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Studies on multi-gravity separator for rejection of acid insolubles in a copper concentrate

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ABSTRACT

The copper ore from Malanjkhand, India is of very low grade in nature with major amounts of quartz as gangue. In addition to chalcopyrite, the ore also contains oxidized copper minerals in considerable amounts. During flotation, these oxidized minerals require additional amounts of reagents for reporting into concentrate. Higher reagent dosage not only floats the oxidized copper minerals but also results in collection of high amounts of acid insolubles in the copper concentrate resulting in inferior metallurgical grade. To alleviate this problem it was planned to process the copper flotation concentrate further in a Multi-Gravity Separator (MGS), exploiting the specific gravity differential between the copper bearing minerals and the associated gangue under enhanced gravitational fields. A 3^3 full factorial set of experimental design was used to understand the effect of change in important MGS variables on copper and acid insolubles grade and copper recovery in the concentrate. The results have indicated that an increase in wash water and drum inclination and a decrease in drum revolutions will increase copper grade, decrease the acid insolubles grade and decrease the copper metal recovery in the concentrate. Statistical analysis of the results have indicated that among the variables studied, the change in drum revolution influences the metallurgical results most followed by drum inclination and wash water. Further, the equations developed have indicated that there is complex inter-actional effects between wash water, drum inclination and drum revolutions which influences the metallurgical values to a considerable extent.

Keywords: Acid insolubles; Gravity separation; Flotation, Copper

1. INTRODUCTION

The ore from Malanjkhand mine of Hindusthan Copper Limited, India, contains copper ore minerals in the form of sulfides along with oxides in considerable amounts. Quartz is the major gangue mineral. The ore is being processed using flotation technique. During flotation, the presence of oxidized copper minerals requires additional amounts of reagents, which result in non-selective separation, and the concentrate produced is contaminated with high amounts of acid insolubles. In the present study, attempts were made to reject the acid insolubles from a flotation concentrate by exploiting the specific gravity differential between copper bearing minerals and acid insolubles (gangue) in a Multi-Gravity Separator (MGS).

MGS is an enhanced gravity concentration technique utilizing superimposed effects of centrifugal acceleration on forces acting on a conventional Wilfley table for concentration of minerals. The particle separation chamber inside an MGS is a cylindrical drum with a to and fro shaking mechanism. The drum is positioned at an inclination with an elevation at the front end. This mechanism allows the material flow towards the opposite end. The drum is further rotated at some speed to generate centrifugal forces on particles. The heavy mineral particles, due to higher settling rates, forms initial layers on the drum surface. The lighter minerals form overlaying beds on the heavy mineral layers. At this stage mineral bed inside the drum surface contains progressive layers of lighter mineral particles with heavies at the innermost positions, however, minor entrapment of coarse and lighter particles with the heavies. For flowing film concentration to occur, fresh water is continuously sprinkled on the settled bed at the front end of the drum. The outer layers of the lighter minerals are selectively washed and are continuously collected in tailings launder

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provided at the back end of the drum. The heavy mineral bed along with entrapped coarser & lighter minerals is continuously scrapped towards the front end with the help of a rotating spiral scrapper mechanism. During the process of continuous scrapping, the wash water causes flowing film action on the heavy mineral bed before it is finally discharged. Thus the entrapped coarser & lighter material particles in the heavy bed will be selectively washed into the tailings before the heavies are discharged into the launder at the front end. Due to combined actions of forces acting on MGS drum, mineral concentration based on differential specific gravity takes place several times before the products are discharged.

Additional information on the principles of particle concentration in an MGS is available in literature (Wills, 1997). Further, research on MGS for processing different heavy minerals has been reported elsewhere (Chan *et al.*, 1989, 1991; Tucker *et al.*, 1991; Turner and Hallewell, 1993; Clemente *et al.*, 1993; Traore *et al.*,1995; Burt *et al.*, 1995, Patil *et al.*, 2000; Udaya Bhaskar *et al.*, 1999, 2001, 2002, 2003). All the reports indicate that MGS has potential application in concentration of heavy minerals at fines and slime sizes. Thus, in the present study, attempts were made to exploit the specific gravity differential between copper bearing minerals and gangue for bringing out separation in MGS.

2. MATERIALS AND METHODS

Copper flotation concentrate was collected from the operating plant at Malanjkhand Copper Concentrator in a 100 litres slurry container. Water was decanted, filtered and the solid cake was dried. Representative samples of dried material each weighing 10kg were prepared by using standard sampling methods (Wills, 1997) and were preserved in plastic containers. From randomly selected sample containers, small amounts of the feed samples were collected for testing the size distribution, and mineralogical and chemical composition. The size wise weight and assay distribution of the feed sample is presented in Table 1. The table indicates that 36.7% of the feed is in the form of fines below 25 microns and 12.9% of the feed is coarser than 100 microns size. This indicates that considerable portion (about 50.4%) of the feed material is between the sizes 100 and 25 microns. The size wise copper and acid insolubles distribution in the feed indicates that the copper content increases with decrease in particle sizes down to 25 microns. However, at fines below 25 microns size, there is a reduction in copper content. The acid insolubles are concentrated at fractions above 100 microns (18.48%) and below 25 microns (22.96%). Between sizes 100 and 25 microns, the acid insolubles content is more or less similar. A microscopic study on the samples has indicated that considerable amounts of locked particles with small amounts of copper are present in fraction above 100 microns. However, fractions below 100 microns are more or less completely liberated (95% on average).

Table 1
Size-by-Size assay distribution of feed sample to MGS

Size (μm)	Weight (%)	Cu (%)	Acid insolubles (%)
+100	12.9	20.75	18.48
+75	11.6	22.30	10.88
+53	11.2	23.30	9.22
+38	12.4	24.40	8.60
+25	15.2	24.90	10.50
-25	36.7	21.60	22.96
Feed	100	22.59	15.70

3. EXPERIMENTAL

The experimental set-up used for the present study is presented in Figure 1. The set-up consists of a feed tank with a stirrer, a peristaltic pump for supplying feed to MGS at consistent rate, a pilot scale MGS unit and sample containers for collecting the concentrate and tailing samples. Measured quantity of solids and water were mixed to achieve 25% by weight solids consistency in the feed tank. MGS variables were adjusted at required levels as per the experimental design. The feed slurry was pumped into the drum at 2L/m flow rate while the MGS was in operation. Samples from the concentrate and tailing streams were collected at steady state condition, which was achieved after 5 minutes of operation. The samples were filtered, dried and analysed for total copper and acid insolubles contents. From the copper and acid insolubles assay values in the feed and experimental products, metallurgical results were generated using suitable mass balance equations.

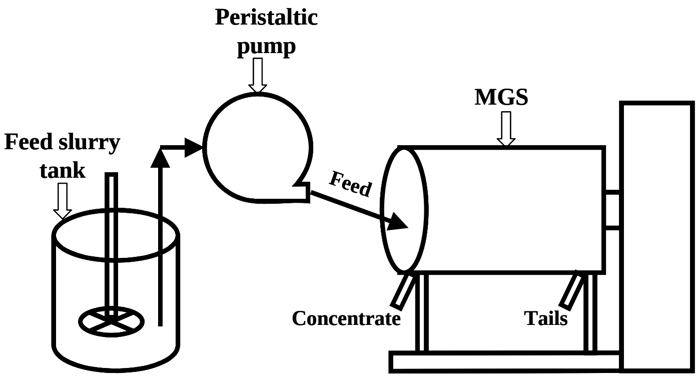

Figure 1. MGS experimental set-up

4. RESULTS AND DISCUSSION

A set of 27 experiments by changing important variables like wash water, drum inclination and drum revolutions was carried out at three different levels. The MGS variables and the levels studied in the present investigation are presented in Table 2. The wash water flow rate was varied at 2, 3, and 4Lpm, drum inclination was varied at 3, 4, and 5° to horizontal and drum revolutions was varied at 160, 200 and 240rpm. The results have indicated that the wash water and drum inclination qualitatively have similar effects. Thus for convenience, the influence of these two variables on the MGS performance is discussed together and the effect of drum revolutions is discussed separately as follows:

Table 2
The variables and levels studied during experimental work on MGS

Exp.No.	Wash water (Lpm)	Drum inclination (degrees horizontal)	Drum revolutions (rpm)
1	2	3	240
2	3	3	240
3	4	3	240
4	2	4	240
5	3	4	240
6	4	4	240
7	2	5	240
8	3	5	240
9	4	5	240
10	2	3	200
11	3	3	200
12	4	3	200
13	2	4	200
14	3	4	200
15	4	4	200
16	2	5	200
17	3	5	200
18	4	5	200
19	2	3	160
20	3	3	160
21	4	3	160
22	2	4	160
23	3	4	160
24	4	4	160
25	2	5	160
26	3	5	160
27	4	5	160

4.1. Effect of wash water and drum inclination on concentrate copper grade

The effect of change in the levels of wash water and drum inclination on the concentrate copper grade is presented in Figures 2a, 2b, and 2c. The individual figures (a, b, and c) indicate the effects of wash water and drum inclination at three different drum revolutions i.e., 240, 200, and 160rpm, respectively. The figures indicate the following effects:

- An increase in wash water level between 2 and 4Lpm has increased the copper grade in the concentrate at all the levels of drum inclinations and drum revolutions.
- An increase in drum inclination between 3 and 5° increases the concentrate copper grade at all the levels of wash water and drum revolutions.
- The increase in concentrate copper grade with increase in wash water and drum inclination is more pronounced at lower drum revolutions.

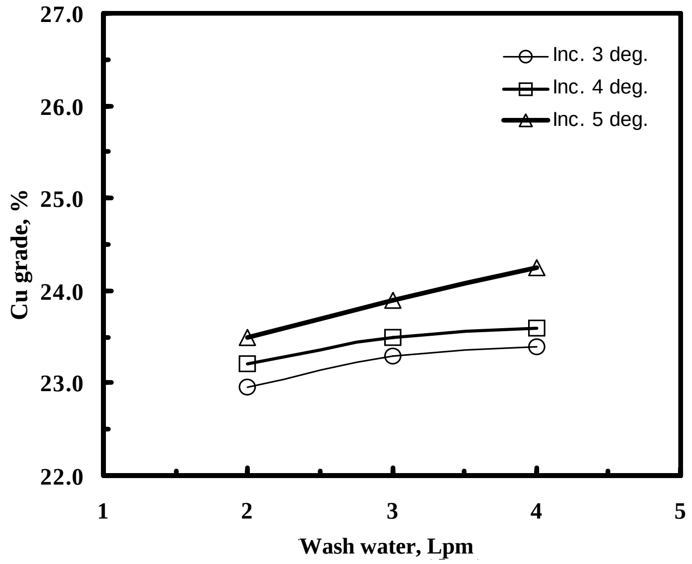

Figure 2a. Effect of wash water on copper grade at different inclinations and at 240 drum revolutions

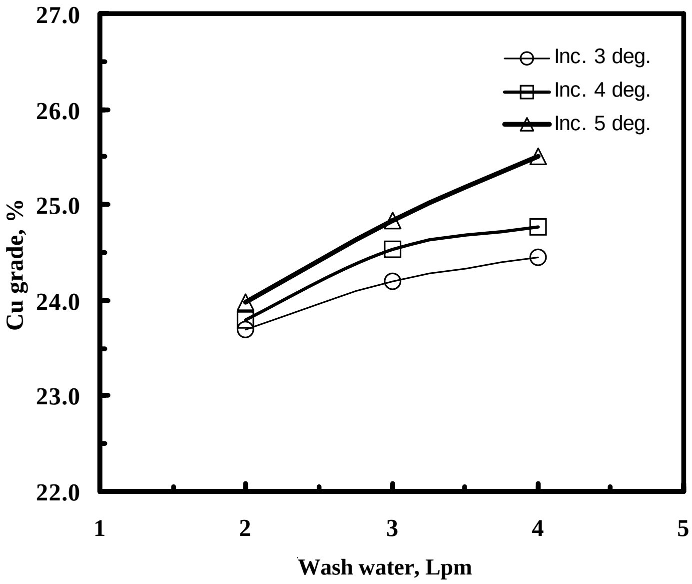

Figure 2b. Effect of wash water on copper grade at different inclinations and at 200 drum revolutions

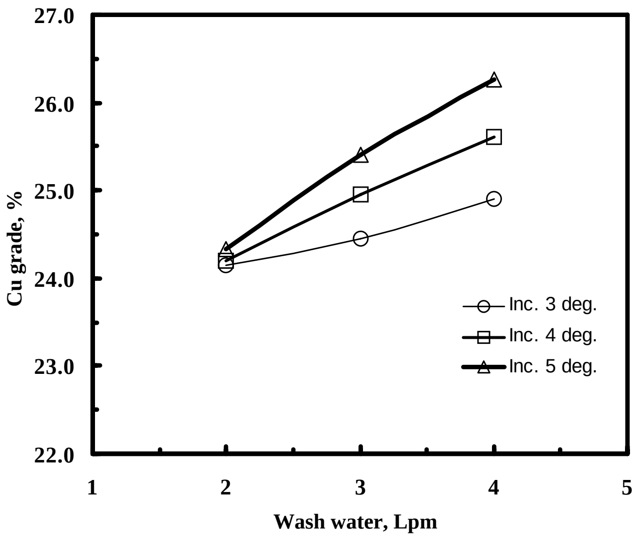

Figure 2c. Effect of wash water on copper grade at different inclinations and at 160 drum revolutions

An increase in concentrate copper grade with increase in wash water and drum inclination may be explained due to increased water velocity inside the MGS drum which in turn increases washing effects on the upper layers of the settled bed. Similarly, at lower drum revolutions, the centrifugal forces acting on the mineral particles are lower and the layers of solid bed thus formed are loosely packed. An increase in water velocity at higher levels of wash water and drum inclination will have more washing effect on the loosely packed outer layers of lighter silica bearing mineral particles (Acid insolubles).

4.2. Effect of drum revolutions on concentrate copper grade

The effect of change in drum revolutions at different wash water levels and at 3° drum inclination is presented in Figure 3. It can be noticed from Figure 3 that an increase in drum revolutions from 160 to 240rpm decreases the concentrate copper grade. This effect can be observed at all the levels of wash water. Increased drum revolutions generate higher centrifugal forces on particles which not only allows the heavier copper bearing mineral particles reach the compact solids bed, but also allows some portion of lighter silica bearing minerals to penetrate the heavies bed. Similar observations were made at other levels of drum inclinations i.e. 4°and 5°.

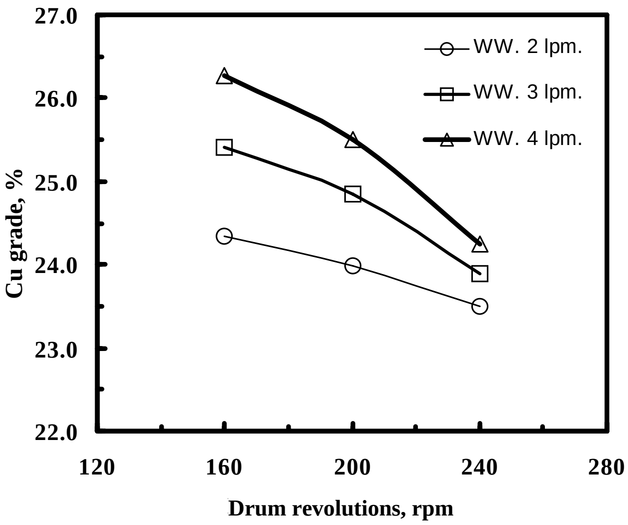

Figure 3. Effect of drum revolutions on copper grade at different levels of wash water and at 3 deg. drum inclination

4.3. Effect of wash water and drum inclination on acid insolubles grade

The concentrate acid insolubles grade obtained at different levels of wash water and drum inclination are presented in Figures 4a, 4b, and 4c. The individual figures (a, b, and c) indicate the effects of wash water and drum inclination at three different drum revolutions i.e., 240, 200, and 160, respectively. It can be observed from the Figure 4a that an increase in the wash water rate and the drum inclination decreases the acid insolubles. Higher levels of wash water and drum inclination results in increased water velocity inside the drum causing more push of fluid on the lighter material laying on the outer layers of the settled bed. As most of the acid insolubles are in the form of quartz, which is a lighter mineral compared to copper bearing minerals it is more prone for washing. This observation of decrease in acid insolubles grade with increase in the wash water rate and the drum inclination is also found at other 200 and 160rpm drum revolutions in the study (Figures 4a and 4c).

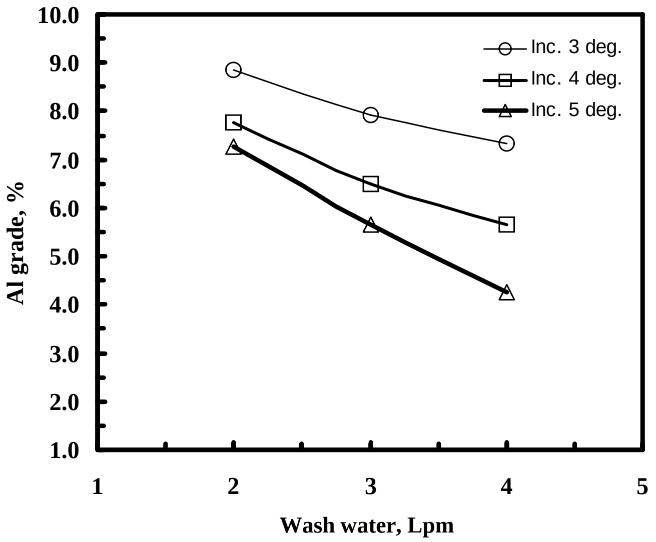

Figure 4a. Effect of wash water on acid insolubles at different inclinations and at 240 drum revolutions

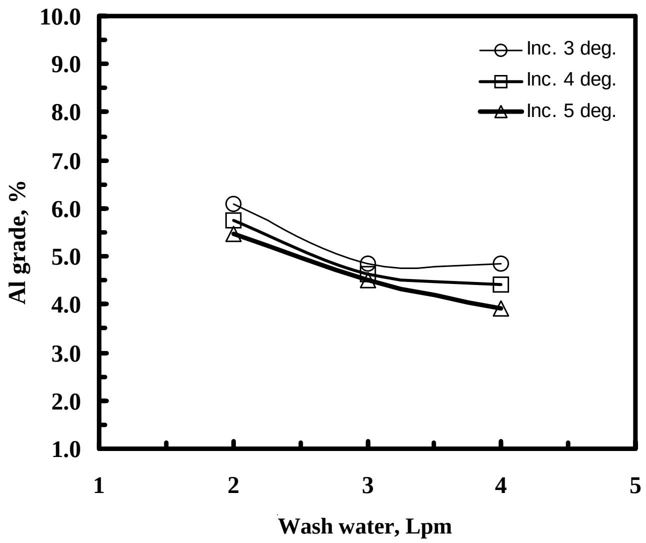

Figure 4b. Effect of wash water on acid insolubles at different inclinations and at 200 drum revolutions

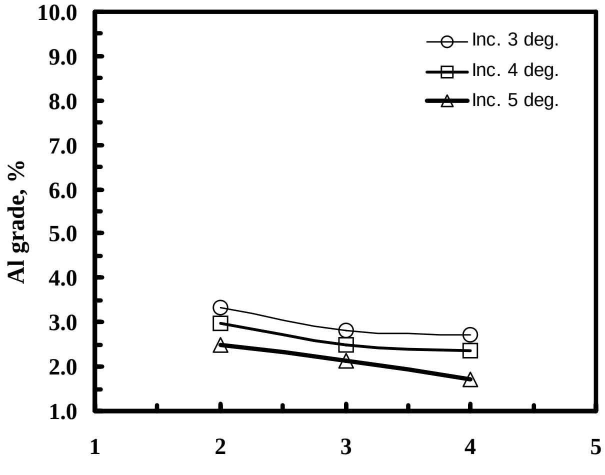

Figure 4c. Effect of wash water on acid insolubles at different inclinations and at 160 drum revolutions

4.4. Effect of drum revolutions on acid insolubles grade

The effect of change in drum revolutions on concentrates acid insolubles grade at different levels of wash water and at a particular drum inclination of 3° is presented in Figure 5. The figure indicates that there is a general trend of decrease in acid insolubles grade in the concentrate with decrease in drum revolution. A decrease in drum revolutions decreases the centrifugal forces on particles and forms a loosely packed bed of lighter mineral particles on the upper layers, which is amenable for easy washing. However, it can be observed that the slope of these curves changes with change in wash water level indicating a complex interaction between the individual variables in study. This observation of decrease in acid insolubles grade with decrease in drum revolutions was observed at all the combinations of wash water and drum inclination levels.

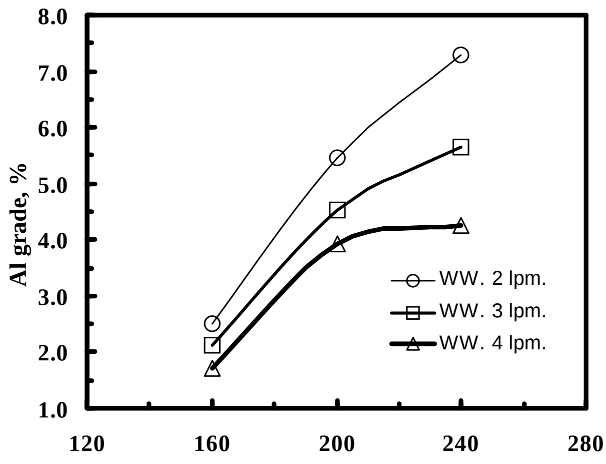

Figure 5. Effect of drum revolutions on acid insolubles at different levels of wash water and at 3 deg. drum inclination

4.5. Effect of wash water and drum inclination on copper recovery

The effect of wash water and drum inclination on concentrate copper recovery at different drum revolutions i.e. 240, 200, and 160rpm is presented in Figures 6a, 6b, and 6c respectively. It may be noticed from Figure 6a that an increase in wash water and drum inclination decreases the copper recovery. Similar observation can be made from Figures 6b and 6c representing the effect at 200 and 160rpm drum revolutions.

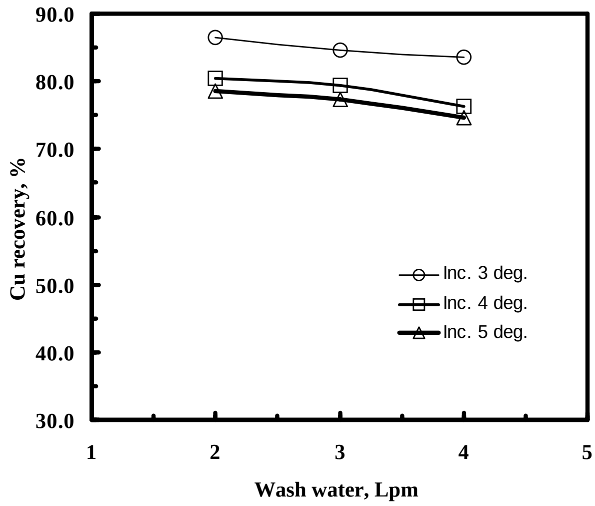

Figure 6a. Effect of wash water on copper recovery at different inclinations and at 240 drum revolutions

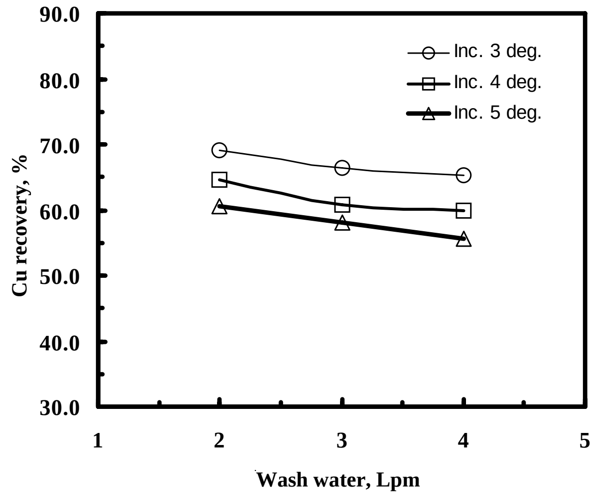

Figure 6b. Effect of wash water on copper recovery at different inclinations and at 200 drum revolutions

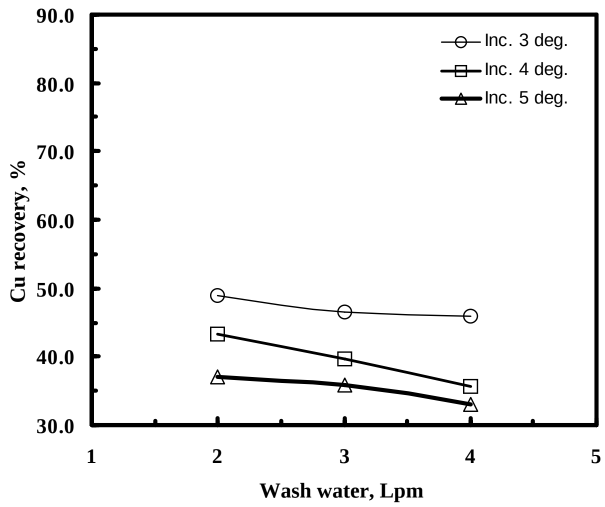

Figure 6c. Effect of wash water on copper recovery at different inclinations and at 160 drum revolutions

An increase in water velocity at higher levels of wash water and drum inclination not only causes major washing effects on lighter material, but it also washes some portion of entrapped fine heavy material into the tailings. This might have caused a decrease in the metal recovery into the concentrate.

4.6. Effect of drum revolutions on copper recovery

The effect of drum revolutions on concentrate copper recovery at a constant drum inclination of 3° is presented in Figure 7. It may be noticed from the figure that a decrease in drum revolutions decreases the copper recovery in the concentrate. Further, the reduction of copper recovery with decrease in drum revolutions was found comparatively less from 240 to 200 than from 200 to 160. A decrease in drum revolution decreases the centrifugal accelerations on particles and results in a loosely packed bed of solids. Thus concentration at lower drum revolutions not only washes major amount of lighter material into tailings but also carries some portion of heavies too. A reduction in drum revolutions from 240 to 200 might have resulted in loosening more of lighter mineral bed, which was amenable for washing. Thus a major decrease in copper recovery was not observed for this change in drum revolutions. However, a further decrease in drum revolutions from 200 to 160 might have resulted in loosening some outer layers of heavy mineral bed. Further, due to dominating effects of water velocity over the centrifugal forces on these loosely packed layers, heavy mineral particles also might have been washed into tailings along with lighter minerals. Similar effects of drum revolutions are found at all the combinations of wash water and drum inclinations.

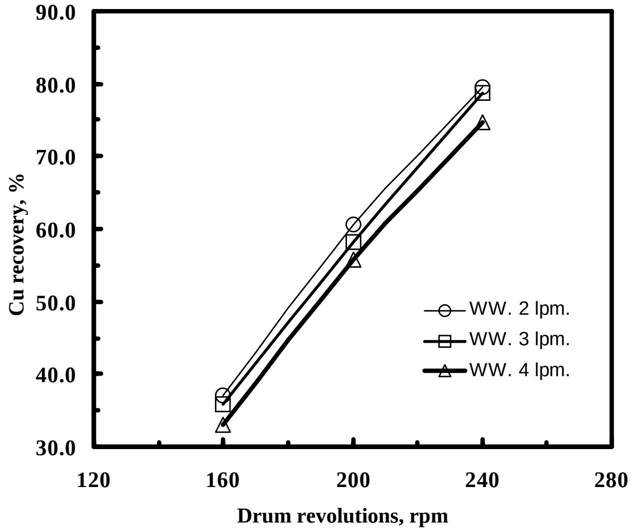

Figure 7. Effect of drum revolutions on copper recovery at different levels of wash water and at 3 deg. drum inclination

4.7. Statistical analysis

Having understood that there is a complex interaction between individual variables in study, a statistical analysis of the experimental results has been carried out to quantify the individual and combined effects. Using eight experimental results (taken from the total 27 experimental set) obtained at maximum and minimum levels of the three variables, 2^3 full-factorial statistical analyses was carried out. Suitable linear-regression equations were developed for copper and acid insolubles grade and concentrate copper recovery:. The standard equation used is

$$Y = k_0 + k_1A + k_2B + k_3C + k_4AB + k_5AC + k_6BC + k_7ABC \quad (1)$$

Where,

Y is the response variable (concentrate grade or recovery)

k_0, k_1, k_2, ... k_7 are the constants and

A, B, C are the dimensionless values for wash water, drum inclination and drum revolutions. The details of generation of these values have been presented elsewhere (Udaya Bhaskar *et al.*, 1999). The constants generated for copper and acid insolubles grades and copper recovery in the concentrate are presented in Table 3. From the table the following effects may be noticed.

Table 3
Coefficients generated for predicting the grade and recovery values from Model Eq. 1

Factor	Coefficient estimate		
	Cu grade	Al grade	Cu recovery
Intercept	24.223	4.74	61.175
A-ww	0.488	-0.745	-1.850
B-inc	0.373	-0.805	-5.075
C-rpm	-0.698	2.185	19.925
AB	0.188	-0.210	-0.400
AC	-0.189	-0.390	-0.100
BC	-0.023	-0.350	1.125
ABC	-0.113	-0.165	-0.100

4.7.1. Individual effects

It can be observed from the table that the drum revolutions has the maximum effect followed by drum inclination and wash water. Negative coefficient of drum revolutions for copper grade indicates a decrease in copper content in the concentrate with increase in drum revolutions. Similarly, negative coefficients of wash water and drum inclination indicate a decrease in acid insolubles grade and copper recovery at increased levels of these variables.

4.7.2. Interactional effects

Negative interaction coefficients of AC and BC on copper grade (-0.189 and -0.023 respectively) indicate the dominating effect of drum revolutions over wash water and drum inclination. The interactional coefficients of AB however is positive (0.188) indicating an increase in the lead grade for a simultaneous increase in the levels of wash water and drum inclination.

Similarly, negative coefficients for AB, AC and BC interactions on acid insolubles grade indicate that a simultaneous increase in any two of these variables decrease the acid insolubles grade in the concentrate. This indicates that for a simultaneous increase, wash water and inclination have dominating effects over the drum revolutions in washing out the lighter mineral layers. Within the AC and BC interactions, the coefficient for AC is found to be more (-0.390) than the BC interactional coefficient (-0.350) indicating prominent effect of wash water.

The interactional effect of drum inclination and drum revolutions (BC) on the copper recovery has a positive coefficient (1.125) indicating an increase in lead recovery at higher drum revolutions though at higher drum inclination. This indicates dominating effect of drum revolutions over drum inclination. Similarly, the interactional effect of wash water and drum revolutions (AC) with a negative coefficient (-0.100) indicates that the wash water has dominating effect at higher drum revolutions. Further, a negative coefficient (-0.400) for wash water and drum inclination (AB) indicates that a simultaneous increase of these variables decrease the copper recovery in the concentrate. This indicates wash water is a key variable in determining the copper recovery in the concentrate.

Negative coefficients for triple interaction of wash water, drum inclination and drum revolutions (ABC) indicate that for a simultaneous increase in the wash water, drum inclination and drum revolutions, the copper grade decreases indicating the dominating effect of drum rotation. Further, the negative triple interactional coefficients of acid insolubles grade and copper recovery indicates that a simultaneous increase in these variables decreases the acid insolubles grade and copper recovery in the concentrate indicating dominating effects of wash water and drum inclination.

4.7.3. Validation of models

From the models developed, the copper and insolubles grades and copper recovery values are generated at different intermediate levels of the remaining 19 experimental conditions in the original 27 experimental set and are compared with the actual results. The actual and predicted values of copper grade, acid insolubles grade and copper recovery values are presented in Figures 8, 9 and 10, respectively. The figures indicate that the data points are close to the ideal line connecting the minimum and maximum values with R^2 values 0.98, 0.95, and 0.99 respectively indicating good fitness of the equations.

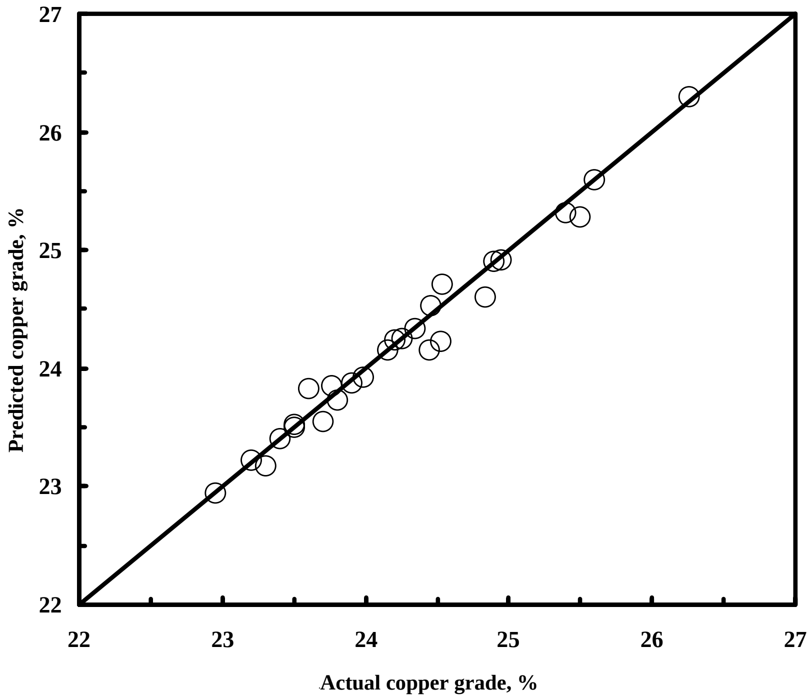

Figure 8. Actual and predicted values of copper grades

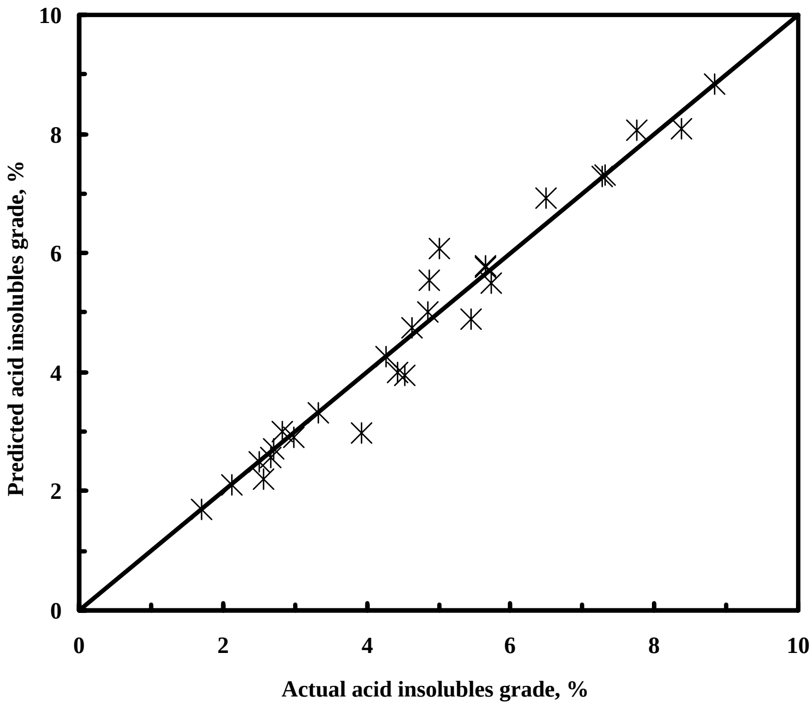

Figure 9. Actual and predicted values of acid insolubles grades

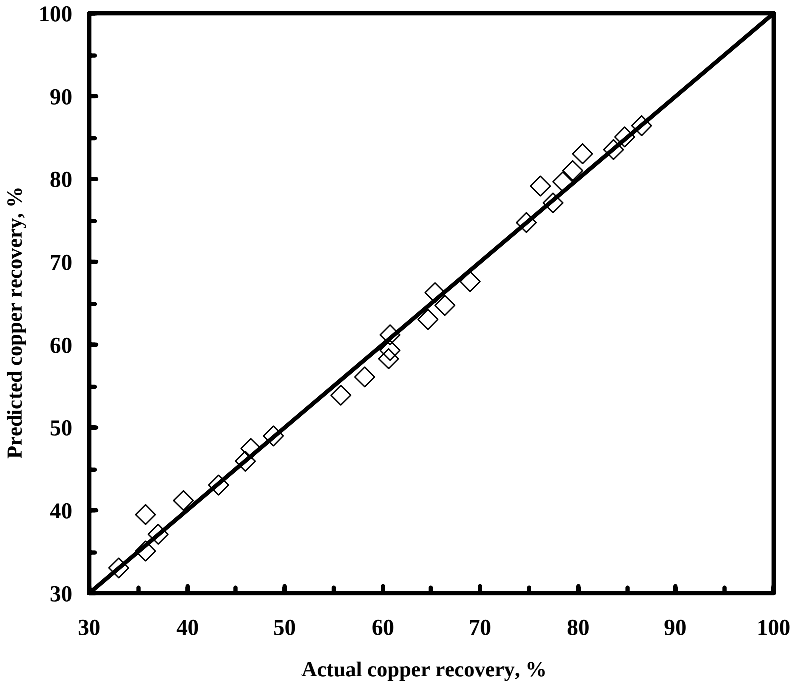

Figure 10. Actual and predicted values of copper recoveries

5. CONCLUSIONS

Based on the experimental work carried out and followed by discussion, the following conclusions are drawn:

- The lighter gangue minerals can be efficiently separated from oxidized copper concentrates using MGS technique.
- A concentrate containing 26.05% Cu and 1.7% Al contents can be produced from a feed containing 22.59% Cu and 15.7% Al
- While the effects of wash water and drum inclination are qualitatively similar, the statistical analysis has indicated that quantitatively the later has higher effect.
- Among the variables studied, the drum revolutions is found to have maximum effect.
- The analysis has also indicated that the interactional effects of the variables have considerable influence on metallurgical results.
- The models developed have shown good prediction over the entire study range.

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