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Abstract. Crushing plants are of great interest in reducing particle size of rocks and ores as milling operations need to consider sustainable development. Since the crushing plants operate under harsh conditions and involve very abrasive material, multiple factors can influence their performance. This paper assesses a number of factors affecting the performance of a crushing plant by addressing the critical design parameters and consideration of ore characteristics, operability and maintainability. Due to the fact that the ore properties should remain the same during milling, its control may become difficult for yield and quality of a product. However, an operation factor can contribute positively to the performance if it is well managed by experienced operators. The present paper also considers the operational, instrumental, mechanical and maintenance aspects of crushing plant, focusing on the capacity and quality.

Keywords: crushing, monitoring, equipment, ore characteristics, operator, performance

Introduction

In industries supporting mining and milling operations, crushing plays an important role in reducing particle sizes of rocks and ores. To reach desirable end product size, the feed material endures a few crushing stages that form a circuit. A crushing plant system consists of a combination of unit operations for storing, feeding, crushing, screening, and conveying (Viilo, 2011). The crushing plants are often designed to be able to produce certain throughput on predefined specification and a size distribution while keeping the plant capacity and quality, resulting in a reasonable cost and energy consumption (Beerkircher et al., 2003, Lindqvist, 2008; Asbjornsson et al., 2012). The main challenging of running a crushing plant as competently as possible is to know how each production unit affects efficiency of the whole plant (Svedensten and Evertsson, 2004). Therefore, these units should be built up with technologies and improvements which give savings at great amounts for every ton (megagram, Mg) of
ore crushed, high capacity of use, ability to consume little energy and low repair-service costs (Utley, 2003; Wills and Napier-Munn, 2006, Drzymala, 2007).

The crushing plants like any other production process are greatly affected by changes over time, since it is a continuous process where equipment is subjected to variations. These variations can be caused by unmatched or degrading equipment performance, which can be minimized overall plant capacity and thus a decreased product quality (Major, 2003; Bengtsson et al, 2009; Itavuo, 2009). In order to attain a certain product quality, numerous crusher settings (i.e., closed size setting, speed etc.) can be varied by plant operators on a daily basis. Ore properties play also a vital role in the product quality and plant performance (Schonert, 1996; Guimaraes et al., 2007). Practitioners are striving to build up better and more reliable crushing plants. One of the central functions of well-running and professionally-managed crushing plants is to present several documents for owners, engineers, operators, practitioners, or even visitors (Boyd, 2008). Those documents will allow them to review and better understand recent developments in operating areas.

In this paper, factors that affect the performance of the crushing plant operation are evaluated by focusing several critical design parameters associated with downtimes and production losses. It also provides the operational, instrumental, mechanical and maintenance aspects of crushing plant. Specific objectives are: i) to get detailed knowledge, which can be used for assessing the plant performance and control development, ii) to collect a bunch of system data, which can be used for calculating plant availability and utilization, and finally iii) to better describe the bottlenecks of crushing plant, which can lead to production delays.

**Ore crushing plant**

The mine studied is located at Rize in eastern Turkey and is the first fully mechanized underground copper and zinc mine operating since 1994. The run-of-mine ore is delivered directly from both underground and over a distance of 1 km from the shaft to the stockpile (having a 24 gigagram (Gg) capacity) by trucks. Based on their types and grades, the ores extracted are then stored in bins. To get optimal metallurgical results, the ore is blended and fed to crusher by loader bucket for size reduction. Crushing is done in three stages with a combination of one jaw and two cone crushers that work in close circuit with a screen (Fig. 1).

A feed hopper which feeds jaw crusher has 50 Mg capacity and it has a 45×45 cm grizzly screen on it. Materials finer than 45 cm pass through a screen. At entry of the jaw crushe, there exists a vibrating feeder equipped with steel chains for homogeneous feeding. A 80% of crusher final product is less than 8–9 mm. A rock breaker is also used to break oversize rocks accumulating over the feed hopper grizzly. The crushing circuit consists mainly of the jaw and cone crushers, double deck vibrating screens, belt conveyors, transfer house, fine ore bin, metal collection systems (magnets and metal detectors) and de-dusting system.
Factors affecting crusher performance

Figure 2 shows a number of factors that can affect the performance in ore crushing plant. However, these factors can be illustrated by three categories of influence: ore characteristics, equipment factor and operation factor. The following subsection will discuss these factors in details. The aspects, which affect the process are site-specific and subjected to change based on the operation. Identifying problems and debottlenecking in a crushing plant is a challenging task because it requires information and experience of the plant. The bottleneck in an open circuit is often the last production unit, which ensures steady output from plant. In closed circuit, it may however be a bit more complex causing some problems.

The main reasons behind the low crusher throughput were identified to originate from the stockpiling run-of-mine ores, which may wet or contain non-ore materials, such as wood, plastic, metal, etc. This issue will be clearly mentioned in the following
subsections. The vibrating feeder under the feed hopper grizzly is another important factor since it provides the ore to the crusher. Sometimes it is not efficiently running due to tacky ore and/or structural mechanical problems, such as easy wear, etc. The ore crushed per hour will remarkably drop, giving rise to a low throughput. In similar way, crushers and their size settings and mantle types will directly play a role on the sum of crushed run-of-mine ore while making an allowance for the dimension and speeds of belt conveyors. Based on a structural formation of the crushed ore, a proper screen, which prevents wear and stratification should be chosen.

The fine ore bin capacity presents a clear flexibility to make maintenance in the crushe in a timely manner, especially when its level is high. Due to a combined problem caused by the bin geometry, some run-of-mine ores remain in the dead zones, which are positioned around three feeders within the fine ore bin. To trim the front surface of ores and hence provide ores to feeders for better operation, the hydraulic powered bin cleaning system was used efficiently. It is also worth to mention that the crusher operation cannot be performed without a metal and dust collection system. Due to the fact that there are metals pieces within ore and dust particles during crushing, it is of great importance to integrate those items to the system from the operational, mechanical and environmental points of view.

**Ore characteristics factor**

Material characteristics play a major role in the quality of the end product in the crushing plant. The ore entering the crusher will affect the plant performance, based on its change in the mineral content, grain size distribution and moisture. In addition, ores that contain non-ore products, such as sticky, mixed-up, wet, and dry materials, metals, woods and plastics can influence crusher performance resulting in lower production rate. Wet and sticky ores may clog chutes, lessen the live storage capacity of bins or silos. Drier ores are dustier because they are likely to stick together into larger particles. Based on the ores mineralogical composition, copper and zinc grades, there exist six types of run-of-mine ores: yellow YO, black BO, clastic CO, bornite yellow BYO, bornite clastic BCO and low grade LYO. CO contains more than 10% sphalerite clasts in matrix. BO and YO types are based on contained zinc grade and mined singly to allow for the most favourable grade blending from stockpile bins. These two ore types are referred to “Spec Ore”. BO is defined as the ore with more than 4.5% Zn and a Cu/Zn ratio of less than 1. YO consists of pyrite and chalcopyrite clasts up to 20 cm in size, in matrix containing less than 10% sphalerite.

Figure 3 shows thin sections of different ore types. Although CO looks like a hard ore in its physical appearance initially, its crushing process is easy due to numerous small scattering grains. These grains are very susceptible to breaking because they are the residues of weathering. One can also say that bornite could exhibit plastic behavior in which crushing may become problematic. However, bornite-free ores such as YO, BO, and LGO act as the massive sulphide blocks, and can be crushed in a hardly
manner. The loose joints and well-developed ores, such as CO, are easily broken in the crushing plant.

Figure 4 shows the variation in the total amount of the crushed run-of-mine ore for year 2012. It can be seen that the crusher shows a fairly good performance in 2012, except April, when the production remained behind a threshold value of 100,000 wmt (wet metric tons), resulting in a production rate of 94,610 wmt. The cogent reasons behind this are mechanical, instrumental, maintenance and operational downtimes, causing a drop in production for a time period of 66, 57 and 110 hours, respectively.
The most important factor is that, if the ore is clean, excluding non-ore materials and when its brittleness is high, the ore is being crushed in a quicker and easier way without causing any problem. More fragile particles are easily broken into smaller particles. The harder the ore is, the higher compressive strength is and more effortless to be crushed. The crusher capacity will be drastically low if the ore material contains more chunks, dust, wet and ore fines, which will eventually expand the stickiness of ore and accordingly reduce ore the discharge speed. As discussed earlier, there are six different ore types in order to make four campaigns as follows: Spec, Non-spec CO, BCO and BYO. Table 1 lists the crushed ore according to campaign type and distribution. The use rates of Spec, CO, BYO, and BCO ores are respectively 29%, 42%, 10%, and 19%, taking into consideration the crusher throughput of 1,283,695 wmt. The most problematic ore campaign is BCO since its mineralogy (i.e. bornite) is different. The ores requires steps and different ways of crushing. Some of them will be crushed readily, while others generate difficulty to be crushed efficiently. The degree of difficulty will vary according to the texture of bornite-bearing minerals. Some minerals, like quartz and feldspars, are very brittle, while others, like micas and calcite, are more ductile. This is mainly a result of the chemical bond types that hold them together. Consequently, the mineralogical composition of ore will be a great factor in determining deformational behavior during crushing. Another aspect is the presence or absence of water within the mass. Water appears to weaken the chemical bonds and forms films around mineral grains along which slippage can take place. As a matter of this fact, wet rocks or ores tend to behave in ductile manner, while dry rocks or ores tend to behave in brittle manner. How a material behaves will furthermore rely on the following factors: temperature, confining pressure, and strain rate.
The best crushing performance is respectively obtained for the CO, YO, BYO, and BCO ores. Due to the fact that CO contains groups of broken fragments within the ore mass in micrometer size, its breakable rate is higher when compared with others. In fact, these fragments disperse homogenously in the ore and help to increase its crushing performance. Since CO is of loosen structure and fracture cleavage within the mass, the particle fragility index gets higher, hence offering the higher crusher capacity. Figure 5 shows the variation in crushed run-of-mine ore in a month, taking into consideration six different ore types. Results reveal that the usage percentages of CO, BCO, YO, BYO, BO, LGO are respectively 36, 19, 18, 11, 8 and 8%. The usage amounts of the ores by month are strictly depending on both present ROM ore availability at stockpile area and the campaign switches. Overall, a specific order for ore campaigns is used as following: Spec → BYO → Non-Spec CO → BCO → BYO → Spec. Because of the high availability of clastic ore being extracted from underground, this type of ore is often used in the plant for Spec (with YO) and Non-Spec (with BO) campaigns. LGO are hauled from underground as least as possible since the stockpile copper and zinc grades are decreased appreciably.
carrying out of the process is very important. Excessive grinding may give rise to high costs, while fine grinding usually makes further difficult with upgrading. The Bond grindability test is widely used for predictions of ball and ball mill energy requirements and for selection of the plant scale comminution equipment. This work provides the Bond ball mill work index, which expresses the resistance of material to ball milling. Table 2 lists a number of physico-mechanical properties of ores used in the facility. For each ore type, the standard Bond work index tests (unconfined compression) and moisture content tests were carried out individually on the representative ore samples. The results indicate that there is no significant change in the Bond work index values of samples. The highest work index (10.1 kWh/Mg) was achieved with the bornite yellow ore. The unconfined compression test confirms that CO has the maximum compressive strength of 27.5 MPa. The unconfined compressive strengths of YO, BYO and BCO are respectively 19.2, 18.8, and 17.8 MPa. The samples moisture remains in the range of 3.3-3.8%.

Table 2. Physicomechanical properties of ore campaigns

<table>
<thead>
<tr>
<th>Blend type</th>
<th>Bond work index (kWh/Mg)</th>
<th>Compressive strength (MPa)</th>
<th>Moisture content (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spec</td>
<td>9.9</td>
<td>19.2</td>
<td>3.5</td>
</tr>
<tr>
<td>CO</td>
<td>9.3</td>
<td>27.5</td>
<td>3.8</td>
</tr>
<tr>
<td>BYO</td>
<td>10.1</td>
<td>18.8</td>
<td>3.3</td>
</tr>
<tr>
<td>BCO</td>
<td>9.7</td>
<td>17.8</td>
<td>3.6</td>
</tr>
</tbody>
</table>

**Equipment factor**

To control the quality of ore produced from the crushing plant, the appropriate equipments should be selected for the sustainable operation. The choice of crusher equipment depends on the type and amount of material to be crushed. The equipment parameters, such as speed, model and less maintenance need are more closely related to the success of a confident level of the product quality. Higher rotate speed can increase crusher productivity, but it consumes more energy and may lead to blockages. Due to the fact that changing the equipment parameters affects the product quality, they are more susceptible to changes at any time based on the crusher production requirements. Figure 6 indicates the usage hours of three loaders (17-655, 17-662, and 17-663) and rock breaker (17-666), which are the key items to feed the ore stockpiling to the crusher and to control the grain size of ore on the surface stockpile area.

It is clear that the usage of 17-662 loader is reduced, while there is an inread usage of both 17-655 and 17-663 loaders over time (Fig. 6). Note that 17-663 loader is used as a spare one when others are out of service. The rock breaker shows a stable usage over years, since it is most often used for crushing the coarse-size ores on the feed hopper grizzly in the beginning and end of the shifts. It is noteworthy to mention that
Fig. 6. Usage hours of three loaders and rock breaker used in crushing operations

Fig. 7. The cost change in bottom (left) and top (right) deck screens as a function of time

Loaders are crucial to the crushing and milling operations, since the blending and concentrate loading are made through these items. Figure 7 shows the change of frequency and connected costs of bottom deck vibroflex, polyurethane screens (800×1850 mm) and top rubber-clad screens (600×300 mm). The bottom deck screens (equipped with an aperture size of 15×15 mm) are constantly subjected to abrasive wear due to the ore relative motion. To prevent overloading in the circuit and thus to reduce the wear rate of screen, vibroflex screens, which are anti-static and
hydrophobic are preferred. The screen apertures were initially often plugged. Operators tried to open them by using air pressure, which is time-consuming and costly. Lately, the change rate of bottom decks was increased substantially from a time period of 30 to 45 days, based on a well collaboration between the mechanical and operational teams.

![Fig. 8. The cost change in the major equipment of crushing plant](image)

Figure 8 shows the change frequency and connected costs of the major equipment used in the crushing plant, which include the crusher, feeder, screen, conveyor, air cannon, magnet and metal detector. The cost change is expressed as a function of time. The crushing performance is directly based on operating time of the equipment without being out of service. Change in performance due to wear differs acutely depending on the feed material and equipment. The wear plates are of great importance for the lifetime of liners and crushers and therefore, high manganese plates are utilised by increasing the capacity and obliging less mechanical repair. On the whole, the maintenance costs of both jaw and cone crushers are decreased palpably. The key reason behind this reduction may be well explained by the oil and lubrication systems and by the reduced crusher wear parts. Serious improvement in the feeder, chutes, and conveyor were realized by keeping the particle size distribution of the crushed material constant. However, the cost of the B01.012 belt conveyor seems to be increased in 2012. This is mainly due to a number of sharp metals or objects, which
are dropped on the conveyor for different reasons and causing damages. To prevent this to happen again, a rip detection system was installed in this belt conveyor.

In addition, the double deck screen costs are significantly reduced by implementing a new strategy during and after its placement. The strategy relies on more maintenance and care for a couple of days just after panel replacement, and also the clean-up process of non-ore materials (i.e. plastics and woods) on screens at shift breaks on a daily basis. Due to a more efficient blend preparation, the magnet and metal detectors costs are lowered to a great extent, while the air costs have dimly increased in 2012. This increase is due to the wet, sticky ores, which may clog the surfaces, and therefore it deteriorates their proper functions. This situation is observed especially in the winter season.

One can conclude that, although crushers, chutes and belts are all a subject to extensive wear, and wear of parts and places can be heavy, the crushing performance is getting better. This is perceptibly a result of talented, experienced operators, well-organized teams and a well-developed collaboration between the mill and maintenance departments.

**Operation factor**

An efficient operation of the rock crusher plays an important role in crushing productivity. Not only design and layout of equipment, but also the cost of running should be considered in order to reach the best performance of the plant. This process is succeeded by experienced operators and their practical appliances during shifts. To meet the production goals for a given budget, the equipment used for crushing should have high operating availability, which is reached by keeping maintenance requirements to the minimum level as much as possible. Figure 9 illustrates the change in crusher performance in terms of both availability and utilization percents. The average availability and utilization rates were respectively 89% and 78%, thus corresponding to an overall asset utilization of 69%. Note that February 2012 conferred the best performance.

![Fig. 9. Change in crusher performance in terms of availability and utilization](image-url)
There are also production losses in the crushing plant, which can cause a disruption in normal operations leading to inefficiency, and thereby increase the costs. Figure 10 shows the change in production losses, which are mainly categorized as the ore, selection of non-ore material retained over the conveyor, rock breaker and fullness induced by wet, sticky ores. One can conclude that during the winter season, the ore may become problematic due to raining and inadequate ore production. This causes to fullness of the cone crushers, screens and t-house. Producton loss induced by ROM ore, selection, rock breaker and fullness were respectively 259, 887, 273 and 611 minutes. To boost the crushing plant performance, a project relating to non-ore material sorting from ROM ores stockpiled just before letting them introduce to the crushing plant is now in progress. Details will be given later.

![Fig. 10. Change in crusher production losses](image)

There are times in the crushing plant, in which the system is non-operational and keeps downtime associated with mechanical repair, corrective/ preventive maintenance, instrumental and operational delays. Figure 11 shows the change in crusher down times. It is shown that the down times induced by maintenance, operational, mechanical and instrumental were respectively 2862, 5049, 2015 and 328 minutes. The most down times are caused by operational issues such as daily clean-up, chute plugs, crusher plugs and settings (close side setting which enables the production of products in desirable size). Operators have to regularly clean the cone crusher and bottom deck screen chutes for 30 minutes during shift.

Attention must be paid that operators need to check a number of equipment set-ups if their functions are running well. In fact, there has to be a clearance distance of 90 mm between fixed and moving jaws for jaw-type crushers. This clearance distance gets larger when wear appears on the jaws. The shims are mounted to the studs, which are holding the jaws to lessen the clearance to 90 mm, when it reaches more than 120 mm. As mantle wears, the bowl is also tightened in order to increase the pressure on the mantle. The main objective of taking this action is to take mantle closer to the
bowl since crushing action is accomplished between the mantle and bowl. This is also known as the adding bar.

![Graph showing change in crusher down times](image1)

**Fig. 11. Change in crusher down times**

Figure 12 illustrates the change in metal alarms, which are considered as one of down times experienced in the crushing plant. Data is presented monthly as both count and time. Considering that each metal alarm takes five minutes, the average count number and time of metal alarms were respectively 520 and 43 hours. The total number of the metal-induced alarms corresponded to 22 days during which the plant was not running. To end up the number of metal alarms, a project was initiated recently to sort metals within ores stockpiled in the bins. The preliminary results prove that crusher performance is getting superior.

![Graph showing change in metal alarms as a function of count and time](image2)

**Fig. 12. Change in metal alarms as a function of count and time**
One of contributions behind metal sorting at stockpile is also that the number of damages to both, belt conveyors and crushers, causing belt cuts and crusher blockages has dropped significantly. This makes the equipment to remain in the operation, which increases their availability and utilization rates. The non-ore material selection project will also decrease both cone crusher and double deck screen plugs, as shown clearly in Fig. 13.

![Fig. 13. Photos showing crusher and screen plugs](image)

Due to the fact that ores entering the circuit is metal, plastic, and wooden free, the apertures of screens, and the chutes of cone crusher and transfer house will never block. This first helps to reduce circulating load and then increases the capacity of crushing plant. Overall, sticky, woody and plastic materials plug chutes and damage the equipment. This project will eventually help to maximize profit, increase the product quality and equipment efficiency.

**Conclusions**

This paper shows factors that affect the performance of crushing plant operations at the Cayeli Mine (Rize, Turkey). There are three main factors of influence: ore characteristics, equipment and operation. Besides that other factors can contribute positively to the overall crushing performance, if they are well managed by experienced operators. However, due to the fact that ore properties should remain the same during ore processing, its control may become difficult for yield and quality of a product. In controlling a crushing plant performance, an operator must consider these three factors at the same time since one may change quality of the end product to a
great extent, while the others have a lesser effect on the product. Based on the results of the present study, the following conclusions can be drawn.

1. Crusher settings play a leading role in achieving product quality. Regular controls can augment the performance of crushing plant operations.
2. Daily crusher records will let the operator to better realize the actual bottlenecks behind production, and state a way of solution for efficiency.
3. An optimal ore blending will decrease appreciably the need of corrective and preventive maintenance, thus reaching higher operating availability.
4. Sorting a non-ore material within ores, which travels over the plant, is of great importance in increasing the crushing performance.

This paper shows that a newly-started reporting data for the crushing plant will bring a new outlook in assessing the performance of production units in terms of availability and utilization rates.

Acknowledgement

The author wants to express his sincere appreciation to the senior management of Cayeli Bakir Isletmeleri A.S. for granting permission to publish this work. Mill management, including engineers, supervisors, and operators, who directly or indirectly contribute to this work are gratefully acknowledged as well.

References


