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Research Article

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Experimental investigation of air pressure drops on different mesh layers using air filter performance test rig

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Abstract: This paper focuses on the experimental investigation of pressure drops obtained on different mesh layers setup with the use of Air Filter Performance test rig according to EN 61591 and verification of specially designed test piece and results in quality. Two different mesh sizes and a combination of both were investigated during the experiment. Pressure drops on filters setups were measured, plotted against flow rate, and compared. Test outcome proves that test piece was designed appropriately and pressure drop results obtained on filter setups are aligned with the theory.

Keywords: Filtering, Mesh, Pressure drop, Strainer

1 Introduction

Dust particles and impurities in the air are usually unwanted or even harmful factors in the operation of various machines or for processes. Particles present in the air vary in many aspects. Particles could be classified into four main groups, namely classification with particle formation method, origin, size, and common classification method [1]. The motion of those small-scale loose particles caused by gas movement is referred to as pneumatic transport. In industry, three main types of air movers can be selected to be used, which are fans, blowers, and compressors. Fans due to their relatively low cost and price to efficiency ratio are commonly used in different branches of industry [2, 3]. Dust particles and impurities can be absorbed into the air streams generated by the before-mentioned air movers, either on purpose via the usage of specially designed equipment such as ejectors. or as an undesirable result of operation [4, 5]. To prevent any impurities from getting into process air a vast number of purifying systems are used, depending on the system requirements. One could distinguish four main methods for separating unwanted solid or liquid particles from the air, which are mechanical type, e.g., cyclone separators, electrostatic force, washing, e.g., water curtains and filtration [1, 6]. The last-mentioned method represents the most commonly used approach for separating particles from process air. It is simple, low-cost, and relatively effective solution which could be found in many different branches of industry from household appliances to aerospace applications. Fiber-based filters are one of the most commonly used [7].

The high filtering efficiency is usually connected with low air permeability. Unfortunately, that dependency is causing a great pressure drop which could be observed behind the filtering medium, which is a major drawback of the filters. The result of such phenomena is the usually greater power consumption of the system to overcome an unwanted effect. Low-pressure drop, on the other hand, results in low particle collectability which lowers the filtering efficiency [8–10]. That creates a technical and physical contradiction for the system, which greatly obstructs the design of optimal filtering setup. Different approaches are used to cope with that specific phenomena, starting at changing the fibers and structure of the filters through geometrical changes to various filtering layers combinations [7–9, 11].

Another filtering aspect worth mentioning is the clogging tendency of the filters, as they continue to collect impurities over time. This behavior leads to a reduction of air permeability of the filters herewith enhancing the pressure drop on the filter, which harms machine operation [10, 11]. To sustain high performance of the machinery manufacturers have developed several maintenance approaches for filtration systems. Filtering setups are either periodically cleaned or removed and exchanged by the brand new setups. However, both of these approaches generate additional costs. Therefore it is highly beneficial to optimize filtering setups in such a manner that it poses high particle

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collectability alongside with relatively great permeability and long lifetime/durability.

This article focuses on verifying the quality of pressure drops obtained as a result of the use of different meshes in a dedicated test piece, as an introduction for further filter setups investigations considering filtering efficiency and independence of geometrical boundaries of tested filtration setups, providing quick and reliable mesh verification method.

2 Experiment Setup

The experiment was conducted on air performance test rig for functional tests of components, which was manufactured according to EN 61591 standard for cooking fume extractors, where the working point is calculated on a reference density of 1.2 kg/m^3 [12]. This test bench was designed mainly for determination of volumetric flow providing a very wide range of applications for numerous measurements on air-conditioning devices including filter resistance characteristics. Test bench allows volumetric flow measurements in the range of 25–1200 m^3/h with a test pressure of up to ±2500 Pa. According to the test stand manual, in the specified measuring range, the total measurement uncertainty for the volume flow is <1.4% and for the test, pressure is <0.6%.

2.1 Test stand

The test stand consists of several segments. Determination of the volume flow rate is done using an orifice measuring section. The measuring range is covered by 2 measuring screens in the measuring section. To compensate for the pressure loss resulting from the volumetric flow measurement test stand is equipped with a speed-controlled radial fan. The measuring section is connected to the test chamber via the use of the connection tube. Also, an auxiliary fan

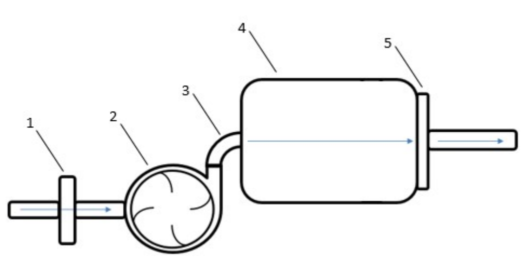

Figure 1: Schematic of air performance test rig; 1- measuring section; 2-support fan; 3-connection tube; 4-test chamber; 5-test piece

enables the build-up of overpressure or negative pressure in the test chamber for resistance characteristics measurements. The stand is equipped with quick-release clamps for easy assembly of test pieces assembled to the adapter plates. The schematic of the test stand is presented in Figure 1.

2.2 Test piece

To conduct measurements on filtration setups, a special test piece was designed. The flow took place through a 75 mm diameter pipe (according to ISO 9001:2008). on which filtration setups are assembled. Filtration setups are changeable and the system is designed in a way that enables mounting of single as well as multilayer meshes combinations. Such a solution creates the possibility to investigate the impact of meshes exclusively on the pressure drops, not including the specific geometries of filtration setups used in real-life appliances. Therefore the filtration setups shall provide the possibility to compare different meshes either on a project phase or for reverse engineering purposes. The pipe is connected with an adapter plate via a specially designed adapter. Complete assembly of the test piece is presented in Figure 2.

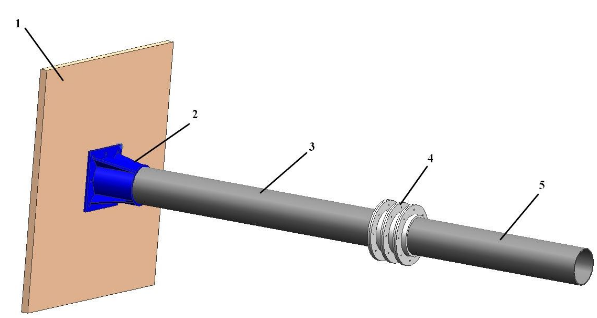

Figure 2: Assembly of test piece; 1-adapter plate; 2-adapter; 3-pipe 600 mm; 4-filtration setup; 5-pipe 400 mm

2.2.1 Filtration setup

During the experiment, several different filtration setups were investigated. Two mesh types were considered during the investigation. Characteristics of meshes used in the investigation are described in Table 1 below.

The design of a single layer is presented in Figure 3. The working diameter of mesh assembled in a single layer is equal to 70 mm. Meshes that were tested were clamped inside filtration setups and sealed with a rubber seal to prevent air leakages.

Table 1: Characteristic of mesh samples used

Sample Description	Mesh opening (µm)	Open area (%)	Mesh count (n/cm)	Thread diameter (µm)
A	55	31	100	40
B	200	43	32	100

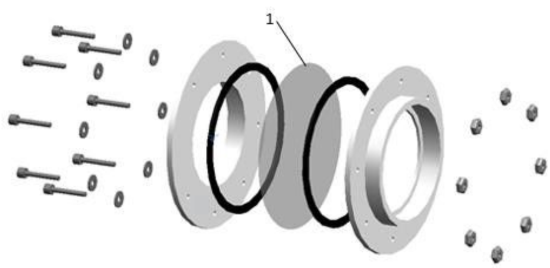

Figure 3: Assembly of Filter setup – single layer; 1-mesh sample

3 Experiment Performance

Several test runs were conducted during the investigation. They are divided into groups and described in the below section of the article. Combinations verified during the experiment are presented in Table 2 below.

Table 2: Combinations used for investigation

Combination	Mesh
1	Free stream
2	A
3	B
4	A + B

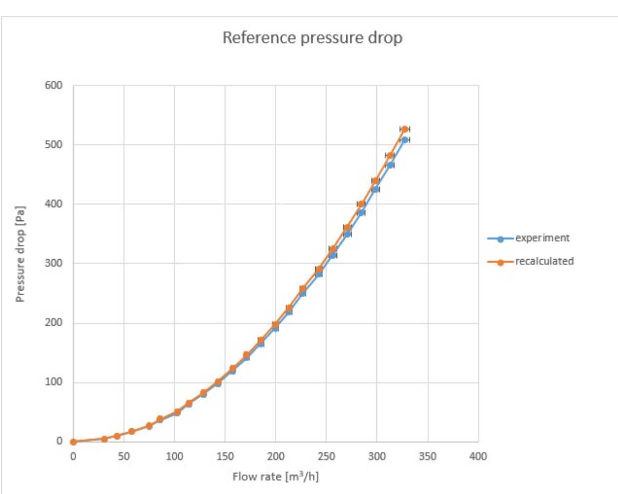

Figure 4: Characteristic of reference pressure drop vs. flow rate

3.1 Reference run

To obtain values of a pressure drop on a specimen a reference pressure obtain at the specific flow rate in the test piece had to be determined. Therefore a reference test run with a free stream was conducted, as a result of which graphical representation of a flow rate vs. pressure was obtained. The measured air density during test duration was equal to 1.16 kg/m^3, hence pressure values obtained were recalculated from Eq. (1) to fit standard air density equal to 1.2 kg/m^3, as stated in ISO 5801:2017 standard [13]. Such an approach is used for further comparison of test outcomes. The obtained results are presented in Figure 4.

$$P_r = \frac{P_e \cdot \rho_s}{\rho_e} \tag{1}$$

Where:
P_r – recalculated pressure drop in Pa
P_e – experimental pressure drop in Pa
ρ_s – standard air density equal 1.2 kg/m^3 according to ISO 5801:2017 standard [13]
ρ_e – experimental air density in kg/m^3

In case of reference run the recalculated pressure drop would be referred further in text as reference pressure drop – P_{ref}.

3.2 Single mesh runs

Single layers of samples A and B were investigated on the test stand. Like in the reference run, all pressure values obtained were recalculated to fit standard air density equal to 1.2 kg/m^3, as stated in ISO 5801:2017 norm [13]. Reference pressure drop value was subtracted from results obtained in test pieces containing pipe and filter setup to obtain pressure drop value for filter setup exclusively, according to Eq. (2). The system for which filters setups are investigated operates at a flow rate of 150 m^3/h, therefore Graphs were adjusted from 0 m^3/h to 160 m^3/h to include the value of the interest in the presented range. Graphical representations of obtained results for Sample A and B are presented in Figure 5.

$$P_m = \frac{P_e \cdot \rho_s}{\rho_e} - P_{ref} \tag{2}$$

Where:
P_m – pressure drop on mesh in Pa according to ρ_s
P_e – experimental pressure drop in Pa
ρ_s – standard air density equals 1.2 kg/m^3 according to ISO 5801:2017 standard [13]
ρ_e – experimental air density in kg/m^3
P_{ref} – reference pressure drop in Pa

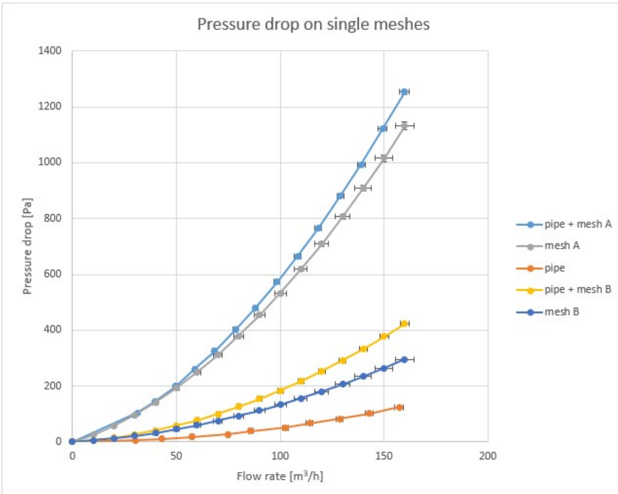

Figure 5: Characteristic of pressure drop vs. flow rate for meshes A and B

3.3 Double mesh runs

A combination of layers of samples A and B were investigated on the test stand. The testing procedure was analogical to the one described for the previous run. A graphical representation of obtained results is presented in Figure 6 below.

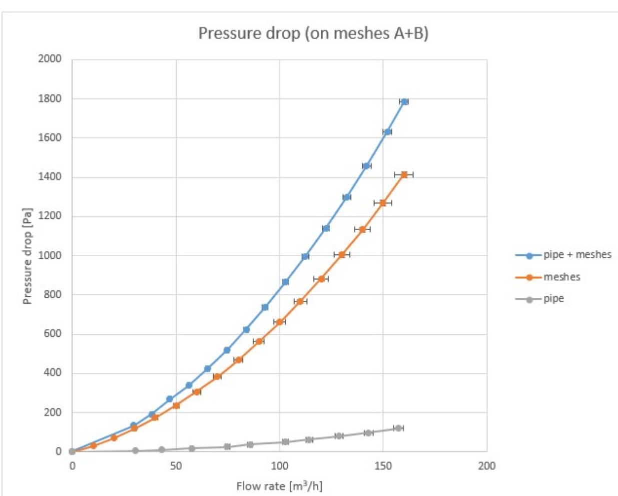

Figure 6: Characteristic of pressure drop vs. flow rate for meshes A+B

3.4 Testing setup reliability

To check the reliability of the testing setup pressure drops obtained separately on filtering setups A & B were added up and compared to the measured system of two filters setups connected in series (combination 4). Results obtained are presented in Table 3 and Figure 7 below.

Table 3: Comparison of pressure drop values for double mesh combination

Flow rate (m^3/h)	Pressure drop experimental (Pa)	Pressure drop verified (Pa)	Difference (%)
0	–	–	
10	30.5	29.1	4.41
20	70.8	70.0	1.23
30	118.6	118.3	0.27
40	173.8	174.1	0.18
50	236.4	237.4	0.44
60	306.4	308.2	0.59
70	383.8	386.5	0.70
80	468.6	472.2	0.78
90	560.7	565.4	0.83
100	660.3	666.1	0.88
110	767.3	774.3	0.91
120	881.7	890.0	0.94
130	1003.5	1013.1	0.96
140	1132.7	1143.7	0.98
150	1269.3	1281.8	0.99
160	1413.2	1427.4	1.00

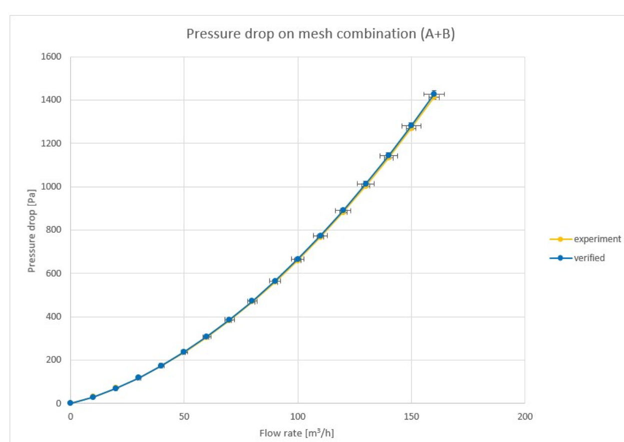

Figure 7: Comparison of pressure drops obtained for double mesh combination via two different approaches

3.5 Results comparison

All test pressures for every step of 10 m^3/h of flow rate obtained during investigations are presented in Table 4. Graphical representation of compared pressure drops is presented in Figure 8.

Table 4: Comparison of pressure drop values

Flow rate (m^3/h)	A (Pa)	B (Pa)	A + B experiment (Pa)	A + B verified (Pa)
0	–	–	–	–
10	24.2	5.0	30.5	29.1
20	57.7	12.3	70.8	70.0
30	96.9	21.4	118.6	118.3
40	141.9	32.2	173.8	174.1
50	192.7	44.7	236.4	237.4
60	249.3	58.9	306.4	308.2
70	311.6	74.9	383.8	386.5
80	379.6	92.6	468.6	472.2
90	453.5	112.0	560.7	565.4
100	533.0	133.1	660.3	666.1
110	618.4	155.9	767.3	774.3
120	709.5	180.5	881.7	890.0
130	806.4	206.7	1003.5	1013.1
140	909.0	234.7	1132.7	1143.7
150	1017.4	264.4	1269.3	1281.8
160	1131.5	295.9	1413.2	1427.4

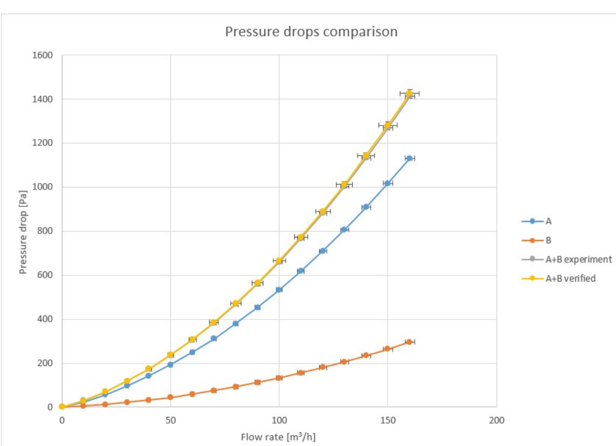

Figure 8: Comparison of pressure drops obtained during investigations

4 Conclusions

Mesh "A" with 31% open area causes greater pressure drop than mesh "B" with 43% open area, as was predicted. With a 12% difference in the opening, the pressure drop obtained on filter "A" is about 4–5 times greater. At the flow rate equal to 150 m^3/h, which was the point of interest during the investigation, it does create a significant difference.

Comparison between experimental and verified double filtering setup result in about 1% differences in pressure drop.

Greater difference of values obtained at a low flow rate (10 and 20 m^3/h) most probably was the result of relatively low-pressure drops obtained at those points, which could be easily interfered by the surrounding environment. Therefore in the manual effective volumetric flow measurements are stated to start from 25 m^3/h, nonetheless, points below the effective range of the stand are also captured and saved by the system, however, they shall not be considered as reliable in case of further investigations.

Interesting is the tendency of differences to increase alongside with increasing flow rate. The main reason for such phenomenon is adding of measurement errors of single filters, which will tend to increase with greater values of pressure drops. Such tendency shall be taken into consideration in the case of further investigations planned and conducted on the test stand.

Relatively insignificant difference between results obtained via two approaches (meshes A+B experiment and verified) proves, that the test piece was designed appropriately and drops obtained on multilayer setups can be effectively verified via a summary of values obtained as a result of a single mesh test runs.

Moreover, pressure loss obtained as a result of the distance between meshes in filters setup and geometry of test piece assembly have proven to be negligible. Therefore test piece could be assumed as reliable, connections between assembled pieces are tight and the test piece could be used for further investigations of filtering setups including investigations of filtration efficiency alongside with pressure drop and flow rate measurements.

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