# THE EFFECT OF SUPERFICIAL FEED VELOCITY ON THE COLUMN FLOTATION RECOVERY IN COMPARISON WITH THE CONVENTIONAL FLOTATION CELLS

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**ABSTRACT:** *Flotation is the most important process for concentrating mineral ores. This process may occur in any vessel such as column flotation, which has been used widely during the last decade and the conventional flotation cells. The effect of superficial feed velocity on the copper recovery was investigated using pilot-scale column flotation of "Sarcheshmeh Copper Complex". The results were compared with the conventional flotation cell data. It was reveled that for coarse particles($d_{80}=90\mu m$) this column could not be used instead of cells and rougher cells, but for small particles ($d_{80}=44\mu m$) it could. For coarse particles, recovery curve demonstrated a maximum with increase in feed rate. However, a minimum was observed for fine particles.*

**KEY WORDS:** *Column flotation, Flotation cell, Recovery, Collecting zone, Cleaning zone.*

## INTRODUCTION

Column flotation, CF, was patented in 1965 by *Pierre Boutin.* It is sometimes called Canadian Column. The first commercial CF was operated in Canada in 1980. Commercial columns are typically 9 to 15 m in height and 0.5 to 3 m in diameter [1,2]. Slurry feed enters the column about one third the way down from the top. It descends againts ascending sparger-generated bubbles. The bubbles collect the floatable particles, that's why this zone is called collection zone. Collected particles are transferred into the froth and are stabilized by wash water. The wash water's prime role is to clean the froth from particles entrained in the water in collection zone. This zone is called froth zone or cleaning zone.

Flotation cell in the other hand, is a device which has parallel cells with rectangular cross-sections.

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Agitator is used for generation of bubbles. In industry flotation cells are arranged in many rows and each row has a particular name. At first slurry enters the rougher cells then it is fed to cleaner and recleaner cells. Generally, exit streams from rougher cells tail is fed to scavenger cells [3].

Since CF has no moving parts, it has a lower maintenance and energy costs. It also needs less space compared to the flotation cells.

Many researchers have compared CF and flotation cells from different aspects. In this work these two have been compared to assess the possibility of replacing cell flotation with CF in Sarcheshmeh Copper Complex keeping the feed physico-chemical conditions constant. In this respect the effect of superficial feed velocity on copper recovery of column, which is considered to determine the optimum capacity of the column was studied.

Although the effect of superficial feed velocity on the recovery of fine particles of coal has been reported [4], but such research on the fine coarse particles and comparison between them is not known for cooper ore. Hence, in Sarcheshmeh Copper Complex this study on the fine and coarse particle of copper ore was carried out.

## EXPERIMENTAL

### *Recovery in CF*

Recovery is defined as the ratio of the amount of solid particulate in the product to that in the feed. Recovery in CF depends on the recovery in the collection and cleaning zones and the relationship that exist between them.

To determine the recovery in the collection zone, the particle collection process was considered to follow a first order kinetics with respect to the solid concentration [3]. Several models for recovery in this zone based on the residence time distribution (RTD) has been reported [5,6]. Among them the dispersion model is thought to be the most acceptable [1,2]. According to this model recovery is given by Eq. 1 [1,7].

$$R=1-\frac{4\,a\,\exp(0.5\,N_d)}{(1+a)^2\exp(a/2\,N_d)-(1-a)^2\exp(-a/2N_d)} \tag{1}$$

where;

$a = (1 + 4\,k\,t\,N_d)^{0.5}$

This shows that recovery in the collection zone depends on three variables i.e., collection rate constant (k), mean residence time (t) and vessel dispersion number($N_d$). Collection rate constant is given by Eq.2 [1].

$$k = \frac{E_k\,J_g \times 1.5}{d_b} \tag{2}$$

If $d_b$ which is the bubble diameter is less than 2 mm then the requirement of bubbling flow in the column is met. $J_g$ is superficial gas velocity (volumetric flow rate per unit cross-section) and $E_k$ is the collection zone efficiency. $E_R$ is defined as the product of collision efficiency($E_c$) and attachment efficiency ($E_A$)[1].

$$E_k = E_c\,.\,E_A \tag{3}$$

Collision and attachment efficiencies depend on the bubble and particle diameters, hydrophobicity and settling velocity of particles and bubble rise velocity. It is believed that if particle size increases, the collision efficiency increases wheras the attachment efficiency decreases [1].

Mean residence time can be calculated by the use of RTD data or from Eq. 4.

$$t = \frac{H_c(1-\varepsilon_g)}{J_{sl}} \tag{4}$$

Where $H_c$ is the height of collection zone, $J_{sl}$ is the superficial slurry velocity ($J_{sl}$=Jf) and $\varepsilon_g$ is the gas holdup in the collection zone.

Eq. 4 shows that mean residence time for liquid and solid particles is less than that for the gas bubbles. Also coarse particles have lower mean residence time than fine particles [1,2].

Vessel dispersion number is given by Eq. 5 [1,2].

$$N_d = \frac{E(1-\varepsilon_g)}{J_{sl}\,.H_c} \tag{5}$$

Where E is the axial dispersion coefficient. Estimation of E can be found in many references [1,2]. Recovery may be calculated by assuming a simple plug flow model for cleaning zone.

$$R = \exp(-k_d \frac{H_f}{J_g}) \tag{6}$$

Where $k_d$ is the detachment rate constant, $H_f$ is the height of cleaning zone and $H_f/J_g$ is equivalent to bubble retention time in the froth [2].

Recovery in cleaning zone is thought to decrease with increasing particle size. However, it needs further investigation. A 50% recovery is likely for an experimental column, but it is probably less for an industrial column. At the interface between the two zones, particle transport occurs in both directions. Particle transport occurs at first from collection zone to the cleaning zone through attachment of particles to rising bubbles. Subsequently they are transported from the cleaning zone back to the collection zone due to the coale scence and detachment of particles from bubbles. The relationship between the zones is shown in the Fig. 1. If $R_c$ and $R_f$ show recovery in collection zone and froth zone respectively, then the overall flotation column recovery could be calculated by Eq. 7 [8].

$$R = \frac{R_f \cdot R_c}{R_f \cdot R_c + 1 - R_c} \tag{7}$$

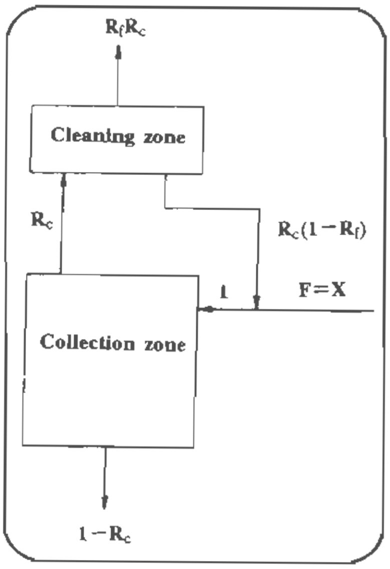


*Fig. 1: Shows dependency of cleaning and collection zones.*

A mass balance around the column using particulate solid percentage (grade) in the feed, f, product, c, and exit stream, t, gives the overall recovery. The results is given by Eq. 8 [9].

$$R = \frac{c(f - t)}{f(c - t)} \times 100 \tag{8}$$

CF like flotation cells may be arranged in series or it can be mixed in a circuit of cells and columns.

### *Description of Apparatus*

Sarcheshmeh Copper Complex is located 160 km South-West of Kerman city. It has a conventional and a column flotation plant for copper ore concentration research.

The capacity of this conventional pilot plant is 1.6 ton/h and it contains 32 conventional cells. Before grinding the ore, it is first mixed with water, lime and the chemical reagents. Then it enters to 14 rougher cells. The concentrate of the rougher cells is regrinded and enters to 6 cleaner and 6 recleaner cells. The concentrate of recleaner is the final concentrate that makes the product. The cleaner exit stream enters to 6 scavenger cells. The scavenger and the rougher exit make the final exit.

The pilot column is shown schematically in Fig. 2. The column diameter is 0.2 m and its height is 6.40

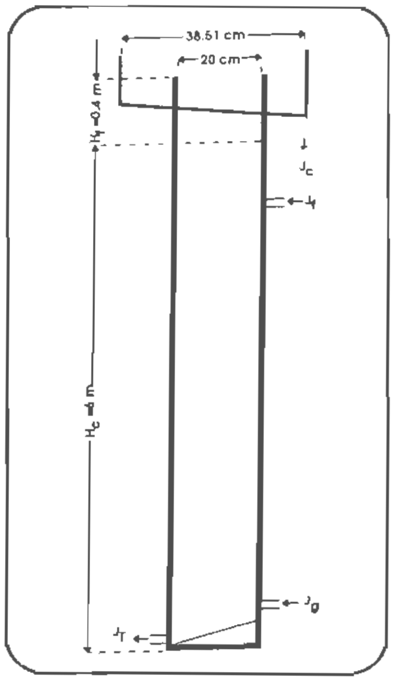


*Fig. 2: Schematic view of Sarcheshmeh Copper Complex column flotation.*

m. The feed enters 1.30 m from the top of the column. Feed is pumped by a variable speed pump to a feed tank which is positioned on top of the column and then to the column. Compressed air is generated by a compressor and after regulating its pressure it passes through a sparger and then enters into the column at the base.

The superficial gas velocity was kept low in order to bubbling flow regime exits during the process. The sparger was of internal kind. It consisted of a horizontal tube, which at its end a vertical flexible rubber tube was fixed. This rubber tube had many holes for generation of bubbles. Its height was 50 cm. This construction made sure that the hole plugging of the sparger holes by the particulate solids is reduced to its minimum. This column was used in our experimental work.

### *Experimental Method*

Preliminary runs were made in order to make sure that the column works under bubbling flow conditions and the churn turbulent flow did not exit. The conditions for having bubbling flow regime was found to be as follows; pressure= 12 psig, volumetric flow rate= 0.492 lit/s or superficial velocity= 1.57 cm/s. Existence of bubbling flow regime under the above mentioned conditions was checked by viewing bubbles with almost equal size in the column.

Liquid flow rate was measured by collecting a fixed volume of feed and recording the collection time. Feed and wash water flow rates were controlled manually by the corresponding valves. Wash water flow rate was 4 lit/min.

The froth depth was measured by using a floatable cork that was put in the column. The cork position was measured by a ruler that was attached to it. Sampling usually began two hours after commencement of the experiment to make sure that steady state was attained. Several samples from each run were sent to the laboratory for analyzing the copper grade of the feed, exit and the concentrated product. In this way the recovery could be determined.

The same amount and grade of chemical reagents were used for all runs. So the effect of chemicals on the recovery were not investigated. The effect of superficial feed velocity on the copper recovery was studied by changing feed flow rate and copper grade. To compare column performance with that of flotation cells column was first replaced with all 32 cells of the pilot flotation plant and then with the 12 cleaner and recleaner cells.

The results of the experiments are presented in the next section.

## RESULTS

### *Column in place of all cells*

The effect of feed superficial velocity on the copper ore recovery was investigated experimentally. The results are presented in Tables 1, 2, 3 and Fig. 3. The copper ore that was used consisted of different minerals such as, pyrite, silica, calco-pyrite and molybdenite. A small amount of gold and silver were also present.

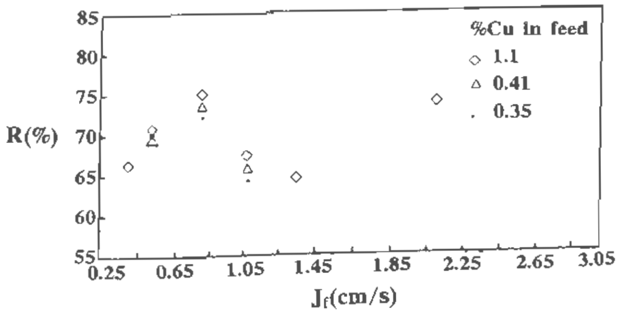


*Fig. 3: The effect of feed velocity upon copper recovery.*

The amount of chemical reagent which were used in each run were kept the same. The constant conditions of the column were;

Superficial gas velocity= 1.57 cm/s;
Particle density= 2.5 g/cm3
Superficial wash water velocity= 0.21 cm/s;
Pulp density= 1.2 g/cm3
Solid content of feed= 28% ;
Collector= 20 g/ton;
Frother= 15 g/ton

Several experiments were carreied out to compare the column performance with all cells and with the rougher cells. Results are presented in Table 4 for all cells. The recovery of rougher cells and the column are given in Table 5.

### *Column in place of 12 cells*

In the pilot plant the concentrate from rougher cells and the scavenger cells were regrinded and after passing through the hydrocyclone then they were fed to the cleaner and scavenger cells. In this set of experiments column flotation replaced cleaner and recleaner cells and a circuit such as that in Fig. 4 was arranged.

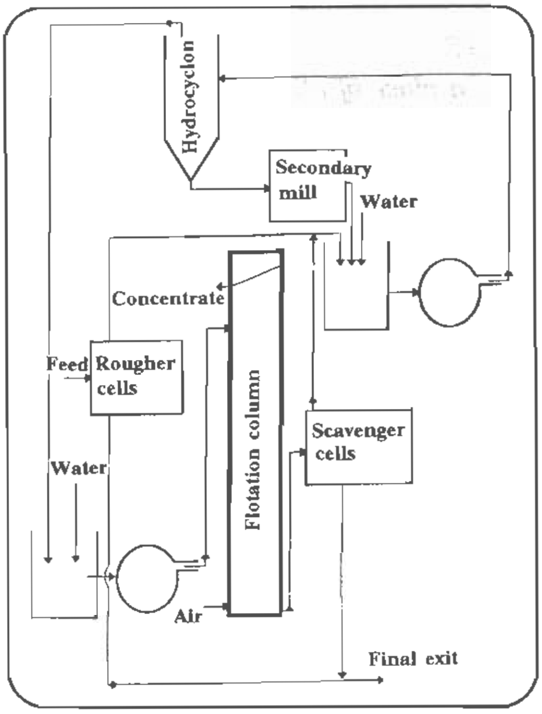


*Fig. 4: Flow sheet of pilot plant that is used in this work.*

Two series of experiments were carried out with this circuit. At first recovery of column was calculated for three different flow rates of feed and then recovery of the circuit was compared with that of the cells. In these runs all conditions were kept the same except the particle size was $d_{80}=44\ \mu m$ and particle fraction of the feed was changed. The results are presented in Tables 6 and 7.

## DISCUSSION

The overall column recovery is related to the froth zone recovery and collection zone recovery by Eq. 7. Since superficial gas velocity, froth depth and superficial wash water velocity were constant, then froth zone recovery was also constant for both fine and coarse particles. Therefore, there was no evidence that froth zone recovery of fine particles were more than coarse particles[1].

Collection zone recovery was dependent on three parameters; namely rate constant, mean residence time and vessel dispersion number (Eq. 1). Increase of superficial feed velocity increases gas holdup in collection zone [1], which in turn increases collection efficiency and collection rate constant and finally recovery[1].

Increase of superficial feed velocity decreased vessel dispersion number hence recovery increased (Eqs. 1 and 5). On the other hand superficial feed velocity decreases mean residence time which leads to a decrease in recovery (Eqs. 1 and 4). If the rate of recovery increase become more than the rate of recovery decrease the recovery curve will ascend, otherwise it will descend. This is evident from the maximum of recovery curve in Fig. 3. Solid fraction of feed had a lesser effect on the recovery curve. Recovery is low when solid content of the feed is low; but if residence time is high, the recovery is not affected by solid content of the feed because the solids will have enough time for attachment to the bubbles. Run no. 6 of Table 1 shows a lower recovery. This is attributed to the high gas velocity which causes churnturbulent flow. This causes particle detachment from bubbles. Since for fine particles attachment efficiency was high, the increase of gas holdup due to the increase of superficial feed velocity had a small effect on the collection efficiency. Thus increase in collection rate constant was low and therefore, recovery decreased due to the decrease of mean residence time. In conclusion the effect of decrease in mean residence time on the reduction of recovery was more pronounced compared to the effect of high gas holdup.

From Tables 4 and 5 it is evident that if the column is replaced with all the cells or with rougher cells the recovery would be low therefore, several columns in series must be used in order to improve the recovery. If one column is used the grinding of ore particles to a higher mesh is needed which is a costly process. These tables also show that the copper grade in the column exit is more than the copper grade of cells. This means that more copper ore will be lost by the columns. In addition the copper grade of the cells concentrate is higher than that of the column. It worth to mention that the column operation was made optimum in each experimental run. Therefore, from Tables 4 and 5 it is concluded that the column cannot be used instead of the cells. But from Table 7 it is evident that the column could not be replaced for cleaner and recleaner cells only if fine particles involved.

## CONCLUSION

When column flotation replaced all 32 cells the optimum, superficial feed velocity was found to be 0.8 cm/s. This is evident from Tables 1,2,3 and Fig. 3. Gas holdup at this condition was 0.15. Therefore, from Eq. 4 the mean residence time of collection zone is found to be 11 minutes. This residence time could be used for scale up purposes.

Table 4 shows that all cells recovery is higher than the column recovery and loss of copper ore in exit is high for CF. The low recovery of column is due to the existence of coarse particles. Hence the column could not be replaced with all cells or the 14 rougher cells (Tables 4 and 5 ).

When the column was set as is shown in the circuit of Fig. 4, it is evident from Table 6 that an increase in superficial feed velocity diminishes column recovery. Thus the optimum superficial feed velocity and gas holdup were found to be 0.53 cm/s and 0.14, respectively. The calculated mean residence time was found to be 17 minutes. However, it was found that the column could replace the 12 cleaner and recleaner cells, if the superficial feed velocity remained 0.53 cm/s as was shown by Table 7.

Comparison of Tables 1,2 and 3 with each other concluded that column recovery of circuit of Fig. 4 was high only for the last condition. This was due to the existence of fine particles. This result showed that fine particles ($d_{80}$=44 $\mu$m) give a higher recovery in column flotation when compared with the recovery of rougher cells or all 32 cells. Therefore, coarse particles ($d_{80}$=90 $\mu$m) must be groinded if the column is going to be replaced with the conventional cells. Nevertheless grinding process is costly and particles of low diameter ($d_{80}$=20 $\mu$m) may have an adverse effect on the recovery [1,3], therfore, an economical analysis is inevitable.

*Table 1: The effect of feed rate on recovery ( feed copper content %1.1)*

| Run No. | Feed rate Qf lit/min | Feed velocity Jf cm/s | Copper concenteration in feed % | Copper concenteration in exit % | Copper concenteration in concentrate % | Recovery% |
|---|---|---|---|---|---|---|
| 1 | 8 | 0.42 | 1.10 | 0.038 | 20.00 | 66.7 |
| 2 | 10 | 0.53 | 1.10 | 0.35 | 18.80 | 69.488 |
| 3 | 15 | 0.80 | 1.10 | 0.29 | 25.10 | 74.50 |
| 4 | 20 | 1.06 | 1.10 | 0.39 | 19.49 | 65.86 |
| 5 | 25 | 1.33 | 1.10 | 0.41 | 14.20 | 64.59 |
| 6 | 40 | 2.12 | 1.10 | 0.30 | 21.00 | 73.78 |

*Table 2 : The effect of feed rate on recovery (feed copper content %4.1)*

| Run No. | Feed rate Qf lit/min | Feed velocity Jf cm/s | Copper concenteration in feed % | Copper concenteration in exit % | Copper concenteration in concentrate % | Recovery% |
|---|---|---|---|---|---|---|
| 1 | 10 | 0.53 | 0.41 | 0.13 | 10.20 | 69.17 |
| 2 | 15 | 0.8 | 0.41 | 0.11 | 13.30 | 73.78 |
| 3 | 20 | 1.06 | 0.41 | 0.15 | 6.50 | 64.91 |

***Table 3: The effect of feed rate on recovery (feed copper content %3.5)***

| Run No. | Feed rate Qf lit/min | Feed velocity Jf cm/s | Copper concenteration in feed % | Copper concenteration in exit % | Copper concenteration in concentrate % | Recovery% |
|---|---|---|---|---|---|---|
| 1 | 10 | 0.35 | 0.35 | 0.11 | 9.90 | 69.34 |
| 2 | 15 | 0.8 | 0.35 | 0.10 | 11.10 | 72.08 |
| 3 | 20 | 1.06 | 0.35 | 0.13 | 8.90 | 63.78 |

***Table 4: Comparison between column and cell performance***

| | Copper concenteration in feed | Copper concenteration in exit | Copper concenteration in concentrate | Recovery% |
|---|---|---|---|---|
| column | 0.32 | 0.08 | 10.20 | 75.59 |
| cell | 0.32 | 0.07 | 14.288 | 78.51 |
| column | 0.66 | 0.17 | 23.76 | 74.78 |
| cell | 0.66 | 0.15 | 27.889 | 77.69 |
| column | 0.80 | 0.20 | 24.63 | 75.61 |
| cell | 0.80 | 0.17 | 26.83 | 78.96 |
| column | 1.2 | 0.30 | 25.25 | 75.90 |
| cell | 1.2 | 0.28 | 31.31 | 78.35 |

***Table 5: Recovery of rougher cells***

| Run No. | Copper concenteration in feed | Copper concenteration in exit | Copper concenteration in concentrate | Recovery% |
|---|---|---|---|---|
| 1 | 0.73 | 0.06 | 12.34 | 92.22 |
| 2 | 0.66 | 0.04 | 15.20 | 94.19 |
| 3 | 1.2 | 0.16 | 2.12 | 93.74 |

***Table 6: The effect of feed rate on the recovery (column in plase of the rougher and the re cleaner cells)***

| Run No. | Feed rate Qf lit/min | Feed velocity Jf cm/s | Slurry concenteration % | Copper concenteration in feed % | Copper concenteration in exit % | Copper concenteration in concentrate % | Recovery% |
|---|---|---|---|---|---|---|---|
| 1 | 10 | 0.53 | 4.50 | 11.62 | 21.52 | 4.05 | 80.25 |
| 2 | 15 | 0.80 | 4.25 | 11.42 | 26.83 | 3.70 | 78.41 |
| 3 | 20 | 1.06 | 3.70 | 11.53 | 27.89 | 4.60 | 71.98 |

***Table 7: The overall comparison of the cells and combination of cells and column (PFD of Fig. 4)***

| | Copper concenteration in feed | Copper concenteration in exit | Copper concenteration in concentrate | Recovery% |
|---|---|---|---|---|
| Fig.4 | 0.73 | 21.52 | 0.17 | 77.32 |
| cells | 0.73 | 29.18 | 0.17 | 77.16 |
| Fig.4 | 0.67 | 25.40 | 0.14 | 79.54 |
| cells | 0.66 | 31.21 | 0.12 | 82.13 |
| Fig.4 | 0.70 | 28.26 | 0.15 | 80.57 |
| cells | 0.71 | 29.17 | 0.16 | 77.89 |

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