Minerals Engineering 73 (2015) 69–76

Contents lists available at ScienceDirect

Minerals Engineering

journal homepage: www.elsevier.com/locate/mineng

Vertical Agitated Media Mill scale-up and simulation

Douglas B. Mazzinghy [a,*], Claudio L. Schneider [b], Vladmir K. Alves [c], Roberto Galéry [a]

[a] Programa de Pós-Graduação em Engenharia Metalúrgica, Materiais e de Minas, Universidade Federal de Minas Gerais, Av. Antônio Carlos, 6627, Pampulha, Belo Horizonte, MG CEP 31270-901, Brazil
[b] Centro de Tecnologia Mineral, Av. Pedro Calmon 900, Ilha da Cidade Universitária, Rio de Janeiro, RJ CEP 21941-908, Brazil
[c] Centro de Desenvolvimento Mineral, Vale S.A. BR 381, km 450, Santa Luzia, MG CEP 33.040-900, Brazil

ARTICLE INFO

Article history:
Received 2 June 2014
Revised 3 November 2014
Accepted 5 November 2014

Keywords:
Vertical Agitated Media Mill
Vertimill™
TowerMill®
Grinding
Simulation
Modeling

ABSTRACT

Vertical Agitated Media Mill modeling has become subject of a research project due to its potential application as a secondary grinding mill as well as regrind and pellet feed preparation projects. A test campaign with a pilot scale vertical mill was carried out with five different ore samples to elaborate a simple and robust methodology to scale-up vertical mills and perform simulations. The methodology proposed considers breakage parameters determined from tests in a conventional batch ball mill and population balance model for simulations. The tests can be performed very quickly in any process laboratory with a small quantity of sample. Two different models can be used for scale-up purposes: the first is based on the specific grinding energy and the corresponding tests were carried out on samples with natural size distribution. The second is based on particle residence time distribution and the tests carried out with narrow sized particles. Breakage and selection function parameters were estimated from each test procedure. The results indicate that it is possible to perform vertical mill scale-up and simulations with acceptable accuracy using the results from laboratory ball mill tests. The data analysis showed that the ratio of grinding net powers between ball and vertical mills is approximately 1.35 for all samples tested.

1. Introduction

The TowerMill® was developed in Japan in the 1950s, by the *Tower Mill Kubota Corporation*, for applications in fine and ultrafine grinding, and it was the first vertical mill used in the mineral industry (Stief et al., 1987). The Vertimill™, manufactured by Metso has basically the same principle of operation and was introduced in the 1990's (Kalra, 1999). Fig. 1 illustrates the TowerMill® manufactured by Eirich and the Vertimill™ manufactured by Metso.

The vertical mills have a large vertical double-helical steel screw agitator located centrally in a vertical cylindrical shell. The agitator rotates and stirs the media while simultaneously lifting and circulating it throughout the mill (Morrison et al., 2009). These mills have found applications in regrinding circuits during the last few years because on their higher efficiency and their small foot print. For regrind the vertical mill is already a consolidated reality and it is being applied for most new process flowsheet designs. It also recently has been considered as an alternative to ball mills in secondary grinding applications.

It has been reported in the literature that the vertical mills are more efficient when compared to conventional tubular ball mills (Jankovic et al., 2006; Junior et al., 2011; Vanderbeek, 1998). Normally vertical mills are loaded with smaller media, and part of this extra efficiency would be due to the increased specific surface of the smaller media and, consequently, increase in grinding action, especially for smaller particles. Morrison et al. (2009) showed that the basic difference between vertical and tubular ball mills arises from differences in the frequency and energy intensity of balls collisions. The higher efficiency of the vertical mills is due to the higher frequency of lower energy impacts and, by the same token, smaller frequency of higher energy impacts when compared to conventional ball mills (Mazzinghy et al., 2013).

Ideally, a laboratory, small scale vertical mill could be used for scale-up purposes in the same way as the batch tubular ball mills are used for scaling-up industrial ball mills. However, due to its geometry, the size of the ball charge of the laboratory vertical mill must also be scaled-down, to allow the ball charge to flow freely, or similarly to the flow of the ball charge in an industrial vertical mill. This limits the laboratory scale vertical mill to tests with very small particles. In the case of ball mills, the laboratory prototypes enable the use of balls with a diameter similar to or slightly smaller than

* Corresponding author.
E-mail addresses: douglasmazzinghy@ufmg.br (D.B. Mazzinghy), cschneid@cetem.gov.br (C.L. Schneider), vladmir.alves@vale.com (V.K. Alves), rgalery@demin.ufmg.br (R. Galéry).

http://dx.doi.org/10.1016/j.mineng.2014.11.003
0892-6875/

the balls used in industrial operations. For vertical mills, however, the balls must be scaled-down proportionally to the mill, preserving the ratio between the diameter of the largest ball and the gap between the screw and the inner wall of the mill. It turns out that the maximum particle size that can be tested in a batch vertical mill is very small, not reflecting the desired feed size of industrial applications. To solve this problem, trial tests on batch tubular ball mills have been used to scale-up vertical mills. This initiative originated at Metso, manufacturer of Vertimill™. The results of these tests turned out to be very good, and it is only necessary to implement an efficiency factor which corrects the higher rate of breakage of vertical grinding mills when compared to ball mills. This factor is easily implemented when scaling-up mill power. The energy specific selection function can be easily corrected taking into account the operational parameters from both, the laboratory mill and the industrial mill, since all relevant parameters are taken into account in their respective equations of power (Mazzinghy, 2012; Mazzinghy et al., 2012, 2013). This scaling-up method is known as the Herbst–Fuerstenau scale-up procedure, in honor of the authors. For scaling-up purposes the procedure works perfectly well for both ball and vertical mills.

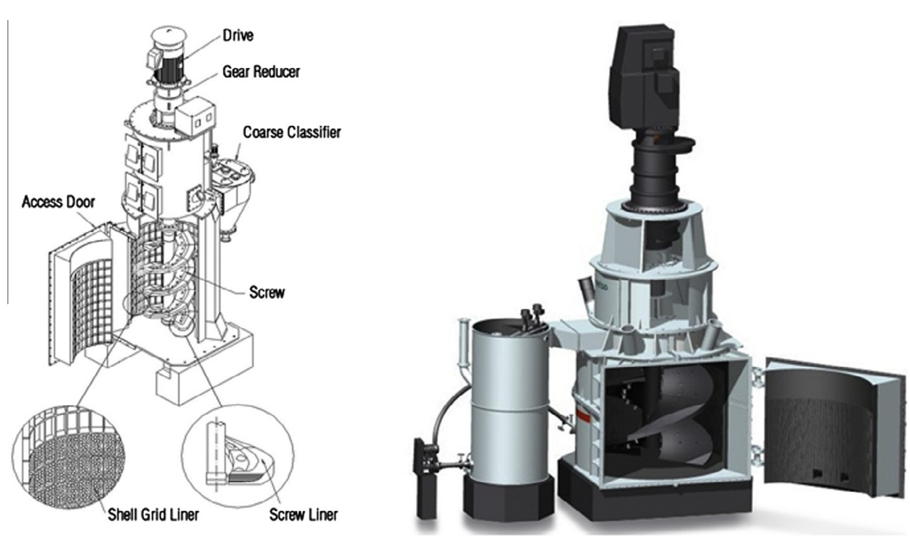
The scale-up model based on particle residence time can be carried out using the same efficiency factor that is used with the energy specific selection function, correcting the values of the selection function. It is important to keep in mind that the ratio between the efficiencies of both types of grinding mills is independent of the ore type. Scale-up methods based on the residence time, notably the Austin method (Austin et al., 1984), take into account all the operational parameters that influence the residence time, i.e. the feed rate, diameter, length (height in the case of vertical mills) and ball charge. This methodology is appropriate in the case of tubular mills, but a problem arises in applying it to scale-up vertical mills from tests performed in a laboratory batch ball mill. For example, a test performed in a batch ball mill operating at a specific fraction of the critical mill speed; this parameter is taken into account in the particle residence time distribution model for scaling-up ball mills, but this is not an operating parameter for scaling-up industrial vertical mills. When the batch grinding test is performed, a fraction of the critical speed is selected, and the specific selection function parameters are dependent on its value. In other words, the resulting selection function is a function of the fractional critical speed. Thus, a correcting factor must be considered when applying this parameter for scaling-up and simulating industrial vertical mills. Clearly, it is postulated that the factor used for scaling efficiency in vertical mills varies with the fraction of critical speed used in the batch ball mill test. To determine this relationship, a series of milling batch tests with different fractions of critical speed must be performed with the same ore. Other issues that arise in relating operating grinding parameters of a batch ball mill are the ball fractional charge J, the powder fractional filling U and the diameter of the test mill. In order to simplify the methodology, consider as a premise that an efficiency correction factor, similar to that applied in the power scale-up system, can be similarly used in a residence time based scale-up system. It should be considered that the batch tests be always performed under a standard set of conditions, thus establishing a single scale-up factor that is constant for the set of conditions chosen.

This study presents the results of a test campaign with five different ore samples. Three pellet feed samples, an iron ore sample and a copper ore sample. Laboratory scale tests with a batch ball mill were performed in order to determine the selection function and the breakage function for all samples. Pilot scale tests were performed with a vertical mill in closed circuit. All process and operating variables were measured under controlled conditions to produce comprehensive data that was used to check the accuracy of the simulations. The models based on power and on residence time were implemented to simulate the vertical mill pilot scale tests.

The objective of the work is to simulate and scale-up the pilot vertical mill from parameters obtained in batch ball mill tests using small quantities of samples and simple laboratory equipment.

2. Modeling

The first continuous probability formulation of the differential size-mass balance as applied to breakage processes was given by Epstein (1947). Sedlastscheck and Bass (1953) were the first to present the formulation that is used today. The general continuous formulation is a particular case of the Population Balance Modeling (PBM) approach which was originally developed for keeping track of populations of cells in biology. PBM is usually expressed in terms of continuous probabilities of number distributions. The PBM concept was first applied for chemical engineering purposes



TowerMill® Vertimill™

Fig. 1. TowerMill® (Eirich courtesy) and Vertimill™ (Metso courtesy).