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Improvements of the cyclone separator performance by down-comer tubes

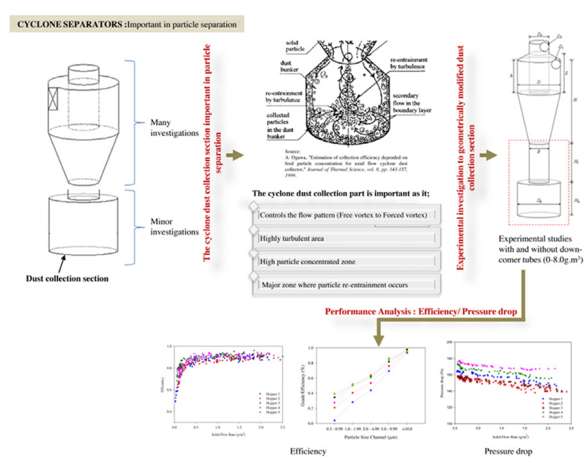
Sakura Ganegama Bogodage*, A.Y.T. Leung

Department of Architectural and Civil Engineering, City University of Hong Kong, 83 Tat Chee Avenue, Kowloon, Hong Kong Special Administrative Region, China

HIGHLIGHTS

- Experiments were done on cyclone separators with/without bottom down-comer tubes.
- Cyclone performance parameters were evaluated for different solid loading rates.
- Discussed improvements of fine particle collection (PM 2.5) with down-comer tubes.
- Results were compared with established theories.

GRAPHICAL ABSTRACT



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ABSTRACT

Enhancement of fine particle (PM2.5) separation is important for cyclone separators to reduce any extra purification process required at the outlet. Therefore, the present experimental research was performed to explore the performance of cyclone separators modified with down-comer tubes at solid loading rates from 0 to 8.0 g/m^3 with a 10 m/s inlet velocity. The study proved the effectiveness of down-comer tubes in reducing the particle re-entrainment and increasing the finer separation with acceptable pressure drops, which was pronounced at low solid loading conditions. The experimental results were compared with theories of Smolik and Muschelknautz. Theories were acceptable for certain ranges, and theory breakdown was mainly due to the neglect of particle agglomeration, re-entrainment and the reduction of swirling energy, as well as the increase of wall friction due to presence of particles.

1. Introduction

Although cyclone separators are popular in today's particle-handling industry, the enhancement of fine particle collection is still a demanding topic. Filters or recirculation of processed air are usually combined with cyclone operation to increase the fine par-

* Corresponding author.
E-mail addresses: sganegama2-c@my.cityu.edu, sakurabogoda@gmail.com (S. Ganegama Bogodage).

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Nomenclature

A_R	Total wall area of cyclone contributes to frictional effect, m^2
a	Cyclone inlet height, m
B	Cyclone bottom/down-comer tube diameter, m
C	Solid loading rate (as a mass fraction)
C	Solid loading rate (concentration), g/m^3
$C_{(.)}$	Solid concentration, g/m^3
C_{0L}	Critical loading as a mass fraction
D	Cyclone body diameter, m
D_e	Vortex finder diameter, m
D_h	Hopper diameter, m
d	Particle diameter, μm
D_i, D_o	Inlet/outlet diameter of the tested cyclone, m
d_{fact}	Modification factor in Muschelknautz d_{50} equation
d_{50}	Cut size diameter, μm
f	Friction factor
f'	Frictional effect contributes with the effect of air and solid
H	Cyclone separator height, m
H_h	Hopper height, m
H_t	Down-comer tube height, m
h	Cyclone cylinder height, m
M_c	Mass of particles collected, g
M_{in}	Mass flow rate of incoming particles, g
MF_i	i^{th} mass fraction
P, p	Pressure, Pa
Q	Flow rate, m^3/s
R	Radius, m
S	Vortex finder height, m

Greek Letters

Δ	Difference in
η	Collection efficiency
θ	Tangential coordinate
μ	Dynamic viscosity of air, m^2/s
ρ	Density, kg/m^3

Subscripts

0	Start or reference
1, 2	Indicating spatial points or solids loadings
acc	Due to acceleration into the cyclone inlet
body	Cyclone body
CS	Cyclone control surface
e	Vortex finder
g	Gas
i	i^{th} fraction
in	Inlet
m	Geometric mean
p	Particle
str	Of a strand of solids
tot	Overall
w	Cyclone wall

ticle separation, which may increase the operational cost as well. Previous studies found that the major role of particle separation governs by the lower section of the cyclone separator due to effects of the natural vortex length of the flow, higher tangential velocities, particle re-entrainment and high particle concentrated zones [1–3]. However, further geometric modifications to this section are difficult (*i.e.*, the height of the cyclone cone and the diameter of the bottom opening) due to natural vortex length of the flow [1] (as quoted by Xiang et al. [4]).

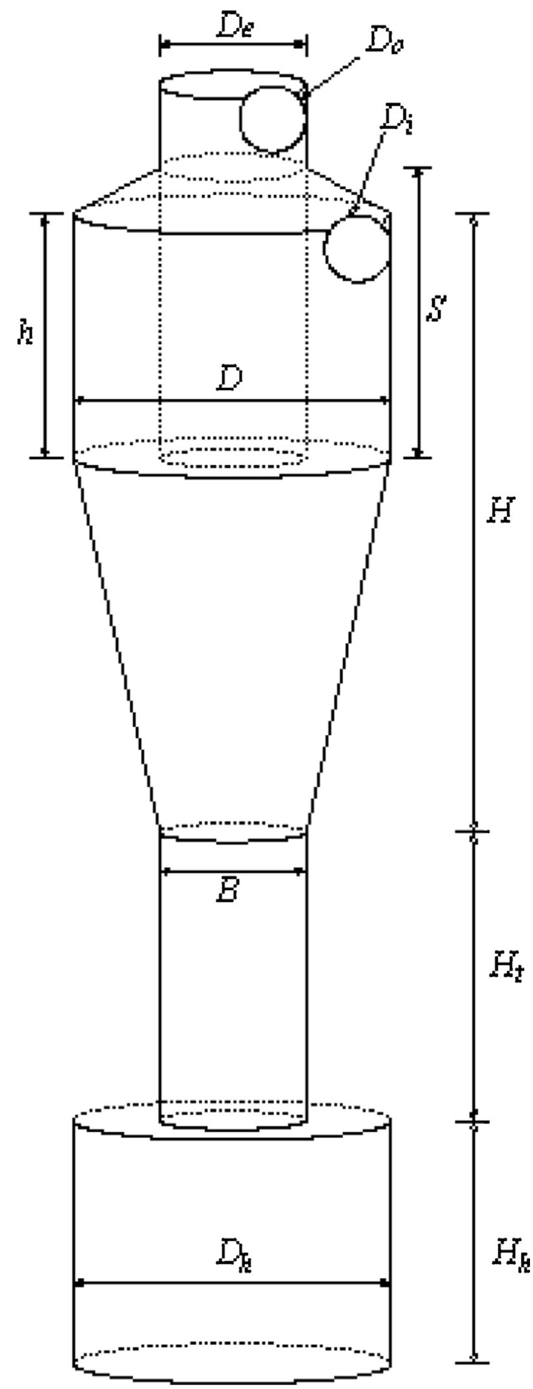

Fig. 1. Geometry of the cyclone separator.

The solid re-entrainment from the hopper is certain, as it is stifled at the cyclone bottom [5]. Mothes [2] investigated the movements of particles inside the cyclone separator and found higher particle concentrations near the cyclone bottom rather than at the cyclone inlet due to the particle concentrations that were 1) in the gas flow entering the dust collection hopper, and 2) re-entraining with the exit gas flow (as quoted by Obermair et al. [6]). This study indicated a requirement for control of particle re-entrainment from collection hoppers. However, in the literature, only a few studies investigated this section to minimize the solid re-entrainment from the dust collection hopper. For example, the studies modified the cyclone dust collection section by introducing apex cones [6–10], additional hoppers [6,9] and down-comer