AGGLOMERATION BINDERS TO IMPROVE EFFICIENCY OF COPPER HEAP LEACHING

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Abstract

Heap leaching efficiency is reduced by poor solution flow characteristics (channeling and ponding), which result from fines migration. Agglomeration of the ore can immobilize fines, but copper leaching requires an acid-resistant binder to stabilize the agglomerates. Until now, there has not been a satisfactory way to evaluate whether a binder was effective, other than squeezing a handful to see if it "feels right". We have developed procedures to quantitatively determine whether a binder gives good performance in an acidic solution, and have identified several binders that will be suitable for copper heap leaching.

Introduction

Heap leaching is a method which is used to recover metal from low grade ores in a reasonable amount of time, at low operating and capital costs (Eisele et al., 1984; Dixon, 2003; McClelland, 1985; Weir, 1984). However, leaching heaps are plagued with permeability problems, which result in less than ideal metal recoveries. Poor permeability is the result of fine particles migrating downwards in the heap with the leach solution, clogging the spaces between the larger ore particles (Chamberlin, 1986; Lipiec, 1998). These fine particles build up and begin to form impermeable layers within the ore bed. The build-up prevents air and leach solution from flowing freely through the heap. Thus, the solution chooses to either flow down the path that gives the least amount of resistance (channeling), or tends to pool within the heap (ponding), as shown in Figure 1. Either of these actions will result in solution not coming in contact with all the ore, leaving zones that are either non-leached or only partially leached by diffusion. The air may also channel upwards creating the same problems associated with solution channeling. Due to this, inadequate metal recoveries would be experienced unless the leach time was extended (McClelland, 1986; Trincado, 2003; Ortiz, 2003; Wadsworth, 1981).

Agglomerating the ore would allow the fine material to adhere to the coarser material, shown in Figure 2. This would help to increase permeability by limiting the fine material which would be available to migrate downwards in the heap, also lessening the channeling and ponding effects. Increased permeability will lead to a better interface between the leach solution, air, and ore, which in turn will result in improved metal recovery rates.

A greater increase in permeability is needed within the heap, to help increase metal recovery rates. The use of a cost effective binder in the agglomeration step could greatly enhance the overall recovery of the heap by preventing agglomerate breakdown and limiting the migration of fines (McClelland, 1986). However, copper heap leaching requires a highly acidic environment, pH of approximately 2, to help the bacteria convert ferrous iron (Fe²⁺) back into ferric iron (Fe³⁺), which is needed for the copper extraction to progress. Most agglomeration binders which are used successfully in non-copper or non-acidic heap leaching, such as Portland cement, are alkaline, and therefore would breakdown in the acidic environment needed for copper heap leaching (Chamberlin, 1986; Effthymiou et al., 1998; Serrano, 2003). Acid resistant binders are needed for copper operations which will not breakdown in acid, while allowing access of air and leach solution to reach the ore particles. The use of a proper binder will result in a more uniform percolation throughout the heap. Currently, there is at least one copper heap leaching facility in the United States which uses agglomeration. However, due to lack of an acid-resistant binder, they are agglomerating with raffinate, the leach solution. This facility is still observing copper outputs below the desired recovery rate, due to the rapid breakdown of the agglomerates.

Soak Test

It was important that the binders chosen for copper heap leaching agglomeration would be able to withstand the acidic conditions which would be experienced in the heap. Therefore, the soak test was devised to narrow down a large field of binders, to determine which would not breakdown when in contact with an acidic environment. The binders chosen for agglomeration fell into three general classes: organic, inorganic, and polymer. The binders which have been examined are presented in Table 1 (see Appendix). These binders were chosen based on the following factors:

- Organic binders, such as modified cellulose and lignin, were chosen based on several factors. Both were integral parts of plant cell walls and were difficult to degrade. Cellulose was used in paper making process’ binding to themselves to give strength. Cellulose especially was a very abundant organic compound along with being highly hydrophilic, allowing it to absorb water (Bailey et al., 2000; Water Structure & Behavior, 2006; Wikipedia, 2006).
Before any binders were able to be tested, an experimental procedure needed to be developed. This procedure needed to give insight as to how well the agglomerates held together after being agglomerated with raffinate and/or various binders while being subjected to acidic conditions which would be found in a heap. The soak test, Figure 3, was developed to accomplish this task. First, approximately 500 grams of ore was agglomerated in a drum with raffinate and a binder. The ore was then placed on a Tyler 10 mesh screen and allowed to cure or air dry, in ambient conditions for 24 hours. The screen was then lowered into a bucket filled with a 6 g H$_2$SO$_4$/L H$_2$O solution (pH = 1.8), and allowed to sit for 30 minutes. After 30 minutes, the screen was carefully removed from the solution. The material which had passed through the screen, and was collected in the bucket, was weighed and dried.

\[ \text{Fines Migration} = \frac{\text{Weight of ore migrated out of the sample}}{\text{Total weight of } -10 \text{mesh fines available in the sample}} \]  

A binder which improves the stability of the agglomerates will have a low percentage of fines migration. This indicates that the agglomerates are not breaking down, and not releasing the fine material from their surfaces. All of the binders were tested at a dosage rate of 2.5 grams binder per kilogram of ore for comparison purposes. However, the polyacrylamide 1, when in solution, was too viscous and therefore was used at an application rate of 0.5 grams binder per kilogram of ore.

The results for all the binders are presented in Figure 4. Out of all the binders tested, overall the polymer binders gave the best performance, with the lowest degree of fines migration, in comparison to the raffinate-agglomerated test. The top 4 binders include tall oil pitch, polyvinyl acetate 1, waste treatment additive, and polyacrylamide 1. All four of these binders showed good results in the soak test. The polyvinyl acetate 2 was also chosen for studies in the percolation flooded column tests, Figure 5, were used to evaluate the permeability of an ore bed agglomerated with the various binders which were able to improve agglomerate stability when coming in contact with an acidic environment. The following procedure was used when running the percolation flooded column experiments. First, approximately 1.5 kilograms of ore was agglomerated in a drum with raffinate and a binder. The ore was then allowed to cure, or dry, in ambient conditions for 24 hours before being transferred into the column apparatus. The leach solution was then dripped onto the top of the column, where it slowly began to flood the column. Bulk density and hydraulic conductivity measurements were then taken at various increments over a 72 hour period. After 72 hours, the pumps were stopped, and the columns were allowed to drain for one hour. The ore was then emptied from the column, weighed, and dried.

The binders chosen for the percolation flooded column studies included tall oil pitch, polyvinyl acetate 1, waste treatment additive, and polyacrylamide 1. All four of these binders showed good results in the soak test. The polyvinyl acetate 2 was also chosen for studies in the percolation flooded column test, although it did poorly in the soak test. The use of the polyvinyl acetate 2 would show how poor acid resistance of an agglomeration binder affects the permeability and solution flow of an ore bed.

The bulk density of the ore bed indicates the degree of permeability. The lower the bulk density the more void spaces there are within the bed, leaving more room for solution to flow. A high bulk density indicates less void space between the agglomerates, which would impede solution flow. The bulk density in the percolation flooded columns was determined by dividing the weight of the ore by the volume of the ore bed, shown in Figure 6.
The raffinate had the highest change in bulk density, indicating that the agglomerates in this column were breaking down. While breaking down, fine material was being released from the agglomerates which migrated downward in the heap, clogging the spaces between the other agglomerates. The use of binders in agglomeration helped to decrease the bulk density by up to 82% in comparison to using raffinate alone. A decrease in bulk density indicated that the use of a binder in agglomeration provided increased stability in the agglomerates. The polyvinyl acetate emulsion 2, which had the greatest breakdown in the soak test, had the highest change in bulk density in comparison to the raffinate agglomerated test. This means that the polyvinyl acetate emulsion 2 helped to decrease the density in comparison to raffinate. However, it performed the poorest out of all the other binders tested in the percolation flooded columns by having a higher bulk density than the other binders.

Another measure of permeability is hydraulic conductivity. The hydraulic conductivity is a way to evaluate the ease of solution flow through the ore bed. Darcy’s Equation (Equation 2) can be used to calculate the hydraulic conductivity using the percolation flooded columns (Figure 7).

\[ Q = \frac{A \cdot K \cdot \Delta h}{L} \]

Where:
- \( Q \) = volumetric flow rate (m³/s)
- \( L \) = flow path length (m)
- \( A \) = flow area perpendicular to \( L \) (m²)
- \( \Delta h \) = change in hydraulic head (m)
- \( K \) = hydraulic conductivity (m/s)

A high hydraulic conductivity indicates that the solution is able to flow through the ore bed freely, due to greater permeability of the bed. If the solution is able to flow easily though the bed, it will be able to come in contact with more ore, leading to better extraction. If channeling were to occur, an increase in they hydraulic conductivity over time would be expected. A high hydraulic conductivity also indicates things such as ponding, and the build up of impermeable layers, are not occurring.

All the binders produced higher hydraulic conductivities than the raffinate agglomerated column. The polyacrylamide 1 in particular produced the highest hydraulic conductivities, increasing the hydraulic conductivity rates by up to 90% in comparison to agglomerating with raffinate alone. The polyvinyl acetate emulsion 1, waste treatment additive, and tall oil pitch, all helped to increase the ease of solution flow, hydraulic conductivity, over using raffinate alone. The polyvinyl acetate emulsion 2 once again produced the poorest results out of all the binders, in comparison to raffinate. This was to be expected, as had shown poor acid resistant in the soak test.

Similar to the soak test, percent of fines migration can also be determined using the percolation flooded columns. The raffinate agglomerated column had the highest degree of fines migration, Figure 9. This is an indication that the agglomerates are breaking down with time, releasing fine material which can migrate through the ore bed. In an industrial heap this material could build up, forming impermeable layers which would impede solution flow, and in turn decrease metal recovery. All of the binders produced less fines migration than the raffinate column. The tall oil pitch and the waste treatment additive had the lowest percentage of fines migration, indicating the agglomerates were breaking down the list. The polyvinyl acetate emulsion 1 and polyacrylamide also produced lower fines migration than the raffinate.
highest fines migration out of the binders in comparison to the raffinate.

Figure 8. Hydraulic conductivity for the best performing binders. A low hydraulic conductivity means the solution is not able to flow freely, due to agglomerate breakdown. The polyacrylamide 1 had the highest hydraulic conductivity indicating the best solution flow, whereas the raffinate has the lowest hydraulic conductivity.

Figure 9. Ratio of fines in flooded column tests. A percentage of fines migration means that the agglomerates are not breaking down, and releasing the fine particles from their surfaces. The raffinate agglomerated test had the highest percentage of fines migration indicating the highest degree of breakdown. The binders produced much lower fines migration.

Conclusion

In the past there had been no quantitative methods to determine the quality of agglomerates in copper heap leaching. There was also no known binder that could be used in agglomeration to form stable agglomerates. The soak test and percolation column tests were developed in order to test agglomerates so that potential binders could be properly evaluated. The soak test has shown that polymer binders are best able to resist the attack of acid. The tall oil pitch, polyvinyl acetate emulsion 1, waste treatment additive, and polyacrylamide gave very low percentage of fines migration in comparison to the raffinate agglomerates column. This shows that the use of the binder is able to help increase stability of the agglomerates when subjected to acidic conditions.

The percolation flooded columns also showed that the use of the binders was able to increase stability over using raffinate alone. This was shown by an increase in the hydraulic conductivity, and a decrease in the bulk density and percent fines migration. This shows that the use of a binder in agglomeration will help to increase permeability. Increased permeability will lead to improved solution flow, allowing for a better interface between leach solution, air, and ore which will lead to better recovery rates.

The use of tall oil pitch, polyvinyl acetate emulsion 1, waste treatment additive, and polyacrylamide 1 in agglomeration showed to improve the permeability of the ore bed. The polyvinyl acetate emulsion 2 binder produced higher fines migration results in the soak test. It also produced high bulk density and fines migration, and low hydraulic conductivity in the percolation flooded columns. This is an indication that binders which are unable to maintain stability when subjected to an acidic environment, are not able to help greatly to increase solution flow characteristics. Therefore, by using an acid resistant binder in copper heap leaching agglomeration, the permeability of the heap will be able to be increased which will lead to an improvement in copper recovery rates.

References

## Table 1. Summary of binders which were examined. Many binder compositions were proprietary, and only limited composition information was available.

<table>
<thead>
<tr>
<th>Binding Agent</th>
<th>Manufacturer</th>
<th>Polymer Type</th>
<th>Charge</th>
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<td>Sodium Ligninsulfonate</td>
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<td>Lignin Derivative</td>
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<td>Ciba</td>
<td>Cellulose Derivative</td>
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<td>Dow Chemical</td>
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<td>Entac</td>
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<td>Ciba</td>
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