Introduction

Water is a fundamental resource for life. In the mining industry, water is used in a broad range of activities including mineral processing, dust suppression, slurry transport, and employee needs. In recent decades, the industry has made much progress in developing closed-circuit approaches that maximize water conservation. However, among the challenges faced by the mining industry is the need to minimize water losses during processing while maximizing water recycling. Today, it is unusual for a mine not to have a unit operation dedicated to the recycling of waste water, which is retained within the mine’s closed cycle and stored either in a tailings facility or in a dedicated water storage facility. Concerted efforts to save water this way could have major benefits. However, the use of recycled water in flotation could have significant effects on selectivity of the flotation process because it contains additional dissolved inorganic and organic compounds, which may alter the chemistry of the system radically.

Froth flotation is a highly versatile method for physically separating particles based on differences in the ability of air bubbles to selectively adhere to specific mineral surfaces in a mineral/water slurry. The particles with attached air bubbles are then carried to the surface and removed, while the particles that remain completely wetted stay in the liquid phase. Froth flotation can be adapted to a broad range of mineral separations, as it is possible to use chemical treatments to selectively alter mineral surfaces so that they have the necessary properties for the separation. It is currently in use for many diverse applications such as separating coal from ash-forming minerals[5,8].

In Moatize, Tete province (Mozambique), the Mining Industry facilities are located within walking distance of the Rovubwe and Zambezi rivers, although this, companies are faced with problems transport these waters, making the recycling of water imperative. This paper describes effects of recirculated water on the flotation of Kushiro and Mozambique Coals.

Samples and reagents

Coal samples were collected from Chipanga layer level 46 of “Minas de Moatize” and Kushiro coal Mine in Japan. High purity quartz and kaolinite were obtained from Wako Pure Chemical Industries, Ltd. and Kampaku mine in Tochigi prefecture, Japan, respectively.

In the flotation tests, kerosene and Methyl Isobutyl Carbinol (MIBC) were used as collector and frother, respectively. For the flocculants, Praestol 2540 (ASHLAND) and Accofloc (MT Aqua Polymer) were selected because both are anionic.

Characterization of the Samples

X-ray diffraction analysis of raw coal samples
Samples for the XRD analysis were prepared by grinding the raw coal samples to less than 50 μm and analyzed using an X-ray diffractometer (RINT2000, Rigaku Corporation, Japan). The XRD patterns of the raw samples show that the main gangue minerals are kaolinite (Al2Si2O5(OH)4) and quartz (SiO2) in Moatize coal, and quartz (SiO2) and calcite (CaCO3) in Kushiro coal.

Ashing and X-ray fluorescence
The raw coal samples were heated in a furnace at 815 °C for 2 hours and the ash was analyzed by X-ray-fluorescence (XRF) using an EDXL300 (Rigaku Corporation, Japan). Table 1 shows the analytical results of the chemical analysis after ashing. The predominant components in the ash of Kushiro coal are CaO (38%), Al2O3 (19%), SiO2 (15.6%), and Fe2O3 (9.2%). In the ash of the Moatize coal, SiO2 (61.4%) and Al2O3 (31.4%) are the main components.

Experimental method
The modified release analysis method of Tsunekawa et al. [3], which was based on the method developed by Forrest [2], is useful to characterize flotation performance of coal, and used in this study. In this procedure, coal is subjected to a series of flotation with multiple reagent additions. Flotation tests were carried out in a batch flotation cell of the Agitair-type (FT-1000, Heiko). 400 mL suspension containing 20 g “model” coal samples(16 g raw coal, 3 g quartz, and 1 g kaolinite).

Fig.1. Samples used to make the “model” coal samples (<75μm)
The impeller speed of the flotation cell was 1000 rpm, and the aeration rate was 0.75 L/min. 20 g of sample was agitated with distilled water in a flotation cell for 3 min and then 15 µl of MIBC was added and further conditioned for 3 min before air was introduced. Froth products were recovered for 3 min without a collector. After this, 15 µl of MIBC was added to the flotation cell and agitated for 3 min and 2 µl of kerosene (collector) was added and agitated for 3 min, air was introduced and froth products were recovered for 3 min. This procedure was repeated with 3 µl, 5 µl, and 15 µl of kerosene. Cumulatively the volumes of kerosene used in these flotation experiments were 2, 5, 10 µl, and 15 µl. The froth products were collected separately from each flotation stage and ash values of the froth and tailing products were determined using the standard JIS procedure (JIS-M8812). The same process was repeated for recirculated water, 0.5 and 50 g/t of flocculant and finally with 200 mg/l of Ca²⁺ and 50 g/t of flocculant.

Results and discussion

The results with the sequential flotation method was plotted on a cumulative combustible or ash recovery versus yield curve. Typical curves are shown in Fig. 3, where the difference between A and B on the upper abscissas (or between C and 100 on the lower abscissas) is equal to the ash value of the coals. When the liberation is perfect (the degree of liberation = 100%), the combustible matter preferentially floats, and the mineral matter (ash) floats under ideal flotation conditions. The 0-B and C-A straight lines present ideal recovery curves for the combustible component and the ash, respectively. If mineral matter is uniformly distributed in the coal sample, the degree of liberation would be 0%, and the ideal recovery curve of combustibles and ash become the straight 0-A line. In practice, the recovery curves for the combustible and ash portions are presented as the curved lines, 0-E-A and 0-D-A, respectively [3].

In coal flotation, water is reused after the flotation because of the lack of water resources in mining site. In this study, the water recovered after flotation was 90% but only 60% of which was reused in flotation. The remaining 40% was fresh water. Cumulative ash or combustible recovery in Moatize case (Fig. 4 (left)) contains an area equal to 1, and by using recirculated water treated by 0.5 g/t of Praestol 2540 flocculant (Fig. 4 (right)) there is a small increase of the area indicating that the effects of recirculated water was negligible. In comparison, the area became smaller indicating that the selectivity of flotation of Kushiro coal decreased when recirculated water and flocculant are used (Fig. 5 (right)).

From the results of XRD and XRF, Kushiro coal contain calcite (CaCO₃), which could release Ca²⁺ and affect selectivity of coal flotation. According to Slater [1], Ca²⁺ is one of the typical contaminants in coal flotation that have substantial effects on performance. To further elucidate the effects of Ca²⁺, flotation were conducted after adding Ca²⁺ and the results are plotted in the Fig. 6.

Table 1. Elemental analysis of the ash of the samples (shown as oxide).

<table>
<thead>
<tr>
<th></th>
<th>MgO</th>
<th>Al₂O₃</th>
<th>SiO₂</th>
<th>P₂O₅</th>
<th>K₂O</th>
<th>CaO</th>
<th>TiO₂</th>
<th>Fe₂O₃</th>
</tr>
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<tbody>
<tr>
<td>Kushiro</td>
<td>4.9</td>
<td>19.0</td>
<td>15.6</td>
<td>3.8</td>
<td>0.2</td>
<td>38.0</td>
<td>1.3</td>
<td>9.2</td>
</tr>
<tr>
<td>Moatize</td>
<td>0.2</td>
<td>31.4</td>
<td>61.4</td>
<td>0.1</td>
<td>1.5</td>
<td>0.1</td>
<td>2.1</td>
<td>2.7</td>
</tr>
</tbody>
</table>
In flotation with fresh water, the area is 1.0, and it decrease to 0.6 after adding flocculants (Fig. 6 (a) and (b)). In the presence of Ca^{2+}, however, it become 0.1 as shown in Fig. 6 (c) indicating that the absorption of Ca^{2+} by both gangue and coal promoted flocculation.

Zeta potential measurements were conducted. The results is plotted in Fig. 7. The blue dots in Fig. 7 represent the curve of Moatize coal a), Kushiro coal b), kaolinite c) and quartz d). In the entire pH range, Moatize coal was negatively charged. In comparison, Kushiro coal had an isoelectric point (IEP) at pH 3.7. Kaolinite and quartz also have IEPs at pH 5 and 2, respectively. This suggests that anionic flocculants promoted repulsion with the negatively charged surfaces of the minerals and minimized flocculation. The red dots in Fig. 7 a), b), c) and d) show the zeta potential measurements in the presence of Ca^{2+}. The results showed that the IEPs of coal and quartz shifted towards higher pH values, while that of kaolinite disappeared (i.e., it became positive). These results suggest that Ca^{2+} is adsorbed on the surface of coal and gangue minerals, which promoted flocculation that decreased the selectivity of flotation.
Conclusion

- Flotation tests with fresh and recirculated water were carried out and flotation behaviors did not show the significant difference. The effect of recirculated water on flotation was negligible.

- Flotation tests with Praestol (0.5 g/t, 50 g/t) were also carried out. The effects of Praestol addition on Moatize coal flotation was negligible; however, selectivity of flotation decreased when Praestol was added to Kushiro coal.

- Zeta potential measurements of coal, quartz and kaolinite were carried out and the results showed that coal, quartz and kaolinite have negatively charged surfaces under neutral pH condition. This suggests that repulsion between anionic flocculant and the negatively charged surfaces of minerals was substantial.

- To elucidate the mechanism of flocculation on coal and minerals, flocculation tests were conducted with and without flocculant and Ca$^{2+}$. The settling velocity of interface dramatically increased when flocculant and Ca$^{2+}$ were added together. IEP of coal and quartz shifted towards high pH, while zeta potential of kaolinite became positive in the presence of Ca$^{2+}$. These results suggest that Ca$^{2+}$ adsorb on the surface and flocculant attachment to the adsorbed Ca$^{2+}$ became more extensive.

References