

Design, Modeling, and Evaluation of a Cost Effective Particulate Control System

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ABSTRACT

A cost effective, portable particulate control system was developed, built, and evaluated at the University of Louisiana at Lafayette. Prototype of the presented system was developed for experimental assessment and its computational model was also created for CFD simulation. The experimental and computer simulation results showed that the developed system could efficiently and safely remove and dispose accumulated particulate matter (in the size range of 5 ~ 1000 μm), and be tolerant to the abrasive properties that the particulate matter may have. The developed particulate control system as well as the applied technology can be further optimized and extended to be applied in aerospace and space engineering to remove suspended particles out from the closed cabinet of aircrafts or spacecrafts. The outcome of this project will also impact other commercial sectors and industries.

CITATION: Liu, Y., Alidoust, S. and Qi, B., "Design, Modeling, and Evaluation of a Cost Effective Particulate Control System," *SAE Int. J. Aerosp.* 5(1):2012, doi:10.4271/2012-01-1882.

INTRODUCTION

Particulate control system is broadly used in many industries and commercial sectors for removal and disposal of particles and controlling contamination. Such industries and sectors include aerospace industry, automotive industry, chemical and pharmaceutical production, fossil fuel power plant operations, ore processing, HVAC industry, and environmental protection. Due to its significance and wide applicability in industry, many advanced particulate control systems and technologies have been developed and put into use. Meng et al. [1] developed a household filtration process to use phosphate and silicate to remove arsenic from Bangladesh groundwater by hydroxides. The household filtration process included co-precipitation of arsenic by adding a packet of ferric and hypochlorite salts to well water and subsequent filtration of the water through a bucket sand filter. Experimental results proved that the household treatment process removed arsenic from approximately 300 $\mu\text{g/L}$ in the well water to less than 50 $\mu\text{g/L}$. Bedrikovetsky et al. [2] designed a deep bed filtration system and formulated a mathematical model for it. This system can effectively remove solid and liquid particles dispersed in injected water through porous medium. Fritsky et al. [3] developed a catalytic filter system to replace the woven fiberglass filter bags and used the new system to control the medical waste. It was found that with the using of the catalytic filter system, the particulate emission was 12-17 times less than the

regulatory limit. Blanchard et al. [4] equipped a diesel particulate filter system which uses a ceria-based fuel-borne catalyst in PSA Peugeot Citroen. The engine test results clearly demonstrated the attractiveness of fuel-borne catalyst technology for the particulate filter system in series applications. Akoum et al. [5] investigated a permeate flux and chemical oxygen demand reduction in dairy process waters using a vibratory shear-enhanced filtration system (VSEP) and various nanofiltration and reverse osmosis membranes. A definite advantage for the VSEP operated at the same pressure and temperature were showed by comparing its performance to existing filtration systems. The better performance of the VSEP was attributed to its higher membrane shear rate which reduces lactose concentration at membrane and its transmission. Shi et al. [6] focused on the development and application of predictive-based strategies for control of particle size distribution in continuous and batch particulate processes described by population balance models. The presented control algorithms were designed on the basis of reduced-order models, utilized measurements of principle moments of the PSD, and were tailored to address different control objectives for the continuous and batch process. The strategy was shown to be able to reduce the total volume of the fines by 13.4% compared to a linear cooling strategy and was shown to be robust with respect to modeling errors.

Based on the previously developed systems, a cost effective, portable particulate control system is designed and prototyped for experimental validation. Capacity and efficiency of the developed particular system are evaluated through experiments, from which the advantages of the presented design are demonstrated.

DESIGN PROCESS

Design Objective

The main objective of this system is to trap, absorb, and remove particulate and fibrous matter (ranging in size from 5 - 1000 μm) from the circulating air without losing material or dispersing content into the air. It is expected that the designed system can collect and dispose all particulate matter generated and suspended within a confined space.

Theoretical Background

A fundamental hydrodynamic equation, Bernoulli's principle, will be used in designing the system. In fluid dynamics, Bernoulli's principle states that for an inviscid flow, an increase in the speed of the fluid occurs simultaneously with a decrease in pressure or a decrease in the fluid's potential energy. According to that principle, when a pipe is partially immersed such that one end is above the liquid level and the opposite end is near the bottom of a plastic container partially filled with liquid and a suction is applied to that bag at a point significantly above the liquid level, the particles entering the liquid through the pipe will be trapped there. After absorbing the particles, the liquid level will rise to a certain level while air/gas is bubbling through it, but will never reach the suction point. Such a rise in the liquid level will be carefully calculated using Bernoulli's equation, which will ensure that the liquid will stay in the container to trap the particulate matter without being discharged through the suction point and outside the container.

Fig. 1 illustrates the Bernoulli principle, where the mixture of air and particles of various sizes will enter the suction head at certain velocity and under suction (negative) pressure. The suction pressure and the air velocity will be regulated via a simple valve, which only allows the viscous liquid in the container to rise within certain, pre-determined levels in the container. Once the particles travel through the suction tube and enter the viscous liquid or foam section, they will meet with the viscous resistance of liquid phase or foam under a regulated pressure and at entrance velocity. In this way, the particles will be trapped and settled at the bottom wall of the container. In this work, a particle control system is designed and prototyped based on the Bernoulli principle as explained in Fig. 1.

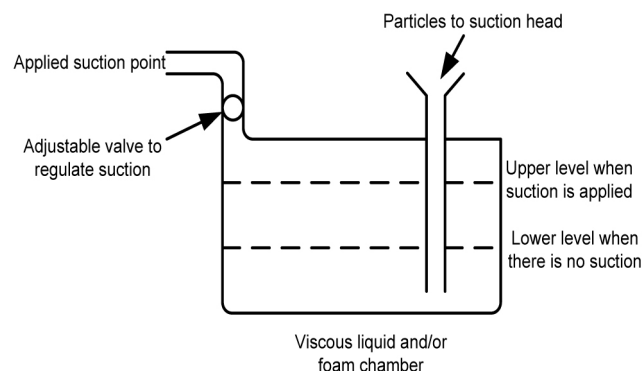


Figure 1. Illustration of the Bernoulli principle

Initial Design

Based on evaluation and comparison of all design alternatives, the initial design scheme was selected for further prototyping and experimental validation (Fig. 2). In this design, filter papers are used as indicators to measure the absorbing capability of this system. Viscous liquid is used as the main filter medium, through which the air passes and is cleaned. As shown in Fig. 1, after passing through the filter medium (liquid), the air enters a triple valve outlet where only one is open for flow at a time. Afterwards, the cleaned air will pass through the filter paper. In the selected design, three valves are installed for air to pass but at one time, only one of them is open and the other two are closed. Such mechanism allows us to measure the particles captured by a filter paper and/or replace the filter paper during the experiment without affecting the circulation. For example, after a while if we want to inspect the filter paper from the first tube, we can turn off the first valve and turn on the second valve, while removing the filter paper from the first tube, the air will flow through the second valve and we can continue running the experiment.

This design scheme was selected because compare to the aforementioned design options, the present design offers unique advantages. At first, this apparatus is designed based on a simple but innovative idea. The usage of filter papers to measure the capacity and efficiency of the system decreases design and manufacturing costs and allows users to easily observe the progressive absorption of the particles by the filter medium. Secondly, the overall size of this system can be scaled within its size limits to be employed for a wide variety of applications with different requirements. Another attractive advantage of this design is its low cost and high flexibility, which will be illustrated through experimental validation.