The 3-D visualization of the granular particle on various diameter porous surfaces

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Abstract. Granular particles have applications in various fields, one of which is the beauty industry. One crucial part of this industry is the character of powder-size interactions with skin-faces. The simulation of granular particles with a porous surface can model this interaction. The purpose of our simulation to visualize the process of granular attachment on a horizontal porous surface. This simulation is 3-dimensional visualization using unified particle physics solver method in uFlex assets on unity software. We generate the pores to three sizes. Each order is tested using five particle sizes. The results showed that the porous hole diameter and the granular restitution coefficient influenced the particles entering the porous surface system. In summary, the number of grains entering the pore is proportional to the diameter, but not linear.

1. Introduction
Simulation of granular material has developed in the last decade using simple particle geometry [1]. Complex mechanical properties of particles are generally studied, taking into account the nature of contact particles that occur. Interactions that need to be analyzed further in granular simulations is the effect of micro-scale geometric configurations on macroscopic scale responses [2]. Preliminary research has been carried out including numerical simulation techniques using the discrete element method (DEM) to study the character of sand containing dissociated gaseous hydrate [3], the structural characteristics of the internal flow of microscopic particles in pipes [4], and simulate the dispersion process of Active Pharmaceutical Ingredients (API) after collision of powdered inhaler powder used for lung healing [5].

The granular computation systems and particles will generate valuable identification of the structure underlying the particle system [6]. Granular computing is an interdisciplinary computational study inspired by structured thinking, problem-solving, and information-processing [7].

In this study, a granular system simulation was carried out on the application of cosmetics to porous surfaces. Skin pores were detected at a detection threshold of 250 μm, correlating with clinical assessment by experts. The pores are enlarged in size and amount based on sun exposure and lifestyle, which are open problems for the skin [8]. The size of cosmetics in the market is very diverse and taken
as a sample in the diameter range of 1 to 3 μm [9-11]. Recently, the researcher concerns the presence of nanoparticles in products such as cosmetics that are under 100 nm [10, 12]. Some techniques only report the center point and distribution of distribution; others provide greater detail in all detected top and bottom particle sizes. The granular size distribution can be calculated based on various models: most often as numbers or volume/mass distribution [10]. The pore that makes the sample pores on the human face area (scalp excluded) with comparable density (i.e., 200-300 /cm²) has a different size and is about 5–10 μm in diameter [8,13]. Our simulation aims to carried out and analyze the effect of attaching the granular system to the porous surface.

2. Method

2.1. Discrete Element Method (DEM)
Discrete Element Method (DEM) simulations have been used to investigate cosmetic properties: in the shifting process from manufacturing to natural antioxidant skin [12], the skin aging and wrinkles [14], makeup for manipulating appearance [15], the particles exposure and droplets in the air during the products application [16], the properties of undrained shear from sand containing dissociated gas hydrate [3], the characteristics of the internal flow structure of microscopic movements of coarse particles in pipe [4].

![Figure 1. The particle sizes in simulation. D means diameter.](image)

Each particle in the system acts as a rigid object and will not break, which reflects the properties of a cosmetic component that cannot be destroyed. Figure 1 shows the particle size in our simulations, with a grain diameter of 1 μm - 5 μm. The granular used is categorized as most considerable for cosmetic purposes.

2.2. Skin pores
Pores are sebaceous glands and sweat that widens on the surface of the skin. The appearance of the skin, when viewed perpendicularly, will consist of several presentations, namely wrinkles, pores, moles, and spots that envelop them [17].

![Figure 2. The human skin pore sizes: a. Smallest; b. Normal; and c. Biggest size.](image)

In Figure 2, the area is defined as the sample taking simulation. The skin sample used in this simulation has a length of 150 μm, the width of 130 μm, and the distance between pore holes 20.5 μm, and has 35 holes in the sample.
Figure 3. The illustrations of the range of pores in human skin from small to the largest.

In this simulation, three sizes of porous sections are assumed to be pore patterns on human skin. Figure 3 describes a comparison of the cross-section of the pore. The diameter of each porous system hole is an interpretation of the minimum, average, and maximum width of the human pore. The surface system generated as to fit the state of the pores of human skin. In each simulated pore, the diameter in the range of 5 µm to 10 µm, and the pore depth is 10 µm.

3. Results

This simulation demonstrates granular attachment to porous systems. The simulated granular fall will be carried out at five different sizes: 1 µm, 2 µm, 3 µm, 4 µm, and 5 µm. While the simulated pores have three different sizes, 5 µm, 7.5 µm and 10 µm in diameter. Figure 4a-c and 5a-c simulate the final condition of 1 µm and 2 µm granular attachment on a porous surface.

Figure 4. The simulation of granular attachment: a. The 5 µm porous surface and 1 µm granular; b. The 7.5 µm porous surface and 1 µm granular; and c. The 10 µm porous surface and 1 µm granular.

Figure 5. The simulation of granular attachment: a. The 5 µm porous surface and 2 µm granular; b. The 7.5 µm porous surface and 2 µm granular; and c. The 10 µm porous surface and 2 µm granular.

Table 1. The illustration of a maximum number of 1 µm granular attached in various pores sizes.

| No. | Simulation | Pore Sizes | Particle Sizes | Maximum Number |
|-----|------------|------------|----------------|----------------|
| 1   | ![Simulation](image1.png) | 5 µm       | 1 µm           | 145            |
| 2   | ![Simulation](image2.png) | 7.5 µm     | 1 µm           | 333            |
Table 1. Cont.

| No. | Simulation | Pore Sizes | Particle Sizes | Maximum Number |
|-----|------------|------------|----------------|----------------|
| 3   | 10 µm      | 1 µm       | 646            |

Table 1 dan Figure 4 shows the maximum number of 1 µm granular attached in various pores sizes. In Table 1, the maximum number of attachments obtained in the pore size of 5 µm, 7.5 µm, and 10 µm were 145, 333, and 646 respectively.

Table 2. The illustration of a maximum number of 2 µm granular attached in various pores sizes.

| No. | Simulation | Pore Sizes | Particle Sizes | Maximum Number |
|-----|------------|------------|----------------|----------------|
| 1   | 5 µm       | 2 µm       | 17             |
| 2   | 7.5 µm     | 2 µm       | 45             |
| 3   | 10 µm      | 2 µm       | 60             |

Table 2 and Figure 5 show the maximum number of 2 µm granular attached in various pores sizes. In Figure 2, the maximum number of attachments obtained in the pore size of 5 µm, 7.5 µm, and 10 µm were 145, 333, and 646, respectively.

Figure 6a-c, 7a-c, and 8a-c simulate the final condition of 3 µm, 4 µm, and 5 µm granular attachment on a porous surface. Table 3, 4, and 5 show the maximum number of 3 µm, 4 µm, and 5 µm granular attached in various pores sizes.

Figure 6. The simulation of granular attachment: a. The 5 µm porous surface and 3 µm granular; b. The 7.5 µm porous surface and 3 µm granular; and c. The 10 µm porous surface and 3 µm granular.
Figure 7. The simulation of granular attachment: a. The 5 µm porous surface and 4 µm granular: b. The 7.5 µm porous surface and 4 µm granular; and c. The 10 µm porous surface and 4 µm granular.

Figure 8. The simulation of granular attachment: a. The 5 µm porous surface and 5 µm granular: b. The 7.5 µm porous surface and 5 µm granular; and c. The 10 µm porous surface and 5 µm granular.

Table 3. The illustration of a maximum number of 3 µm granular attached in various pores sizes.

| No. | Simulation | Pore Sizes | Particle Sizes | Maximum Number |
|-----|------------|------------|----------------|----------------|
| 1   | 5 µm       | 3 µm       | 4              |
| 2   | 7.5 µm     | 3 µm       | 12             |
| 3   | 10 µm      | 3 µm       | 24             |

Table 3 and Figure 6 show the maximum number of 3 µm granular attached in various pores sizes. In Figure 2, the maximum number of attachments obtained in the pore size of 5 µm, 7.5 µm, and 10 µm were 4, 12, and 24, respectively.

Table 4. The illustration of a maximum number of 4 µm granular attached in various pores sizes.

| No. | Simulation | Pore Sizes | Particle Sizes | Maximum Number |
|-----|------------|------------|----------------|----------------|
| 1   | 5 µm       | 4 µm       | 3              |
| 2   | 7.5 µm     | 4 µm       | 4              |
Table 4. Cont.

| No. | Simulation | Pore Sizes | Particle Sizes | Maximum Number |
|-----|------------|------------|----------------|----------------|
| 3   | 10 µm      | 4 µm       | 9              |

Table 4 and Figure 7 show the maximum number of 4 µm granular attached in various pores sizes. In Figure 2, the maximum number of attachments obtained in the pore size of 5 µm, 7.5 µm, and 10 µm were 3, 4, and 9, respectively.

Table 5. The illustration of a maximum number of 5 µm granular attached in various pores sizes.

| No. | Simulation | Pore Sizes | Particle Sizes | Maximum Number |
|-----|------------|------------|----------------|----------------|
| 1   | 5 µm       | 5 µm       | 2              |
| 2   | 7.5 µm     | 5 µm       | 3              |
| 3   | 10 µm      | 5 µm       | 5              |

Table 5 and Figure 8 show the maximum number of 5 µm granular attached in various pores sizes. In Figure 2, the maximum number of attachments obtained in the pore size of 5 µm, 7.5 µm, and 10 µm were 2, 3, and 5, respectively.

4. Conclusion

The resulting visualization confirms that the maximum number of particles entering the pore depends on the granular diameter. However, this maximum amount becomes a very significant difference in the size of the granular diameter, which is equal or almost the same as the pore diameter. For cosmetic purposes, it is necessary to simulate combinations of granular particles. The advanced simulation will be future work.

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