Kinetics and Mechanism of the Ammonia Pressure Leaching of Laterite Ore Containing Nickel*

By Kazuyoshi Shimakage**, Masayoshi Hoshi** and Tatsuhiko Ejima**

In the presence of oxygen more than an atmospheric pressure, laterite ore containing nickel which is previously reduced dissolves in a \( \text{NH}_3-(\text{NH}_4)_2\text{SO}_4 \) solution by the following reaction:

\[
\text{Ni} + 2\text{Fe} + n\text{O}_2 + (n + m - 4)\text{NH}_3 + 4\text{NH}_4^+ \rightarrow \text{Ni}(\text{NH}_3)_2^{2+} + \text{Fe}(\text{NH}_3)_2^{2+} + 2\text{H}_2\text{O}
\]

where \( n \) and \( m \) are the integral numbers between 1 and 6, respectively. In the current investigation, the kinetics of this reaction has been examined by changing the concentrations of \( \text{NH}_3 \) and \( \text{NH}_4^+ \) ion, partial pressure of oxygen, stirring velocity, temperature, and surface area. The leaching reaction of laterite ore in a solution containing both ammonia and ammonium sulfate is shown to be the zero-th order, because of the linearity found in the leaching time curve. The leaching reaction is accelerated by increasing temperature and stirring the leaching solution.

According to the experimental results obtained, the leaching rate equation for laterite ore containing nickel in a \( \text{NH}_3-(\text{NH}_4)_2\text{SO}_4 \) solution under the presence of pressurized oxygen is as follows:

\[
\text{Leaching rate} = K \cdot S \cdot P_{O_2} \cdot V(x) \cdot e^{-\frac{4690}{RT}}
\]

where \( K \) is the rate constant, \( S \) the surface area of the laterite ore reduced, \( P_{O_2} \) the partial pressure of oxygen, kg/cm\(^2\), \( V(x) \) the stirring velocity, rev/min (\( x \) is unknown because the sample is in the pulverized state), \( R \) the gas constant, and \( T \) the absolute temperature.

I. Introduction

Recently, there has been a wide interest\(^1\) in the development of a process which extracts the nickel from nickel-bearing laterite ore economically and preferably under mild conditions, because the mineral resources of nickel ores in the world is gradually decreasing with the growing use of nickel.

Various methods have been reported for the treatment of laterite ore containing nickel by many workers\(^2\)\(^-\)\(^9\). Most of them have been concerned with the development of the iron mineral resources rather than that of the nickel mineral resources. Moreover, the mechanisms of these processes are not well clarified yet. The method of ammonia pressure leaching is considered in the current investigation to be very effective for recovering nickel from laterite ore. This method can be divided into the following two processes; the partial reduction of laterite ore and the extraction of nickel from the reduced laterite ore in the leaching solution. It is therefore necessary to clarify the rate-determining step in the reduction reaction of laterite ore and the leaching kinetics of laterite ore under the ammonia pressure leaching.

The present authors previously made some fundamental experiments\(^10\)\(^-\)\(^13\) on the recovery of nickel from laterite ore by means of the ammonia pressure leaching and found satisfactory conditions for the roasting reduction and the ammonia pressure leaching.

The current investigation has been made as a part of this study and the leaching kinetics of laterite ore in ammonia-ammonium sulfate solution under the presence of oxygen higher than atmospheric pressure was studied over a wide range of \( \text{NH}_3 \) and \( \text{NH}_4^+ \) ions concentration, oxygen pressures, stirring velocities, temperatures and the surface areas of laterite ore.

II. Materials

In this work, Manicani laterite ore was used as the sample for reduction. Laterite ore was first dried in a drying apparatus and then ground to minus 100 mesh in a ball mill. To make dehydration of the ore, it is calcined in an alumina boat (22.5 x 1.2 x 1.0 cm) with an electric furnace heated at 800°C for 1 hour. Chemical compositions of laterite ore calcined are given in Table 1. Laterite ore used contains 0.87% nickel. Laterite ore reduced with \( \text{H}_2 \) gas at 850°C for 1 hour, was used as the leaching sample. In addition, the samples obtained by the reduction and leaching experiments were examined by using an X-ray diffractometer. X-ray diffraction patterns obtained are shown in Fig. 1. Diffraction lines due to hematite and corundum are observed in the diffraction pattern obtained from the laterite ore calcined. On the other hand, the diffraction lines due to magnetite, nickel-iron alloy\(^14\) and z-iron are found in the diffraction pattern for the laterite ore reduced. However, the diffraction lines of nickel-iron alloy and z-iron are not observed in the diffraction pattern of the leaching residue. This fact may indicate that nickel-iron alloy and z-iron contained in the reduced laterite ore are completely dissolved in the leaching solution under the conditions

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Table 1 Chemical composition of sample.

<table>
<thead>
<tr>
<th>Elements</th>
<th>T. Fe</th>
<th>Ni</th>
<th>Cr₂O₃</th>
<th>MgO</th>
<th>CaO</th>
<th>SiO₂</th>
<th>Al₂O₃</th>
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</thead>
<tbody>
<tr>
<td>(wt%)</td>
<td>55.66</td>
<td>0.87</td>
<td>2.01</td>
<td>0.30</td>
<td>0.48</td>
<td>3.45</td>
<td>10.80</td>
</tr>
</tbody>
</table>

Temperature of the sample was maintained at a constant temperature within ±2°C.

The experimental procedure of reduction is as follows. The sample previously weighed was placed in the center of reaction vessel with silica wools. The vessel was put into the center of the silica tube and a Pt-Pt-Rh thermocouple previously calibrated was set in the center part of the sample. After the reaction tube was thoroughly raised, nitrogen was slowly introduced into it and then the sample was heated up to a desired temperature by passing the dried nitrogen. Then the sample was reduced by the purified hydrogen passing through the reaction vessel with the flow rate of 300 mL/min at 850°C for 1 hour. After reduction, hydrogen was turned off and the sample was cooled in the nitrogen atmosphere for 72 hours.

On the other hand, the leaching experiment was carried out by using an autoclave of 1 liter in capacity which was made of stainless steel, as shown in Fig. 3. This autoclave was designed for a maximum pressure of 200 kg/cm² and had a magnetic stirrer installed. The stirring velocity can easily be adjusted in the range of 100~700 rev/min. The solution and the sample used for the experiment were 500 milli-liter and 12 grams. Temperature of the solution in the autoclave was measured by a mercury thermometer and maintained at a certain temperature within ±1°C. The partial pressure of oxygen was controlled in consideration of the partial pressures of water and ammonia. The experimental procedure of leaching is adopted for the ammonia pressure leaching.

III. Experimental Apparatus and Procedure

A schematic diagram of the reduction apparatus used is shown in Fig. 2. Purified hydrogen was used as a reducing gas, while nitrogen dried with silica gel, calcium chloride and phosphorus pentoxide was used as a substituting gas. The flow rates of hydrogen and nitrogen were measured respectively by the capillary type flow meters. The sample was reduced in a transparent silica tube, 3.5 cm in diameter and 100 cm in length, which was placed in an electric furnace of horizontal type, 21 cm in diameter and 50 cm in length. A vessel of the sample made of a transparent silica, 2.5 cm in diameter and 9.5 cm in length, was connected with a gas inlet tube by a connector made of glass.
as follows. After the sample and the leaching solution were put into the autoclave, the dissolved oxygen in the leaching solution was replaced by nitrogen. The solution was heated up to the desired temperature with an electric furnace and oxygen gas was then introduced into the autoclave in order to obtain the pressure required. The course of the leaching reaction was determined on the basis of the concentrations of nickel ions in the solution which is taken out at certain intervals through the sampling valve installed in the autoclave. Nickel ions were analyzed by the dimethylglyoxime method with a Hirama colorimeter.

IV. Experimental Results

1. Leaching time curve of laterite ore containing nickel

Some typical leaching curves of laterite ore in the solutions containing both ammonia and ammonium sulfate under the oxygen pressure of 10 kg/cm² are shown in Fig. 4. Irrespective of the stirring velocity, the amount of nickel leached from laterite ore increases in direct proportion to the time up to the leaching degree of less than 85%. The leaching reaction of laterite ore in the NH₃-(NH₄)₂SO₄ solution in the presence of oxygen more than an atmospheric pressure is found to be the zero-th order and the leaching rate can therefore be calculated from the slope of a straight line obtained in the time curve. This linear relation may also show that the effective surface area of laterite ore in contact with the leaching solution does not decrease with the progress of the leaching reaction.

2. Effect of stirring velocity

The leaching reaction of laterite ore in the NH₃-(NH₄)₂SO₄ solution under pressurized oxygen may be considered to take place through the following steps.

(a) Diffusion of oxygen through the gaseous boundary layer to the surface of the leaching solution.

(b) Dissolution of oxygen into the leaching solution from the gaseous boundary layer.

(c) Diffusions of the dissolved oxygen, NH₃, and NH₄⁺ ion through Nernst's boundary layer from the bulk of the leaching solution to the surface of laterite ore.

(d) Adsorption of these reactant at the surface of laterite ore.

(e) Chemical reaction at the surface of laterite ore.

(f) Desorption of Ni(NH₃)₆²⁺ ion produced from the surface of laterite ore.

(g) Diffusion of Ni(NH₃)₆²⁺ ion produced through Nernst's boundary layer from the surface of laterite ore to the bulk of the leaching solution.

Here \( n \) is the integral number of 1~6. To clarify the rate-determining step, the effect of stirring velocity on the leaching rate of laterite ore is at first measured by varying the stirring velocity. Under the condition of oxygen pressures of 3 and 10 kg/cm², the leaching rates of laterite ore increase with increasing stirring velocity, as shown in Fig. 5. The relation between the leaching rate and the stirring velocity cannot be determined quantitatively due to a simultaneous movement of the leaching solution and laterite ore powder, but the leaching reaction of laterite ore in a solution containing both ammonia and ammonium sulfate under the condition of pressurized oxygen is found to be a
diffusion-controlled one because a chemically controlled process is independent of the stirring velocity.

3. Effect of temperature

Under the condition of oxygen pressures of 3 and 10 kg/cm², the effect of temperature on the leaching rate of laterite ore was examined over the temperature range 20 to 150°C. The logarithm of the leaching rates at various temperatures are plotted against the reciprocal value of the absolute temperature. As shown in Fig. 6, there is a linear relation at temperatures between 20 and 150°C. Apparent activation energies calculated from the slopes of the straight lines obtained are 4630 and 4690 cal/mol under oxygen pressures of 3 and 10 kg/cm², respectively. These values approximately agree with the activation energy, 4390 cal/mol, of the diffusion coefficient of oxygen in water. From these values, the rate-determining step in the leaching reaction of laterite ore is found to be a diffusion-controlled process.

4. Effect of amount of laterite ore containing nickel

The rate-determining process in the leaching reaction of laterite ore is considered to be a diffusion either at the gas-liquid interface or at the liquid-solid interface. The effect of sample weight on the leaching rate of laterite ore was measured by changing the sample weight from 5 to 20 grams and the results obtained are shown in Fig. 7. The leaching rate of laterite ore increases linearly as the sample weight increases, i.e. the leaching rate of laterite ore directly increases with increasing surface area of the sample. This result indicates that the leaching rate of laterite ore is governed by the diffusion process at the interface between the surface of laterite ore and the leaching solution.

5. Effect of Ni(NH₃)₂⁺ ion

The experimental results obtained by adding 2.2×10⁻³ mol/ℓ of NiSO₄·6H₂O previously to the leaching solution under the same leaching condition without ammine nickel complex ions are given in Table 2. The leaching rate of laterite ore is the same as the value obtained in the absence of ammine nickel complex ions in the leaching solution. This can also be confirmed by the fact that the leaching curve is directly proportional to time. From this result, it is concluded that the nickel leached during the reaction, mainly as Ni(NH₃)⁺₆⁺ ion, does not affect the leaching rate of laterite ore.

6. Effect of ammonia concentration

From the results described above, the diffusion of either ammonia, ammonium ions or the dissolved oxygen through Nernst's boundary layer from the bulk of the leaching solution to the surface of laterite ore is considered to be the rate-determining step of the leaching reaction. Thus, the effect of ammonia concentration on the leaching rate of laterite ore in a NH₃–(NH₄)₂SO₄ solution containing 1 mol/ℓ ammonium sulfate was studied under the partial pressures of 0.5, 3, 6 and 10 kg/cm². As shown in Fig. 8, the

<table>
<thead>
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<th>Table 2 Effect of Ni(NH₃)₂⁺ ion.</th>
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<tbody>
<tr>
<td>NiSO₄·6H₂O</td>
</tr>
<tr>
<td>0 mol/ℓ</td>
</tr>
<tr>
<td>2.2×10⁻³ mol/ℓ</td>
</tr>
</tbody>
</table>

Leaching conditions: Sample weight as 12 g
Leaching solution 500 mℓ
NH₃ concentration 3 mol/ℓ
(NH₄)₂SO₄ concentration 1 mol/ℓ
Oxygen pressure 3 kg/cm²
Stirring velocity 300 r.p.m.
Temperature 100°C

† In this report, processes as adsorption and desorption are included in the term of "chemically."
leaching rates of laterite ore increase with increasing concentration of ammonia in the range 0 to 3 mol/l, but not in the range more than 3 mol/l. It also shows that nickel can be leached from laterite ore even in the case of (NH₄)₂SO₄ solution without ammonia. This may probably be explained by the formation of double salt such as NiSO₄·(NH₄)₂SO₄·6H₂O(16), indicating that the presence of ammonia in the leaching solution is not the essential factor for the leaching reaction of laterite ore.

7. Effect of the concentration of ammonium sulphate

The effect of the concentration of ammonium sulphate on the leaching rate of laterite ore in the leaching solution containing the ammonia of 3 mol/l was investigated under the oxygen pressures of 1, 3 and 6 kg/cm². As shown in Fig. 9, the leaching rates of laterite ore increase with increasing concentration of (NH₄)₂SO₄ in the leaching solution containing 1 mol/l ammonium sulfate or less and show a constant value depending on the partial pressure of oxygen in the range of ammonium sulfate more than 1 mol/l. The experimental results that the leaching rate does not increase in the case of the leaching solution containing more than 1 mol/l ammonium sulfate and the rate depends on the partial pressure of oxygen, may indicate that ammonium ion is not directly related to the rate-determining step of the leaching reaction of laterite ore.

8. Effect of the partial pressure of oxygen

In general, the weight of gas dissolved in a given volume of the solvent at a constant temperature is proportional to the pressure of gas in equilibrium with the solution(17). When a mixture gas dissolves in the solution, the solubility of each gas is proportional to its own pressure, respectively. The concentration of the dissolved oxygen in the leaching solution is therefore regulated by changing the partial pressure of oxygen in the autoclave. The effect of the partial pressure of oxygen on the leaching rate of laterite ore is measured by changing the concentrations of ammonia and ammonium sulfate in the solution, and the results obtained are shown in Figs. 10 and 11, respectively. Irrespective of the concentration of ammonia and ammonium sulfate, the leaching rates are directly proportional to the partial pressure of oxygen. When the solution contains the dissolved oxygen, the leaching reaction of laterite ore occurs even in ammonium sulfate solution without ammonia, indicating...
that the oxygen dissolved in the leaching solution participates in the rate-determining step of reaction, i.e. the diffusion of the dissolved oxygen through Nernst’s boundary layer from the bulk of the leaching solution to the surface of laterite ore may be the rate-determining step for the leaching reaction of laterite ore in a NH₃-(NH₄)₂SO₄ solution under the pressurized oxygen atmosphere.

V. Discussion

In general, nickel dissolves in aqueous ammonia in the form of Ni(NH₃)₃²⁺ ion under the presence of oxygen and the reaction can be expressed by

\[
Ni + \frac{1}{2}O_2 + nNH_3 + H_2O \rightarrow Ni(NH_3)_n^{2+} + 2OH^-, \quad (1)
\]

where \( n \) is an integral value between 1 and 6. In order to dissolve nickel into a solution of limited volume in an autoclave, OH⁻ ion produced must be removed by the addition of either ammonium sulfate or ammonium carbonate. In this case, the following reaction (2) may occur:

\[
OH^- + NH_4^+ \rightarrow NH_4OH \rightarrow NH_3 + H_2O. \quad (2)
\]

Thus, the dissolution reaction of nickel in a NH₃–(NH₄)₂SO₄ solution under the presence of pressurized oxygen can be represented by the following equation:

\[
Ni + \frac{1}{2}O_2 + (n-2)NH_3 + 2NH_4^+ \rightarrow Ni(NH_3)_{n-2}^{2+} + H_2O. \quad (3)
\]

In the current investigation, nickel oxide contained in laterite ore is reduced with hydrogen and finally forms nickel-iron alloy \(^{14}\). The leaching reaction of the reduced laterite ore in a NH₃–(NH₄)₂SO₄ solution under the presence of pressurized oxygen can be rewritten as follows:

\[
Ni·Fe + O_2 + (n + m - 4)NH_3 + 4NH_4^+ \rightarrow Ni(NH_3)_m^{2+} + Fe(NH_3)_n^{2+} + 2H_2O \quad (4)
\]

where \( m \) is the integral number of 1~6. Under the condition of the ammonia pressure leaching, Fe (NH₃)₂⁺ ions produced may rapidly decompose to ferric hydroxide and precipitate in the leaching solution \(^{13}\). Although nickel-iron alloy in the reduced laterite ore exists in the pulverized state, the amount of nickel leached from laterite ore according to eq. (4) is proportional to the leaching time, as shown in Fig. 4. This fact may easily be understood from a schematic diagram shown in Fig. 12, indicating that the actual surface area of nickel-iron alloy contained in the reduced laterite ore does not change with the progress of the leaching reaction. According to the results of X-ray analysis, magnetite, wüstite, corundum and \( \alpha \)-quartz contained in the reduced laterite ore are considered to be quite irrelative to the leaching reaction of nickel-iron alloy and \( \alpha \)-iron in the NH₃–(NH₄)₂SO₄ solution. It may be expected from the influence of these oxides that the reduction in the size of nickel-iron alloy particle with the advance of the leaching reaction, i.e. the decrease in the effective surface area of nickel-iron alloy, is compensated by the increase in the surface roughness of nickel-iron alloy powder, which gradually increases with the progress of the leaching reaction. Therefore, the actual surface area of nickel-iron alloy contained in the reduced laterite ore remains almost constant throughout the entire leaching reaction. This phenomenon was also observed for the dissolution reaction \(^{18}\) of metallic copper in aqueous ammonia.

Equation (4) can also be represented by the following electro chemical processes:

**Anodic process**

\[
Ni \rightarrow Ni^{2+} + 2e, \quad (5)
\]

\[
Ni^{2+} + nNH_3 \rightarrow Ni(NH_3)_n^{2+}, \quad (6)
\]

\[
Fe \rightarrow Fe^{2+} + 2e, \quad (7)
\]

\[
Fe^{2+} + mNH_3 \rightarrow Fe(NH_3)_m^{2+}, \quad (8)
\]

**Cathodic process**

\[
2OH^- + 2e \rightarrow H_2O + H_2. \quad (9)
\]

\[
2NH_4^+ + 2e \rightarrow 2NH_3 + H_2. \quad (10)
\]
Fig. 13 An electrochemical model for the leaching reaction of laterite ore in NH$_3$-(NH$_4$)$_2$SO$_4$ solution in an atmosphere of pressurized oxygen.

$$O_2 + 2H_2O + 4e^- \rightarrow 4OH^-, \quad (9)$$
$$4OH^- + 4NH_4^+ \rightarrow 4NH_4OH \rightarrow 4NH_3 + 4H_2O. \quad (10)$$

The NH$_3$ produced according to eq. (10) is utilized by the anodic process shown in eqs. (6) and (8). An electrochemical model estimated for the leaching reaction of laterite ore in the autoclave is given in Fig. 13. Ammonia diffuses through Nernst's boundary layer from the bulk of the leaching solution to the surface of the anodic zone of nickel-iron alloy and reacts with the liberated nickel and ferrous ions, according to eqs. (6) and (8). Oxygen which diffused through the gaseous boundary layer from the gas phase to the surface of the leaching solution and dissolved into the leaching solution and ammonium ion, diffuse through Nernst's boundary layer to the surface of the cathodic zone in nickel-iron alloy. The diffused oxygen takes up electrons at the surface of the cathodic zone, according to eq. (9), and ammonium ion reacts with hydroxyl ion according to eq. (10). When nickel-iron alloy dissolves into the leaching solution in the forms of Ni(NH$_3$)$_2^{2+}$ and Fe(NH$_3$)$_2^{2+}$ ions, ammonia and oxygen are both necessary for the leaching reaction of laterite ore. Kinetics equations for these reactions may be represented as follows. The reaction rate of eq. (6) can be given by eq. (11), when the first order kinetics is followed:

$$V_a = k_a' \cdot S_a \cdot [C_{NH_3}] \quad (11)$$

where $k_a'$ is the rate constant, $S_a$ the surface area of the anodic zone of nickel-iron alloy and $[C_{NH_3}]$ the concentration of ammonia at the interface between nickel-iron alloy and leaching solution. The reaction rate of eq. (10) can be given by eq. (12),

$$V_c = k_c' \cdot S_c \cdot [C_{O_2}] \quad (12)$$

where $k_c'$ is the rate constant, $S_c$ the surface area of the cathodic zone of nickel-iron alloy and $[C_{O_2}]$ the concentration of oxygen at the interface between nickel-iron alloy and leaching solution. In the steady state, the rate of the anodic reaction is equal to that of the cathodic reaction, and therefore

$$k_a' \cdot S_a \cdot [C_{NH_3}] = k_c' \cdot S_c \cdot [C_{O_2}]. \quad (13)$$

The total surface area of nickel-iron alloy in contact with the leaching solution can be given by eq. (14), because it does not decrease with the progress of the leaching reaction as shown in Fig. 12.

$$S = S_a + S_c \quad (14)$$

where $S$ is the total surface area of nickel-iron alloy. Substituting eq. (14) into eq. (13), eqs. (15) and (16) are obtained:

$$S_a = \frac{k_a' \cdot [C_{NH_3}]}{k_c' \cdot [C_{NH_3}] + k_c' \cdot [C_{O_2}] \cdot S}, \quad (15)$$
$$S_c = \frac{k_c' \cdot [C_{NH_3}]}{k_a' \cdot [C_{NH_3}] + k_c' \cdot [C_{O_2}]} \cdot S. \quad (16)$$

Substituting the value of either $S_a$ or $S_c$ in either eq. (11) or eq. (12), the dissolution rate can be given as follows:

$$\text{Dissolution rate} = \frac{k_a' \cdot [C_{NH_3}]}{k_c' \cdot [C_{NH_3}] + k_c' \cdot [C_{O_2}]} \cdot S. \quad (17)$$

When the concentration of ammonia is much higher than the concentration of oxygen, the term of the oxygen concentration in the denominator of eq. (17) may be neglected in comparison with the term of the concentration of ammonia. Therefore, the dissolution rate can be represented by eq. (18):

$$\text{Dissolution rate} = k_c' \cdot S \cdot [C_{NH_3}]. \quad (18)$$

In this case, the rate of dissolution is shown as the functions of the concentration of oxygen and the surface area of nickel-iron alloy. Equation (18) gives a best fit with the experimental results obtained, as shown in Figs. 7, 10 and 11, respectively. It is seen from these considerations that the leaching reaction of the reduced laterite ore in a NH$_3$-(NH$_4$)$_2$SO$_4$ solution under the pressurized oxygen is well explained by the electrochemical mechanism and the cathodic reaction of oxygen at the surface of nickel-iron alloy is the rate-determining step in the leaching reaction.

As described above, oxygen is the most important factor in the control of the reaction for the ammonia pressure leaching of laterite ore. The leaching reaction cannot proceed when the electrons of nickel are not removed by oxygen in accordance with the reaction (9). The leaching rate of laterite ore in a NH$_3$-(NH$_4$)$_2$SO$_4$ solution increases linearly with increasing partial pressure of oxygen and increasing surface area of nickel-iron alloy. The leaching reaction is accelerated by increasing the temperature and the stirring velocity of the leaching solution. The apparent activation energy calculated from the Arrhenius plots is 4690 cal/mol. The rate equation for the leaching reaction of laterite ore is as follows:

$$\frac{d[Ni]}{dt} = K \cdot S \cdot P_{O_2} \cdot V(x) \cdot e^{-4690/T}.$$
where \( d[\text{Ni}] / dt \) is the leaching velocity of laterite ore, g/min at time \( t \), \( K \) the rate constant, \( S \) the surface area of laterite ore, \( P_{O_2} \) the partial pressure of oxygen, kg/cm\(^2\), \( V(x) \) the stirring velocity, r.p.m. (\( x \) is unknown because the sample is in the pulverized state), \( R \) the gas constant, and \( T \) the absolute temperature.

VI. Conclusions

Kinetics and mechanism of the ammonia pressure leaching of laterite ore containing nickel were investigated over a wide range of \( \text{NH}_3 \) and \( \text{NH}_4^+ \) ion concentrations, the partial pressure of oxygen, stirring velocity, temperature and the surface area of laterite ore. The experimental results obtained are summarized as follows:

(1) The leaching reaction of laterite ore in a \( \text{NH}_3-(\text{NH}_4)_2\text{SO}_4 \) solution in an atmosphere of pressurized oxygen is shown to be the zero-th order, because the leaching curve is directly proportional to the time.

(2) The leaching rate of laterite ore is proportional to the surface area and the partial pressure of oxygen. The leaching reaction is also accelerated by increasing the temperature and the stirring rate of the leaching solution. The apparent activation energy calculated from the Arrhenius plots is 4690 cal/mol. This value is in good agreement with the activation energy for the diffusion coefficient of oxygen in water.

(3) The rate-determining step of the leaching reaction of laterite ore is the transport process of the dissolved oxygen to the surface of nickel-iron alloy and the chemical process is much faster than the diffusion rate of oxygen.

(4) The leaching reaction of laterite ore in a \( \text{NH}_3-(\text{NH}_4)_2\text{SO}_4 \) solution under the atmosphere of pressurized oxygen may be explained by an electrochemical mechanism and the cathodic reaction of oxygen at the surface of nickel-iron alloy serves as the rate-determining step of the leaching reaction.

(5) From the experimental results obtained, the equation for the leaching rate of laterite ore in a solution containing both ammonia and ammonium sulfate under the atmosphere of pressurized oxygen can be given as follows:

\[
\frac{d[\text{Ni}]}{dt} = K \cdot S \cdot P_{O_2} \cdot V(x) \cdot e^{-\frac{4690}{RT}},
\]

where \( d[\text{Ni}] / dt \) is the leaching rate of laterite ore, g/min at time \( t \), \( K \) the rate constant, \( A \) the surface area of laterite ore, \( P_{O_2} \) the partial pressure of oxygen, kg/cm\(^2\), \( V(x) \) the stirring velocity, r.p.m. (\( x \) is unknown because the sample is in the pulverized state), \( R \) the gas constant, and \( T \) the absolute temperature.

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