ARTICLE IN PRESS

Journal of Aerosol Science xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Journal of Aerosol Science

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

Particle size cut performance of aerodynamic cyclone separators: Generalized modeling and characterization by correlating global cyclone dimensions

Bingtao Zhao[a,*], Yaxin Su[b]

[a] School of Energy and Power Engineering, University of Shanghai for Science and Technology, 516 Jungong Road, Shanghai 200093, China
[b] School of Environmental Science and Engineering, Donghua University, 2999 North Renmin Road, Shanghai 201620, China

ARTICLE INFO

Keywords:
Particle cutoff size
Aerodynamic cyclone
Global cyclone dimensions
Generalized modeling

ABSTRACT

To generalize the characterization of particle-size cut performance for aerodynamic cyclones, a data-driven modeling approach using two varied correlating strategy $\Psi_{0.5}=C_c^{1/2}d_{p0.5}/D$ and $Stk_{0.5}=(C_c\rho_p d_{p0.5}^2 v_i)/(18\,\mu D)$ was proposed. This approach correlated the global influencing parameters including cyclone dimensions, operating conditions and multiphase properties which have not ever completely included before. The proposed models integrated the external geometrical dimensions (cyclone inlet area (ab/D) and vortex finder diameter D_e/D) into a annular Reynolds number $Re_a=\rho_g Q(D\text{-}D_e)/[\mu(ab)]$, and used a special body dimensionless parameter D_B/D derived from an equivalent volume method to characterize effect of the cyclone body dimensions: vortex finder length S/D, cyclone height H/D, cylinder height h/D and particle outlet diameter B/D. Results showed that the proposed $\Psi_{0.5}$–based correlation improves the predictive ability and generalization performance compared to the other corresponding theoretical and regression models. Furthermore, the influence of cyclone dimensions and operating parameters on particle cutoff size was quantitatively addressed based on the proposed model. The result may provide a reference for performance assessment, design improvement and global optimization of aerodynamic cyclones applied both industrial process and aerosol sampling.

1. Introduction

Although the aerodynamic cyclone separator (Fig. 1) has been widely and successfully used for gas-particle separation and classification in the fields of aerosol/particle science technology, it still has the challenging issues particularly the characterization of separation performance (Cortés & Gil, 2007; Duquenne, Coulais, Bau, & Simon, 2017; Ganegama & Leung, 2016; Hiraiwa, Oshitari, Fukui, Yamamoto, & Yoshida, 2013; Mazyan, Ahmadi, Ahmed, & Hoorfar, 2017; Siadaty, Kheradmand, & Ghadiri, 2017). Generally, two indicators are used as the criterion for cyclone separation performance: particle cutoff size and grade separation efficiency. Defined as the particle aerodynamic diameter with 50% grade efficiency, particle cutoff size is of primary importance because it is the fundamental to determine cyclone grade efficiency in most cases. A cyclone with small cutoff size is usually considered to have the high separation performance.

To model and characterize the cyclone cutoff size, a series of efforts have been made using different approaches. Although computational fluid dynamics (CFD) and artificial neural network (ANN) gained great attention recently due to their potential of numerical simulation and approximation to the gas-particle vortex flow and separation (Griffiths & Boysan, 1996; Hoekstra, Derksen,

---

* Corresponding author.
E-mail address: zhaobingtao@usst.edu.cn (B. Zhao).

https://doi.org/10.1016/j.jaerosci.2018.02.009
Received 7 September 2017; Received in revised form 22 January 2018; Accepted 27 February 2018

Please cite this article as: Zhao, B., Journal of Aerosol Science (2018), https://doi.org/10.1016/j.jaerosci.2018.02.009

Nomenclature

a	inlet height, [m]
b	inlet width, [m]
B	particle outlet diameter, [m]
$d_{p0.5}$	particle aerodynamic cutoff size, [m]
D	cyclone diameter, [m]
D_a	annular space dimension ($D_a = D$ - De), [m]
D_B	characteristic body dimension (equivalent separation dimension), [m]
D_e	vortex finder diameter, [m]
DR	dimensionless ratio of cyclone, [-]
e	mean absolute error (MAE)
E^2	mean squared error (MSE)
f	$f = \mathrm{r/ref}$, ref is the reference radius
h	cylinder height of cyclone, [m]
H	total height of cyclone, [m]
H_E	equivalent/effective height of gas vortex flow, [m]
L_v	natural vortex length, [m]
Q	gas flow rate, [m^3/s]
r	radius, [m]
R^2	coefficient of determination
Re	Reynolds number, [-]
Re_a	annular Reynolds number, [-]
S	vortex finder length, [m]
$Stk_{0.5}$	cutoff Stokes number, [-]
v_i	gas inlet velocity, [m/s]
v_o	gas outlet velocity, [m/s]
v_t	gas tangential velocity, [m/s]
V_E	equivalent volume of cyclone, [m]
Greek letters	
α,β,γ	regression coefficients
ρ_g	gas density, [kg/m^3]
ρ_p	particle density, [kg/m^3]
μ	gas dynamic viscosity, [Pa s]
$\Psi_{0.5}$	dimensionless cutoff size number, [-]

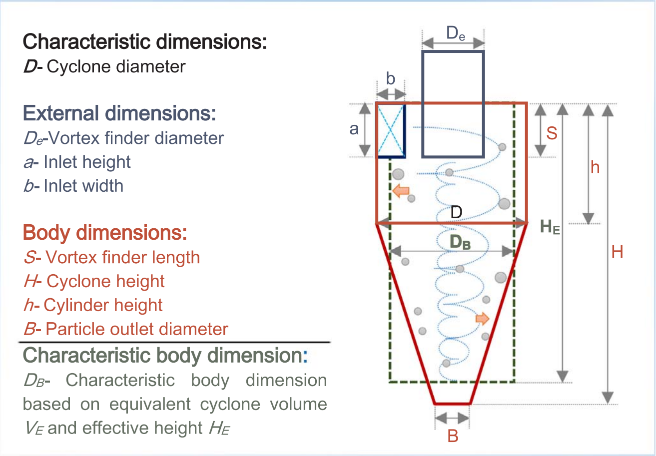

Fig. 1. Schematic diagram of aerodynamic cyclone design.

& Akker, 1999; Safikhani, 2016), they are faced with the challenge of turbulence modeling, parameter optimization and computational cost. Therefore, cyclone cut-performance modeling, assessment and optimization actually mostly rely on non-numerical approaches in particular for the cyclones with varying geometrical configuration and operating conditions (Hsiao, Huang, Hsu, Chen, & Chang, 2015; Ravi, Gupta, & Ray, 2000).

Depending on technical method, the non-numerical approaches can be categorized into the mechanism approaches derived from gas-particle centrifugal separation theory and, the semi-empirical approaches built via data-driven statistical regression. The former includes the models based on time-of-flight theory (Lapple, 1950), back-mixing concentration theory (Leith & Licht, 1972) and equilibrium-orbit theory (also called static particle theory) (Barth, 1956; Iozia & Leith, 1989), respectively. Due to the incorporation of assumptions and simplifications, these mechanism approaches have been demonstrated to be limited in predicting of the cyclone cutoff size. By contrast, the semi-empirical approaches show the great potential in representativeness and generality.

The popularly used cutoff size modeling approaches, as shown in Table 1, are established by the gas-particle dynamic governing equation or the Buckingham π theorem (Burkholz, 1985; Buttner, 1988, 1999; John & Reischl, 1980; Kenny & Gussman, 1997; Kuo & Tsai, 2001; Lidén & Gudmundsson, 1997; Overcamp & Scarlett, 1993; Zhao, 2010; Zhu & Lee, 1999; Saltzman & Hochstrasser, 1983; Moore and McFarland, 1990, 1993, 1996). Currently, most of them correlate the particle cutoff size with only Reynolds number in terms of cyclone diameter D (Overcamp & Scarlett, 1993), vortex finder diameter D_e (Moore & McFarland, 1990) or annular dimension (D-D_e) (Moore & McFarland, 1996; Kuo & Tsai, 2001; Lidén & Gudmundsson, 1997; Zhu & Lee, 1999). Although they are able to predict cutoff size for the cyclone with a specified design, the outstanding questions remain: (1) almost all correlations only consider the cyclone diameter D and vortex finder diameter D_e while neglects the other else key cyclone dimensions, which have been demonstrated to have significantly effect on the particle cutoff size (Altmeyer et al., 2004; Avci & Karagoz, 2003; Azadi, Azadi, & Mohebbi, 2010; Elsayed & Lacor, 2011; Xiang & Lee, 2005; Zhao & Su, 2016). (2) In case of varying structural, operating and physical