A pilot scale study of pulse-jet cleaning of a rectangular bag filter system: optimization of operating parameters

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Abstract. Fabric bag filters are widely used for air pollution control. The most commonly used type is a cylindrical bag filter, which has been the focus of much research. However, in recent years, despite the concurrent use of rectangular bag filters, only a small number of studies have attempted to determine the appropriate conditions for the maximum efficiency of this filter type. Therefore, the purpose of this study is to ascertain working conditions for an effective removal of particulate matter from the air stream, using rectangular bag filters with pulse-jet cleaning. Experiments were performed with different values of various factors. The results showed that a spray distance of 10 cm, spray pressure of 3 kgf/cm\textsuperscript{2}, six spray holes of 6 mm diameter each, polyester filter material, and a spray time of 0.3 seconds were the best possible conditions for the effective removal of dust using a rectangular bag filter.

Keywords: Fabric filters, Optimum dedusting conditions, Pulse-jet cleaning system, Rectangular bag filter.

1. Introduction

Fabric filters are equipment that removes coarse and fine particulate matter from the air stream in industries. Regardless of weather conditions and industrial operation, these filters have high removal efficiencies for capturing fine dust that is harmful to human health [1]-[3]. The most common fabric filter for industrial use is a cylindrical fabric filter [4]. This type of air pollution control equipment, along with an air dedusting system, has been used and developed over a long period of time [5], [6]. Although some research has been performed on pulse jet fabric filters, only a few studies have focused on rectangular fabric filters [7]. In this study, we focus on the use of rectangular fabric filters, because considering the shape of the air stream, they have higher dedusting efficiencies and require less installation area compared to cylindrical type systems [8]. This research is aimed at deriving enhanced performance of rectangular fabric filter by investigating appropriate dedusting conditions. Only factors that affect the dust removal efficiency, of which adjustment can be directly performed at the machine are included (i.e., pulse distance, pulse pressure, number of pulse holes, filter material, and pulse time) [9] whereas environmental factors related to the process system (i.e., filtration velocity, dust concentration, dust density, etc.) are not considered in this study.

2. Experimental Apparatus and Method

2.1. Sample and filter media

The dust used in the experiment was aluminium oxide powder, collected from a fabric filter installed in an aluminium smelting plant. Impurities were first removed through a sieve grading separation (# 100). The dust was then dried over a period of 12 hours in a 110 °C electric oven to remove moisture, and then cooled at room temperature for at least 30 minutes. The particle size distribution was analysed by a laser particle size analyser (Malvern mastersizer). The particle size distribution of the dust ranged from 1 to 100 µm, with an average of about 20 µm. Polyester, Nomex, and glass materials of similar weights, expansibilities, and strengths, as shown in Table 1, were used for the comparative analysis.
Table 1: Major properties of filter fabrics

<table>
<thead>
<tr>
<th>Major properties</th>
<th>P.E.</th>
<th>Nomex</th>
<th>Glass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight unit (g/m²)</td>
<td>550±30</td>
<td>500±30</td>
<td>570±20</td>
</tr>
<tr>
<td>Expansibility (Length, kg)</td>
<td>160±20</td>
<td>140±20</td>
<td>150±20</td>
</tr>
<tr>
<td>Expansibility (Width, kg)</td>
<td>180±20</td>
<td>160±20</td>
<td>150±20</td>
</tr>
<tr>
<td>Strength of explosion (kg/m³)</td>
<td>50±10</td>
<td>50±10</td>
<td>50±10</td>
</tr>
<tr>
<td>Ventilation rate (cm³/cm²·sec)</td>
<td>15±2</td>
<td>15±2</td>
<td>15±4</td>
</tr>
</tbody>
</table>

2.2. Experimental apparatus

2.2.1. Single-filter experimental apparatus

A rectangular filter fabric (L×H×W = 1500×300×50 mm) was equipped in a single filter test device, as shown in Fig. 1. For the variation of parameters, the speed control dial of the screw particulate filter injector was used to set the dust supply amount, and the spray pressure was maintained by the compressor. The spray distance was adjusted by the movement of the spray nozzle, and the spray time and period were adjusted with the help of a timer. The filtration rate was altered by the damper and blower, and the differential pressure of the system was recorded by an automatic micro manometer once every 10 seconds.

![Fig. 1: Schematic diagram of experimental setup for single-bag filter system.](image)

2.2.2. Differential pressure measurement apparatus

The evaluation method for determining the dedusting efficiency was partly based on the differential pressure distribution of the system, due to its effect on the overall bag filter performance [10]. To maximize the filter’s service life, as well as to minimize energy consumption, the differential pressure of the system should not be excessively high. To overcome this limitation, experiments were performed under different conditions, and the results were verified through a comparison with the pressure difference distribution of the dedusted filter. The filters used in each experiment were removed from the case, and 30 points on the filter, each separated by a distance of 15 cm, were selected for the measurements of relative differential pressures.
A self-developed differential pressure measuring device was produced (Fig. 2) that contained a small blower, which created an air inflow in the filter through the holes of the porous pipe. The measurement of duct pressure was performed with a liquid column manometer. The differential pressure measurement values of selected points indicated the degree of dedusting of the associated section. Highly dedusted parts have lower differential pressure, and higher differential pressures are associated with parts subject to a lesser degree of dedusting. Therefore, the final analysis of the measurement results can be compared to the filter exhaustion of each part, which determines the uniformity of the degree of exhaustion.

2.3. Method

The experimental method used to evaluate the dedusting effect of the filtering bag through airflow involved measuring the differential pressure of the system every 10 seconds, for at least 7 hours, using an automatic micro-manometer, and then using the data for analysis. After each experiment, the uniformity in distribution of filter differential pressure over the filter surface was determined through the measurement of pressure differences of each part. If the differential pressure of the system was low and uniform over the filter surface, the dedusting effect of the system was considered to be excellent. This method was repeated for varying conditions of spray distance, spray pressure, number of spray holes, spray time, and filter material to find optimum values for efficient and uniform dedusting. For each experiment, a T-shaped nozzle was solely used, because it was considered to be the most effective type in the case of rectangular bag filter systems [11].

2.4. Experimental conditions

The experimental conditions of the single-filter system listed in Table 2 were classified into two categories: general and cleaning conditions. A general condition does not change consistently throughout the entire course of the experiment once selected at the start. The selection of the general condition values was derived from the preliminary test results. For the cleaning condition, the experimental conditions were based on results from existing research, accepted for the factors mentioned below. Before the start of each experiment, changes in only one condition from the selected factors were measured. When the experiment was initiated, all other factors involved in the experiment were analyzed under general conditions. The
relative stability of such systems made it possible to verify through the cross-comparison by changing each influence factor, depending on experimental conditions.

Table 2: Experimental conditions

<table>
<thead>
<tr>
<th>General conditions</th>
<th>Cleaning conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample dust</td>
<td>Pulse distance</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>2, 10, 20 cm</td>
</tr>
<tr>
<td>Dust concentration</td>
<td>Pulse pressure</td>
</tr>
<tr>
<td>30 mg/m³</td>
<td>2, 3, 4 kgf/cm²</td>
</tr>
<tr>
<td>Face velocity</td>
<td>Pulse time</td>
</tr>
<tr>
<td>1.65 m/min</td>
<td>0.1, 0.2, 0.3, 0.4 sec</td>
</tr>
<tr>
<td>Pulse interval</td>
<td>Pulse hole quantity</td>
</tr>
<tr>
<td>10 min</td>
<td>4, 6, 8</td>
</tr>
<tr>
<td>Nozzle type</td>
<td>Bag material</td>
</tr>
<tr>
<td>T-type</td>
<td>P.E, Nomex, Glass</td>
</tr>
</tbody>
</table>

3. Results and Discussion

As the differential pressure values were different for each measurement due to a continuous dedusting process, a comparison was difficult to obtain. For this reason, at a constant time interval, an average was taken to simplify the cross-comparison of the results. Additionally, the data and analysis concerning the uniform or non-uniform distribution of pressure drop are not shown in this paper for brevity. The details of the analysis can be found in our previous study [11]. The influence of changes in different parameters on the pressure drop observed with the single bag filter is presented in Fig. 3-Fig. 7.

3.1. Optimum spray distance

Fig. 3 shows the average pressure drop of the system at spray distances of 2, 10, and 20 cm. The data indicate that the pressure drop values at 2 and 10 cm were similar to each other, but were lower than that observed at a 20 cm spray distance. Although the system pressure differences were similar at spray distances of 2 and 10 cm, the differential pressure of the filter at 2 cm was non-uniform as compared to the 10 cm spray distance. Based on these results, it was determined that the optimum spray distance was around 10 cm for the T-shaped nozzle.

3.2. Optimum spray pressure

It was recommended in previous studies that the spray pressure of the fabric filters could be increased in order to lower the pressure drop, but an excessively high spray pressure could increase the damage to bag materials and could reduce filter bag life [10]. From Fig. 4, it can be seen that the pressure drop of the system decreased by increasing the pressure from 2 to 4 kgf/cm². Although the pressure drop was similar for pulse pressures of 3 and 4 kgf/cm², the differential pressure distribution was more uniform for former pulse pressures.
pressure. Regardless, given the risk of filter damage arising from pressure increase a pulse pressure of 3 kgf/cm² was taken to be an optimum value.

3.3. Optimum number of injection holes

Generally, the number of injection hole in fabric filters is just one. However, for rectangular filter types, the installation of at least two or more nozzles in the longitudinal direction of the inlet to spray the air stream could increase dedusting efficiencies [12]. If the number of spray holes is low, the dedusting may not be distributed properly, while if the number is too high, there is a possibility of degradation in efficiency due to excessive dispersion. It is difficult to determining an absolute standard for spray hole number, because the size of the spray aperture could also affect dedusting efficiencies. In this study, 4, 6, 8, and 10 mm diameter spray apertures were selected with the T-shaped nozzle, and an adequate dedusting effect was observed at a diameter of 6 mm. Four, six, and eight spray holes were tested with the 6 mm diameter nozzle.

The differential pressure measurements, shown in Fig. 5, indicate that the efficiency was higher when the number of holes was increased from four to eight, but when eight holes were used, there was a non-uniform distribution of filter differential pressure. Hence, six holes are optimal for this system, because this amount results in a higher dedusting efficiency, and a low and uniform filter differential pressure.

3.4. Selection of the filter material

From the measurements of the system differential pressure, the dedusting efficiency of polyester material and Nomex was fine and similar, but was very low for the glass fiber material (Fig. 6). The pressure difference observed with the glass fiber was very high, with a non-uniform distribution over the filter surface.
Nomex had a low pressure difference, but a relatively non-uniform differential pressure distribution. Unlike glass fiber and Nomex, the polyester fiber filter had both a low pressure drop and a uniform pressure drop distribution. Hence, among the three materials, polyester fabric filter was best suited for use in the rectangular bag filter.

![Graph showing the influence of fiber material on average pressure drop.](image)

Fig. 6: Influence of fiber material on average pressure drop.

3.5. Optimum pulse time

In general, a spray time of 0.1 seconds was the most recognized and has been in use for a long time through experimental study and validation. For this study, spray times of 0.1, 0.2, 0.3, and 0.4 seconds were used and the results were compared. From Fig. 7 we can see that the average pressure drop decreased by increasing spray time up to 0.3 seconds, but no significant decrement was observed at longer spray timings. From the experimental results, it can be concluded that the optimum spray time was 0.3 seconds.

![Graph showing the influence of pulse time on average pressure drop.](image)

Fig. 7: Influence of pulse time on average pressure drop.

4. Conclusion

The experiments were aimed to derive the optimum conditions for rectangular bag fabric filter systems. The optimum spray distance was found to be 10 cm, because it was associated with a low pressure drop, and the pressure was uniformly distributed in the filter. The spray pressure of 3 kgf/cm² was considered to be optimal, because the dedusting efficiency at this pressure was excellent and uniform and higher pressure increased the possibility of uneven distribution of pressure causing damage to the filter. A relatively good dedusting effect was observed when six spray holes of 6 mm diameter were used, so this was considered to be the optimum spray holes configuration. The pressure drop decreased significantly by increasing the pulse time from 0.1 to 0.3 seconds, but beyond 0.3 seconds, there was no significant improvement in the pressure
drop achieved. Hence, a pulse time of 0.3 seconds was considered as the optimum time period. Among polyester, Nomex and glass fiber materials, the polyester material had the highest dedusting efficiency, as well as a uniform distribution of differential pressure. Therefore, polyester can be used as an effective filter material. For the next step phase, experiments should be conducted to derive optimum parameters for a bag house using multiple rectangular fabric filters, based on the results of this project.

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6. References


