Evaluating the Impacts of Jaw Crusher Design Parameters by Simulation

B. Tufan and E. Tufan

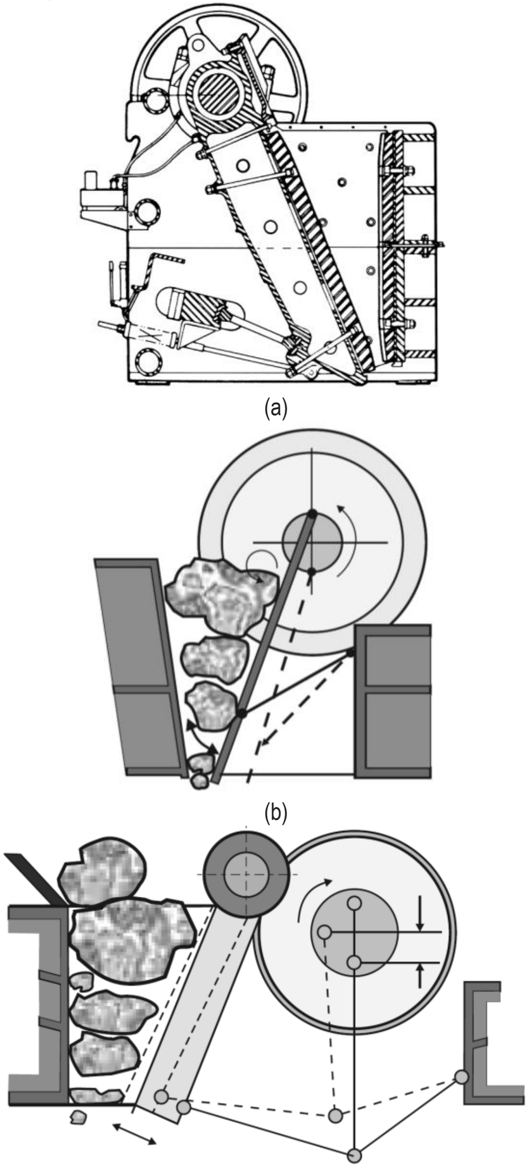
***Abstract*—In mineral processing, to obtain the desired particle size, aka liberation size, comminution is applied. This process may involve both crushing and grinding operations. The primary crushers handles the size reduction of the run of mine with maximum particle size and capacity. There are several factors that will enhance crusher capacity and performance. In order to determine all these factors to design the proper primary crusher, many experimental and field studies should be performed or a consulting service from a manufacturer should be provided. This study evaluates the impacts of these factors on design of a primary jaw crusher by a simpler and faster way, simulation.**

***Keywords*—Primary crusher, jaw crusher, design, simulation, gradation, mineral liberation, size reduction**

I. INTRODUCTION

Crushing is the first mechanical stage in the process of comminution in which the main objective is the liberation of the valuable minerals from the gangue. It is generally a dry operation and is usually performed in two or three stages. Run of mine ore can be as large as 1.5m and can be reduced in the primary crushing stage to 10–20 cm [1], [2]. The process of size reduction is normally designed to take place in single stage open circuit, single stage closed circuit or multiple stage open or closed circuit. In some cases a combination of these methods are adopted. In a single stage, single pass, open circuit size reduction operation, the product consists of a range of particle sizes which seldom achieves the desired degree of liberation. Hence second or even third stages of size reduction are often necessary to progressively reduce the remaining particle size to liberate mineral particles to an acceptable degree. In closed circuit, the product from the stage of size reduction is separated into relatively fine and coarse fractions. The coarser fraction is then collected and recrushed in the same unit. Therefore, the load on the equipment for size reduction is increased and a circulating load is established [1], [3].

Primary crushers are heavy-duty machines, used to reduce the run-of-mine ore down to a size suitable for transport and for feeding the secondary crushers or AG/SAG mills. They are always operated in open circuit, with or without grizzlies. There are two main types of primary crusher in metalliferous operations, jaw and gyratory crushers [4]-[6]. Jaw crushers are designed to impart an impact on a rock particle placed between a fixed and a moving plate (jaw). The faces of the plates are made of hardened steel. Both plates could be flat or the fixed plate flat and the moving plate convex. The surfaces of both plates could be plain or corrugated. The moving plate applies the force of impact on the particles held against the stationary plate. Both plates are bolted on to a heavy block (Fig.1a). The jaw crushers can be designed as single (Fig. 1b) or double toggled (Fig. 1c).


(a)

(b)

(c)

Fig. 1. a) Cross-section of a jaw crusher [1], b) Illustration of a single toggle crusher [7], b) Illustration of a double toggle crusher [7]

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The moving jaw dies are mounted on a pitman that has a reciprocating motion. The jaw dies must be replaced regularly due to wear. In the single toggle jaw crusher, an eccentric shaft is on the top of the crusher. Shaft rotation causes, along with the toggle plate, a compressive action. A double toggle crusher has, basically, two shafts and two toggle plates. The first shaft is a pivoting shaft on the top of the crusher, while the other is an eccentric shaft that drives both toggle plates. The moving jaw has a pure reciprocating motion toward the fixed jaw. The chewing movement, which causes compression at both material intake and discharge, gives the single toggle jaw better capacity, compared to a double toggle jaw of similar size [7]. Jaw crushers are commonly designed to operate 75% of the available time, mainly because of interruptions caused by insufficient crusher feed and by mechanical delays in the crusher [2], [8].

The size of a jaw crusher is usually described by the gape and the width, expressed as gape x width. Jaw crushers range in size up to 1680 mm gape by 2130 mm width. This size machine will handle ore with a maximum size of 1.22 m at a crushing rate of approximately 725 tph (tons per hour) with a 203 mm set. However, at crushing rates above 545 tph, the economic advantage of the jaw crusher over the gyratory diminishes; and above 725 tph, jaw crushers cannot compete with gyratory crushers [2]. Therefore, capacity is a significant parameter in the design of a crusher. In addition, the closed side setting (particle reject) of the crusher defines the particle size gradation of the products. Measurement of the crusher's closed side setting varies depending on the jaw profile that is being used and has an impact on the crusher's capacity and product gradation. There are several factors that will enhance crusher capacity and performance, such as, proper selection of the jaws, proper feed gradation, controlled feed rate, sufficient feeder capacity and width, adequate crusher discharge area and discharge conveyor sized to convey maximum crusher capacity. In order to determine all these factors to design the proper jaw crusher, many experimental and in-situ studies should be performed or a consulting service from a manufacturer should be provided. However, a simulation of the crusher planned to be purchased would give an idea and pre-knowledge about the design parameters and the product characteristics of crushing circuit.

Simulation and modeling are described as designing flowsheets and optimization in mineral processing technologies. The main purpose of simulation and modeling is to reduce the unit cost. Today, designs of mineral processing plants are more complicated and difficult due to increasing cost of construction and operation. Thus, this problem can be overcome by simulation as straight and as cheap as possible [9]-[11]. Experts of simulation comprehend the strength and weaknesses of the model to give early responses when necessary during design studies. The first step is to determine the flowsheets to be used in AggFlow™ Simulation Package Program. Selection of machinery and equipment should be accomplished following the selection of flowsheet. The operating parameters of this machinery such as power and capacity can be accessed from the database of AggFlow. The design of flowsheet not only involves machinery and equipment selection, it also consists of initial investment and operating cost feasibility [12]. In most of the cases, the entrepreneurs establish the processing plant without being aware of how much product is going to be fabricated of what is the maximum production capacity in reality. Therefore, many processing plant operates with under or over capacities and/or with low efficiencies. The optimization of plant efficiency should be applied by comparing the real data and data gathered from simulation software to reach an optimum resultant potential of the plant [13].

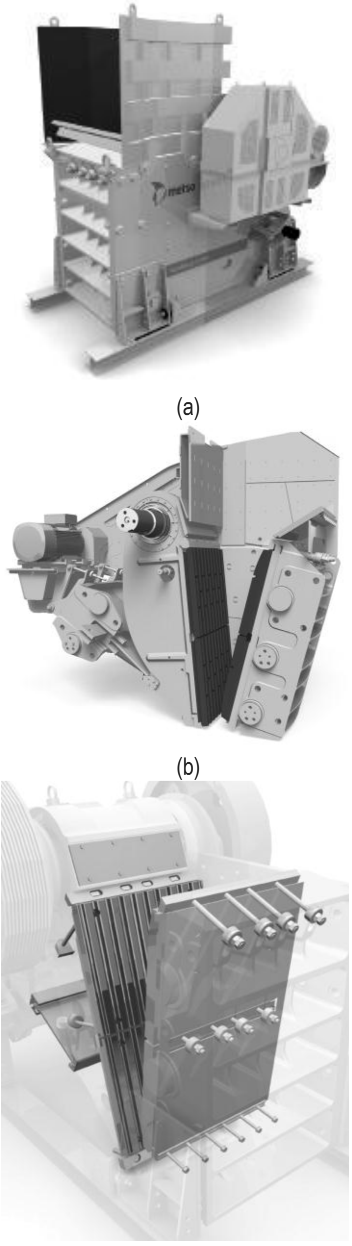
Simulation is not a miracle. The practical use of software interfaces with many different adoptable parameters would bring in the success in simulation. In addition, technical abilities of specialists, error and deviation estimations, application of several different what-if scenarios, brain storming sessions among engineers and essentially rapid and flawless execution of these aspects are the main reasons for a successful simulation in a mineral processing plant. In order to achieve that, the impacts of primary jaw crusher design factors on the resultant product was determined by applying several what-if scenarios on the same run of mine with near capacity crushers.

II. DESIGN PARAMETERS FOR JAW CRUSHERS

The fundamental goal for the design of a crushing plant is an installation that meets the required production requirements, operates at competitive cost, complies with today's tough environmental regulations, and can be built at a reasonable price despite the rising costs of equipment, energy and construction labor. There are three main steps in designing a good crushing plant: process design, equipment selection, and layout. The principal design parameters that drive crushing plant selection and configuration include; production requirements, capital cost, ore characteristics, safety and environment, project location, life of mine and expansion plans, operational considerations, maintenance requirements and climatic conditions.

Jaw crushers should be selected such that the feed opening should be considerably larger than the maximum lump size to be crushed. This reduces the danger of irregular shaped lumps blocking the feed inlet and as a result material can be fed continuously, the capacity of the whole plant is increased. To achieve the average desired capacity, losses in working conditions should be taken into consideration and crushers should be selected above theoretical values.

The design parameters to be selected can be summarized as; ***the feed opening:*** the horizontal dimension between the fixed and moving jaw plates, measured from a tooth top on one jaw plate, to a root between two teeth on the other; ***the crusher setting:*** the discharge opening between the jaw plates farthest down in the crushing chamber, measured in the same way as the feed opening, when the discharge opening is in the fully closed position; ***the nip angle:*** the angle between the fixed and moving jaw plates, this angle must not be greater than the optimum value otherwise the jaw plates cannot grip the material properly and the capacity will fall considerably. The crusher setting effects the product size and the capacity. Adjustment of the crusher setting is generally made by means of a hydraulic cylinder which positions the moving jaw according to required setting. Best crushing efficiency is obtained at optimum nip angles and to achieve this, discharge openings should be adjusted within certain limits. The illustrations regarding the design parameters belonging to Metso brand, Nordberg C Series jaw crusher are given in Fig. 2 [14].



(c)

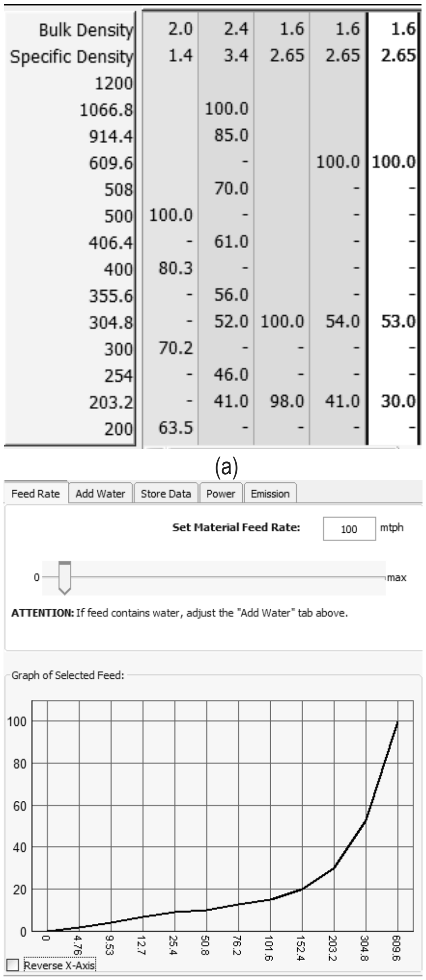
Fig. 2. a) General view of Metso, Nordberg C series jaw crusher [14], b) Cross-section of Metso, Nordberg C series jaw crusher [14], c) Crushing chamber of Metso, Nordberg C series jaw crusher [14]

The jaw crushers of Metso brand, Nordberg C series was selected to be simulated in AggFlow, with respect to feed opening, capacity, closed side setting, reduction ratio, and size gradation of the product.

III. SIMULATION STUDIES

A simple flowsheet design with a surge bin with feeder, a primary jaw crusher and a vibrating screen was applied in order to determine the impact of different parameters on the product characteristics. The plant operates at 100 tph capacity and the feed material was selected as quartz, regular quarry run, (Fig. 3a) with a maximum particle size of 610 mm (P_{80}:479.9 mm) and a feed size gradation given in Fig.3b. The particle size of the streams and products are compared with respect to their P_{80} sizes (screen aperture at which 80% of the material by weight passes through the screen to the underflow). The feed characteristics, capacity (feed rate), vibrating screen (100 mm aperture size) and the product piles remained constant in the simulation scenarios. The aim was to simulate several crushers with different closed side settings (CSS) and reduction ratios (RR) to monitor the tonnage and P_{80} of the product screened dry from a single deck, 100 mm aperture sized vibrating screen.

The designed flowsheet was simulated with different crusher design parameters (Fig. 4) and the characteristics of the underflow product file was monitored. The gathered data is listed in Table 1.



Bulk Density	2.0	2.4	1.6	1.6	1.6
Specific Density	1.4	3.4	2.65	2.65	2.65
1200					
1066.8		100.0			
914.4		85.0			
609.6		-		100.0	100.0
508		70.0		-	-
500	100.0	-		-	-
406.4	-	61.0		-	-
400	80.3	-		-	-
355.6	-	56.0		-	-
304.8	-	52.0	100.0	54.0	53.0
300	70.2	-	-	-	-
254	-	46.0	-	-	-
203.2	-	41.0	98.0	41.0	30.0
200	63.5	-	-	-	-

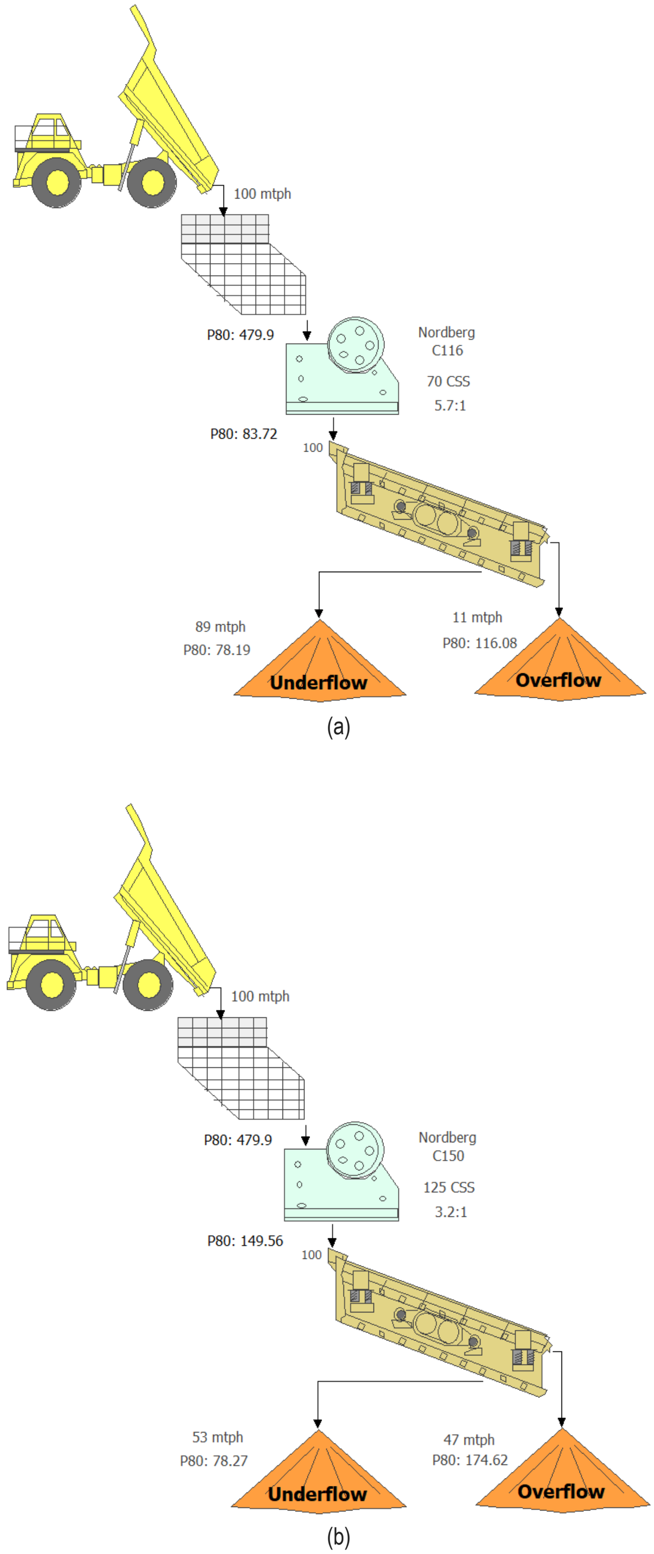
(a)

Set Material Feed Rate: 100 mtph

ATTENTION: If feed contains water, adjust the "Add Water" tab above.

(b)

Fig. 3. a) Characteristics of the feed, quartz, b) Size gradation of the feed material



(a)

(b)

Fig. 4. Sample screenshot of the software simulating the given flowsheet with given design and operating parameters, a) Nordberg C116 with CSS of 70 mm; b) Nordberg C150 with CSS of 125 mm

TABLE I. COMPARISON OF THE SIMULATION OUTPUTS W.R.T. DESIGN PARAMETERS AND PRODUCT SPECIFICATIONS

Crusher Model (Feed Opening, mm)	Design Parameter (CSS, mm - RR)	Undersize Product (tph - P_{80} ,mm)
C116 (813x1143)	70 - 5.7:1	89 - 78.19
C116 (813x1143)	90 - 4.5:1	71 - 78.20
C116 (813x1143)	100 - 4.0:1	65 - 78.27
C150 (1200x1400)	125 - 3.2:1	53 - 78.27
C150 (1200x1400)	200 - 2.3:1	39 - 74.81
C150 (1200x1400)	250 - 2.0:1	31 - 74.05
C200 (1500x2007)	275 - 1.9:1	31 - 73.79
C200 (1500x2007)	300 - 1.9:1	30 - 73.67

IV. RESULTS AND CONCLUSION

The simulation scenarios performed on a single model jaw crusher with different feed openings and capacities put through different output values and properties. The crusher with the smallest closed side setting, C116 with 70 mm CSS, produced 89 tph undersize material with P_{80} of 78.19 mm. At that scenario, the reduction ratio of that crusher was calculated as 5.7 to 1. The feed opening of 813x1143 mm was more than adequate for a feed material with maximum particle size of 610 mm. That's a clear fact that the smaller the product reject area (CSS) is, the finer the product will be. The increasing capacity and feed opening of crushers resulted in less undersize products crushed. However, P_{80} values remained close, fluctuated between 78.27 and 73.67 mm. The reason behind that result is "the material entering the crusher contains a high percentage of rocks smaller than the crusher would normally produce at its current setting", which is also the warning AggFlow put through. In addition, the bigger the crusher is, higher it costs. So, in determination of the appropriate crusher for the feed, the aim should be selecting the smallest crusher producing the desired product, both in amount and size.

Therefore, with this study, the impacts of design parameters such as closed side setting, feed opening, capacity and reduction ratio on product size and amount was revealed simpler, cheaper and faster by simulation method.

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