Available online at www.sciencedirect.com

ScienceDirect

Procedia Manufacturing 35 (2019) 808–813

Procedia MANUFACTURING

www.elsevier.com/locate/procedia

2nd International Conference on Sustainable Materials Processing and Manufacturing (SMPM 2019)

Assessing Efficiency in a unified size reduction plant when reducing large ore into powder particulate matter

Gaesenngwe Gaesenngwe*, Danha Gwiranai, Bhero Shephered

Botswana International University of Science and Technology, Private Bag 16, Palapye, Botswana 10071
P. O Box 1099, Palapye, Botswana

Abstract

In this study, the effects of reduction ration on different mineral ores was investigated when using common size reduction equipment's and also factors affecting the working efficiency during crushing. A laboratory model of a unified crushing operation was used as an estimate to account for performance at industrial level, how energy consumption in a treatment plant can be minimized. Prediction on breakage behavior and fracture energy was estimated for common crushers how chemical and physical properties of ore materials play a significant role in determining the crusher product specifications following PSD analysis. The rock ore studied in the research were modeled as granular particles subjected to crushing, grinding, and milling activities and their breakage mechanism was closely observed. Comparison between applied energy of the Jaws was studied and compared to estimated fracture energy for single particle breakage.

Keywords: Fragmentation, Jaw Crusher, Gyratory Crusher, Autogenous & Semi-autogenous grinding mills, PSD-Particle Size Distribution

---

1. Introduction

For any industrial work and/ or mining activity, size reduction is employed as the first stage step of processing where run-of-mine (ROM) is crushed and reduced to smaller manageable sizes [1]. Large scale crushing operations performed mechanically through Jaw crushers, gyratory crushers and roll crushers are employed to attain desired material size range required for further processing [2]. Different breakage mechanisms are adopted for specific ore material depending on the material properties, here large ore pieces that are too big and dense maybe first require percussion rock breakers before receiving them to feeders [3, 4]. The selection of machinery/ device between the many alternative remains a difficult tusk since it intricately takes to consideration the materials properties as well as the chemical morphology of economic products [5]. Comminution patterns or characteristics is a measure of material resistance to crushing, size reduction and grinding which is significantly related to the loading technique as well as the physical properties, chemical properties and quantification of component – rank that were petro-graphically analysed [5]. Throughout history, several crusher machines such as Jaw crusher, gyratory crusher and/ or roll crushers

---

* Corresponding Author: Tel.: +267 77860814; fax: +267 4900102.
Email: gaesenngwe.gaesenngwe@studentmail.biust.ac.bw

10.1016/j.promfg.2019.07.015

have significantly degraded in pricing and have because economically affordable even to the common locals following scientific investigations of experimental parameters i.e., grinding time, operation speed (rpm), feed material strength, feed size and choke feeding [6]. Research have tremendously improved size reduction efficiency not only through development of new advanced technological equipment with enhanced energy utilization but also via designed optimal unit techniques that render the whole comminution process a friendly operation [1]. Growth in scientific statistics and investigation in recent years indicate new operating variables have improved performance efficiency even in former technology, a concept that is important in mineral processing technology reducing energy consumption of the plant and therefore the cost of expenditure in electrical bills [6]. It has been estimated on average annually that billion tons of material are mined, crushed and fragmented to size, a process that utilize thousands of kilowatt/hours energy of electricity in a year [6].

1.1 Design of Jaw Crushers

Jaw crushers are designed with an intricate mechanical network of moving hardened high carbon steel overlaid on a heavy block and fastened with bolts [7]. Many types of Jaw crushers exist in the current market differing to a large extent by component assembly, area of application (size), and model of design (operation). The principal operation of the device hinges around compression breakage exerted by a movable Jaw plate against a stationary Jaw plate [8]. Primarily, only three (3) types of Jaw Crushers designs exists i.e. (a) Blake-type crusher: - where the movable Jaw plate is pivoted at the top end near the *gape* or *feed* opening, (b) Dodge-type crusher: - a Blake crusher type with a movable jaw plate pivot located at the bottom of the crushing chamber closer to the *set* discharge zone and also, (c) The Universal crushers: - with a fulcrum position located middle of the reciprocating Jaw such that compressive impact apply at the top and bottom of the opening chamber [9]. As illustrated in Figure 1, the basic operation and performance of a Blake Jaw crusher takes from its simplified mechanical design, such that, the reciprocating motion provided via the *eccentric* shaft will selectively allow particles smaller to the *set* diameter to be discharged while large lumps trapped within the crushing chamber are successive compressed and breakage occur through particle interaction by attrition which work the material feed until it fragment to size less than the discharge zone [9].

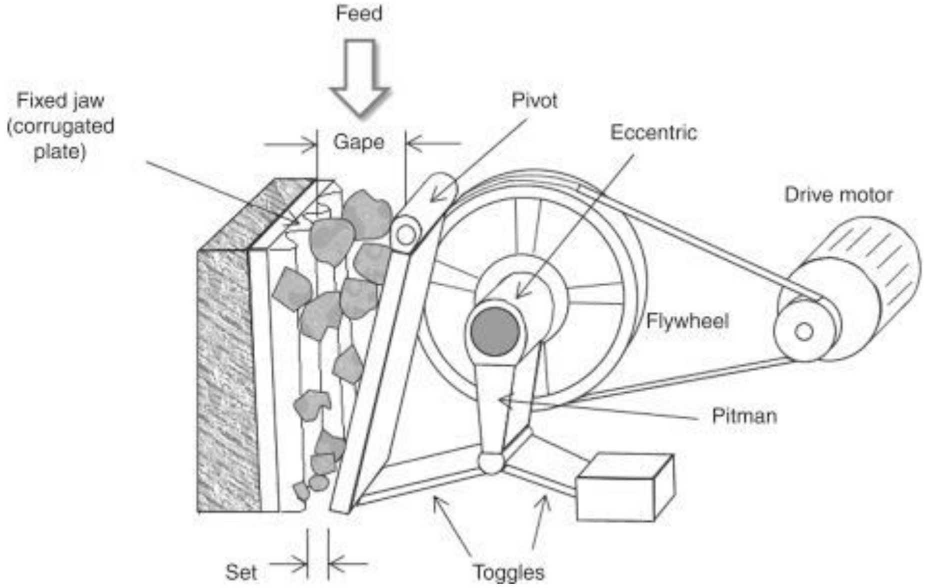

Figure 1. Double-Toggle Jaw Crusher [1]

Therefore, the undersize material will move to the next stage for further treatment via scalping screens that control feed size material only receiving material with size less than the gape opening and thus creating an efficiently smooth operation within the circuit environment, a development that also avoid deformation of the equipment therefore improving its lifespan[9].

1.1.1 Jaw crusher size and associated equation

Important factors to consider when selecting a jaw crusher for a specific task are easily followed by application of basic equations that identifies loading size as well as the gape size computation in meters (*m*) on the device [6]. Jaw crusher size are normally described using the gape and width dimensions across all process engineering from small laboratory crushers to large industrial crushers, expressed as *gape x width*.

Vertical height of crusher 2 x Gape

Width of Jaw > 1.3 x Gape < 3.0 x Gape

Throw = $0.0502(\mathrm{Gape})^{0.85}$

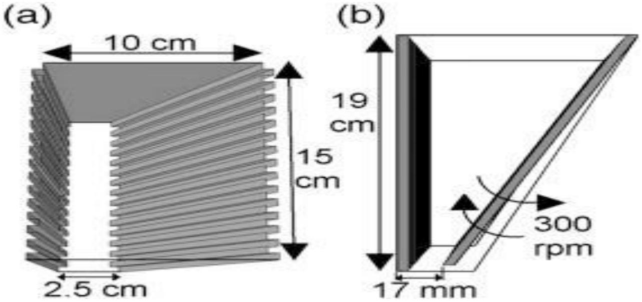

Figure 2. Laboratory Jaw Crusher top and side views, 100 mm x 1500 mm [9]

1.1.2 Circuits

Jaw crushers are naturally employed in science labs for investigation on material properties as well as in large industries for mineral processing operations [10]. Depending on the required particle size, they are usually connected in series with other crushers either in an open-circuit connection or a closed-circuit connection which consist of primary crushers, secondary crushers, and tertiary crushing. The last crusher in a unified size reduction treatment plant always operate under closed circuiting conditions in order to screen and re-crushed material products for easy management on particle size of interest [10].

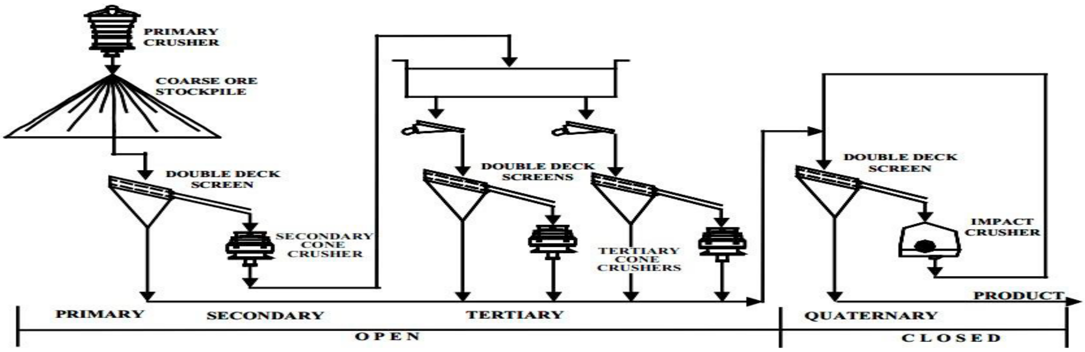

Figure 3. open and closed-circuit crusher connection [11]

Installation on industrial crushers can either be underground or above ground depending on the mode of feeding and application. Crushers installed underground are normally choke feed to liberate fine particles via the action of interparticle attrition and compression [12]. Choke feeding demand careful feed control when in operation and it is thus desirable in industry where valuable minerals are liberated. Surface installation is normally applied in construction and quarry industries where large mass material is crushed to achieve only the required particle size [12].

1.1.3 Assessing Energy efficiency of a Jaw Crusher

During mineral treatment procedures via numerous size reduction processes, mainly three (3) operations are engaged until the valuable component of the ore is fully liberated (i.e. breaking, crushing, grinding etc.,). Therefore, it is with clarity that the efficiency of operation during comminution activity thus depends on energy dissipation at each stage [1]. However, study have suggested that only 10% of input power is utilized to diminish the particles to size of interest while a great percentage is dispersed as heat and noise and for ineffective deformation of the material being processed together with elastic strains absorbed by the device. To optimize energy consumption for a typical processing plant electric power supplied is simultaneously measured during operation as well as other feed material parameters that maybe vital in estimations when applied to an analysing commercial software (Discrete element modelling, DEM) [10]. Following recent years, many efforts have been implemented that attempt to address problems caused by carbon-dioxide emission into the atmosphere and also the constant increase of energy costs, therefore it is empirical to control power consumption and efficiency during ore processing [8]. Inside the comminution device, the feed material usually fed to assume random orientations creates difficulty during breakage such that imparted impact force on the material is random, consequently resulting to asymmetric particle fracture of components due to attrition of between particles, elastic and inelastic deformation which also generates heat and noise within the device [7, 1]. Therefore, due to these unaccountable energy loses, it has been strenuous to engineers to completely understand the optimum power input required by the equipment for maximum efficiency and production [10]. For a proper unit optimization data must be gathered on various parametric aspects that maybe influential towards equipment output, therefore information about the device geometry, shaft velocity, feed particle size and feed material properties amongst many other factors that may be affecting performance on specific equipment [8]. It is common practice that optimization is established for each equipment after which a model is designed that take into account all the relevant variables and simulate them into one controlled operation. Because it is difficult to generate models that take into consideration all relevant aspects for a single unified operation, other alternatives have been developed that used different approach to modify material properties of the feed material in order to favour the process [13,14]. Feed material pre-treatment is normally suggested to destabilize material internal structure before being subjected to the final size reduction, however because modelling energy and operation efficiency consider diverse other aspects of the operation that also irregularly consume energy in many form such as noise, heat and bond breaking methods (single or multiple impacts), it is therefore generally concluded that size reduction procedures are very inefficient due to unavoidable parameters that constantly alter-results [10].

2. Theoretical Background

Experimentally it was reached to the conclusion that during size reducing procedure the mean particle size is inversely proportional to the surface area of particulate constituents that are produced as products [9]. Focus has been on measuring the surface area of the sample material before and after size reduction so as to account for energy (E) used in the comminution procedure. A technique that was appropriate for data analysis in three (3) different equations and was generally represented via the equation 1.

$$\frac{dE}{dL} = KL^n \qquad (1)$$

Where **K** is a constant, f_c is the crushing strength of rock, **E** (energy) and **L** (Length dimension) [15].

Table 1.

THEORY	EQUATION
RITTINGER (RITTINGER'S CONSTANT)	$E = K_r f_c \left(\frac{1}{L_2} - \frac{1}{L_1}\right) \quad (2)$
KICK (KICK'S CONSTANT)	$E = K_k f_c \ln\left(\frac{L_1}{L_2}\right) \quad (3)$
BOND (BOND'S CONSTANT) (E_I IS THE WORK INDEX) L IS IN μm	$E = E_i \sqrt{\left(\frac{100}{L_2}\right)}\left[\left(1 - \frac{1}{\sqrt{\frac{L_1}{L_2}}}\right)\right] \quad (4)$

The above equations have been adopted as models that quantify energy dissipation required to produce particle size of interest. However, each equation has its own limitation with regards to application. Rittinger's law (Equation 2) is most applicable for energy estimation that involve fine powders where new large surface areas are being generated therefore the theory is more fitting for modelling results obtained from working with primary crushers such as Jaw crushers, gyratory crushers etc. [10]. On the other hand, experimentally Kick's theorem is much better suited for energy approximation of data acquired from grinding procedure of coarse particles where surface area per unit mass is relatively small [7].

Consequently, operations undertaken under milling equipment are better optimized via kick's theorem which is not comparatively limited to larger particulate group distribution specifically but also to even smaller surface area particles in the microscopic domain [15]. The third equation of Bond's theory also pertains specifically to certain devices where the energy amount required in generating particle size of interest from an infinitely large particle size down to a particle size approximately $100\ \mu m$. During a comminution operation energy is utilized in various ways and forms that render the whole operation to be consuming large quantities of energy [16, 10]. Impact force exerted onto the material produce elastic deformation on the particle prior any fracture of the ore, therefore with high potential of generating inelastic deformation of the crushing chamber material if the material undergoing treatment possess high internal energy within its chemical bonds. Also, some energy is dissipated due to friction factor occurring between particles as well as with the particles and the machine jaws, an aspect that over the years have presented problems to mineral processing engineers to properly quantify and model the power consumption utilized in a single unit operation [15, 10].

3. Conclusion

Numerous methods have been developed that attempts to measure efficiency of a size reduction operation in order to control power input into the system. A continuous comparison between the theoretically ideal system that spend energy effectively and the real behaviour when practically utilized for ore processing, the ratio that defines efficiency for a productive size reduction plant. Therefore, via an understanding and knowledge of parameters that otherwise affect processing, efficiency can be controlled and managed in this manner [10].

However, the practical energy required to generate new surface areas are always expected to several orders of magnitude higher that theoretical estimations due to unavoidable aspects that also consume energy when processing thus only a small percentage of the energy input (10%) is translated into permanent deformation of the species [8].

References

[1] D. Legendre and R. Zevenhoven, "Assessing the energy efficiency of a jaw crusher," *Energy*, vol. 74, no. C, pp. 119–130, 2014.
[2] B. A. Wills and J. A. Finch, "Ore Handling," *Wills' Miner. Process. Technol.*, pp. 29–40, 2016.
[3] B. A. Wills and J. A. Finch, "Crushers," *Wills' Miner. Process. Technol.*, pp. 123–146, 2016.

[4] B. A. Wills and J. A. Finch, “Comminution,” *Wills' Miner. Process. Technol.*, pp. 109–122, 2016.

[5] D. Saramak and R. A. Kleiv, “The effect of feed moisture on the comminution efficiency of HPGR circuits,” *Miner. Eng.*, vol. 43–44, pp. 105–111, 2013.

[6] V. Deniz, “Effects of two important parameters on capacity of a laboratory Jaw crusher of different coals: Choke feed level and effective reduction ration,” *Int. J. Coal Prep. Util.*, vol. 31, no. 6, pp. 335–345, 2011.

[7] M. Johansson, M. Bengtsson, M. Evertsson, and E. Hulthén, “A fundamental model of an industrial-scale jaw crusher,” *Miner. Eng.*, vol. 105, pp. 69–78, 2017.

[8] B. P. Numbi, J. Zhang, and X. Xia, “Optimal energy management for a jaw crushing process in deep mines,” *Energy*, vol. 68, pp. 337–348, 2014.

[9] Metso, “Basics in minerals processing,” p. 354, 2015.

[10] A. Refahi, J. Aghazadeh Mohandesi, and B. Rezai, “Discrete element modeling for predicting breakage behavior and fracture energy of a single particle in a jaw crusher,” *Int. J. Miner. Process.*, vol. 94, no. 1–2, pp. 83–91, 2010.

[11] B. A. Wills and J. A. Finch, “Classification,” *Wills' Miner. Process. Technol.*, no. 1993, pp. 199–221, 2016.

[12] A. Gupta and D. Yan, “04 Jaw Crusher,” *Miner. Process. Des. Oper. - 2nd Ed.*, pp. 1–7, 2016.

[13] a Gupta and D. Yan, “Introduction mineral Processing Design and Operation,” pp. 1–704, 2006.

[14] P. P. Rosario, “Technical and economic assessment of a non-conventional HPGR circuit,” *Miner. Eng.*, vol. 103–104, pp. 102–111, 2017.

[15] G. R. Ballantyne, M. Hilden, and F. P. van der Meer, “Improved characterisation of ball milling energy requirements for HPGR products,” *Miner. Eng.*, vol. 116, no. January 2017, pp. 72–81, 2018.