Minerals Engineering xxx (2015) xxx–xxx

Contents lists available at ScienceDirect

Minerals Engineering

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

# An operational model for a spiral classifier

Claude Bazin [a,*], Maryam Sadeghi [a], Marilène Renaud [b]

[a] Department of Mining, Metallurgy and Materials Engineering's, Laval University, Quebec, QC, Canada
[b] COREM, 1180 rue de la Minéralurgie, Quebec, QC, Canada

ARTICLE INFO

*Article history:*
Received 21 July 2015
Accepted 28 September 2015
Available online xxxx

*Keywords:*
Iron ore
Hematite
Spiral concentrators
Partition curves

ABSTRACT

Spirals are gravity concentrators used for the valorization of coal and heavy minerals. Coarse hematite iron ores in Canada are usually concentrated by spirals. Spirals classify the particles according to their size and specific gravity. Several mathematical models were proposed to simulate the operation of spirals using a balance between the various forces acting on particles. However few models provide a method to account for wash water addition and the opening of concentrate ports that are two strategic variables for the operation of spiral classifiers. This paper proposes a model to incorporate these variables in a simulation scheme and validates the model with pilot plant data.



## 1. Introduction

The processing of heavy minerals and coal is often carried out using spiral classifiers. Processing of iron ore to separate coarse iron oxides such as hematite from light gangue mineral, such as quartz, is carried out in circuits with several hundreds of rougher, cleaner and re-cleaner spirals (Bazin et al., 2014). The development of spiral circuit flow sheets and the tuning of the various units of these circuits are mainly done through trials and errors experimentation. Such approach poses several challenges as spirals offer several tuning variables. Indeed for some models of seven turn spirals the operator may adjust the openings of 14 concentrate ports, 14 wash water distribution valves as well as the total wash water injection. A mathematical model that can simulate the effects of the concentrate port openings and wash water distribution can be of considerable help for the operator to identify possible tuning strategies.

Most of the models for spirals are fundamental and use a balance of forces to calculate the equilibrium position of a particle as it flows down the trough of a spiral (Das et al., 2007; Holland Batt, 1989; Holtham, 1992a,b; Kapur and Meloy, 1999; Sivamohan and Forssberg, 1985). The equilibrium position varies with the size and density of the particle, the slurry flow rate and solids concentration, and with the spiral design. Despite all the efforts put in the development of these models they are not yet suitable for the development of flow sheets or the optimization of circuits. Some empirical approaches have been used with a limited success to simulate the spiral operation (Srivastava et al., 2001). Except for the work of Mishra and Tripathy (2010) that used finite element simulation it was not possible to find a mathematical model that could be used to simulate the effect of the concentrate port openings and wash distribution into a spiral. The absence of such study is well summarized by the comment of Holland-Batt (1990):

> '*The separation mechanism on spirals is complex and does not lend itself to any simple mathematical descriptor capable of expressing the influence of the control variables on the metallurgical performance.*'

This paper describes a possible structure for a model that can incorporate the effect of wash water distribution and concentrate port openings on spiral operation.

The first section of the paper recalls the operating variables of a spiral. The structure of the proposed model is then presented and the following sections describe the different units of the model. The model calibration and some simulation results are presented in the last sections.

## 2. Spiral classifiers

A typical spiral classifier is shown in Fig. 1. The geometry of a spiral is characterized by the length or number of turns, the diameter, the pitch and the shape of the trough (Burt, 1984). The spiral feed is a mixture of water and ground particles that is gravity fed at the top of the spiral. As the particles flow down the spiral, various forces pull the heavy particles toward the inner part of the spiral troughs and transport lighter particles outwardly. For the

* Corresponding author.
*E-mail address:* claude.bazin@gmn.ulaval.ca (C. Bazin).

http://dx.doi.org/10.1016/j.mineng.2015.09.024
0892-6875/© 2015 Elsevier Ltd. All rights reserved.

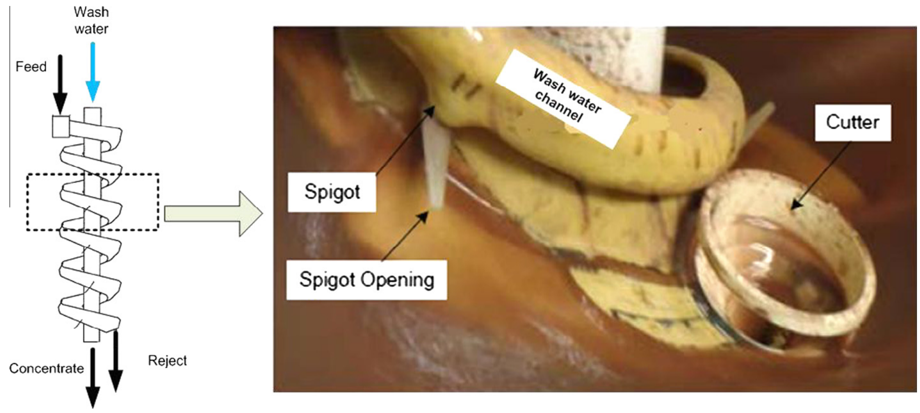


**Fig. 1.** Spiral, concentrate cutters and wash water addition.

concentration of heavy minerals such as iron oxides the valuable minerals are collected from the inner part of the spiral while gangue minerals are rejected to the outer part of the spiral trough. This paper deals with the spiral concentration of heavy valuable minerals.

Heavy mineral particles sliding down the spiral are extracted by adjustable concentrate ports or cutters located in the inner part of the spiral trough as shown in Fig. 1. Although the opening of the concentrate cutters is a strategic operating variable to control a spiral operation (Tripathy and Murthy, 2012) it was not possible to find a model of the particle capture by the concentrate cutters.

Wash water is added at different vertical positions to fluidize the inner stream bands of particles allowing the valuable mineral particles to percolate toward the concentrate ports as well as to wash entrained gangue particles away from the concentrate ports. Various systems are used to distribute the wash water into the spiral trough (Burt, 1984). For the Mineral Technologies WW−6E spiral that is used to generate the data reported here, the wash water is added at the top of the spiral at a flow rate selected by the operator. The wash water then flows down a twisted channel wrapped around the central axis of the spiral (see Fig. 1). Several outlets with valves or spigots are installed along the twisted channel to distribute the water. A spigot is shown in Fig. 1. The total wash water flow rate can be automatically controlled to a set point value while the distribution of the wash water inside the spiral trough is manually controlled by adjustment of the spigot openings.

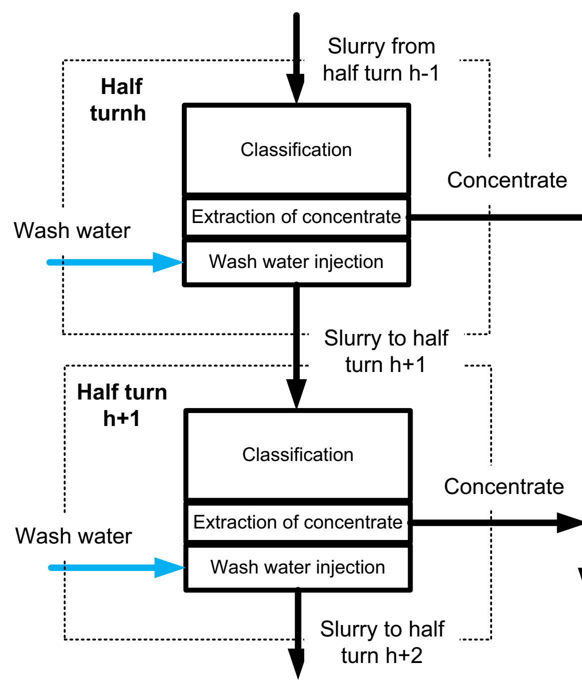


**Fig. 2.** Division into half turns.

## 3. Structure of the proposed model

The proposed model divides a $N_T$ turn spiral into $N_{HT}$ half turns ($N_{HT} = 2N_T$) as illustrated in Fig. 2. The use of a half turn as a discrete unit is related to the fact that some spiral types may have two concentrate ports and two wash water addition points per half turn. It is also possible to use one turn or a quarter of turn as the discrete unit.

Each half turn unit shown in Fig. 2 consists of three zones:

- A classification zone in which the particles are separated according to their size and density. Some authors (e.g. Atasoy and Spottiswood, 1995; Mishra and Tripathy, 2010) reported that less than three turns are sufficient to classify the particles.
- A concentrate extraction zone from which the particles are collected into the concentrate stream.
- A wash water addition zone that is used to simulate the effect of the wash water addition into the inner stream bands of the spiral trough.

The slurry circulating in a spiral trough is divided into $N_B$ stream bands as shown in Fig. 3. Each stream band can exchange particles with adjacent or further stream bands. The exchange travel distance depends of the particle characteristics and the shape and operating conditions of the spiral. For instance a heavy and coarse particle in stream band $N_B$ (outer band) may flow to the 3rd band in less than half a turn depending on the slurry flow rate and composition of the intermediate stream bands. A similar particle leaving the 3rd band could end up in stream bands 1 or 2 (see Fig. 3). A small and light particle in stream band $N_B$ would probably remain in that stream band. The same small and light particle leaving stream band 3 may end up in one of the above 4 to $N_B$ stream bands (see Fig. 3).

The proposed model structure requires several pieces to be put together to construct the spiral model i.e.:

- A description of the spiral feed characteristics.
- A method to describe the distribution of wash water into the spiral.