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Performance and capacity of centrifugal gas cleaning devices

Mohamed S. Saad

University of Wollongong

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By

Mohamed S. SAAD

BSc, MEng.

School of Mechanical, Materials and Mechatronic Engineering.

Faculty of Engineering

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DECLARATION

I, Mohamed SAAD, declare that this thesis, submitted in fulfillment of the requirements for the award of the degree of Doctor of Philosophy, in the Faculty of Engineering at the University of Wollongong, is wholly my own work unless otherwise referenced or acknowledged. The document has not been submitted for qualifications at any other academic institution.

Wollongong, Australia

Mohamed SAAD
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ABSTRACT

The purpose of dust control systems is to capture, collect and dispose of contaminant in an efficient manner. This research examines how to improve the operational and collection efficiency of gas cleaning devices via variations in geometry of different cyclone components. Unfortunately many of the predictive models provide inaccurate and contradictory results. Furthermore, many practical issues such as outlet and inlet configurations have not been investigated properly or at all. This study investigates the effect of cyclone outlet (vortex finder) diameter on cyclone pressure drop. Two cyclone configurations were used: air discharging directly to atmosphere; air discharging through a pipe connected to a filter. The measured values of cyclone pressure drop were compared with pressure drop predictions from various models (e.g. EEUA, 1997; Jacob et al., 1979; Rhodes, 1998; Mason et al., 1983; and Zenz, 1999). This comparison showed significant variations and differences compared with the experimental results. The models of Jacob and Dhodapkar (1979) and Mason et al. (1983) predicted similar values and were closest to the experimental data. The research evaluated existing models and developed new improved models for this purpose. A new theoretical model for pressure drop prediction across the cyclone is presented based on the consideration of the dissipative loss of flow in the cyclone system. Two
different sizes of vortex finder (gas exit diameters) were used for this modeling of pressure drop. The models of Stairmand (1949), Jacob Dhodapkar (1979), Mason et al. (1983), Rhodes (1998), EEU (1987) and Zenz (1999) predicted significantly lower pressure drops than the experimental values. The model of Barth (1956), with two values of $k_1$ and $k_2$ for rounded and sharp edges, respectively, predicted significantly higher values than the experimental data. Furthermore, the maximum solids flow capacity of cyclone separators was investigated. Different bulk solids and air flows were tested under different conditions: maximum solids flow rate under pneumatic conveying conditions (before choking); choked gravity flow from the test cyclone; and different gravity flow conditions from a hopper. The results obtained in this study were compared with the predictions of Beverloo et al. (1961), Brown (1961), Zenz (1962) and Johanson (1965). Results show that the Johanson (1965) model provides reasonable agreement with the experimental results.
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LIST OF SYMBOLS

A : cross sectional area of the silo [m²]

A₀ : outlet cross sectional area [m²]

Aᵣ : total wall area of the cyclone body [m²]

a : constant at section 2.2.3.4 [-]

a : condition at section 2.2.3 [-]

a : height of the cyclone inlet as defined in Fig. 2.1 [m]

a : average vertical acceleration of the material [m/s²]

aᵥ : bulk material acceleration in hopper due to
convergence of the channel [m/s²]

aᵥ : bulk material acceleration in the hopper due to
increase in the velocity at the hopper outlet after
the discharge [m/s²]

B : dust outlet diameter as defined in Fig. 2.1 [m]

B : barrel at section 3.5.5 [-]

b : width of the cyclone inlet as defined in Fig. 2.1 [m]

b : condition at section 2.2.3 [-]

b : constant at section 2.2.3.4 [-]

C : constant at section 3.5 as shown in Fig. 3.4 [-]
C : loss coefficient at section 3.5.4 [-]
C : constant at section 5.5 [-]
c : concentration of particles in inlet gas stream at section 2.2.3 [g/m³]
c : vortex core at section 3.4 [-]
c : cyclone at section 3.5 [-]
CS : in the surface CS, as shown in Fig.3.4 [-]
D : diameter [m]
D : the distance between the starting point to the ending point for a single particle at section 4.6.1 [m]
Dd : diameter of cyclone dust outlet [m]
De : diameter of gas exit (vortex finder) [m]
DP : differential pressure drop between the entrance point and the gas exit point [Pa]
D0 : hopper outlet diameter [m]
dp : particle diameter [mm]
din : inlet diameter at section 3.5 [m]
dahi : inlet hydraulic diameter at section 3.5.5 [inch]
d50 : cut particle diameter (50% efficiency) [m]
Eu : Euler number, ΔP/(1/2 ρ v²) [-]
E : exit at section 3.5
ff : critical flow factor based on minimum opining dimension [-]
ff\(_a\) : actual flow factor based on actual opining dimension [-]
f : wall friction factor [-]
G : friction factor in Stairmand equation = \(f/2\) [-]
g : gravity acceleration [m/s\(^2\)]
H : total height of the cyclone as defined in Fig. 2.1 [m]
H : total height of the sample cone at section 4.4.5 [mm]
H\(_1\) : height of the sample plate from the top of the stand [mm]
H\(_2\) : height from the tip of the sample cone to the top of the stand [mm]
H(\(\alpha\)) : factor to take into account the variation in hopper type [-]
h : height of the cyclone barrel [m]
h\(_c\) : height of the cyclone cone [m]
h\(_h\) : vertical height of hopper [m]
K : constant in Barth’s pressure drop model at section 3.4.1.2 [-]
K : flow straightener loss coefficient [-]
k : proportionality constant at section 2.2.3 [-]
k : particle shape constant at section 5.5 [-]
L : length of the sample plate [mm]
M : mass flow of solids [kg/s]
\(M_c\) : mass flow rate of solids collected [kg/s]

\(M_e\) : mass flow rate of solids entrainment [kg/s]

\(M_f\) : mass flow rate of solids fed [kg/s]

\(M_{fa}\) : mass flow rate of air [kg/s]

\(M_i\) : mass flow rate of solids input [kg/s]

\(M.S\) : mild steel sheet [-]

\(m\) : geometry parameter (\(m = 1\) for a conical hopper) [-]

\(m_s\) : mass of solids flow rate at section 3.6.1 [lb/s]

\(N_H\) : number of velocity heads []

\(N_s\) : number of the spirals traverse by gas stream [-]

\(n\) : vortex exponent, which equal 1 for an ideal gas [-]

\(n = -1\) for rotational as solid body [-]

\(n = 0.5 - 0.8\) (in outer vortex) [-]

\(P_i\) : inlet pressure [atm]

\(Q\) : volumetric flow rate \([m^3/s]\)

\(q\) : term appearing in Stairmand’s pressure drop model [-]

\(R\) : radius at section 3.4 [m]

\(Rc\) : vortex core radius [m]

\(R_{ce}\) : ratio of vortex core to vortex finder radii [-]

\(R_e\) : vortex finder radius [m]

\(Re\) : Reynolds number, \((\rho v D)/\mu\) [-]
r : rotational radius [m]

r : reverse flow at section 3.5 [-]

S : height of cyclone vortex finder [m]

SP : static pressure drop [Pa]

S.S : stainless steel (304-2B) [-]

T : gas temperature [°C]

V_{av} : average velocity of bulk material in hopper [m/s]

V_e : gas velocity in vortex finder (exit duct) [m/s]

V_m : average velocity of bulk material discharging from the outlet [m/s]

V_i : gas inlet velocity [m/s]

V_t : tangential velocity [m/s]

V_{tcs} : tangential velocity component in the surface CS [m/s]

z_h : depth below cylinder/hopper transition [m]

α : hopper/cyclone cone angle, measured from the vertical [°]

β_d : solids drained angle of repose [°]

δ : effective angle of internal friction [°]

ΔP : total pressure drop [Pa]

ΔP_r : total pressure drop of gas flow reversal [Pa]

ΔP_e : total pressure drop of gas exit contraction [Pa]

Δt : total interval time for the particle [sec]
\( \Delta x \quad : \quad \) the difference distance between the starting point \((x_1, y_1)\) Coordinates and the finishing point \((x_2, y_2)\) coordinate for a single particle \( [m] \)

\( \varepsilon \quad : \quad \) loss factor, Table (3.1) \([-]\)

\( \eta \quad : \quad \) efficiency \([-]\)

\( \eta_{oc} \quad : \quad \) over collection efficiency \([-]\)

\( \theta \quad : \quad \) ratio of maximum tangential gas velocity, Table (3.1) \([-]\)

\( \mu \quad : \quad \) gas viscosity \( [\text{kg/ms}] \)

\( \rho_g \quad : \quad \) gas density \( [\text{kg/m}^3] \)

\( \rho_b \quad : \quad \) solids bulk density \( [\text{kg/m}^3] \)

\( \sigma_1 \quad : \quad \) major consolidating stress \( [\text{Pa}] \)

\( \overline{\sigma}_j \quad : \quad \) stress acting in equilibrium arch \( [\text{Pa}] \)

\( \phi \quad : \quad \) ratio of maximum tangential gas velocity to velocity within as entry, Table (3.1) \([-]\)

\( \phi_w \quad : \quad \) wall friction angle \( [^\circ] \)