Characterization and filtration performance of pressed non-woven fabric membrane

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***Abstract*— Low cost membranes for water treatment using non-woven fabric membrane are proposed. The non-woven fabric membranes are applied in the novel separation technologies that are the pore diffusion separation and the flow fractional separation. The compression ratio, surface roughness and pore size of the membrane were evaluated in the correlation of their filtration performance. It was able to reduce the membrane thickness, the surface roughness and the average pore size of the non-woven fabric membrane by pressing in wet state. It was confirmed the particles with more than 10 µm could be removed completely and it was maintained almost stable between two days (3000 minutes) and almost no clogging was observed.**

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-scale equipments.

In the case of installing small devices, the operation system must be simple, because the local people has to operate them. A membrane separation may be the most effective. The membrane separation device currently on the market is very expensive. The reason of the price increases is the high production cost of the membrane.

In this paper, one of the low cost membranes for water treatment is proposed. The membrane using non-woven fabric is manufactured by mass production. The authors think the non-woven fabric membrane can be applied for water treatment and it is possible to develop a novel separation membrane having a micron pore size.

The pore diffusion, defined as the diffusion of a substance in a pore of a membrane, is the technique to separate the large particles and water[1]. Water molecule passes through the inside of the membrane with a multilayer structure by diffusion and also is filtered through a bulk flow. The particles shift their position to the place where shows the higher flow rate. The particles cannot be entered to the internal pores of the membrane, and then, is separated from water. One of the features of the pore diffusion is high level of particle removal ability. On the other hand, slow filtration rate is a disadvantage. Non-woven fabric membrane can be satisfied for the demand of low cost in membrane technology.

The flow fractionation separation has been proposed for the porous membrane[2]. The separation mechanism is based on the flow fractionation effect (or the collection axis effect) that occurs by quickened flow rate[3] (Fig.1). The flow fractionation effect is observed in blood flow within the human body[4]. By the use of this effect we may maintain a stable long-term filtration performance. For example, red blood cells moves to the center of the blood vessel by the effect resulting the stable filtration[5][6]. When we use this effect in the filtration prosecc of aqueous solution, it is possible to separate particles and water 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.

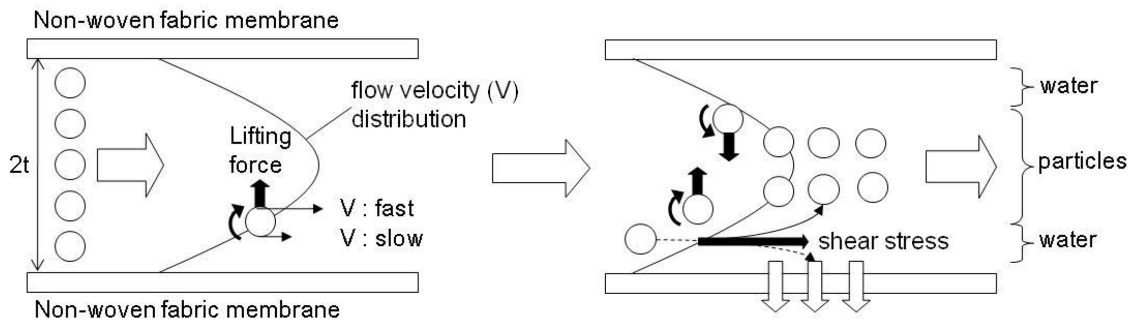


Fig.1: The flow fractionation effect diagram

Even in the case of the non-woven fabric membrane, the flow fractionation is available and also the pore diffusion is applicable. We can expect the development of the novel low cost and small scale equipment for water treatment.

In this paper, we will prepare a prototype non-woven fabric membrane by pressing a commercial available non-woven fabric. The pressed non-woven fabric may be evaluated compression ratio, surface roughness and an average pore size. The wastewater containing particles of a certain particle size may be employed and the separation performances including particle removal ability and filtration speed may be evaluated. We intend to evaluate the potential application for the novel separation technology.

II. Methods

A. 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 or hot pressed in a wet condition. Hot press was operated by hand with a heated iron. Roller press machine was used for the roller press. The average pore size of the original regenerated cellulose filament non-woven fabric was about 100 μm including support mesh pore size.

B. Compression ratio

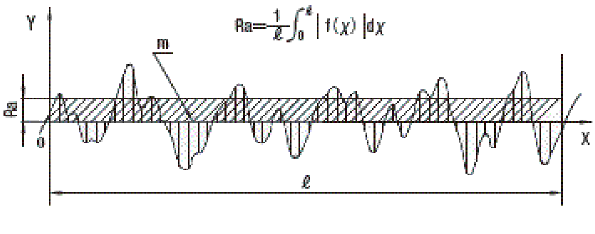
The compression ratio was calculated with the thickness of the membrane before and after pressing. Compression ratio is given by the following equation (2).

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

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

C. Surface roughness

The surface roughness of the pressed non-woven fabric by the roller press was measured. The surface roughness is represented by the average roughness Ra. When the highly of the surface of the fabric is expressed in y = f(χ), in micrometers (μm), Ra value was determined by the equation shown in the figure below the roughness curve.



$$Ra=\frac{1}{\ell}\int_0^{\ell}|f(\chi)|d\chi$$

Fig.2: Surface roughness Figure

D. Average pore size

Average pore size of the membrane, more than 50% compression ratio, was measured by the filtration rate of distilled water by the following formula (3).

$$2rf=2\left(\frac{J\times d\times \eta}{\varDelta P\times A\times Pr\rho}\right)^{1/2} \qquad (3)$$

Where J is the flow rate (mL / min), d is the thickness (μm), ⊿P is pressure difference (mmHg), A is the membrane area (m^2). These are using the measured values. Pr ρ is "1 - (cellulose density / membrane density)". η is the viscosity.

E. Evaluation of filtration performance

The separation performance was evaluated by filtering waste water through the non-woven fabric membrane. The waste water includes the large particle of toxic flocculated materials by using flocculating agent (nucleating agent). The flocculated materials, about 20 μm particle size (measured by DLS, Dynamic light scattering. See Fig.3), were stirred by a pump of the flow fractionation separation unit and crushed by shear force to smaller particles about 10μm to be around. The particles were filtered through the pressed non-woven fabric membrane.

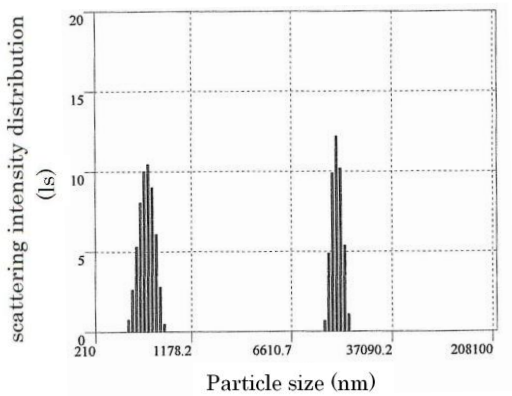


Fig.3: Particle size distribution of the flocculated materials (nm)

III. Results and discussion

A. Non-woven fabric membrane

Regenerated cellulose filament non-woven fabric by copper ammonium process was pressed by roller press machine at 30 C in wet condition.

The cross-section of the pressed non-woven fabric membrane was observed with a microscope. Distribution of fiber was measured as a function of the distance from the surface of non-woven fabric and total fiber number per cross-sectional area unit. The number of fiber cross-section present in the layer of 500 μm length and 50 μm depth of the cross-sectional view was more than 10 in any layer. Pulsation of the number had been within 2 times of the number and the average number of 0 and those values are the number of fiber cross-section present in the layer at 500 μm length 10 μm depth cross-sectional direction also. The pulsation indicates that non-woven fabric membrane has a laminated multilayered structure. This multilayered structure is one of the most important factors for the separation by the use of a membrane. Thus this prototype non-woven fabric membrane can be expected having a certain separation performance.

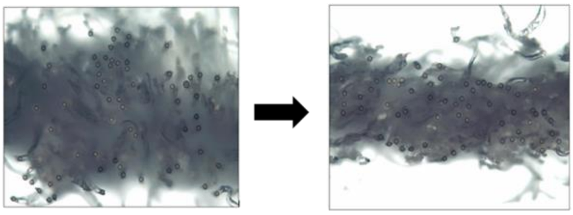


Fig.4: Cross-sectional view of the non-woven fabric membrane (left: original, right: pressed)

B. Compression ratio

Compression ratio of the pressed non-woven fabric membrane was measured. The observed compression rate of the hot pressed membrane was 11.8%. The edge of the Roller Pressed membrane was 52.6% and at the center of it was 43.2%.

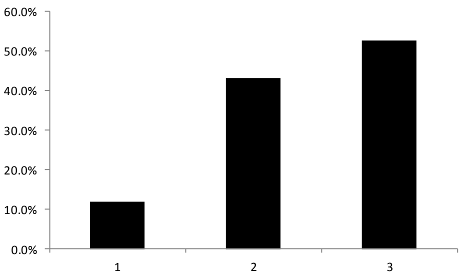


Fig5: Compression ratio of membrane prepared by pressing; 1.Hot press, 2.Rollar press (center), 3.Rollar press (edge)

C. Surface roughness

Surface roughness was measured before and after the press of the non-woven fabric membrane. The original non-woven fabric was Ra (μm) = 21.1, the hot Pressed membrane was Ra (μm) = 13.9, roller pressed (center) Ra (μm) = 17.1, (edge) Ra (μm) = 7.7. For water treatment, it might be necessary to make the surface roughness small as like less than Ra = 10 to realize laminar flow. It is necessary to clarify the condition of the edge of the roller pressed non-woven fabric membrane in order to get the reproducible manufacturing. Fig.6 represents the value of Ra for four membranes.

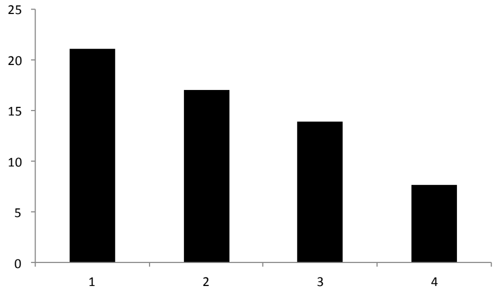


Fig.6:Surface roughness Ra. 1.Original, 2.Hot press, 3.Rollar press (center), 4.Rollar press (edge)

D. Average pore size

Pressed non-woven fabric membranes were prepared in industrial scale under the conditions of 52.6% compression rate. The average pore size of the membrane was measured through the water filtration rate method. The average pore size was about 8 μm degree, as shown Fig.6.

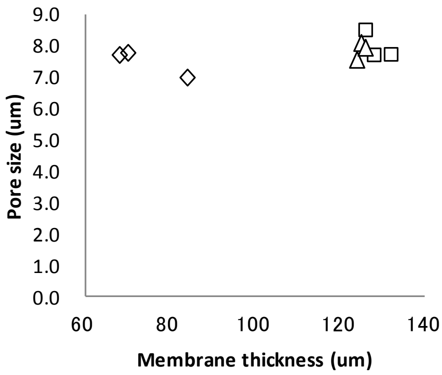


Fig.6: Change in pore size with thickness of membrane; prepared by compression rate 52.6 %

E. Evaluation of filtration performance

By using the non-woven fabric membrane prepared in industrial scale, a wastewater was filtered and its separation performance was evaluated. After filtration, large particles with more than 10 μm in the waste water were almost cleared by visual inspection.

The filtration rate in this filtration experiment could maintain at a stable filtration rate about two days (3,000 minutes) and almost no clogging was observed.

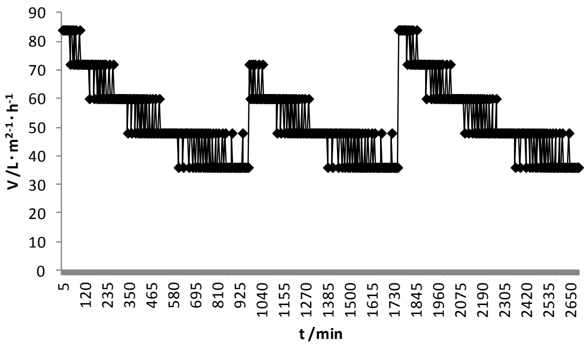


Fig.7: Filtration performance

IV. CONCLUSION

It was possible to compress and reduce the thickness of the non-woven fabric membrane in the wet state.

It was able to reduce the surface roughness and the average pore size of the non-woven fabric membrane by pressing.

It was confirmed the particle removal performance for 10 μm particle size. The performance maintained almost stable between two days (3000 minutes) and almost no clogging was observed under the flow fractionation and the pore diffusion.

V. ACKNOWLEDGEMENTS

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VI. REFERENCES

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