Leaching of an oxide gold ore with chloride/hypochlorite solutions

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Received 3 April 2006; received in revised form 25 July 2006; accepted 6 September 2006

Available online 17 October 2006

Abstract

An oxide gold ore was subjected to chloride/hypochlorite leaching at room temperature. The effects of three factors, including Ca(OCl)₂ vs. NaOCl, OCl⁻ concentration, and HCl concentration on gold leaching performance were investigated. Due to formation of CaOCl⁺ complex in solution and hence less reactivity, calcium hypochlorite produces a sluggish gold leaching kinetics, taking twice the time (46 h) to achieve maximum gold recovery of 58% compared to sodium hypochlorite. 10 g/L of total initial hypochlorite species in solution produces reasonable gold recoveries. The amount of added HCl and hence the initial pH was found to have a major effect on gold leaching kinetics and maximum gold recovery. A high level of 9 g/L of added HCl causes HClO to be very reactive, producing very fast kinetics, reaching 67% gold extraction in 4 h. It also causes a faster consumption of hypochlorous acid, through catalytic decomposition (by NiO and CuO) and disproportionation. Hypochlorous acid reactions with sulfide and ferrous content of ore proceed very slowly in the pH range of 4–11. Gold–chloro complexes are strongly adsorbed on quartz component of ore. To minimize this undesirable adsorption of gold–chloro species, the aging time must be limited to a few hours only.

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Keywords: Chloride; Hypochlorite; Hypochlorous; Lixiviant; Gold; Ore; Leaching; Adsorption; Gold–chloro; Complex

1. Introduction

Chlorine had been used to dissolve gold from ores and concentrates, during the second half of the 19th century in Australia and North America. At the beginning of the 20th century, this process was gradually replaced by the more economical alkaline cyanide leaching (Sparrow and Woodcock, 1995). Nowadays, however, due to the realization of environmental problems of cyanide, there is a worldwide quest to find viable alternatives to cyanide. One of the alternatives is a chloride solution with an appropriate oxidizing agent. One of the strongest oxidizing agents for this system is chlorine. As Reaction (1) shows, chlorine, in presence of chloride ions, readily dissolves elemental gold to gold (III)–chloro complex, [AuCl₄]⁻, provided the pH is less than 2 (Finkelstein et al., 1966).

\[ 2\text{Au} + 3\text{Cl}_2 + 2\text{Cl}^- \rightarrow 2[\text{AuCl}_4]^- \] (1)

The rate of dissolution of gold by chlorine is much faster than that by cyanide (Filmer et al., 1984). Also, due to presence of chloride ions, there is no passivation of gold surfaces during chlorination. The major disadvantage of the chlorine–chloride system is the high reactivity of chlorine in reaction with sulfide and gangue carbonate minerals. As a result, only high grade materials may be treated by chlorine–chloride system economically.
Another widely used oxidizing agent for gold–chloride system is hypochlorite. Jeffrey et al. (2001a,b) recently measured the dissolution rate of pure gold and an Au/Ag alloy in chloride/hypochlorite solutions using a rotating electrochemical quartz crystal microbalance. They showed that at pH=8 where hypochlorite ion (ClO\(^{-}\)) is the dominant oxy-chloride species, the dissolution rate of the gold disk was very low. However, at more acidic pHs, hypochlorous acid forms according to Reaction (2).

\[
H^+ + ClO^- \rightarrow HClO
\]  

(2)

HClO is a stronger oxidizing agent than ClO\(^{-}\), hence leaches gold faster (Jeffrey et al., 2001a,b). Reaction (2) has an equilibrium constant of \(10^{7.5}\) at 25 °C (Snoeyink and Jenkins, 1980); hence, at pH=7.5, concentrations of ClO\(^{-}\) and HClO are equal. For pHs lower than 7.5, HClO becomes the dominant species.

At 1.0 M NaCl concentration and potentials higher than 950 mV (vs. SHE), AuCl\(_4\) species is the stable gold–chloride complex in solution up to pH=10 (Wang, 1992). Leaching of gold with hypochlorous acid follows Reaction (3).

\[
2Au + 3HClO + 5Cl^- + 3H^+ \rightarrow 2[AuCl_4]^- + 3H_2O
\]  

(3)

The mechanism of gold dissolution in chloride solutions involves the initial formation of Au(I)–chloride complex (AuCl) on the surface of metallic gold. AuCl undergoes further complexation with chloride ion to AuCl\(_2\). This complex then moves to solution and is oxidized with HClO to AuCl\(_4\) (Nicol, 1980; Nikolski, 1998).

Based on weight loss of gold strips, Tran et al. (1992, 2001) measured gold dissolution rate in different chloride/hypochlorite mixtures. For instance, with a concentration of 100 g/L NaCl and 10 g/L OCI\(^{-}\) at 20 °C and pH=6.0, gold dissolution rate was measured at 13 mg/cm\(^2\) h. This rate is much higher than the gold dissolution rate of 2.5 mg/cm\(^2\) h obtained in 2 g/L of cyanide solution (Tran et al., 2001).

The performance of chloride/hypochlorite solution for gold leaching also depends on major minerals present in the ore. Gold–chloride complex is rather unstable and may re-precipitate upon contact with a reductant, such as sulfidic materials of ore. Puvvada and Murthy (2000) used chloride/hypochlorite solution to leach gold and silver from a chalcopyrite concentrate. Direct hypochlorite leaching of the sulfidic concentrate yielded gold and silver recoveries of 43% and 45%, respectively. After pressure oxidation of the concentrate and subsequent hypochlorite leaching, the recoveries increased to 90% for gold and 93% for silver. In contrary to reducing ores and concentrates, some ores may naturally contain oxidizing agents, such as MnO\(_2\). Gold in these types of materials can be leached with an NaCl/acid solution only. Since the oxidant Cl\(_2\)/HClO is formed in-situ upon reaction of Cl\(^{-}\) and MnO\(_2\) (Leon and Quispe, 1986), for in-situ chlorine/hypochlorous acid formation, MnO\(_2\) have been used in NaCl and H\(_2\)SO\(_4\) solution to leach gold from anode slimes (Hait et al., 2002).

Another complexity in gold–chloride system is strong adsorption of gold–chloro complexes on mineral surfaces, such as goethite, quartz, and alumina (Machfsky et al., 1991). Gold(III)–chloride adsorption by goethite (FeOOH) was specifically investigated by Machfsky et al. (1991) as a function of pH (4 to 8) and Cl\(^{-}\) concentrations (0 to 0.1 M). In 0.1 M NaCl solution and pH=4, gold adsorption on goethite was 4000 ppm. The adsorption increased as pH increased from 4 to 7. This trend is opposite to typical behavior for anion adsorption onto oxide surfaces. This “retrograde” adsorption trend is due to a shift in dominance from AuCl\(_4^-\) at pH=4 to adsorbed hydroxyl-substituted species (such as AuCl(OH)\(_3\)) at higher pH values (Machfsky et al., 1991). Based on gold and iron Mossbauer spectroscopy, it has been confirmed that gold–hydroxo–chloro complexes are strongly adsorbed by iron oxides such as goethite (Greffie et al., 1996). Based on Mossbauer spectroscopy technique, adsorption of AuCl\(_4^-\) on modified activated carbons was also studied in an aging process through a course of several weeks (Cashion and Brown, 1998). It was shown that adsorption on the solid surface first results in the loss of one of the chloride ions. Subsequent reduction of Au\(^{3+}\) to Au\(^{+}\) results in the loss of two more chloride ions. Finally the last chloride ion may be removed and gold precipitates as Au\(^{0}\). The following species were identified on the solid surfaces: AuCl\(_4^-, \) AuCl\(_3^-\), AuCl\(_2^-\), AuCl\(_2^-\), and AuCl\(_X^-\), where X is an oxygen- or nitrogen-containing group. To avoid the complexity of gold species adsorption and precipitation, some researchers have opted to measure gold leaching kinetics in idealized chloride/hypochlorite system in terms of weight loss of pure gold disk and strips, rather than measuring dissolved gold concentration in solution (Jeffrey et al., 2001a,b; Nikolski, 1998).

The objective of this work was to examine the viability of using chloride/hypochlorite lixiviant system to leach gold from an oxide gold ore. Furthermore, due to the possibility of using heap leaching technique for this deposit, tests were designed to run in the absence of oxygen. This condition mimics the
case of a compact heap, where air can hardly penetrate into the heap.

2. Experimental

A 4 in. core from an oxide gold deposit was crushed and ground to an average size of 150 μm. It was then passed through a Knelson gravity concentrator to separate its coarse gold nuggets. The concentrator tailing was used for leaching tests. Commercial grade reagents, including 36% HCl, 5% NaOCl, solid NaCl, and solid Ca(OCl)₂ were used for the tests. Tap water with a TDS (total dissolved solids) of less than 50 ppm was used.

Leaching tests were performed in a custom-made 10 l Plexiglas stirred tank vessel. A simple drawing of the setup is shown in Fig. 1. A turbine-type Teflon impeller was used for agitation. A large port on the lid was assigned for the feed introduction and sampling. This port was also used for entrance of pH, ORP, DO, and temperature probes. As shown in Fig. 1, two smaller ports were used for nitrogen gas injection, one through a dip tube and another to the top of slurry. To ensure that the reactor pressure does not exceed 10 psig during overnight operation, a suitable relief valve was connected to the second nitrogen gas port. Leaching tests were run at room temperature (24±1 °C).

Before starting a test, pH, ORP, and DO probes were calibrated. 2 kg of ground ore feed was poured to the reactor. 4 kg of tap water was added to the reactor and agitation was set at 600 rpm. Solid NaCl was then added. To de-oxygenate the reactor, nitrogen gas was bubbled into the slurry through the dip tube. It normally took about 30 min for the DO probe to show a zero value reading for dissolved oxygen in slurry. After this period, nitrogen gas injection was switched from the dip tube to the other port. The required amounts of reactive reagents, e.g., 36% HCl solution, and 5% NaOCl solution, were poured into the reactor. Tap water was then added to obtain 6 kg of total solution in the reactor (a solid to liquid ratio of 0.33 was maintained for all tests). pH, ORP, DO, and temperature readings were recorded immediately (at \( t = 0 \) h). After each data collection, the electrodes were taken out, washed and stored. The main port was closed and nitrogen pressure was allowed to build up to set point pressure of 5 psig (by using a gas regulator).

The tests were run for up to 5 days. In day one, electrode readings and samples were collected at 0.25, 1,

![Fig. 1. Experimental setup for chloride/hypochlorite leaching of a gold ore, under 5 psig nitrogen pressure.](image)

![Fig. 2. XRD analysis of an oxide gold ore. A: ankerite, Ca(Fe,Mg)(CO₃)₂; M: muscovite, H₂KAl₃(SiO₄)₃; Q: quartz, SiO₂.](image)

### Table 1

<table>
<thead>
<tr>
<th>SiO₂</th>
<th>Na</th>
<th>K</th>
<th>Mg</th>
<th>Ca</th>
<th>Al</th>
<th>Fe (total)</th>
<th>Fe (ferrous)</th>
<th>C (total)</th>
<th>C (inorganic)</th>
<th>S (total)</th>
<th>S (sulfide)</th>
</tr>
</thead>
<tbody>
<tr>
<td>54.4</td>
<td>0.7</td>
<td>1.3</td>
<td>4.3</td>
<td>4.4</td>
<td>5.8</td>
<td>4.9</td>
<td>4.4</td>
<td>3.1</td>
<td>2.9</td>
<td>0.5</td>
<td>0.5</td>
</tr>
</tbody>
</table>
2, 3, 4, 5, and 6 h. For the following days, data and samples were collected once per day. To perform data collection and sampling, the reactor pressure was released through a valve. The main port was then opened. To inhibit oxygen penetration to the reactor, nitrogen was allowed to sweep through the reactor on top of slurry and exit from the main port continuously. The electrodes were inserted into slurry. After waiting for 2 min for stable electrode readings, the values were recorded and electrodes were taken out. For sample collection, agitator was turned off. The solids were allowed to settle for 5 min. 20 mL supernatant clear solution sample was collected by a syringe. The sample was filtered through a 0.2 μm syringe filter and stored for later solution analyses. Agitation was restarted, the main port was closed and the test was continued. For finishing the test, nitrogen gas was closed and slurry was filtered in a pressure filter using air at 20 psig pressure. The filter cake was twice washed with 2 kg tap water and dried in an oven at 80 °C overnight. After drying, the solid residue was pulverized and sent for gold fire assay analysis. The solution samples were also analyzed for gold by fire assay method. Concentration of hypochlorite ion in a solution sample was measured based on a standard titration method using thiosulfate solution (Clesceri et al., 1998).

3. Results

Due to coarse nature of gold in the ground ore (the Knelson tailing), gold head assay for each leaching test was calculated by adding gold remained in solid residue

<table>
<thead>
<tr>
<th>Test no.</th>
<th>Solid/liquid ratio (S/L)</th>
<th>Oxidant type</th>
<th>OCl⁻ (g/L)</th>
<th>Cl⁻ (g/L)</th>
<th>HCl (36%) (g/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.33</td>
<td>Na(OCl)</td>
<td>10</td>
<td>61</td>
<td>3.3</td>
</tr>
<tr>
<td>2</td>
<td>0.33</td>
<td>Ca(OCl)₂</td>
<td>10</td>
<td>61</td>
<td>3.3</td>
</tr>
<tr>
<td>3</td>
<td>0.33</td>
<td>Ca(OCl)₂</td>
<td>2.7</td>
<td>61</td>
<td>3.3</td>
</tr>
<tr>
<td>4</td>
<td>0.33</td>
<td>Na(OCl)</td>
<td>10</td>
<td>61</td>
<td>9</td>
</tr>
<tr>
<td>5</td>
<td>0.33</td>
<td>Na(OCl)</td>
<td>10</td>
<td>61</td>
<td>0</td>
</tr>
</tbody>
</table>

Fig. 3. Chloride/hypochlorite leaching. Temperature=25 °C, solid/liquid (S/L) ratio=0.33, Cl⁻ = 61 g/L. The performance of Ca(OCl)₂ vs. Na(OCl).
and the gold leached. The calculated gold content was in the range of 1–2 g/t. The analyses of major elements of ore, obtained by flux fusion-ICP technique, are reported in Table 1. An XRD analysis of the ground ore was performed to obtain its mineralogical characterization. As shown in Fig. 2, the major minerals identified were: ankerite, Ca(Fe,Mg)(CO₃)₂ (A); muscovite, H₂KAl₃(SiO₄)₃ (M); and quartz, SiO₂ (Q). Three minor phases may also exist (very small peaks not marked in Fig. 2). These are: albite, (Na, Ca)Al(Si,Al)₃O₈; diaspore, Al₂O₃.H₂O; and chlorite, (Mg,Fe)₅(Al,Si)₁₀(OH)₈.

Five gold leaching tests were performed for up to 5 days. The experimental conditions of these tests are reported in Table 2. The solid to liquid ratio for all tests was set at 0.33. The concentration of NaCl for all tests was set at 100 g/L, equivalent to 61 g/L of Cl⁻ ion. Three other factors, including oxidant type, concentration of OCl⁻, and concentration of HCl varied among tests. In tests #1 and #2, two oxidizing agents, Ca(OCl)₂ and NaOCl, were compared. The initial concentration of OCl⁻ = 10 g/L and HCl = 3.3 g/L were the same for both tests. The results of these tests are shown in Fig. 3. Fig. 3A shows that percent leached gold peaked at 58% and then dropped in both cases. In test #1 for NaOCl, the peak occurs at 23 h, and in test #2 for Ca(OCl)₂, it occurs at 46 h. In Fig. 3B, hypochlorite ion concentration in solution vs. time is shown. Fig. 3C shows that the initial pH for both tests was 8. The solution pH dropped to a value between 5.5 and 6 in about 23 h, and then increased. The solution redox potential is shown in Fig. 3D. By comparing Fig. 3B and D, it is understood that as long as small amounts of OCl⁻ exists in solution, redox potential remains higher than 1000 mV (vs. SHE). When all hypochlorous acid is consumed, redox potential drops below 1000 mV and gold starts to drop out of solution either through precipitation to metallic gold or through adsorption on mineral surfaces (Fig. 3A). From the results of tests #1 and #2, it is seen that Ca(OCl)₂ and NaOCl behave rather similarly, except that maximum leached gold for Ca(OCl)₂ occurs at a longer time (Fig. 3A). This may be due to formation of Ca(OCl)⁺ complex in solution. The formation of this complex, in turn, reduces concentration of HClO in

Fig. 4. Chloride/hypochlorite leaching. Temperature=25 °C, solid/liquid (S/L) ratio=0.33, Cl⁻=61 g/L. Effect of OCl⁻ concentration on gold leaching behavior of the ore.
solution, which results in slower gold leaching kinetics (refer to Reaction (3)).

The effect of initial concentration of oxidizing agent on gold leaching performance was investigated at two concentrations of $\text{OCl}^-$, 10 and 2.7 g/L. The results of these tests (#2 and #3) are presented in Fig. 4. As shown in Fig. 4A, maximum dissolved gold in solution was 58% and 24% for the high and low values of $\text{OCl}^-$, respectively. As depicted in Fig. 4C, the initial pH for test #2 at 10 g/L $\text{OCl}^-$ is higher than that for test #3 with 2.7 g/L $\text{OCl}^-$. According to Reaction (2), this is due to higher consumption of $\text{H}^+$ for test #2 with higher $\text{OCl}^-$. However, after 10 h, the solution pH for test #2 becomes more acidic. Obviously, the higher level of HClO have caused acid-producing reactions (as discussed later) to proceed faster. In conclusion, the initial concentration of $\text{OCl}^-$ must be at least 10 g/L to achieve high gold leaching values for the tested ore.

The effect of initial acidity on gold leaching performance was studied at three levels of added HCl. The results of these three tests at 9, 3.3, and 0 g/L of added HCl (tests #4, 1, and 5, respectively) are shown in Fig. 5. The best performance of gold leaching, in terms of fast kinetics and maximum recovery, occurs at 9 g/L of added HCl, i.e., test #4 in Fig. 5A. As shown in Fig. 5C and B for test #5 with 0 g/L HCl, the initial pH equals 11 and $\text{OCl}^-$ reactivity and its initial consumption are low. The low reactivity of $\text{OCl}^-$ causes very slow kinetics for gold leaching, Fig. 5A. On the other extreme, when 9 g/L HCl was added in test #4, the initial pH was 7.3, and very fast gold leaching kinetics was achieved, i.e., 67% in 4 h. However, as shown in Fig. 5B, initial consumption of $\text{OCl}^-$ in this test was very high, i.e., 63% in 0.25 h. In summary, at least 9 g/L of HCl must be used to achieve fast and high gold recoveries. Among the three factors tested in this study, initial solution pH

![Fig. 5. Chloride/hypochlorite leaching. Temperature=25 °C, solid/liquid (S/L) ratio=0.33, Cl$^-$_=61 g/L. Effect of HCl concentration on gold leaching behavior of the ore.](image)
has the most profound effect on gold leaching in hypochlorite/chloride system. One of the effects of pH is on the distribution of solution species. Using HSC Chemistry software (Outokumpu Research, Pori, Finland), \( \text{Eh} - \text{pH} \) diagram of chloride/hypochlorite system at 25 °C (for total Cl concentration of 2 M) was constructed (Fig. 6). A similar diagram (for total Cl=1e−4 M) is also given elsewhere (Snoeyink and Jenkins, 1980). The total Cl concentration only affects the Cl₂-dominant region for very acidic pHs. Fig. 6 shows that for pH values less than 7.5 and redox potentials higher than 1200 mV, the dominant species is HClO. According to Reaction (3), high concentrations of HClO and \( \text{H}^+ \) causes a very high extraction rate of gold, as evidenced in test #4, Fig. 5A.

Two of the leach residues (#1 and #4) were selected for elemental and XRD analyses. The obtained results showed virtually no differences with those of ore feed, in terms of sulfide, ferrous, and ankerite content. Hence, it is concluded that these compounds would react very slowly with hypochlorite solutions at the pHs investigated in this study. To verify this further, two solution samples from test #1 were analyzed for dissolved metals by ICP. The only significant elements found were Mg and Ca with concentrations in the range of 150 to 700 ppm. Among the identified major minerals of ore (Fig. 2), ankerite is the only mineral that contains inorganic carbon and calcium. Based on values in Table 1, molar ratio of C/Ca in ore feed is 2.2 which is close to the theoretical value of 2 in ankerite. Ferrous iron also exists only in ankerite. Mass balance calculations showed an Fe/Ca molar ratio of 0.71. Charge neutrality of ankerite also dictated an Mg/Ca molar ratio of 0.29. Therefore, ankerite in the feed is estimated to have the composition \( \text{Ca(Fe}_{0.71}, \text{Mg}_{0.29})(\text{CO}_3)_2 \), with a weight percentage of roughly 23%. Ankerite reacts slowly in hypochlorite/chloride solution and produces the dissolved \( \text{Ca}^{2+} \) and \( \text{Mg}^{2+} \) species in solution. Based on the measured concentrations of \( \text{Ca}^{2+} \) and \( \text{Mg}^{2+} \), percentage of ankerite leached was calculated, as shown in Fig. 7 (leached values are consistent for both Ca and Mg). This figure shows that less than 6% of ankerite has been leached; hence, it re-confirms the low reactivity of ankerite in the experimental range of this study.

4. Discussion

It is estimated that only a few percentage of ferrous iron and sulfide content of ore feed react with hypochlorite solution in pH range of 4 to 11. Hypochlorous acid is reduced to chloride ion (Reaction (4)); sulfide-containing components are oxidized and produce sulfate ions (Reaction (5)); and ferrous iron is oxidized to ferric iron (Reaction (6)).

\[
\begin{align*}
\text{HClO} + \text{H}^+ + 2e^- & \rightarrow \text{Cl}^- + \text{H}_2\text{O} \quad (4) \\
(1/4)\text{S}^{2-} + \text{H}_2\text{O} & \rightarrow (1/4)\text{SO}_4^{2-} + 2\text{H}^+ + 2e^- \quad (5) \\
2\text{FeO} + \text{H}_2\text{O} & \rightarrow \text{Fe}_2\text{O}_3 + 2\text{H}^+ + 2e^- \quad (6)
\end{align*}
\]

In addition to Reaction (4) that consumes hypochlorous acid due to reaction with sulfide and ferrous iron,
hypochochlorous acid may also disproportionate chemically to chlorate ion, Reaction (7) (Currey and Pumplin, 1988). It may also undergo a decomposition reaction, Reaction (8).

\[ \text{ClO}^- + 2\text{HClO} \rightarrow \text{ClO}_3^- + 2\text{Cl}^- + 2\text{H}^+ \]  

(7)

\[ 2\text{ClO}^- \rightarrow 2\text{Cl}^- + \text{O}_2 \]  

(8)

For all tests, except #3 (with low initial \text{OCl}^\text{-}), solution pH initially drops, reaches a minimum, and then slightly increases. The initial pH drop must be due to net acid generation in Reactions (4)–(7). These are predominant reactions when hypochochlorous acid concentration is relatively high. When it decreases sufficiently, acid in solution is slowly neutralized with alkali components of ore.

It is shown in Figs. 3B, 4B, and 5B that depending on solution pH, a large proportion of hypochlorite content of solution disappears in 0.25 h. If this large drop in \text{ClO}^- concentration were due to Reactions (4)–(7), the solution pH would have reduced to very low levels, and virtually all sulfide and ankerite of ore feed would have reacted. On the other hand, if the drop were due to Reaction (8), catalyzed on \text{NiO} and \text{CuO}, the fast rate of decomposition of \text{ClO}^- would have continued. As a result, it is postulated that the initial rapid drop in \text{ClO}^- concentration is due to its adsorption on some mineral surfaces.

In Figs. 3A, 4A, and 5A, whenever gold leached curves show a drop, adsorption of gold–chloro complexes on some mineral surfaces must have played a role. For instance, in tests #1 and #4 (Fig. 5), after gold concentration in solution peaks, it decreases while some \text{OCl}^- still exists in solution (ORP is also higher than 1000 mV). In general, the amount and nature of adsorbed gold–chloro–hydroxo complexes on mineral surfaces is a function of (a) solution pH and redox potential, (b) the extent of oxidation of sulfide and ferrous content of ore, and (c) the aging time. It is well known that \text{Au(III)}–chloride hydrolysis species are strongly adsorbed by goethite, quartz, and alumina (Machfsky et al., 1991). Of these minerals, quartz is abundant in the tested ore.

Hence, it is anticipated that quartz is the main adsorbent of gold–chloro complexes in our system. For an industrial gold leaching application, any form of adsorption of gold–chloro complexes on solid surfaces is undesirable. In the current investigation, the best result with minimum gold adsorption was achieved in test #4, when 67% of gold was dissolved into solution in 4 h (very low aging time).

5. Conclusions

Chloride/hypochlorite lixiviant system at room temperature was used to leach gold from an oxide gold ore. To find the optimal operating conditions, the effect of three factors, including \text{Ca(OCl)}_2 vs. \text{NaOCl}, \text{OCl}^- concentration, and \text{HCl} concentration were investigated. Calcium hypochlorite produced a sluggish gold leaching kinetics, requiring twice more time (46 h) to achieve the maximum gold recovery of 58% compared to sodium hypochlorite. To have a reasonable gold leaching kinetics, it was found that \text{OCl}^- in solution must be equal or higher than 10 g/L. The amount of \text{HCl} added and hence initial pH was found to have a major impact on gold leaching kinetics and maximum gold recovery. A very slow gold leaching kinetics was obtained when no acid was added. On the other extreme, 9 g/L of added \text{HCl} caused a very high reactivity that produced a very fast gold leaching kinetics. Hypochlorite species reactions with sulfide and ferrous content of ore were found to be insignificant in the pH range of 4 to 11. Adsorption of gold–chloro complexes is anticipated to occur on quartz minerals in our system. To minimize adsorption of gold–chloro complexes, it works best to minimize the aging time.

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