NUMERICAL INVESTIGATION OF EXPERIMENTAL METHODOLOGY FOR SIMULATING SELF-WASTAGE PHENOMENON USING SIMULANT MATERIALS

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ABSTRACT

In a steam generator of sodium-cooled fast reactor, Sodium-Water Reaction (SWR) may takes place if high-pressured water vapor will leak into sodium through a tiny defect on the surface of the heat transfer tube. The SWR may bring deterioration of mechanical strength of the heat transfer tube at the initial leakage site. As a result, the defect will be suddenly enlarged and the leak rate will be sharply increased. This is called Self-wastage phenomenon. In order to evaluate the mechanism of the self-wastage phenomenon, we suggest a new method to evaluate the damage that the surface of the tube by the self-wastage phenomenon. It is assumed that it is able to evaluate damage on the surface of the leak by making the Neutralization reaction with hydrochloric acid (HCl) solution and sodium hydroxide (NaOH) solution. In the present study, a numerical investigation has been carried out to validate the feasibility of the new method and to decide the conditions for the experiment. As the result of the numerical simulation, it is observed that the temperature at the surface near the leak increased by 332.6 K, when 5 mol of HCl solution was injected to 10 mol of NaOH solution with an injection rate of 1.6E-2 cc/sec.

1. INTRODUCTION

A secondary cooling system for a liquid sodium-cooled fast breeder reactor consists of an intermediate exchangers, steam generators, secondary cold traps and liquid sodium pumps. As seen in Fig. 1, in a steam generator of sodium-cooled fast reactor, there exists liquid sodium and a high-pressured water vapor through a thin heat transfer tube. So if a tiny defect occurs at the surface of the heat transfer tube, the high-pressured water vapor will leak into sodium side (outside of tube) so that Sodium-Water Reaction (SWR) will take place. Erosion and Corrosion caused by the SWR may bring a deterioration of mechanical strength of the heat transfer tube at the initial leak site. As a result of the SWR, the defect will be suddenly enlarged and the leak rate will be sharply increased. This is called Self-wastage phenomenon. If the leak continues, the enlarged jet will heat the adjacent heat transfer tube and it will bring impingement wastage (Target wastage).

In order to understand the mechanism of the self-wastage phenomenon, twenty-nine micro leak tests were carried out in three stagnant sodium pots of the SWAT-4 test rigs (SWAT-4 mock-up test) installed in PNC/OEC(1986). According to the experimental measurement, even though the initial leak rate was very small (less than 0.05g/sec), the increased the leak rate reached in the range from 1 to 10g/sec which can cause wastage damage on adjacent tube. This means that if the leakage is continued, the increased reaction jet by the self-wastage phenomenon may affect the adjacent heat transfer tube and may bring the secondary failure of the heat transfer tube.

Fig. 1 Schematic image of Sodium-Water Reaction

Therefore understanding the mechanism of the self-wastage phenomenon and detecting the phenomenon in its early stage are key issues from the view point of designing a steam generator and its leak detection system. So far, in order to evaluate the mechanism of the self-wastage phenomenon, experimental approaches such as the SWAT 4 mock-up test has been carried out to derive a relation about wastage rate using thermal hydraulic properties, under the same conditions as that of the steam generator of the Monju prototype fast breeder reactor. However, since many factors such as initial leakage rate, sodium temperature, steam temperature and shape of the leak, are related to the phenomenon and there exists a large uncertainty in the experiment caused by the lack of accuracy in the measurement skill of thermal hydraulic properties in the
reaction zone. Thus the conventional experimental approach is not sufficient to investigate thermal-hydraulic characteristic of the SWR and the mechanism of the Self-wastage phenomenon.

So we suggested a new method to assess the self-wastage phenomenon through an experiment using a simulant material. This new method focuses on the quantification of the increase rate of the leakage caused by the self-wastage phenomenon. The maximum size of the enlarged leak and its shape are considered to evaluate the increase rate of the leakage.

Since the self-wastage phenomenon is attributed to a chemical reaction which takes place near the outside of the leak. We assumed that it is able to evaluate damage on the surface of the leak by making the Neutralization reaction with hydrochloric acid (HCl) solution and sodium hydroxide (NaOH) solution.

In the present study, a numerical investigation was carried out to validate the feasibility of the new method and to decide the conditions for the experiment. In the analysis, governing equations of concentrations of acid and alkali were implemented in to a commercial CFD tool, Fluent Ver.6.3.26. The reaction rate was calculated based on the Arrhenius law.

2. EXPERIMENTAL METHODOLOGY FOR SIMULATING SELF-WASTAGE PHENOMENON USING SIMULANT MATERIAL

2.1 Experimental Scheme

The sharp increase of the leak rate would take place, when the Self-wastage phenomenon penetrates the surface of the heat transfer tube, so that the width of the leak is enlarged. Therefore, to detect the Self-wastage phenomenon in its early stage and prevent the secondary failure of the heat transfer tube, it is necessary to evaluate the increase rate of the leak rate so that it is available to expect the length of time which take for penetration of the surface by the Self-wastage phenomenon. It is also necessary to assess the maximum size of the enlarged leak to expect the maximum leak rate.

An experiment is designed to evaluate the shape of enlarged leak and the maximum size of the enlarged leak. The self-wastage phenomenon is attributed to a chemical reaction which takes place near the initial leak site. We assumed that it is possible to simulate the damage on the surface of the leak by making the Neutralization reaction. In the experiment, hydrochloric acid solution (HCl) and sodium hydroxide solution (NaOH) were adopted as simulant materials. Paraffin wax (C_{32}H_{62}) which has a low melting point (115°F, 320.5K) was chosen as a simulant material for the nozzle which simulate the heat transfer tube. A schematic of the experiment is shown in Fig. 2. Experimental setup consists of a reaction tank, a paraffin wax nozzle and a solution supply system. In the experiment, HCl solution is injected to the reaction tank which is filled with NaOH solution, so that the neutralization reaction would take place in the outside of nozzle and the reaction heat would be released. As the result of the neutralization reaction, temperature of the wax at the surface would be increased and if the temperature exceeds the melting point of the paraffin wax, the surface of the wax would be melted, so the size of the nozzle would be enlarged. The maximum width of the enlarged the nozzle is evaluated since it is one of key factor to dominate the increase of the leak rate.

![Fig. 2 Experimental Apparatus: A schematic of experiment](image)

2.2 Simulant Material

When HCl solution and NaOH solution are mixed, the following neutralization reaction takes place.

\[
HCl_{(aq)} + NaOH_{(aq)} \rightarrow NaCl_{(aq)} + H_2O + \Delta H
\]  

This reaction is exothermic, as a result of the reaction, a reaction heat ($\Delta H = 55.6 \text{kJ/mol}$) is released. In aqueous solution each reactants are dissociated fully, so that above reaction can be written in the following form (Eigen, M., et al., 1955)

\[
H_3O^+ + OH^- \stackrel{k_f}{\rightleftharpoons} H_2O + 2H_2O
\]

Where $k_f$ and $k_r$ are the rate constants for the chemical reaction. These are listed in Table 1.

<table>
<thead>
<tr>
<th>Rate constant</th>
<th>$k_f$ (mol$^{-1}$m$^{-3}$s$^{-1}$)</th>
<th>$k_r$ (s$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(2)</td>
<td>1.4E+8</td>
<td>2.6E-5</td>
</tr>
</tbody>
</table>

The rate constants show that eqn. (2) consists of the forward reaction and backward reaction. However, compared to the rate constant for the forward reaction, the rate constant for backward reaction is relatively small. Therefore, in the present study the effect of backward reaction was neglected.

The neutralization reaction, which takes place at the outside of the nozzle, simulates the SWR that occurs at the outside of the leak. The surface of the paraffin wax would be melted as the temperature of the surface is increased by the reaction heat which is released from the neutralization. As a result, the size of the wax nozzle would be enlarged. This procedure simulates the
mechanism of the Self-wastage phenomenon.

3. NUMERICAL INVESTIGATION OF EXPERIMENTAL METHODOLOGY

A three-dimensional numerical analysis was conducted to verify the feasibility of the new experimental methodology. In this study, a commercial CFD software, Fluent Ver. 6.3.24 were used for numerical simulation.

3.1 Governing Equations

A three-dimensional unsteady flow of mass transfer with chemical reaction was calculated in this study. The local mass fraction of each species $Y_i$ are predicted through the solution of a convection diffusion equation for the $i$th species. This conservation equation is given by the following form:

$$\frac{\partial}{\partial t}(\rho Y_i) + \nabla \cdot (\rho v Y_i) = -\nabla \cdot \vec{j}_i + R_i \tag{3}$$

Where $R_i$ is the net rate of production of mass of species $i$ per unit volume by chemical reaction. $\vec{j}_i$ is the diffusion flux of species I, which arises due to concentration gradients. The dilute approximation is adopted so that the diffusion flux can be written as

$$\vec{j}_i = -\rho D_{im} \nabla Y_i \tag{4}$$

Here $D_{im}$ is the diffusion coefficient for species $i$ in the mixture. For the net reaction rate, the laminar finite-rate model is adopted. This computes the chemical source terms using the Arrhenius expression. The net rate of production of mass of species $i$ is computed as the sum of the Arrhenius reaction sources over the $N_r$ reaction which the species participate in

$$R_i = M_{m,i} \sum_{r=1}^{N_r} R_{r,i} \tag{5}$$

Where $M_{m,i}$ is the molecular weight of species $i$ and $R_{r,i}$ is the Arrhenius molar rate of creation/destruction of species $i$ in reaction $r$. The molar rate of creation/destruction of species I in reaction $r$ is given by

$$R_{r,i} = k_r \left[ [HCl] [NaOH] \right]^{\eta'_{r,i}} \tag{6}$$

Where

- $k_r$ = rate constant for reaction
- $C_{j,r}$ = molar concentration of species $j$ in reaction $r$
- $\eta'_{r,i}$ = rate exponent for reactant species $j$ in reaction $r$
- $\eta''_{j,r}$ = rate exponent for product species $j$ in reaction $r$

For the neutralization reaction with HCl and NaOH, the rate exponents are 1 respectively so that the rate expression can be written as

$$R_{r,i} = k_r \left[ [HCl] [NaOH] \right] \tag{7}$$

The rate constant does not depend on the concentrations of reactant but the temperature. It is computed using the Arrhenius equation.

$$k_r = A_r e^{-E_r/k_B T} \tag{8}$$

Where

- $A_r$ = pre-exponential factor ($\text{mol}^{-1}\text{m}^{-3}\text{s}^{-1}$)
- $E_r$ = Activation energy for the reaction ($\text{Jmol}^{-1}$)
- $R = \text{universal gas constant (Jmol}^{-1}\text{K}^{-1}$

In the present study, Pressure-based solver was adopted and Simple algorithm was chosen to enforce mass conservation and to obtain the pressure field. To get discretization equation for the momentum, the chemical species and the energy, the first-order-upwind algorithm was applied.

3.2 Modeling and Analytical conditions

A three-dimensional analytical region and mesh arrangement are shown in Fig. 3 and Fig. 4, respectively. The analytical region consists of reaction tank, nozzle and wax. The dimensions of nozzle were determined to keep the aspect ratio of the nozzle, which is 1/20, that was used in the SWAT-4 experiment. The purpose of the numerical simulation is to check out the temperature increase near the outside of the nozzle so that evaluate the feasibility of assessing the self-wastage phenomenon by using a simulant material. Therefore the mesh spacing in the domain is relatively coarse. The width of the nozzle was divided into equally two and the depth of the nozzle was divided equally 10. The height of the nozzle consists of 10 equal nodes. The size of mesh was increased with a constant ratio in all direction. The constant ratio is 1.15. Table 2 shows the number of the meshes for the entire computational domain. The boundary conditions for the numerical simulation are shown in Fig. 5. As shown in Fig. 5 the constant velocity was adopted for inlet, for the outlet, front, side wall and pressure outlet were selected. For the wax, a nonslip wall condition was used.

\[ \text{Fig. 3 An analytical region for the numerical simulation} \]
To determine initial condition for the analysis, the experimental data of the SWAT4 mock-up test were used. HCl aqueous solution was injected to the reactor tank with constant velocity, concentration and temperature. Inlet velocity was calculated by means of Reynolds number approximation of the initial flow of the SWAT4 experiment. The dimensions of the numerical analytical region are shown in Fig.2 and the initial conditions for the calculation are given by Table 3. The gravitational acceleration works in the negative y-direction. Table 4 shows the fluid properties which are also defined to be constant.

<table>
<thead>
<tr>
<th>Mesh</th>
<th>Reactor</th>
<th>Wax</th>
<th>Nozzle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number</td>
<td>60452</td>
<td>12440</td>
<td>200</td>
</tr>
</tbody>
</table>

Table 3 The initial condition for the numerical simulation

<table>
<thead>
<tr>
<th>Concentration of HCl</th>
<th>10</th>
<th>[mol/L]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concentration of NaOH</td>
<td>5</td>
<td>[mol/L]</td>
</tr>
<tr>
<td>Inlet velocity</td>
<td>0.08</td>
<td>[m/s]</td>
</tr>
<tr>
<td>Temperature of Solution</td>
<td>298</td>
<td>[K]</td>
</tr>
<tr>
<td>Pressure</td>
<td>101325</td>
<td>[Pa]</td>
</tr>
</tbody>
</table>

Table 4 Thermal hydraulic properties of solution

<table>
<thead>
<tr>
<th></th>
<th>HCl</th>
<th>NaOH</th>
<th>NaCl</th>
<th>H2O</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density [kg/m³]</td>
<td>1082</td>
<td>1328</td>
<td>1131</td>
<td>998.2</td>
</tr>
<tr>
<td>Specific heat [J/kg-K]</td>
<td>3100</td>
<td>3350</td>
<td>3390</td>
<td>4182</td>
</tr>
<tr>
<td>Thermal Conductivity [W/m-K]</td>
<td>0.518</td>
<td>0.645</td>
<td>0.59</td>
<td>0.6</td>
</tr>
<tr>
<td>Viscosity [kg/m-s]</td>
<td>0.00179</td>
<td>0.0033</td>
<td>0.00156</td>
<td>0.00103</td>
</tr>
<tr>
<td>Molecular Weight [kg/m-s]</td>
<td>36.461</td>
<td>39.997</td>
<td>58.443</td>
<td>18.015</td>
</tr>
<tr>
<td>Standard state Enthalpy [kJ/mol]</td>
<td>-1.56E+8</td>
<td>-4.69E+8</td>
<td>-4.07E+8</td>
<td>-2.86E+8</td>
</tr>
<tr>
<td>Standard state Entropy [J/mol]</td>
<td>56500</td>
<td>48100</td>
<td>1555000</td>
<td>69900</td>
</tr>
</tbody>
</table>

Fig. 4 The orthogonal mesh grid near the nozzle

Fig. 5 Boundary conditions for the numerical analysis

4. RESULT AND DISCUSSION

4.1 Temperature Distribution near Surface of Nozzle

In the calculation, the time step was set to 1E-5 sec. In real situation, the density of water vapor which is leaked from the inside of the heat transfer tube is lighter than that of liquid sodium outside. Since the density of 5 mol HCl solution is lighter than 10 mol of NaOH solution, so it was decided to fill the reaction tank with NaOH solution and inject HCl solution to the reaction tank. Using equation (9), the initial inlet velocity was obtained as 0.08m/s so that Reynolds number at the inlet was 10 which equals to the Reynolds number that is calculated with the SWAT4 experimental data.

\[ v_{inlet} = \frac{\mu Re}{\rho D_H} \]

Where \( \rho \) is density, \( Re \) is Reynolds number, \( D_H \) is hydraulic diameter and \( \mu \) is viscosity. For hydraulic diameter for rectangular channel, is determined by equation (10)
$$D_H = \frac{2LW}{L+W}$$  \hspace{1cm} (10)

Where $L$ is length and $W$ is width of cross section.

Figure 6 shows the temperature distribution at the surface of wax, 2.6 second after injecting HCl solution to Reactor tank. As seen in Fig. 6, temperature around the nozzle increased due to the neutralization reaction which takes place around the nozzle. Along the x-axis the width of the area, where the surface temperature is increased, is larger than the area of wax surface along the y direction. The color of the surface shows that the surface temperature near the nozzle is increased by about 330K. In order to observe the temperature distribution at the surface wax and beneath the surface, a face which is aligned with x-axis and across the center of the nozzle (along Horizontal X) was prepared. In the same manner, another face which is aligned with z-axis (along Horizontal Z) was also prepared.

A front view of the temperature distribution is shown in Fig.7 and a side view of the temperature distribution is given in Fig. 8.

![Fig. 6 Temperature contour of the surface of wax near the outside of the nozzle (T=2.6sec)](image)

As shown in Fig. 7, temperature of the wax beneath the surface risen by the reaction heat that is released from the neutralization reaction. Under the surface of the wax, the reaction heat was conducted through the paraffin wax, so that the temperature beneath the wax went up about 330K which is higher than the melting point of the paraffin wax. From the temperature distribution, it was observed that temperature increase dominantly takes place along the x-direction. This means that the injected flow was spread radially so that the shape of the area where temperature was increased in the shape as shown in Fig.6. This observation is harmonized with the experimental result of the SWAT4 mock-up test about shape of the injected flow which form radial configuration. Fig. 8 also shows a side view of temperature distribution near the nozzle. Compared to the Fig. 7, the temperature increase along the z-direction was relatively smaller than that along the x-direction. Because the injected flow of HCl solution was spread almost directly to the reaction tank. It was also well agreed with the side view of the configuration of injected flow from the SWAT4 experiment. This suggests that the enlargement of the nozzle in z-direction is smaller than that in x-direction.

In order to get the detail information about temperature increase at the surface of the wax, the temperature distribution along the white dot-dashed line (aligning x-direction) and green dot-dashed line (aligning z-direction) were investigated. The results are shown in Fig. 9 and 10, respectively. Vertical axis indicates Temperature and horizontal axis represents position in x and z-direction. In the figure, the red dot-dashed line represents the melting point of the paraffin wax, orange-colored area indicates the width of the nozzle.

As shown in Fig. 9, the highest temperature of the surface wax is 328.6K which exceeds the melting point of the paraffin wax. The temperature between -0.00038m to 0.00038m, exceeds 320.5K so that the surface of the paraffin wax would be melted by the reaction heat.

![Fig. 9 Temperature distribution at the surface of the wax along x-direction. (T=2.6sec)](image)

Figure 10 shows the temperature at the surface of wax is went by 327.2K which is also higher than the melting point of the paraffin wax. However, as shown in
figure 6, the width of the area of the surface wax where temperature is over 320.5K is approximately 0.0002 m that is relatively smaller than 0.00033m in Fig. 10. Therefore it is able to assume that the wax nozzle would be dominantly enlarged toward x-direction.

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![Fig. 10](image1)

Fig. 10 Temperature distribution at the surface of the wax along z-direction. (T=2.6sec)

In order for the surface of the wax to be melted, the temperature of the surface should be sustained over the melting point of the paraffin wax for a certain time. To examine that the temperature of the surface could be kept for several seconds, the temperature variation with time at the surface was investigated along with x-direction. The result is shown in Fig. 11. The temperature was obtained in 0.6 sec, 2.6 sec, 3.8 sec respectively. As seen in Fig. 11, in general, temperature distribution is almost coincided through whole region. From the result, it is assumed that the neutralization reaction would become a stable state quickly so that the temperature near the nozzle is kept for several seconds. From this result, it could be expected that the surface of the wax would be melted by the reaction heat released from the reaction.

![Fig. 11](image2)

Fig. 11 Temperature variation with time at the surface of the wax along x-direction

4.2 Temperature distribution near Surface of Enlarged Nozzle

Another numerical investigation was carried out with an enlarged nozzle mesh arrangement. As mentioned in previous section, the temperature at the surface near nozzle was increased by the reaction heat, so that it is expected that the area where temperature exceeds 320.5K was melted. Therefore the wax nozzle would be enlarged. As shown in Fig. 9, since the width of the area where the temperature increased over 320.5K is about 0.0003m. A new mesh was made under the assumption that the edge of the surface wax was melted, so that the shape of the surface of the wax becomes a surface with rounded edge. Fig. 12 shows the shape of the enlarged nozzle that is used for the numerical simulation. The edge of the wax nozzle was rounded with a radius 0.0003m ($\phi=0.0006m$) which is the width of the area where temperature increased over 320.5K. With this new mesh arrangement, another numerical calculation was carried out under the same condition of the former numerical simulation. Temperature distribution at the surface of wax near the nozzle is shown in Fig. 13. Fig. 13 shows the temperature distribution of 2 second after injecting HCl solution to the reactor. It was observed that the temperature increased about 330K around the nozzle. The area, where temperature is risen, became wider than before the nozzle is enlarged. This suggests there is possibility that the surface of wax would be more enlarged by the reaction heat. It is expected that the width of the enlarged nozzle would be wider.

![Fig. 12](image3)

Fig. 12 Mesh arrangement of the surface of the enlarged nozzle wax

![Fig. 13](image4)

Fig. 13 The temperature contour of the surface near the outside of nozzle. (T=2.0 sec)

As described in Fig. 6, in this time too, in order to observe the temperature distribution at the surface wax and beneath the surface, a face which is aligned with x-axis and including the white dot-dashed line was prepared. In the same manner, another surface which is aligned with z-axis and including the green dot-dashed line was also prepared. Figures 14 and 15 show a front view and side view of the temperature contour near the nozzle, respectively. In Fig. 14 and 15, it was also observed that temperature of the surface near the outside of nozzle increased by about 330K and it is expected
that the surface would be melted by the reaction heat. Regarding the direction of the enlarging of the nozzle, it is supposed that the nozzle would be enlarged dominantly toward x-direction because the width of area where temperature went up over 320.5K in x-direction is longer than that of z-direction.

Fig. 14 A front view of temperature contour near the nozzle with the enlarged mesh arrangement (T=2.0sec)

In order to get the detail information about temperature increase at the surface of the wax, the temperature distribution along the white dot-dashed line were investigated. The results are shown in Fig. 16. Vertical axis indicates Temperature and horizontal axis represents position in x and z-direction. In the figure, the red dot-dashed line represents the melting point of the paraffin wax, orange-colored area indicates the width of the nozzle.

Fig. 15 A side view of temperature contour near the nozzle with the enlarged mesh arrangement (T=2.0sec)

As shown in Fig. 16, the highest temperature of the surface wax is 328.1K which exceeds the melting point of the paraffin wax. The temperature between 0.000177 m and 0.0003m exceeds 320.5K so that the surface of the paraffin wax would be melted by the reaction heat. Since the graph seems symmetric, it could be assume that the surface wax between -0.0003m and -0.000177 would be melted by the reaction heat. As a conclusion, the surface of wax of enlarged nozzle arrangement would be melted so that the nozzle would be enlarged toward x-direction.

Fig. 16 Temperature distribution at the surface of the wax along x-direction. (T=2.0 sec)

In order to get the detail information about temperature increase at the surface of the wax, the temperature distribution along the white dot-dashed line were investigated. The results are shown in Fig. 16. Vertical axis indicates Temperature and horizontal axis represents position in x and z-direction. In the figure, the red dot-dashed line represents the melting point of the paraffin wax, orange-colored area indicates the width of the nozzle.

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5. CONCLUSION

Three-dimensional thermal hydraulic simulations of the flow with chemical reaction were carried out using a commercial CFD tool, FLUENT Ver. 6.3.26. The temperature variation at the surface of the wax due to the neutralization reaction was examined to validate the feasibility of the new experimental methodology of the self-wastage phenomenon. As a result it was observed that by injecting 10mol HCl solution to the reactor with 1.6E-2cc/s, the temperature of the surface of wax near the nozzle increased over 320.5K, which is higher than the melting point of the paraffin wax, so that the paraffin wax could be melted. The temperature variation at the surface of the wax with the time shows that the temperature at the surface of the wax would be kept for several seconds so that the surface of the wax would be melted. Considering the temperature of the wax at the surface near the nozzle is increased in radial direction, it is expected that the nozzle of the wax would be enlarged radially. This result is well agreed with the direction of the injected flow from the SWAT4 experiment.

From the temperature distribution around the surface of the enlarged wax suggested that the wax at the surface of wax near the nozzle would keep being melted by the reaction heat, so that the width of the enlarged nozzle would be getting wider. It is also expected that the wax nozzle would be enlarged dominantly toward x-direction.

In this study, we have observed that the new experimental methodology using simulant material could simulate the self-wastage phenomenon. Therefore the new methodology would give an opportunity to evaluate the increase rate of leakage and the shape of enlarged nozzle. The new methodology would be helpful to understand the mechanism of the self-wastage phenomenon and develop a detection technology for the self-wastage phenomenon.

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