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How to optimize design and operation of dense medium cyclones in coal preparation

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ABSTRACT

The dense medium cyclone (DMC) is a high-tonnage device widely used to upgrade run-of-mine coal in the modern coal industry. It is known that a small improvement on the performance of DMC may greatly enhance industrial profitability. Therefore, it is very useful to develop an effective method to help optimize the design and operation of DMCs. Recently, based on the numerical experiments performed by Computational Fluid Dynamics and its combination with Discrete Element Method; the authors have established a PC-based mathematical model that looks promising to achieve this design and operational goal. In this paper, the authors will first discuss how to use this model to design high capacity or high efficiency DMCs for coal preparation through representative examples, in comparison with several typical designs in the industry. Some rules for DMC scale-up are then proposed for general application. The results further demonstrate that this DMC model can indeed offer a convenient way for optimum design and/or operation of DMCs under different conditions.

1. Introduction

The dense medium cyclone (DMC), also known as the heavy medium cyclone, is the work horse of modern coal preparation to upgrade run-of-mine coal in the 0.5–50 mm size range. Its working principle has been well documented (King and Juckes, 1984; Svarovsky, 1984; Wills, 1992; Chu et al., 2009a). A small improvement on the performance of DMC may significantly improve industrial profitability. One important way to achieve this goal is to manipulate geometrical design variables and/or operating conditions. Therefore, the study on how to optimize the design and operation of DMCs is very important.

Most of the previous expertise related to the design of DMC circuits has been developed based on well-established empirical criteria. The researchers at the Dutch State Mines developed a proprietary technical manual for DMC circuit design in the 1940s and 50s. This manual provides recommendations for cyclone geometry, inlet pressure, feed medium density and so on, required to achieve a given throughput and cutpoint. However, the manual provides no indication of how sensitive the separation is to variations in operating parameters (Anon, 1985). Consequently, plant operators are often unaware of the impacts that normal variations in operating pressure or circulating medium may have on DMC performance. Several noteworthy performance models regarding the design and operation of DMC circuits were developed during the 1980s by Napier-Munn (1984), Rao et al. (1986), Davis (1987), King and Juckes (1988) and Scott (1988). Nevertheless, few of these early models were able to directly link the independent design and operating variables (geometry, inlet pressure, magnetite type, etc.) to dependent variables such as specific gravity cutpoint (D_{50}) or Ecart probable (Ep). Accordingly, the engineering knowledge required to properly design and operate DMC circuits remained largely incomplete. Since the late 1980s, in conjunction with other researchers, Wood (1990) and Clarkson and Wood (1993) developed a mathematical model together with simulation program and user handbook for the design, evaluation and optimization of DMC circuits. However, these relationships are all derived from an analysis of experimental data. Such an empirical model can only be used within the range of the experimental data from which the model parameters were determined. For example, it cannot be used for large DMCs which have become more and more popular in the coal industry. Moreover, it gives no indication as to why changes in cyclone geometry influence separation behavior in any fundamental sense. In fact, constrained by the research techniques and conditions, previous empirical work has to be limited to phenomenological descriptions that rarely touch upon the underlying physics (e.g. the particle–particle, particle–fluid and particle–wall interactions).

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Nomenclature

a,b	fitting parameters	RD	relative density
X_i	independent variable (input condition)	D_{50}	cut density, RD
Y	dependent variable (performance)	E_p	Ecart Probable, RD
D_c	cyclone diameter, mm	Q	flow rate, m^3/h
L_i	inlet diameter, mm		
D_0	vortex finder diameter, mm	*Greek letter*	
D_u	spigot diameter, mm	ρ_f	medium feed density, kg/m^3
L_c	length of cylindrical part, mm		
L_v	length of vortex finder, mm	*Subscript*	
L_p	length of conical section, mm	f	feed medium
α	cone angle, °		

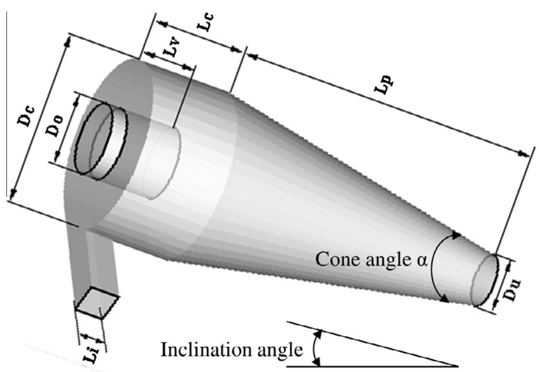

Fig. 1. Geometrical representation of a DMC unit in this work.

Fundamental modelling offers the potential to overcome the empirical limitations as mentioned above. It is also able to provide a better understanding of the working mechanisms of DMCs. In recent years, Computational Fluid Dynamics (CFD) and its combination with Discrete Element Method (DEM) have been developed to study the complex medium-coal multiphase flow in a DMC. This approach has been successfully applied to dense medium cyclones (Chu et al., 2009a; Wang et al., 2009a). The CFD or CFD–DEM model in particular, however, suffers from high cost of computation. Typically, the computational time required to simulate a given DMC operational condition is many weeks/months on a single central processing unit available in the market. Clearly, this is an important research tool that can be used on a case-by-case basis, but it is not suitable as an industrial engineering tool, as simulation results could not be generated in a realistic time frame to satisfy most engineering needs. To overcome this difficulty, based on the concentrated CFD and CFD–DEM simulated results, a mathematical model which can be readily run by a personal computer (PC), has been formulated to describe the performance of DMCs as a function of a range of variables in a cost-effective way (Chen et al., 2012).

In this paper, the PC-based mathematical model is used to optimize several typical DMC designs for the coal industry through representative examples. It will be shown that the optimized designs may be able to achieve high capacity or high efficiency goals in coal preparation. Moreover, some DMC scale-up rules are proposed. These results should be useful for the design, evaluation and optimization of DMC units in coal preparation.

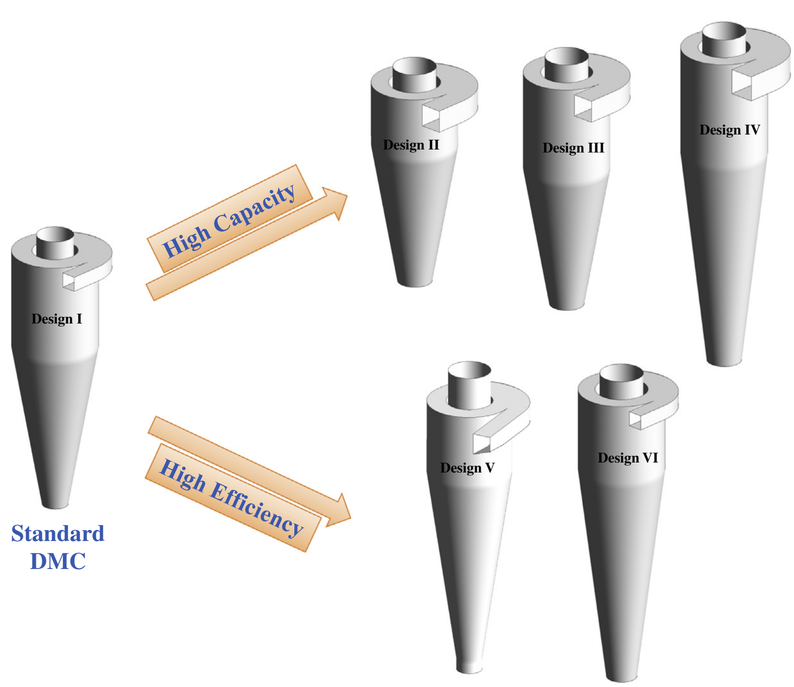

Fig. 2. Different DMC designs (Dc = 1000 mm) considered in this work (see Table 1 for details).