Time Resolved Measurement of Dielectric Particles Velocity on Standing Wave Electric Conveyor using PTV Technique

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Abstract. The interaction between micro-sized dielectric particles and standing wave electric field is investigated experimentally in this paper. The particles are deposited on a conveyor made of a series of copper electrodes on a dielectric surface and moved by an electric field. The standing wave electric field is generated by applying 2-phase voltage signals to the electrodes. Particles motion is recorded using high speed camera, and then a Particles Tracking Velocimetry (PTV) based post-processing is carried out in order to track each particle and evaluate its velocity. The main results indicate that the particles move toward both directions perpendicular to the electrodes close to the surface and their velocity increases. Some of them can reach the synchronism velocity equivalent to that of the electric wave. However, most of the particles cannot reach this velocity because of the contribution of adhesion and drag forces.

1. Introduction

The manipulation of micrometer sized particles is a process encountered in a lot of industries such as: electro-photography, pharmaceutical, recycling, among others [1]. By applying an external electric field, one can effectively manipulate particles through electrostatic forces. Recent studies demonstrate the great potential of standing wave electric field to transport micro-sized particles from a surface [2]. One of the most promising applications concerns the field of surface cleaning and dust mitigation from solar panels [3,4]. The electric field can levitate and remove the charged particles over the surface with very low energy consumption and without any moving parts within the conveyor.

In the present work, we investigate the particles behavior in such device experimentally using high speed camera and advanced post-processing technique. A 2D Particle Tracking Velocimetry (PTV) technique is employed in this investigation. With this technique, particles are tracked individually based on Lagrangian approach contrary to the conventional PIV, which employs Eulerian approach [5]. In this study, the particles are displaced on the surface of a Standing Wave Conveyor (SWC) energized by two-phase sine applied voltage. The particles used here are made of PMMA; they have a spherical shape and a median diameter $d_p [50\%]$ of about 57 $\mu$m.

This paper is divided into two main sections. In the first one, the used configuration and the experimental setup for particles visualization are described. In the second one, the principle of PTV algorithm and the post-processing parameters are presented, then, the results of particles velocity and trajectories are analyzed and discussed.
2. Experimental setup

2.1. Power supply and SWC design

The two-phase applied voltage (HV) waveforms are supplied by two high voltage power amplifiers (Trek, model 2220, ±2 kV, ±20 µA). The HV amplifiers are controlled by a digital function generator output (TTi, TG1010A). A digital pulse generator (Stanford, model DG645) is used as a synchronizer for triggering the visualization system with the electrical signal supplied to the SWC. The phase difference between the two HV signals is fixed at 180°.

The SWC investigated in this work is illustrated in figure 1. The system is made on a 10 × 10 cm² epoxy substrate of printed circuit board (PCB). Durability, ease of manufacturing, and robustness of the connections are the main reasons for using PCB for the electric conveyor’s conception. The results of this study can be applied and projected in other types of electric conveyors such as transparent or flexible screens, depending on the targeted application. The electrodes, made of copper, are 7 cm long. They have width and inter-electrode spacing of 1 mm, and a thickness of 35 µm.

2.2. Particles Visualization

The experimental setup for particles visualization is illustrated in figure 2. Particles motion is visualized and recorded experimentally using a time-resolved imagery system manufactured by LaVision. This system uses a high-speed pulsed light LED illuminator (HARDsoft, IL-105/6X) coupled to a high-speed camera (Photron, Fastcam SA1.1, resolution of 1024×1024 pixels, 5400 frames per second), the assembly is compatible with DaVis software provided by LaVision.

The experimental protocol is as follows: for each experiment, a mass of 20 mg of PMMA particles is deposited in the middle of the board on a surface of 1 × 20 mm². Once the experimental parameters are fixed, we apply the voltage signals and start the video recording at the same time using a synchronizing signal. The acquisition rate is set to 1000 Hz allowing a good analysis of the particle dynamics. Sequences of 1000 images are recorded for each experience, thus the total acquisition time is about 1 s. After each experiment, the board is cleaned and brand-new particles are used. All the experiments are carried out at atmospheric pressure and the room temperature.

The PMMA particles used in this investigation are spherical in shape, and their size range has the following characteristics according to volume density distribution: \(d_p[10\%] \approx 37 \mu m\), \(d_p[50\%] \approx 57 \mu m\) and \(d_p[90\%] \approx 86 \mu m\). A size classification process using an automatic sieving device (Endecotts, model Octagon 200) has been used to separate this size range.

2.3. PTV principle and post-processing

In this work, PTV technique is used instead of PIV because of two main reasons: the low density of particles and the non-homogeneity of their distribution in the interrogation window. In fact, in order to
get a readable data using PIV, a homogeneous and high density of particles in the whole area (minimum of 10 particles/interrogation window) is necessary. Nevertheless, PIV algorithm is needed to predict particle displacement in parallel to PTV post-processing. PTV technique, in which the trajectories of individual particles are tracked, uses the same experimental setup as PIV. The PTV post-processing passes through three steps; the first step consists in localizing the particles and assigning their position in the image. This process starts by classifying the image pixels into two categories by analysing their luminous intensity, noise image and particle image. Then, the images are correlated with a Gaussian function and the particle’s outlines and centers are detected. The second step consists of tracking the particles in the successive image. Finally, the last step consists of calculating the particles displacement and velocity [5]. Figure 3 illustrates a schematic diagram of the different step of PTV algorithm.

3. Results and discussion

Figure 4 shows a grey level image of the particles deposited on the surface at \( t = 0 \) s before applying the electric field (Figure 4.a) and the particles in motion at the instant \( t \approx 212 \) ms (Figure 4.b). In order to obtain a clear description of the phenomenon, we have focused the camera on the zone just above the SWC surface. The applied voltage and the frequency are fixed at 1 kV and 100 Hz, respectively. We notice that once the electric field is applied, the particles start jumping over the surface and move toward both right (\( x > 0 \)) and left (\( x < 0 \)) directions. Using PTV, we can get the velocity of individual particles above the surface. The velocity vectors are represented in Figure 4.c. In this figure, one can see that the instantaneous particles velocity depends on particles position; it is higher close to conveyor’s surface. By accumulating the particles positions over 50 images, the trajectories of particles during \( 50 \) ms can be extracted. The results are represented in figure 5.a, the Vx component of the particles velocity is considered here and the particles trajectories are coloured in orange scale if they are moving right and blue scale if they are moving left. One can notice that the particles velocity is bigger in the right and left ends of the SWC, which means that the particles accelerate (their velocity increases with time). Figure 5.b illustrates a typical example of the Vx-component of particles velocity values along x-direction for \( y = 0.5 \) mm. One can observe that the particles have nearly the same average velocity in both directions. Some particles can reach the so called synchronism velocity, which is equivalent to the electric potential wave speed propagated toward each direction. In fact, the standing wave can be represented as the sum of two traveling waves having the same magnitude and the same frequency, but propagating in opposite directions. In this system, the propagation velocity of each wave is expressed by: \( V_s = f \cdot \lambda = 0.4 \) m/s, where \( f = 100 \) Hz is the frequency of the applied voltage signal, and \( \lambda = 4 \) mm is the wave length, called also the geometric period [2]. Most of the particles cannot follow the electric wave at this frequency value, probably due to the contribution of several forces such as adhesion, gravitational and drag forces. Consequently, their velocity is slower than the electric wave’s one.
Figure 4. Grey level images of the particles at (a) $t = 0 \text{ ms}$ and (b) $t = 212 \text{ ms}$, and (c) the instantaneous particles velocity. Conditions: $V = 1 \text{kV}, f = 100 \text{ Hz}$

Figure 5. Illustration of (a) particles trajectories and (b) Vx component velocity values along x-direction for $y = 0.5 \text{ mm}$

4. Conclusion
This work consists of an experimental investigation of particles velocity when they are moving by two-phase standing wave electric field. The velocity of particles is measured experimentally using PTV technique. This technique allows us to track each particle and calculate its velocity using Lagrangian approach. Results show that the particles velocity depends on their position; it is bigger near to the surface as well as in the right and left ends of the SWC, which means that the particles passes by an acceleration phase during which their velocity increases with time. Some particles can reach the synchronism velocity; however, most of the particles cannot reach this velocity at the studied frequency value because of the contribution of adhesion, gravitational and drag forces. The effect of experimental parameters and the conveyor’s configuration on particles velocity will be the subject of a future work.

References
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