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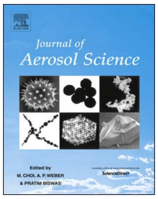

Experimental study of cyclone performance for blow-by gas cleaning applications

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ABSTRACT

The aim of this experimental study is to investigate the separation performances of a new set of small cyclones. The diameter of these cyclones spans the range of 20–45 mm, which is the typical size of these devices when they are used for separating oil mist from blow-by gases in internal combustion engines. To reproduce the flow rates and oil load of combustion engines, we developed a flow bench, with a polydisperse aerosol generator producing engine oil droplets with diameter in a 0.3–10 µm range. Measurements of the aerosol particle concentrations upstream and downstream of the cyclone permitted the determination of the particle collection efficiency, for the six devices that were tested, with flow rates ranging from 20 to 200 Nl/min which are typical operating conditions. For the six cyclones, the geometry is normalized and all internal dimensions within the cyclone are proportional to its diameter. With the operating conditions of this study, the annular Reynolds number varied in the range 1.27×10^3 to 12.2×10^3. From the measured fractional collection efficiency curves, dimensionless cut-off aerodynamic diameters were determined. These measurements have been compared with available correlations for the determination of this dimensionless diameter as a function of the annular Reynolds number. Different correlations are proposed in this study, for the evaluation of the cut-off diameter and for the shape of the collection efficiency. We were able to establish that the collection efficiency curve dimensionless slope is correlated to a Reynolds number.

1. Introduction

Cyclone separators are commonly used in industry to remove solid or liquid particles from a gas stream. These devices are frequently applied to large-scale processes, for both separation and drying applications. Small cyclones have also found various applications, such as personal cyclone samplers applied to environment control. They are also widely used in the automotive industry, particularly in internal combustion engines for the separation of oil mist from blow-by gases. These so-called “blow-by gases” result from leakages between the combustion chamber and the crankcase. These gases flow through the crankcase which contains lubricating oil and the resulting oil mist has to be cleaned up, for pollution control, oil consumption reduction and also to avoid turbo charger oil coking. This is an important feature of crankcase venting systems, and the design of the separation cyclone is of great importance for its collection efficiency: a reduction of the cyclone diameter produces an increase of the collected oil flow, but also results in increased pressure drops.

Various numerical or experimental studies have been carried out to determine the influence of the flow rate and cyclone

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Nomenclature

a	first regression coefficient (dimensionless cut-off aerodynamic diameter), dimensionless
A_i	regression coefficient (Lidén & Gudmundsson, 1997), dimensionless
b	second regression coefficient (dimensionless cut-off aerodynamic diameter), dimensionless
B_i	cyclone dimensional ratios (Lidén & Gudmundsson, 1997), dimensionless
C_{cmd}	Cunningham-Millikan-Davies coefficient, dimensionless
c_o	ratio of particle mass flow to the air mass flow, dimensionless
d	particle geometric diameter, (m)
d_{ae}	particle aerodynamic diameter, (m)
$d_{50,MM}$	cut-off diameter evaluated using Muschelknautz's model, see Eq. (3), (m)
D	cyclone body diameter, see Fig. 1, (m)
D_o	cyclone vortex finder diameter, see Fig. 1, (m)
D_t	10 mm tube diameter used in connecting parts, see Fig. 2, (m)
$D_{t,mod}$	$D_{t,mod}$ = 30 mm, large tube diameter in improved set-up, see Fig. 20, (m)
D_p	particle diffusivity (Mothes and Löffler's model), ($m^2\,s^{-1}$)
E	collection efficiency, dimensionless
Eu_{in}	Euler number, see Eq. (16), dimensionless
f	wall friction factor in Muschelknautz's model, see Table 1, dimensionless
H	height of cyclone inlet slit, see Fig. 1, (m)
Kn	Knudsen number, dimensionless
L	characteristic cyclone length, (m)
L_b	height of cylindrical part of cyclone, see Fig. 1, (m)
L_c	height of conical part of cyclone, see Fig. 1, (mm)
Q_v	volumetric flow rate, $Nl\,min^{-1}$ (Normal Liter per Minute, Normal conditions being 0 °C and 1.01325 Pa)
R_{in}	radial position of the center of the inlet in Muschelknautz's model, see Table 1, (m)
R_m	geometric mean radius in Muschelknautz's model, see Table 1, (m)
Re_R	cyclone body Reynolds number in Muschelknautz's model, see Table 1, dimensionless
Re_{ann}	annular cyclone Reynolds number, dimensionless
Re	Reynolds number, dimensionless
S	vortex finder length, see Fig. 1, (m)
S_f	friction surface in Muschelknautz's model, see Table 1, (m^2)
St	Stokes number, see Eq. (1), dimensionless
U	characteristic gas velocity in cyclone, ($m\,s^{-1}$)
u_{in}	average gas velocity at cyclone inlet, ($m\,s^{-1}$)
v_o	outlet axial velocity in the vortex finder, in Muschelknautz's model, see Table 1, ($m\,s^{-1}$)
v_{zw}	“wall axial velocity” in Muschelknautz's model, see Table 1, ($m\,s^{-1}$)
$v_{\theta CS}$	“spin velocity near the wall” in Muschelknautz's model, see Table 1, ($m.s^{-1}$)
$v_{\theta m}$	“geometrical mean rotational velocity” in Muschelknautz's model, see Table 1, ($m.s^{-1}$)
W	width of cyclone inlet slit, see Fig. 1, (m)
W_1	dimensionless slope, see Eq. (15), dimensionless
$x_{fact,MM}$	correction factor in Muschelknautz's model, see Eq. (3), dimensionless

Greek letters

α	entrance “constriction coefficient” in Muschelknautz's model, see Table 1, dimensionless
η	collection efficiency, dimensionless
κ_1	steepness parameter for cyclone efficiency, see Eq. (15), dimensionless
μ_g	gas dynamic viscosity, ($kg\,m^{-1}\,s^{-1}$)
ρ_g	gas density, ($kg\,m^{-3}$)
ρ_p	particle density, ($kg\,m^{-3}$)
ξ_b	cyclone body pressure loss coefficient, based on v_o in Muschelknautz's model, see Table 1, dimensionless
ξ_o	outlet tube pressure loss coefficient, based on v_o in Muschelknautz's model, see Table 1, dimensionless
ξ	$W/(0.5D)$ in Muschelknautz's model, see Table 1, dimensionless
Ψ_{50}	dimensionless cut-off aerodynamic diameter or cut-off parameter, see Eq. (5), dimensionless

Subscripts

50	at 50% efficiency
in	at the inlet conditions
MM	corresponding to Muschelknautz's model, see Table 1.
ML	corresponding to Mothes & Löffler's model

geometrical parameters on the separation performances. Cut-size diameters which correspond to 50% collection efficiency have been reported in the literature, for a wide range of cyclones, together with theoretical models. Cortés and Gil (2007) proposed a review of these models developed for the evaluation of the cyclone separators collection efficiency. However, it should be noted that currently available studies on small cyclones with liquid aerosol are limited.

In this experimental study, we propose to investigate the collection efficiency performances of a new set of six small cyclones with diameters in the range of 20–45 mm (C-20 to C-45), which are typical of combustion engine crankcase applications where oil droplets polydisperse aerosols are collected. This set of cyclones which are fully homothetic will be referred to as the SFYB family.

2. Review of cyclone modeling

2.1. Cut-off diameter

Together with the pressure drop, the major characteristic of a cyclone flow is the cut-off diameter $d_{ae,50}$ that corresponds to a 50%