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Research Article

Systematic Selection of a Bag Filter Unit and Filter Fabric for Dust Removal from Silty Loam Based on System Analysis

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Abstract

This article examines the critical issues surrounding the selection of an appropriate bag filter unit and filter fabric specifically designed for the removal of finely dispersed silty loam dust generated following the drum drying process in cement production. A comprehensive analysis of the gas flow parameters subsequent to the cyclone stage revealed that the dusty gas velocity ranges between 10–25 m/s, with a dust concentration of approximately 1640 mg/m^3, an operating temperature of 145–160°C, and the predominant fraction of particles situated within the 2–10 μm range. The evaluation of various equipment designs and filtration materials was conducted based on a rigorous four-stage system analysis. Consequently, a bag filter construction featuring pulse-jet regeneration was identified as the most optimal solution for these specific industrial conditions. Comparative assessments of various fabrics demonstrated that a combined material based on glass fibre, basalt, and polyester exhibited the highest performance levels in terms of thermal stability, mechanical durability, resistance to abrasive wear, and the efficient capture of fine particulate matter.

Keywords

Silty loam dust, bag filter, combined filter fabric, glass fibre, basalt fibre, polyester, system analysis, aerodynamic resistance, cleaning efficiency, pulse-jet regeneration.

INTRODUCTION

In the industrial production of cement, following the drum drying process of loam, the gas stream exiting the cyclone apparatus continues to retain a significant concentration of finely dispersed dust particles, primarily within the size range of 2–10 µm [1, 2]. To achieve the efficient capture of such microscopic particulates, it is imperative to enhance existing dust removal equipment and carefully select filtering fabrics that are precisely adapted to the specific operational environment [3, 4]. From this perspective, evaluating the design of the bag filter unit and the filtering media as a singular, integrated system of interconnected parameters is of paramount importance [5, 6]. The primary objective of this research is to identify the most optimal bag filter construction and a suitable combined filter fabric for silty loam dust through the application of a comprehensive systematic analysis [7, 8].

The parameters of the gas flow exiting the cyclone apparatus during the drum drying of loam were rigorously analysed [9, 10]. It was determined through empirical observation that the velocity of the dusty gas stream post-cyclone ranges between 10–25 m/s, with an initial dust concentration of approximately 1640 mg/m^3 and an operating temperature varying from 145°C to 160°C [11, 12]. The particle size distribution analysis revealed that the dust is predominantly composed of fractions between 2–10 µm, with a calculated average equivalent diameter of 9.71 µm [13, 14]. These technical indicators underscore the persistent presence of finely dispersed loam dust at the post-cyclone stage, necessitating the implementation of a high-efficiency bag filter design [15, 16]. Furthermore, the selection of a filtering material that remains stable under the specified thermal and aerodynamic loads is essential to ensure sustainable industrial purification [17, 18].

METHODS

To effectively resolve the technical challenges identified, the filtration units and fabric media were evaluated using a comprehensive four-stage systematic analysis. In this assessment, each variant was compared against multiple technical criteria, and the most optimal solution was determined through integral evaluation.

Stage 1: Analysis of Bag Filter Unit Constructions. In the initial stage, contemporary bag filter designs suitable for dusty gas purification were comparatively evaluated. Primary focus was directed towards aerodynamic resistance, the mechanism of conveying dusty gas to the bags, cleaning efficiency, the stability of the regeneration process, and the compatibility of functional components.

According to the results of the analysis, a construction featuring pulse-jet regeneration, integrated with a pre-chamber and gas distributor, where the dusty gas is supplied to the outer layer of the bag (outside-in mechanism), emerged as the most optimal variant. In this specific design, finely dispersed dust is primarily captured on the external surface of the sleeve, ensuring the formation of a dust cake on the surface and limiting the deep penetration of particulates into the fabric matrix. Consequently, hydraulic resistance remains more stable, pulse-jet regeneration occurs more effectively, and the operational lifespan of the filter bag is extended. The systematic analysis results are presented in Figure 1.

Conversely, constructions utilizing an internal surface supply mechanism were deemed less suitable for this process. This is due to the high risk of fine particles (2–10 μm) penetrating deeper into the fabric structure, which inevitably leads to an increase in residual resistance.

Stage 2: Analysis of Filter Fabrics. In the second stage, various types of filter fabrics were subjected to a comparative evaluation. The criteria established for this stage included the resistance coefficient, specific contact surface area, thermal stability, mechanical and abrasive durability, and overall process compatibility.

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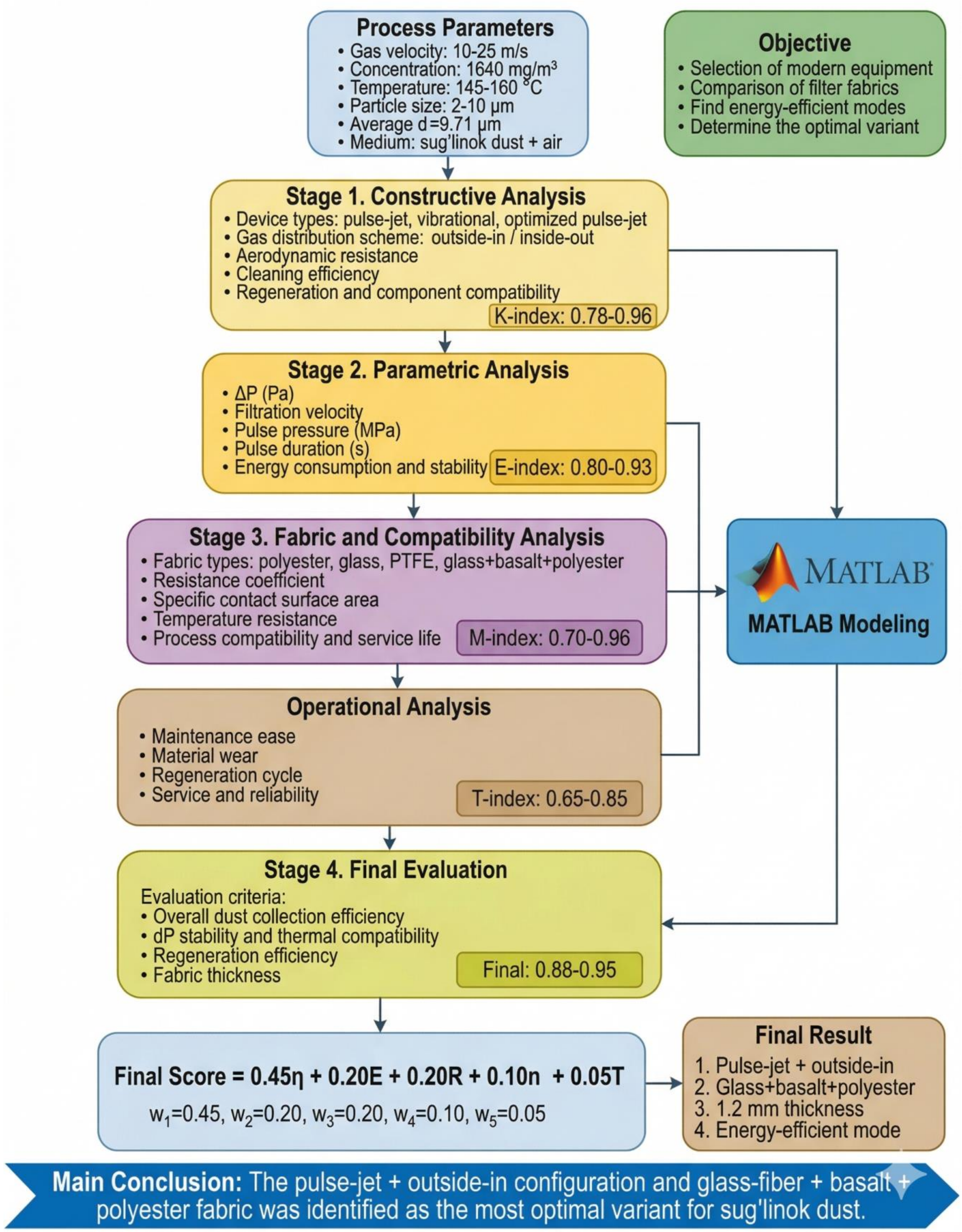

Figure 1. Results of a four-stage linear analysis conducted in MatLab software.

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The analysis considered variants such as polyester, glass fibre, PTFE, and a combined fabric composed of glass fibre, basalt, and polyester. Based on the evaluation results, the combination of glass fibre, basalt, and polyester received the highest integral score. This outcome is attributed to the fabric's ability to simultaneously meet several critical requirements:

– **Polyester layer**: Functions as the primary mechanical support and structural base.

– **Basalt fibre**: Provides exceptional resistance to high temperatures and abrasive wear.

– **Glass fibre**: Creates an additional active surface area specifically for capturing finely dispersed particles.

Furthermore, the high specific contact surface area in the combined fabric intensifies the dust collection process. A reduction in the proportion of open zones decreases the probability of fine particles passing through the media. Therefore, this fabric type was assessed as the most suitable material for silty loam dust.

Stage 3: Evaluation of the Unit-Fabric Pair Technical Parameters. The third stage involved the pairwise analysis of the selected equipment constructions and fabric types. During this phase, indicators such as overall dust collection efficiency, stability of pressure loss, regeneration efficiency, thermal compatibility, and service life were taken into account.

The results demonstrated that the pairing of the pulse-jet unit with the combined glass fibre, basalt, and polyester fabric provides the highest technical performance. This combination ensures high purification efficiency, relatively stable pressure drops, effective regeneration cycles, and suitability for both thermal and mechanical loads. This is because the equipment design facilitates surface-level dust collection, while the combined fabric acts as a highly efficient barrier against finely dispersed particles, achieving superior results for loam dust in the 2–10 µm range.

Stage 4: Complex Evaluation of Parameters and Determination of the Optimal Variant. In the final stage, all primary parameters of the units and fabrics were comprehensively evaluated to identify the definitive optimal variant. During this stage, thickness options of 1.0 mm, 1.2 mm, and 1.5 mm for the combined fabric were also compared.

The findings indicated that while the 1.5 mm thickness provides the largest specific contact surface area, it also carries a higher risk of increased hydraulic resistance. The 1.0 mm variant exhibited lower resistance but offered a smaller surface area for dust capture. Consequently, the 1.2 mm thickness was identified as the most balanced option between energy efficiency and cleaning effectiveness. For further experimental studies, verification within the 1.0–1.5 mm range is recommended. To facilitate the complex assessment, evaluation system codes and correlation graphs were developed based on results calculated using Matlab software within the systematic analysis framework. A comparative graph of the results from the four-stage systematic analysis is presented in Figure 2.

RESULTS AND DISCUSSION

The four-stage systematic analysis conducted demonstrates the necessity of evaluating the equipment design and the fabric type in

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conjunction when selecting modern bag filter units for the purification of dusty gases following the drum drying of loam. According to the analytical results, a pulse-jet bag filter construction, in which the dusty gas is supplied to the inner layer of the sleeve, is considered the most optimal for capturing the 2–10 μm loam dust particles that remain in the gas stream after the cyclone stage.

The comparative analysis of various materials indicated that a combined fabric based on glass fibre, basalt, and polyester is the most effective option for this specific process. This fabric simultaneously ensures high-temperature resistance, mechanical strength, durability against abrasive impacts, and the capacity to capture finely dispersed dust. Consequently, this combined fabric has been recommended as the most suitable material for application in bag filters designed for loam dust.

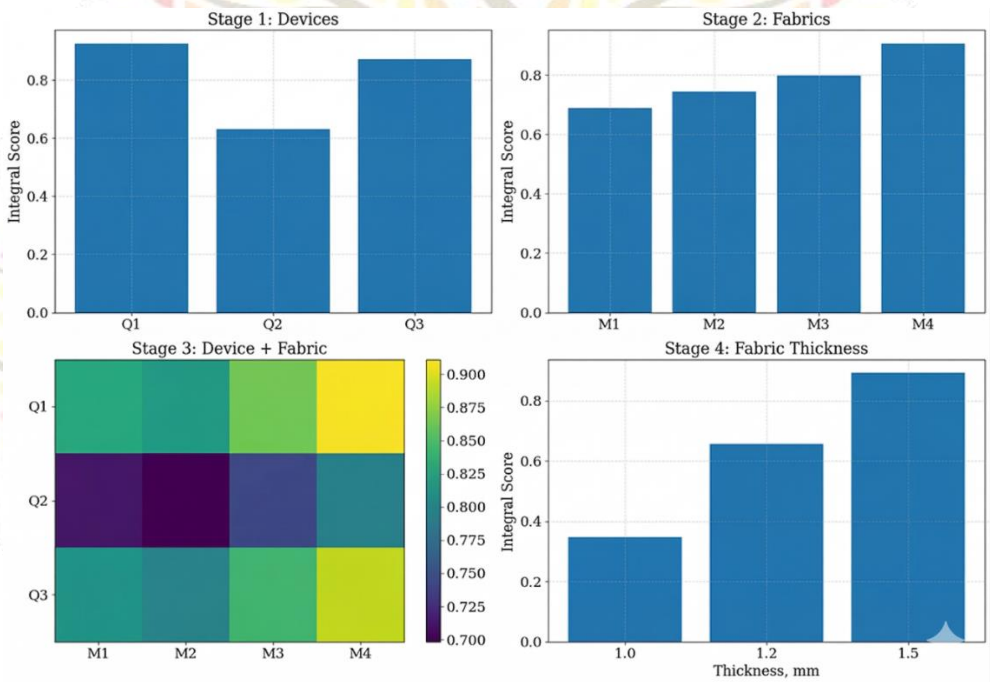

Figure 2. Histograms of the systematic evaluation of unit and fabric types.

Based on the aforementioned findings, a structural diagram of the bag filter construction and the combined fabric was developed for the loam dust purification process. The proposed bag filter scheme is illustrated in Figure 3, while the conceptual diagram of the filter fabric is shown in Figure 4.

The apparatus has been specifically engineered for the high-efficiency purification of finely dispersed dusty gases generated after the drum drying process. It is equipped with the following components:

– A cylindrical housing (1);

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– Filter sleeves (2);

– A dusty gas inlet pipe (3);

– A distribution chamber (4);

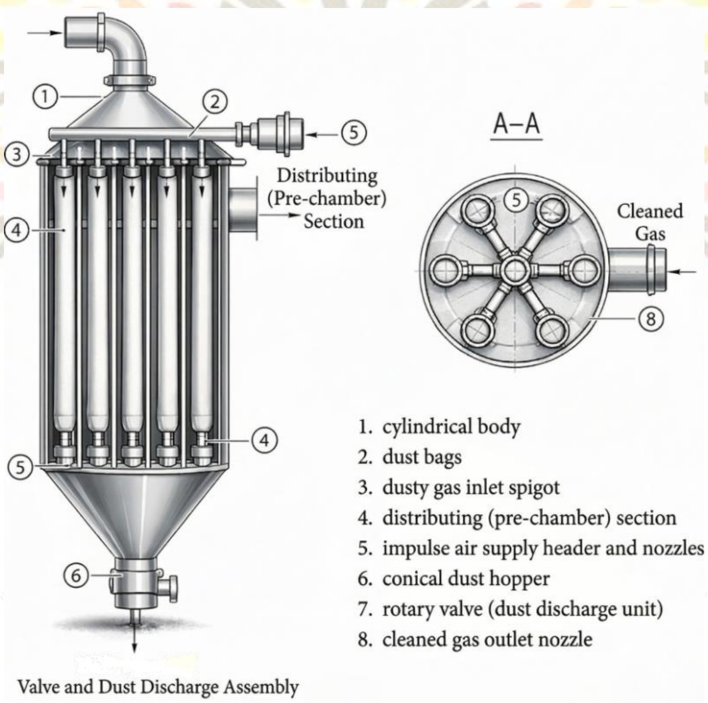
– A pulse air supply manifold and nozzles (5);

– A conical dust hopper (6);

– A rotary valve (7);

– A purified gas outlet pipe (8).

The primary constructive advantage of the unit lies in the inclusion of a distribution chamber (4), which serves to evenly distribute the dusty gas flow across the filter sleeves, and a pulse air supply unit (5) designed for the regeneration of the sleeves. This configuration ensures the uniform formation of a dust cake on the surface of the filter sleeves, restricts local increases in hydraulic resistance, and enhances the efficiency of the regeneration process. Such an approach is of significant importance when capturing finely dispersed particles in the 2–10 μm range, such as loam dust, as it reduces the deep penetration of dust into the filter fabric and extends the service life of the sleeves.



1 — Cylindrical housing; 2 — Filter sleeves (bags); 3 — Dusty gas inlet pipe; 4 — Distribution (pre-chamber) section; 5 — Pulse air supply manifold and nozzles; 6 — Conical dust hopper; 7 — Rotary valve (dust discharge unit); 8 — Purified gas outlet pipe (indicated on the side in the figure).

Figure 3. Diagram of the recommended bag filter unit.

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Operating Principle of the Unit. This bag filter apparatus is designed for the high-efficiency purification of dusty gases, and its functional principle is based on the process of passing the gas stream through filter sleeves to separate particulate matter.

The dusty gas is introduced into the unit via the inlet pipe (3) located at the upper section and is conveyed into the distribution chamber (4). Within this chamber, the gas flow is uniformly distributed across the filtration zone and subsequently directed into the interior of the sleeves.

The distributed dusty gas enters the filter sleeves (2) through the zone where the pulse air supply manifold and nozzles (5) are positioned. The gas stream moves from top to bottom along the internal cavity of the sleeves, directed towards the conical hopper (6) located at the lower portion of the apparatus.

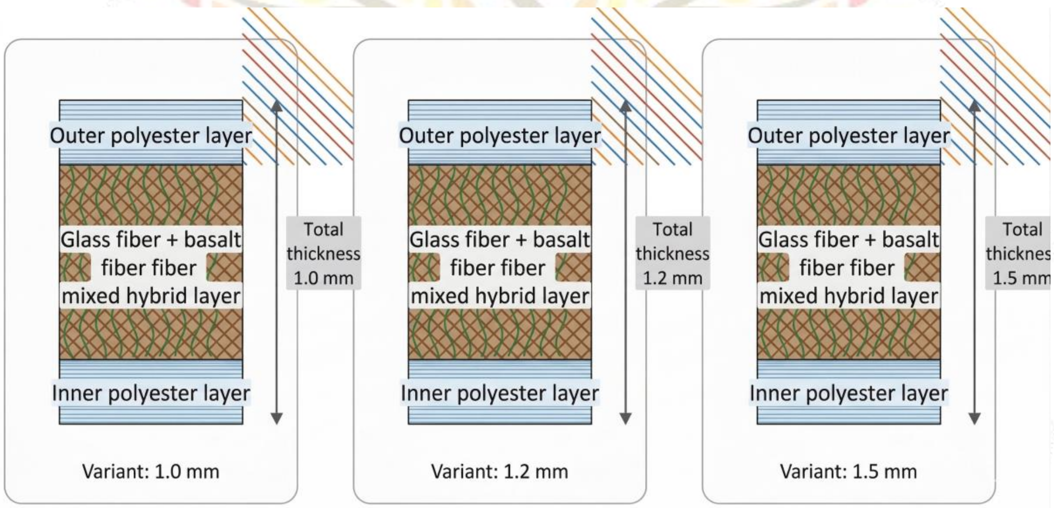

Figure 4. Conceptual diagram of the recommended combined filter fabric.

As the flow reaches the lower section, the gas transitions from the inner layer to the outer layer through the filter fabric due to the distribution of pressure and the change in flow direction. During this process, dust particles are captured on the internal surface of the filter sleeves, while the purified gas passes through the sleeve and accumulates in the external volume of the housing.

The purified gas is subsequently discharged into the atmosphere via the outlet pipe (8). Throughout the filtration process, dust accumulated on the internal surface of the sleeve is periodically detached using compressed air pulses supplied by the pulse-air system (5).

The separated dust particles descend under the influence of gravity, collect in the conical hopper (6), and are subsequently removed through the discharge unit (7). This cycle ensures the continuous and stable operation of the apparatus. However, no prior research has been conducted on the application of combined filter fabrics within this specific recommended unit. Therefore, this research work is dedicated to providing the scientific and practical substantiation of the results obtained from using a filter fabric based on glass fibre, basalt, and polyester within the enhanced bag filter apparatus.

Based on the aforementioned considerations, a programme for theoretical research was established. This programme includes calculating the specific contact surface areas of the combined filter fabric, developing a calculation scheme for determining the aerodynamic resistance of the unit, and theoretically substantiating the aerodynamic laws, the dependence of regeneration time on various parameters, and the overall cleaning efficiency.

In the initial stage of the theoretical research, analyses and calculations were performed to determine the specific contact surface areas of filter fabrics based on glass fibre, basalt, and polyester. For this purpose, filter fabric samples with an area of 1 m^2 and thicknesses of 1.0 mm, 1.2 mm, and 1.5 mm—identified through the systematic analysis previously conducted in Matlab—were prepared.

Conclusion

The four-stage systematic analysis conducted in this study demonstrates the critical necessity of simultaneously evaluating both the equipment construction and the filtering media when selecting modern bag filter units for the purification of dusty gases following the drum drying of loam. According to the analytical results, a bag filter featuring pulse-jet regeneration, integrated with a pre-chamber and gas distributor and utilizing an "outside-in" gas supply scheme, represents the most optimal construction for capturing the 2–10 μm loam dust particles that remain in the gas stream post-cyclone treatment.

Among the various filtering materials evaluated, the combined fabric based on glass fibre, basalt, and polyester achieved the highest integral score, as it concurrently provides exceptional thermal resistance, mechanical durability, resistance to abrasive wear, and superior efficiency in capturing finely dispersed dust. Furthermore, the comparative thickness analysis indicated that the 1.2 mm fabric variant offers the most balanced technical solution between filtration performance and operational efficiency. Consequently, this specific combination of the proposed bag filter apparatus and the triple-component combined fabric is deemed highly effective for industrial application in silty loam dust purification.

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