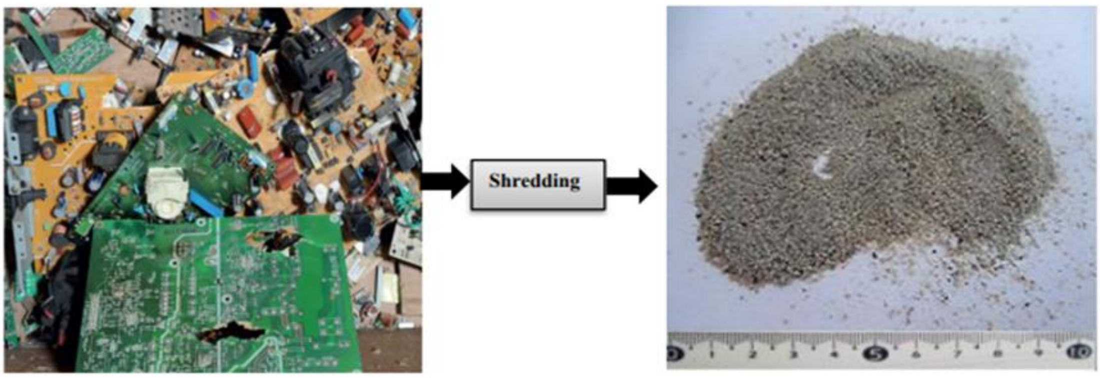


Figure (03): Photographs of the electronic plates of the cathode ray tube before and after grinding

6. Experimental procedure

The experimental setup used is shown in Figure 05. It consists mainly of a traveling wave transporter, HT amplifiers and function generators. Each phase is powered by a voltage amplifier (Trek model 2220, 2 kV - 20 mA). The phase shift, frequency and voltage level applied to each electrode can be varied using two synchronized function generators (SDG Siglent 5122) that control the amplifiers. The square wave AC voltage signals applied to the conveyor electrodes are visualized using a digital oscilloscope with RAM (Gwinstek GDS-3154).

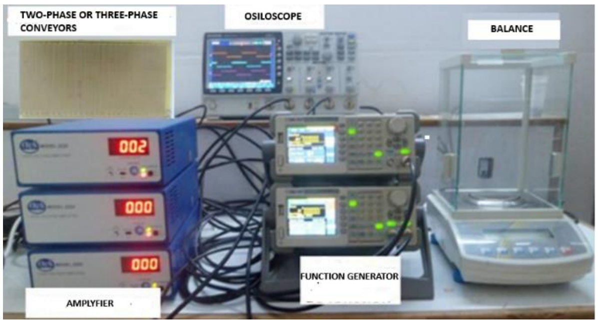


Figure (05) : Photograph of the experimental set-up used

7. Experimental results and discussion

7.1 Influence of the high voltage signal amplitude

The influence of the electrical parameters (frequency, amplitude and ambient humidity) was analyzed. The first parameter tested was the effect of increasing the voltage U applied to the conveyor. The voltage was varied to evaluate the separation efficiency with the three-phase and two-phase devices to clarify the difference between the two.

Figures 06 and 07 show the variation in the recovery of metals and insulators as a function of the value of the voltage applied for the three-phase and two-phase conveyors, for a frequency f= 100 Hz, flow rate D=1 g/s.

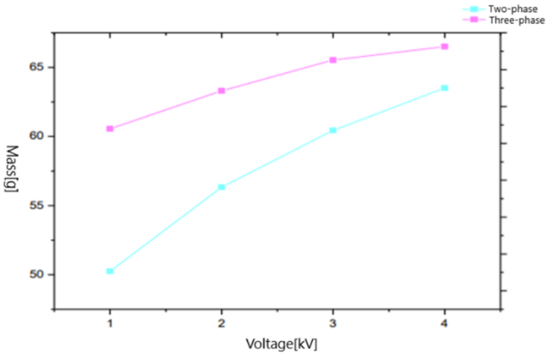


Figure (06): Variation of insulator mass as a function of applied voltage for a two-phase and three-phase conveyor system.

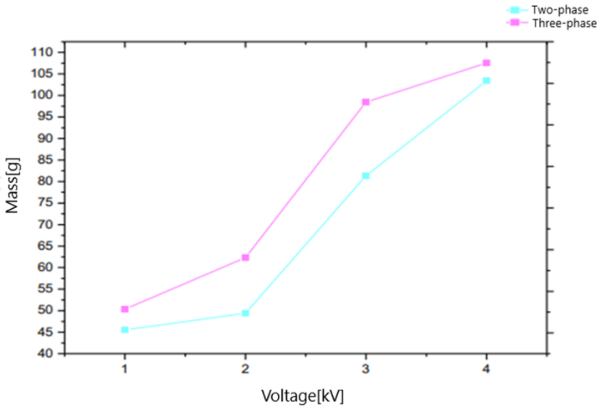


Figure (07): Variation of metal mass as a function of applied voltage for two-phase and three-phase conveyors

For both conveyors, it is clear that the higher the voltage applied, the greater the efficiency, while for the 4 kV voltage the result is better. This is due to the influence of voltage on the Columbus force and the dielectrophoretic force. The high value of these two forces allows them to overcome the opposing force, which is the force of gravity.

There is a difference in the movement of the pellets between the two conveyors used. In the case of the three-phase conveyor, transport is unidirectional and instantaneous, while in the case of the two-phase conveyor, movement is intermittent.

At voltages above 4 kV, sparks appear between the electrodes, causing a short circuit and damaging the conveyor.

7.2 Influence of the frequency of the high voltage signal

The value of the electric field plays a very important role, as it is the value that affects the electric forces. The second part will be dedicated to studying the effect of the frequency of the signal used on a product with an average size of less than 1 mm, for a three-phase conveyor and a two-phase conveyor for which a voltage of U=4 kV has been chosen.

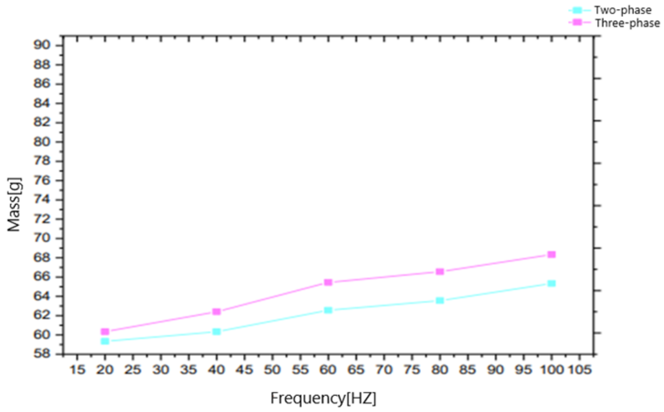


Figure (08): Variation in plastic recovery as a function of signal frequency.

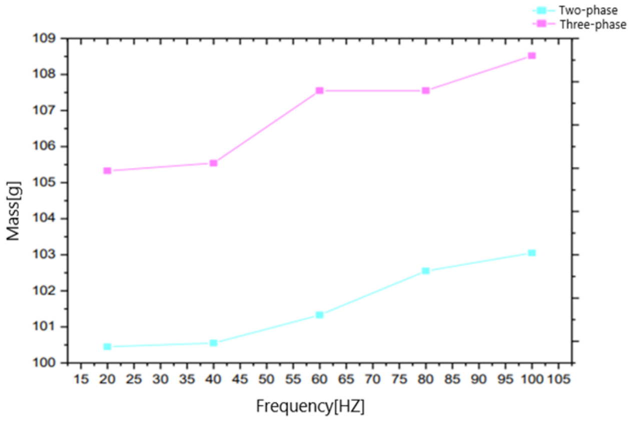


Figure (09): Variation of recovered metal mass as a function of signal frequency

The evolution of the mass recovery of the metal and plastic is shown in Figures 8 and 9, and they remain practically insensitive to variations in the frequency of the applied signal. The results obtained show that, in the range of frequency values used, the frequency has no significant influence on the force of attraction.

7.3 Influence of ambient humidity

The ambient humidity influences the results obtained on different days and, with the same parameters, the results can be different. It should always be measured before each experiment. Figures 10 shows its influence on metal recovery using the three-phase and two-phase conveyor with the following settings:

100 Hz frequency, 50% and 30% humidity and for a voltage range of 1 to 4 kV.

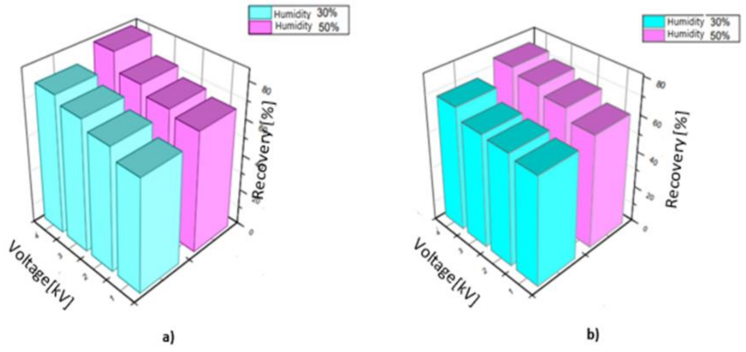


Figure (10): Metallic recovery as a function of ambient humidity

a) Three-phase b) two-phase

It is clear that ambient humidity plays a very important role. For the three-phase conveyor, the difference in metal recovery ranges from 85% to 67% for a humidity of 50% and from 77% to 62% for a humidity of 30%. This represents a margin of almost 10% in efficiency, a not insignificant difference. For two phases, the result is slightly lower, from 75% to 62% for 50% and from 68% to 59% for 30% for metal, a difference of just under 7%. How does humidity affect the behavior of particles? The explanation lies in the relationship between capillary and adhesion forces and ambient humidity values. In other words, the more the particles stick together, the more the image force retains certain particles in the insulating film at high humidity values, due to the water bridges between the particles, which form more persistent and resistant particles.

8. Conclusions:

The movement of micronized particles using the travelling wave technique requires a certain level of adjustment to obtain the best results. We have shown that the parameters that affect the movement of particles on conveyors are: frequency, voltage, ambient humidity, particle load for an average size of less than 1 mm.

The series of tests we carried out showed that:

(1) The attractive force applied by a three-phase electric curtain is greater than that applied by a two-phase electric curtain, and the higher the voltage applied, the greater the efficiency, while for a voltage of 4 kV, the result is better. This is due to the influence of voltage on the Coulomb force and the dielectrophoretic force.

(2) Humidity influences the behavior of the particles because the more the particles stick together, the more the imaging force retains certain particles in the insulating film at high humidity values, due to the water bridges that exist between the particles, which form macroparticles.

(3) On the other hand, the evolution of the metal's mass recovery is practically insensitive to variations in the frequency of the applied signal, and the frequency has no significant influence on the force of attraction.

This study explored in depth the factors that influence the micromanipulation of insulating particles using traveling waves. The results showed that optimizing the geometry of the support, regulating the voltages applied to the electrodes and stabilizing the environmental conditions are essential for improving the efficiency of this technique. The interaction between these factors was better understood, making it possible to propose more effective solutions for the transportation and separation of particles, especially in the context of WEEE recycling.

In conclusion, this work contributes not only to the theoretical knowledge of particle micromanipulation processes, but also to the development of practical solutions for sectors such as recycling, where the precise handling of materials is crucial. The results pave the way for innovations in the design of more efficient equipment, thus improving the overall performance of electronics recycling.

Recommendations:

- ✓ Optimization of electrode design: future research should focus on improving electrode designs to maximize electric field strength and minimize energy losses, while ensuring precise particle movement.

- ✓ Comprehensive environmental studies: further studies into the influence of other environmental factors, such as temperature and atmospheric pressure, on particle micromanipulation, in addition to humidity, would be relevant to improve the robustness of the technique in a variety of environments.
- ✓ Expanded industrial applications: It is recommended that the application of this technique be explored in other industrial sectors outside of WEEE recycling, such as the pharmaceutical or agri-food sectors, where the sorting and handling of fine particles is also important.
- ✓ Development of automated systems: To improve the precision and efficiency of the micromanipulation process, automated systems using artificial intelligence algorithms could be considered to optimize electrical and environmental parameters in real time.
- ✓ Large-scale tests: Finally, it would be prudent to carry out large-scale tests in real industrial environments to validate the performance of particle micromanipulation systems and measure their economic and environmental impact.

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