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Use of Shredded Automobile Scrap for Copper Cementation

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UNITED STATES DEPARTMENT OF THE INTERIOR

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USE OF SHREDDED AUTOMOBILE SCRAP FOR COPPER CEMENTATION

by

W. L. Staker and R. D. Groves

ERRATA

Equation 1 on the first page of text should read as follows:

$$Cu^{++} + Fe^{\circ} \rightarrow Cu^{\circ} + Fe^{++}. \qquad (1)$$

Page 3, second sentence, last paragraph should read as follows:

The nominal capacity of the unit above the grate was 40 cubic feet or 1,000 to 2,500 pounds of shredded automobile scrap.

Page 10, second paragraph, last sentence should read as follows:

Thus the jagged pieces of iron from the hammer-type shredder provided a better self-cleaning bed than did the rounded pieces from the gear-type shredder.

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Use of Shredded Automobile Scrap for Copper Cementation

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USE OF SHREDDED AUTOMOBILE SCRAP FOR COPPER CEMENTATION

by

W. L. Staker[1] and R. D. Groves[2]

ABSTRACT

The Bureau of Mines investigated the use of shredded automobile scrap for copper cementation. Air agitation was used to improve the cementation rate and prevent excessive buildup of copper on the iron. The pieces of scrap were too large to be properly evaluated in the laboratory; therefore, a pilot scale test unit was constructed and the process tested at field locations. Pregnant solution was obtained from industrial leaching operations, processed in the test unit and the barren solution and cement copper were returned to the plant process stream.

The test results showed that the air-agitated launder containing automobile scrap was an effective means for recovering copper from leach solutions. A continuous 14-day test run was made without a noticeable decrease in cementation efficiency. The most suitable scrap product was obtained from incinerated automobile hulks shredded in a hammer type of shredder. However, it was necessary to remove small pieces such as nuts and bolts because they interfered with the discharge of the copper product.

INTRODUCTION

About 15 pct of the current production of copper in the United States is from acid leaching of low-grade ores or waste dumps. For many operations the most practical method to recover copper from the leach solutions is by cementation on scrap iron. Traditionally this has been accomplished by passing the pregnant solutions through beds of shredded tinplate scrap contained in rectangular troughs or launders. Metallic copper (cement copper) precipitates and the iron is dissolved. The following equation represents this reaction:

$$Cu^{++} + Fe^{\circ} \rightarrow Cu^{\circ} + Fe^{+}. \quad (1)$$

[1] Chemist.
[2] Metallurgist.

Theoretically, 0.88 pound of iron is required to precipitate 1.0 pound of copper. In practice, however, 1.5 to 3.0 pounds of iron are required because of the following concurrent iron-consuming reactions:

$$2Fe^{+++} + Fe^{\circ} \rightarrow 3Fe^{++} \quad (2)$$

and

$$2H^{+} + Fe^{\circ} \rightarrow Fe^{++} + H_2 \text{ (gas)}. \quad (3)$$

These reactions represent an inherent but useless consumption of iron. Fortunately the cementation reaction (equation 1) proceeds at a faster rate than the other two reactions and some savings of scrap iron can be attained by contacting the solution and iron only long enough to precipitate the copper.

In industrial cementation operations, shredded tinplate or can scrap is extensively used as the copper precipitant. It has the physical characteristics necessary for use in cementation launders and has been readily available at a reasonable cost. However, with increasing copper production it is becoming more difficult to obtain on a scheduled basis and the price has been variable. A substitute iron product at a stable price is needed. The nearly 9 million automobiles scrapped each year represent a sizeable iron resource and may be a suitable substitute for the tinplate scrap. Also, there are numerous automobile shredders currently in operation that provide materials for the steel industry and this type of product may be suitable for copper cementation. The purpose of the experimental work described herein was to determine the feasibility of using shredded automobile scrap for copper cementation. Because of the heterogeneous nature of the product and the large size of some of the pieces, it could not be properly evaluated in the laboratory. Therefore, after preliminary laboratory tests which indicated the feasibility of using automobile scrap, a larger cementation apparatus was constructed and the process was further evaluated at two different field locations.

One of the difficulties encountered in using automobile scrap for copper cementation arises from the fact that the volume of the cement copper precipitated by a given volume of scrap is greater than the volume of that scrap. Without removal of the precipitated copper the bed of shredded iron becomes plugged and the cementation efficiency decreases. Therefore, one of the requisites of the system was the removal of the cemented copper on a continuous or semicontinuous basis to prevent plugging. Also, during the preliminary laboratory tests it was noted that a coating of fine-grained dendritic copper on the iron enhanced the cementation rate. This effect has also been reported by other investigators (4, 6).[3] Another requisite of the system was the partial removal of the cemented copper to prevent excessive buildup while still retaining enough to take advantage of rate enhancement.

A previous study by the Bureau of Mines (1) has shown that shredded automobile scrap in a revolving drum was an effective means for cementing copper from low tenor solutions. Mixing in the revolving drum promoted a rapid

[3]Underlined numbers in parentheses refer to items in the list of references at the end of this report.

reaction and the tumbling effectively separated the copper from the iron. Cement copper and spent solution were continuously discharged from the drum through a screened device which retained the coarse iron particles in the drum. The process was evaluated with short, 8-hour tests but the effects of continuous operation were not determined. The principal disadvantages of a drum precipitator are the power requirements to turn the drum and cost and wear-life of the drum-lining material.

In the currently reported investigation shredded automobile scrap was used in an air-agitated launder for cementing copper. Air was bubbled upward through the bed of iron to agitate the solution and remove the deposited copper. The air agitation did not keep the iron surface completely free of copper but excessive buildup of cemented copper was prevented and the rate enhancement from the dendritic copper coating was utilized. Prior tests in the laboratory indicated that the cementation rate with air-agitation was considerably faster than rates obtained without air agitation. Also, a test without air agitation was not included in this study because the laboratory test showed that this procedure would result in a plugged launder, channeling of solution, and a decreased cementation rate.

The use of air agitation in copper cementation is not new. Two early U.S. patents describe a cementation system using air agitation (7-8) and later patents (2-3) describe the use of air or oxygen injection in upright column precipitators to enhance the cementation rate. Also, a copper cementation system using air agitation was used by the Cananea Consolidated Copper Co., Sonora, Mexico, in 1924 (5). Most of the iron used in this operation came from the company's scrap heap and was more massive than tinplate scrap. Precipitation was slow without air agitation, and iron salts settled out with cement copper and reduced the grade of the product. The use of air agitation in the "precipitation boxes" proved successful, as the capacity of the precipitation plant was increased many times. During 1925, 2,012,108 pounds of copper were produced by this method. The use of air agitation was noted as the largest factor in making the operation profitable.

MATERIALS EQUIPMENT AND PROCEDURE

The pilot plant cementation unit used in this investigation was a 40- by 40- by 48-inch high launder section with a collection hutch below. A wooden grate with 1-1/2- by 3-inch openings separated the launder from the hutch and the entire apparatus was mounted on legs so that the hutch discharge was 24 inches above ground level. The scrap iron for cementation rested on the grate; both the pregnant solution and air for agitation were introduced below the grate and the barren solution overflowed at the top. The pregnant solution was introduced through a single 1-1/4-inch-diameter inlet port and the air was introduced in a grid pattern through eight pipes containing 1/8-inch holes spaced 6 inches apart. Cement copper was periodically withdrawn from the hutch through a 2-inch valve. However, this was later changed to a 3-inch valve which proved to be more satisfactory.

Figure 1 shows the launder set up at one of the test sites, and figure 2 shows a schematic of the test unit. The nominal capacity of the unit above the grate was 40 cubic feet or 1,000 to 2,5000 pounds of shredded automobile scrap. The wide variation in weights of iron was due to variations in the

FIGURE 1. - The air-agitated cementation unit for precipitating copper with shredded automobile scrap.

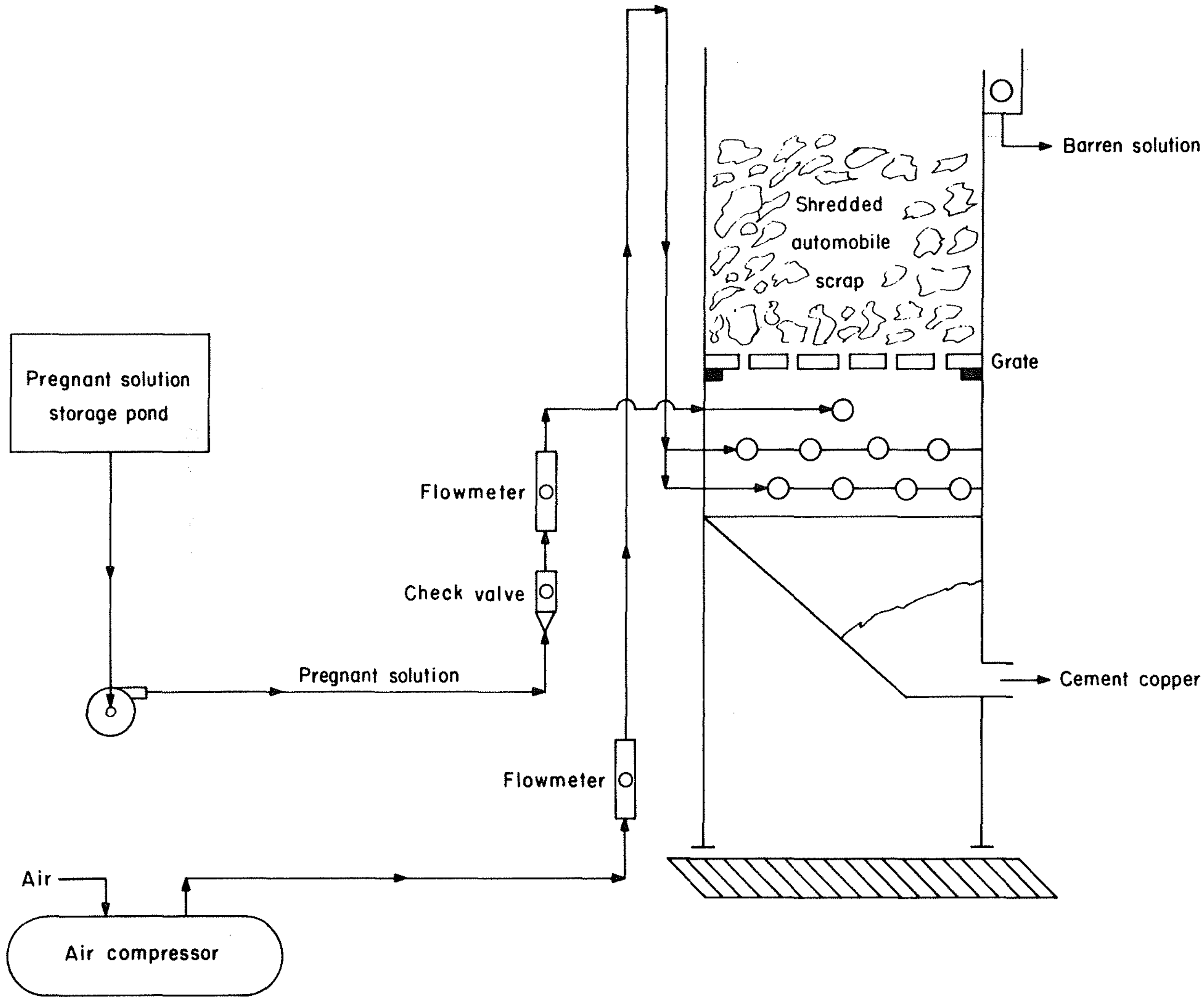

FIGURE 2. - Schematic of air-agitated cementation unit for precipitating copper with shredded automobile scrap.

bulk densities of different scrap products used. The stairway and platform shown in figure 1 provided access to the top of the launder for loading with iron and observations during operation. The blower used to provide air for agitation is located beneath the stairway; however, only the control panel is shown. The blower was a Roots[4] positive rotary blower capable of providing 60 cubic feet per minute of air. In normal operation 30 cubic feet per minute of air at 4 to 6 psig were used. The air was piped through a loop extending well above the top of the launder to a bustle pipe and distributed to the eight individual inlet pipes. The purpose of the high looped pipe was to prevent pregnant solution from backing up to the blower in the event of a power failure.

[4]Reference to specific company or brand name is made for identification only and does not imply endorsement by the Bureau of Mines.

Also shown in figure 1, below the platform, is the flowmeter used for measuring the pregnant solution and the cement copper discharge port on the right of the apparatus. The small stainless trough shown to transport the copper discharge to the plant drainage pond proved to be unsatisfactory and was later replaced with a wooden trough which contained a 1/2-inch stainless steel screen to retain the pieces of unused iron that collected in the hutch and were discharged with the cement copper. Not shown in figure 1 are two rubber-covered 1-1/2-inch sump pumps used to meter pregnant solution to the test unit and to return the barren solution to the plant process stream.

The scrap iron products used as the copper precipitants were obtained from commercial shredding operations. The products included samples of both incinerated and unincinerated auto hulks that had been shredded in hammer-type and gear-type shredders. The hammer-type shredder was a massive machine in which whole automobiles were shredded, whereas the gear-type shredders were smaller and it was necessary to remove motors, transmission, differentials, and axles from the hulks before shredding. In both operations, nonmetallics were removed and magnetic separation techniques were used to provide a finished ferrous scrap. Additional hand sorting was done at the test site to further reject tangled wire, stainless steel trim parts and additional large pieces which would not fit in the 40- by 40-inch launder. The material from the hammer-type shredder was coarsely shredded and consisted of jagged pieces that had a bulk density which varied from 23 to 52 pounds per cubic foot. In contrast, the material from the gear-type shredder consisted of well-rounded fist-sized pieces that had a bulk density of 65 to 70 pounds per cubic foot.

In addition, one test was made with shredded tinplate scrap. This material was obtained from the industrial operation at the test site. This product was chiefly chemically detinned scrap and clippings from a can manufacturing operation. It had a bulk density of 25 pounds per cubic foot.

The operation of the test unit was similar to industrial practice. The unit was filled with shredded scrap iron, and both pregnant solution and air were metered to the precipitator. The hutch product was periodically discharged and a constant volume of iron was maintained by adding iron to the top of the precipitator. Process control and test results were based on assays of solution samples that had been acidified to prevent precipitation of basic iron salts. Weights of iron used and cement copper produced were impractical to obtain owing to the limited facilities available.

CEMENTATION TESTS WITH THE AIR-AGITATED LAUNDER

The air-agitated cementation launder was tested at two different commercial leaching operations. At the first site the launder operating conditions were determined and the cementation efficiency of auto scrap products with various physical properties were compared. At the second site the continuous long-term operating characteristics were determined. Details of this test work and a discussion of the results follow.

Determining the Launder Operating Characteristics

In preparation for the first test to determine the launder operating characteristics, the launder was filled with 1,006 pounds of shredded auto scrap. This product was obtained from unincinerated auto hulks that had been shredded in a hammer-type shredder. Normally shredded auto scrap will have a bulk density of 50 to 70 pounds per cubic foot, but calculations based on the measured inside dimensions of the launder showed that the bulk density of the iron scrap was only 23.6 pounds per cubic foot. This test lot of scrap iron was coarsely shredded and was not representative of typical shredded auto scrap. Many pieces of iron 1 to 3 feet long were noted in the scrap heap. These large pieces along with massive parts such as axles, gears, stainless steel trim parts and tangled masses of wire were removed and discarded.

The composition of the pregnant solution at this test site varied because of variations in plant operating conditions and variations in the composition of the ore. The chief cause of the variations was the intermittent addition of solutions from a single vat leach to the process stream. The range of compositions encountered was, in grams per liter, 1.5 to 5.0 Cu^{++}, 4.5 to 6.0 Fe^{++}, and 0.2 to 1.5 Fe^{+++}. Also, the feed solution pH ranged from 1.0 to 2.6. Because of these variations, the optimum rate of feed solution and airflow could not be readily determined and only average results were considered significant. The procedure adopted for determining the best operating conditions consisted of starting with an airflow of 30 cubic feet per minute and a solution feed rate of 40 gallons per minute, monitoring the feed solution and barren solution and adjusting conditions to attain a copper recovery of about 90 pct. During the first 24 hours of operation, the flow of pregnant solution was lowered in stages to about 10 gallons per minute and with this feed rate the copper recovery was 91.0 pct. During the remainder of the 5-day test these conditions could not be significantly improved. Reducing the airflow to 15 cubic feet per minute resulted in a 2-1/2-pct decrease in copper recovery and an increase to 60 cubic feet per minute did not result in a corresponding increase in recovery. For this test, including the periods of high solution feed rates, the average feed rate was 13.2 gallons per minute, airflow was 30 cubic feet per minute, copper recovery was 88.1 pct, and the iron consumption was 1.1 pounds per pound of copper.

In this test the very large pieces of iron were not used but the very small pieces such as nuts and bolts were included with the charged scrap. This latter product gradually settled through the bed of iron, through the grate and into the hutch. Near the end of the test period the buildup of iron in the hutch was so great that the discharge valve was obstructed and cement copper no longer was discharged. This problem was avoided in subsequent tests by removing the offending small pieces from the iron precipitant. In addition, the 2-inch discharge valve was replaced with a 3-inch valve to aid in removing occasional pieces of iron.

About 96 pct of the cement copper reported to the hutch. The remaining copper overflowed with the barren solution. A settling and decantation system would be required to recover this copper. Also, there were large amounts of other solids in the overflow product such as paint flakes and fabric.

Subsequent tests showed that incineration of the auto hulks prior to shredding reduced this contamination.

During most of this test, the pH of the barren solution was 2.5 to 3.0 and the iron consumption averaged 1.1 pounds per pound of copper. However, on occasion variations in the pregnant solution composition resulted in a barren solution with a pH of 4.0, and an increase in iron consumption to 1.8 pounds per pound of copper. Apparently, at the higher pH, the air used for agitation oxidized dissolved iron which increased the consumption of elemental iron. Therefore, in the operation of an air-agitated launder, it would be essential to regulate the solution pH so that the barren solution would be about pH 2.0 to avoid high rates of iron consumption.

Comparison of Scrap Iron Products

Additional cementation tests were made with the other scrap products previously described to determine the effect on cementation efficiency of such iron preparation procedures as incineration, detinning, and method of shredding. Each test with automobile scrap consisted of 5 days of continuous operation and the single test with detinned tinplate scrap was for a 4-day period. An airflow of 30 cubic feet per minute was used in these tests and the best solution feed rate was determined by the procedure used in test 1. The results of these tests are presented in table 1.

The test results show that copper recoveries of 88.1 to 93.0 pct and copper production rates ranging from 16.3 to 22.8 pounds per hour were achieved with automobile scrap. The effect of iron preparation procedure on copper cementation efficiency could not be determined on the basis of these data because of variation in the other process conditions. Pregnant solution copper analyses ranged from 2.59 to 3.17 grams per liter, solution feed rates varied from 12.2 to 18.9 gallons per minute, and scrap iron bulk densities ranged from 23 to 69 pounds per cubic foot. However, the data do show that the air-agitated launder was an effective method for recovering copper over a wide range of conditions, and the variations in recovery and production rate were not as large as would logically be expected from the large variations in process conditions. Apparently the buildup of cement copper on the iron surface was sufficient to increase the reaction rate and minimize the effect of these variations. Even shredded tinplate scrap with its greater iron surface did not result in a marked increase in cementation efficiency.

Other aspects of the cementation tests were used to determine the effects of iron preparation procedure on copper cementation. Observations indicated that a higher grade product would be produced from incinerated auto scrap. Without incineration the copper product was contaminated with paint flakes and pieces of shredded fabric. This condition was particularly severe in the small amount of copper in the overflow. The fabric particles collected in the overflow sump and occasionally plugged the inlet of the sump pump. With incinerated scrap this source of product contamination and the pumping problems were avoided. Thus, incineration of the auto scrap would be beneficial.

TABLE 1. - Comparison of various scrap products as the copper precipitant in an air-agitated cementation launder

Test	The scrap product: Source of scrap iron	The scrap product: Type of shredder used	The scrap product: Bulk density, lb/cu ft	Average operating conditions: Pregnant solution: Flow, gpm	Average operating conditions: Pregnant solution: Copper analysis, g/l	Average operating conditions: Copper feed rate, lb/hr	Average test results: Barren solution copper analysis, g/l	Average test results: Copper recovery, pct	Average test results: Copper production rate, lb/hr	Average test results: Iron consumption, lb/lb Cu
1	Unincinerated auto hulks.	Hammer[1].	23	13.2	2.80	18.6	0.33	88.1	16.3	1.1
2	Incinerated auto hulks.	..do.[1]..	52	12.2	3.11	19.1	.25	91.8	17.5	1.2
3	Unincinerated auto hulks.	Gear....	67	12.5	3.17	19.8	.23	92.9	18.4	1.2
4	Incinerated auto hulks.	..do....	69	18.9	2.59	24.5	.18	93.0	22.8	1.1
5	Detinned tinplate.	Unknown.	25	29.0	1.84	26.7	.17	90.8	24.3	1.1

[1]Very coarsely shredded. Apparently the hammers were worn and needed to be replaced.

In addition to copper recoveries, production rates, and product contamination the physical aspects of the launder's performance are important. With extended continuous operation, cement copper may build up and partially plug the launder. As a result, solution will flow through open channels and the cementation efficiency will be decreased. This condition will necessitate remedial action such as cleaning the system and starting anew. The result will be loss of production and increased labor costs. Inasmuch as economical considerations are important, the iron products that did not result in excessive copper buildup would be the preferred precipitants.

The 5-day continuous pilot plant tests were not long enough to detect a significant decrease in cementation efficiency due to cement copper buildup. However, at the completion of each test, the unreacted iron was removed from the launder and the buildup of copper was noted. The buildup was most severe with the auto scrap products shredded with the gear-type shredder and the tinplate scrap, and least severe with the auto scrap from the hammer-type shredder. Thus the jagged pieces of iron from the iron-type shredder provided a better self-cleaning bed than did the rounded pieces from the gear-type shredder.

It was concluded from this phase of the testing that (1) the small pieces of iron such as nuts and bolts should be sorted out and removed from the iron product to prevent them from obstructing the hutch discharge valve; (2) incinerated auto hulks should be used to avoid contaminating the cement copper with paint flakes and other organic products; and (3) the incinerated hulks should be shredded with a hammer-type shredder to provide a self-cleaning bed for long continuous operation. It was concluded also that a longer test should be made to determine the long-term cementation characteristics of this type of scrap product.

The Continuous Long-Term Test

Current industrial cementation practice in which launders and shredded tinplate scrap are used usually require daily cleanout to remove the precipitated copper from part of the system. This is a tedious and time-consuming process and results in decreased production during the cleanout period. A self-cleaning launder that can be operated for long periods before a cleanout is required would be an advantage for an industrial cementation operation. Therefore, a long-term cementation test was made to determine the self-cleaning characteristics of the air-agitated cementation launder containing shredded automobile scrap.

The long-term cementation test was made at a second field location. The operating procedure used was similar to that previously described and the scrap product used was from incinerated hulks shredded in a hammer-type shredder. The small pieces of iron, tangled wire, stainless steel trim parts and most of the more massive pieces were sorted out and not used. The bulk density of this product was 34 pounds per cubic foot. As in the previous tests, pregnant solution was obtained from the commercial leaching operation and the barren solution and cement copper were returned to the plant process streams. The launder operation was evaluated by comparing analyses of feed and barren solutions. The composition of the feed solution was, in grams per liter, 1.7 Cu^{++}, 2.6 total Fe, and 1.8 Fe^{+++}. The solution pH was 2.2 to 2.3 and the other components did not vary appreciably from the reported values.

The air-agitated test unit was operated continuously for 14 days with solution feed rates of 10 or 20 gallons per minute and 30 cubic feet per minute of airflow. Scrap iron was added as needed to maintain a full precipitator. The pH of the feed solution, as received from the commercial leaching operation, was about 2.3 and during cementation the pH increased to the extent that iron salts were precipitated and the overflow solution appeared milky. Increasing the feed solution flow from 10 to 20 gallons per minute did not eliminate the milky overflow but clear barren solution was obtained by acidulating the feed liquor to a pH of 2.0. Both of these procedures influenced the copper recoveries. Average results from 12-hour tests with various operating conditions are presented in table 2.

TABLE 2. - The effect of pH and feed solution flow on copper recovery

Feed solution		Copper recovery		Iron consumption, lb/lb Cu
pH	Flow, gal/min	Pct	Lb/hr	
2.3	10	80	6.8	1.53
2.0	10	91	7.7	1.67
2.3	20	74	12.6	1.52
2.0	20	80	13.6	1.47

These results show that with a feed rate of 10 gallons per minute the decrease in pH from 2.3 to 2.0 increased the copper recovery from 80 to 91 pct. A similar increase was obtained with a feed rate of 20 gallons per minute. The iron consumption did not vary significantly with either pH or feed rate variations. Thus, the air-agitated cementation launder operated more efficiently when the pH of the feed liquor was lowered from 2.3 to 2.0.

For the remainder of the test (about 12 days) the pH of the feed solution was adjusted to 2.0 and, because the purpose of the test was to determine the self-cleaning characteristics of the iron bed, the feed solution flow of 20 gallons per minute was used. With these conditions the copper recovery was only 80 percent, but copper production was 13.6 pounds per hour and the self-cleaning characteristics of the apparatus would be more severely tested.

During the entire 14-day test period, 6,650 pounds or 4.7 bed volumes of iron were consumed and the test results did not show a decrease in cementation efficiency. Thus, the launder operated satisfactorily for 14 days and the maximum operating time before a cleanout is required would be in excess of this time. At the end of the test, excessive accumulations of copper were not noted when unloading the launder. There was some copper buildup around the edges of the launder but the center section did not appear to be plugged. The buildup around the edges was about 4 inches in thickness and extended from the grate upward for about 18 inches. Apparently, the lip supporting the grate protected the edges from the scrubbing action of the air agitation.

CONCLUSIONS

The air-agitated cementation launder containing shredded automobile scrap was found to be an effective means of recovering copper from leach solutions. The most suitable scrap product was obtained from incinerated hulks shredded in a hammer-type shredder. With this type of scrap, the launder was self-cleaning and a 14-day continuous test was made without a decrease in cementation efficiency. This self-cleaning characteristic of the air-agitated cementation launder would be an economic advantage for an industrial operation because shutdown time and cleanout labor costs would be minimized.

It was also found that leach solutions that did not contain sufficient acid to prevent oxidation of ferrous ions and the precipitation of iron salt would result in decreased cementation rates and increased iron consumption rates. However, this condition was avoided by acidulation of the leach solution prior to cementation.

The complete specifications for a shredded automobile scrap product suitable for copper cementation were not determined. In addition to using incinerated hulks shredded in a hammer-type shredder, the size of the pieces is important. The iron product used for most of the test work consisted of intermediate-sized pieces. The small pieces such as nuts and bolts were removed because they collected in the hutch and interfered with the discharge of the cement copper. A commercial operation probably would be required to do likewise. The stainless steel parts were sorted out because they will not dissolve or precipitate copper. This stainless steel has ferromagnetic properties and cannot be rejected by magnetic methods. For a commercial operation, hand-sorting the iron product before cementation may not be practical. It may be more convenient to allow the stainless steel parts to collect in the launder and then periodically completely dissolve the soluble iron by cementation. The insoluble scrap can then be rejected by some mechanical means rather than by hand-sorting. Also the large pieces of massive iron and tangled wire masses were not used because of the size of the test unit and the possibility of bridging. A large-sized commercial launder would probably minimize the bridging effect. However, further testing is needed to substantiate this conclusion.

REFERENCES

1. Dean, K. C., R. D. Groves, and S. L. May. Copper Cementation Using Automobile Scrap in a Rotating Drum. BuMines RI 7182, 1968, 12 pp.

2. Denny, J. R., and D. S. Kirshnaswamy (assigned to Kennecott Copper Corporation). Apparatus for Precipitating Metals From a Solution. U.S. Pat. 3,554,516, Jan. 12, 1971.

3. _____. Gas Injection To Leach Precipitation Process. U.S. Pat. 3,457,065, July 22, 1969.

4. Fisher, W. W., and R. D. Groves. Physical Aspects of Copper Cementation on Iron. BuMines RI 7761, 1973, 9 pp.

5. Greenwood, C. C. Underground Leaching at Cananea. Eng. and Min. J., v. 121, No. 13, Mar. 27, 1926, pp. 518-521.

6. Miller, J. D., and L. W. Beckstead. Surface Deposit Effects in the Kinetics of Copper Cementation by Iron. Met. Trans., v. 4, August 1973, pp. 1967-1973.

7. Waterbury, G. H. (assigned to the Waterbury Metals Extraction Co., Spokane, Wash.). Precipitation Process. U.S. Pat. 788,443, Apr. 25, 1905.

8. _____ (assigned one-half to Frank Williams, Denver, Colo.). Process of Extracting Copper From Ores. U.S. Pat. 689,835, Dec. 24, 1901.