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# METHODOLOGY OF PILOT-SCALE STUDIES ON PULSE-JET FILTRATION OF AIR POLLUTED WITH WOOD DUST

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## ABSTRACT

This article describes in detail the construction and operation of the test rig employed for experimental pulse-jet filtration of air polluted with small wood particles created during machining. It enables evaluation of filter media used for wood dust separation and examination of influence of filtration conditions on the filter performance. Exemplary results of some experiments were presented to illustrate research possibilities of the testing filter and the method. More detailed results of studies on the filtration mechanisms and key parameters which determine the performance of a filter will be presented in further papers.

KEYWORDS: Pulse-jet filtration, wood dust, nonwoven filter media.

## INTRODUCTION

The need to understand thoroughly the essence and the course of dust separation processes in pulse-jet filters in any technical-technological conditions makes it essential to develop research methods which would guarantee obtaining results that could have a direct impact on real functioning of facilities and entire systems used to maintain appropriate standards of air cleanliness in areas where manufacturing activities are carried out.

Measurements as well as investigations involving equipment and machines used in industry are always very difficult. In many cases, technical complexity of these facilities, their size as well as numerous, clearly defined operating conditions make it almost completely impossible to conduct detailed observation of their activities. In addition, it is also usually practically impossible to implement serious or, in fact, any parameter changes the observed processes or to exert, in a planned way, any influence on conditions of the phenomena which occur during the examined processes. Capturing and description of interrelationships taking place between the values that characterize the operation of dust collectors in such conditions is not very realistic. The enormous scale on which the described processes happen usually exceed many times the measuring capacities of precise research apparatuses and, therefore, make it impossible to assess accurately mutual interrelationships between the examined values. Therefore, it can be said that in most cases it is impossible to conduct systematic investigations on facilities operating in industry (Dean and Cushing 1988, Mukhopadhyay 2009, Simon et al. 2014).

Application of laboratory methods (using small flat filter samples) provides a viable alternative for the above-mentioned research. Such experiments, first and foremost, allow for free condition modelling of the conducted experiments, which have been carefully prepared earlier, and for carrying out precise measurements of all the observed values. As a rule, their main disadvantage, however, is smaller or greater separation from real conditions since methodological idealisation of conducting experiments in such conditions removes the employed laboratory facilities from machines working in industrial conditions. Therefore, research results obtained in laboratories cannot, in many cases, be transferred directly into conditions affecting courses of processes taking place during production techniques (Binnig et al. 2009, Callé et al. 2001, Callé et al. 2002).

Experiments carried out in the so called ‘pilot scale’ provide a unique kind of bridge between laboratory investigations and a direct application of an object or system in industrial conditions. The above-mentioned term has been adopted widely in laboratory techniques involving investigations of dust-extraction processes in situations in which they employ filter elements (filter bags or sleeves) characterized by dimensions, i.e. such as those mounted in industrial facilities and where the artificially created conditions are very similar to those existing in real time of their application (Lu and Tsai 2003, Saleem and Krammer 2007, Yoa et al. 2001). This makes it necessary to employ a special experimental station which can help achieve the appropriate requirements. The station must be equipped with numerous mechanisms which enable continuous creation of the course of filtration processes with exact reproduction of everything that takes place in the course of the operation of a real industrial dust extractor. Furthermore, it should also be characterized by a considerable flexibility with respect to changes of each and every operational parameter of the industrial pulse-jet filter affecting directly the separation of dust particles from the airflow in which these particles are dispersed.

The aim of this paper is to describe and present the set-up, mode of operation and cognitive potential of the test rig used in pilot–scale investigations on pulse-jet filtration of air polluted with wood dusts, and to present some selected exemplary results of these investigations. These results represent only a sample of the effects obtainable thanks to the described pilot-scale position. Further papers are expected for detailed studies on the filtration mechanisms and key parameters.

## MATERIAL AND METHODS

### Methodological bases of investigations of filtration processes in pilot-scale

Effective realisation of experiments which may have a direct reference to real industrial operation conditions of jet-pulsed filters requires the use of an appropriate experimental system. In addition, it must also allow researchers to watch carefully the behaviour of the examined filter elements and to measure values characterising their separation efficiency, to register resistances of airflow at any stage of the filtration process and to evaluate the efficiency of regeneration treatments carried out.

Conditions which simultaneously need to be fulfilled refer, in particular, to:

- possibilities of the application of a filter element (bag) with the diameter and length equal or very similar to dimensions employed in industrial facilities,
- lack of restrictions in selecting flow parameters in the area of conducting the dust separation process (velocity of air flow into the filter element, gas and dust load of the filtering area, uniform distribution of the airflow on this entire area),
- dust dosage with the intensity imposed for experiments and achievement of its uniform distribution in the entire air volume filling the primary pneumatic circulation of the experimental station,
- carrying out the dust separation process in a continuous way and at any length of time as a result of a permanent action of regeneration impulses on the filter element used in the experiment,
- implementation of changes in the functioning of the pneumatic regeneration system (duration of the pressure pulse, air pressure in this system, frequency of the repetition of impulses),
- establishment - at any level and maintenance - throughout the entire duration of the experiment, of the dust separation process of the airflow humidity flowing in together with dust to the surface of the filter element.

In order to create conditions appropriate to conduct accurate measurements of all the observed values and to exclude dangers of synergistic, uncontrolled influences of several factors affecting the course of the dust separation process in a space filled with a large number of filter elements cleaning the air, it is best to place only one such element in the filtering chamber of the test rig. In such case, each measurement undisturbed by any other additional influence is recorded maintaining full control of the assumed parameters of the process. It is true that this may entail some risk of variations associated with the sterility of such experimental design in comparison with real-life operation of dust separation devices in industry, but these deviations are incomparably smaller than those which occur in the case of laboratory trials carried out on small samples of filter media tested in total disengagement from what happens in large devices operating in production conditions. However, there is no doubt that in such a precisely defined and transparent functional system, it is possible to maintain carefully and on a constant level all the methodologically determined parameters of the course of the process, at the same time ensuring ease of introduction of all corrections in deviations which may occur during such a long-term experiment. Advantages of the system described above undoubtedly outweigh the possibilities of the occurrence of the above-mentioned shortcomings of this research method allowing investigations of very complex phenomena and processes of which the filtering dust separation is made up.

## The test rig

*General structure*

The test rig, in which all the characteristics and requirements described earlier were taken into account, was designed, executed and functionally tested. It made it possible to carry out experiments on filter bags of 150 mm in diameter and with active length of 1485 mm providing the filtering area of 0.7 $m^2$. Therefore, those were the elements separating dust from the incoming inflow of air with dimensions constituting components of the baghouse fitting albeit small but applied in special cases in woodworking industry. Hence, the application in these investigations of such bags referred directly to real-life conditions in which dust is removed from cleaned air.

The bag was pulled over a metal cage equipped, in its upper part, with a Venturi tube causing intensification of the cleaning pulse created by high-pressure air injected inside it by an internal nozzle. In this way, it was possible to operate in circumstances that emulated to a considerable extent the conditions of pulse-jet filters mounted in industrial plants.

The principal part of the test rig is a filtering chamber (1) in which a filtering bag (2) is placed. A flow of dust-laden air is delivered by a dust inlet channel (3) inside the chamber with the dust concentration depending on the output of the feeder (4) and the required dust area density on the tested bag.

The air flow through the entire measuring system is driven by the main fan (5). Cleaning pulses are injected into the bag by the nozzle (6) placed in the clean air chamber (7) over the top of the bag. Air is supplied to the nozzle from the compressed air installation by means of a surge tank (8) which works as a reservoir ensuring pressure stability during each pulse.

*Control and measuring systems*

The test rig is equipped with control systems as well as systems intended for performing measurements. The control systems make it possible to obtain the filtering conditions and parameters required during the experiment. These include:

- a system of dust supply which consists of the feeder and the dust inlet channel in which an aerosol is formed of the required dust concentration in the dust chamber.
- a system establishing the volume flow rate of the main fan with the executing element consisting of a gate valve (9) - it cooperates closely with the dust supply system,
- a system of compressed air supply control to the pulse nozzle. This system is made up of an electromagnetic valve (10) and a device controlling the cleaning system (11) which transfers electrical signals determining impulse frequency and duration of the cleaning pulse,
- a system of air relative humidity control. It consists of a steam humidifier (12) and an equalizing tank (13) in which constant humidity is kept for huge quantities of air needed for the circulation of the experimental station. The output of the humidifier is controlled by means of moisture content sensor (14) located in the clean air chamber.

The entire measuring equipment is divided functionally into individual systems which make it possible to determine precisely:

- dust concentration in the dust chamber – using for this purpose a set which consists of a simple probe (15), measuring filter (16), rotameter (17) with a regulatory valve (18) and a suction fan (19),
- air flow resistance across the filtering bag during the filtering cycle – using a differential manometer (20),
- air flow rate in the dust chamber and, hence, gas load of the surface of the filtering material (air-to-cloth ratio) – using a differential micromanometer (21) cooperating with a Prandtl tube (22) which is mounted into the outflow channel (23),
- the concentration of dust particles in the cleaned air – using a laser particle counter (LPC) type HR5250A (24). A sample of cleaned air was taken from the outflow channel with a probe (26). The measuring range of the counter includes 8 dimensional intervals with upper dimensional limits 0.5, 1, 2, 3, 5, 10, 15, 25 μm. The counter is coupled with an isokinetic dilutor (25) to which air samples are delivered using the isokinetic probe situated in the outflow channel for the cleaned air.

Ways of coupling and cooperation of individual components of the test rig are presented schematically in Fig. 1. Numbers in the text are identical with those in the Fig. 1.

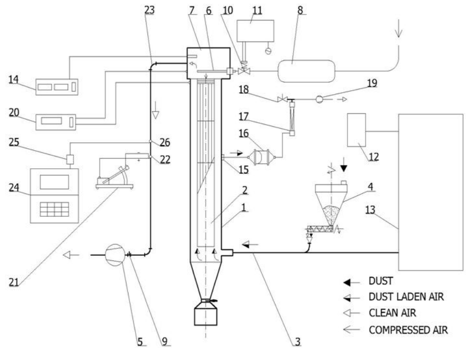


*Fig. 1: Schematic diagram of the filter test rig.*

### The course of experimental filtering

Before the activation of all constituents of the test rig with the aim to perform an experimental cycle of filtering dust collection, it was essential to determine precisely the output of the dust feeder in relation to the volume flow rate in the filtering chamber. This was to ensure maintenance of constant dust concentration in the inflowing air and, hence, consistent dust load of the filter material surface throughout duration of the performed experiment. Initial operations should also include measurements of resistances of the air flow through clean filtering material not yet covered by dust. This provided the basis for the determination of the resistance coefficient of this material used during computational evaluation and modelling of air flow resistances through the filter. Later on, this made it possible to determine precisely airflow resistances through the layer of dust accumulated on this material.

Synchronized initiation of flow through the filtering chamber of air with humidity at the assumed level, activation of the dust feeder and switching on of the cleaning system marked the beginning of the planned experiment. Simultaneously, all measuring and control systems were also activated. Readouts of indications of the LPC showing the content of dust particles in the cleaned air as well as registration of airflow resistances across the filter bag before and after the cleaning pulses were recorded at a fixed frequency. During the initial phase of the experiment, both readouts were carried out at short time intervals because, in this period, changes in these two values occurred very dynamically. During the ensuing phases, symptoms of stabilisation began to appear and they concerned both the separation effectiveness as well as pressure drop on the filter material covered by a dust layer (cake). As a result, it was possible to extend intervals between readings of consecutive readouts on the LPC and differential micromanometer.

Supervision over the appropriate course of the experiment consisted in maintenance throughout its duration of constant filtration velocity and unchanged air humidity flowing into the filtering chamber. Therefore, it was necessary to make appropriate corrections in the setting up of the regulatory gate valve on the outlet of the main fan as well as possible changes in the output of the steam humidifier.

## RESULTS AND DISCUSSION

Advantages of the described test rig as well as of the methodology of detailed process recognition and description of filtering dust extraction were corroborated by the results of numerous experiments. A wide range of filter media, as well as types of wood dust of diverse properties, were tested in them. The investigations were carried out on dusts created during the processing of wood materials - natural wood and various kinds of wood-derived materials. Some examples of research results for such dusts obtained using the described method and the test rig are presented. They show both the separation variability of the examined filter media and variations in airflow resistances in the course of successive phases of dust separation conduction in a continuous manner. In some selected cases, these relationships were observed in conditions of varying humidity of the airflow delivering dust to the place where it was separated from this flow. All the described experiments were conducted in unchanging operational conditions of the cleaning system – at 0.5 MPa air pressure supplying the pulse nozzle and one-minute time intervals of cleaning pulses repetitions. In addition, in all experimental filtering processes, identical dust concentration at inlet – at the level of 10 $g \cdot m^{-3}$ – were maintained.

Pilot-scale studies have been conducted so far on various dusts. Lu and Tsai (1998) used in research a test rig with filter bags for testing the separation of fly ash. Similar method was used by Saleem and Krammer (2007) for testing the coal ash and char dust. Limestone dust was used by Saleem et al. (2012) in the study on the influence of operating parameters on cake formation in pilot scale pulse-jet bag filter. As the filtration of wood dust in the pilot-scale has not been studied so far, the results described below are the first attempt to systematize research in this area.

## Separation efficiency of polyester fabrics

Filter fabric finishing method influences the collection efficiency of bag filters (Mukhopadhyay 2009). The exemplary results of limestone filtration of different surface treated filters confirm this influence (Cirqueira 2017), but there are no studies on wood dust separation efficiency in pilot-scale. Therefore the experiments on two different types of polyester fabric – conventional fabric of uniform structure designated by KYS-PROGRESS symbol and fabric with a microfiber layer on its upstream side designated by KYS-FINESS symbol were carried out. The results of these experiments exhibited a distinct operational advantage of the surface-finished structure. When this fabric was applied, dust concentration at the filter outlet was, on average, 2.5 times lower in comparison with the conventional structure (Fig. 2). Wide introduction of such fabric into wood industry may contribute quite considerably to improving the effectiveness of dust control in areas where production activities associated with the processing of wood materials are conducted (Dobak and Dolny 2004).

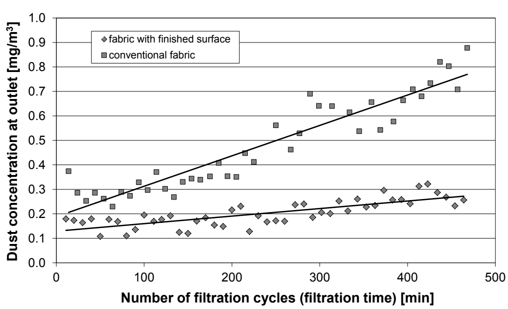


*Fig. 2: Effect of fabric surface finishing on wood dust collection efficiency.*

The mass concentration of dust was calculated basing on the results of the measurements performed with the use of the LPC as follows (Rogoziński 2016):

$$C_{0i} = \sum_{i=1}^{8} n_{0i} \cdot \frac{\pi \bar{d}_i^3}{6} \cdot \rho \cdot 10^{-3} \quad [mg \cdot m^{-3}]$$

where: $n_{oi}$ – the number concentration of dust in interval i of the LPC, pcs·m$^{-3}$,
$\bar{d}_i$ – average size of interval i, mm,
ρ – density of the solid wood substance 1500 kg·m$^{-3}$ (Kollmann and Côté 1968).

## Resistances to airflow during filtration

As a rule, while determining the separation efficiency of the filter, simultaneous observations and measurements are performed on resistances to airflow across the filter bag. This made it possible to conduct a thorough evaluation of the fabric filtration performance in given operational conditions. Furthermore, it also provided a basis for the evaluation of energy consumption for air cleaning when employing pulse-jet baghouses in any technological applications. An example of results obtained from such measurements is presented in Fig. 3 (Dolny and Rogoziński 2014). The curves describe the total air flow resistance across the filter measured in the form of pressure drop during filtration. It can be written as the sum of the clean filter bag $\Delta P_f$ and across the dust cake $\Delta P_c$ deposited on the surface of the bag (Leith and Ellenbacker 1980, Ju et al. 2000):

$$\Delta P = \Delta P_f + \Delta P_c \qquad [Pa]$$

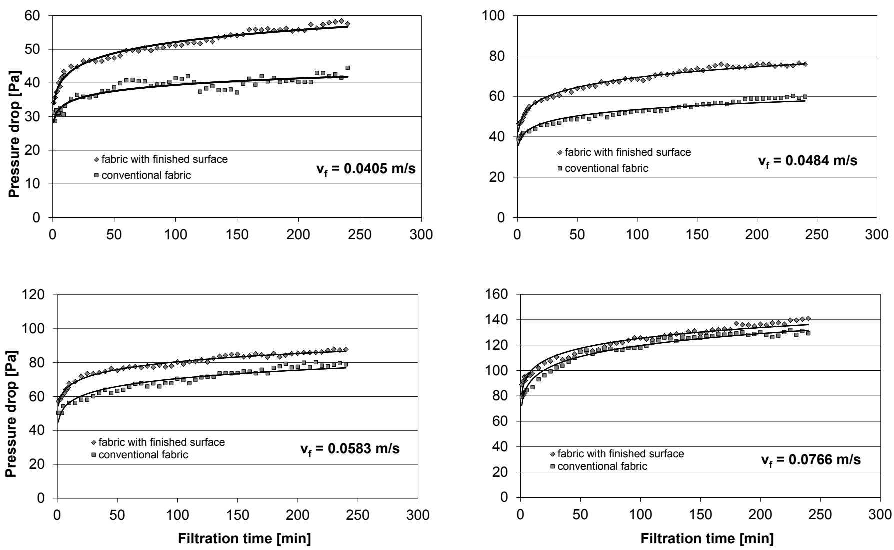


*Fig. 3: Effect of fabric surface finishing on the resistance to airflow in dependence on filtration velocity.*

## Influence of air humidity on filtration process

Apart from parameter modelling of the filtration process influenced by the technological conditions of filters, the described test rig also yields the possibility of carrying out experiments during changing conditions resulting from the impact of environmental factors in which these filters work. One of the most important factors was the effect of air humidity delivering dust particles to the filter bag. This effect was the most intensive in the case of dusts characterized by distinct hygroscopicity (Mukhopadhyay 2010).

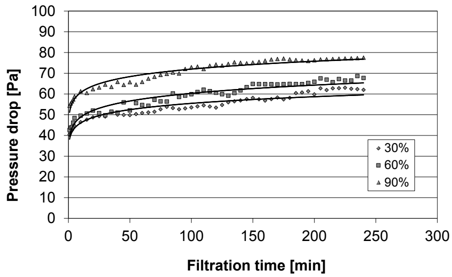


*Fig. 4: Effect of air relative moisture content on maximum pressure drop.*

Wood dusts belong to exactly this kind of materials and changes in the humidity of the carrying air flow do mark their significant influence (Dolny et al. 2006, Dolny and Rogoziński 2010, Dolny and Rogoziński 2014). Fig. 4 presents exemplary results of investigated beech wood dust filtration performance in different moisture conditions at filtration velocity 0.0406 $m \cdot s^{-1}$.

## CONCLUSIONS

Advantages of the described test rig for investigations in pilot-scale, which was developed on the basis of long-term trials improving the research methodology of filter dust separation processes fully emulating industrial conditions of filter technique application, provide a sound basis for reliable research work whose results will, to a very high degree of accuracy, be confirmed in real-scale devices applied in industry. The utilitarian nature of these studies conducted employing all-embracing methodology and measuring procedures is quite clear. This utilitarian value of the described studies is further corroborated and documented by successful attempts of verification of the research results carried out so far in laboratory conditions as well as comparative observations which refer to the work of industrial pulse-jet baghouses.

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