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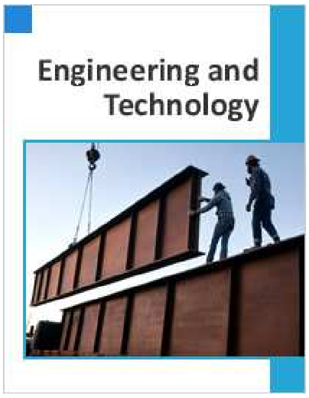

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Effect of Surface Roughness of Filter Media on Filtration Flux

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Abstract
A new filtration system using a ceramic tube filter with an internal spiral guide rod was developed. In this paper, to investigate the effect of the surface roughness of the filter media on the filtration flux, waste water with ink as sample slurry was filtered by various filters with different surface roughnesses. The decrease ratio of filtration flux was shown to have a close relation to the surface roughness of the filter, which was characterized by image analysis. The filter media with a smooth surface was found to be most suitable for this system because such a filter can prevent a disturbed flow field in the filter, which helps in preventing fouling and maintaining a constant filtration flux for a long time.

1. Introduction

Various types of filtration system, such as cross-flow filtration [1-3] and rotating disc filtration [4-7] have been widely used in many industries. However, they also have certain problems. In cross-flow filtration, fouling increases energy consumption and cleaning frequency, which in turn increases production cost. Furthermore, achieving high concentration in a slurry is difficult. Although rotating disc filtration can be applied to high concentration, a large quantity of power is necessary, and such systems are relatively more complex because of the moving parts and mechanical seals associated with filter rotation.

Slurry in a good dispersion state continues to keep flowability if it is concentrated [8-12]. Based on this result, we have successfully developed novel gravity filtration [13] and rotating disc filtration [14] systems, in which dense slurry can be collected continuously without using a scraping device. Unfortunately, the ability to scale up these systems is limited. Thus, we developed a new filtration system, which improved the conventional cross-flow filtration system, using a ceramic tube filter with an internal spiral guide rod [15]. Figure 1 shows the schematic and the internal features of the filtration system.

The following points demonstrate the novelty of the proposed system: (1) this system has the ability to process a high concentration slurry, (2) the slurry concentration achieved by this system is equal to or higher than that of conventional systems, (3) the concentrated slurry has good flowability, and (4) the structure of the system is simple. In our previous report, the effect of technology parameters on filtration performance [15], the ability to process various hard-to-filter materials, and the scaling up of this new filtration system [16] were investigated. Filtration flux was shown to dramatically improve compared with the conventional cross-flow filtration system.

However, the filter most suitable for the proposed system is not clear because we have not yet fully discussed the filter media. In particular, the surface roughness of the inside wall of the filter media is expected to have a great influence on the filtration flux because it also has a great influence on the flow field in the ceramic tube filter. In recent years, the mechanism that how the surface roughness influences the filtration flux has been reported. For example, Gomaa et al. [17] investigated the effect of oscillatory flat surface membranes roughed with thin strips turbulence promoters on the filtration flux and energy dissipation theoretically and experimentally. They reported that using turbulence promoters with oscillations had proven effective in enhancing filtration flux and in reducing energy consumption. However this technic is not applicable for our filtration system because the thickness of turbulence promoters is mm-order, which is comparable with the flow channel of spiral guide rod. As other example, Zhong et al. [18] investigated the effect of surface roughness of the filter on the particle adhesion in cross-flow filtration. In this research, adhesion of particles smaller than the surface roughness such as nano-sized particles depended on the membrane roughness. But in case of particles larger than the surface roughness such as micro-sized particles, roughness had no effect on the filtration flux. In this research, it was discussed about the mechanism of particle adhesion based on the particle diffusion. However, particle diffusion was considered extremely difficult to occur in cross-flow filtration because flow velocity was very high. In such case, the surface roughness of the filter media is expected to have a great influence on the flow field, therefore it is necessary to discuss about the effect of this phenomenon based on the flow field on the surface of filter media. Thus, in this paper, to investigate the effect of the surface roughness of the filter media on the filtration flux based on the particle dynamics and to clarify the most suitable filter for this system, waste water with ink as a sample slurry was filtered by various filters with different surface roughness.

2. Experiment

2.1. Filtration System

The filtration system is composed of a feed tank, pump and filtration unit. This system is made of stainless steel. The feed tank has a capacity of 40 L. The slurry in the feed tank was fed into the filtration unit via a pump (HEISHIN Ltd., NEMO pump 2NY40) and a pressure regulator system as shown in Figure 1. To keep the slurry concentration constant, both the filtrate and the concentrated slurry were returned to the feed tank. The filtration pressure and the flow rate of circulated slurry were controlled by the pressure regulator and the valve at the outlet of the filter, respectively, and measured by a pressure gauge and flow meter, respectively. Filtrate permeated the filter and was collected through the bottom of the filtration unit. The filtration flux was calculated from the measured filtrate masses at corresponding time intervals.

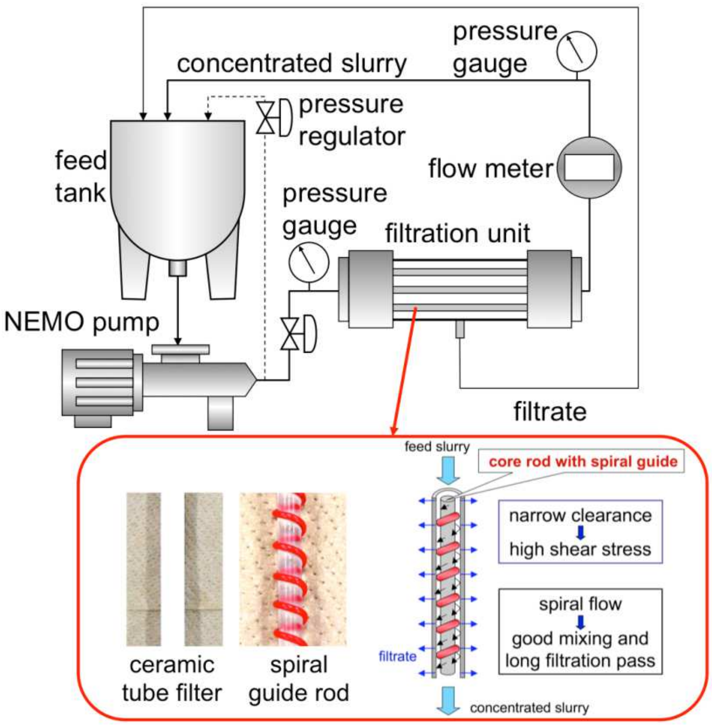

Figure 1. *Schematic indicating the internal features of the new filtration system.*

2.2. Filter Media

Five ceramic tube filters (Filters A to E) with different surface roughnesses were used as filter media. The details of each filter media are summarized in Table 1. Each filter was 300 mm in length. The spiral guide rod was fixed concentrically in the ceramic tube. This internal spiral guide rod consisted of a 1.5-mm-diameter lead wire wound helically with a pitch of 10 mm around a 6-mm-diameter cylindrical acrylic core. This condition brought the fastest filtration flux, as shown in our previous paper [16].

Table 1. *Details of various ceramic tube filters.*

Filter	material	inner diameter [mm]	outer diameter [mm]	pore size [μm]
A	abrasive alumina powder	9	13	several
B	clay	9	13	0.6
C	clay	9	13	1.2
D	alumina	9	12	1.2
E	alumina	9	12	0.1

2.3. Sample Slurry and Filtration Conditions

The sample slurry was waste water with ink at a concentration of 13.7 mass%. The ink was a red mixture of titanium oxide, copper oxide, silica, carbon black, and solid paraffin. Figure 2 shows the particle size distribution of the waste water with ink measured by the dynamic light scattering method (HORIBA, Ltd., LB-550). The average particle size of the slurry was 180 nm. Figure 3 shows the zeta potential of the waste water with ink measured by the electrophoretic method (Nihon Rufuto Co., Ltd., Model 502). Because the pH of the sample slurry was about 7, the zeta potential was high enough to maintain a well-dispersed state in the experimental conditions. The filtration pressure and the flow rate of the concentrated slurry were 0.4 MPa and 13.2 $L \cdot min^{-1}$, respectively.

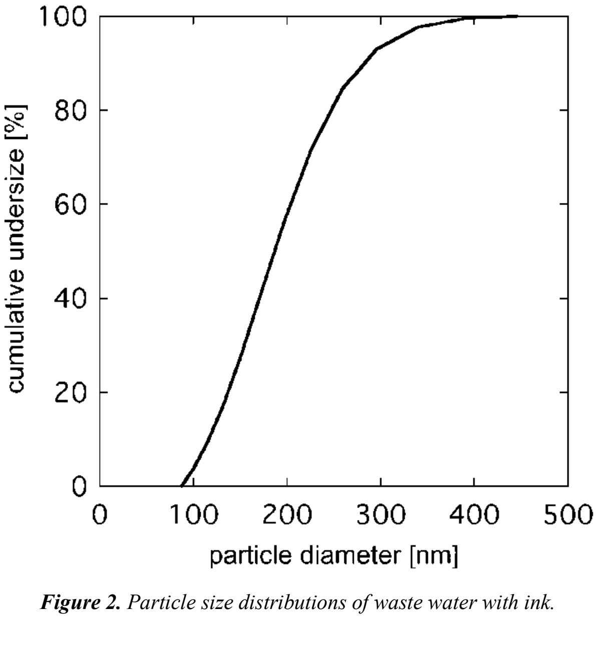

Figure 2. *Particle size distributions of waste water with ink.*

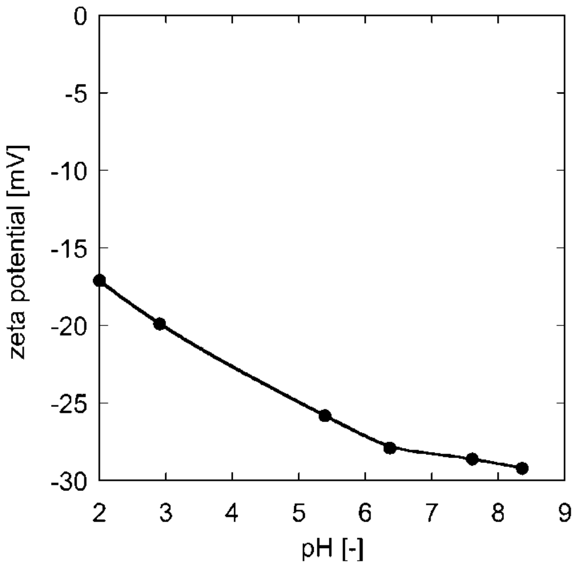

Figure 3. *Zeta potential of waste water with ink as a function of pH.*

3. Results and Discussions

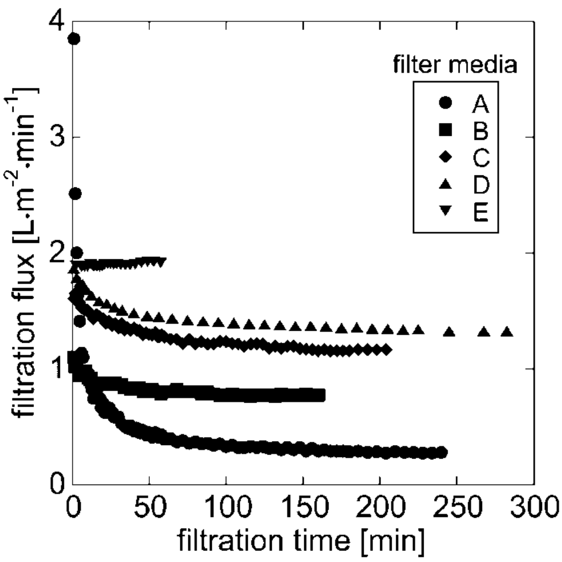

Figure 4. *Time change of the filtration flux.*

Figure 4 shows the time variation of the filtration flux for the different filters. A difference was seen in the decreasing behavior of filtration flux. However, the initial filtration flux depended on the filter media because the pore size or thickness of each filter was different.

To evaluate quantitatively, it was compared by the decreasing ratio of the filtration flux based on the initial filtration flux. We can classify the decreasing behavior of filtration flux into three categories. The first case is that the filtration flux decreased rapidly, such as for Filter A. In this case, the filtration flux was reduced to 10% of the initial value due to the rapid increase of fouled particles. The second case is that the filtration flux decreased slowly, and the filtration flux reduced to about 70 to 80% of the initial value. In this case, such as for Filters B, C, and D, the fouled particle also increased, but its increase rate was slow. In the third case, as with Filter E, the filtration flux did not decrease, meaning that there is no fouled particle in the filter media. These results show that the amount of fouled particle in uniform time is different for each filter.

To analyze this phenomena, SEM images and 3D-SEM images of the surface of the inside wall of each filter media are shown in Figures 5 and 6, respectively. These images show that a filter with a rough surface, such as Filter A, causes a rapid decrease of the filtration flux. On the other hand, in the case of a filter with a very smooth surface, such as Filter E, the filtration flux does not decrease.

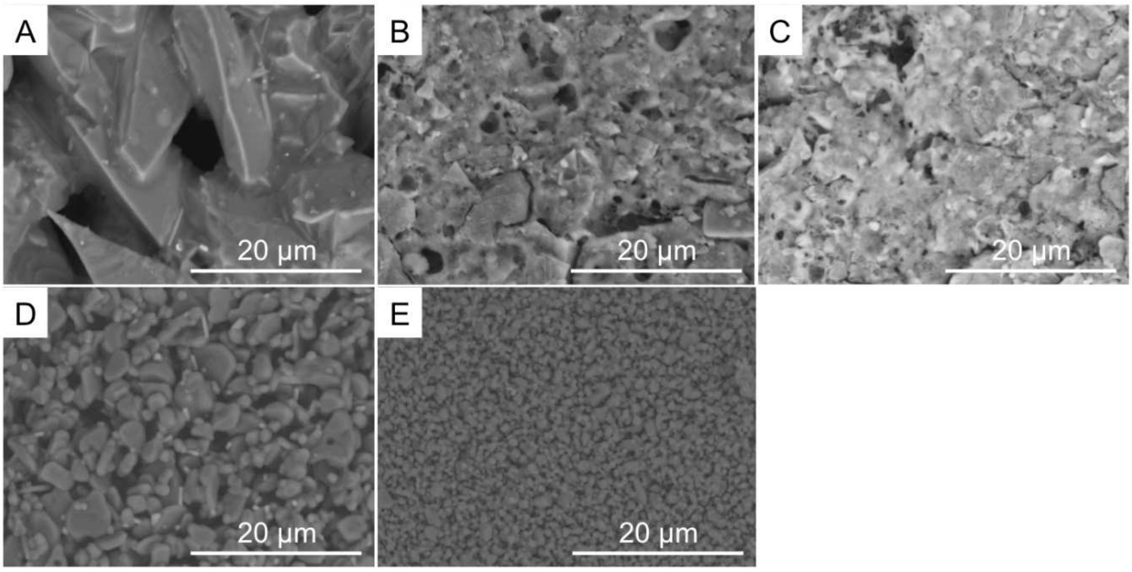

Figure 5. *SEM images of the inside wall surface of various filter media.*

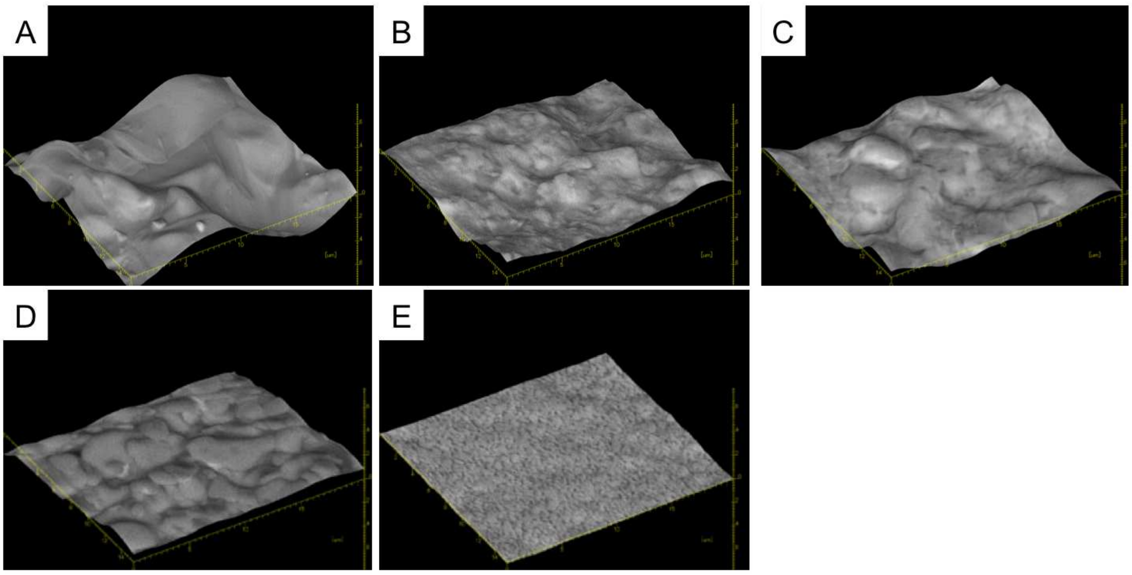

Figure 6. *3D-SEM images of the inside wall surface of various filter media.*

To make the analysis more clear, the classified color map image is shown in Figure 7. The surface image of Filter A is colorful, which shows that Filter A has very high surface roughness. On the other hand, the color in the image of Filter E is uniform, which shows that Filter E has a very smooth surface.

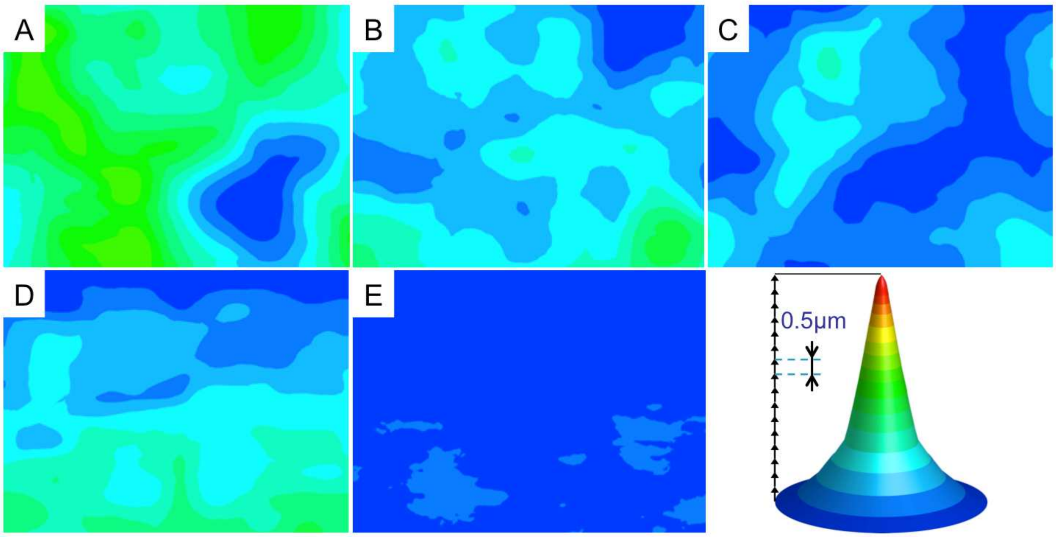

Figure 7. *Surface height distribution of inside wall, classified every 0.5μm, of various filter media.*

To evaluate the effect of the surface roughness quantitatively, the surface height distribution is shown in Figure 8. Here, the average surface height in Figure 8, $\delta_{0.5}$, was defined as the characteristic surface roughness. The relationship between the characteristic surface roughness and the decrease ratio of filtration flux, (the ratio of the filtration flux when it became constant, q_f, to initial one, q_0, in Figure 4) are plotted in Figure 9. This graph shows that surface roughness has a good correlation with the decrease ratio of filtration flux.

These results indicate that, when a filter having high surface roughness of inside wall was used, the flow field in the filter was disturbed and complicated flow occurs on the surface of the filter media, as shown in Figure 10. Thus, particles fouled in the indentation on the filter surface. On the other hand, when a smooth inner surface filter was used, the flow field in the filter was not disturbed. In this case, particles are carried not on filtrate but on a main slurry flow because of their inertia. This mechanism for fouling of particles behind the peaks of the roughness is equally observed in the deposition of sand particles on the leeward side of the obstacles such as behind islands, rocks etc. There are eddys behind the obstacles, which cause low velocity and deposition of particles. Therefore, there are no fouled particles in the filter media. In addition, from the fact that Filter E provided the highest steady filtration flux in Figure 4, it seems to be that the filter having very smooth surface roughness of inside wall has high filtration performance. This is a subject for future analysis.

These results show that to improve efficiency of this system, choose a filter media that has a smooth surface is necessary.

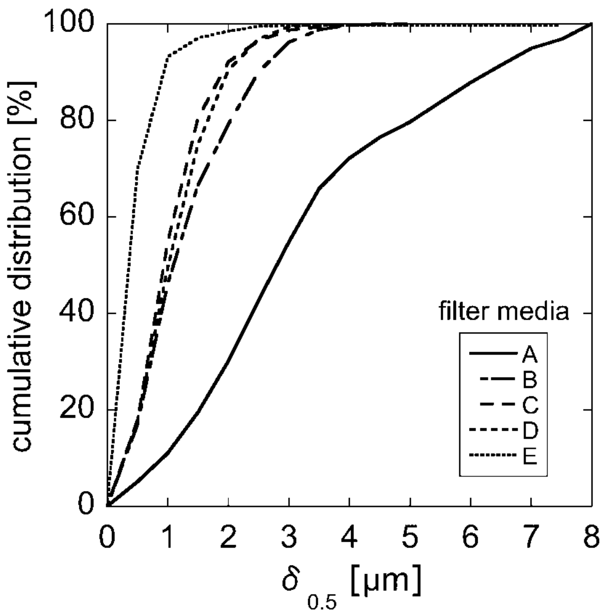

Figure 8. *Surface height distribution of the inner surface for various filter media.*

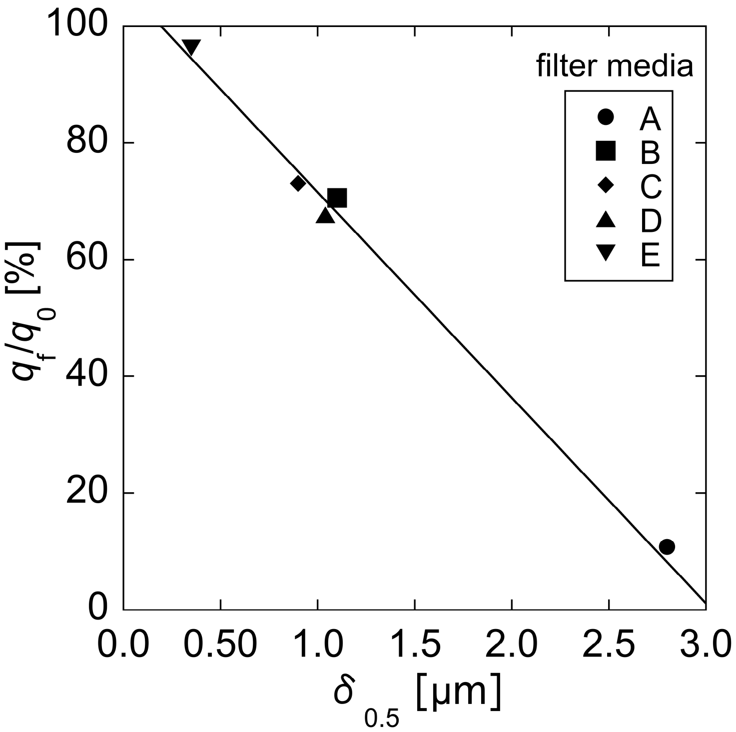

Figure 9. *Relationship between surface roughness and the decrease ratio of filtration flux.*

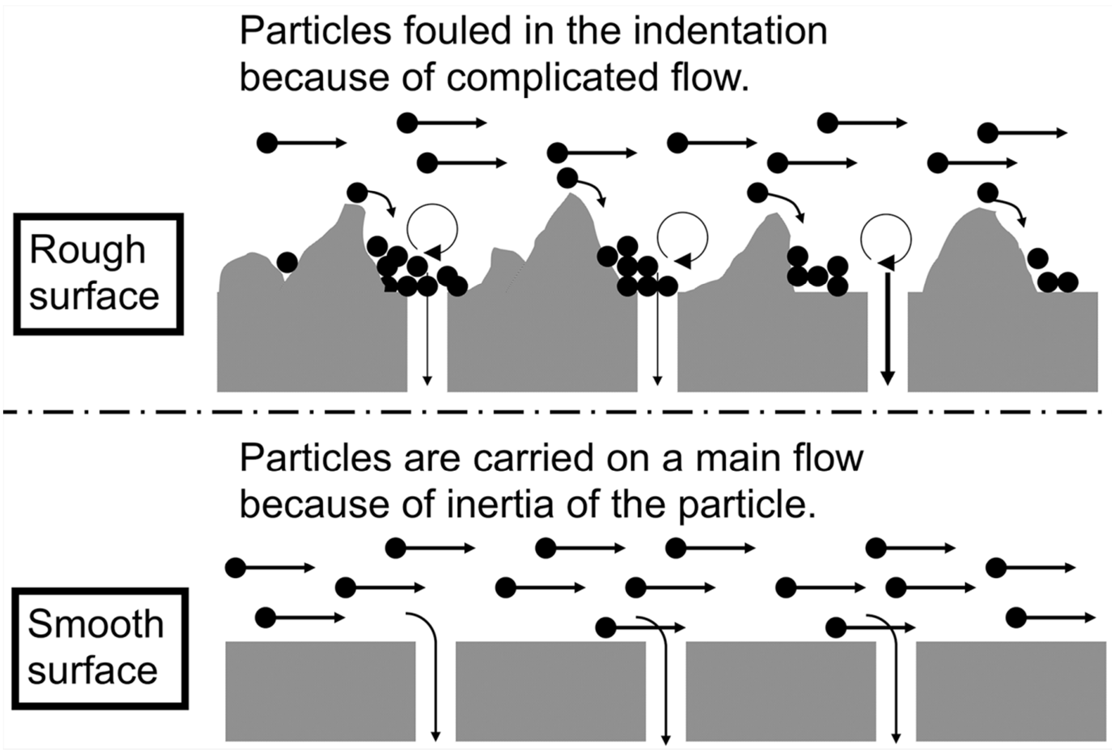

Figure 10. *Schematic of the effect of filter surface roughness on filtration behavior.*

4. Conclusions

In order to investigate the effect of the surface roughness of the filter media on the filtration flux and to clarify the most suitable filter for this system, waste water with ink as a sample slurry was filtered by various filters with different surface roughness. The filter media having smooth surface was determined to be suitable for this system. The reasons are as follows. Such a filter can prevent a disturbed flow field in the filter. In an undisturbed flow field, the particle is carried on a main slurry flow because of its inertia. As a result, there is no fouled particle in the filter media, and the filtration flux is maintained nearly constant for a long time.

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Nomenclature

$\delta_{0.5}$	characteristic surface roughness
q_f	filtration flux when it became constant,
q_0	initial filtration flux

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