The flow simulation in the membrane module of PRO using concentrated brine

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I. INTRODUCTION

Although nuclear energy and a fossil fuels occupy most as our energy source today, considering the influence on safety or environment, and fossil fuel drain, the necessity for clean energy is increasing. Various researches about clean energy generation power were made and those have been put to practical use. For example, as for wind power generation, there are the problem of noise and the instability of electric power. Then for water-power generation, a large-scale institution is required, and its place which can be installed is restricted. In order to solve such a problem, concentration difference power was drafted by S.Loeb.[1]

If the solution in which concentration differed like sea water and fresh water is divided with a semi permeable membrane, a solvent will begin osmosis toward the high concentration solution side from the low concentration solution side, the water level by the side of high concentration will go up, and the low concentration solution side will fall. At this time, concentration difference energy is transformed into mechanical energy as a product of water pressure and permeated water. Concentration difference power is the power generation system which changes this energy to shaft output.

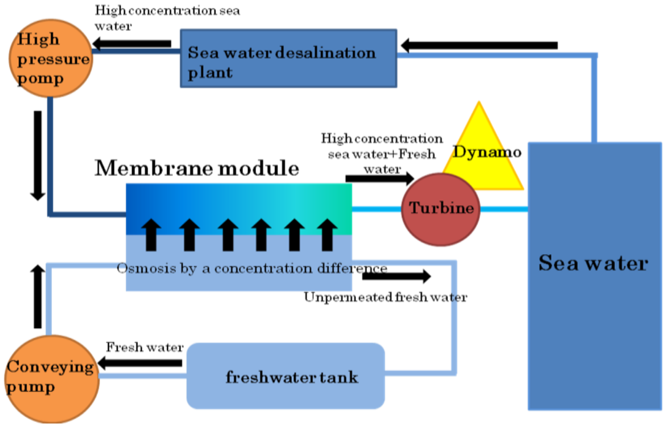

Figure 1. Whale figure of Power Generation

Moreover, there is no noise fundamentally, and it can installed also in the big city where population crowd and can also suppress a power transmission loss.

Honda proposed 2 division type osmosis equipment using a hollow fiber in order to examine an output performance of the submarine installation type and a tank change type, and the power generation simulated prior to now.[2] The output increased about 4 times as compare with the conventional sea water pressurization type, the specific output per membrane surface area has obtained about 0.5 [W/m^2], and the specific output per fresh water supply flow rate has obtained about 0.1 [kWh/m^3] and the following result are pointed out. (1)Presentation of how to predict the sea water PRO (Pressure Returned Osmosis) performance in considering the boundary layer in sea water flow (2) When there is a flow of sea water along emulsion side, it is possible to reduce the influence of a concentration fall. (3) Coincidence of the tendency of the theoretical value and experimental value of the amount of fresh water osmosis (4) It is equivalent to a part for several plants in the main river amount of water in Japan. Those basic researches have been performed by Akio Ihara and others.[3] Moreover, for the high concentrated brine of the sea water, the examination of 2 [kW] of outputs was done and the effective output of 0.5 [kW] was obtained.[4] It is thought that an improvement of the amount of osmosis is exhausted to the prevention of fowling to polymeric membrane and a countermeasure of diffusion polarization of a pressure-retarded osmosis membrane module. Moreover, we pointed out the good relationship between the pressure of the fresh water which flows inside the hollow fiber, and the path of a hollow fiber. But, a flow of the PRO module is not cleaned, and the performance of it is not good.

This research is the analysis about numeric simulation which is associated with the flow of the PRO module.

II. THE THEORY OF FLUID FLOW SIMULATION IN THE MODULE

A. The measurement method of the amount of osmosis

Under the present circumstances, since a pressure-retarded osmosis (POR) membrane module was not developed, the model was aimed at a reverse osmosis (RO) membrane module currently used in the sea-water desalinization

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institution. Figure 2 is the whole module model. High concentration sea water flows in from a center pipe, and spreads in the whole hollow fiber element in a module. Fresh water permeates from the element which one hundred tens of micrometer hollow fiber, figure 3, knit in the diameter, and was crowded, and high concentration sea water is diluted and discharged.

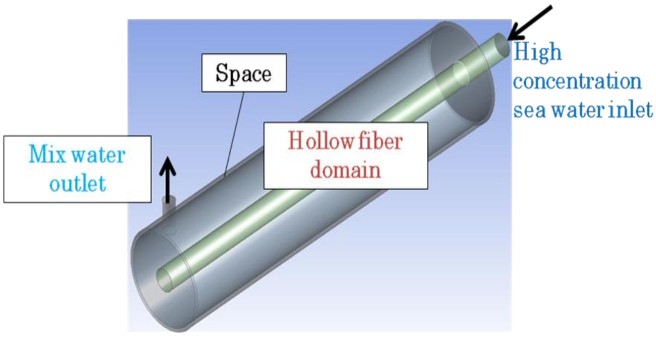

Figure 2. Symuration model of module

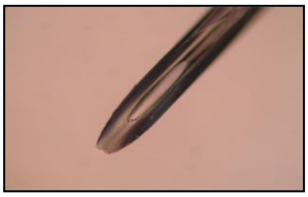

Figure 3. Hollow fiber

The osmotic pressure which arises in the osmotic phenomenon in an element follows the formula of van't Hoff.

$$\pi = MPT \qquad (1)$$

(π: Osmotic pressure[Pa] M: Molar concentration[kmol/m^3] R:Gas constant[kg･ m^2 /s^2･ kmol･ K] T:Temperature[K])

The amount of osmosis J_w [kg/s] follows the following formula.

$$J_w = A(\Delta P - \Delta\pi) \cdot a \qquad (2)$$

(A:Water permeability coefficient[m/s・MPa] ΔP: Difference pressure of sea water and fresh water [MPa] Δπ: Osmotic pressure between sea water and fresh water [MPa] a:Membrane surface area[m^2]).

B. The primitive equation of the sea water side flow

The flow of the sea water in a module and the flow of the fresh water are denoted by the equation of continuity, the Navier-stokes equation, and the diffusion equation.

$$\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial x_j}(\rho U_j) = 0 \qquad (3)$$

$$\frac{\partial \rho U_i}{\partial t} + \frac{\partial}{\partial x_j}(\rho U_i U_j) = -\frac{\partial p}{\partial x_i} + \frac{\partial p}{\partial x_j}(\tau_{ij} - \rho \overline{u_i u_j}) + S_M \qquad (4)$$

$$\frac{\partial(\rho\Phi)}{\partial t} + \nabla(\rho U\Phi) = \nabla\left\{(\rho D_\phi + \frac{\mu_t}{S_{ct}})\nabla_\Phi\right\} + S_\Phi \qquad (5)$$

(ρ:Density[kg/m^3] $U_{i,j}$:Vector of velocity[m/s] P:pressure[Pa] τ:Molecular stress tensor[kg/m・s^2] ρ_{uiuj} :Reynolds stress S_M : Momentum source[kg/m^2・s^2] ϕ:Conservative quantity of a given quantity of matter[kg/m^3] $\Phi=\phi/\rho$:Concentration[ ] S_ϕ:Volume source D_ϕ:Scalar diffusion coefficient S_{ct}:Turblent Schmidt number 0.9 μ_t:Turblent viscosity[kg/m・s])

We substitute the equation (6) which shows a loss in case sea of the water penetrates a hollow fiber domain for S_M term of equation (4).

$$S_{M,i} = -\frac{\mu}{K_{perm}}U_i - K_{loss}\frac{\rho}{2}|U|U_i \qquad (6)$$

(μ:Coefficient of viscosity[kg/m・s] κ_{perm}:Permeability coefficient[m^2] κ_{loss}:Loss coefficient[1/m] U_i:Component of velocity[m/s] |U|:Quantity of velocity[m/s])

III. THE SIMULATION CONDITIONS

The number of elements was 1,520,000. Mass flow rate at the inlet is 0.325[kg/s], temperature is 20 degrees, the salt concentration is 7%. Hydrostatic pressure at the outlet is 0[MPa]. The hollow fiber domain is set up the resistance loss. Permeability coefficient(κ_{perm}) is 0.0000001[m^2], Loss coefficient(κ_{loss}) is 1[1/m]. The loss by the viscous loss of the 1st term in eq.(6) is larger than the inertia loss of the 2nd in eq.(6) type, because flow velocity is slow in this simulation.

IV. THE RESULT OF SIMULATION

Velocity vector diagram in a module is shown Figure 4. To see the flow, the high concentration sea water reaches the center pipe back, it spread the hollow fiber area, and flow toward the direction of Outlet. The velocity in the center pipe is very large, but the flow velocity in the hollow fiber domain is very as slow as 0.004 [m/s]. A flow is seldom seen in the hollow fiber area. The outlet flow velocity is accelerating about 3.7 [m/s]. Salt concentration diagram is shown in Figure 5. To see salt concentration in the hollow fiber area, in the sea water inlet side, salt concentration has fallen very much with 4%. In the outlet side, salt concentration fall gradually from 7%, and final salt concentration is about 6% at outlet. Since fresh sea water is sent one after another in the large velocity portion, salt concentration is higher. In the portion which does not have large speed, concentration has fallen rapidly towards the modular outside from the interval of the contour line. Osmotic pressure diagram of a hollow fiber area is shown

Figure 6. Osmotic pressure was 3.5[MPa]~6[MPa]. In a portion with a large speed, osmotic pressure is high, and osmotic pressure has fallen rapidly in the portion which does not almost have speed. Amount of osmosis diagram of a hollow fiber area is shown Figure 7. It turns out that the osmosis of fresh water is not equal in module each portion. In the accelerated place, since always sea water flows, many amounts of osmosis have been earned. In the place where speed is slow, because of fresh water permeated in large numbers near the center pipe, and sea water doesn't flow to the outside, the amount of osmosis has fallen. Moreover, the concentration is low and fresh water doesn't flow. The low concentration fluid is left. An amount of osmosis flow of the hollow fiber area was 0.4[kg/s]. The percentage of an amount of osmosis flow in an outlet flow (salt water + fresh water) was 0.12, and an osmosis flow is considered to be small compared with the whole flow because of the distortion of the salt water flow and the concentration.

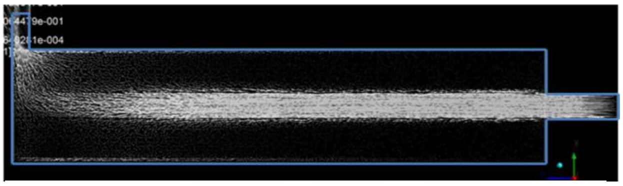

Figure 4. Velocity vector diagram in a module

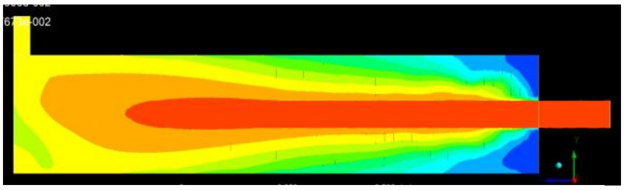

Figure 5. Salt concentration diagram

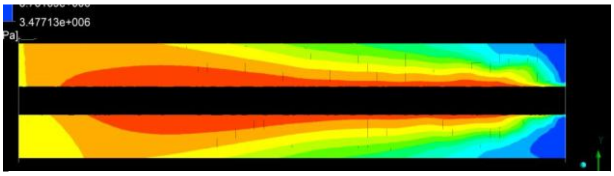

Figure 6. Osmotic pressure diagram of a hollow fiber area

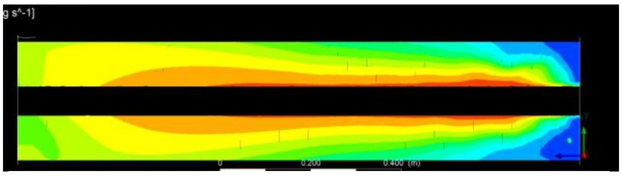

Figure 7. Amount of osmosis diagram of a hollow fiber area

V. CONCLUSION

The flow simulation of the membrane module of PRO, the following results obtained.

1. There is distorted flow in a module.
2. Amount of osmosis is different in a module. At the fresh water collects the amount of osmosis is rapidly decrease.
3. Amount of osmosis in hollow fiber area is about ten percent of the whole.

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