Development of High Temperature Molten Salt Transport Technology for Pyrometallurgical Reprocessing*

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Abstract
Pyrometallurgical reprocessing technology is currently being focused in many countries for closing actinide fuel cycle because of its favorable economic potential and an intrinsic proliferation-resistant feature due to the inherent difficulty of extracting weapons-usable plutonium. The feasibility of pyrometallurgical reprocessing has been demonstrated through many laboratory scale experiments. Hence the development of the engineering technology necessary for pyrometallurgical reprocessing is a key issue for industrial realization. The development of high-temperature transport technologies for molten salt and liquid cadmium is crucial for pyrometallurgical processing; however, there have been very few transport studies on high-temperature fluids. In this study, a salt transport test rig was installed in an argon glove box with the aim of developing technologies for transporting molten salt at approximately 773 K. The gravitation transport of the molten salt at approximately 773 K could be well controlled at a velocity from 0.1 to 1.2 m/s by adjusting the valve. Consequently, the flow in the molten salt can be controlled from laminar flow to turbulent flow. It was demonstrated that; using a centrifugal pump, molten salt at approximately 773 K could be transported at a controlled rate from 2.5 to 8 dm³/min against a 1 m head.

Key words: Pyrometallurgical Reprocessing, High Temperature Fluids, Molten Salt, Gravitation Transport, Centrifugal Pump

1. Introduction

Dry (i.e., non-aqueous) processing technologies are currently being focused in many countries for removing actinides from fuel cycle because of their favorable economic potential (1) and intrinsic proliferation-resistant feature due to the inherent difficulty of using these technologies to extract weapons-usable plutonium (2). Pyrometallurgical reprocessing is one of the most attractive dry processing technologies, because Pu is not separated from the other actinides at any step of the process (3)(4). This property enables us to enhance intrinsic proliferation resistance and to recover long-lived transuranium elements for transmutation in fast reactors without further treatment. CRIEPI has been studying these processes since 1985, and has carried out joint studies with groups including Argonne National Laboratory, European Commission Joint Research Centre - The Institute for Transuranium elements, and Japan Atomic Energy Agency. The feasibility of pyrometallurgical reprocessing has been demonstrated through many laboratory-scale experiments (5)(6). The development of the engineering technology required for pyrometallurgical reprocessing is a key issue for its industrial realization.

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Pyrometallurgical reprocessing mainly consists of electrorefining, cathode processing, and injection casting, and a salt treatment system (waste management), as shown in Fig. 1 (8).

The electrorefining is carried out to dissolve spent fuel and to recover the actinide on the cathodes. Uranium metal and uranium-plutonium-cadmium alloy are deposited on the cathodes. These deposits are entrained with salt and cadmium (Cd), respectively. The cathode processing separates the salt or Cd from the deposits by distillation. The injection casting produces the metallic fuel by casting a uranium-plutonium-zirconium alloy. The salt treatment system separates the fission products from the molten salt in the electrorefiner, and then the treated salt is solidified with glass and zeolite, which occludes the chloride salt in the cage structure. The thick arrows in Fig. 1 indicate the transport of high-temperature liquid products. The development of high-temperature transport technologies for molten salt is a crucial prerequisite; however there have been few transport studies of the high-temperature fluids. For example, the viscosity of molten LiCl-KCl eutectic salt has only been measured in the temperature range 890 to 1070 K (9), whereas the transportation of molten salt is usually carried out at approximately 773 K. It has been estimated that the pump capacity required for pyrometallurgical reprocessing must be sufficient to transport molten salt of approximately 1 dm$^3$/min against a 3 m head (10). However, a previously reported transport molten salt at a rate of more than 150 dm$^3$/min and against a 15 m head (11)(12), was too large for use in pyrometallurgical reprocessing.

In this study, in order to design the suitable equipments of pyrometallurgical process, the transport characteristics of molten salt were determined using experimental equipment that consisted of centrifugal pumps, inclined transportation pipes, and tanks.

**Nomenclature**

- $H$: head, m
- $V$: velocity, m/s
- $g$: gravity acceleration, m$^2$/s
- $l$: length of tube, m
- $D$: inner diameter of tube, m
- $\rho$: density of molten salt, g/cm$^3$
- $\mu$: viscosity of molten salt, mPa·s
- $\xi$: pressure loss coefficient
- $\lambda$: coefficient of pipe friction
- $Re$: Reynolds number
Subscript
T: total
V: valve

2. Experiments
2.1 Regents
LiCl and KCl with purities greater than 99% were purchased from Kojundo Chemical Laboratory Co. Ltd. LiCl-KCl eutectic salt was employed as the product, which was a mixture of 59 mol% LiCl and 41 mol% KCl.

2.2 Experiment apparatus
Due to instability of molten salt under air, all apparatus was installed in a large argon glove box (W: 7 m, D: 2 m, H: 2.5-3 m), as shown in Fig.2.

(1) The gravitation transport experiments
The gravitation transport is a simple transport method, however the transport capacity would be strongly depend on the design of equipment. Therefore, to design suitable equipment, the gravitation transport experiments were carried out using apparatus shown in Fig. 3. The apparatus was used to examine the controllability of the flow rate by adjusting valve and the relationship between the flow rate and the temperature of the molten salt.

The apparatus consisted of a supply tank, a transportation tube, and a recovery tank. The supply tank had a 180 mm inner diameter and was 290 mm deep. The center of the bottom of the supply tank was connected to the transportation tube, which had a 10.1 mm inner
diameter \((D)\). The tube in apparatus had a downward slope of \(10^\circ\). An orifice valve was installed to control the flow and a propeller stirrer agitated in the supply tank. The propeller was 60 mm diameter, and the maximum rotation speed was 3000 rpm. The height from the bottom of the supply tank to the outlet was 435 mm and the length of the tube \((l)\) was 1200 mm. The supply tank and the transportation tube were maintained at temperature between 673 and 923 K by a heater. The recovery tank was made of the stainless steel. The molten salt flowed through the transportation tube from the supply tank to the recovery tank. The temperature of the molten salt was measured in the supply tank. The level of molten salt in supply tank was measured using a potentiometer. The increase in weight of the recovery tank was also measured by the balance (HV-60GL, A&D Co. Ltd).

(2) The centrifugal pump transport experiments
The pump based transport is favorable for controlling the flow rate and the head. Therefore, to determine the performance of the centrifugal pump, the pump transport experiments were carried out using the two sets of apparatus shown in Fig. 4. Apparatus (a) has a fixed head and there is no valve in the transportation tube. In apparatus (b), the transportation routes can be switched to three different heads by opening and closing the valves.

![Fig. 4 Apparatus employed in molten salt transport experiment using centrifugal pump.](image)

Both sets of apparatus consist of a supply tank, a recovery tank, a centrifugal pump, a transportation tube, and a drain tube. The supply tank had a 345 mm inner diameter, was 320 mm high, and had a capacity of 25 dm³. The recovery tank had a 255 mm inner diameter, was 516 mm high, and had a capacity of 25 dm³. The centrifugal pump (MAE-V) was manufactured by Sanwa-Hydrotech Co. The impeller had a 50 mm diameter and the rotation speed could be varied between 1800 and 3000 rpm. The transportation tube was
connected between the outlet of the pump and the inlet of the recovery tank. The drain tube was connected between the bottom of the recovery tank and the side of the supply tank, and a valve was installed in the outlet of the recovery tank. The transportation tube and drain tube had a 10.1 mm inner diameter and the inclination of the tubes was $2^\circ$. All tanks and tubes were maintained at the temperature between 673 and 923 K by a heater. The molten salt temperature was measured in both tanks. The levels in both tanks were measured using potentiometers. The flow rate in the tube was measured by calculating the volumes in the supply and recovery tanks.

Apparatus (a) was employed to measure the flow of the molten salt in a transportation tube without a valve and a fixed head of 0.96 m. The highest point of tube was 1.04 m above the inlet of the pump, but because the effect of the siphon was to decrease the head by 0.08 m of head, the actual head was 0.96 m.

Apparatus (b) was employed to determine the relationship between the flow and the head when the centrifugal pump was used. Three different transportation routes existed resulting in three heads with heights of 1.01, 1.24, and 1.48 m. The transportation tube connected to the recovery tank had a 22.1 mm inner diameter. Because this diameter was larger than that of the transportation tube (10.1 mm), the head of the tube was considered to be unaffected by the siphon. To change the transport route, the bellows sealed valves (U-series, Swagelok®) were installed on the tube side of the supply tank. The valves in Fig. 4 (b) were named DV-1, V-1, V-2, V-3, and V-4.

2.3 Experimental procedure
(1) The gravitation transport experiment

In runs G-1 to G-10, the controllability of the flow in molten salt was tested by adjusting the orifice valve in apparatus of Fig.3. In runs G-11 to G-14, the influence of the molten salt temperature on the flow was investigated using the same apparatus. The experimental conditions are shown in Table 1.

<table>
<thead>
<tr>
<th>Run</th>
<th>Volume (dm³)</th>
<th>Temperature (K)</th>
<th>Stirrer (rpm)</th>
<th>Valve opening (turns)</th>
</tr>
</thead>
<tbody>
<tr>
<td>G-1</td>
<td>5.4</td>
<td>761</td>
<td>2500</td>
<td>1</td>
</tr>
<tr>
<td>G-2</td>
<td>5.5</td>
<td>761</td>
<td>2500</td>
<td>1</td>
</tr>
<tr>
<td>G-3</td>
<td>5.2</td>
<td>763</td>
<td>2500</td>
<td>2</td>
</tr>
<tr>
<td>G-4</td>
<td>5.2</td>
<td>763</td>
<td>2500</td>
<td>4</td>
</tr>
<tr>
<td>G-5</td>
<td>5.3</td>
<td>763</td>
<td>2500</td>
<td>6</td>
</tr>
<tr>
<td>G-6</td>
<td>5.6</td>
<td>763</td>
<td>2500</td>
<td>6</td>
</tr>
<tr>
<td>G-7</td>
<td>5.5</td>
<td>759</td>
<td>2500</td>
<td>8</td>
</tr>
<tr>
<td>G-8</td>
<td>5.7</td>
<td>760</td>
<td>2500</td>
<td>10</td>
</tr>
<tr>
<td>G-9</td>
<td>5.5</td>
<td>759</td>
<td>2500</td>
<td>12</td>
</tr>
<tr>
<td>G-10</td>
<td>5.7</td>
<td>761</td>
<td>2500</td>
<td>14</td>
</tr>
<tr>
<td>G-11</td>
<td>5.6</td>
<td>689</td>
<td>0</td>
<td>6</td>
</tr>
<tr>
<td>G-12</td>
<td>6.0</td>
<td>709</td>
<td>0</td>
<td>6</td>
</tr>
<tr>
<td>G-13</td>
<td>5.7</td>
<td>768</td>
<td>0</td>
<td>6</td>
</tr>
<tr>
<td>G-14</td>
<td>6.5</td>
<td>818</td>
<td>0</td>
<td>6</td>
</tr>
</tbody>
</table>

All molten salt experiments were carried out by almost the same procedure. Seven to ten kg blocks of LiCl-KCl eutectic salt were loaded into the supply tank. The supply tank was heated to the set temperature. In runs G-1 to G-10, the molten salt was mixed by stirring at 2500 rpm after melting. The transportation tube was maintained at approximately 823 K. The valve was opened by a set numbers of turns and then the molten salt flowed into the
recovery tank. The flow rate was calculated from the increase in weight of the recovery tank. The recovered salt was solidified and shattered after each run, then employed in the following run.

(2) The centrifugal pump transport experiments

LiCl and KCl powders were loaded into the recovery tank with adjusting their eutectic composition. The recovery tank was heated to 773 K and the salt was melted. The drain tube and transportation tube were maintained at approximately 823 K and the supply tank was heated to 773 K. The salt was transported to the supply tank from the recovery tank with opening DV-1, after which DV-1 was closed. In apparatus (b) of Fig.4, before activating the centrifugal pump, the transportation route was selected by opening V-1, V-2, or V-3 to determine the head. The centrifugal pump was activated after setting the rotation speed, and the molten salt was transported from the supply tank to the recovery tank. The flow rate was calculated from the signal of the level meter. The molten salt in the recovery tank was transported to the supply tank by opening DV-1 after transportation, and was then used in the next transport. The experimental conditions are shown in Table 2. In run P-1 to P-5, the controllability of flow rate was determined by changing the rotation speed of the apparatus (a) of Fig.4 with a fixed head (0.96 m). In runs P-6 to P-14, the performance of the centrifugal pump was measured using apparatus (b) of Fig.4. In run P-6 to P-8, the flow rates were determined for different heads during rotation 3000 rpm. In run P-8 to P-11, the controllability of flow rate was determined by changing the rotation speed with a 1.48 m head. In run P-12 to 14, the flow rate of molten salt was determined at different temperatures.

Table 2. Experimental condition for molten salt transport using centrifugal pump.

<table>
<thead>
<tr>
<th>Run</th>
<th>Volume (dm³)</th>
<th>Temperature (K)</th>
<th>Rotation speed (rpm)</th>
<th>Head (m)</th>
<th>Repetition (number)</th>
</tr>
</thead>
<tbody>
<tr>
<td>P-1</td>
<td>20</td>
<td>773</td>
<td>3000</td>
<td>0.96</td>
<td>3</td>
</tr>
<tr>
<td>P-2</td>
<td>20</td>
<td>773</td>
<td>2700</td>
<td>0.96</td>
<td>3</td>
</tr>
<tr>
<td>P-3</td>
<td>20</td>
<td>773</td>
<td>2400</td>
<td>0.96</td>
<td>3</td>
</tr>
<tr>
<td>P-4</td>
<td>20</td>
<td>773</td>
<td>2100</td>
<td>0.96</td>
<td>3</td>
</tr>
<tr>
<td>P-5</td>
<td>20</td>
<td>773</td>
<td>1800</td>
<td>0.96</td>
<td>3</td>
</tr>
<tr>
<td>P-6</td>
<td>10</td>
<td>775</td>
<td>3000</td>
<td>1.01</td>
<td>3</td>
</tr>
<tr>
<td>P-7</td>
<td>10</td>
<td>775</td>
<td>3000</td>
<td>1.24</td>
<td>3</td>
</tr>
<tr>
<td>P-8</td>
<td>10</td>
<td>775</td>
<td>3000</td>
<td>1.48</td>
<td>3</td>
</tr>
<tr>
<td>P-9</td>
<td>10</td>
<td>775</td>
<td>2700</td>
<td>1.48</td>
<td>3</td>
</tr>
<tr>
<td>P-10</td>
<td>10</td>
<td>775</td>
<td>2400</td>
<td>1.48</td>
<td>3</td>
</tr>
<tr>
<td>P-11</td>
<td>10</td>
<td>775</td>
<td>2100</td>
<td>1.48</td>
<td>3</td>
</tr>
<tr>
<td>P-12</td>
<td>10</td>
<td>748</td>
<td>3000</td>
<td>1.24</td>
<td>3</td>
</tr>
<tr>
<td>P-13</td>
<td>10</td>
<td>773</td>
<td>3000</td>
<td>1.24</td>
<td>3</td>
</tr>
<tr>
<td>P-14</td>
<td>10</td>
<td>817</td>
<td>3000</td>
<td>1.24</td>
<td>3</td>
</tr>
</tbody>
</table>

3. Results and Discussion

3.1 The gravitational transport experiment

(1) Controllability of the flow rate by adjusting the orifice valve

The relationship between the mean velocity and the valve opening is shown in Fig.5. The velocity in molten salt was controlled from 0.1 to 1.2 m/s by adjusting the orifice valve in the apparatus of Fig.3. The flow in the molten salt can be controlled from laminar flow to turbulent flow by adjusting the valve, because the Reynolds number covers from 700 to 8900, where the Reynolds number is defined as $Re = \frac{\rho \cdot V \cdot D}{\mu}$. The orifice valve seemed
to open completely at greater than 6 turns of valve, because the velocity in molten salt became constant. The velocity in molten salt exhibited good reproducibility at the same valve opening over several repeated experiments in run G-1, G-2, G-5, and G-6. Also, the function of this orifice valve was maintained during 89 times of transport experiments. Consequently, the transport of the molten salt in wide range of flow rate at approximately 763 K was well controlled by the orifice valve.

Fig. 5 Relationship between mean velocity in molten salt and valve opening.

As the kinematic viscosities of LiCl-KCl molten salt at 773 K almost agrees with water at room temperature. The pressure loss coefficient was calculated from the equations based on water experiment.\(^{(13)}\) In the laminar flow, the coefficient of pipe friction (\(\lambda\)) was defined as the Eq. (1) for \(Re < 2000\), and in the turbulent flow for \(3000 < Re < 100000\), \(\lambda\) was defined as the Blasius equation (Eq.(2)). The total pressure loss (\(\zeta_T\)) was indicated as the Eq. (3).

\[
\lambda = \frac{64}{Re} \quad \text{(Re<2000)} \tag{1}
\]
\[
\lambda = 0.3164 \cdot Re^{-0.25} \quad \text{(3000 < Re < 100000)} \tag{2}
\]
\[
H = \frac{\zeta_T V^2}{2g} = \frac{\lambda l V^2}{D 2g} + \zeta \frac{V^2}{2g} \tag{3}
\]

The total pressure loss coefficient was obtained from 7 to 870 depending on the valve opening in the gravitation transport experiment of molten salt. The tube pressure loss coefficient was evaluated to be from 4 to 11 by using eq.(1) or eq.(2). Consequently, the pressure loss coefficient of the valve was changed from 3.5 to 850 with closing the valve. The value of fully opened valve, 3.5, was about one fifth of Swagelok® valve (SS-8UW).

(2) Temperature dependence of flow rate in molten salt

Table 3 shows the relationship between the molten salt temperature and its mean velocity. The velocity of molten salt slowly decreases with decreasing temperature. All flows of the molten salt are considered to be turbulent flow, because the Reynolds numbers are between 5700 and 10500. The coefficient of pipe friction (\(\lambda\)) is given by eq. (2) and it is
applied to eq.(3). Consequently, the velocity of molten salt is estimated using the following
eq.(4) on the basis of the density and viscosity.

$$H = 0.3164 \left( \frac{\rho \cdot V \cdot D}{\mu} \right)^{-0.25} \frac{l}{D} \frac{V^2}{2g} + \zeta \frac{V^2}{2g}$$

The viscosity in table 3 was obtained by extrapolating the viscosity between 890 and 1070
K\(^{(9)}\). The velocity was estimated from a converged calculation using eq. (4) on the basis of
the velocity at 818K, shown in table 3. The relationship between the estimated velocity and
temperature is in agreement with that between the experimentally obtained velocity and
temperature. These results suggest that the viscosity extrapolated from data obtained at high
temperatures is applicable for the transport calculation in the temperature range of 689 to
818 K.

<table>
<thead>
<tr>
<th>Temperature (K)</th>
<th>689</th>
<th>709</th>
<th>768</th>
<th>818</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measured velocity (m/s)</td>
<td>1.13</td>
<td>1.16</td>
<td>1.15</td>
<td>1.21</td>
</tr>
<tr>
<td>Reynolds number</td>
<td>5700</td>
<td>6400</td>
<td>8200</td>
<td>10500</td>
</tr>
<tr>
<td>Density (^{(9)}) (g/cm(^3))</td>
<td>1.67</td>
<td>1.66</td>
<td>1.62</td>
<td>1.60</td>
</tr>
<tr>
<td>Viscosity (^{(9)*}) (mPa·s)</td>
<td>3.31</td>
<td>2.99</td>
<td>2.28</td>
<td>1.87</td>
</tr>
<tr>
<td>Kinematic viscosity (µm(^2)/s)</td>
<td>1.99</td>
<td>1.88</td>
<td>1.40</td>
<td>1.17</td>
</tr>
<tr>
<td>Estimated velocity** (m/s)</td>
<td>1.12</td>
<td>1.14</td>
<td>1.18</td>
<td>1.21</td>
</tr>
</tbody>
</table>

\* This value is extrapolated from the viscosity at 890 K.

\** This value is estimated from eq.(4) on the basis of the velocity at 818 K.

3.2 The centrifugal pump transport experiment

(1) Controllability of the centrifugal pump

In run P-1 to P-5, time dependences of the flow rate were measured with apparatus (a). The
dependences are plotted with the different rotation speed of the centrifugal pump in
Fig. 6.
The flow rate exhibited good reproducibility at the same rotation speed of the centrifugal pump over three times repeated experiments. The first measurement of the flow rate in Fig. 6 became lower than the second measurement, because 5 seconds was necessary obtaining determined rotation speed after start operation. The flow rate was gradually decreased with decreasing the molten salt liquid level in supply tank. The flow rates were averaged with time, and plotted against the rotation speed of centrifugal pump in Fig. 7. The average flow rate of the molten salt was controlled between 2.5 and 8 dm$^3$/min by changing the rotation speed.

In run P-8 to P-11, the flow rates were measured with apparatus (b). The flow rates at 1.48 m were averaged with time, and plotted against the rotation speed as Fig. 7. The molten salt was not able to flow at 2100 rpm of rotation speed, due to high the pressure loss. The average flow rate of molten salt was controlled between 2.5 and 4.6 dm$^3$/min at the rotation speed from 2400 to 3000 rpm. The slopes of the flow rate against the rotation speed measured with apparatus (a) was larger than that measured with apparatus (b), because the apparatus (b) has a valve of high pressure loss.

These results suggest that the transport of the molten salt at 773 K can be well controlled by changing the rotation speed of the centrifugal pump.

![Fig. 7 Relationship between the average flow rate and the rotation speed of the centrifugal pump.](image)

(2) Relationship between head and flow rate

Figure 8 shows the relationship between the head and the flow rate at 775 K in run P-1, P-6, P-7, and P-8. The broken line indicates the relationship obtained by testing water in the factory. The flow rate of run P-1 using apparatus (a) is in good agreement with that of water at the same head. The flow rate for the apparatus (b) is less than that of apparatus (a) at the same head, because the valve in the transportation tube has a loss of pressure. The pressure losses due to the valves are calculated from the relationship between flow rate and pressure loss in the Swagelok catalog $^{14}$. The actual head is corrected by adding the pressure loss of 0.9 to 1.2 m to the head, and the relationship between the flow rate and the actual head is shown by solid squares in Fig. 8. After correcting the head, the relationship between the flow rate and the head in the molten salt is in agreement with that for water. This suggests that the transport behavior of molten salt using the centrifugal pump can be predicted from that of water.
(3) Effect of temperature on the centrifugal pump

In general, the performance of the centrifugal pump is affected by the viscosity of fluid, and performance is decreased with increase viscosity \(^{(15)}\). In the experiment from run P-12 to P-14, the resulting relationship between the flow rate and the molten salt temperature is shown in Fig. 9.

The flow rate decreases with decreasing molten salt temperature, and this trend is in agreement with the relationship between the flow rate and the molten salt temperature in the gravitation transportation experiment. The kinematic viscosity increases from 1.2 to 1.5 \(\mu\text{m}^2/\text{s}\) with the decrease in temperature, and the flow rate decrease was approximately 4%.
In the gravitation transportation experiment, the decrease in velocity was evaluated to be approximately 2.5% for the same decrease in temperature. This suggests that the molten salt temperature has a little effect on the pump performance in the operation temperature from 748 to 812 K.

4. Conclusions

The following transport behaviors of molten salt were determined by various transportation experiments.
(1) The gravitation transport of the molten salt at approximately 773 K could be well controlled at a velocity from 0.1 to 1.2 m/s by adjusting the valve. Consequently, the flow in the molten salt was controlled from laminar flow to turbulent flow.
(2) The relationship between the velocity estimated from viscosity and density and the temperature was in agreement with that between the experimentally obtained velocity and the temperature. Consequently, the viscosity extrapolated from data obtained at high temperatures is applicable for transport calculations in the temperature range of 689 to 818 K.
(3) The molten salt flow exhibited good reproducibility with various rotation speeds of the centrifugal pump. The transport of the molten salt at 773 K could be well controlled at a rate from 2.5 to 8 dm$^3$/min against a 1 m head using the centrifugal pump.
(4) The relationship between the flow rate and the head in molten salt was in good agreement with that for water. The transport behavior of molten salt using the centrifugal pump can be predicted from that of water.
(5) The molten salt temperature has a little effect on the pump performance in the temperature from 748 to 812 K.

Acknowledgments

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References

(2) USDOE, TOPS task force of the Nuclear Energy Research Advisory Committee (NERAC), “Technological opportunities to increase the proliferation resistance of global civilian nuclear power systems”, January (2001).


(10) Hijikata.,T. and Koyama,T., " Development of high temperature transport technologies for molten salt and liquid cadmium in pyrometallurgical reprocessing", to be published J.E.G.T.P.


