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Project Summary

Effect of Parameters of Filtration on Dust Cleaning Fabrics

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This report summarizes 4 years of laboratory- and large-scale tests of the dust filtration process and the basic filtration parameters determining performance. Physical parameters describing fabric and dust cake structure were defined and three basic dust filtration mechanisms were considered: selective precipitation, inertial sedimentation, and diffusion. From test results of two Polish polyester fabrics filtering separated fly ash, three-dimensional probabilistic models of dust collection efficiency and filtration resistance were introduced. A general filtration model, based on random field theory, was also developed that included full mathematical argumentation.

Electrical properties of dusts and fabrics were examined to define the influence of electrostatic phenomena on the dust filtration process. This examination led to a quantitative determination of local electric fields in the fabric and dust cake.

Conclusions from this work are:

- **Air flow through a clean fabric and the dust filtration process are normal stochastic processes.**
- **Dust filtration is a specific dry filtration process, differing from the air filtration process or the high-efficiency air filtration process.**
- **Dust collection efficiency during the dust filtration process depends on three basic filtration mechanisms related to the aerosol particle size distribution.**
- **Woven filtration materials are heterogeneous and anisotropic media characterized by periodic structure that, at high values of face velocity, exhibit transition region flow described by a resistance function, K[1].**

Microscale electric fields formed by triboelectrical charge exchange between fibers and dust particles significantly influence the dust filtration process.

This Project Summary was developed by EPA's Industrial Environmental Research Laboratory, Research Triangle Park, NC, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

For many years the dust filtration process has used textile filtration media in industrial dust collection devices; i.e., filter bags, pocket dust collectors, bag houses, and pulse-jet dust collectors. While all these dust collection devices perform the same overall function, there are considerable differences in their individual process mechanisms.

The dust removal process is very efficient and dust collection efficiency usually exceeds 99 percent. This property promoted the rapid use of fabric filters, despite the fact that their performance has only a weak theoretical base. Different fabric dust collectors were designed during a short time and were optimized for:

- Longer life of the filtration fabrics (mainly by application of less severe regeneration systems).
- Automation.
- Reliability, low pressure drop, and architecture.

As dust collection devices developed, so did the production of improved filtration materials. Filtration materials produced from natural fibers (cotton and wool) were gradually replaced with synthetic fibers (i.e., polyester, polyamide, and polyacrylonitrile), which had better mechanical properties and chemical resistance. The higher temperature resistance of the synthetic fibers led to greater industrial use of fabric filters.

However, it is noteworthy that the development of new raw fiber materials with improved physicochemical properties did not lead to new production methods for woven filtration materials. The new filtration materials were similar in structure to those produced from the natural raw materials. This situation may have been caused by failure to communicate the importance of fiber spatial structure to fabric producers. Such requirements were difficult to define because of fragmentary research and limited understanding of the dust removal process. Moreover, early research focussed primarily on quantitative process data.

The situation is paradoxical because contemporary industrial-scale filters are nearly perfectly constructed and successfully operate as highly automated systems. No systematic theoretical base for the dust filtration process exists, however, from which to direct further research on industrial gas filtration with woven filtration materials and to further optimize the process and the filtration medium. Further improvement in filter construction without compromising the filtration process constitutes progress in dust removal because it does not jeopardize clean air. Knowing what changes will interfere with dust collection requires theoretical understanding of the dust filtration process, so such a theoretical base must be developed.

Theoretically, dust filtration is a multiparameter process differing from other filtration processes. Some researchers have tried to explain the peculiarities observed with industrial dust collectors by resorting to the classical filtration theory and especially the single fiber theory. This approach led to confusion in research planning and in interpreting results. Many papers are incomprehensible because the authors did not know what type of filtration process they were studying.

At present scientists agree, however, that the basic mechanisms of dust particle precipitation from an aerosol stream that determine the process effectiveness in the classical theory of filtration are also observed in dust filtration. However, their physical interpretation is different because of differences in the basic assumptions of the two processes.

In the Phase I and II reports of this project we proposed standardized process nomenclature and defined our initial assumptions. Our proposal was based on a theoretical physical model of dust filtration, which is presented in Section IV of the Project Report. The efficiency of dust collection, the primary qualitative parameter of the process, was examined as a function of filtration parameters; i.e., face velocity and dust flux. We also tried to correlate filtration efficiency with some structural parameter of the filtration medium.

The preliminary mathematical model of dust filtration, based on experiments conducted in our Institute and further analyzed at the Institute of Mathematics of WSP Opole, is an integral part of this report. Some experimental results obtained in other projects are also included in an attempt to make this report as complete a description of filtration as possible and hence as useful as possible in planning further research.

Research Objectives

The basic objectives of the program financed by EPA and conducted by the Institute of Cement Building Materials in Opole were:

- To describe the effects of fabric structural parameters on the pressure drops associated with gas flow through the clean fabric.
- To describe the effects of structural parameters of both the fabric and the dust cake on pressure drops during the filtration process.
- To describe the functional dependence between dust collection efficiencies and the variables of the dust filtration process.
- To test, by mathematical modeling, fabric structures with the best filtration properties.

Total program research includes:

- Laboratory testing, including testing of dust and fabrics.
- Large-scale testing.
- Auxiliary studies.
- Application of mathematical methods, including modeling.

Conclusions

Both experimental testing and theoretical analyses formed the basis for the conclusions reached during this project.

Dust Filtration Process

- Three types of dust filtration occur during laboratory testing:
- Filtration Type I: filtration beginning with the virgin fabric and ending at the initiation of the first regeneration cycle.
- Filtration Type II: filtration by the fabric and accumulating dust but before the equilibrium state is reached (the quantity of dust collected during the filtration cycle exceeds that removed during the subsequent regeneration cycle).
- Filtration Type III: steady state filtration by the fabric and its dust cake characterized by stable pre- and post-regeneration conditions (the quantity of dust removed during regeneration is approximately equal to that collected during the filtration cycle—the large-scale test conditions representative of industrial dust filtration).

- Dust collection efficiency and filtration resistance, apart from the type of filtration, are determined by initial aerosol state parameters, filtration parameters, and structural parameters of the dust-fabric system.

- Dust collection efficiency and filtration resistance can be adequately described by probabilistic mathematical models over the range of the empirical data.

- Mean dust collection efficiency during a filtration cycle (Filtration Types I and III) depends on the time required to build a dust cake and its thickness.

- The collection efficiency of the dust cake cannot be compared to the collection efficiency of the filtration layer (the fabric) because of the physically different filtration media.

- Consideration of the effect of the particle size distribution of the aerosol on the dust collection efficiency permits a correlation of the dust-fabric system efficiency with important, initial aerosol state parameters.

- The main mechanisms that determine filtration process efficiency in the dust cake. are selective precipitation, inertial sedimentation, and diffusion.

- Dust collection efficiency and filtration resistance depend on the pore size distribution of the dust-fabric system.

- The pore size distribution function is a characteristic of each fabric dust cake system and has a log-normal distribution.

True Filtration Processes

- The dust collection efficiency for Filtration Process Type I depends on the degree of dust pulverization, the dust concentration, the shape of the aerosol particles, the face velocity (q_g) and the areal dust loading of the filter (L_o).

- Areal mass density of the dust in or on a dust-covered filter (the terminal dust load, L_o) is a reliable parameter for estimating filtration effects.

- Increases in q_g and the degree of dust pulverization decrease dust collection efficiency and increase filtration resistance.

- Increases in dust concentration and L_o both increase dust collection efficiency.

- Dust collection efficiency for Filtration Process Type III depends on q_g and the areal mass density of the dust cake, L_p.

- Increasing q_g decreases efficiency and increases filtration resistance.

- Increasing L_p increases efficiency and shifts process performance toward higher filtration resistance

- The functional dependence of dust collection efficiency on q_g is determined by the kind of fabric included in the dust-fabric system.

- Both Filtration Processes Type I and Type III are characterized by dust cake defects, which influence dust collection efficiency and filtration resistance.

- The formation of dust cake defects is related to disturbed equilibrium between the dust particles comprising the dust cake, resulting in the dislocation of the dust particles and the formation of ducts/canals after a certain pressure drop is reached.

Recommendations

The results of this project point to the need for further investigation in the following areas:

- Development of the relationship between the porosity of woven materials and their free area (FA) and basket free area (BFA) distribution, and empirical verification of this relationship over a wide range of materials.

- The relationship between the pulverization state of suspended dust and the specific area of the dust layer formed from it, including the role of particle shape and the hydraulic properties of the layer.

- Empirical verification of the role of fabric properties in the process of filtration through a dust layer.

Investigation of these areas would help perfect, qualitatively and quantitatively, mathematical models of the dust filtration process.

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***J. H. Turner** and **L. S. Hovis** are the EPA Project Officers (see below).*
The complete report, entitled "Effect of Parameters of Filtration on Dust Cleaning Fabrics," (Order No. PB 81-188 542; Cost: $32.00, subject to change) will be available only from:
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