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Prediction of magnetite segregation in dense medium cyclone using computational fluid dynamics technique

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Abstract

Multi-phase simulations of turbulent driven flow in a dense medium cyclone with magnetite medium have been conducted in Fluent, using the Algebraic Slip Mixture model to model the dispersed phases and the air-core, and both the Large Eddy Simulation turbulence model (LES) and Reynolds Stress Models (RSM) for turbulence closure. The predicted air-core shape and diameter were found to be close to the experimental results measured by gamma ray tomography. It is possible to use the LES turbulence model with ASM multi-phase model to predict the air/slurry interface accurately. Multi-phase simulations (air/water/medium) show appropriate medium segregation effects but over-predict the level of segregation compared to that measured by gamma ray tomography near the wall. This is believed to be because of unaccounted back-mixing of the dispersed phase due to turbulence in the basic Algebraic Slip Mixture model. The predictions of accurate axial segregation of magnetite medium are investigated using the LES turbulence model in conjunction with the multi-phase mixture model and viscosity corrections according to the feed particle loading factor. At higher feed densities the agreement between the Dunglison [Dunglison, M.E., 1999, A general model of the dense medium cylone, PhD thesis, JKMRC, University of Queensland] correlations and experimental measurements and the CFD is reasonably good, but the overflow density is lower than the model predictions. It is believed that the excessive underflow volumetric flow rates are responsible for under prediction of the overflow density. The effect of size distribution of the magnetite has been fully studied. As expected, the ultra-fine magnetite sizes (i.e. 2 and 7 microns) are distributed uniformly throughout the cyclone. As the size of magnetite increases, more segregation of magnetite occurs close to the wall.

Keywords: Dense medium cyclone; Magnetite; Multi-phase modeling; Navier–Stokes equation; Particle segregation; Turbulence; Tomography; Empirical models; Viscosity

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1. Introduction

A dense medium cyclone (DMC) effects a sharper separation than can be obtained in other types of coal-washing equipment handling the same size range, usually 50–0.5 mm size range. For hard-to-clean coal (+ 10% near gravity material) in the size range of 50 mm to 0.5 mm, DMCs are very effective. In a typical DMC, illustrated in Fig. 1(a) mixture of medium and raw coal enters tangentially near the top of the cylindrical section, thus forming a strong swirling flow. The refuse or high ash particles move along the wall of the cyclone due to the centrifugal

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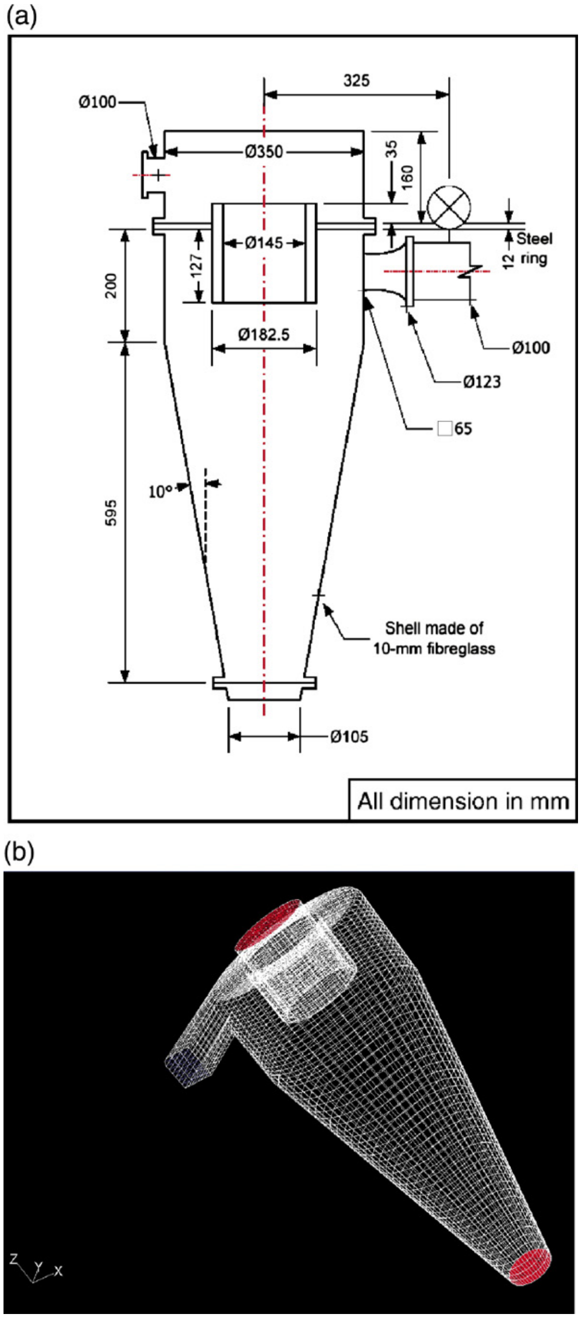

Fig. 1. (a) Detailed dimensional drawing of the 350 mm DSM dense medium cyclone used for simulations, (b) Grid generated in Gambit.

force, where the velocity is least and is discharged through the underflow orifice or the spigot. The lighter washed coal moves towards the longitudinal axis of the cyclone due to the drag force where a high velocity zone exists and passes through the overflow orifice, or vortex finder, also termed as overflow chamber.

The flow behavior in DMC is quite complex. This complexity of fluid flow in DMCs is basically due to the existence of the medium, the dominance of particle turbulence and the density effect on separation. The complexity of flow processes has led designers to rely on empirical equations for predicting the cyclone performance. These empirical relationships are derived from an analysis of experimental data and include the effect of operational and geometric variables. Different sets of experimental data lead to different equations for the same basic parameters. However, these models suffer from the inherent deficiency of any empirical models — they can only be used within the extremes of the experimental data from which the model parameters were determined. In view of this shortcoming, mathematical models based on fluid mechanics are highly desirable.

Computational Fluid Dynamics (CFD) is a versatile means to predict velocity profiles under a wide range of design and operating conditions. The numerical treatment of Navier–Stokes equations the back-bone of any CFD technique, gradually crept into the analysis of hydrocyclones in the early 1980s. This resulted from the rapid improvement in computers and a better understanding of the numerical treatment of turbulence.

Detailed studies in regard of experimental, empirical and analytical modeling and computational modeling of the fluid flow pattern, pressure drop, and solids motion in hydrocyclones have been widely carried out by many researchers (Kelsall, 1952; Pericleous and Rhodes, 1986; Hsieh, 1988; Davidson, 1988) however, for DMCs such information is very limited. DMCs have been mainly subjected to experimental and analytical studies (Davis, 1994; Napier-Munn, 1990; Wood 1990). Within the experimental studies, only parametric studies analyzing the influence of geometrical and operating variables on the efficiency of separation are reported. The utility of this information is limited. There is an extensive literature on the performance of dense medium separation (DMS) processes in both coal (low density) and mineral (high density) applications (Napier-Munn, 1990). However, very few workers have grappled successfully with the problem of developing effective mathematical models of DMS processes for simulation, other than the trivial option of using partition curves with arbitrary parameter selection.

Reported computational modeling of DMCs is very limited (Zughbi et al., 1991, Suasnabar, 2000 and Brennan et al., 2003). CFD studies on cyclone separators have been reviewed by Brennan et al. (2003), Suasnabar (2000) and also by Slack et al. (2000). The seminal CFD study is that of Hsieh (1988) with further publications by co-workers (Hsieh and Rajamani, 1991,