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Determination of the Optimal Construction Parameters of Dust Collection Facilities after Pneumatic Transport Installation

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ABSTRACT

In metallurgy pneumatic transport installations for powders and metal particles (swarfs, shavings, etc.) generated during production processes are widely used. Fine-grained metal waste and/or intermediate products are characterized by a wide range of particle size composition, different particle shapes and significant differences in the densities of individual components of the disperse system (from 2 to 10 g·cm-3).

The listed features of the materials intended for pneumatic transport create certain difficulties in determining the parameters of the disperse system intended for carrying out the transport purposes. The differences in the physical characteristics and properties of the dispersed particles also cause significant differences in their aerodynamic behaviour in the facilities for separating the two phases (solid and gaseous) and for purifying the fluid (most often air) before releasing it into the environment. Unlike dust collection systems for process flue gases, pneumatic conveying systems require initial sedimentation of the transported material and subsequent purification of the transporting fluid (air).

The present report summarizes the results of analytical determination of the physical characteristics of waste fine-grained metal materials and calculation of the aerodynamic parameters of dust collection equipment included in the system for the separation of solid-phase particles with sizes greater than 100 µm and subsequent purification of the waste gas to achieve concentration of fine dust particles lower than 5 mg·m-3.

Based on the physical parameters of the disperse system, the best available techniques are determined for the separation of the solid phase particles and the purification of the waste fluid that is released into the atmosphere, as follow: gravity dust chamber;inertia cylindric cyclone.

As a result of calculating the design parameters of the specified dust collection devices, the optimal conditions have been determined for the most complete separation of the transported material from the air flow and the subsequent purification of the air released into the atmosphere to meet the legal limit for emissions of dust particles.

Keywords: pneumatic transport, gravity dust chamber, dust collecting systems, metal particles.

INTRODUCTION

In conditions of increasing demand for raw materials, respective rise of their price, depletion of mineral deposits on a global scale and ongoing transition to a circular economy, the capture of valuable and usable materials for metallurgy and their utilization/recycling in technological cycles is an important element of the resource

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efficiency. This process is of great importance both for the establishment of profitable and sustainable production, because it ensures the recovery of materials and their reuse, and for the environment protection due to the reduction of generated waste and the emission of dust particles into the atmospheric air.

There are studies on pneumatic transport of different materials, for example cement and ashes [1, 2], plastics [3, 4], coals [5] and milk powder [6]. Regarding the fine dispersed materials used in metallurgy, they are mainly for metal powders [7].

In metallurgical practice, there are several options for pneumatic transport of metal particles (swarfs) generated as a result of various mechanical processes such as cutting, milling, grinding. Depending on the parameters of the disperse system and the physical characteristics and properties of the treated particles (size, mass, velocity, mass flow, etc.), metallurgical processes can use a pneumatic transport system in combination with one or several series-connected collecting devices for particles, such as cyclones, fabric filters, gravity chambers, etc. [8 - 10].

In case of inappropriate selection of the dust collection equipment after the pneumatic transport installation, as well as in case of incorrect determination of their optimal construction parameters, there is a high probability of technical, technological and environmental problems. They can arise from the imperfections of the dust collection installation, such as inefficient operation of the facility for separating the metal particles (swarfs) from the air and significant residual amounts of swarf after the unit, presence of excessive concentration of dust particles in the waste air stream discharged into the atmosphere, etc. [8, 11 - 15].

In the present work, the parameters of a typical process for a metallurgical plant are considered, in which during the mechanical processing of metal blocks, a certain amount of metal particles (dust and swarfs) are generated, which are transferred by means of a pneumatic transport system. The appropriate type of dust collection equipment and its parameters are determined to ensure effective capture of the transported metal particles, as well as the subsequent purification of the waste air flow.

CALCULATIONS

For the purposes of the present study, the following parameters were initially determined:

- maximum swarf mass subject of transportation per unit of time: 12 $t \cdot h^{-1}$;
- diameter of the transporting pipeline: 710 mm;
- cross section area of the transporting pipeline: 0.396 m^2;
- maximum volumetric speed of the transporting air: 50000 $m^3 \cdot h^{-1}$;
- maximum linear speed of the transporting air: 350.73 $m \cdot s^{-1}$;
- volumetric quantity of the air for the transportation of 1 kg of swarfs: 4.165 $m^3 \cdot kg^{-1}$;

The next step is to determine granulometric composition of the swarfs which must be separated from the pneumatic transferring air. It was determined on the basis of samples taken from characteristic points of the pneumatic transport system.

The granulometric composition of the metal swarfs generated from the processing of metal blocks is given in Table 1.

With the determined parameters of the metal swarfs and the transferring air, as well as with the obtained results of the granulometric analysis, a reference was made for the most suitable equipment for capturing the swarfs and subsequent dust capture for the specific case, described in [16]. As such, a gravity (separating) chamber according to item 3.5.1.4.2, as well as a cyclone according to item 3.5.1.4.3 of the cited document are indicated, which are given as the best available technique for capturing particles with characteristics analogous of the above mentioned.

Table 1. Granulometric composition of the metal swarfs generated from the processing of metal blocks.

Size, mm	$\%_{mass}$	Size, μm	$\%_{mass}$
+4	5.68	-100 +80	0.01
-4 +3	10.95	-80 +60	0.044
-3 +2	75.56	-60 +40	0.016
-2 +1	6.04	-40 +30	0.017
-1 +0.5	1.54	-30 +20	0.003
-5 +0.315	0.11	-20 +10	0.003
-0.315 +0.160	0.015	-10	0.01
-0.160 +0.100	0.0014		
	S_1 = 99.8964		**S_2 = 0.1036**
$S_1 + S_2$ = 100 %			

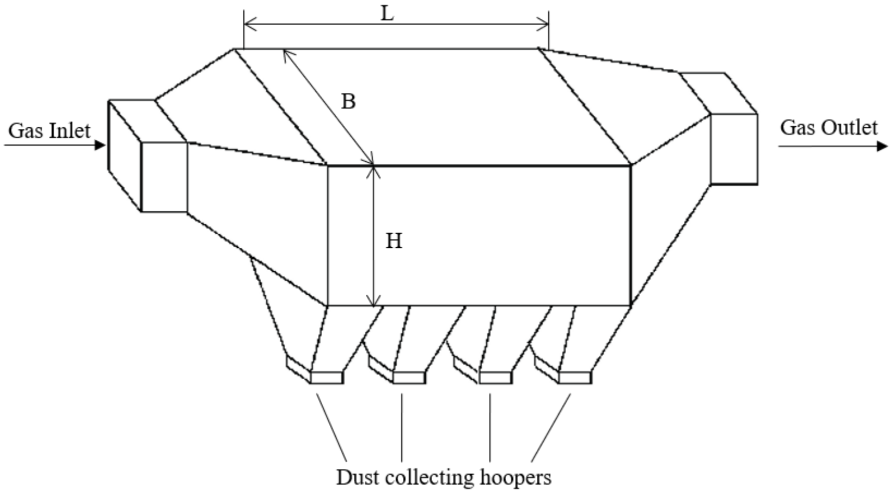

Fig. 1. Gravity chamber.

Calculation of chamber for swarfs gravitational separation from the transportation air

The purpose is to choose optimal dimensions of a rectangular dust collecting chamber, in which laminar movement of the air flow to be achieved and conditions for swarfs gravitational separation with as much as possible lowest dimensions to be chosen. As it might be seen from Table 1, more than 99.8 % of the swarfs are with sizes bigger than 0.1 mm (100 μm). In conformity to the Best Available Techniques (BAT), powdered particles with sizes greater than 0.07 mm (70 μm) might be 100 % effectively collected in dust chambers. In our case the process of separation is favoured by the high density of the metal swarfs.

Following the preliminary calculations made in according to the method developed by [17], the following dimensions of rectangular chamber for gravitational separation of swarfs from the transportation air, are accepted:

- height $H = 2$ m;
- width $B = 2$ m;
- length $L = 5$ m.

In Fig. 1 is given a general view of the chamber for swarfs' gravitational separation.

In order the chamber efficiency to be

determined, the following initial parameters are used:

- maximum volumetric speed of the transportation air: 13.89 m·s^{-1};
- maximum swarfs mass transporting per unit of time: 3.333 kg·s^{-1};
- maximum swarfs' density: ρ_p = 8700 kg·m^{-3};
- swarfs' density when the swarfs are in bulk: ρ_p^* = 1700 kg·m^{-3};
- ratio solid material/air in the pneumotransport flow: 1 kg/4.164 m^3;
- air density at 20°C: ρ = 1.2 kg·m^{-3};
- air viscosity at 20°C: ν = 1.5·10^{-5} m^2·s^{-1};
- dynamic air viscosity at 20°C: μ = 1.8·10^{-5} Pa·s;
- maximum volumetric diameter of the particles: d_v = 1 mm;
- maximum surface diameter of the particles: d_s = 5 mm;
- Reynold's criteria for the particles with max. surface diameter d_s:

$$R_e = \frac{\rho . u . d_S}{\mu} \tag{1}$$

- sphericity of the particles:

$$\psi = \frac{d_v^2}{d_s^2}; \tag{2}$$

- coefficient of frontal resistance during the particles' movement:

$C_D = 5.31 - 4.88\,\psi$ when $Re < 2000$;

- final relative speed of the particles in the air flow under the action of a gravitational force:

$$u_t = \sqrt{\frac{4\, d_p (\rho_p - \rho) g}{3 \rho C_D}}, \text{ m/s}; \tag{3}$$

- d_p – diameter or linear size of the particle, m;
- g = 9.81 m·s^{-2} – gravitation force;
- α – efficiency collection in the gravity chamber: ratio of the road passed under the action of the gravitation force towards the chamber height in %.

Following the results of the calculations made, were determined the values of the main parameters needed for the design of the gravitation chamber:

- average linear speed of the air flow in the chamber: V = 3.47 m·s^{-1};
- dwell time in the air flow in the gravitation chamber: t = 1.44 s;
- maximum value of the coefficient of frontal resistance at movement of the particles: C_D = 5.1148;
- final relative speed of the particles with maximum size of 1 mm in the air flow under the action of the gravitation force: u_t = 4.3 m·s^{-1};
- distance travelled by the particles with maximum size of 1 mm under the action of the gravitation force in the volume of the chamber for the dwell time in the gas flow: 6.2 m;
- final relative speed of the particles with maximum size of 0.1 mm (100 μm) in the air flow under the action of the gravitation force: u_t = 1.36 m·s^{-1};
- distance travelled by the particles with maximum size 0.1 mm under the action of the gravitation force in the chamber volume for the time of stay in the gas flow: 1.96 m;
- final relative speed of the particles with maximum size of 0.01 mm in the air flow under the action of the gravitation force: u_t = 0.43 m·s^{-1};
- distance travelled by the particles with maximum size 0.01 mm under the action of the gravitation force in the chamber volume for the time of stay in the gas flow: 0.62 m.

In Table 2 are systematized the results obtained at the calculation of the theoretical efficiency of the different sizes of swarfs' and powdered particles' collection.

RESULTS AND DISCUSSION

The above results from the calculations allow the following conclusions to be made:

1. The swarfs with a maximum size larger

Table 2. Efficiency collection of metal swarfs generated from the processing of metal blocks depending on the granulometric composition.

Size, mm	$0\%_{mass}$	Efficiency collection, %	Size, µm	$\%_{mass}$	Efficiency collection, %
+4	5.68	100	-100 +80	0.01	87.6
-4 +3	10.95	100	-80 +60	0.044	75.9
-3 +2	75.56	100	-60 +40	0.016	62.0
-2 +1	6.04	100	-40 +30	0.017	53.7
-1 +0.5	1.54	100	-30 +20	0.003	43.8
-5 +0.315	0.11	100	-20 +10	0.003	31.0
-0.315 +0.160	0.015	100	-10	0.01	0
-0.160 +0.100	0.0014	98			
Σ = 99.8964			Σ = 0.1036		
$\Sigma_1 + \Sigma_2$ = 100 %					

than 0.1 mm is possible to be collected in the gravitation chamber with maximum efficiency of 100 %. For the dwell time (downtime) of the gas flow in the chamber, said particles may travel a distance larger than 2 m under the action of the gravitation force, i.e. as the height of chamber is, and to precipitate.

2. The particles with maximum size equal to 0.1 mm, under the action of the gravitation force, for the dwell time in the volume of the chamber travel 1.96 m. The maximum possible efficiency of precipitation of said particles in the chamber is 98 %.

3. The efficiency of precipitation in the gravitation chamber of particles with sizes less than 0.1 mm, is given in Table 2. In line with the BAT, for the purposes of the present work, is accepted the conservative assumption that the particles with size smaller than 0.01 mm, are not collected in the chamber.

Due to the high linear velocity of the air flow in the gravity chamber, the actual swarf collection efficiency will be lower. 100 % efficiency is assumed to capture particles with a maximum size greater than 0.16 mm (160 µm). These swarfs represent 99.895 % of the total flow that is transported. Particles with a size smaller than this limit represent 0.105 % of the total amount.

As we ascertained above, the maximum mass of the swarfs, which are transported per unit of time is 200 kg·min^{-1} with the help of an air flow of 833 m^3·min^{-1}. If in the gravitation chamber are precipitated 99.985 % of the swarfs' mass, then in 1 m^3 air at the chamber outlet will be contained dust particles of 252.1 mg·m^{-3} at emission limit value = 20 mg·m^{-3}. As it was mentioned above, the necessary degree of air cleaning might be achieved in a properly dimensioned cyclone.

Calculation of a cyclone for cleaning of the transported air after the chamber for the swarfs' gravitation collection

The purpose is to calculate the dimensions of equipment for inertial cleaning of the transferring air after the chamber for gravity swarfs separation so to provide the required degree of completion of this process.

As a result of preliminary calculations made in accordance to the methodology given in [17], the following main dimensions of a cyclone with tangential inlet of the gas flow (Fig. 2) are accepted:

- diameter of the outlet pipe: D_e = 800 mm;
- inner diameter of the cylindrical part: D = 1900 mm;
- height of the cyclone: H = 5000 mm;
- height of the cylindrical part of the cyclone: h = 2000 mm;
- height of the outlet pipe in the cylindrical part of the cyclone: S = 960 mm;
- inlet hole of the gas flow: $a = b$ = 800 mm;
- diameter of the outlet hole for the collected dust particles: B = 600 mm;
- angle of the conical part of the cyclone: $\alpha = 26°$;
- angle of the inlet hole: $\beta = 180°$.

In order to determine the cyclone efficiency the following initial parameters and calculation dependences are used:

- maximum volumetric speed of the transporting air: $Q = 13.89\ \mathrm{m^3{\cdot}s^{-1}}$;
- maximum mass of the dust particles in 1 $\mathrm{m^3}$ of air: 0.2521 $\mathrm{g{\cdot}m^{-3}}$;
- maximum particles diameter: d_p = 0.16 mm;
- gas velocity at the cyclone inlet, $\mathrm{m{\cdot}s^{-1}}$:

$$u_i = \frac{Q}{a.b}; \qquad (4)$$

- effective cyclone volume, $\mathrm{m^3}$:

$$V = \frac{\pi}{4}\left\{\left(\frac{H-h}{D-B}\right)\left(\frac{D^3-B^3}{3}\right) + D^2h - D_e^2 S\right\} \qquad (5)$$

- dwell time of the gas flow in the cyclone, s:

$$t = \frac{V}{Q}; \qquad (6)$$

- critical diameter of the particles collected with an efficiency of 100 %, m:

$$d_{cr} = 3\sqrt{\frac{2\mu}{\pi\rho_p u_i}\frac{R}{N}\left(1-\frac{2R}{D}\right)} \qquad (7)$$

- m - mass of the particles, kg;
- u_{T} - tangential velocity of the gas flow, $\mathrm{m{\cdot}s^{-1}}$;
- distance from the center of the cyclone, where it is assumed that $u_i = u_{\mathrm{T}}$, m:

$$R = \frac{D}{2} - \frac{b}{2}; \qquad (8)$$

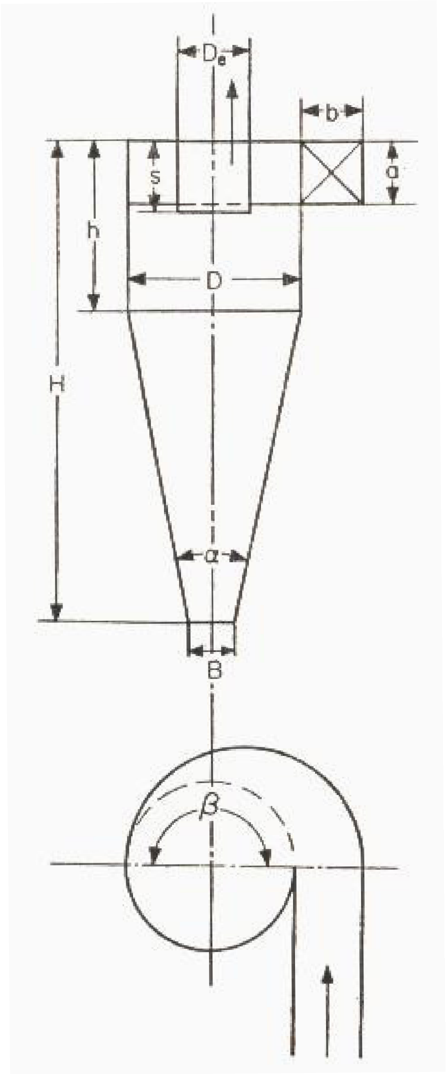

Fig. 2. Cyclone with tangential inlet of the gas flow.

- centrifugal force acting on the particles, N:

$$F = m\frac{u_{\mathrm{T}}^2}{R}; \qquad (9)$$

- number of revolutions of the gas flow in the cylindrical part of the cyclone:

$$N = \frac{tu_i}{\pi D} \qquad (10)$$

πDN - length of the effective gas flow path in the volume of the cyclone, m.

As a result of the calculations made, the values of the basic parameters needed for the design of the cyclone were determined:

- speed (velocity) of the gas at the cyclone inlet: $u_i = 21.7\ \text{m}\cdot\text{s}^{-1}$;
- effective volume of cyclone: $V = 9.59\ \text{m}^3$;
- dwell time of the gas flow in the cyclone at $Q = 13.89\ \text{m}\cdot\text{s}^{-1}$: $t = 0.69$ s;
- number of revolutions of the gas flow in the cylindrical part of the cyclone: $N = 2.51$;
- distance from the center of the cyclone: $R = 0.55$ m;
- critical diameter of the particles collected with 100 % efficiency: $d_{cr} = 2.3$ μm.

The above-mentioned results of the calculations of the dust collection efficiency in a cyclone with construction dimensions shown in Fig. 2, allow the following conclusion to be drawn:

The calculated theoretical critical size of the particles collected in the cyclone with a 100 % efficiency ($d_{кр} = 2.3$ μm), shows that the treated pneumotransported air emitted into the atmosphere has a maximum concentration of dust particles lower than $5\ \text{mg}\cdot\text{m}^{-3}$.

CONCLUSIONS

The defined design parameters of the chamber for gravity separation of the swarfs from the transporting air and of the cyclone for cleaning of the transporting (conveying) air after it can be effectively used in systems for pneumatic transport in various mechanical processes for metals processing.

The two pieces of equipment selected for the capture and separation of the metal particles (swarfs) as well as the subsequent purification of the remaining finest particles in the waste air flow, ensure material recovery with an efficiency of over 99.9 % and compliance with the standards for particulate matters emissions into the atmospheric air.

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