Minerals Engineering 126 (2018) 44–51

Contents lists available at ScienceDirect

Minerals Engineering

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

Particulate concentration distribution in centrifugal air classifiers

Mohammad Barimani, Sheldon Green*, Steven Rogak

Department of Mechanical Engineering, University of British Columbia, Canada

ARTICLE INFO

Keywords:
Centrifugal air classifier
CFD
Particle concentration

ABSTRACT

Centrifugal air classifiers are used to separate particles as small as 3 microns from a mixed-size dust. In this paper, the flow in a high-speed classifier is simulated. The 3-d air-phase Reynolds-averaged Navier–Stokes equations are solved in the classifier with two different turbulence closure models. The Discrete Phase Model, which neglects inter-particle interactions, is utilized to track particles in the airflow. The model also permits one to calculate particulate concentration contours in the classifier. We find that particles of diameter near the classifier cut-point are dramatically concentrated (by factors in excess of 100) in locations near the outer blade radius. We speculate that this high concentration makes particle–particle interactions much more important than expected based on the feed concentration, which could in turn reduce the acceptance of the smallest particles.

1. Introduction

Centrifugal air classifiers are used to separate the fine portion from a mixed-size dust (Shaprio and Galperin, 2005; Galk et al., 1999). For example, they are used industrially to produce ultrafine calcium-carbonate with aerodynamic diameter below 5 µm. Recently, Fu et al. (2017, 2016) have shown the capacity to separate dust particles as fine as 2.5 µm in a custom hydrocyclone, although this separation was done with very dilute dust (2000 mg/m^3), at a concentration well below what would be suitable in a bulk classification process in industry. Fig. 1, shows a typical centrifugal classifier. Air carrying the mixed-size feed is introduced around the outer diameter of the rotating vaned rotor (Fig. 2). Nearly all of the air flows through the rotor, radially inward, dragging the finest particles with it. The drag on coarser particles is lower than the centrifugal force acting on them, and consequently they are flung to the outside radius of the classifier, where they may be collected either by gravity or by way of a small airflow.

As alluded to above, the underlying principle of centrifugal air classifiers is the balance between the inward drag force due to the air flow and the outward centrifugal force due to the high speed rotation (additional forces due to particle radial acceleration are orders of magnitude less than the other forces). For fine particles, the drag exceeds the centrifugal force and the particles migrate to the “accept” stream. For this ideal classifier, 100% or particles smaller than a particular size, d_c = “cut-size”, migrate to the accept stream, and 100% of particles larger than d_c are rejected. In contrast, non-ideal classifiers do not have a very sharp delineation between the size of the accept and reject streams, but rather, for all but very large diameter particles, some fraction of a particular size of particles is rejected, and the other fraction is accepted.

The performance of a centrifugal air classifier is characterized by the transfer function F, which is the fraction of particles of a given size that end up in the reject stream. The main purpose of classifier modelling is to predict and understand the shape of F. The size distribution of the feed, convolved with F, determines the size distribution of the reject particles. The transfer function F is described by d^x, where x percent of all particles with diameter d are recovered in the coarse fraction (reject stream), as shown in Fig. 3.

As particles in the classifier move quasi-statically, the radial equation of motion of an individual particle is:

$$F_c + F_d = 0 \tag{1}$$

where F_c and F_d are respectively the centrifugal force produced by the rotation of the particle about the classifier center and the drag force produced by the surrounding (inwards) airflow. From Eq. (1) it is possible to derive the “cut-size” of an ideal classifier subject to the following assumptions: the drag on a particle is given by the drag on an isolated sphere of diameter d in the Stokes flow regime; particulate classification occurs at an effective radius R between the root and the tip of the blade; the tangential velocity of a particle at R is ωR; the radial velocity is uniform circumferentially; the flow is incompressible. Then the cut size, d_c, is given by Eq. (2):

$$d_c = \sqrt{\frac{9\nu\rho_a Q}{\pi\rho_p hR^2\omega^2}} \tag{2}$$

where ω is the angular velocity of the rotor, Q is volumetric flow rate, h is rotor height, ν is kinematic viscosity, ρ_a is air density and ρ_p is particle density.

---

* Corresponding author.
E-mail addresses: barimani@alumni.ubc.ca (M. Barimani), green@mech.ubc.ca (S. Green), rogak@mech.ubc.ca (S. Rogak).

https://doi.org/10.1016/j.mineng.2018.06.007
Received 10 April 2018; Accepted 6 June 2018

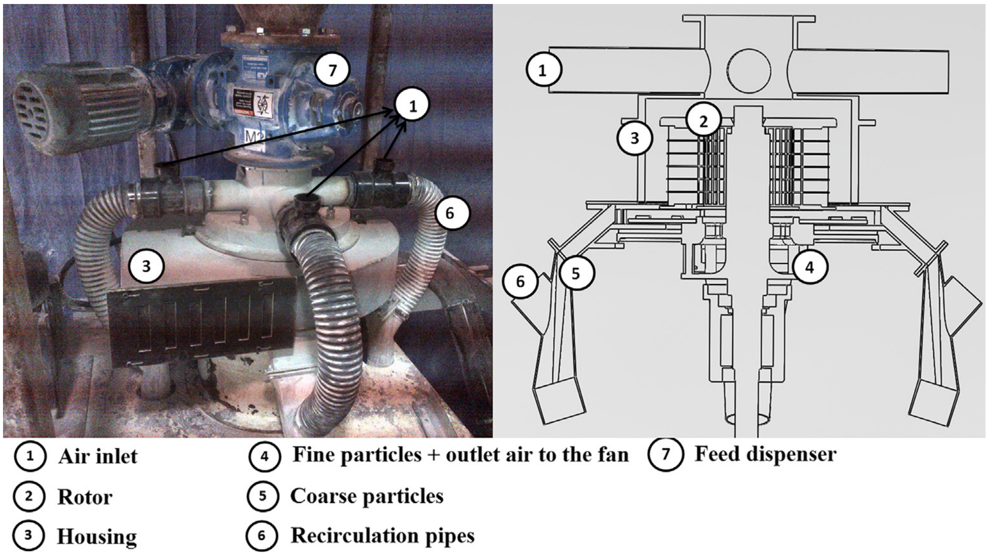

Fig. 1. Different sections of the classifier.

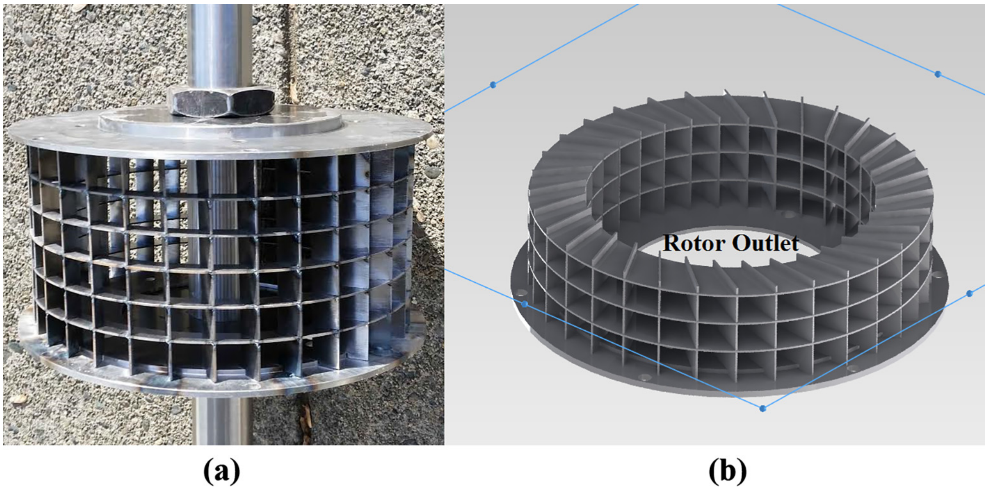

Fig. 2. Rotor cross-section.

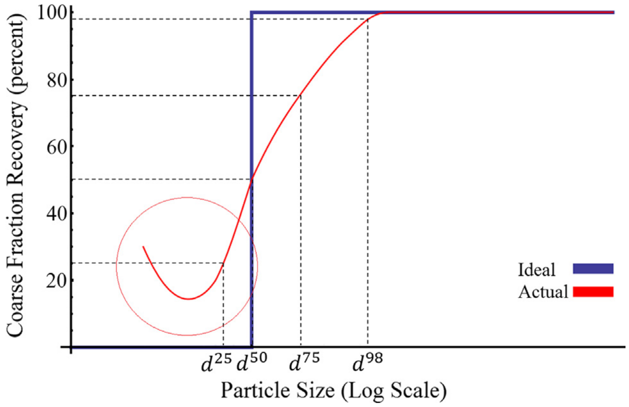

Fig. 3. Cut-size and fishhook.

Many models have been proposed for predicting the transfer function as a function of classifier parameters. Wang et al. (1998) proposed a mathematical model that predicts the cut size in which the effect of rotor blade angle is emphasized. Gimbun et al. (2005) compare one CFD and four established empirical models for hydrocyclones with their own experimental data and conclude that the CFD is more accurate. In recent years many studies employing CFD have been used to predict classifier performance. For example, Karunakumari et al. (2005) developed a geometrically complete model of a centrifugal air classifier and focused on the influence of stationary vanes and rotor rotational speed on the flow structure and particle trajectories.

In recent years the focus of the CFD simulations has shifted to the “fish-hook” effect, which is an unexpected increase in the recovery of fine particles in the underflow (reject stream; see red circle on Fig. 3). Based on their simulations, Eswaraiah et al. (2012) conclude that the main cause is particulate bounce in circulation air classifiers. Guizani et al. (2014) subsequently discovered secondary recirculation flows and bubble-type vortex breakdown occur inside the rotor and consider it to be the main cause of fish hook.

All CFD simulations of air classifiers in the literature consider the whole geometry of the device. Due to the limitation of computational resources, a relatively large cell length is hence incorporated. In this paper, on the other hand, we focus on a periodic section of the rotor while using almost the same number of cells (up to a million cells). This results in a more accurate solution to the flow. Additionally, prior simulations have not provided details of the particle classification mechanism nor how particles are distributed in the rotor. In this article the flow field and particulate concentration distribution occurring in a classifier is simulated. The simulations show that the mean residence