

Leaching hydrodynamics of weathered elution-deposited rare earth ore^①

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[Abstract] Both porosity (φ) and permeability (k) of the weathered elution-deposited rare earth ores are basic hydrodynamic parameters for RE leaching. The relationship between k and φ of two typical rare earth ores of South China in the packed bed was investigated by measuring the flow (Q) under various leaching pressure difference (Δp). The experimental results show that the relationship between k and φ is unique, moreover the relationship between Q and Δp is in accord with the Darcy's law. The effects of the type of ores, the leaching reagents and its concentration, the granule ore size on the leaching permeability have also been investigated. It is demonstrated that k_H (for heavy RE ore, $k_H = 35.98 \text{ mm}^2$) $>$ k_{M-H} (for middle-heavy RE ore, $k_{M-H} = 28.50 \text{ mm}^2$), whereas $k(\text{NH}_4\text{NO}_3) > k(\text{NH}_4\text{Cl}) > k[(\text{NH}_4)_2\text{SO}_4]$, and the k value increases with increasing leaching reagents concentration and granule ore size ($k_{0.60 \sim 0.75 \text{ mm}} = 99.96 \text{ mm}^2$, $k_{0.125 \sim 0.60 \text{ mm}} = 11.83 \text{ mm}^2$, $k_{0.074 \sim 0.125 \text{ mm}} = 0.84 \text{ mm}^2$).

[Key words] hydrodynamics; rare earth ore; leach; porosity; permeability

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1 INTRODUCTION

The weathering crust elution-deposited rare earth ore is a kind of rich rare earth resource^[1]. The rare earth in the weathering crust elution-deposited rare earth ore mainly exists with the ion phase adsorbed on clay minerals^[2], and can be leached by ion exchange method^[3]. Many industrial practice demonstrated that the leaching effect would not only be controlled by the properties of the rare earth ore, the leaching reagent and its concentration, but also be influenced by the kinetics and mass transfer of the leaching operation^[4, 5]. However, it has little knowledge so far on the leaching hydrodynamics of the weathered elution-deposited rare earth ore. In recent years, with the application and popularization of the in-situ leaching process, the mathematics simulation on the leaching process becomes more and more important in industrial design^[6]. Therefore it is necessary to investigate the relationship between the porosity (φ), permeability (k), pressure difference (Δp) of the rare earth ore in the packed bed. The weathering crust elution-deposited rare earth ore is unconsolidated particle bed, the stock-still pressure of reagent solution in the packed bed is so little that it could not change the skeleton structure of the leaching ore^[7-10]. The relationship between permeability, porosity and ore granule size in ore leaching follows the laminar flow laws in porous media. The empirical

equation of the physical parameters could be established by macroscopic hydrodynamic theory and experiments^[11-13], and it would be useful to design and simulate the process of leaching the weathering crust elution-deposited rare earth ore^[14].

2 EXPERIMENTAL

2.1 Properties of experimental rare earth ore

The samples of experimental ore are the weathering crust elution-deposited heavy rare earth ore and the weathering crust elution-deposited middle-heavy rare earth. Different granule size samples were prepared for the hydrodynamic experiments. The main chemical compositions of two kinds of ore sample are listed in Table 1.

Table 1 Main chemical compositions of two South China rare earth ores %

Ore	RE	Al	Fe	Mn	Ca	Mg	SiO ₂
Middle-heavy rare earth ore	0.127	11.44	3.79	0.05	0.29	0.62	62.7
Heavy rare earth ore	0.102	14.66	3.24	0.04	0.32	0.57	60.4

2.2 Experimental principle

The leaching hydrodynamics experiments need be carried out in a glass column, the height of the dry rare earth ore sample packed in the column is L , the

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radius of the column is r and the crossing area is F . The ore sample should be homogeneously distributed in the column and its packed loosen structure can not be destroyed under a minor pressure difference (Δp) in the leaching process. According to Darcy's law, the ore sample bed permeability (k) with the leach reagent flow Q and the medium viscosity η etc exist the following relation:

$$k = Q\eta L / (F \Delta p) \quad (1)$$

Here η is the viscosity of leach reagent which could be measured by the Ostwald viscometer.

The porosity (Φ) is the important parameter of determining the packed density ρ_s of the ore sample, and can be calculated from the following formula:

$$\Phi = 1 - m_s / (F \cdot L \cdot \rho_s) \quad (2)$$

where m_s is the mass of the experimental sample. The porosity (Φ) would be varied with installing the different ores to the leaching column. The k - Φ relation curve can be determined by the porosity (Φ), the leaching solution flow rate (Q) under corresponding Δp and the permeability k .

3 RESULTS AND DISCUSSION

3.1 Relationship between permeability and porosity for different type ores

The weathering crust elution-deposited heavy rare earth ore and the weathering crust elution-deposited middle-heavy rare earth ore (with the same granule size, $d = 0.125 \sim 0.75$ mm) were installed to the leaching column respectively, and leached with ion exchanged water under different pressure-difference (Δp) and the leaching solution flow rate (Q). The experimental results are shown in Fig. 1.

The results show that the relationship between the leaching liquid flow (Q) and the pressure-difference (Δp) is linear, which follows Darcy's law under experimental conditions. It proves that the weathering crust elution-deposited rare earth ore has the character of the unconsolidated particle bed. The flow process of leaching solution should be laminar flow

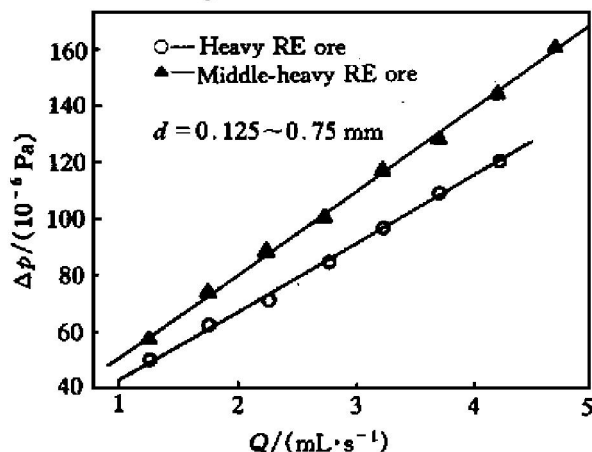


Fig. 1 Relationship between flow and leaching pressure-difference for two types of ore

rather than whirlpool flow attributed to the low inertia effect for low liquid flowing rate. The permeability (k) are calculated from the slope of two straight lines in Fig. 1. They are $k_H = 35.98 \text{ mm}^2$ and $k_{MH} = 28.50 \text{ mm}^2$ respectively. It further demonstrates that the permeability (k) of heavy RE ore is larger than the middle-heavy RE ore in the packed bed.

3.2 Relationship between flow and pressure-difference for various ore granule size

Three granule sizes middle-heavy rare earth ores were installed to the leaching column, leached with ion exchanged water under different pressure-difference (Δp) and leaching solution flow rate (Q). The results are shown in Fig. 2.

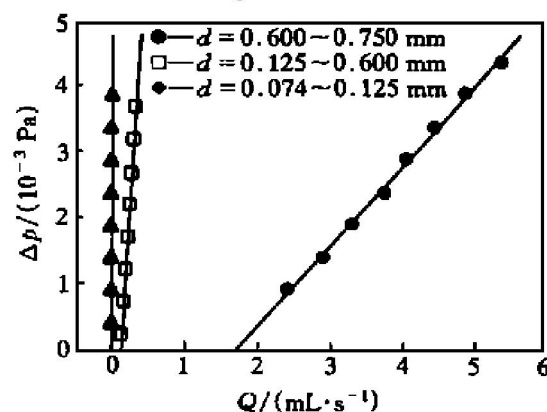


Fig. 2 Relationship between flow rate (Q) and leaching pressure-difference (Δp) under various ore particle sizes

The results illustrate that the relationships between the leaching liquid flow rate (Q) and the pressure-difference (Δp) is linear, and it similarly follows Darcy's law. It indicates that the weathering crust elution-deposited rare earth ore with various particle sizes has the same character of the unconsolidated particle bed. Their permeability (k) could also be calculated from the slope of three straight lines in Fig. 2. They are $k_{0.60 \sim 0.75 \text{ mm}} = 99.96 \text{ mm}^2$, $k_{0.125 \sim 0.60 \text{ mm}} = 11.83 \text{ mm}^2$ and $k_{0.074 \sim 0.125 \text{ mm}} = 0.84 \text{ mm}^2$ respectively. The permeability (k) increases with the ore granule size.

3.3 Relationship between permeability and porosity

In order to further understand the relationship between the permeability and the porosity, the weathering crust elution-deposited middle-heavy rare earth ores of two kinds of particle size are installed into the leaching column respectively. At the same time, their porosity are changed by quivering the ore with various intensity, then measure the porosity and corresponding leaching permeability. The results are shown in Fig. 3.

The results indicate that the permeability is not

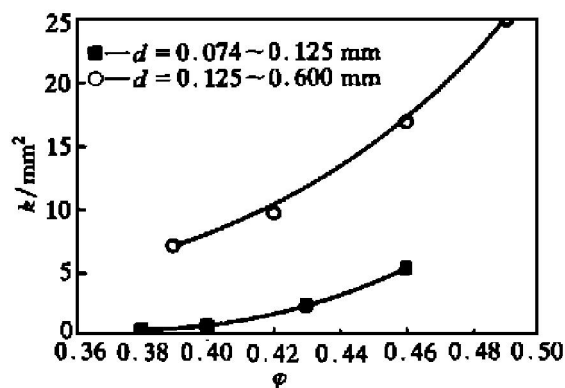


Fig. 3 Relationship between k and φ

only related with the ore granule size, but also related with the packed porosity under experiment conditions. The smaller the ore granule size is, the less the permeability is because the fluid channels become more narrow and curved at the small particle size of the ore.

3.4 Effect of concentration of leaching reagent on permeability

Different concentration of leaching reagent $(\text{NH}_4)_2\text{SO}_4$ under various pressure difference are applied to leach the middle-heavy rare earth ore in the leaching column. The relationship between Q and Δp is calculated as Fig. 4 based on the experiment results.

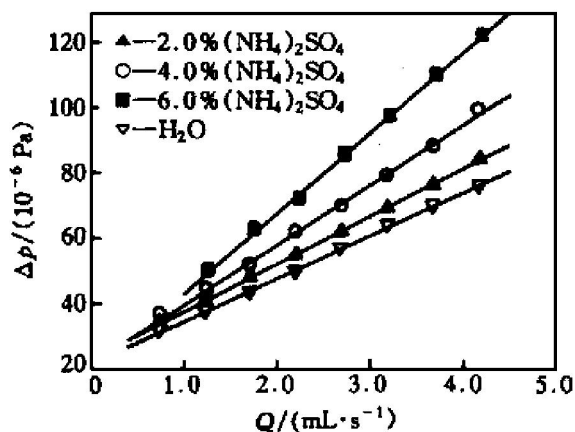


Fig. 4 Relationship between flowing rate and leaching pressure difference at different concentrations of reagent

The results illustrate that the relationship between the leaching liquid flow rate and the pressure difference follows Darcy's. The higher is the concentration of leaching reagent, the less is the permeability. This can be explained by higher concentration of the leaching reagent $(\text{NH}_4)_2\text{SO}_4$ resulting in the higher fluid viscosity ($\eta_{6\%} = 0.9395$, $\eta_{4\%} = 0.9177$, $\eta_{2\%} = 0.8749$, $\eta_{\text{H}_2\text{O}} = 0.8513$).

3.5 Effect of types of leaching reagent on permeability

$(\text{NH}_4)_2\text{SO}_4$, NH_4Cl and NH_4NO_3 solution are used to leach the ore in order to investigate the effect of the leaching reagent types on the permeability. The experimental results are shown in Fig. 5. It illustrates that the leaching reagent types have a great influence on permeability, the order of their permeability is $k(\text{NH}_4\text{NO}_3) > k(\text{NH}_4\text{Cl}) > k((\text{NH}_4)_2\text{SO}_4)$, which can be explained by the different viscosity of the leaching reagents ($\eta_{6\%(\text{NH}_4)_2\text{SO}_4} = 0.9395$, $\eta_{6\%\text{NH}_4\text{Cl}} = 0.9014$, $\eta_{6\%\text{NH}_4\text{NO}_3} = 0.8953$). Therefore the permeability can be improved by selection of the suitable leaching reagents.

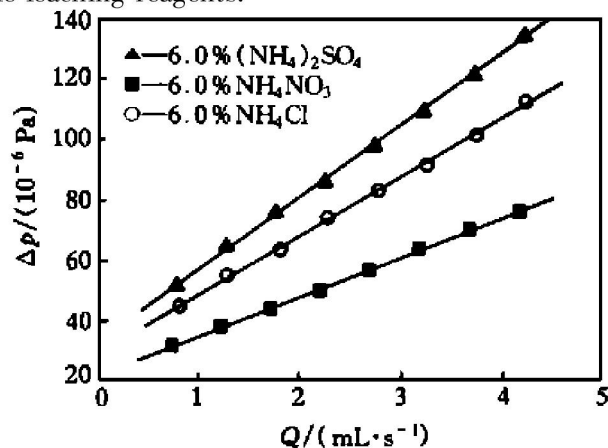


Fig. 5 Relationship between flowing rate and leaching pressure difference for different kinds of reagents

4 CONCLUSIONS

The relationships between the permeability, the porosity and the leaching pressure difference were investigated for the weathering crust elution-deposited heavy rare earth ore and the weathering crust elution-deposited middle-heavy rare earth ore. The effects of the ore types, ore granule size, the ore porosity, the type of leaching reagents and its concentration on the leaching permeability were studied. The experimental results show that k_{H} (for heavy RE ore, $k_{\text{H}} = 35.98 \text{ mm}^2$) $>$ $k_{\text{M-H}}$ (for middle-heavy RE ore, $k_{\text{M-H}} = 28.50 \text{ mm}^2$), $k(\text{NH}_4\text{NO}_3) > k(\text{NH}_4\text{Cl}) > k[(\text{NH}_4)_2\text{SO}_4]$. The higher the concentration of leaching reagent is, the less the permeability is, and k increases with increasing ore granule size ($k_{0.60 \sim 0.75 \text{ mm}} = 99.96 \text{ mm}^2$, $k_{0.125 \sim 0.60 \text{ mm}} = 11.83 \text{ mm}^2$, $k_{0.074 \sim 0.125 \text{ mm}} = 0.84 \text{ mm}^2$).

In despite of the flow of the leaching liquid and diffuse in rare earth ore is complicated, there are effects of the gravity-potential, the capillary potential and the macroscopic pressure potential, but only the macroscopic pressure is the active effect under the experimental conditions. Therefore the relationship of k - φ is unique, and the relationship of Q - Δp follows Darcy's law. The investigation would provide basic parameters to design and simulate the leaching RE

process for the weathering crust elution-deposited rare earth ore.

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