The 8th European Congress on Computational Methods in Applied Sciences and Engineering
ECCOMAS Congress 2022
5-9 June 2022, Oslo, Norway

SEPARATION BEHAVIOUR OF SMALL FOREIGN OBJECTS IN DRY FOODS

SHUNSUKE TAKEDA[1] AND MASATO SAEKI[2]

[1]Graduate school of Engineering and Science, Shibaura Institute of Technology,
3-7-5 Toyosu, Koto-Ku, Tokyo, Japan
e-mail: md20052@shibaura-it.ac.jp

[2] Dept. of Mechanical Engineering, Shibaura Institute of Technology,
3-7-5 Toyosu, Koto-Ku, Tokyo, Japan
email: saeki@sic.shibaura-it.ac.jp, www.particle.mech.shibaura-it.ac.jp

Key words: Electric Field Strength, Electrostatic Separation, Finite Difference Method, Food Safety, Foreign Objects.

Abstract. It is difficult to detect small foreign objects such as hair and soft plastics in dry foods. In our laboratory, an electrostatic separator of small foreign objects in dry foods was developed. The separator consists of a grounded inclined rotating drum, a cylindrical electrode fixed at the centre of the drum, and a suction device. The principle of the separation is based on the difference in the charge per unit mass of the dry food and foreign objects. Although it was found that it is possible to obtain a high purity and a high recovery rate of foods using this separator, the understanding of the separation mechanism is still limited.
In this study, we numerically investigated the separation behaviours of foreign objects and dry foods in the inclined rotating drum. The behaviours of the foreign objects and dry foods were calculated, considering the electrostatic force. The electric field strength was calculated by the finite difference method. The effect of the inclination angle of the rotating drum on the trajectory of the particles to be separated was investigated. To examine the validity of the calculation method, the experimental result was compared with the calculated result.

1 INTRODUCTION

When we consume food, we usually do not expect to find foreign objects in it. Foreign objects in the food products may pose several health concerns. Thanks to a continuous improvement of separation techniques in food industry, food manufacturers and suppliers have recently become able to remove most foreign objects that do not belong in the product [1], [2]. However, it is difficult to detect small foreign objects such as hair and soft plastics in dry foods because it is easy for small foreign objects to adhere to dry foods owing to electrostatic force. Therefore, an electrostatic separator of small foreign objects in dry foods was developed in our laboratory [3]. The separator consists of a grounded inclined rotating drum, a cylindrical electrode fixed at the centre of the drum, and a suction device. The cylindrical electrode has some needle electrodes. The principle of the separation is based on the difference in the charge per unit mass of the dry food and foreign objects. The mixtures to be separated are charged using a corona charging

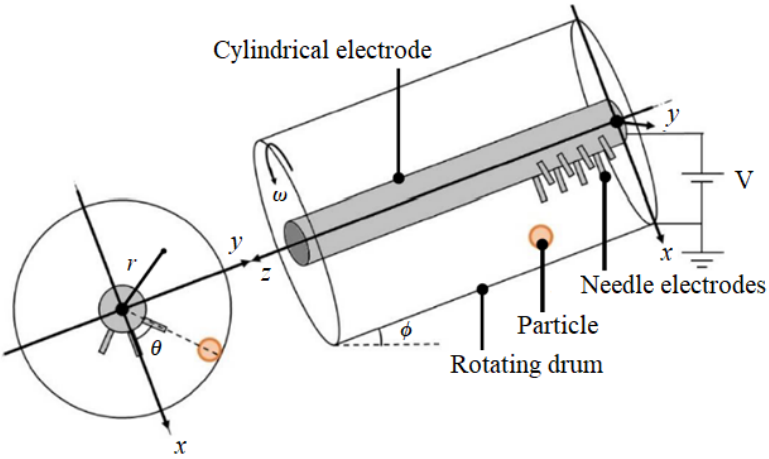


Figure 1: Model of the electrostatic separator

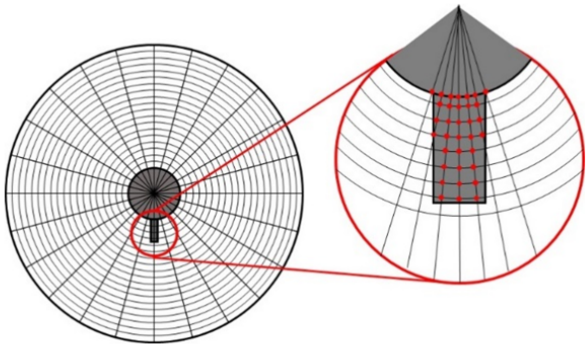


Figure 2: Cylindrical coordinates system

device. When the charged mixtures are fed into the inclined rotating drum, the foreign objects are attracted to the inside surface of the rotating drum and are recovered with the suction device. As the dry foods are much heavier than the foreign objects, they are recovered at the end of the inclined rotating drum. Therefore, the mixtures can be separated because of the different positions at which they are recovered. Although it was found to be possible to obtain a high purity and a high recovery rate of foods using the separator, the understanding of the separation mechanism is still limited.

In this study, we numerically investigated the separation behaviours of the foreign objects and the dry foods in the inclined rotating drum. The behaviours of the foreign objects and dry foods were calculated considering the electrostatic force. The electric field strength was calculated by the finite difference method. The effect of the inclination angle of the rotating drum on the trajectory of the particle was investigated. To examine the validity of the calculation method, the experimental result was compared with the calculated result.

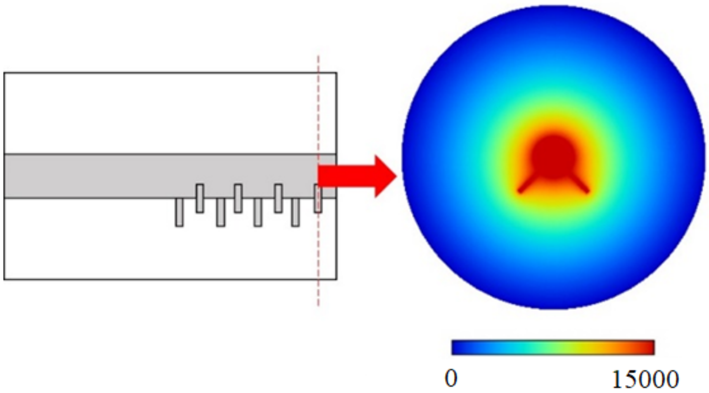


Figure 3: Contour map of electric potential (V=15kV)

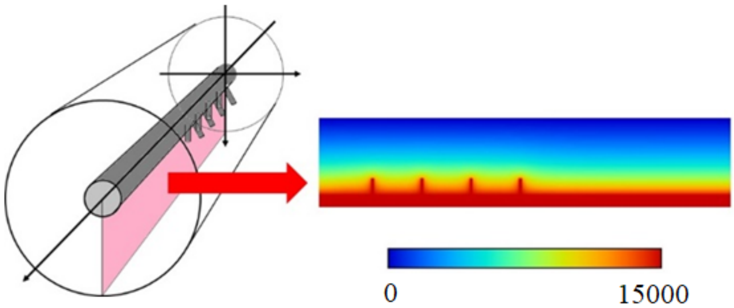


Figure 4: Contour map of electric potential (V=15kV)

2 SEPARATION PRINCIPLE

Figure 1 shows the model of the electrostatic separator that we used in this study. The separator consists of an inclined rotating drum, a cylindrical electrode fixed at the centre of the rotating drum, and a suction device. The cylindrical electrode has some needle electrodes and is maintained at a constant high voltage. The rotating drum is grounded. In this study, the separation of foreign objects such as plastic strings or hair in dry foods such as lettuce is carried out. The characteristic of particles to be separated is that the mass of foreign objects is much smaller than that of the dry foods. When the particles to be separated enter the rotating drum, the particles become positively charged because of corona charging. Then, the particles are attracted toward the inside surface of the rotating drum owing to the Coulomb force. On the contrary, the foreign objects move up with the rotation of the drum and are recovered with the suction device. As the dry food is heavier than the foreign objects, the dry foods are discharged from the rotating drum. Therefore, the foreign objects are separated from the dry foods because of the difference in their trajectories.

The equations of motion for the particles to be separated are given by

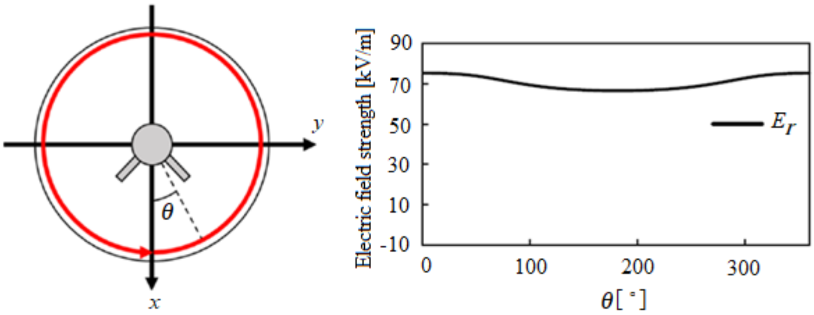


Figure 5: Electric field strength (V=15kV)

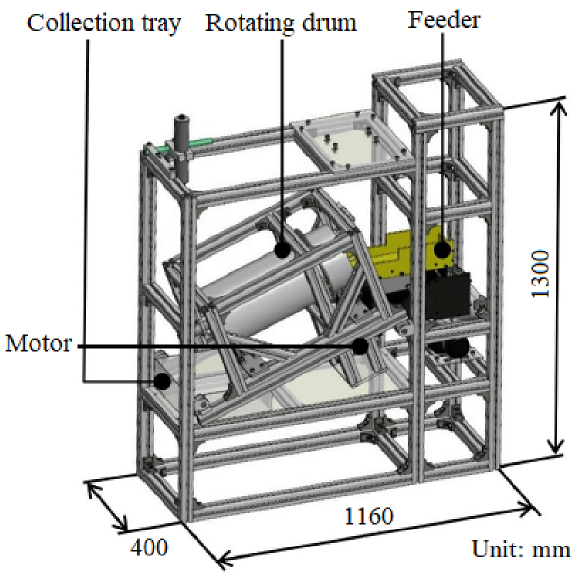


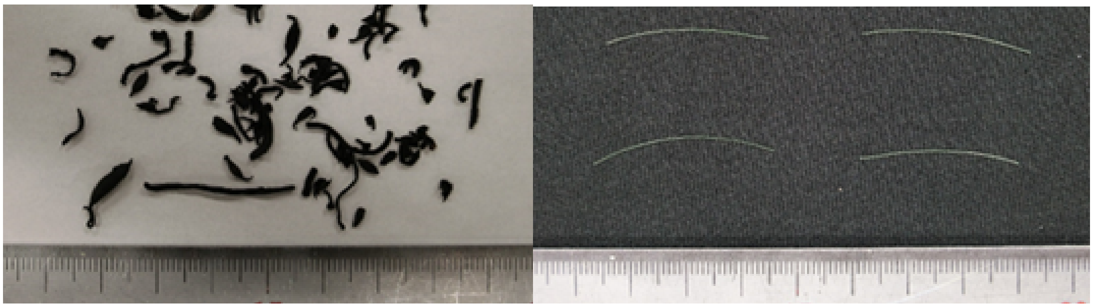
Figure 6: Electrostatic separator

$$mR\ddot{\theta} = -mg\cos\theta\sin\theta - \mu_d(mg\cos\lambda + qE_r + \frac{q^2}{16\pi\epsilon_0 r^2} + mR\dot{\theta}^2)\frac{R(\dot{\theta}-\omega)}{\sqrt{R^2(\dot{\theta}-\omega)^2 + \dot{z}^2}} \tag{1}$$

$$m\ddot{z} = mg\sin\phi - \mu_d(mg\cos\lambda + qE_r + \frac{q^2}{16\pi\epsilon_0 r^2} + mR\dot{\theta}^2)\frac{\dot{z}}{\sqrt{R^2(\dot{\theta}-\omega)^2 + \dot{z}^2}} \tag{2}$$

$$\lambda = \cos^{-1}(\cos\phi\cos\theta) \tag{3}$$

where m is the particle mass, R is the radius of the rotating drum, g is the gravitational acceleration, ω is the angular velocity, q is the charge accumulated on the particle, and E is the electric field strength. The subscripts r and θ refer to r and θ directions, respectively. Assuming that the electric field strength is independent of the charge q accumulated on the



(a) hiziki seaweed (b) plastic strings

Figure 7: Particles to be separated

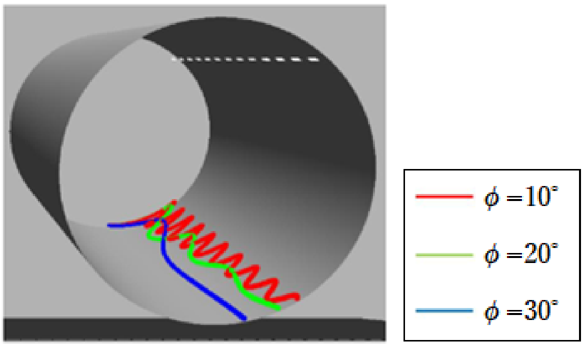


Figure 8: Particle behaviors (m=2.77mg, μ_s=0.38, μ_d=0.41, ϕ=23.7°, ω=20rpm, q=0.1nC, V=15kV)

particle, we solved Laplace's equation in cylindrical coordinates to determine the electric field strength. In the calculation, the finite difference method was used. The node points in the needle electrodes were located as shown in Figure 2.

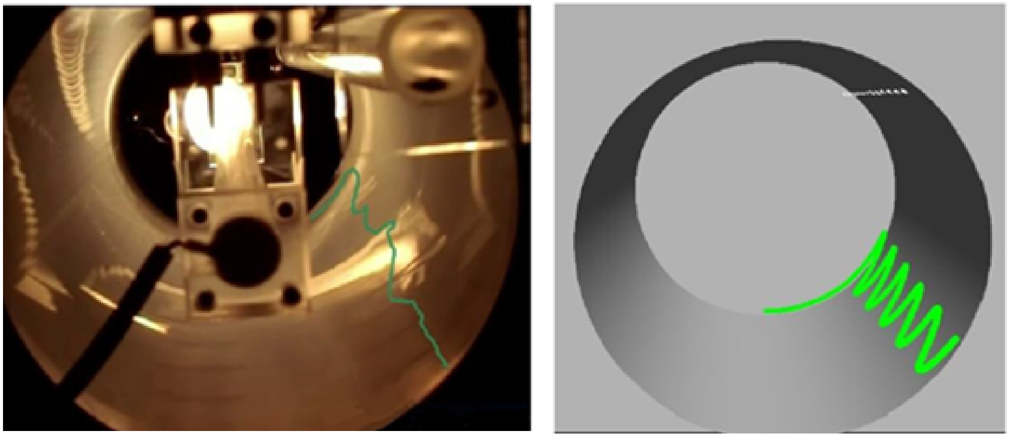
3 ELECTRIC-FIELD STRENGTH

Figures 3 and 4 show the front and side views, respectively, of the contour maps of electric potential. The radius of the cylindrical electrodes is 15mm and the diameter of the rotating drum is 108.5mm. The length and the diameter of the needle electrodes are 20mm and 3mm, respectively. As shown in these figures, the electric potential near the needle electrodes is high.

Figure 5 shows the electric field strength at the inside surface of the rotating drum. It is found that the electric field strength near the angle θ =180° is smaller than that for other angles. The reason is that the inside surface of the rotating drum at θ =180° is far from the needle electrodes.

4 EXPERIMENTS

Figure 6 shows the electrostatic separator used in this study. Particles to be separated enter a rotating drum using a vibrating feeder. The drum was rotated with a motor. Dry foods were



(a) experimental result (b) calculated result

Figure 9: Calculated and experimental results (m=2.77mg, μ_s=0.38, μ_d=0.41, ϕ=23.7°, ω=20rpm, q=0.47nC, V=0kV)

recovered in a collection tray. Foreign objects were recovered with a suction device. The suction device was fixed at the angle θ =117°.

Figure 7 shows the particles to be separated. *Hiziki* seaweed and nylon strings were used as dry foods and foreign objects, respectively. When the *hiziki* seaweed is harvested from the ocean, nylon strings used for fishing are often mixed with the *hiziki* seaweed.

5 TRAJECTORIES OF PARTICLES

Figure 8 shows the trajectories of particles obtained by the calculation. We also plot the effect of the inclination angle ϕ of the rotating drum on the trajectories. In this figure, a dot-and-dash line shows the location of the suction device. As shown in this figure, the particles move up and down the inside surface of the rotating drum and then are discharged from the rotating drum. It is found that the frequency of moving up decreases as the inclination angle ϕ of the rotating drum increases.

Figure 9 shows the experimental and calculated results. In this experiment, positively charged *hiziki* seaweed was used. The *hiziki* seaweed was attracted toward the inside surface of the rotating drum owing to the image force. The behavior of the *hiziki* seaweed was photographed using a high-speed camera and the displacement was obtained with an image processing system. From a comparison of these results, it is clear that the calculated results follow the experimental trend. However, the trajectory of the particle obtained by the calculation is less smooth than that obtained by the experiment. The reason is that the *hiziki* seaweed was assumed as a mass in the calculation.

6 CONCLUSIONS

The separation behaviour of foreign objects and dry foods in an inclined rotating drum was investigated. The behaviours of the foreign objects and dry foods were calculated considering the electrostatic force. The electric field strength was calculated by the finite difference method. The effect of the inclination angle of the rotating drum on the trajectory of the particle was investigated. To examine the validity of the calculation method, an experiment was conducted. From the trajectory of the *hiziki* seaweed, it was found that calculated result follows the experimental trend.

REFERENCES

[1] Meftah, H., and Mohd, E. A. Detection of foreign bodies in canned foods using ultrasonic testing, *International Food Research Journal*, (2012) **19(2)**:543–546.

[2] Einarsdttira, H., Emersona, M. J., Clemmensena, L. H., Schererb, K., Willerb, K., Bechb, M., Larsena, R., Ersblla, B. K., and Pfeifferb, F. Novelty detection of foreign objects in food using multi-modal X-ray imaging, *Food Control*, (2016) **67**:39–47.

[3] Suzuki, M. , Iwase, S., Koike, Y, and Saeki, M. Development of electrostatic separator of foreign objects in dried foods, *Japan Society for Food Engineering Journal*, (2017) **18**:61–69.