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WOOD DUST COLLECTION EFFICIENCY IN A PULSE-JET FABRIC FILTER

The performance of pulse-jet bag filters is characterised by two contradictory parameters: separation efficiency and pressure drop. Both parameters depend on the filtration time when the dust layer is created. The time between cleaning pulses – the filtration cycle – is also of great importance for the separation efficiency of the filter. This paper describes the results of experimental studies on the wood dust separation efficiency of a pilot scale pulse-jet filter during the initial phase of the process when the number of particles penetrating the filter visibly decreased.

Keywords: wood dust, filtration efficiency, pulse-jet filter

Introduction

The rational use of industrial pulse-jet filters is related to the need to balance two contradictory requirements. The aim is to achieve the highest possible separation (dust collection on the filter surface) efficiency while avoiding an excessive increase in pressure drop. During the filtration process carried out at constant parameters – filtration velocity and dust loading – separation efficiency and pressure drop depend on the properties of the dust layer formed on the surface of the filter material. Industrial filtration devices very often operate with a higher separation efficiency at the cost of increased airflow resistance [Mukhopadhyay 2009].

Total separation efficiency can be taken to evaluate the performance of the filter. However, if the particle size distribution of the dust flowing into the filter is known, more information can be obtained by calculating the fractional efficiency.

According to the theory described by Leith and Ellenbecker [1980], the mass of dust penetrating through the filter depends on the areal density of the dust collected on the filter surface, the filtration face velocity and the time between cleaning pulses (filter cycle duration). The characteristics of the collected dust and used filter medium also have an indirect impact. However, there are also

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a number of interactions between the accumulating dust and the surface of the filter material, which manifest in the variability of all kinds of factors taken into account in theoretical studies on filter performance. In practice, the properties of the dust and filter medium should not be regarded separately because during filter operation the dust creates a layer permanently associated with the medium structure. Therefore, all design activities concerned with the selection of the filter construction, the filter medium and the parameters of the filtration process must take into account the results of experimental studies on the relationship between the dust layer and the filter surface [Mračková et al. 2015].

Dolny [2005] observed the decrease in wood dust particle concentration during the filtration process. The number of particles decreased rapidly in the first phase of the process. The dust concentration in the air flowing out of the filter then stabilized in the subsequent cycles. However, thus far it is not known how this affects the fractional separation efficiency of the filter in terms of wood dust collection.

The aim of the study was to determine the separation efficiency of a non-woven polyester filter fabric in terms of wood dust collection during the initial phase of the filtration process, when the number of particles penetrating the filter rapidly decreases, and within a single selected filtration cycle of this phase, when the properties of the accumulated dust layer greatly change due to an increase in thickness.

Materials and methods

The experiments were carried out using a pilot-scale test bag filter. The operation of this testing device and the impressive results obtained with it were described in previous papers [Dolny 1998; Dolny and Rogoziński 2014]. The parameters of the experimental filtering process are given in table 1. The properties of the filter material, type KYS – PROGRES series, and the characteristics of the inlet dust were also described by Dolny and Rogoziński [2014].

Table 1. Parameters and characteristic constants of filtration process

Parameter	Value
Filtration velocity	0.077 m/s
Dust concentration at inlet	10 g/m^3
Air pulse pressure	5 MPa
Duration of filtering cycle	5 min

The separation efficiency in the 5th and 45th filtration cycle was calculated based on the average mass concentrations of dust at both the inlet and outlet. However, the separation efficiency in the 35th cycle was calculated based on the same constant inlet mass concentration and the outlet concentrations obtained in the first and fifth measurements during this cycle. The general formula is expressed as follows:

$$\eta = \frac{C_1 - C_0}{C_1}$$

where: η – general separation efficiency,
C_1 – mass concentration of dust at the inlet of the filter,
C_0 – mass concentration of dust in the air at the outlet.

For the wood dust (polydisperse dust) used in the test, the fractional separation efficiency η_i of the filter was determined:

$$\eta_i = f(d_i)$$

where: d_i – particle size of fraction *i*.

Then the general separation efficiency is a sum of the efficiencies in particular size ranges:

$$\eta = \sum q_i \eta_i$$

where: q_i – mass fraction of dust.

For this purpose the number concentration of the dust particles in the outlet was determined using a HR5250A laser particle counter. The measuring range of the counter included 8 channels with the upper dimensional limits 0.5, 1, 2, 3, 5, 10, 15, and 25 μm. The air flow rate of the counter was 0.0283169 m^3/min (1 ft^3/min). A sample of cleaned air was taken from the outlet tube using the isokinetic probe. The air sample was then diluted with an isodilutor (dilution factor 1:10). The sampling time was set at 30 s, and the delay time between successive samples was also 30 s. The integral software of the counter calculated the results expressed as counts of particles in m^3 based on these assumptions. At these settings, five measurements of particle content were carried out in each filtration cycle and then the average values were calculated.

The mass concentration at the outlet of the filter was calculated using the data obtained by the particle counter as follows:

$$C_0 = \sum_{i=1}^{8} n_{0i} \cdot \frac{\pi \bar{d}_i^3}{6} \cdot \rho$$

where: n_{0i} – the number concentration of dust measured on channel *i* of the counter,
$\bar{d}_i$ – average size of channel *i*,
ρ – density of wood substance 1500 kg·m^{-3}.

The mass concentration of dust particles at the filter inlet in the assumed channels was calculated on the basis of the empirical function of the particle size distribution of dust and the general dust concentration at inlet C_1 = 10 g/m^3. The particle-size distribution of the tested dust was determined using an Analysette 22 MicroTec Plus laser particle sizer. Then, based on this function obtained during the particle size analysis by the sizer, the q fractions were calculated. Therefore, the mass concentration of particular dust fractions is as follows:

$$C_{1i} = C_1 q_i$$

Similar procedures for calculating the fractional efficiency of filter materials and separators were also described in detail by Maus and Umhauer [1996]; Warych [1998]; Simon et al. [2014].

Results and discussion

The particle size distribution of the beech wood dust used in the test was previously presented in the paper of Dolny and Rogoziński [2014]. The fractions of the inlet dust calculated in reference to assumed dimensional channels according to the empirical function of particle size distribution are shown in table 2.

Table 2. Fractions of the inlet dust

Upper limit [μm]	0.5	1	2	3	5	10	15	25
Mass fraction of the inlet dust q [%]	0.60469	0.0954	0.06238	0.02597	0.04274	0.58091	1.5075	5.27633

Figure 1. shows the average values of total particle number concentration in the air at the outlet recorded during all the filtration cycles of the experimental process. A gradual decrease in the concentration of particles during the conditioning of the filter material – the formation of a permanent dust layer on its surface – can be noticed. After the 50th cycle, only a small decrease in the particle number in the cleaned air can be observed. This is an effect of the stabilization of the separation efficiency of the filter material in this phase of the process. Figure 2. presents the results of measurements of the particle concentration in the air at the outlet within the 35th filtration cycle. These values were taken to calculate the separation efficiency in this cycle. An increase in the mass areal density of dust on the filter surface during the cycle caused a decrease in particle content in the air at the outlet.

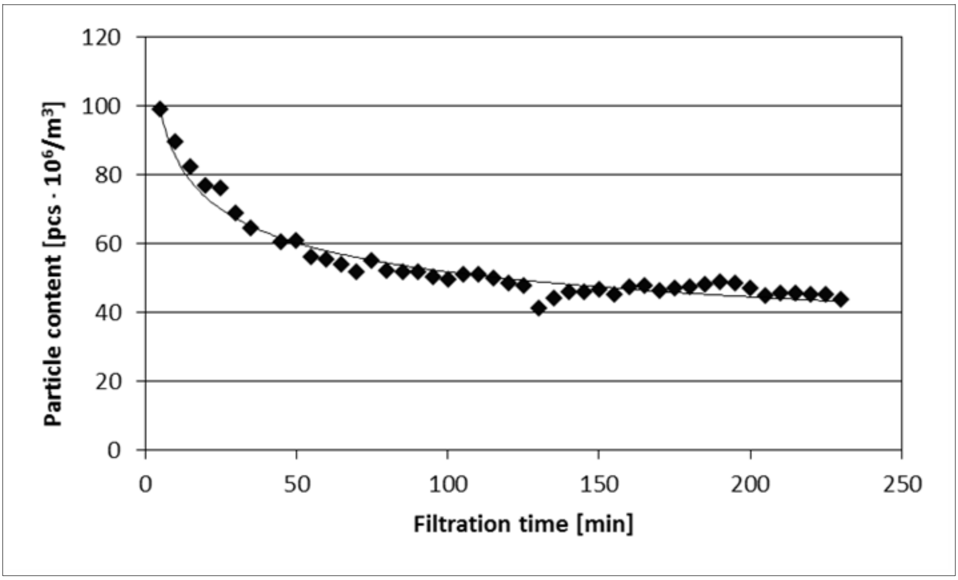

Fig. 1. Total particle number concentration in air at outlet

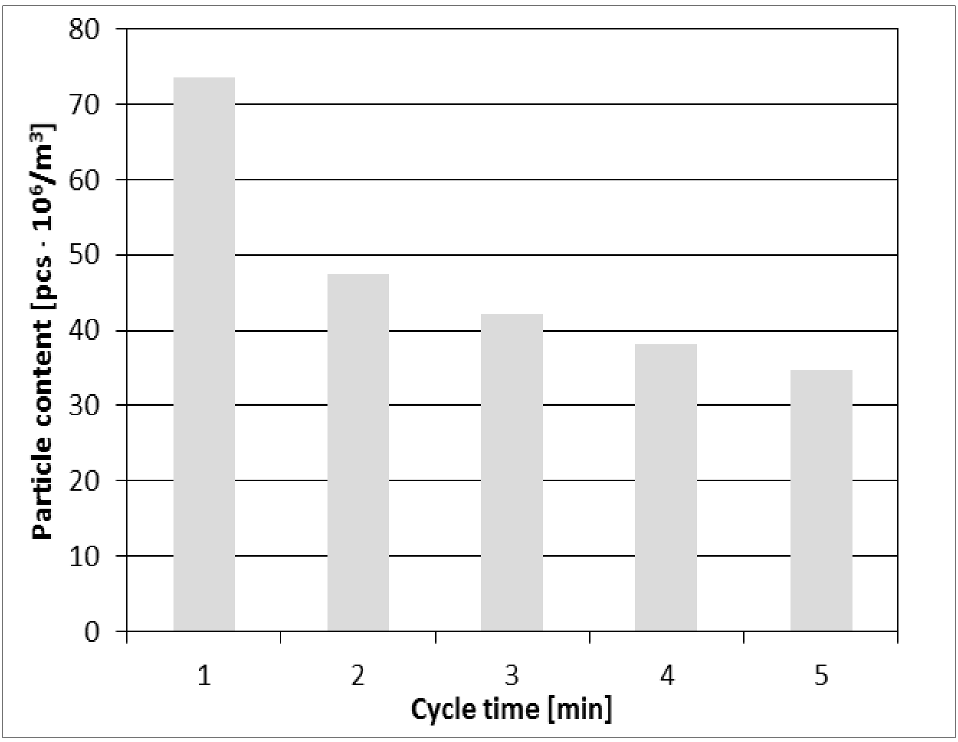

Fig. 2. Particle concentration in air at outlet during the filtration cycle

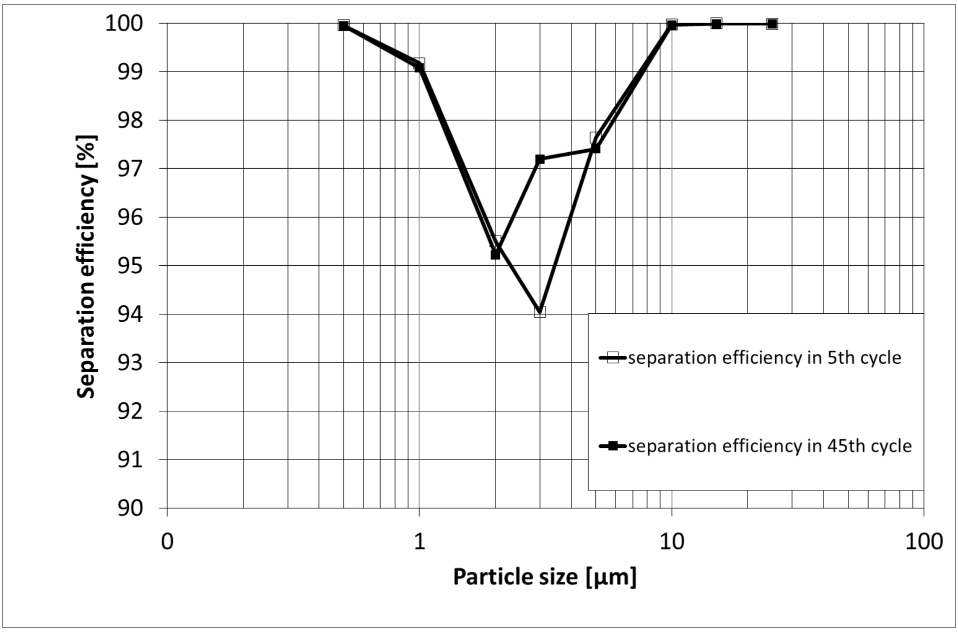

Fig. 3. Separation efficiency in the filtration process

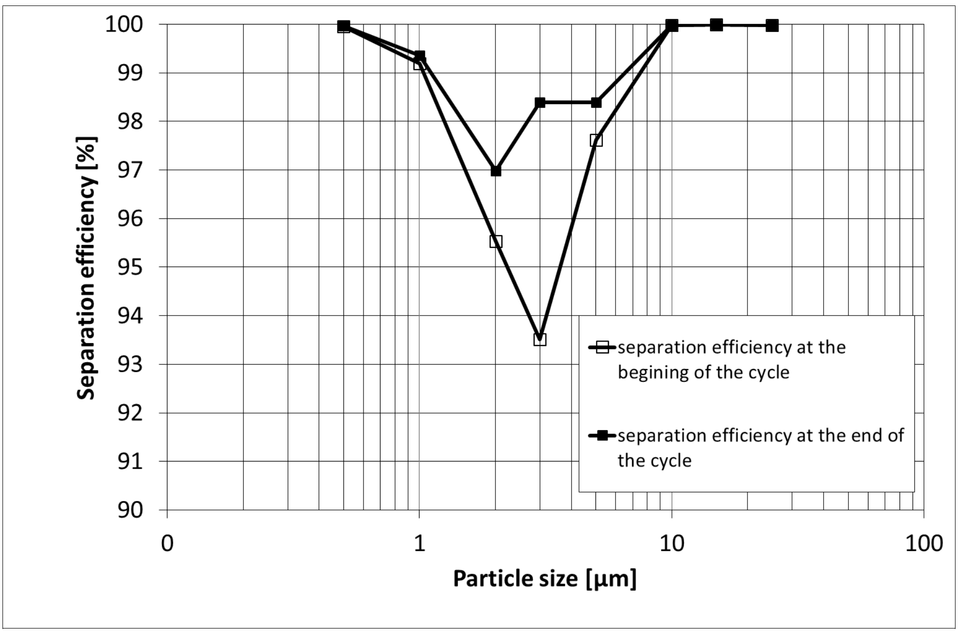

Fig. 4. Separation efficiency in the filtration cycle

The fractional filtration efficiency related to the average concentration of dust particles in the 5th and 45th filtration cycles is shown in figure 3. The results shown in figure 4 refer to the fractional efficiency within the 35th cycle immediately after the cleaning pulse and just before the end of the cycle when the accumulated dust layer on the filter surface was the thickest. The curves of the fractional separation efficiency have a typical V shape. The lowest point of a curve represents the size of the most penetrating particles. The combination, interaction and simultaneous operation of the main capture mechanisms (diffusion and interception) are the weakest at this point. The total efficiency of the capture mechanisms depends on the particle, gas and fiber properties and is characteristic of particular filtration conditions. In addition, there were some problems with particle measurement, because the counters represented the results in the form of distribution according to equivalent diameter. However, wood dust particles are irregularly shaped and their length is often greater than other dimensions.

The increase in the separation efficiency shown in figure 3. refers mainly to particles measuring 2-3 μm. The number of these particles was mostly reduced under the influence of the conditioning of the filter material during the first phase of the process.

Changes in the dust layer characteristics are the reason for the increase in separation efficiency within the cycle shown in figure 4. This increase related to cycle time covered a wider dimensional range of dust particles. However, the results relating to the average dust concentration suggest that the described increase occurred in every filtration cycle. Nevertheless, this should be confirmed by more detailed research. These changes are related to particle puffs particularly described by Simon et al. [2014]. Sharp increases in downstream dust concentrations during and immediately after each cleaning pulse were observed in this work, but its authors did not calculate the separation efficiency during the cycles. Results obtained in different baghouse dust collectors at different operating parameters, filter and dust properties, cannot be directly compared but the changes observed in the fractional separation efficiency are a confirmation of the phenomenon of momentary increased particle penetration caused by the sudden impact of a pulse.

Conclusions

The results described in this paper illustrate the effect of the time of dust layer accumulation during the filtration process on the separation efficiency of the tested filter medium. In the initial phase, between the 5th and 45th cycles, this effect is most noticeable for particles measuring 2-3 μm, which are the most penetrating particles. Changes in the separation efficiency within a single filtration cycle occurred with a wider range of particle size. However, this was not transferred to the separation efficiency in the 5th and 45th cycles, which was related to the average particle concentration.

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