Applied Mathematical Modelling 37 (2013) 5680–5704

Contents lists available at SciVerse ScienceDirect

Applied Mathematical Modelling

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

CFD modeling and multi-objective optimization of cyclone geometry using desirability function, artificial neural networks and genetic algorithms

Khairy Elsayed *, Chris Lacor

Vrije Universiteit Brussel, Department of Mechanical Engineering, Research Group Fluid Mechanics and Thermodynamics, Pleinlaan 2, 1050 Brussels, Belgium

ARTICLE INFO

Article history:
Received 2 August 2011
Received in revised form 1 October 2012
Accepted 15 November 2012
Available online 14 December 2012

Keywords:
Cyclone separator
Response surface methodology (RSM)
Computational fluid dynamics (CFD)
Multiobjective optimization
Desirability function
Genetic algorithms

ABSTRACT

The low-mass loading gas cyclone separator has two performance parameters, the pressure drop and the collection efficiency (cut-off diameter). In this paper, a multi-objective optimization study of a gas cyclone separator has been performed using the response surface methodology (RSM) and CFD data. The effects of the inlet height, the inlet width, the vortex finder diameter and the cyclone total height on the cyclone performance have been investigated. The analysis of design of experiment shows a strong interaction between the inlet dimensions and the vortex finder diameter. No interaction between the cyclone height and the other three factors was observed. The desirability function approach has been used for the multi-objective optimization. A new set of geometrical ratios (design) has been obtained to achieve the best performance. A numerical comparison between the new design and the Stairmand design confirms the superior performance of the new design. As an alternative approach for applying RSM as a meta-model, two radial basis function neural networks (RBFNNs) have been used. Furthermore, the genetic algorithms technique has been used instead of the desirability function approach. A multi-objective optimization study using NSGA-II technique has been performed to obtain the Pareto front for the best performance cyclone separator.

1. Introduction

Gas cyclones are widely used gas–solid separators using centrifugal forces. Cyclones are popular because of economy, simplicity in construction and adaptability to a wide range of operating conditions [1]. Reversed flow cyclones with a tangential inlet are the most common cyclone design as shown in Fig. 1. It consists of seven main geometrical parameters: inlet section height a and width b, cylinder height h, cyclone total height H_t, dust exit diameter (cone tip diameter) B_c, gas outlet diameter (also, called vortex finder diameter) D_x and vortex finder length S. All these parameters always given as a ratio of the cyclone body diameter D. It is generally known that these seven dimensions characterize the collection efficiency (cut-off diameter) and pressure drop of the cyclone separator [1–3].

1.1. Performance parameters

The cyclone performance is characterized by two parameters: the pressure drop and the collection efficiency. For low mass loading cyclone separators, the collection efficiency can be represented by the cut-off diameter (the particle diameter

* Corresponding author. Tel.: +32 26 29 2368; fax: +32 26 29 2880.
E-mail addresses: kelsayed@vub.ac.be, kelsayed75@gmail.com (K. Elsayed).

0307-904X/$ - see front matter
http://dx.doi.org/10.1016/j.apm.2012.11.010

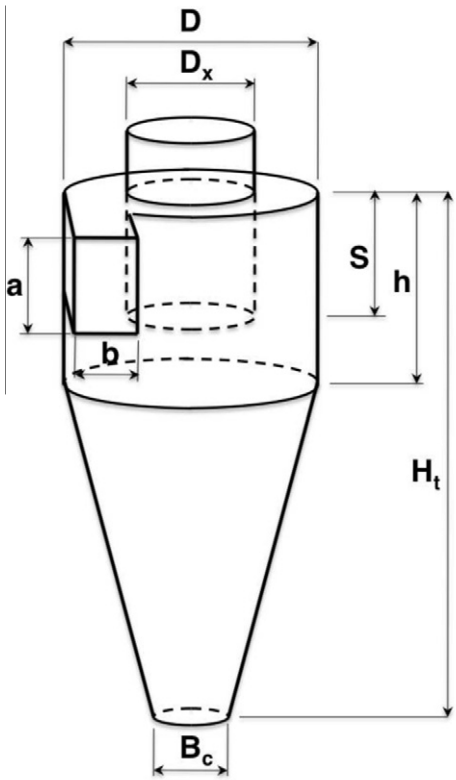

Fig. 1. Schematic diagram for Stairmand cyclone separator.

which produces 50% collection efficiency). Elsayed and Lacor [1] classified the different approaches to model the cyclone performance into four classes.

1. The theoretical and semi-empirical models, e.g., Shepherd and Lapple [4], Alexander [5], First [6], Stairmand [7], Barth [8], Avci and Karagoz [9] and Zhao [10].
2. Statistical models through multiple regression analysis, e.g., Casal and Martinez-Benet [11], Dirgo [12] and Ramachandran et al. [13].
3. Computational fluid dynamics (CFD) approach, e.g., Gimbun et al. [14], Zhao [15], Elsayed and Lacor [1,3,16].
4. Artificial neural networks come into picture as an efficient approach to model the cyclone performance, e.g., Zhao and Sub [17] and Elsayed and Lacor [18,19].

1.2. Previous optimization studies

In 1951, Stairmand [7] presented the geometrical ratios for high-efficiency cyclones. Until now, these ratios are still in use (cf. Fig. 1 and Table 1). Elsayed and Lacor [1] reported the following shortages in the Stairmand model for pressure drop calculation [20] which has been used to obtain these geometrical ratios: (1) the velocity distribution has been obtained from a moment-of-momentum balance, estimating the pressure drop as entrance and exit losses combined with the loss of static pressure in the swirl, i.e., neglecting the entrance loss by assuming no change of the inlet velocity occurs at the inlet area; (2) assuming a constant friction factor [21].

Due to the wide range of industrial applications of the cyclone separator, it was a matter of study for decades. However, the optimization studies on it is quite limited in literature. Moreover, many of these studies are not coherent studies or focus on a specific problem.

Table 1
The geometrical parameters values for Stairmand design.

Cyclone	a/D	b/D	D_x/D	H_t/D	h/D	S/D	B_c/D
Stairmand design	0.5	0.2	0.5	4	1.5	0.5	0.375