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Eti Copper Siirt flotation plant revision studies

Yaşar Kara, Ali Tatar ,Ahmet Hasyamanlar

Eti Bakır A.Ş.

Corresponding author: ahmet.hasyamanlar@etibakir.com.tr (Ahmet Hasyamanlar)

Abstract: Several optimization studies were made to increase metal recovery and reduce operational costs of the concentrator in Siirt Madenköy copper mine. In consequence of these studies, effects of the changes in operating parameters, cost and plant recovery will be examined at this article. In this article, we will discuss two important revision studies, which are (i) replacement of 500 mm hydrocyclone set used in ball mills with 350 mm of hydrocyclone set, (ii) replacing the present Ball Mill with a SAG mill. Correspondingly elimination of the crushing and screening plant, (iii) increasing the scavenger cells from 4 to 6 by the addition of 2 more cells. In consequence with this feeding the middling tail to the increased scavenger cells which was treated as a part of final tail before this change. We will examine the effect of all these changes to the final recovery, concentrate grade and final cost.

Keywords: flotation, hydrocyclone, scavenger, SAG Mill, recovery, ball mill

1. Introduction

Striving for improvement every day is our most important task in mineral processing plants. In this article, we will discuss the increased recovery and cost savings achieved in the plant. The importance of liberation minerals is significant in flotation plants. Our R&D studies have concluded that reducing the particle size of the ground ore to 40 microns will result in an increase in recovery and concentrate. Moreover, instead of the existing 4-battery 500 mm hydrocyclone set, a new 8-battery 350 mm hydrocyclone set has been put into operation. Additionally, the selection of the most appropriate size of apex and vortex has been made. The changes made have had a positive impact on both concentrate grade and recovery. Our other revision work, the commissioning of the SAG mill, has provided cost savings and operational ease. The crushing-screening unit and the ball mill with primary grinding function, which we used to use before, have been deactivated and replaced with a SAG mill. It has been observed that comparing the energy, ball, rubber, and crushing-screening unit costs of these changes, the activation of the SAG mill has resulted in significant cost savings. Furthermore, by deactivating the crushing-screening unit, all bottlenecks in that area have been eliminated, resulting in operational convenience.

1.1. Eti Bakır Siirt Madenköy Flotation Plant

It is an enrichment plant in a copper mine operated by Eti Bakır A.Ş. in Madenköy, Şirvan, Siirt. The copper concentrate is produced by the beneficiation of the copper ore that is mined from the underground operation. The copper concentrate produced is transported to the Eti Bakır Samsun Copper Smelter via haul and railway.

In Madenköy Plant, flotation is applied as an enrichment method. After liberation of associated minerals, copper ores are floated by froth flotation. Then, the copper concentrate is obtained selectively.

The flotation process has a typical flowsheet which include rougher flotation, rougher scavenger, middling, regrinding and 3 stage cleaner flotation. The stages are as shown in the Fig. 3 – Flotation Flowchart.

2. Recent improvements in processing plant

The revision work we have carried out in the hydrocyclone set and flotation cells will be discussed under the following headings.

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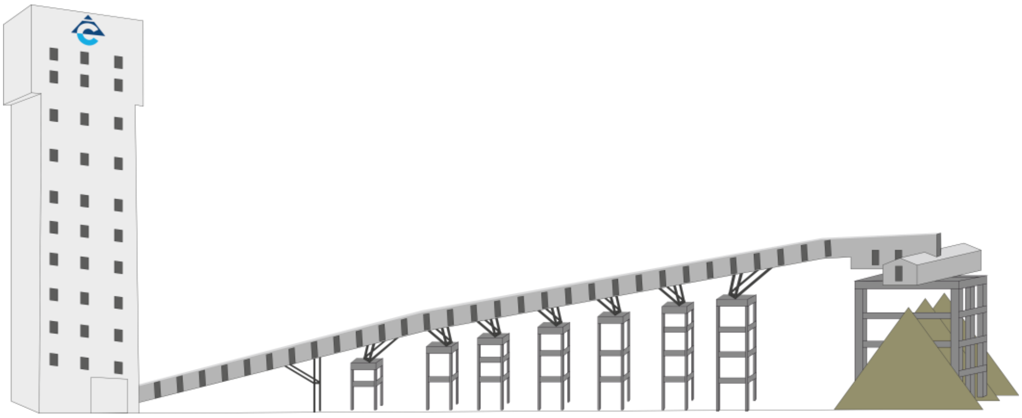

Fig. 1. Shaft and Apron feeders

As shown in the Fig. 1, run-of-mine ore produced as underground method is transported stock hole by shaft carriage system. The feed material is stocked on three different apron feeders by taking the mineralogical characteristics of the ore and its copper grade into consideration. The stocked ore is fed to the SAG mill through belt conveyors after blending in the required proportions through 3 aprons.

The SAG mill operates in closed cycle with hydrocyclone. After SAG mill, ground ore is subjected to a secondary grinding circuit by a ball mill-hydrocyclone closed circuit. After arranging the optimum particle size by hydrocyclone overflow, the pulp is fed to the cells at the desired solid ratio.

As a final product, the copper concentrate is dewatered by thickener and filtration (press filter) with 7-8% moisture. Then, It is stocked to be transported to the Eti Bakır Smelter in Samsun.

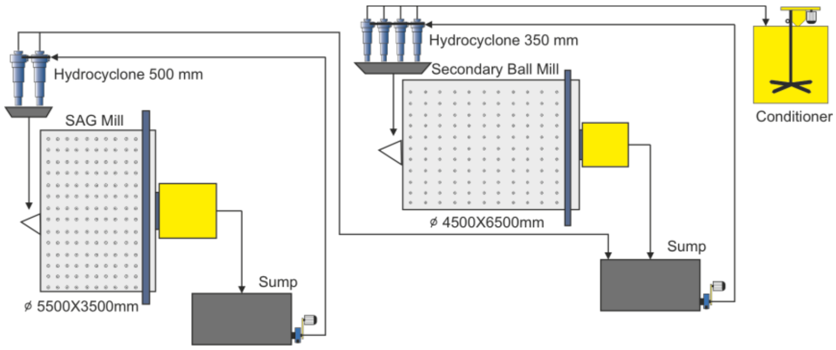

Fig. 2. SAG mill and Secondary Mill flow diagram

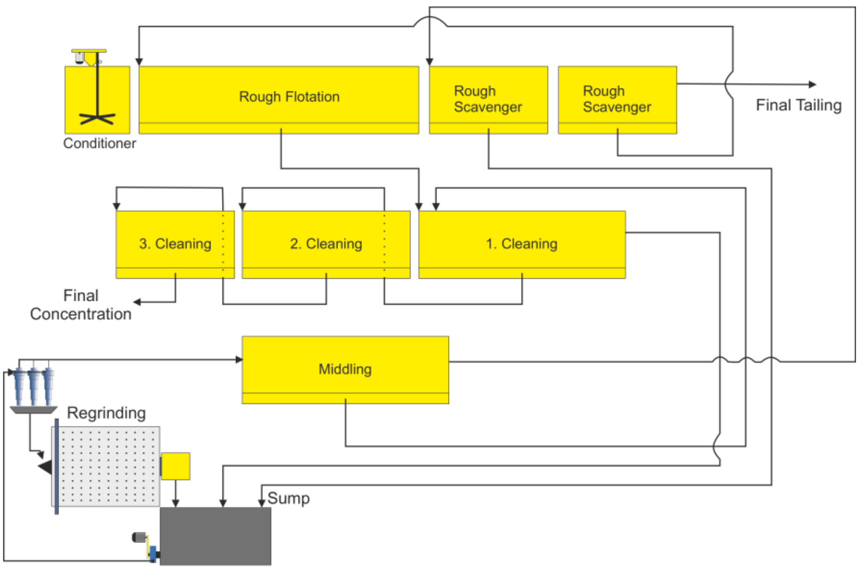

Fig. 3. Flotation Flowchart

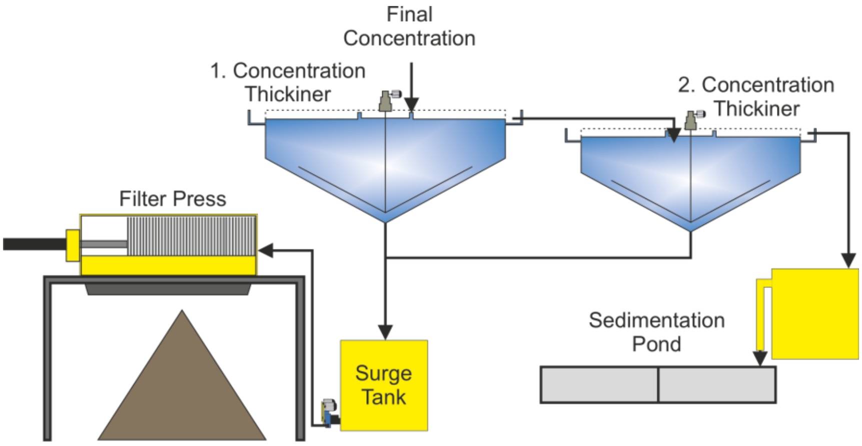

Fig. 4. Dewatering unit

2.1. Replacement of 500 mm hydrocyclone set used in ball mills with 350 mm

It has been determined in the research of Eti Bakır R&D department that in case the d_{80} size of the pulp supplied to the cellulose from the top of the cyclone in the existing 500 cyclones of ball mills is reduced to 40 µm while it is around 75 µm, significant increases will be achieved both in concentrate grade and recovery (Canbazoğlu and Özdemir, 2019; Göktaş, 2019).

Within this frame, decision was to replace the existing 500 mm 4 battery cyclone with 350 mm 8 battery cyclone. The 350 mm hydrocyclone cluster of Krebs gMAX is proposed to achieve the targeted cutting size of 40 µm was provided.

Optimum cyclone performance relies on minimizing turbulence while maximizing tangential velocity. The gMAX cyclone focuses on these two important factors, significantly advancing cyclone performance.To achieve these two design criteria, the gMAX incorporates performance-enhancing improvements to the inlet head, cylinder section, cones, and apex. In fact, the performance level reached by the gMAX was once only achievable using many small-diameter cyclones, at a much higher capital cost (Krebs gMAX brochures, 2019).

Those cyclones have been assembled in the grinding cycle to operate in a closed cycle with the secondary ball mill.

Not only the various apex & vortex diameters but also number of cyclones in operation were tested to select the most suitable conditions.

2.1.1. Result

The tests have been performed with the different size apex and vortex supplied, and the results have been compiled. The aim was achieving 40 µm of the cyclone cut-off size or at least as close as possible to 40 µm, and another criterion which is at least as important as is not creating an unstable operating environment which will disrupt the system, such as any overflow etc., by creating a stable working environment in the mill and cyclone. For this, the load from the cycle operating in a closed cycle with the cyclone should be neither too high nor too low. When the circulating load on the cycle is too low, the yield of the cyclone will decrease, and the grinding will be insufficient. In case the circulating load is high, there will be overflows in the cyclone sump and the secondary mill. In such cycles, the desired ideal circulating load should be between 180-250%. We can include pulp concentrations, specific gravity of the ore, and cyclone pressure as the most important factors affecting those criteria.

By considering these two criteria, working with 3″ apex, 4.75″ vortex, and operating with 4 cyclone batteries have provided the most appropriate results. A stable working environment has been achieved on site with 44-47 µm d_{80}, which are the closest values for the targeted 40 µm d_{80} size.

The feed supply for the primary mill has been considered as 150 tph in all those works. In case the capacity is 130 tph instead of 150 tph, it is obvious that the cyclone cutting size will decrease a little more. The reason for desiring to reduce the cyclone cutting size is to increase the concentration grade and yield as a result of decrease in particle size and increased liberation.

Table 1. Some apex and vortex studies in different sizes and numbers

Apex-Vortex	inch	3.25-5.25	3.25-5.25	3.25-5.25	3.25-5.00	3.25-4.75
Cyclon	count	5	3	4	4	4
Cyclon Pressure	bar	0.5	1.0-1.2	0.4-0.5	0.7-0.9	0.8-0.9
Density						
Primary Mill	g/dm³	2020	2100	2000	2010	2050
Secondary Mill		2330	2650	2300	2480	2320
Sump		1710	1710	1710	1720	1720
Overflow		1370	1360	1360	1400	1360
Underflow		2340	2280	2280	2500	2400
Sieve Analysis d_{80}						
Primary Mill	µm	203.06	192.06	207.43	361.22	320.95
Secondary Mill		102.82	95.74	97.52	128.36	120.74
Sump		104.23	98.35	106.89	98.92	131.82
Overflow		58.50	49.23	48.50	48.44	47.05
Underflow		147.39	104.31	149.60	170.71	120.74
Bypass	%	40.23	34.37	45.95	29.74	38.04
Circulating Load	%	195	200	218	154	206
Cyclone Efficiency						
d25	µm	29.29	28.12	26.31	32.63	27.89
d50		46.90	43.08	38.30	46.46	37.53
d75		79.22	58.82	72.34	84.35	61.34
(I)Imperfection Parameters		0.53	0.36	0.60	0.56	0.45
(Ep) Ecart Probable		0.025	0.015	0.023	0.026	0.017

(Wills and Finch, 2016) (Doroodchi et al., 2006)

2.2. Commission of two additional cell in the rougher scavenger stage

The rougher+scavanger flotation stage originally consisted 8+4=12 tank cells which are 20 m³. The average retention time of rougher+scavanger flotation is 44 minutes at 150 tph capacity. To increase the overall Cu recovery, 2 more 20 m³ cells were added to scavenger unit. The average retention time in rougher + scavenger flotation stage increased to 52 minutes. After addition of 2 more cell to rougher scavenger there had been more room at scavenger cell so that middling tail could also be accommodated. Considerable increase had been gained in recovery with the addition of two extra cell to scavenger and also feeding the middling tail to scavenger unit.
Middling tail copper content is normally twice as much as final tail.

3. Commissioning the sag mill

Before the SAG mill commission, the feed was being crushed, screened to 15 mm and blended to get the desired grade. Grinding was done by primary & secondary ball mills in series. It was decided to purchase a SAG mill instead of existing primary ball mill (Ø 3600x5240 mm) to increase production capacity and cost saving. Another aim was to eliminate the crushing operation which will simplify the operation in addition to saving cost. With the commisioning of SABC(SAG mill-Ball mill closed circuit), crushers, screens and the primary ball mill have been deactivated. The capacity of previous grinding circuit (two stage ball milling) was 130 tph. Then SABC circuit have increased this capacity to 150 tph. In this work, the following issues are taken into consideration for SAG mill instead of crushing and screening and primary ball mill:

- comparing the energy consumptions
- comparing the ball consumptions

- comparing the rubber consumptions
- Spare part cost comparison of old crusher unit and new apron feeders unit

3.1. Comparing the energy consumptions

As seen in the table, 350 kW is saved as instant consumption and 231.000 kW is saved as monthly consumption in the system before and after including the SAG mill.

While 21.15 kW is consumed per ton in the old primary-secondary ball mill model including crushing stage, 16 kW of energy is consumed per ton in the secondary mill version including the new SAG mill.

Table 2. Comparison of the Energy Consumptions

	Energy Consumption Before SAG Mill			Energy Consumption After SAG Mill		
	Instant Consumption (kW)	Monthly Consumption (kW)	Monthly Consumption ($)	Instant Consumption (kW)	Monthly Consumption (kW)	Monthly Consumption ($)
Crushing Unit	700	462 000	$ 110 880	100	66 000	$ 15 840
Primary Mill	850	561 000	$ 134 640	0	0	$ -
Secondary Mill	1 200	792 000	$ 190 080	1 200	792 000	$ 190 080
SAG Mill	0	0	$ -	1 100	726 000	$ 174 240
Total	2 750	1 815 000	$ 435 600	2 400	1 584 000	$ 380 160

Table 3. Comparison of the Energy Consumptions

Comparing the Energy Consumptions					
	Instant Consumption (kW)	Monthly Consumption (kW)	Monthly Consumption ($)	Consumption Per Ton (kW/t)	Cost Per Ton ($/t)
Primary-Secondary Mills Crushing unit	2 750	1 815 000	$ 435 600	21.15	$ 5.08
*SAG Mill *Remas 2 *Aprons	2 400	1 584 000	$ 380 160	16.00	$ 3.84
Difference	350	231.000	$ 55 440	5.15	$ 1.24

3.2. Comparing the ball consumptions

Table 4. Comparison of the Ball Consumptions

Comparing the Ball Consumptions					
	Ball Consumption			Cost ($/Month)	Cost Per Ton ($/t)
	Barrel/Month	Kg/Month	Consumption Per Ton (g/t)		
Remas 1 (Primary)	40	36 000	420	$ 50 400	$ 0.59
Remas 2 (Secondary)	80	72 000	839	$ 100 800	$ 1.17
Total	120	108 000	1 259	$ 151 200	$ 1.76
	Ball Consumption			Cost ($/Month)	Cost Per Ton ($/t)
	Barrel/Month	Kg/Month	Consumption Per Ton (g/t)		
SAG Mill	80	72 000	727	$ 100 800	$ 1.02
Remas 2 (Secondary)	94	84 600	855	$ 118 440	$ 1.20
Total	174	156 600	1 582	$ 219 240	$ 2.21
Difference	-54	-48 600	-323	$ 68 040	$ -0.45

As seen in the table, while the monthly total ball consumption of the old primary and secondary mill model is 120 barrels, the monthly ball consumption of the new SAG mill and secondary mill model is 174 barrels. More than 54 barrels of balls have been consumed monthly in the system including the new SAG mill. While 1259 g/t ball is consumed per ton in the old model with primary and secondary mills, 1582 g/t ball is consumed per ton in the new SAG mill and secondary mill model.

When two models are compared, it is concluded that 323 g/t more ball per ton have been consumed in the new system SAG mill than the old system Ball Mill.

3.3. Comparing the rubber consumptions

While total 1615 kg of rubber has been consumed monthly in the old primary and secondary ball mill model, 3233 kg of rubber has been consumed in the new SAG mill and secondary ball mill model.

While the old primary and secondary mill model consumes 18.8 g of rubber per ton, the new SAG mill and secondary mill model consumes 32.7 g of rubber. Finally, 13.8 g/t more rubber has been consumed in the Sag Mill model as compared to the consumption of the old primary ball mill model.

Table 5. Comparison of the Rubber Consumptions

Comparing the Rubber Consumptions				
Old Primary and Secondary Ball Model Including Crushing and Screening	Monthly Rubber Lining Consumption			
	Amount (kg/month)	Consumption Per Ton (g/t)	Cost $/month	Cost Per Ton $/t
Primary Ball Mill (Remas 1)	1 101	12.83	$ 6 606	$ 0.08
Secondary Ball Mill (Remas 2)	514	5.99	$ 3 082	$ 0.04
Total	1 615	18.82	$ 9 688	$ 0.11
Model with Sag Mill and Secondary Ball	Monthly Rubber Lining Consumption			
	Amount (kg/month)	Consumption Per Ton (g/t)	Cost $/month	Cost Per Ton $/t
SAG Mill Semi-autogenous	2 915	29.44	$ 17 488	$ 0.18
Secondary Ball Mill (Remas 2)	319	3.22	$ 1 912	$ 0.02
Total	3 233	32.66	$ 19 400	$ 0.20
	Monthly Rubber Lining Consumption			
	Amount (kg/month)	Consumption Per Ton (g/t)	Cost $/month	Cost Per Ton $/t
Difference	-1 619	- 13.8	$ - 9 712	$ - 0.08

3.4. Spare part cost comparison of old crusher unit and new apron feeders

When commissioning the SAG mill and deactivating the Crushing-Screening and Primary Ball mill in terms of cost:

- $1.24 savings per ton in energy consumption has been gained.
- $0.08 extra cost per ton in rubber consumption
- $0.45 extra cost per ton in ball consumption
- Compared to the old Crushing-Screening unit and the new Apron unit, the spare parts, labor, fuel, oil, and overhead costs have resulted in $0.29 savings per ton.

Overall, commissioning the SAG mill resulted in a savings of $0.99 per ton.

Table 6. Cost comparison of spare parts, fuel, labor, general expenses of old Crusher unit and new apron feeders

	Annual Costs	Monthly Costs	Cost Per Ton $/t
CRUSHING UNIT			
Labor Cost	$ 117 660	$ 9 805	$ 0.114
Electrical equipment	$ 10 540	$ 878	$ 0.010
Lubricant	$ 9 592	$ 799	$ 0.009
Spare part, general expenses and fuel	$ 452 767	$ 37 730	$ 0.440
TOTAL	$ 590 560	$ 49 213	$ 0.574
APRON UNIT			
Labor Cost	$ 92 400	$ 7 700	$ 0.078
Electrical equipment	$ 1 200	$ 100	$ 0.001
Lubricant	$ 560	$ 46	$ 0.000
Spare part, general expenses and fuel	$ 244 366	$ 20 363	$ 0.206
TOTAL	$ 338 526	$ 28 210	$ 0.285
Difference	$ 252 033	$ 21 002	$ 0.289

3.5. Result

Table 7. Total Remedity

	Difference (per ton)		
	Consumptions	Unit	Cost ($/t)
Comparing the Energy Consumptions	5,15	kW/t	$ 1.24
Comparing the Rubber Consumptions	-13.84	g/t	$ -0.08
Comparing the Ball Consumptions	-323.00	g/t	$ -0.45
Spare Part Cost Comparison of Old Crusher Unit and New Apron Feeders Unit			$ 0.29
Total benefit			$ 0.99

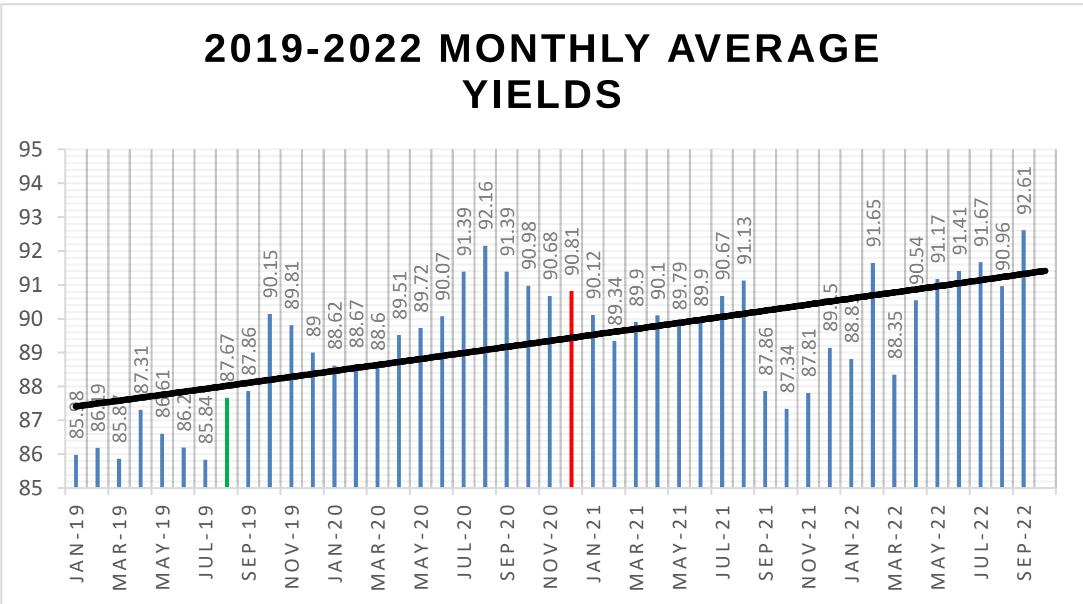

Fig. 5. 2019-2022 Monthly Yield Averages

4. Conclusion

The monthly average Cu recovery between 2019 and 2022 are presented in Fig. 5.

Green line shows the time when 350 mm cyclone group has been commissioned instead of the 500 mm cyclone group in August 2019.

Red line (December 2020) shows the time when SAG mill has been commissioned instead of the primary ball mill together with addition of two 20 m^3 cells to scavenger. The effect of those changes on the yield is shown in the diagram. Within the period between January 2019 and September 2022, the trend line is in the upward direction.

Between September 2021 and May 2022, a considerable decrease in recovery was due to processing of heavily oxidised ore.

Serious of remediation works had been going on in the last few years of the plant and the improvements that had already been gainded from these works can be summarized as below.

- Simpifying the operation by elimination of crushing plant
- Increasing the plant capacity from 130 tph to 150 tph
- Considerable increase in final recovery
- Saving in Total Plant Cost

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