AGGLOMERATION FOR COPPER HEAP LEACHING

K.A. Lewandowski and S.K. Kawatra*

Michigan Technological University, Houghton, Michigan, U.S.A.
(*Email: skkawatr@mtu.edu)

ABSTRACT

Agglomeration of ore used in heap leaching allows for the immobilization of fine particles that would otherwise migrate and cause permeability problems in the heaps. For copper ore, binders are needed in order to make stable agglomerates. However, the majority of binders break down when introduced to an acidic environment, allowing fine particles to be released from the agglomerate surfaces. These particles migrate through the heap impeding solution flow, leading to a decrease in metal recovery rates. The authors have developed a series of testing procedures to determine the acid resistance of several binders. Only five binders were shown to be acid resistant in soak tests, decreasing fines migration by up to 93%, compared to tests which were agglomerated with leach solution, raffinate, as a binder. Flooded percolation column testing also showed that these binders were able to reduce the “slump” of the ore by up to 82% and increased the hydraulic conductivity by up to 90%, when compared to agglomerating with leach solution alone. The use of binders in the agglomeration of copper ore also showed no negative effects on the bacterial populations throughout a leach cycle.
INTRODUCTION

The use of binders in copper ore agglomeration has been shown to help to increase permeability within heap leaching ore beds. Poor permeability has been one of the main problems afflicting leaching heaps. Heap leaching of copper sulfide minerals requires the ability for solution, with dissolved iron, to maintain access to the ore particles. There also must be an easy flow of air through the heap to provide oxygen for bacterial growth, to allow for the conversion of ferrous sulfate into ferric sulfate. Reduced access, or contact, is due to poor permeability. One main cause of this is due to fine particles migrating downward in the heap with the flow of leach solution [1]. The fine particles begin to build-up, clogging the spaces between the larger ore particles. As the particles begin to clog the spaces between the larger ones, impermeable layers are formed, which make it difficult for the air to flow upwards through the heap, and for the leach solution to flow downwards freely, as illustrated in Figure 1. Thus, the solution flows down the path that gives the least amount of resistance (channeling), or tends to pool within the heap (ponding). This leads to an uneven distribution of the leaching solution and air, which limits the availability of contact made between the ore, air, and leach solution, slowing the speed at which the extraction takes place [2]. This results in achieving poor copper recovery rates.

Ideally, the ore bed should be constructed of an ore distribution, as illustrated in Figure 2. This figure is shown in two dimensions, however in an actual three dimensional situation, the ore particles would be resting on other particles in the third dimension. Entrapping the fine particles onto the coarser particles will create a more permeable ore bed, allowing solution and air to flow freely and evenly through the heap. In the optimum leach heap, there would be limited free fine particles which would clog the spaces between particles, and result in permeability problems.

There was one copper heap leaching facility in the United States which currently uses agglomeration; however, they agglomerate with only raffinate, the leach solution. This facility was still observing copper outputs below the desired recovery rate, due to the rapid breakdown of the agglomerates in the heap. Preventing agglomerate breakdown and limiting the migration of fines by the utilization of cost effective binders in the agglomeration step would enhance the overall recovery of the heap. The use of a binder would help the problem causing fine material to adhere to the coarser material. The result would be an increase in the permeability of the heap. However, copper leaching requires a high use of acid solutions which decrease the pH of the heap to very acidic conditions. Most agglomeration binders which have been used successfully in other operations, such as Portland cement and lime, require a more neutral or alkaline pH. These cement-type binders dissolve readily in acid, and are ineffective in an acidic leaching environment. Acid resistant binders are needed for these copper heap leaching operations which will not breakdown in the acidic conditions, allowing access of air and leach solution to reach the ore particles.
Past research in copper ore agglomeration has been hampered by the lack of a quantitative measurement of agglomerate quality. Measurement attempts have included visually observing agglomerate breakdown in a beaker, or screening the agglomerates in water. One of the first concerns has therefore been the determination of a satisfactory set of tests that can be used to evaluate binders. After a thorough review of the literature and extensive discussions with the industrial partners various testing protocol have been devised. The objective of this project has been to develop and implement binders and agglomeration procedures that will increase the efficiency of copper heap leaching processes.

EXPERIMENTAL

One of the primary problems in using a binder or additive in copper heap leaching agglomeration is due to the acidic environment which needs to be maintained to ensure high bacterial populations are able to thrive. Most binders which have been used in copper heap leaching agglomeration breakdown under highly acidic conditions. Previously, there have been no standard operating procedures to test the performance and durability of selected binders for copper heap leaching.
Soak Test

The soak test procedure was developed to give insight as to how well agglomerates would hold together with raffinate (leach solution) and a chosen binder, and then subjected to acidic conditions which would be found in a heap. The procedure for the soak test included agglomerating approximately 500 grams of ore in an agglomeration drum with raffinate and a binder. The ore was then placed on a Tyler 10 mesh screen where it was allowed to air dry, or cure, in ambient conditions for 24 hours. After curing, a 22 liter bucket was filled with 6 g/L sulfuric acid water solution, resulting in a pH of approximately 1.8. This concentration represented the acidity of the solutions from the leaching operation in which the ore was obtained. The Tyler screen, with cured agglomerates, was then slowly lowered into the acidic solution, ensuring the ore was completely submerged. The agglomerates were allowed to soak in the solution for 30 minutes. The screen and remaining material was then carefully removed from the acid solution. The remaining solution was decanted, and the fine material which had passed through the screen was dried and weighed.

The binders were judged on the percent of material which had passed through the Tyler 10 mesh screen, and is termed the amount of fines migration. Fines migration was the only quantitative measurement which was able to be recorded from a soak test. The fines migration was calculated by taking the ratio of the weight of ore which migration out of the sample to the total weight of -10mesh fines which were available in the sample. This test gave a quick assessment for the ability of each binder to retain its agglomerates when subjected to acidic conditions.

Percolation Flooded Column Test

Even if the binders were able to withstand acidic conditions, this did not mean that the use of these binders would result in an increase in permeability within the ore bed. Increased permeability was needed to ensure that the leach solution and air were able to flow evenly through the heap. Determining the degree of permeability would allow the binders to be compared. Permeability can be determined by measuring the ore bed bulk density, fines migration, and the ability for the solution to flow through the heap, which is also called hydraulic conductivity. However, a standard procedure for doing this had not been developed for copper heap leaching testing. Therefore, flooded percolation flooded column tests were constructed to test these parameters.

The following procedure was used for the percolation flooded column testing. First, approximately 1.5 kilograms of ore was agglomerated with raffinate and a chosen binder. The ore was then allowed to air dry, or cure, for 24 hours before being transferred to a column. Leach solution was slowly dripped onto the top of the ore bed, where it slowly began to flood the column, exiting through an overflow loop. After 72 hours, the pumps were stopped, and the solution was allowed to come to equilibrium. The columns were then allowed to drain for 1 hour before the columns were emptied, and the ore was placed in the oven to dry.
The degree of permeability within the ore bed could be related to the amount of void space within the heap. A greater void space would allow for an increased ability for solution to flow freely through the heap. One way to determine the degree of void space within the heap was to calculate the bulk density, or ‘slump’, of the ore bed. This can be determined by taking the ratio of the weight of the ore over the volume of the ore bed. The ease of solution flow through the ore bed can be determined by calculating the hydraulic conductivity. The hydraulic conductivity was another measure of the strength of the agglomerates. It can be calculated using Darcy’s Equation.

**Long-Term Leach Column Test**

After the binders were tested in the soak test, and the percolation flooded column tests, they were then used in agglomeration for the long-term leach column tests. This test was used to determine whether the use of binders in agglomeration would have any negative effects on the copper recovery rates or on the bacterial populations in the columns. These columns were originally built to simulate the full scale heap. The columns height, air flow rates, and solution flow rates were all scaled down from the values that were being used in industry at the time. However, one difficulty with these columns was that factors such as channeling, blinding, and ponding were not accurately represented, as the space for this to occur was limited to 15.24 cm rather than the whole length of a heap. Due to this factor, the tests would only indicate whether the binders were having a negative effect on copper recovery and bacterial growth.

The procedure for preparing the long-term leach columns was as follows:

1. Approximately 36.29 kilograms of ore were agglomerated with raffinate, using a solution amount of 0.08 mL/gram of ore, and a chosen binder.
2. The agglomerated ore was then allowed to air dry, or cure, in ambient conditions for 72 hours.
3. The ore was then distributed into the column.
4. The column was capped to create a controlled environment.
5. An air line was connected to the base of the column, and the air flow rate was set at 16.68 mL/min.
6. Raffinate was pumped to the top of the column at a rate of 27.9 mL/hr, where it was dripped onto the surface of the ore bed.
7. Raffinate slowly percolated through the column and was collected in a bucket below, as pregnant leach solution (PLS).
8. The PLS was analyzed for copper and iron concentration by atomic absorption spectroscopy, pH, oxidation/reduction potential (ORP), and temperature.
RESULTS AND DISCUSSION

The acidic environment needed in the heaps causes most binders to breakdown, resulting in inadequate agglomerates. There was no known economically feasible binder which would work satisfactorily in an acidic environment, and there was no standard procedure to test heap leaching agglomerate stability. Such a procedure was needed in order to determine which binders could potentially work in acidic leaching heaps.

The binders chosen for testing included binders which were inorganic, organic, and polymeric. These binders also had various charges including non-ionic, cationic, and anionic. Organic binders, such as cellulose and lignin, were chosen based on several factors. Both are integral parts of cell walls, difficult to degrade, and are also used in paper making processes, binding to themselves to give strength. Inorganic binders, such as sodium silicate, that were chosen were expected to react with acid to form a silica gel which could have possibly acted as a binder. Polymer binders needed to have the ability to resist the action of acid, and to have the ability to bond to the hydrogen ions that adsorb onto the mineral surfaces.

Soak Test

The soak test was developed as a method to test the ability of agglomerates to resist acid attack. During each soak test the agglomerated samples were photographed to give a visual comparison between the tests. This visual progression of agglomerate deterioration in a soak test, and the final fines collection, are shown in Figure 3 and Figure 4.

The fine material which had migrated through the Tyler 10 mesh screen could be quantified by a fines migration calculation. Fines migration is the ratio of the amount of -10 mesh material which had been collected at the end of the test, compared to the amount of -10 mesh material which was originally in the sample. A high fines migration value means the agglomerates were breaking down when coming in contact with the acid, releasing fine material. A low fines migration was desired, as it indicates that the agglomerates were maintaining their strength or bonds, even when subjected to highly acidic conditions.

The length of time the agglomerates had to cure, or air dry, was an important consideration. The stacking process of the ore in heap leaching usually takes approximately 72 hours or more, and a major function of the binder is to keep the agglomerates from breaking down as they dry. A first set of agglomerates were allowed to cure, or air dry, for 24 hours before being tested. A second set of agglomerates were tested immediately after agglomeration. The results, given in Figure 5, show that the agglomerates which were allowed cure time released a greater percentage of fine material, than those which were tested immediately after agglomeration. This was an indication that some of the bonds which were providing strength initially were deteriorating as the agglomerate was allowed to dry. Therefore, it was concluded that all
tests should be completed with cure time, as this was more representative of the conditions which the agglomerates would be experiencing in the heap.

Once it was determined that a cure time was necessary, a variety of organic, inorganic, and polymer binders were tested to determine which types would resist acid attack the best. The fines migration results for all the binders tested are given in Figure 6. For comparison purposes, all the agglomerates were prepared using a binder addition rate of 2.5 grams of binder per kilogram of ore. However, the “polyacrylamide 1” was too viscous at a 2.5 g/kg dosage to be sprayed evenly during agglomeration, and was therefore applied at 0.5 grams of binder per kilogram of ore. The test agglomerated with raffinate was the baseline test, as this was what was currently being used in the industry. Any binder which had a lower fines migration than the baseline had the potential to produce more stable agglomerates than raffinate when subjected to a highly acidic environment.

The polymer binders, including “polyvinyl acetate emulsion 1”, “waste treatment additive”, and the “polyacrylamide 1”, had considerably lower fines migration results than the remaining binders. There was one organic binder, “tall oil pitch”, which had considerably lower fines migration than the other organic binders.

![Image of agglomerates](image1)

Figure 3 – Visual deterioration of agglomerates in soak test

![Image of agglomerates and bucket](image2)

Figure 4 – On the right is the Tyler 10 mesh screen holding the previously immersed agglomerates. The bucket on the left contains the fines which have been released due to the breakdown of the agglomerates
Figure 5 – Effect of cure time on fines migration using various chemical agents

Figure 6 – Fines migration using various chemical agents
Percolation Flooded Column Tests

As soon as it was determined that fine binders were able to resist acidic conditions, it was necessary to determine if the permeability of the heap would be able to be increased with the use of binders in agglomeration. Percolation flooded column tests were used to measure fines migration, changes in bulk density, and hydraulic conductivity for agglomerates made with each of the following binders: “raffinate”, “polyvinyl acetate emulsion 1”, “polyvinyl acetate emulsion 2”, “polyacrylamide 1”, “waste treatment additive”, and “tall oil pitch”.

The change in bulk density, or ‘slump’, of the ore bed was determined by calculating the bulk density. A small change in bulk density meant that the agglomerates were not breaking down over time and were not releasing fine material from their surfaces. A smaller change in bulk density was also an indication of greater void space, which would allow for increased interface surface between the leach solution (raffinate), ore, and air. Reporting the change in bulk density allows each run to be normalized, eliminating differences such as small changes due to column loading. The change in bulk density, Figure 7, decreased with the use of all the binders. Similar to the fines migration, the “polyvinyl acetate 2” which showed only marginal results in the soak test, showed the highest change in bulk density aside from the baseline (raffinate) agglomerated test. The “tall oil pitch” gave the best bulk density results, lowering the change in bulk density by approximately 82%. The other 3 binders (polyvinyl acetate emulsion 1, polyacrylamide 1, and the waste treatment additive) also showed a lower change in bulk density, in comparison to the raffinate agglomerated column.

Results from the flooded percolation column testing showed that the use of binders in agglomeration allowed for increased hydraulic conductivity over the baseline (raffinate) test, Figure 8. The hydraulic conductivity was an indication of how easily the solution was able to flow through the ore bed. A high hydraulic conductivity indicated that the solution was able to flow easily though the ore bed. The easier the solution was able to flow, the greater the chance it would be able to come in contact with all the ore, allowing for better recovery opportunity. The “polyacrylamide 1” gave the best hydraulic conductivity results. The use of this binder was able to increase the hydraulic conductivity of the agglomerated ore to approximately 2.5 mm/sec, compared to a hydraulic conductivity of only 0.25 mm/sec when no binder was used. The “polyvinyl acetate 2” once again showed poor results in comparison to the rest of the binders chosen. The remaining three binders (polyvinyl acetate emulsion 1, waste treatment additive, and the tall oil pitch) all showed hydraulic conductivities better than that of the test agglomerated with only raffinate and no binder.
Figure 7 – Change in ore bulk density vs. time for best performing binders

Figure 8 – Hydraulic conductivity for the best performing binders
Long-Term Leach Column Tests

Once it was determined that there were several binders which were able to resist acid attack, minimize fines migration, decrease the change in bulk density, and increase hydraulic conductivity, it was imperative to verify that these binders would not interfere with copper recovery. Up to this point in testing, leach conditions had not been considered. Therefore, long-term leach column were conducted to determine whether binders had adverse effects on the leaching reactions. The four binders which did the best in the soak test and the flooded percolation columns were optimized using the flooded percolation columns to determine the amount of binder needed for the best results and then tested in the long-term leach columns. These binders included “polyacrylamide 1”, “polyvinyl acetate emulsion 1”, “waste treatment additive”, and the “tall oil pitch”. A baseline test, agglomerated with only raffinate, was also run at the same time.

Copper recovery results, Figure 9, indicated that the use of the binders in the agglomeration step did not have any harmful effects. This was shown by hardly any variation in copper recovery between the various binders. The oxidation/reduction potential (ORP) allowed for the bacterial population to be assessed, Figure 10. A high ORP or high bacterial population was necessary to convert ferrous iron back to ferric iron, to allow for chalcocite breakdown to continue. From these results, it could be seen that ORP was higher with binders than without, indicating that the binders were beneficial for promoting bacterial activity.

CONCLUSIONS

These experiments have shown that the use of a binder in heap leaching agglomeration has the ability to increase agglomerate stability and improve solution flow, without interfering with the leaching reactions. The binders which showed the most benefit were polymer binders. These binders were able to resist acid attack the best, by not breaking down and releasing fines. The polymer binders were also shown to help decrease the fines migration in column testing along with decreasing the change in bulk density and increasing the hydraulic conductivity. All of these factors were important as they indicated more void space within the heap. Greater void space would allow for a greater possibility of interface between the ore, leach solution, and air. Increased contact would allow for improved copper recovery to be achieved uniformly throughout the ore bed. These binders have also been shown to have no adverse affects on copper recovery, which is necessary for industrial application.
Figure 9 – MTU Long-term leach column copper recoveries

Figure 10 – Oxidation/Reduction potential results from MTU long-term leach columns
REFERENCES
