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Detecting changes in the operational states of hydrocyclones

M.J. Janse van Vuuren, C. Aldrich *, L. Auret

Department of Process Engineering, University of Stellenbosch, Private Bag X1, Matieland, 7602, Stellenbosch, South Africa

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ABSTRACT

In this investigation, video recordings of the underflow discharge of a pilot plant hydrocyclone were collected during classification of different precious metal ores. The underflow shape was monitored by determining the underflow width along a horizontal line through the image. This was accomplished by employing various noise reduction methods and identifying the flow boundaries via motion analysis. Subsequent monitoring of dilute, transitional and dense flow could be automated by embedding the underflow width measurements and making use of one-class support vector machines to estimate the distributional densities of the data in the resultant phase space. Experimental results suggest that the approach could provide a practical and inexpensive means of monitoring the operational states of hydrocyclones.

1. Introduction

Hydrocyclones are used extensively in the mineral processing industries, owing to their versatility and the simplicity of the equipment. It is widely known that the performance of these separators can have a significant impact on a plant and that the efficiency of the equipment can be strongly affected by small fluctuations in the feed pressure, solids concentration or volumetric flow rates (Hou et al., 2002). As a consequence, efforts have been made over the past two decades to develop instrumentation to facilitate the online monitoring and control of hydrocyclones. A sizeable number of these methods rely on the determination of the hydrocyclone operating state.

Fig. 1a–c illustrates the three basic hydrocyclone operating states as identified by Neesse et al. (2004), viz. dilute flow separation, a transitional state and dense flow separation. These operating states differ with regards to the amount of sediment stored in the conical section, the extent of air core development and the shape of the underflow. Of these three operating states, the transitional state is the most favourable state, as it provides the best separation conditions. Reference to normal operating conditions would therefore also refer to this state. Dense flow separation or roping, on the other hand, is the least desired, owing to general instability and the increased likelihood of blocking of the equipment.

Most of the methods proposed for monitoring of hydrocyclone operating states have focused on determining the shape of the air core inside (Hararah et al., 2010). Sensing techniques employed with these methods include electrical impedance (Gutiérrez et al., 2000; Dyakowski et al., 2000), electrical resistance (Bond et al., 1999; Williams et al., 1999) and ultrasound tomography (Schlaberg et al., 2000). Other monitoring schemes have attempted to determine the operating states from the internal solids concentration in the hydrocyclone (Schweitzer, 1972; Galvin and Smitham, 1994; Gutiérrez et al., 2000; Hou et al., 2002), while a third approach relies on detection of the operating state from the shape of the underflow discharge. Previous sensing methods used in this regard include mechanical detection (Hulbert, 1993) and acoustic monitoring (Neesse et al., 2004).

Although these techniques have all been applied with varied success, none has found widespread adoption yet. This might be attributed to the fact that these methods lack robustness, require expensive equipment or involve significant alterations to the hydrocyclone setup (Petersen et al., 1996; Neesse et al., 2004). Although positive results have been obtained from the industrial application of the method developed by Hulbert (1993), continuous use of the device is limited, since it is not a contact-free method, and therefore requires regular replacement or maintenance. In contrast, previous work performed by Petersen et al. (1996) suggests that image analysis of the underflow might serve as a viable alternative monitoring technique.

Image analysis performed by Petersen et al. (1996) could be used to determine the discharge spray angle. As detailed in a follow-up study (Van Deventer et al., 2003), these angle measurements were combined with fundamental, semi-empirical and empirical models to develop a soft sensor. Although the technique was promising based on its low cost and non-invasiveness, the video data could not be processed as a continuous data set, owing to computational limitations at the time. Discrete images were therefore extracted instead and used to calculate an average underflow

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* Corresponding author. Fax: +27 21 8082059.
E-mail address: ca1@sun.ac.za (C. Aldrich).

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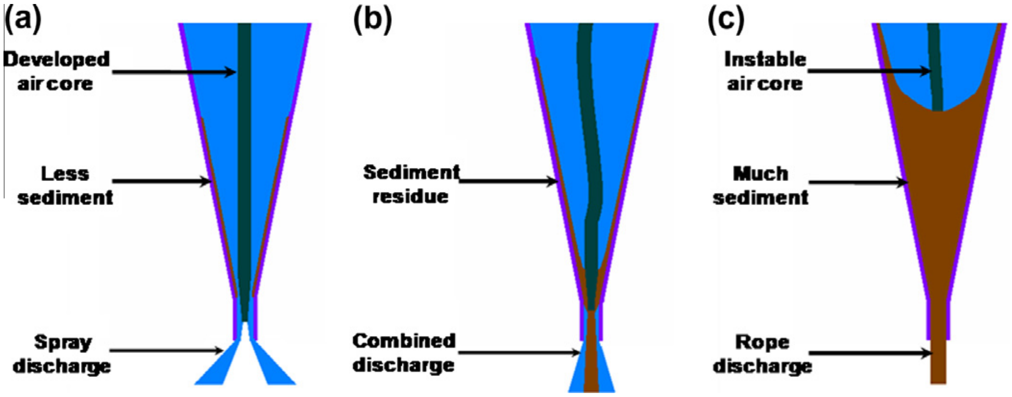

Fig. 1. Hydrocyclone operating states as identified by Neesse et al. (2004): (a) Dilute flow separation, (b) a transitional state and (c) dense flow separation.

angle. More recent work by Neesse et al. (2004) using a laser optical sensor, has likewise suggested that imaging of underflow shapes can be used to identify operating states in hydrocyclones. This study is an extension of the work done by Petersen et al. (1996) and Van Deventer et al. (2003) in that spray profiles are continuously approximated through the determination of an underflow width variable that can be used as a basis for online monitoring of hydrocyclone operating states.

2. Experimental work

Fig. 2 illustrates the hydrocyclone setup used at the University of Stellenbosch. The pilot plant scale hydrocyclone was suspended above a mixing tank into which the overflow and underflow streams discharged. These streams were fed back to the feed inlet through a basic recirculation system.

A video camera (Sony DCR-SX44E) was mounted on the side of the mixing tank and directed towards the underflow. To protect the camera, it was placed in a box with a sight glass through which images could be recorded. All experiments were initiated as pure water systems to which small amounts of ore were added at discrete time intervals to simulate varying inlet concentrations. Consequently, the underflow varied from dilute flow to dense flow separation as illustrated in Fig. 3.

3. Analytical methodology

3.1. Image analysis

3.1.1. Image acquisition

Footage recorded by the CCD camera was saved as separate video segments in MPEG format and subsequently imported into MATLAB™. Thereafter, video segments were divided into individual frames denoted as F_k, where $k = 1, 2, \ldots, N$, with N the total number of frames. Based on the shutter speed of the camera, 30 frames were obtained for every second of video data. Further analyses, as described in the following sections, were performed on each individual frame or image, F_k.

3.1.2. Conversion to greyscale colour field

Images represented in colour require a comparatively large amount of storage space, since three colour values are assigned to each pixel (red, green and blue in the RGB colour field). To reduce the processing time and storage space required, the number of colours was therefore reduced by converting each image to greyscale. Consequently, each pixel attained one colour value between 0 (black) and 255 (white) (Russ, 1995).

3.1.3. Image enhancement through contrast and brightness adjustments

Image enhancement was used to make the underflow stream more recognisable to the computing system. Contrast and brightness manipulations were specifically used to transform input pixel values to a desired output range. Fig. 4 shows how this technique was applied to achieve a more prominent underflow stream and fainter background noise. Regions indicated in red rectangles highlight the most noticeable background noise reduction.

3.1.4. Extraction of horizontal line

To keep processing requirements to a minimum, a single horizontal line was extracted from the images along which the underflow width was determined. That is, instead of processing an entire (two-dimensional) image, a single (one-dimensional) vector of intensity values only was processed. The conceptual spray profile,

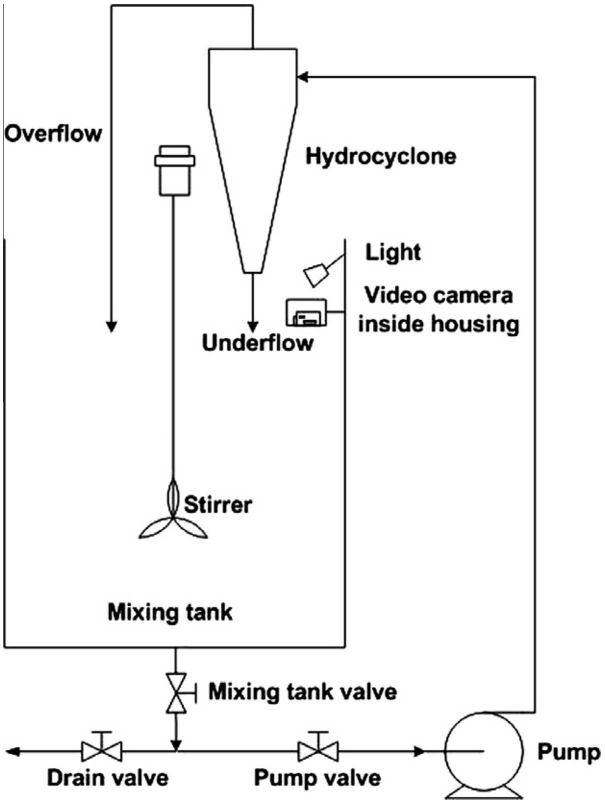

Fig. 2. Schematic diagram of hydrocyclone monitoring setup.