Grinding Circuit at Mouteh Gold Mine

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ABSTRACT

This study was conducted in Mouteh grinding circuit. Mouteh gold processing plant is located in Esfahan province,center of Iran, close to Mouteh open pit mine. One of the main problems in this circuit is low efficiency grinding operation. In this study, first grinding circuit and its performance parameters are evaluated. Laboratory and corrected operating Bond work index subsequently were calculated to be 16.8 and 21.47 (kwh/t), respectively. Bond efficiency factor then estimated to be 78.24%. Low value of this index means that the grinding operation is inefficient. Finally, efficiency of hydrocyclones evaluated and its cut size was calculated to be 85 microns.

1. INTRODUCTION

Optimization studies of grinding circuits have been focused in many researches in recent years. Optimization is continuous activity that treated as an exercise of limited scope aims to take the operating performance from the current level to another improved level. This can be done by direct experimentation and action on the plant, or as an off-line simulation exercise followed by implementation of the results of the simulation, or some of the two [1]. Comminution circuits in any ore processing plant are very important because of their high energy utilization. Therefore the main concern of any processing engineer is to optimize the comminution circuits and minimize their energy utilization. A new technique was developed recently based on a mill filling measurement system in grinding control and optimization operation[2]. Makokha studied the effect of liner/lifter profiles on kinetics of batch grinding and milling capacity and optimize rate of reduction and capacity in ball milling[3]. Svedensten and Evertsson optimize the crushing operation and increase its performance by means of structural modeling of crushing plants by utilizing mathematical models that a genetic evolutionary algorithm has been included in software[4]. Kwade carried out a few tests on grinding circuit and determined its parameters and developed a physical grinding model and its use in optimization of ball milling process[5]. Morrell developed an alternative energy-size relationship to that proposed by Bond for the design and optimization of grinding circuits. This new relationship, which does not rely on the need for correction factors, was used to predict the specific energy requirements of a number of autogenous, semi-autogenous and ball mill grinding circuits[6]. Schnatz carried out a huge test program on a semi-industrial ball mill which operates in a closed circuit. He evaluated performance of a ball mill circuit by varying the L/D ratio, ball charge filling ratio, ball size and residence time and determined their optimum value[7]. Kawatra etal used mathematical model to study methods for optimizing product size distribution of grinding circuit, so that the amount of excessively fine materials produced can be minimized[8]. Gupta developed "enumeration" method and it's utilization in optimization of grinding circuits [9]. Loveday and Dong simulated autogenous primary, so that the secondary grinding circuits and secondary grinding circuit efficiency was improved [10]. Fernandes and Peres used process simulation by computer mathematical modeling, with the objective of implementing an optimized grinding. Classification circuit and the ball mill and hydrocyclones models were after calibrated in [11].

By changing in ore properties, power draw of grinding circuit can be changed. Knowing the fact that inexact circuit control and circuit production quality can increases energy utilized by the plant, an optimization study is necessary to improve plant performance[12].

A successful process optimization exercise requires two elements:

1. A knowledge of the unit process involved, in the form

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of theory, experience, models (via simulator), or some combination.

2. A methodology within which to apply this knowledge to achieve the object of the optimization.

The first step of optimization is selecting suitable criteria. They are usually based on operational experiences such as "maximizing the throughput at constant product quality" or "minimizing energy utilization at constant throughput"[1]. Grinding circuit performance is related to breakage system efficiency as well as classification system efficiency. In other words, greater compatibility between grinding and classification product size, indicate greater grinding circuit performance. Figure 1 illustrates relationship between design and operating variables to the overall efficiency of grinding circuit[13].

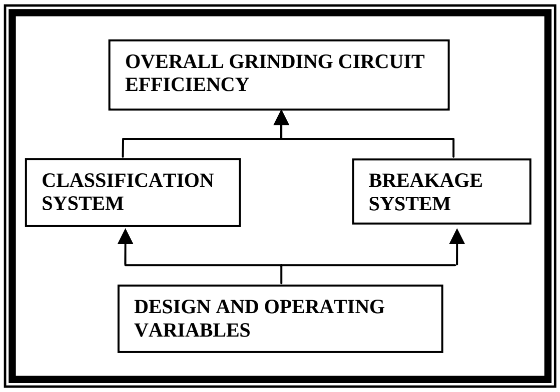

Figure 1. Design and operating variables relate to overall grinding circuit efficiency[13].

The second step is full campaign survey of circuit which includes collecting data and samples from the circuit over a particular operating period, which is representative of the circuit operation during that period. This survey would determine the problems of the circuit.

The third step is evaluating the problems by means of simulation and modeling methods, and then testing a few solutions, attained by simulation, on the circuit and comparing results of simulation and direct experimentations [1].

Mouteh gold processing plant is located in Esfahan province and a ball mill is in its grinding circuit. The main problem is high energy utilization in the ball mill. An optimization study therefore has been carried out in this circuit. To determine grinding circuit performance, Bond efficiency factor was selected. The survey results were then analyzed and the bugs of the circuit were determined.

2. ENERGY MINIMIZATION

The optimization criterion is determined exactly; for example minimizing energy utilization when the rate of production and quality is constant. The common objective in this kind of optimization is to match product sizing criteria, as accurately as possible, to comminution equipment capability. This can be done by calibrating any of the equipment in the circuit and increasing their efficiency as much as possible.

The most common criteria used to determine grinding efficiency is the Bond efficiency factors [1, 12]. This factor can be calculated by Eq. (1). The advantage of this factor is that it uses only two size distributions (feed and product) to estimate the equipment power draw.

$$E = \frac{W_i}{W_{iopc}} \qquad (1)$$

where E, W_i and W_{iopc} denote Bond efficiency factor (%), Laboratory Bond index (kwh/t), and corrected operating Bond index (kwh/t) respectively.

Bond efficiency factor values of more than 100% means that the mill consumes less than the laboratory Bond tests estimate and therefore the throughput can be increased. However values of less than 100% mean that the operation is inefficient and the energy is wasted by grinding operation[1, 13, 14].

To calculate the Bond efficiency factor, to the laboratory Bond index of ore should be determined by Bond standard test and the corrected operating Bond index should be then determined by data collected from survey and mill feed and product size distribution analyses.

Various literatures have explained the exact procedure of Bond standard test but in spite of widespread use for over 70 years, there is often great confusion about how to conduct Bond tests accurately and precisely. Mosher and Tague conducted test sensitivity analyze and stated equations indicating that the calculation is mathematically most sensitive to grams per revolution (G_{pr}), less sensitive to feed and product size distribution (F_{80} and P_{80}), and least sensitive to the closing size (P_i) of the test. They also pointed out that for Bond testing, test closure should include a maximum deviation from the highest and lowest G_{pr} (suggested value of 3%) and a reversal in the rate of mill production during last three cycles (failure to reverse indicates instability). The final criterion is a minimum number of cycles (with the suggested number of seven)[15].

In some instances it was found that the work index for the fine limiting sizes (such as 53 μm) was abnormally high. Tüzün developed wet Bond mill test procedure to solve this problem. Wet grinding requires less power than dry grinding for equivalent operations in the Bond mill. In order to calculate the standard Bond index, the Bond index obtained from the wet procedure must be multiplied by the efficiency factor of 1.3 established by Bond (1961), who stated that dry grinding requires 1.3 times as much power as wet grinding[16].

Operating Bond index can be calculated by equation (2).

$$W_{iop} = \frac{W}{Q\left(\frac{10}{\sqrt{P_{80}}} - \frac{10}{\sqrt{F_{80}}}\right)} \qquad (2)$$

Where operating work index (kwh/t) is W_{iop}, mill power draw (kw) is W, Q is mill throughput (t/h) and P_{80}, F_{80} are respectively mill product and feed size distributions. Operating Bond index is not comparable to laboratory standard Bond index; therefore a few correction factors should be multiplied to obtain of corrected operating Bond index[13, 17].

These factors are:

- Correction factor of dry grinding method that is 1.3.
- Correction factor of open circuit grinding obtained from Table 1.
- Overflow, 350% circulating load and 2.44m diameter mill correction factor that is calculated from Eq. (3).
- Correction of particles greater than optimum size of feed (which is calculated from Eq. (4)) obtained by Eq. (5).
- Correction of fine particles in mill product and is implied when product size is less than 75 microns. This factor can be calculated by Eq. (6).
- Correction factor that is used for rod milling operations.
- Correction for operation with a rate of reduction less than 6 and can be calculated by Eq. (7).

By implying operating work index in correction factors, corrected operating work index W_{iopc} was calculated.

$$EF_1 = \begin{cases} \left(\frac{D}{2.44}\right)^{0.2} & D < 3.81 \text{ m} \\ 0.914 & D > 3.81 \end{cases} \qquad (3)$$

$$F_{optimum} = 4000\sqrt{\frac{13}{W_i}} \qquad (4)$$

$$EF_5 = \frac{P + 10.3}{1.145\, P} \qquad (5)$$

$$EF_6 = \frac{R_r + (W_i - 7)\left(\frac{F - F_{optimum}}{F_{optimum}}\right)}{R_r} \qquad (6)$$

$$EF_7 = \frac{2(R_r - 1.35) + 0.26}{2(R_r - 1.35)} \qquad (7)$$

TABLE1. OPEN CIRCUIT INEFFICIENCY MULTIPLIERS [13]

Product size control reference 80% passing	Correction factor (inefficiency multiplier)
50	1.035
60	1.05
70	1.10
80	1.20
90	1.40
92	1.46
95	1.57
98	1.7

where $R_r = \frac{F}{P}$ and F, P are respectively mill product and feed size distribution[13, 17].

3. INEFFICIENT OPERATION OF BALL MILL

Efficiency of a closed grinding circuit is related to two parameters: breakage efficiency and classification efficiency. In other words, ore should be ground to a desired size and removed from the circuit. So the overall efficiency of a grinding circuit equals to breakage efficiency multiplied by the classification efficiency [12].

Generally two types of mill inefficiency can be defined. The first type is called *indirect* inefficiency. In this type, ore is charged into the mill and excessive fine is produced. This is because of hydrocyclone operates inefficiently and can not remove fine materials from the grinding circuit. The second type, which is called *direct* inefficiency, occurs when the mill condition causes poor breakage actions. Examples are: (1) underfilling of the mill by powder, so that the energy of tumbling balls is used in steel-to-steel contact without causing particle breakage, (2) overfiling of the mill, so that the ball-powder-ball action is cushioned by excessive powder, and (3) too high slurry density in wet grinding, which gives a thick slurry that can absorb impact without giving breakage. I short to determine which type of inefficiency occurs in grinding mill, all conditions of grinding circuit ought to be determined in a full campaign survey[17, 23].

4. RESULTS AND DISCUSSIONS

Grinding circuit of Mouteh processing plant has a 3×3 (L×D) ball mill and six hydrocyclones by 15 cm diameter. In the design study balls diameter were selected 80 mm and feed size was 1 cm (80% passing size) that must be ground to 63 μm. Also, in the design study the bond work index of ore was calculated approximately 16.6 (kwh/t), with a standard Bond test with 5 cycles. The crushed ores ($d_{80} = 1 cm$)

were charged to mill with rate of 25 tph, so the mill power draw was 594 kw and motor of mill was 600 kw power. The condition of Mouteh grinding circuit at the time of survey was determined by the data collected from the survey of circuit. Figure 2 depicts this condition.

Density of discharging pulp of mill is approximately equal to pulp density in the mill. Most of ball mills operate by pulp density of 60-80% w/w and in Mouteh grinding circuit design study this value was selected about 72% w/w [1, 14, 20, 23]. However analyzing samples were collected in two month survey raises two problems. First, the pulp density of ball mill has more flocculation which might be the result of hand control of added water to grinding circuit and that the pulp control equipment (Marcy scale) is not calibrated. Second, pulp densities of mill discharge and hydrocyclone overflow and underflow were determined to be 73.26, 36.5 and 69.4% w/w, respectively. While in the design study these values were selected 72, 42 and 68% w/w.

Based on design studies added water to mill feed and discharge ought to be respectively 3.3 and 31.25 (m^3/h). But, survey analysis shows this value in mill feed was not changed and in mill discharge was decreased (Table 3 & Figure 2) and caused density of hydrocyclone feed pulp to be reduced to less than 60 %w/w (optimum value).

Furthermore cut size of hydrocyclone should be 69.24 μm (based on design studies) though sampling analysis showed that two values were 85 μm that is coarse.

Mill feed size and product size should be respectively 1 cm and 63 μm (80% passing), however sampling showed these are about 2cm and 200 μm respectively. Lead tests were done to determine closed side setting (CSS) of tertiary crusher. This value should be 10mm through lead tests it becomes 12.5mm. Wearing rate of balls should be 0.4 (kg / ton ore) but sampling analyses determined it to be 2.1 (kg / ton ore) which is very high.

In order to calculate the laboratory work index (W_i), 30 Bond standard ball mill tests were done on samples (Table4) and W_i was determined to be 16.8 (kwh / t). Also, the operating work index (W_{iop}) was calculated by data given in table 3 collected in sampling (15 days) as given below:

$$W_{iop} = \frac{W}{Q \times \left(\frac{10}{\sqrt{P}} - \frac{10}{\sqrt{F}} \right)}$$

$$W_{iop} = \frac{564}{25.83 \times \left(\frac{10}{\sqrt{200}} - \frac{10}{\sqrt{19900}} \right)} = 34.31 \ \text{kWh/t}$$

⇒

By multiplying inefficiency factors to the operating work index, corrected operating work index was calculated to be $W_{iopc} = 21.47 \ (kwh/st)$.

TABLE2 : PULP DENSITY OF GRINDING CIRCUIT

Density of hydrocyclones underflow (w/w %)	Density of hydrocyclones overflow (w/w %)	Density of mill discharge (w/w %)
69.4	36.5	70.3

TABLE3 : DATA WERE COLLECTED FROM MOUTEH GRINDING CIRCUIT IN FULL CAMPAIGN SURVEY

Date	Mill throughput (t/h)	Mill power (kwh)	Added water to mill feed (m^3/h)	Added water to mill discharge (m^3/h)
1	26.46	562.5	4.92	5.37
2	26.82	564.5	5.16	5.13
3	25.95	567.5	4.8	5.56
4	23.05	567	3	7.46
5	26.78	568.2	3.54	5.61
6	24.04	569	2.13	3.8
7	25.23	566.5	3	4.33
8	22.95	573.8	3.13	5.95
9	26.12	572.7	2.3	5.76
10	25.96	568.6	2	4.06
11	26.43	565.5	2.95	6.74
12	27.89	565	3.92	5.24
13	27	514.5	2.92	9.08
14	28.5	566.3	2.7	9.7
15	25.8	563.8	3.96	6.05
Avg	**25.83**	**564**	**3.3**	**5.98**

TABLE 4

WORK INDEX WERE CALCULATED FROM STANDARD BOND TESTS ON 30 SAMPLES

Date	1	2	3	4	5	6	7	8	9	10
Work index (kwh/t)	16.8	16.96	17.01	16.61	16.83	16.91	16.87	16.93	16.16	16.34
Date	11	12	13	14	15	16	17	18	19	20
Work index (kwh/t)	15.8	17.17	17.24	16.93	16.58	16.06	17.04	16.76	16.8	16.63
Date	21	22	23	24	25	26	27	28	29	30
Work index (kwh/t)	17.07	16.58	17.08	16.82	16.72	17.02	17.2	17.05	17.3	16.81

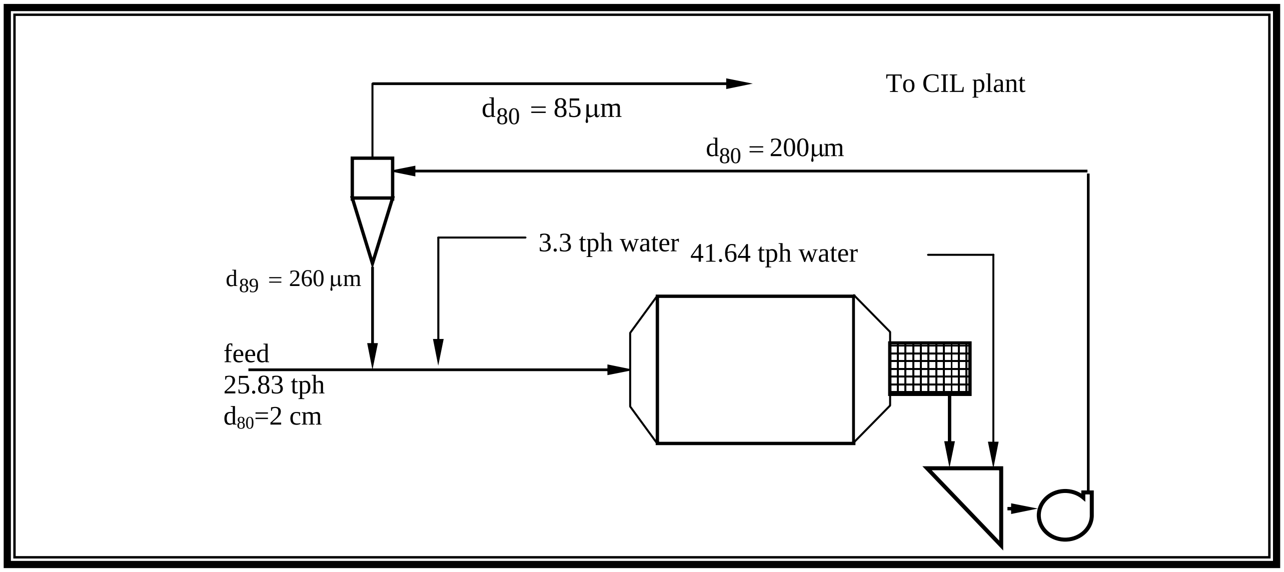

Figure 2. Grinding circuit of Mouteh

Finally, the Bond efficiency factor of Mouteh grinding circuit was obtained to be 78.24%.

$$E=\frac{W_i}{W_{iopc}}=\frac{16.8}{21.47}\times 100=78.24\ \%$$

These results show that Mouteh grinding circuit has very low efficiency.

5. CONCLUSION

This paper studied the optimization of Mouteh gold mine grinding circuit and the following conclusions have been achieved:

- The Bond work index obtained was similar to that obtained at the plant design studies, 16.6 (kwh/t) and 16.8 (kwh/t), respectively.
- Pulp density in the mill and in hydrocyclone overflow was obtained to be 70.3 and 36.5 %w/w respectively that was less than the optimum values in design (72 and 42 %w/w). Pulp density of underflow was determined to be 68.4 %w/w though in the design study, it was selected 69.4 %w/w. Therefore, the change in this parameter was not significant.
- Added water to mill discharge is less than the optimum value that causes pulp density of hydrocyclone feed to be less than 60 %w/w. This can decrease classification efficiency.
- Optimum value of hydrocyclone cut size was selected 69.4 μm in design studies. But, sampling analysis indicated a hydrocyclone cut size of 85 μm that is greater than liberation degree of gold particles and caused the CIL recovery decreased.
- Sampling analysis revealed that mill feed and product size is very coarse.
- Wearing rate of balls in Mouteh mill was $2.1(\mathrm{kg/ton\ ore})$ that was very high compared to the design optimum value ($0.4\ \mathrm{kg/ton\ ore}$).
- Also, the Bond efficiency factor was obtained 78.24%. Low value of this index means that the grinding operation is inefficient.
- Althought the value of closed side setting (CSS) of tertiary crusher was selected in the design study about

10mm, lead tests determined this parameter to be $12.5\,\mathrm{mm}$. This indicates a significant increase in CSS.

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