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Dust Features Used to Calculate Dust Removal Performance in Cyclones

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1. Introduction

Almost all the manufacturing processes connected with air pollution with the industrial dust. This pollution has a huge impact to the health of people working at the factories. That's ways the air purification of the industrial gas is a very actual problems nowadays. It is highly important to specify properties of suspended solids, i.e. dust to be removed from air and fluids, in order to determine dust removal performance and state whether it is rational to use one or another type of a deduster.

It is necessary to consider features of dust particles and their interaction with fluids to develop a mathematical method supposed to evaluate dust collecting performance. Provided filters are used as dust collectors geometric dimensions of a particle (diameter) can be essential when choosing an appropriate filter. When cyclones are used the following features are more often considered: density of particles, their geometric dimensions (diameter) and shapes.

2. Literature background

When a shape of an article differs from a spherical one an equivalent diameter d_{ekv}, which is determined by various researchers in different ways, is normally taken to carry out calculation. For instance, [11], take the distance between two the most remote particles for d_{ekv}. In this case the value of the diameter is initially overestimated. Shilyaev offer to consider the equivalent diameter d_{ekv} equal to the diameter of a sphere, the mass equal to the mass of the given particle or the density equal to the material density [8].

Use of an effective diameter as a basic feature of particles, in the case of the mathematical simulation of particles settling in a cyclone, is related to a possibility to apply the Stokes' formula [1]. Whereas the following discrepancies and inaccuracy may arise:

- When using the equivalent diameter of the particles their shapes, which affect hydraulic resistance, are not considered;
- Use of the effective diameter with the aim to apply the Stokes' formula may only be essential in the case of small particles, which movement is ensured by the Reynolds number Re<1. There is no point to use an effective diameter in the case of the large-size particles;
- A possible interaction of particles with fluids is not taken into account;
- the density of the material should be considered to take into account interaction of particles with fluids and determine their relaxation time. This may create tolerances due to the difference between the material density and the effective density of particles since the mass of fluid involved in movement should be also considered in the case of the particles with complicated shapes.

3. Materials and methods

When developing a mathematical model to compute the dust removal performance a calculation practice applied in hydrology with regard to particles settling is suggested to be used. It is also suggested to take a hydraulic size w – hydraulic size under action of the gravity force of each participle in quite large volumes of fluid at rest (gas) as a basic feature of a particle. This value ensures that different factors such as size and shape of particles, fluid (gas) viscosity, relative density of particles and others are considered integrally. Settling of particles under action of the gravity force is considered in hydrology. For this reason let us denominate this value as a gravity settling wg. There is also such a name as an aerodynamic diameter in literature [2, 3, 10].

When computing gravity clarifiers the following is assumed: the hydraulic size of a suspended particle in moving fluid in relation to the volume of this fluid for both the fluid at rest and turbulent flow is equal to the gravity settling w_g. The same assumption is used to compute performance of cyclones.

The value of the gravity settling can be determined in theoretical and empirical ways.

In theory the gravity settling of particles can be obtained by making difference between the gravity force and Archimedes' buoyant force equal to the value of the force of any frontal resistance of a particle falling uniformly with the velocity w:

$$\rho_p \cdot \frac{\pi d^3}{6} g - \rho_f \cdot \frac{\pi d^3}{6} g = c_r \frac{\rho_{ж} w^2}{2} \frac{\pi d^2}{4}, \quad (1)$$

where: $\rho_ч$ – particie density; ρ_f – fluid density; d – particle diameter; c_r – drag coefficient (resistance force);

$$w = \frac{4}{3} \frac{\rho_ч - \rho_{ж}}{\rho_{ж}} \frac{g d^2}{c_x \mathrm{Re}_d \nu}, \quad (2)$$

where: $\mathrm{Re}_d = \frac{wd}{\nu}$.

In the case of small particles (Re_d<1) when the Stokes' formula is true and has the following form: $c_x = \frac{24}{\mathrm{Re}_d}$, we can obtain:

$$w = \frac{1}{18} \frac{\rho_p - \rho_f}{\rho_f} \frac{d^2}{\nu} g, \quad (3)$$

In the case of large-size particles (Red>100) we may take $c_r = 0{,}47$ and obtain:

$$w = \sqrt{\frac{\frac{4}{3} \frac{\rho_p - \rho_f}{\rho_f} g d}{c_r}}, \quad (4)$$

As to the model of a particle movement in a cyclone let's introduce the notion of a centrifugal hydraulic size w_c, which is the velocity of the quasi-uniform motion of a particle in relation to the fluid volume moving this particle under action of the centrifugal force caused by its curvilinear motion path. Evidently, when it comes to the centrifugal field we obtain an analogical ratio of the centrifugal hydraulic size w_c, to the centrifugal acceleration u_ε^2 / r on the grounds of the same assumptions.

Let's express the hydraulic size in terms of the gravity one with the help of the following ratio; consequently, we obtain the following for small particles:

$$w_c = \frac{u_\varepsilon^2}{gr} w,$$

for large-size particles:

$$w_c = w\sqrt{\frac{u_\varepsilon^2 g}{r}}.$$

When conveying the gravity settling w into the centrifugal hydraulic size wцб it is necessary to ensure that the numbers Red, to be determined for the values w and wцб, are related to the same field of resistance (quadratic and Stokes' one). From the practical point of view it can be accepted that the boundary between these fields is equal to Re_d=10 [5, 9]. The median radial velocity of the particle motion towards a wall of the cyclone under action of the centrifugal force, which is entered into the mathematical model, is considered to be equal to the value of the centrifugal settling velocity.

There is a comprehensive way to determine the gravity settling of particles which is empirical measurement.

In this case the velocity of falling particles of different types due to the gravity force should be measured, i.e. it is easier to state the time within which a certain particle (evolved from a source of pollution) due to its dead-weight can pass through a fixed distance vertically. This can be named as a basis of experimental arrangement.

An initially motionless particle falls with acceleration until environmental resistance put the gravity force in equilibrium – according to [7]. The time, within which the particle moves uniformly, is known as the relaxation time of the particle [5, 6]:

$$t_r = k\frac{w}{g}, \tag{5}$$

where k=1 – for small particles when the Reynolds' number Red is related to the Stokes' resistance for large-size particles, and k=1,8 when the Reynolds' number Red is related to the quadratic resistance.

When carrying out experiments the distance lr, to be passed by the particle appears to be a more accessible way for the particle to move uniformly. This value can be named as the relaxation length. The minimum value l_r is as follows:

$$l_r = w \cdot t_r = k\frac{w^2}{g}. \tag{6}$$

The top point of the basis should be lower by the value lr comparing with the point at which the particles enter the area given; consequently, it is necessary to set the basis with the height 1–2 m. The length of the basis is to be determined in relation to the type of the dust so an acceptable accuracy in measuring the time, within which the particle passes through the basis, is ensured. The required condition is that the particle must move from the top point of the basis up to the lowest one with the velocity equal to the gravity settling w. In relation to the type of dust it is necessary to identify fixation techniques of the particle passing through the top and the lowest points of the basis if there is the uniform motion of the particle.

4. Experimental methods and results

When carrying out the experiment the basis of 1,5m has been given. A stopwatch and camera shooting have been used to determine the time when the particle passes a certain distance moving uniformly. A subsequent computer processing has been executed.

The particles of flour, powder and caster sugar have been taken as full-size particles. The results obtained for the hydraulic size are given in the Table 1.

The research on solid particles recovery from air in welding industry is considered to be an up-to-date one. A part of these particles may continue moving at constant high temperature resulting in oxidation (combustion), another part represents the 'cold' metal dust. There is no point of measuring diameter or density for the particles under combustion. It is impossible since the particle under combustion has a solid and fluid component, and the only way to identify the features of the particles is to measure the gravity settling.

In this case as in the case of other dust types the most accurate findings can be obtained by carrying out a full-scale experiment. Welding industry has been used as a source of pollution; metal particles evolved while electric welding have been taken as an alloy. As an outcome of this experiment the gravity settling of the particles under combustion has been determined being nearly equal to 1–4 m/s, and, consequently, the relaxation length of the particles l_r, approximately amounts to 0,5–1,5 m (fig. 1).

The results of measuring the hydraulic size *w* for the metal particles evolved while welding have been obtained when carrying out the full-scale experiment, and are given in the Table 2 [2, 4, 9].

Table 1. Hydraulic size for model particles
Tabela 1. Wymiar hydrauliczny modelowanych cząstek

w, m/s					
meas	powder particles	meas	flour particles	meas	semolina particles
1	0.25	1	0.47	1	0.94
2	0.13	2	0.64	2	1.64
3	0.19	3	0.70	3	1.09
4	0.14	4	0.29	4	0.99
5	0.18	5	0.46	5	0.90
6	0.17	6	0.70	6	1.16
7	0.18	7	0.64	7	1.79
8	0.14	8	0.39	8	0.94
9	0.15	9	0.47	9	1.64
w_{av}	0.15	w_{av}	0.51	w_{av}	1.5

Fig. 1. Measuring the hydraulic size of the dust particles evolved while welding
Rys. 1. Pomiar hydraulicznego wymiaru cząstek pyłu podczas spawania

Table 2. Hydraulic size for nature particles
Tabela 2. Wymiar hydrauliczny rzeczywistych cząstek

meas	w, m/s	meas	w, m/s	meas	w, m/s	meas	w, m/s
1	6.25	1	4.38	1	4.00	1	3.83
2	3.75	2	5.50	2	4.69	2	4.25
3	6.00	3	4.00	3	5.00	3	5.00
4	4.50	4	3.75	4	5.08	4	4.75
5	3.50	5	4.25	5	4.64	5	4.25
6	3.61	6	4.25	6	5.17	6	4.75
7	5.42	7	4.00	7	4.06	7	3.50
8	4.06	8	3.75	8	3.38	8	5.75
9	3.75	9	4.00	9	3.45	9	4.25
10	3.89	10	4.25	10	3.30	10	3.75
w_{av}	4.41	w_{av}	4.21	w_{av}	4.41	w_{av}	4.57

In this case fractional composition can be neglected since the particles act following no particular pattern.

It should be considered that the features of particles may differ in the context of different industries in relation to individual special aspects of the welding machinery, technologies and materials.

The experiments have proved this method to be quite simple. The findings have been obtained privately and given as an example.

The methods used to measure and calculate the gravity settling w make it possible to eliminate the tolerances related to determination of the effective diameter and effective density when computing dust collecting performance in a cyclone. This improves estimation accuracy with reference to the technical performance of the equipment.

5. Conclusion

The notion of the hydraulic size is widely used in hydrology what can be explained by a simplified expression for the hydraulic size of suspended particles in various environments. For instance, in the case of sand pumps the water features are constant; the density and viscosity of water do not change (at the temperature of 200ºC); the shape of suspended sand particles is close to spherical; the gravity settling for the sand particles in fluid only depends on the particle diameter. It would be sufficient to state the ratio of the hydraulic density to the diameter of the particles and enter the result data into the table sheet.

The case of dust is more complicated. First and foremost, the gravity settling depends on the material density (from 500 kg/m^3 (for wood) to 7000 kg/m^3 (for metal)), and in the case of the «non-spherical» particles – on the effective density. Besides, the air viscosity may change to a large extent in relation to the temperature; and fractional composition of the dust is more varied. For this reason the hydraulic size should be determined empirically for each type of the particles.

The method to determine the hydraulic size w described above can be feasible in working environment without using special equipment and well-trained specialists to carry out this experiment.

References

1. **Szkarowski A., Janta-Lipińska S.:** E*xamination of boiler operation energy-ecological indicators during fuel burning with controlled residual chemical underburn.* Rocznik Ochrona Środowiska (Annual Set the Environment Protection). 15, 981–995 (2013).
2. **Vatin N., Chechevichkin V., Chechevichkin A., Shilova Y., Yakunin L.:** *Application of natural zeolites for aquatic and air medium purification.* Applied Mechanics and Materials. 587–589, 565–572 (2014).
3. **Petrochenko M., Yavtushenko E.:** *Diffused structure of drained and back-ventilated rainscreen claddings*. Advanced Materials Research. 945–949, 1015–1022 (2014).
4. **Strelets K., Kitain M., Petrochenko M.:** *Welding spark parameters determination for cyclone removal calculation*. Advanced Materials Research. 941–944, 2098–2103 (2014).
5. **Girgidov A.:** *Deposition of Solid Particles from a Concentrated Suspension.* Power Technology and Engineering. 48 (1), 29–33 (2014).
6. **Dąbrowski J., Piecuch T.:** *Mathematical Description of Combustion Process of Selected Groups of Waste*. Rocznik Ochrona Środowiska (Annual Set the Environment Protection). 13, 253–268 (2011).
7. **Girgidov A., Vatin, N., Strelets K.:** *Numerical modelling in three dimension velocity field in cyclone.* Magazine of Civil Engineering. 5, 5–9 (2011).
8. **Shiljaev M.I.:** *Hydrodynamics, heat and mass exchange in sprayer sprinkling chambers.* Thermophysics and Aeromechanics. 18(1), 13–24 (2011).

9. **Girgidov A.:** *Mekhanika zhidkosti i gaza (gidravlika) (Fluid Mechanics).* SPBSPU, Saint-Petersburg 2002.
10. **Zhongchao T.:** *Mechanism or particle separation in aerodynamic air cleaning.* for the degree of PhD, Urbana, Illinois 2004.
11. **Shtokman E.A.:** *Ochistka vozduha.* Izdatel'stvo ASV. 62–64 (1998).

Właściwości pyłów wykorzystywane w obliczeniach sprawności odpylania w cyklonach

Streszczenie

Praca poświęcona została badaniom właściwości cząstek pyłów podlegających usuwaniu w odśrodkowych odpylaczach – cyklonach. Podczas oczyszczania powietrza ważne znaczenie maja właściwości zawiesin, czyli pyłów podlegających usuwaniu ze strumienia gazowego. W celu opracowania modelów matematycznych do oceny efektywności odpylania należy uwzględniać charakterystyki cząstek pyłów oraz ich współdziałanie ze strumieniem gazu. Jeśli do odpylania stosuje się filtry, to głównym wskaźnikiem do ich dobory są geometryczna charakterystyka cząstki (srednica). W przypadku zastosowania cyklonów najczęściej wykorzystywane są następujące charakterystyki: gęstość substancji, wymiary geometryczne cząstek (średnica). W literaturze jako główna charakterystykę cząstek pyłów najczęściej stosuje się ich średnicę lub średnicę efektywną, w przypadku kształtu nie sferycznego. To powoduje szereg niedokładności podczas obliczeń sprawności odpylania. Autorzy proponują jako główna charakterystykę cząstek pyłów wprowadzaną do obliczeń sprawności systemów odpylania, stosować ich hydrauliczny wymiar zamiast wymiaru geometrycznego, korzystając z doświadczenia obliczeń osadzania się cząstek wykorzystywanych w hydrologii. Ta wielkość fizyczna w sposób zintegrowany uwzględnia różne czynniki, takie jak wymiary i kształt cząstek, lepkość płynu (gazu), względna gęstość i inne. Zaproponowano sposoby określenia wymiaru hydraulicznego dla cząstek pyłów powstających podczas spawania, jak pokazano na rysunku 1, a także dla innych rodzajów pyłów. Wyniki badań przedstawiono w tabeli 1 i 2. Opracowano możliwość wykorzystania tej charakterystyki w obliczeniach sprawności odpylania w cyklonie.

Słowa kluczowe:
cyklon, grawitacyjny wymiar hydrauliczny, odśrodkowy wymiar hydrauliczny cząstek

Keywords:
cyclone, gravitation hydraulic size, centrifugal hydraulic size