Preprint 17-024

CHROMITE PLANT CAPACITY INCREASE USING EXPERIMENTAL AND MODELING TECHNIQUES

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ABSTRACT

In order to sustain the operations in chromite processing plants, due to concentrate selling cost, plants are in need of optimization in terms of capacity and recovery increase. In this study, DAMA Engineering carried out a methodological study for the purpose after a detailed sampling campaign in a plant which is situated in one the main chromite zones in Turkey;

1 The current status of the plant was investigated quantitatively with the bottlenecks, Plant overall efficiency in terms of recovery, Efficiencies of the particular equipment (mill, screen, gravity circuit),

2 A new circuit was proposed with the available equipment,

3 The new circuit that is product of modeling and experimental effort, was evaluated quantitatively as if it is a running plant, After 4-5 months continuous effort, the capacity of the plant was almost doubled (37 tph to 70 tph) and the plant overall recovery was increased from 48% to 63% by grinding adjustments and additional shaking tables theoretically. It was shown that the plant may move into profit with the minimum amount investment using readily available system.

INTRODUCTION TO THE CURRENT PLANT

The objective of the study is to increase the capacity and recovery of the chromite plant owned by Kurmel Group, Akmetal Inc. The complete study is given elsewhere (DAMA, 2016). The plant is situated in one of the main chromite zones in Turkey; Aladağ. The current capacity of the plant is around 35 tph and the overall recovery declared by plant engineer is around 47 %. The chromite plant mainly has 3 units; crushing, grinding and gravitational circuits. The crushing circuit has 3 stages; a jaw crusher, a secondary cone crusher and a tertiary cone crusher operating in closed circuit with a vibrating screen with the aperture size of 15mm. In grinding circuit, a rod mill (2.44 m x 3.6 m) and a ball mill (2.13 m x 2.3 m) are used for primary and secondary grinding, respectively. Derrick screens are used for the size separation. Additionally, for the size classification of the system, hydrosizers are used and each size fraction is sent to the shaking table sets. The middling product of the tables is subjected to re-grinding with a ball mill with the dimensions of 2.1 m x 2.9 m. The capacity and the recovery are affected by several bottle necks; hydrosizers' pure classification, primary/secondary mill power vs capacity problems, re-grinding product's high slime content and so on. These combined factors made the plant to run in low recovery and capacity. Hence, DAMA was asked to make a study to investigate current status of the plant and propose a new solution to increase capacity and recovery of the plant. The conceptual flowsheet of the circuit is given in Figure 1 below.

The summary of the industrial analyses for the capacity and performance measurements are listed as;

1. work index analysis for rod and ball mills,
2. size and capacity analysis for mills,
3. power transmitted to grinding,
4. load vs power analysis in mills,
5. grinding performance analysis in rod mills (feed, size distribution and rheology),
6. grinding performance analysis in ball mills (feed, size distribution and rheology),
7. functional performance analysis in ball mill / classification analysis (McIvor, 1988; McIvor et al. 1990),
8. efficiency analysis in screening,
9. pump capacity analysis,
10. efficiency analysis in shaking tables,
11. hydrosizer performance evaluation.

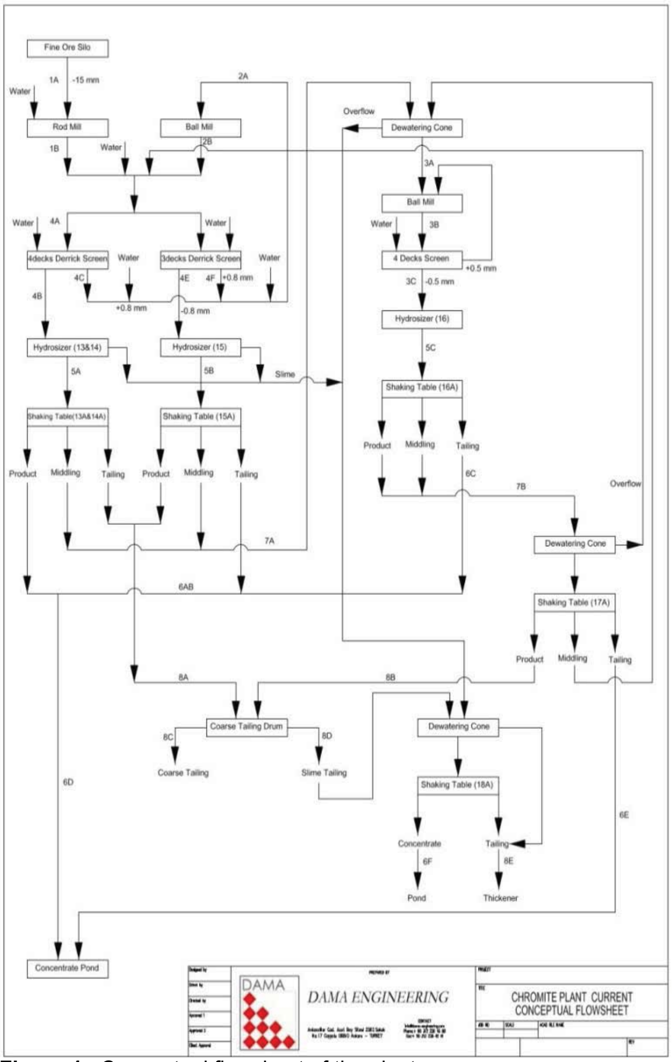

Figure 1. Conceptual flowsheet of the plant.

The optimization study schematic is given in Figure 2. Both the current plant and proposed solution are subjected to the equal basis performance evaluation.

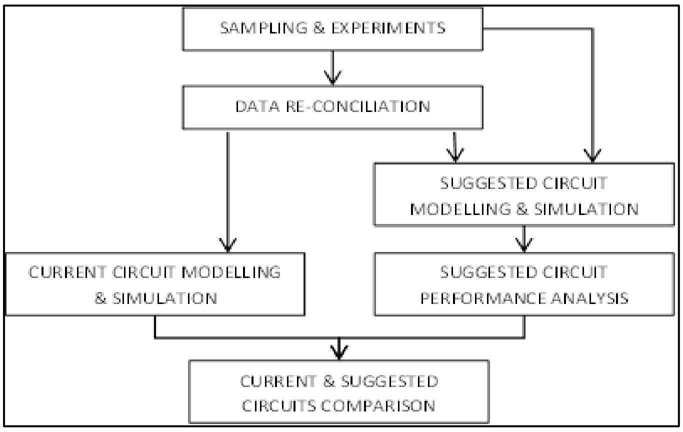

Figure 2. The optimization study schematic.

SAMPLING CAMPAIGN AND ANALYSES DONE

The sampling campaign of the plant covers 4 sets of sampling in the following shifts. Although 30 nodes had been planned for sampling, only 20 nodes were able to be made suitable for sampling. The sampling campaign was summarized in the Table 1.

Table 1. Sampling campaign summary.

	Shifts			
Type of analysis/experiment	**1**	**2**	**3**	**4**
Size Distribution	20	20	20	20
Grade (XRF & Chemical)	20	20	20	20
Density	20		20	
Flow Rate	20		20	
Bond Index	1	1	1	
Liberation	1	1	1	1

DATA RECONCILIATION

4 sets of sampling data were combined as a representative set of data. Least square methodology used in data reconciliation as described by following equations;

$$F.f - C.c - T.t = 0 \qquad \text{equation (1)}$$

F, C and T represent feed, concentrate and tailing flow rates, respectively. f, c, and t also represent feed, concentrate and tailing grades, respectively

$$F.f - C.c - T.t = \Delta \qquad \text{equation (2)}$$

Δ represents the error of the sampling.

$$\sum \Delta_i^2 = \sum (f_i - t_i)^2 + C^2 \sum (c_i - t_i)^2 - 2C \sum (f_i - t_i)(c_i - t_i) \qquad \text{equation (3)}$$

$\Sigma\Delta i2$ cannot be zero but the minimum value is obtained at the point where derivative is equal to zero. ($\frac{d \sum \Delta_i^2}{dC} = 0$)

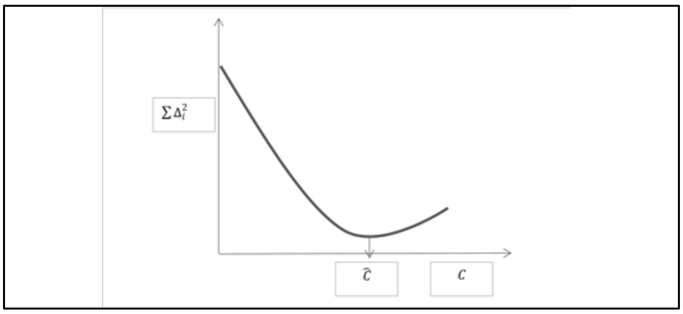

Figure 3. Least square method: The point of the minimum error in concentrate measurement (Wills, 2006).

The sampled and reconciliated data is shown in Figure 4 below. Data reconciliation was done manually using Excel together with above equations and as well as using USIMPAC process simulation software.

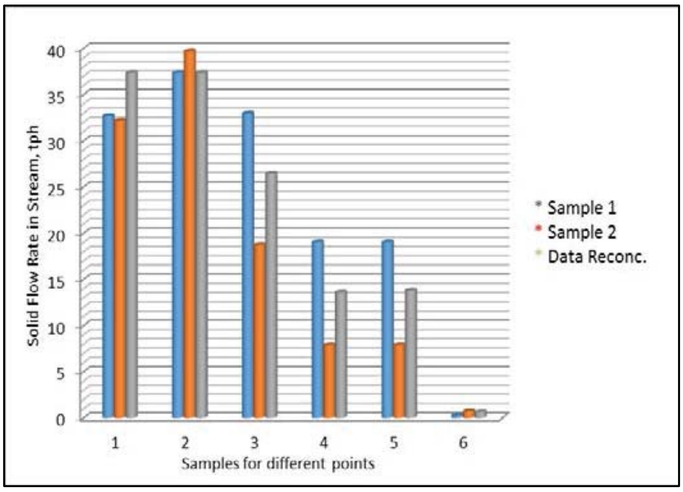

Figure 4. Sampled and reconciliated data.

DETERMINING THE CURRENT SITUATION AND PERFORMANCE ANALYSIS

The most systematic data (power, capacity, size, grinding media size etc) was collected for the mills. In other words, the representative operational data for each individual mill is available. Hence, the collected plant and experimental data provided a chance for detailed analysis on the current grinding circuit. On the other hand, the other equipment in the plant such as the hydrosizers, screens, pumps and shaking table groups were evaluated based on the mass balance data generated after reconciliation process. Also, it was not possible to take samples from each shaking table; the evaluation of the shaking tables was made in groups.

CHECKLIST FOR THE ANALYSIS

According to the collected and produced data (flow rates, size distribution, energy measurements, grade, liberation size and bond index), the analyses done during the study are listed in the table below.

Table 2. Analysis list.

Equipment	Analysis done
Mills	
Rod Mill	mill motor power efficiencies & power transferred to pinion
	mill load & power relation
	power efficiency analysis
	work index efficiency of rod mill circuit
	feed size distribution analysis of rod
	inefficiency due to the reduction ratio in rod mill
	proposed rod diameter
	pulp characteristic of rod mill
	capacity & max. available capacity of the rod mill
Ball Mills	mill motor power efficiencies & power transferred to pinion
	mill load & power relation
	power efficiency analysis
	capacity vs power analysis
	capacity vs product and particle size analysis
	ball size analysis
	ball mill rheology analysis
	feeding pulp speed & circulating load
	functional performance analysis
Screens	
800 microns Screens	screening efficiency & circulating load analysis
300 microns Screens	screening efficiency & circulating load analysis
Shaking Tables	
1. Group Tables (First Enrichment)	feed material (particle size and solid, %) analysis
	shaking table capacity analysis
2. Group Tables(Middling Enrichment)	feed material (particle size and solid, %) analysis
	shaking table capacity analysis
3. Group Tables (Tailing Enrichment)	feed material (particle size and solid, %) analysis
	shaking table capacity analysis
Pumps	
Mill Pumps	material (particle size and pulp viscosity) analysis
	capacity analysis
Middling to Re-Grinding Pumps	material (particle size and pulp viscosity) analysis
	capacity analysis
Hyrosizers	
8 cells hydrosizer	particle size analysis

PROPOSED FLOWSHEET

In order to reach the design criteria for the proposed flowsheet, changes in feed particle size, grinding operation, classification and shaking table units are made; both the equipment itself and equipment settings were changed were necessary. USIMPAC was used as the main simulation software during the study. Three main grinding concepts were evaluated at variety of conditions (several different settings and configurations were evaluated with the available equipment). The mills were kept constant through the study in order to avoid mill investment for the proposed solution. However, new cyclone investment and additional shaking tables were not avoided for better process. Three main grinding scenarios can be summarized as;

- ✓ Case 1: 2 Primer Rod Mills + 1 Secondary Ball Mill
- ✓ Case 2: 2 Primer Rod Mills + 1 Secondary Ball Mill
- ✓ Case 3: 1 Primer Rod Mill + 2 Secondary Ball Mills

In first case an operated ball mill (180 kW) was thought to be converted into a rod mill through some modifications as the ball mill originally was produced as rod mill.

The summary of the cases is given in the below.

Table 3. Summary of cases.

	Unit	Case 1	Case 2	Case 3
Grinding Feed Rate	tph	76	66	70
Grinding Feed Size (%80)	mm	12.38	8.9	8.9
Grinding Product Size (%80)	mm	0.49	0.4	0.39

Case 1: 2 Primer Rod Mills + 1 Secondary Ball Mill

In this case, as primary grinding, 2 rod mills (250 kW and 180 kW) were used in parallel and a ball mill (132 kW) was used for the secondary grinding in a closed circuit with 800 microns wet screening unit. In this case, the capacity of the secondary ball mill (132 kW) could not provide the desired throughput.

Case 2: 2 Primer Rod Mills + 1 Secondary Ball Mill

As in case 1, 2 rod mill (250 kw and 132 kW) for primary grinding and 1 ball mill for secondary grinding were used in case 2. 180 kW ball mill was used as secondary grinding mill in the closed circuit with 800 microns wet screening units. This case also could not provide what we expect from the circuit after several different combinations in simulations.

Case 3: 1 Primer Rod Mill + 2 Secondary Ball Mills

In the last case, 250 kW Rod mill was used in primary grinding. Furthermore, 132 and 180 kW ball mills were used in parallel and in a closed circuit with 800 microns wet screening units as secondary grinding. The aimed 80% particle size of 390 microns was achieved in case 3. Other advantages, such as low slime percent in product, higher recovery and tonnage advantage made this case superior. This case was taken as the main scenario and optimized its settings and other operational conditions (solid / water feed rate, ball size, rod size etc) to compare at the original plant situation. The proposed grinding flowsheet, Case 3, is shown in Figure 5.

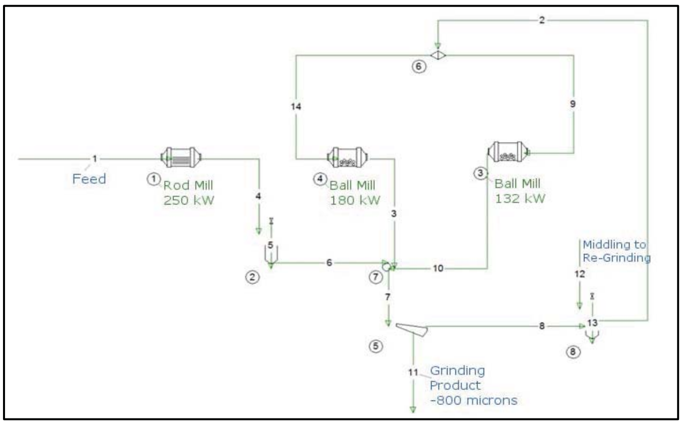

Figure 5. Case 3 Grinding circuit flowsheet.

PERFORMANCE ANALYSIS OF THE PROPOSED FLOWSHEET AND COMPARISON WITH THE OLD ONE

The proposed circuit is the product of modeling and simulation study together with extensive sampling and ore characterization tests. Hence, it needs to be tested as if it is an operating plant. Testing or performance analyses were carried out based on the concrete criteria given in Table 4, 5, 6 and 7. The similar studies were carried out by DAMA Engineering personnel (Tuzcu, 2016; Tuzcu and Vural, 2014). The results of the performance analysis of the current and the proposed circuit for the mills, screens, shaking tables and overall plant are given in the tables below.

Table 4. Mill analysis.

	Unit	Current Circuit			Proposed Circuit		
		Rod	Ball1	Ball2	Rod	Ball1	Ball2
Work Index Efficiency	%	86%			82%		
Rod Mill Performance Analysis							
Feed Size (F80)	mm	12.4			8.9		
Product Size (F80)	mm	0.82			1.77		
Reduction Ratio	--	15.12			5.02		
Capacity (Throughput)	tph	37			70		
Max. Physical Capacity	tph	44			85		
% Solid by w	%	66%			74%		
Motor Power	kW	250			250		
Power transferred to Pinion	kW	220			217		
Rod Diameter	mm	90			70		
Ball Mill Performance Analysis							
Feed Size (F80)	mm		1.68	0.51		1.79	1.79
Product Size (F80)	mm		0.85	0.4		1	0.99
Reduction Ratio	--		1.98	1.28		1.79	1.80
Capacity (Throughput)	tph		26	30		66	46
Max. Physical Capacity	tph		69	168		113	82
Ball Diameter	mm		80	80		60	60
% Solid by w	%		38%	49%		77%	77%
Proposed % solid by w	%					%77-80	%77-80
Proposed pulp density	tons/m3					1.8-2.1	1.8-2.1
Functional performance index of the circuit	(ton/kWh)/(g/rev)		0.046	0.024		0.106	0.1

Table 5. Screen efficiency analysis.

Current Circuit	
Screen Name	**Eff. %**
Screen 1 - 800 micron	69%
Screen 2 - 800 micron	69%
Screen 3 - 500 micron	41%
Proposed Circuit	
Screen Name	**Eff. %**
Screen set 1-800 micron	80%
Screen set 2-300 micron	80%

Table 6. Shaking table efficiency analysis.

	Efficiency	Current Circuit	Proposed Circuit
1. Group Tables (First Enrichment)	%	29	32
2. Group Tables (Middling Enrichment)	%	22	43
3. Group Tables (Tailing Enrichment)	%	30	39

Table 7. General plant evaluation.

	Unit	Current Circuit	Proposed Circuit
Feed Rate	tph	37.35	70.00
Concentrate Flow Rate	tph	1.64	3.87
Concentrate Grade	% Cr_2O_3	46.60	49.68
Produced Cr_2O_3	tph	0.76	1.92
Overall Plant Efficiency	%	47.68	63.30

CONCLUSIONS

Investigation of the current status of the plant; sampling and analyses campaign, detecting bottlenecks, proposing a new circuit and evaluation of the proposed circuit via modeling and simulation techniques were carried out in 4 months of continues effort. The study showed a complete and a successful combination of the theory and practice for the chromite plant optimization and capacity increase. Theoretical and experience based rules were successfully applied in the modeling effort to obtain the results with minimum and meaningful number of simulation scenario trials. The modeling approach together with functional performance analysis have provided estimation power for not only the effect of the grinding parameters on grinding performance but also the effect of the crushing, screening and hydrosizing parameters on grinding performance. Each piece of equipment's performance was evaluated in a quantitative and concrete way before and after the study as given in Tables 4, 5, 6 and 7. Minimum investment requirement due to proposed circuit was aimed and achieved. After the study was completed, DAMA Engineering proposed a road map to the Akmetal Pınar Mining Company including detailed engineering works and layout optimization for the possible equipment installation. The detailed engineering work will be followed by construction, commissioning and finally re-evaluation of the performance of the proposed plant.

ACKNOWLEDGEMENT

Authors would like to thank to Atilla Alptekin (CEO of Kurmel Group) for releasing this study, Esen Tuncer (Process Superintendent of the Company) for her helps during the study and Sabri Karahan (General Manager of DAMA Eng.) for his support to this SME contribution.

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