Model analysis and its evidence for particle removability of pressed non-woven fabric membrane

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***Abstract*— Low cost membranes for water treatment using a pressed non-woven fabric membrane are proposed. The pressed non-woven fabric membranes are applied in the novel separation technologies of the pore diffusion separation under the flow fractionation. The particle removal was evaluated by both computer simulation and experimental method. The simulation demonstrated that when the particle size increased the probability of the particle ejection through the membrane pores decreased and when the particle located far from the membrane surface the above probability decreased also. The experimental results showed the similar tendency to the model computer analysis.**

I. Introduction

Due to the increase in the world population and the economic development, the water shortage has become a serious problem. To solve the water shortage, many technologies of water treatment have been developed. The water treatment required for developing countries must be small size, easy to handle and low cost, since it is not easy to build large-scale infrastructure. A problem of a centralized city is also needed to concern. Due to old facilities of domestic infrastructure, it will be good chance to convert them to such small size equipments.

In the case of installing small equipments, the operation system must be simple. A membrane separation may be the most effective for these demands. The current membrane separation is known to be very expensive due to the high production cost of the membrane.

In the previous paper, the pressed non-woven fabric membrane for water treatment has been proposed as the low cost membranes[1], and the novel low cost separation technology such as the pore diffusion and the flow fractionation has been evaluated.

The pore diffusion, defined as the diffusion of a substance in a pore of a membrane, is the separation technique under no plugging [2]. Water molecule passes through pores in the membrane by diffusion and also is filtered through a bulk flow under the low trans membrane pressure such as less than 0.1 atm. The particles shift their position to the place where shows the higher flow rate. This shift has been named as the flow fractionation[3],[4] originated from the σ effect[3]. The particles cannot pass through pores of the membrane, and then, is separated from water. One of the features of the pore diffusion is high level of particle removability. On the other hand, slow filtration rate is a disadvantage.

The flow fractionation separation has been proposed for the porous membrane[4]. The separation mechanism is based on the flow fractionation effect that occurs by quickened flow rate[5]. The flow fractionation effect is observed in blood flow[6]. By the use of this effect we may maintain a stable long-term filtration performance. For example, red blood cells move to the center of the blood vessel by the effect resulting the stable filtration[7][8]. When we use this effect in the filtration process of aqueous solution, it is possible to remove particles by low pressure filtration. The flow fractionation effect is observed only in the case of the shear stress to the particles exceed over the critical value that originates the rotational motion of the particles in a flow stream. This indicates that the flow stream of a given aqueous solution must be the laminar flow and the flow should give the shear rate to the particles. The shear rate, τ, is given by the following equation (1).

$$\tau = V / t \qquad (1)$$

Where V is the flow rate (mm/s), t is the width of the flow path (mm). When the particles size are a sub-micron, more than 20 sec^{-1} shear rate works effectively on the rotational motion of the particles.

Even in the case of the pressed non-woven fabric membrane, the flow fractionation and also the pore diffusion may be applicable since the surface of the

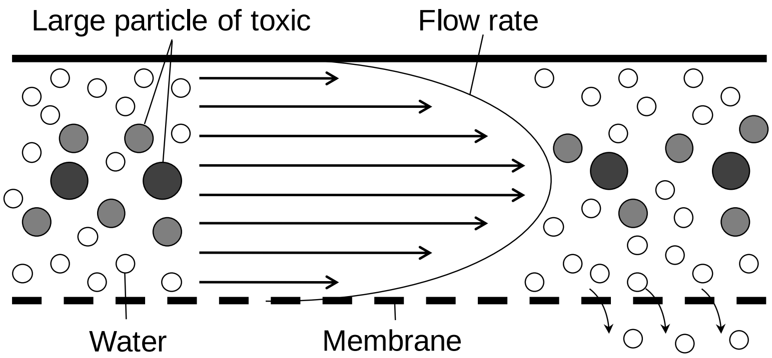

Fig.1: Schematic representation of the flow fractionation mechanism: The lengths of arrows stand for the amount of flow rate and are represented by a parabolic curve.

membrane is smooth[1] although its mean pore size exceeds over 1 µm. We can expect the development of the novel low cost and small scale equipment for water treatment.

In this paper, we will evaluate the particle removability using both methods of the computer simulation and experimental filtration with the membrane. The wastewater containing particles may be employed and the separation performances including particle removability may be evaluated. We intend to show (1)the separation mechanism for the novel separation technology including the pore diffusion and the flow fractionation, and (2)confirmation of the effectiveness of the no-woven fabric membrane to the solution treated with the nucleating reagent.

II. Methods

A. Pressed non-woven fabric membrane

Regenerated cellulose filament non-woven fabric (The non-woven fabric membrane) was prepared by copper ammonium process (100g / m² basis weight, 390 µm thickness, Ra=21.1 µm surface roughness), and roller pressed to more than 50 % of the compression rate in a wet condition by a mechanical roller press machine. The average pore size of the original non-woven fabric was about 100 µm including support mesh pore size.

Average pore size of the membrane 2rf was calculated by putting the filtration rate of distilled water J into the following formula (2).

$$2rf = 2\left(\frac{J \times d \times \eta}{\Delta P \times A \times Pr\rho}\right)^{1/2} \qquad (2)$$

Where J is the observed value in (mL / min), d is the membrane thickness (µm), ⊿P is pressure difference (mmHg), A is the membrane area (m^2). Prρ is porosity of the membrane and in calculated though the eq. of "1 - (cellulose density / membrane density)". η is the viscosity of water.

The compression ratio was calculated with the thickness of the membrane before and after pressing. Compression ratio is given by the following equation (2).

$$\text{Compression ratio} = (T1-T2)/T1 \times 100 \qquad (2)$$

Where T1 is the thickness of non-woven fabric membrane before pressing, T2 is the thickness after pressing.

B. Nucleation of particles in raw water

A sewage waste water was employed as a raw water where the particles were generated. The sewage was sampled from a sewage farm of the city of Kitakyushu in Japan. Original COD of the solution was 185 ppm.

After, 40 ppm of sodium hypochlorite and 50 ppm of ferric chloride added to the sewage waste water for oxidation and mixed by aeration in 30 minutes, 500 ppm of $Ca(OH)_2$ was added for nucleation and mixed by aeration in 30 minutes. The size and quantity of particles were measured by Laser particle size analyzer LS 230 (Beckman Coulter inc.).

C. Computer simulation of particle ejection

A computerized simulating software, STREAM ver.8 (CRADLE Inc.), was used for the estimation of the location of the particle in the laminar flow as the function of time and of the position of the particle in generation. The ejection means that the particle goes through out from primary side(original waste water side) to secondary side(filtrate side) via membrane.

The flow pass had the orthogonal cross section of 2 mm x 2 mm x 200 mm (Fig.2). The flow rate in the primary side, V_{in}, was 92 mm/s. The particle size was selected 3 sizes of 1, 10, 100 µm. The distance from particles to membrane surface, h, was 250-750 µm. The filtrate speed condition, V_{yout}, was 0.022-0.33 mm/s.

D. Experimental evaluation of filtration performance

The filtration performance was evaluated by filtering waste water through the pressed non-woven fabric membrane using the filtration equipment designed for the pore diffusion and the flow fractionation. The waste water includes the nucleated particle of toxic materials. The particles were filtered through the pressed non-woven fabric membrane. The Filtration performance was evaluated by measuring the particle size and the quantity of the particles in the raw water and the filtrate.

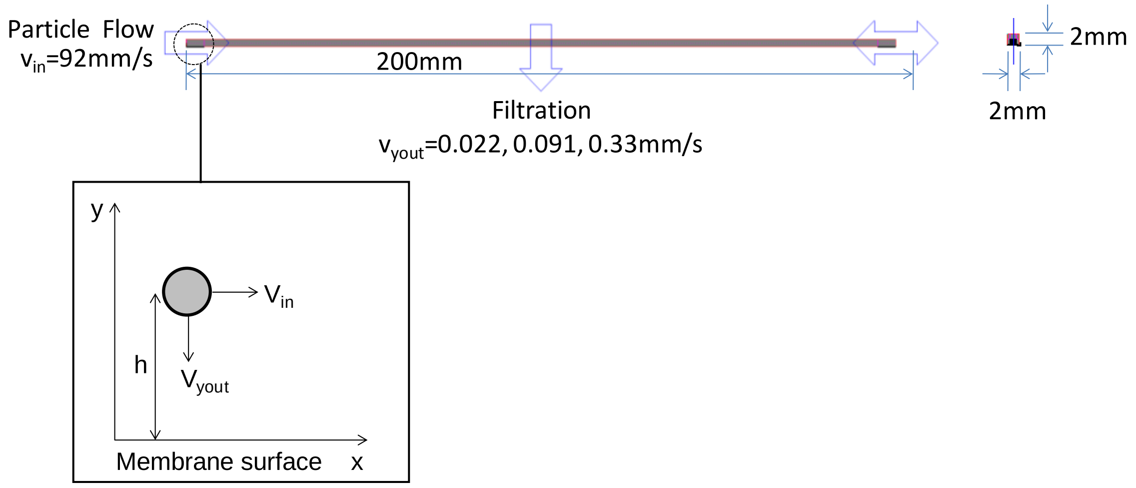

Fig.2: Model analysis condition

III. RESULTS AND DISCUSSION

A. *Pressed non-woven fabric membrane*

The pressed non-woven fabric membrane was prepared under the same condition in the previous paper[1]. The compression rate was 52.6%. The average pore size was about 8 μm after the compression.

B. *Nucleation of particles in raw water*

The particle size in the raw water was 17 μm as a peak in the distribution curve vs log (particle size) and 31 μm as average size (Fig.3). There were two peaks located at 17 μm and 1 gentle curve of 0.1-1μm. It might be occurred by stirring of a circulation pump of the filtration equipment.

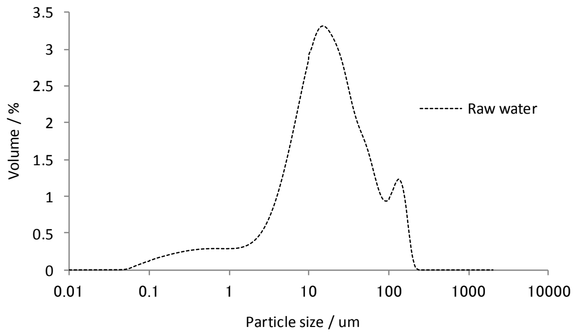

Fig.3: Particle size distribution of the raw water

C. *Model analysis of particle ejection*

The simulation results are summarized in Fig.4. The figure shows the area, expressed by the co-ordinates of V_{yout} (y-axis) and particles size (x-axis), where the particles at the heights of 250 μm, 500 μm and 750 μmfrom the membrane surface retain in the flow without ejection through pores. In the case of further distance between a particle and membrane surface, the particle ejection was decreased. In the case of bigger particle, the ejection probability of the particle at the same position is decreased.

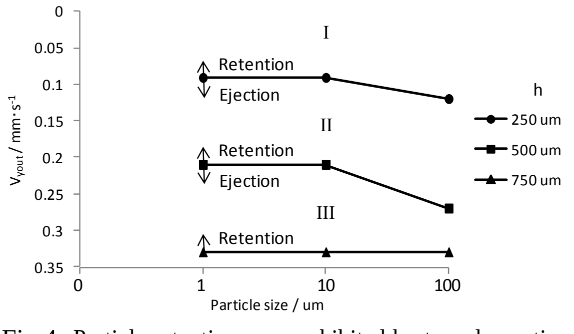

Fig.4: Particle retentive zone exhibited by two-dementional map of V_{yout} and particle size; Zone I stands for the region where the particle located at h=250um remains in the flow solution under V_{in} of 92mm/s, Zone I+II stands for the remaining region for the particle at h=500um and Zone I+II+III stands for the remaining region for the particle at h=750um.

D. *Experimental evaluation of particle removal*

Fig.5 shows experimental filtrate of each of V_{yout}. The rightmost is the raw water and it has the most vivid color. With slower V_{yout} speed, its color becomes clear. It means slower V_{yout} gives higher removability of the particle with wide range of size. The experimental filtrates showed mostly the same results of the model simulation.

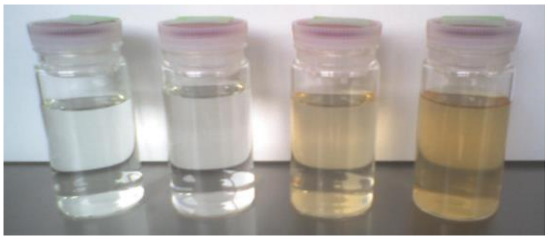

Fig.5: Observation of solutions before and after treatment; From left side, the solutions are treated under V_{yout}=0.022mm/s, 0.091mm/s and 0.33mm/s, respectively, and the solution at right end is the solution before treatment.

Fig.6 is the particle size distributions of raw water and two filtrates. Filtrate 1 indicates the filtrate obtained under 0.33mm/s of V_{yout}, and the Filtrate 2 indicates the filtrate obtained under 0.091mm/s. The Filtrate of 0.022mm/s could not be evaluated through a light scattering method because of too clear. A comparison between the solution before treatment and the filtrate 1 indicates that particles over 40 μm were removed by the filtration, and the filtrate 2 indicates that particles over 3 μm were removed.

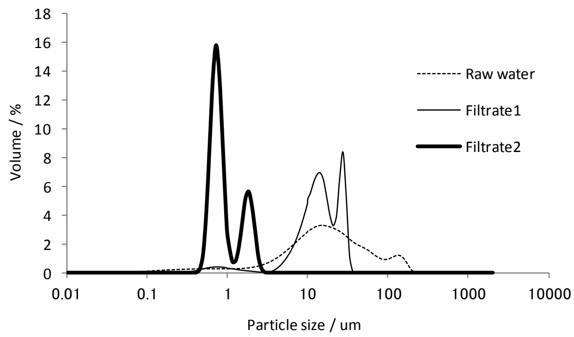

Fig.6: Particle size distribution of the raw water and the filtrate;
Filtrate1: V_{yout}=0.33mm/s, Filtrate2:V_{yout}=0.091mm/s

In the filtrate2, it has no peak around 10μm. It means the nucleated particles around 10 μm stay in the primary side in 0.091mm/s of V_{yout}. As for two big peaks around 1 μm of the filtrate 2, bigger particles than 1 μm in the primary side might be comminuted by the shear stress of the circulation pump of the filtration equipment.

IV. CONCLUSION

The novel membrane separation technology employed both of the pore diffusion and the flow fractionation mechanisms worked effectively to the solution treated with the nucleating reagent for the removal of particles with the non-woven fabric membrane. The removability was originated from the flow fractionation mechanism and the activity of the Brownian motion in addition to the sieving of pores.

The contribution of the flow fractionation was reproducible by the computer simulation of the movement of a particle in fluid flow.

V. Acknowledgements

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VI. References

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