Acoustic Monitoring of Mill Pulp Densities

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Abstract

Acoustic sensing measurement technique is of interest as an alternative tool for online monitoring of mill internal operation due to the mill hostile environment. In this paper, acoustic sensor has been utilised in a laboratory batch ball mill operation to investigate the effect of pulp density dynamics (50, 57, 61 and 67 wt. % solids). The results showed good acoustic response with changing mill pulp density. The mill product size distributions were statistically the same for the investigated pulp densities. While subtle differences occur between some selected pulp densities, sudden change in acoustic response occurs at certain pulp density thresholds. Acoustic sensor shows potential and promise for detecting mill internal events, monitoring ball mill pulp density dynamics, and controlling performance.

Keywords: Acoustic sensing, Pulp density, Magotteaux ball mill, Spectral analysis, Mill noise

1 Introduction

Industrial ball mill performance is known to be affected by several operating parameters such as pulp density, mill speed, grind time and ball to ore charge ratio (Ebadnejad, 2016). Given its notable energy consumption (> 30 %), real-time monitoring and control of business-critical parameters are crucial for efficacious optimisation and mine financial performance (Napier-Munn, 2015). The mill pulp density is determined by mill water addition and ore feed rate, defining the transport of ore during milling (Michaud, 2015). Mill pulp density further affects ball milling efficiency in terms of ore breakage rate, product particle size distribution, pulp rheology and mill energy consumption (Clermont and De Haas, 2010; Klimpel, 1982; Lux and Clermont, 2014; Watson and Morrison, 1986). A small variation of mill pulp density can make a considerable difference in energy consumption (Clermont and De Haas, 2010). The study of Clermont and De Haas (2010) reports that slurry density difference of 2-3 wt.% solids could result in about 10 % variation on the energy (kWh/t) for an identical grind condition.

It is practically difficult to monitor and control small changes in pulp density directly in an operating mill in real-time. Conventionally, the mill feed rate and water addition are used to determine the mill pulp density of an operating mill, however, the approach does not reflect the milling density, given multiple pulp charcteristics during grinding (Watson and Morrison, 1986). The measurement options are also limited in practice by the hostile environment and mill internal inaccessibility and do not truly represent the pulp density in the mill. It is therefore important to have an alternative unsophisticated measurement technique that could provide more accurate information about the mill internal pulp density. It has been reported that mill noise can provide indications of the condition of an operating mill such as charge size distribution, breakage rate, and ore type (Watson and Morrison, 1986). Watson and Morrison (1986) demonstrated using a 20 × 20 cm laboratory mill, operated at 65 rpm (69% critical speed), that mill noise measurement can reflect pulp density behaviour. The mill noise is recorded and measured as sound pressure level using either sound pressure meter or microphone (Pax, 2001; Watson and Morrison, 1986).

Toward the advancement of online monitoring system in industrial mill control and optimisation, acoustic sensor measuring technique has been investigated in detecting changes in mill pulp densities during grinding. The following questions are addressed:

1. How do changes in mill noise reflect variation in pulp density?
2. Can mill acoustic measurement provide indication of different mill pulp densities?
3. What notable relationships exist between mill frequency characteristics and pulp density variations?
4. What are the relationships between different pulp densities and their product grind curves?

2 Experimental Methods

2.1 Ore Sample and Preparation

Iron ore sample obtained from SIMEC mining, South Australia was used for the study. The as-received sample was subject to further size reduction through jaw and roll crushers to obtain -3.35 + 1.06 mm feed particles. A series of screens were built using the Tyler series to obtain the feed size distribution. Figure 1 shows the feed size distribution coupled with a photograph of the feed.

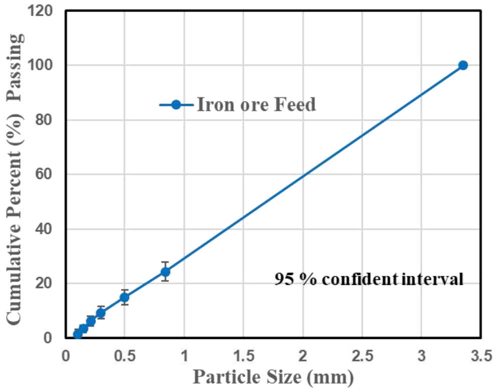


Figure 1. Feed size distribution analysis

The XRF and XRD results are shown in Table 1. The sample consists of iron (Fe) as a major element with small inclusion of other elements as shown by XRF. The mineralogical phases verified by XRD analysis also show that the ore sample contains predominantly magnetite coupled with some considerable amount of goethite and hematite and traces of other mineral phases.

Table 1 Elemental and Mineralogical Analysis

Element	% wt.	Mineral	% Mass
Fe	45.23	Magnetite	37.95
Si	10.37	Hematite	5.39
Mg	8.10	Goethite	16.06
Ca	3.82	Pyroxene	5.24
Al	2.34	Quartz	6.81
P	0.10	Chlorite	6.52
Mn	0.39	Carbonates	14.00

2.2 Experimental Set-up

Series of batch ball mill grinding tests were conducted using a laboratory Magotteaux ball mill. A schematic diagram of the Magotteaux ball mill drum and the experimental set-up are shown in Figure 2. During grinding process, the mill noise was recorded using an acoustic sensor/microphone (PreSonus AudioBox^{TM} iOne) placed about 10 cm from the toe position of the mill. The closer the sensor, the more sensitive and quality of the acquired mill noise (Si *et al.*, 2009). The sensor was connected by means of a cable through an amplifier to a computer. Signal readings were visualised and monitored with audacity software installed on the computer. To obey the Nyquist theorem, 44.1 kHz sampling frequency or rate was selected to discretise the continuous analog signal generated. The tests were carried out in a quiet environment to reduce environmental noise interferences and improve data analysis. All recorded mill noise signals were analysed with Matlab software.

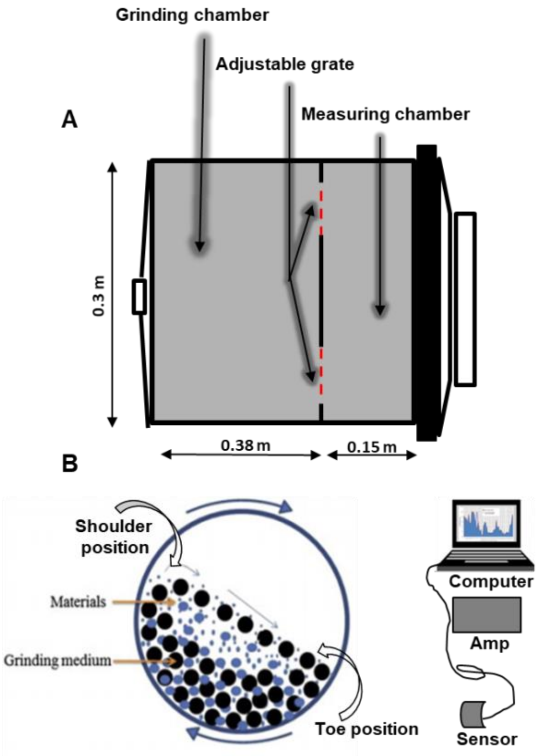


Figure 2 Schematic (a) Magotteaux mill drum (b) experimental set-up

2.3 Grinding Studies

Mill charge of 1kg ore sample and 10 kg steel balls of different sizes (26.5, 32, and 38 mm) were fed into a Magotteaux ball mill. Different volume of water additions (1000 ml, 750 ml, 650 ml and 500 ml), representing 50, 57, 61 and 67 wt. % solids respectively were used for the study. The mill was operated at a speed of 44.8 rpm equivalent to 58 % critical speed and falls within the cascading regime. For each of the test, 15 minutes grind time was allowed. Product size distributions analysis were carried out after grinding to estimate the efficiency of the grinding performance for the different pulp densities.

2.4 Signal Pre-Processing

In time domain signal visualisation, limited information of the mill conditions could be deduced. Further processing is required to evaluate the signal for meaningful analysis. Fast Fourier Transform (FFT) was used to convert the time domain graphs to frequency domain plots. Moreover, Welch's method was employed to estimate the Power Spectral Density in the signals produced by each of the grinding conditions. Before the conversion of the signal to spectra plots, Finite Impulse Filter (FIR) was used to pre-process (filter) the measured acoustic signals.

3 Results and Discussions

3.1 Mill Product Size Distribution Analysis (PSD)

The product size distribution analysis (PSD) of the pulp densities are correlated and presented in Figure 3. It can be seen that the size fraction produced are closely related and statistically identical. The grind characteristics of the 67 % pulp density are relatively distinct from the other pulp densities investigated and support the production of more fines. The size analysis of 50 %, 57 %, and 61 % pulp densities are almost superimposed on one another at various positions, indicating no clear variation. With the observed particle size distribution, noted variation in acoustic response could be ascribed to varied pulp densities.

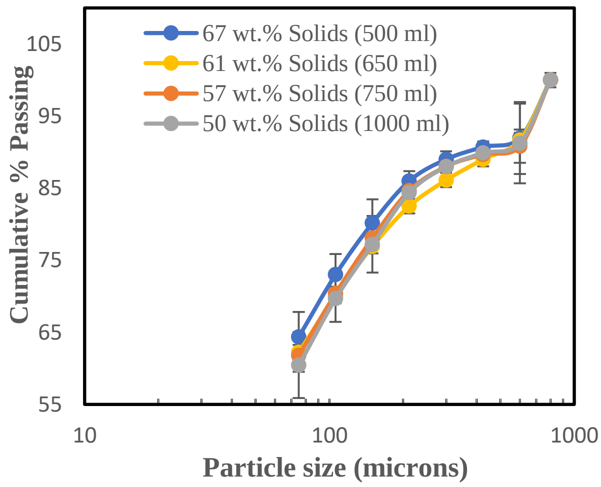
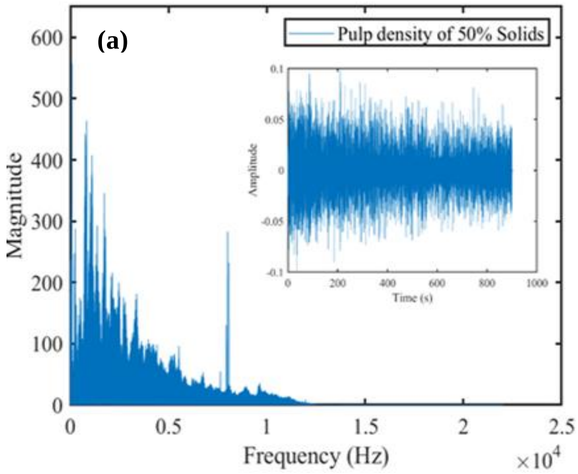
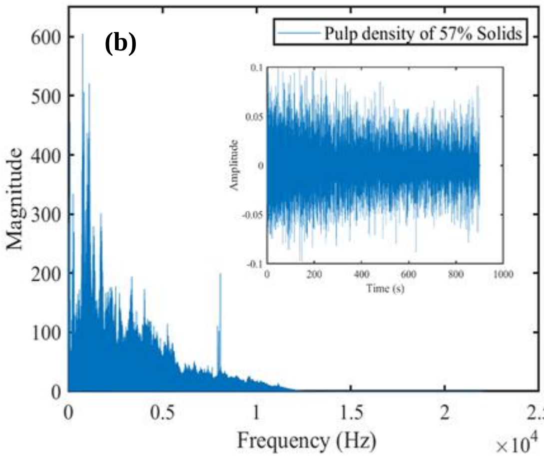


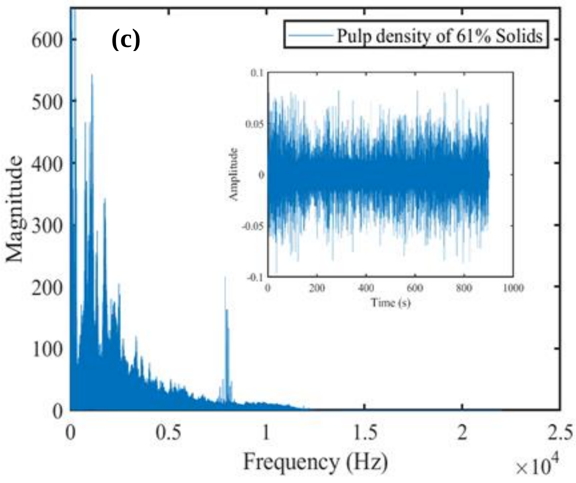
Figure 3 Product particle size distribution

3.2 Time and Frequency Signal Domain

The results of grind behaviour of the different pulp densities are shown in time and frequency domain plots in Figure 4. Notably, in the time domain, limited variations relating to different mill conditions are observed. The noise amplitudes of the signal produced by 50, 57, 61 and 67 wt.% solids charge are retained within 0.1, indicating small differences in the mill noise. Random signal spikes are generated for different mill pulp densities. This could be attributed to the collision between steel ball and steel ball/mill liner. On the other hand, the frequency domain plots generally show higher amplitudes at lower frequency and reduce significantly with increasing frequency bandwidth. The frequency spectrum tends to have similar pattern with small variation at specific frequency peaks. The lower frequency with the maximum amplitude could largely relate to the interaction between the steel ball and steel ball/mill liner.







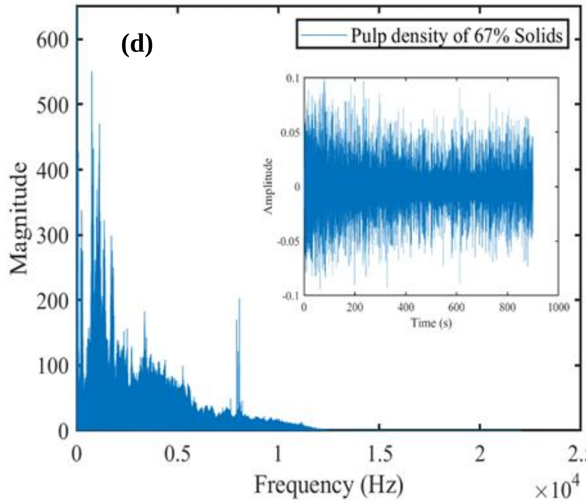


Figure 4 Time and frequency domain characteristics of (a) 50% (b) 57 % (c) 61 % and (d) 67 % wt. % solids

3.3 Power Spectral Density Estimate (PSDE)

The power spectral density estimate (PSDE), resulting from the grind characteristics of the different pulp densities are presented in Figure 5. In general, the results show identical trends of PSDE with increasing frequency. At lower frequencies, the PSDE for all the pulp densities is relatively higher with gradual reduction until frequency of 11 kHz where a sharp decline is observed. The PSDE of the 50, 57 and 67 % pulp densities are closely related, in that they tend to overlay on one another in a large proportion throughout the trend. However, the PSDE of the 61 % pulp density fall below the aforementioned trends at frequencies above 2 kHz.

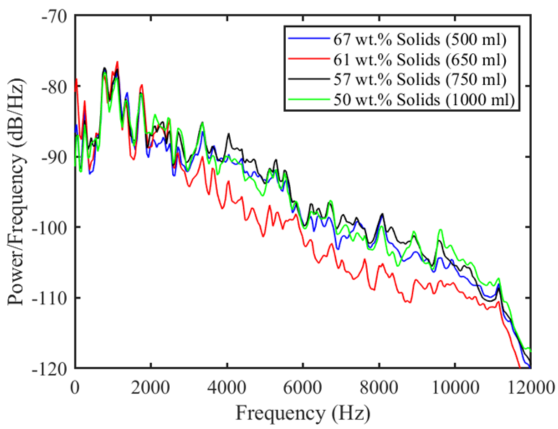


Figure 5 PSDE of different pulp density grind characteristics

3.4 Root Mean Square Amplitude Analysis (RMS)

For a quick comparison of the mill noise generated by each of the pulp density dynamics, the average noise amplitude of the signal data was determined using the root mean square (RMS) and shown in Figure 6. The root mean square value of the raw acoustic emission signals can be computed using the expression (Aguiar *et al.*, 2012);

$$RMS_{AE} = \sqrt{\frac{1}{\Delta T}\int_0^{\Delta t} AE^2(t)dt} = \sqrt{\frac{1}{N}\sum_{i=1}^{N} AE^2\,(i)} \ldots \ (1)$$

Where AE is acoustic emission, Δt is integral time constsant, and N is number of discretise AE data set within Δt.

The results show that the RMS or average amplitude of the noise differs slightly from one pulp density to another. In broad terms, the mean noise during grinding remains virtually constant with increasing pulp density from 50 % to 57 % (while reducing water addition) with minor increase and decrease at 61% and 67% pulp densities, respectively. Collectively, the 50 % 57 %, and 67 % pulp densities also produce more or less the same noise amplitude, with no distinct variations. The 61 % pulp density tends to somewhat produce the highest noise intensity, indicated by the RMS value. Generally, the results show that the different pulp densities investigated produced approximately or statistically the same average acoustic signal during grinding in the cascading regime. An increase in pulp density beyond certain point increases the average acoustic signal.

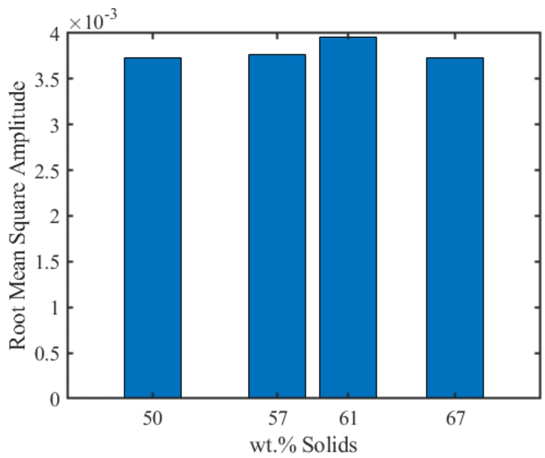


Figure 6 The mean noise amplitude of different pulp densities

4 Summary and Conclusions

In this paper, the acoustic responses of selected mill pulp densities have been investigated. From the study, the following are deduced;

- The product particle size distribution during grinding are statistically identical, which could contribute to observed spectral characteristics.
- The mill acoustic response changes with mill pulp density.
- Mill monitoring using an acoustic sensor is sensitive to pulp density changes beyond certain thresholds and could estimate even small changes in noise emission resulting from the pulp density variations.

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