Design of a crushing system that improves the crushing efficiency of gold ore at a local mine: case of Zimbabwe

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Abstract

Mining involves a number of processes which are useful in gold extraction. The processes involved are gravity concentrations, flotation, etc. are available for the extraction of gold metal from its ores. The common processes for recovery of gold solution includes: (I) Carbon adsorption, Merrill-Crowe process, (II) electro winning and (III) ion-exchange / solvent extraction. All these processes require the particles involved to be in certain sizes. Hence crushing and grinding are used to attain the required sizes. This leads the mine plant to be set in a way which let the gold extraction process to be attained economically and at a high rate. The local mine, a gold mine in Zimbabwe has been growing for the past years and production of gold ore from the ground has increased. The current crushing setup is operating at 15 tonnes per hour which is low compared to their production rate such that ore from the ground is piling up. This paper addresses the critical design parameters that will increase the crushing capacity of the plant to 35 tonnes per hour. There are three main steps in designing a good crushing plant: process design, equipment selection, and layout. The paper analyses all of these steps

Keywords
Gold mining, crushing, Zimbabwe, jaw crusher, cone crusher

1.0 Introduction
Gold mining is the process of mining gold ores from the ground up till the stage where pure gold is extracted (Richiewiki, 2010). The gold ores are usually big and have to be crushed to reduce them to a size of about 12mm diameter before pure gold can be extracted from them. The ore usually has to pass various crushing stages, each reducing the ore to a certain size. Crushing plant layout is of vital importance. Gold-containing rocks are crushed for several reasons. Crushing reduces the physical size of large rocks, exposing more surface area of rock, thus exposing any gold that may be in the rock and increasing the probability of obtaining the gold from the rock by gravity concentration or by leaching with cyanide. There may be several sizes and shapes of gold grains in the rock--round, flat, coarse or tiny. Because of this, several stages of crushing or grinding can be required (WebElements, 2015). Secondary factors to consider when crushing are the desired size of the crushed material and quantity of material to be crushed ("feed rate"). The desired particle size of determines the number of stages of crushing (primary, secondary and tertiary) and the type of machine to be used. The quantity of material entering the crusher determines the size of the machine selected. The type of crushing or grinding method also impacts the way in which the rock is broken during crushing or grinding. The current system is slow and failing to keep up with their increased production rate. This paper

proposes the design of a better crushing system at the mine will improve the crushing efficiency and result in the process being faster and processing more tonnage per hour than the current system.

1.1 Background

The mine is a company which mines gold along the great dyke. Currently, the process involves passing the stones through a jaw crusher (14x16 inch). The products are then sent to a twin deck screen which is 25mm top screen and15mm bottom screen. Screen oversize are then sent to a 36 inch cone crusher running on a closed operation. The products are then sent to a 280 tonne bin.

Research on the current crushing system led to the arrival of a decision to design a better crushing system. Some of the reasons are stated below:

1. The current system can only process 12 tonnes per hour. To fill the bin, three 8 hour shifts have to be performed thus increasing company operating costs. A better system which can fill the 280 tonne bin in 8 hours is required.
2. The current system is slow, trying to increase the speed by increasing the gap between jaws of the jaw crusher will result in the jaw crusher producing stones above 30mm diameter which will strain the cone crusher and will result in it breaking down. Decreasing the space between jaws will result in the process being extremely slow. Therefore a system that is faster and produces smaller diameter stones of less than 12mm diameter is required.
3. Major repairs are frequently being done, every Wednesday they have to run maintenance operations which is done by shutting the system down thus losing the company precious production time. The cone crusher mantle has to be replaced after only1 month since the cone crusher is being strained. A more durable system that can go for at least 2 years with minor maintenance routines being done.

1.2 Problem Statement

The current system is only processing 15 t/hr. A new design which will increase capacity to 35 t/hr is required.

1.3 Aim

The project aims to design a system that will increase the crushing rate and improves the crushing efficiency of gold ore at Muriel mine.

1.4 Project Objectives

The main objective of the project is to design a suitable crusher layout combination that will result in:

❖ increased production rate from 12 tonnes/hour to 35 tonnes/hour
❖ increased company profits by producing 3 shifts' production in one shift
❖ minimal downtime and maintains a high level of productivity
❖ a system that will produce fine quality product of less than 10mm

1.5 Project Justification

The study will result in:

❖ Increased production
❖ Reduced downtime
❖ Increased crushed ore quality which is good for the ball mill

2.0 Literature Review

2.1 Introduction

Crushing plants usually consist of set of machines that are put together to form a process to gradually reduce the size of the processed material until the desired output size is met. The machines include the following:

1. Size reduction machine(crushers)
2. Separation Machines (screens)
3. Transporting machines(conveyer belts)
4. Storage equipment(Bins or stockpiles)

Crushing is the first mechanical stage in which the main objective is the liberation of valuable minerals from the gangue. This is usually performed in two or three stages. Feed to the crushers can be as large as 1m across.

The number of crushing stages necessary to reduce ore to the proper size varies with the type of ore. Hard ores like gold, iron, and molybdenum ores, may require as much as a tertiary crushing. To design a good crushing plant one has to follow these three steps: crusher selection, crusher layout and process design.

2.4 Crushers
A crusher is a tool or machine that is used to reduce the size of a large solid particle to a smaller solid particle. The ore can have a size of up to 400mm. There are many types of crushers but the major ones are the jaw, gyratory and the cone crusher.
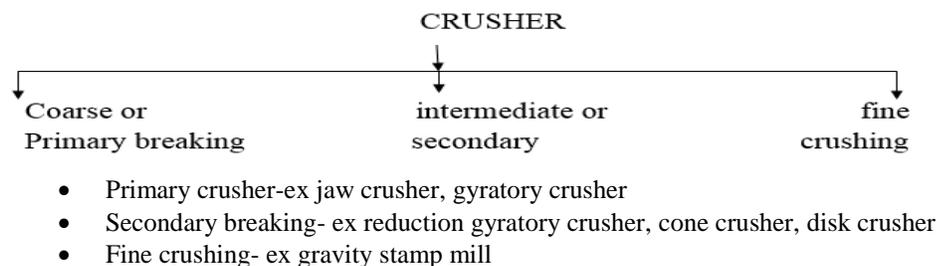
2.4.1 Types of Crushers
2.4.1.1 Jaw Crusher
Jaw crushers operate by squeezing a rock particle placed between a fixed and a moving plate (jaw). Both plates could be flat or the fixed plate flat and the moving convex. The moving plate is the one which applies the force of impact particles held on the stationery plate. There are two main types of jaw crushers. These are the Blake type and the Dodge type. In the Blake type, the moving plate is pivoted at the top end while in the Dodge type the moving plate is pivoted at the bottom end. The size of a jaw crusher is measured by its gape and width, expressed as gape x width. The gape is the size of the feed opening. The opening at the discharge end of the jaws is known as the set. For example, 400 by 600mm, indicates a distance of 400mm from fixed jaw plate to moving jaw plate where the feed enters, and 600mm is the dimension across the jaw plates.

2.5 Crusher Sizing
Jaw crushers are sized on the basis of the maximum particle size to be crushed and/or the tonnage rate to be crushed. Maximum particle size should not exceed 80% of the gape. For example, a 400- by 600-mm crusher will accept a maximum lump size of 400 by 0.8 = 320mm. In actual operations, the crusher will occasionally accept particles up to the gape size, as long as bridging does not occur. The overhead eccentric is an integral part of the moving plate, which moves up and down. Crushers can be classified into groups as follows:

CRUSHER

| Coarse or Primary breaking | intermediate or secondary | fine crushing |

- Primary crusher-ex jaw crusher, gyratory crusher
- Secondary breaking- ex reduction gyratory crusher, cone crusher, disk crusher
- Fine crushing- ex gravity stamp mill

Following are the crushers under the scope of our syllabus
- Jaw crushers
- Gyratory crushers
- Cone crushers

2.5.1: Gyratory Crusher
Gyratory crushers are the most efficient primary crushers for dealing with blasted hard rock in ore and natural stone mining. Due to different crushing chamber designs these machines can either prepare materials for downstream processing with a high crushing ratio, or reduce overburden to a size suitable for belt conveying with a low crushing ratio (Smith, 2013).

2.5.2: Cone crusher
Cone crusher is applied to break all kinds of minerals and rocks with the compressive strength below 250MPa and all those hard and medium hard materials in the mining, metallurgy, building materials and chemical industries (FTM Pvt Ltd, 2014).

2.6: Process flow
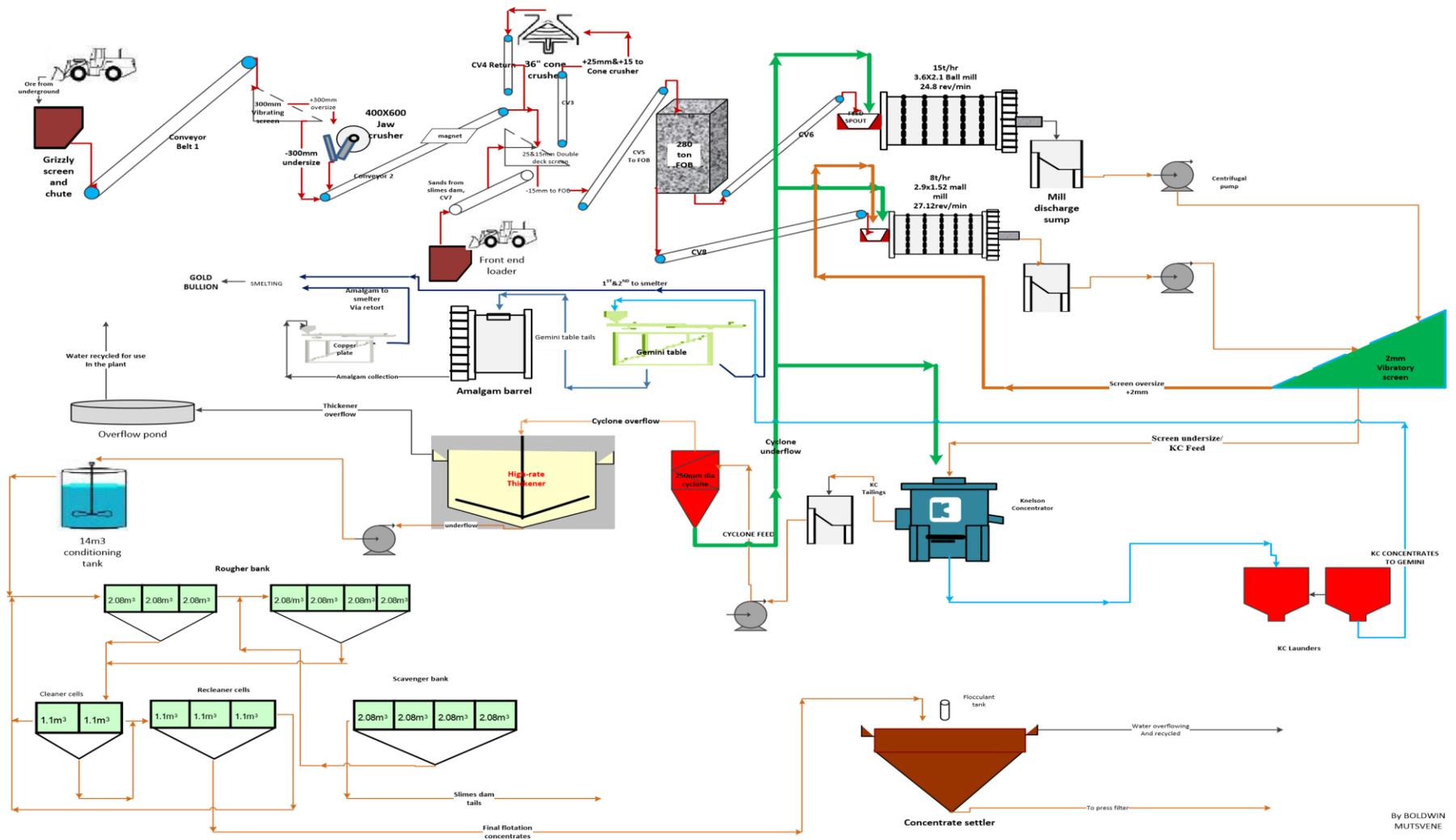Figure 1 shows the flow process.

Ore from underground

Grizzly screen and chute

Conveyor Belt 1

300mm Vibrating screen

+300mm oversize

-300mm undersize

400X600 Jaw crusher

Conveyor 2

magnet

CV4 Return

36" cone crusher

+25mm&+15 to Cone crusher

CV3

25&15mm Double deck screen

-15mm to FOB

Sands from slimes dam, CV7

CV5 To FOB

280 ton FOB

CV8

CV6

15t/hr 3.6X2.1 Ball mill 24.8 rev/min

FEED SPOUT

8t/hr 2.9x1.52 mall mill 27.12rev/min

Mill discharge sump

Centrifugal pump

Front end loader

GOLD BULLION

SMELTING

Amalgam to smelter Via retort

Copper plate

Amalgam collection

Amalgam barrel

Gemini table tails

1ST&2ND to smelter

Gemini table

2mm Vibratory screen

Screen oversize +2mm

Water recycled for use in the plant

Overflow pond

Thickener overflow

Cyclone overflow

Cyclone underflow

Screen undersize/ KC Feed

High-rate Thickener

250mm dia cyclone

CYCLONE FEED

underflow

KC Tailings

Knelson Concentrator

KC CONCENTRATES TO GEMINI

14m3 conditioning tank

Rougher bank

2.08m³ 2.08m³ 2.08m³

2.08/m³ 2.08m³ 2.08m³ 2.08m³

KC Launders

Cleaner cells

1.1m³ 1.1m³

Recleaner cells

1.1m³ 1.1m³ 1.1m³

Scavenger bank

2.08m³ 2.08m³ 2.08m³ 2.08m³

Flocculant tank

Water overflowing And recycled

Slimes dam tails

Concentrate settler

To press filter

Final flotation concentrates

By BOLDWIN MUTSVENE

Figure 1: Process flow

3.0: Methodology

The run-of-mine from the underground is hoisted to the surfaces where the tramming team delivers the ore to the rough ore bin through the use of a tractor, from where the reduction department takes over. The ore which is 350mm or less is hoisted and deposited on a grizzly screen in a rough ore bin of about 60 tonnes in capacity. The rough ore is conveyed onto conveyor belt 1 through a 350mm chute and this marks the beginning of the crushing activities, after which the ore is taken throughout the crushing circuit. The ore is reduced from about 350mm to about 15mm using a classification screen of 15mm aperture size.

In designing a plant for size reduction the three main features 0f interest are:
1. The power required for size reduction
2. The choice of crushers and grinders
3. Throughput rate

The power or energy required is the sum of the work required to crush or grind the rock as well as rotate the mill. The power required depends on the hardness of the rock, the initial size and the final product size required to achieve reasonable liberation of the mineral of interest, from the host rock. The output diameter of the products to be send to the ball mill have to be less than 12mm and they must have the right shape for the ball mill to operate at optimum conditions. Preferably a diameter of 6mm is perfect and will result in the ball mill operating at maximum capacity.

Currently the ball mill is being fed 12mm diameter products.
The shape of the output product is also important.
Initial rock diameter is usually from 180mm to 300mm.

The following concepts were generated from the specifications, standards and by consulting patents, however, paying due regard to copyright violations. Not all detail is shown in these drawings (sketches) as the idea is to bring out the concept only without, however, comprising on clarity. Accompanying the concepts are brief explanatory notes. The concepts will be considered using suitable criteria to come up with the most suitable and economic design.
To develop a crushing circuit it is useful to remember that the ranges of reduction ratios of Crushers are:
- Primary crusher 3:1 to 10:1
- Secondary crusher 6:1 to 8: 1
- Tertiary crusher = 10:1

3.1 Energy for Size Reduction-Work Index
It had been generally observed that in the process of size reduction, as the size of the particles diminishes the surface area of the particles increases. So a measure of size or surface area before and after size reduction would indicate the extent of energy expended in the comminution process. For size reduction of ore in a closed circuit reduction process Bond derived the specific energy for grinding as:

$$E = 10W_i \left[\frac{1}{\sqrt{P}} - \frac{1}{\sqrt{F}} \right] \ kWh/t$$

Where F= 80% passing size of the feed in microns, (written as F_{80})
P=80% passing size of the product in microns, (written as F_{80})
W_i=A constant for the ore
W_i is known as the Bond Work Index and represents the work required to reduce the ore from an infinite size to 100μm.
For Gold the work index, W_i = 14.83 kWh/t

3.2 Power Consumption
To compute the power consumption of gyratory crushers, knowledge of the ore work index
And crusher capacity is necessary. In its simplest form, the power consumption is given by:

$$P = W_i \ Q \left[\frac{\sqrt{F_{80}} - \sqrt{P_{80}}}{\sqrt{F_{80}}} \right] \sqrt{\frac{100}{P_{80}}}$$

Where   P= Power, kW
W_i =Work Index, kWh/t

Q= Capacity, t/h
F_{80}=Size through which 80% of the mineral feed passes
P_{80}=Size through which 80% of the product passes
Generally for primary crushers the power is given by:

Total kW= crushing capacity x kWh/t x K

For primary crushers, K=0.75 and for secondary crushers K=1

The following concepts were generated after careful consideration of design specifications and standards. The concepts will be considered using a suitable selection criteria and the most suitable concept will be selected.

3.3 Concept that will solve the problem
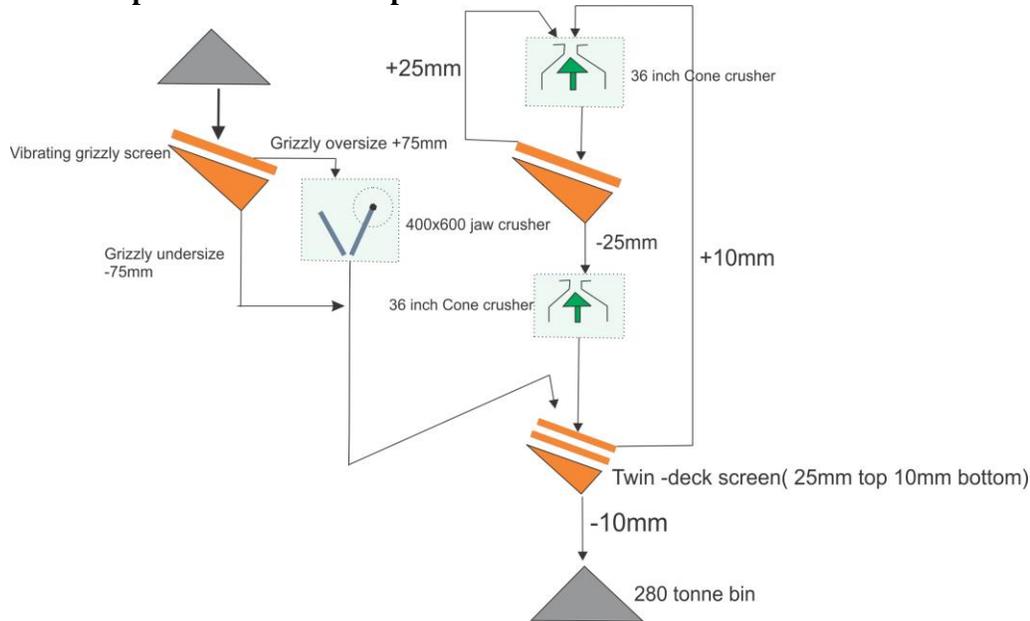
Figure 2: Concept solving the problem.

3.3.1: Principle of operation

The first stage involves passing feed into a jaw crusher. The jaw crusher operates at a reduction ration of 4:1 thus ore with a diameter of 300mm will be reduced to 75mm. Products are then sent to a 25mm 10mm twin deck screen. Output is then conveyed to a secondary cone crusher which operates with a reduction ration of 3:1 thus ore with a diameter of 75mm will be reduced to 25mm. The particles which are less than 10mm in diameter pass through the 25mm and 10mm, and then discharged onto conveyor belt where they are stored in the fine ore bin awaiting grinding. Those particles which would not have passed the 25 and 10mm limits are then carried by conveyor belt to the tertiary cone crusher for further size reduction. The products are then carried by conveyor belt back to the double deck screen for further classification and particles less than 10mm are conveyed to the fine ore bin. Thus a circulating load of particles greater than 10 mm is produced.

4.0: Detailed Design
4.1 Primary crushing circuit

$$reduction\ ratio = \frac{feed\ size}{product\ size}$$

For the jaw crusher

$$reduction\ ratio = \frac{300mm}{75mm}$$
$$=4$$

The Gape which is the size of the feed opening is set at 400mm.
The set which is the opening at the discharge end of the jaws is set at 75mm.

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Width of jaw > 1.3 x Gape
>1.3 x 400
>520 mm
Vertical height of crusher ≈ 2 x gape
≈2 x 400
≈800 mm
Throw= 0.052(Gape)$^{0.85}$
=0.052(0.4)$^{0.85}$
=0.024

A capacity of 35 t/hr is required.

$$Power = W_i \ Q \ 10 \left[\frac{1}{\sqrt{P_{80}}} - \frac{1}{\sqrt{F_{80}}} \right]$$
$$P = 14.83x35x10 \left[\frac{1}{\sqrt{70}} - \frac{1}{\sqrt{300}} \right]$$
$$=9.16 \text{ kW}$$

Therefore a motor with a capacity of 9.16 kW is required.

4.2 Secondary crushing circuit

$$reduction \ ratio = \frac{feed \ size}{product \ size}$$

For the cone crusher

$$reduction \ ratio = \frac{75mm}{25mm}$$
$$=3$$

The gape for the secondary cone crusher is set at 75mm.

The close side setting which is the shortest distance between the mantle and the concave will be set at 25mm. This will ensure that only particles less than 25mm will pass while those greater will be crushed until they are less than 25mm.
This crusher will also operate at 35 t/hr.

$$Power = W_i \ Q \left[\frac{\sqrt{F_{80}} - \sqrt{P_{80}}}{\sqrt{F_{80}}} \right] \sqrt{\frac{100}{P_{80}}}$$

The calculated power was found to be =42 kW

4.3 Tertiary crushing circuit

$$reduction \ ratio = \frac{feed \ size}{product \ size}$$

For the tertiary cone crusher

$$reduction \ ratio = \frac{25mm}{10mm}$$
$$=2.5$$

The gape for the secondary cone crusher is set at 25mm.
The close side setting which is the shortest distance between the mantle and the concave will be set at 10mm. This will ensure that only particles less than 10mm will pass while those greater will be crushed until they are less than 10mm.
This crusher will also operate at 35 t/hr.

$$Power = W_i \ Q \left[\frac{\sqrt{F_{80}} - \sqrt{P_{80}}}{\sqrt{F_{80}}} \right] \sqrt{\frac{100}{P_{80}}}$$

The calculated power was found to be 30 Kw

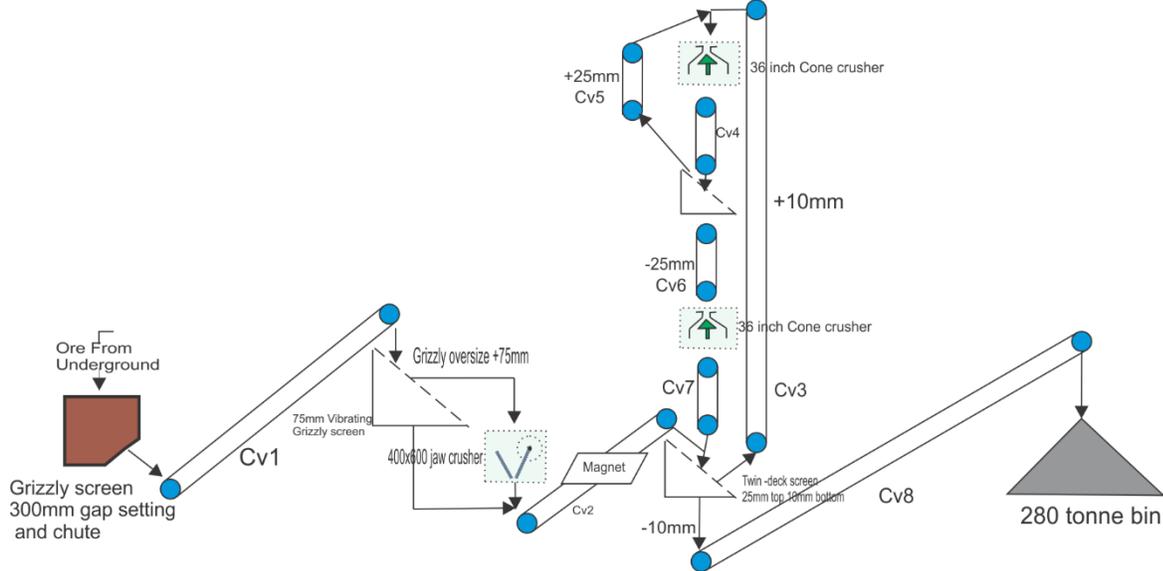## 4.4 Conveyor System
The concepts uses a total of 8 belts

Figure 3: 8 belt operating system

5.0: Costing
5.1 Introduction
This topic is to do the cost measurements and analysis of implementing the project recommendations. It helps the organisation to realise the feasibility of the study.

The crusher prices below were taken on 15 May 2014 and are subject to change.

Cost of 1 cone crusher ≈ $220 000

Cost of 1 jaw crusher ≈ $110 000

Total installation cost ≈ $530 000

The total installation cost is quite a high figure but however the increased production rate will cater for the costs incurred in installing the new setup as shown below.

Price of Gold (As at 23 May 2014) = $53.56/g

The new setup will result in about 35kg being produced thus net profit will be about $1,821,040

6.0: Recommendations and Conclusion
6.1 Introduction
The research involved a lot of research on crushers and crushing plant designs from the internet and books. This research was more focused on the choice and combination of crushers.

6.2 Recommendations
I would recommend that other critical sections not principally focused by this project be dealt with. Conveyor belts should not slack as this may cause them to fail and they will transport feed at a reduced speed. These will result in loss of precious production time. Worn out rollers are also damaging the belts and results in ore spills. I recommend that rollers be replaced timely.

6.3 Conclusion
Most of the objectives have been met. The design results in the plant operating at 35 t/hr with minimum wear to the crushers and a finer product quality of less than 10mm was produced. Finer product quality is good for the next milling stage. Therefore the project was successful.

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Biography

Tawanda Mushiri received the B.Sc. (Hons) in Mechanical Engineering and M.Sc. Manufacturing Systems and Operations Management degrees from University of Zimbabwe in 2008 and 2012, respectively. During 2008 – 2010, he went on to do a Graduate Trainee Learner ship from Oil Company under the Ministry of Energy and Power Development in Zimbabwe. He also worked as a Graduate Teaching Assistant at Chinhoyi University of Technology from 2011 to early 2013 teaching machine intelligence and advanced control and robotics. He is now a lecturer at the University of Zimbabwe from March 2013 to date teaching Engineering dynamics and design. He is a PhD student at the University of Johannesburg.

Charles Mbohwa's research activities and interests are in logistics, supply chain management, life cycle assessment and sustainability, operations management, project management and engineering/manufacturing systems management. His current Google Scholar h-index is 6 and Scopus h-index is 5. Currently is the Vice Dean of Research at University of Johannesburg and a full professor.