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Experimental and Computational Study of Effects of Viscosity of the Filter Media in a Developed Particulate Trapping System

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ABSTRACT:

A cost effective, portable particulate management system was developed, prototyped, and evaluated for further application and commercialization, which could remove and dispose particulate matter suspended in air efficiently and safely. A prototype of the present system was built for experimental assessment and validation. The experimental data showed that the developed particulate management system can effectively clean the air by capturing the particles inside it. Effects of viscosity of filter medium on the performance of the developed system were also discussed. The present system is very flexible, whose size and shape can be scaled and changed to be fit for different applications. Its manufacturing cost is less than $10. Based on the experimental validation results, it was found that the present system can be further developed, commercialized, and applied for a variety of industries. The experiments and experimental data were simulated and validated using computer fluent dynamics. A relatively good agreement was achieved between the experimental and computational results.

KEYWORDS:

Particulate management system; Experimental analysis; Filter medium; Bernoulli principle; Prototype

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1. Introduction

Particulate management 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. 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 300µg/L in the well water to less than 50µg/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 Peugeout 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 nano filtration 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 and portable particulate management system was designed and prototyped in the University of Louisiana at Lafayette (UL Lafayette) for experimental validation and further optimization. Capacity and efficiency of the developed particular system in processing the particles were evaluated through the experiments. Effects of filter medium's viscosity on the developed system's performance were also discussed. From the experimental results, the advantages of the presented design were demonstrated and the future optimization strategy was presented. In this study, computational fluid dynamics (CFD) analysis was also performed on the developed particulate control system to simulate its performance in capturing particles suspended in the air flow and to validate the experimental data. CFD is a branch of fluid mechanics that uses numerical methods and algorithms to solve and analyze problems that involve fluid flows.

A number of investigators had used CFD to model and solve multiphase flow problems including simulate different particulate management systems. Chen et al [7] combined CFD techniques with motion blur, particle blending, and texture mapping to simulate physically-based empirical models in generating dust particles and controlling their behaviors. In their computer models, the dust behavior was divided into three stages and simplified particle system models were established for each stage. Muller et al [8] proposed an interactive method based on smoothed particle hydro-dynamics (SPH) to fast simulate fluids with free surfaces. That method was developed by deriving the force density fields directly from the Navier-Stokes equation and by adding a term to model surface tension effects. In the presented particle-based fluid simulation, the free surface was tracked and visualized using point splatting and marching cubes-based reconstruction. It was proved that the proposed animation method is fast enough to be used in interactive systems and to allow for user interaction with models consisting of up to 5000 particles.

Holmberg and Chen [9] investigated the supply and exhaust conditions of the ventilation air flow and discussed their role in the control of air quality. In their study, particle concentrations, thermal conditions and modified ventilation system solutions were calculated using CFD. Yang et al [10] conducted CFD simulation to study the effects of particle clusters in concurrent-up gas-solid two-phase flow on interfacial drag coefficient by using two-fluid models and the energy-minimization multi-scale (EMMS) approach. Chen and Zhang [11] used a CFD program with a Lagrangian particle tracking method to predict particle dispersion and concentration distribution in ventilated rooms. It was validated that although the overall computational cost was considerable, the CFD results agreed well with associated experimental data. Based on the CFD models, the particle removal performance of three different ventilation systems were evaluated.

Liu et al [12] developed a two-dimensional algebraic slip mixture (ASM) CFD model to simulate the flow and mixing of liquid-gas-particle system in a rotary drum. The simulation showed that there were several flow regimes in slurry phase, including anti-clockwise circulation flow of liquid, rising stream of bubbles, circumferential flow and eddy. Wang et al [13] conducted CFD simulation to investigate the temperature and airflow distribution as well as the energy saving potential of the bio-cleanroom. The computational results revealed that the improvement of energy consumption could be achieved satisfactorily by reduction of supply airflow rate and increase of supply air temperature. Heiland et al [14] addressed the simulation of dispersions using population balance equations and described the coupling of the CFD solver fastest 3D, which simulates the dispersion in stirred tanks, with MATLAB. An exemplary control design that used an identified model and a linear quadratic regulator was presented and evaluated through CFD. The CFD techniques demonstrated in previous literature were referred and applied in modeling and simulating the particulate management system developed in this study. The commercial CFD software, ANSYS fluent, was used here for all the modeling and simulation work.

2. Design process

2.1. 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.

2.2. 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.

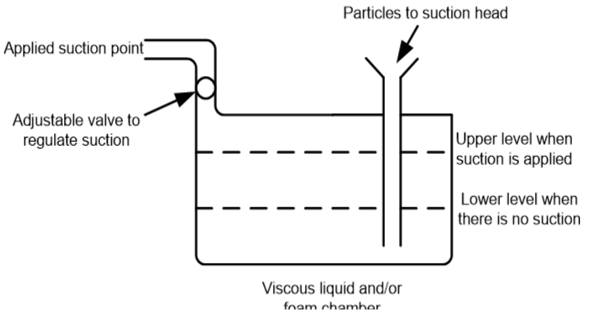

Fig. 1: Illustration of the Bernoulli principle

2.3. Initial design

Based on evaluation and comparison of all design alternatives, an initial design scheme was selected for further prototyping and experimental validation Fig. 2 [15]. 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.

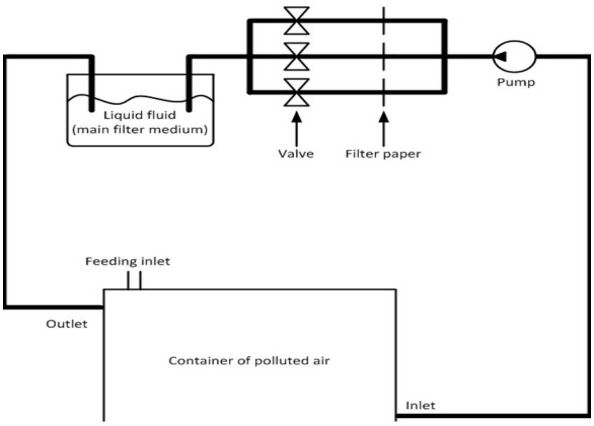

Fig. 2: Schematic of the initial design

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.

3. Prototyping

As shown in Fig. 2, the particulate control system includes a container, three valves, filter papers and tubes that connecting them together. In the prototype, a plastic container with 1.8ft×1.25ft×1.25ft is used to store the filter medium (we use water for our validation), which was well sealed with silicone to avoid any leakage. The plastic container, instead of a glass container, was chosen for experiments because the glass material is very fragile and extremely hard to be drilled. With the plastic container, holes can be easily drilled onto it for adding tubes and fittings. Also, the plastic container significantly reduces the overall weight of this system and makes it very portable and cost efficient. Three cylinders were connected to the container in parallel, each of which has a valve and filter paper inside. The valve controls the air flow and the filter paper, as mentioned before, was used as an indicator to show the particles being caught by this system. Besides major components in this system, several auxiliary apparatus were installed in order to run experiments.

A flask with ashes and other particles were prepared for polluting the air, which would be caught and trapped by the system. A 12V rechargeable air compressor was employed to compress air and pump the ashes and other particles from the flask into the air. The compressed and polluted air then goes into the container and would be trapped there. The flask, compressor, as well as other components were connected in series through tubes and fittings, which were sealed with epoxy and silicone to avoid potential leakage due to the pressurized water. Fig. 3 shows the container with the compressor and Fig. 4 displays the flask and three cylinders.

Fig. 3: Partially water-filled container attached to air outlets

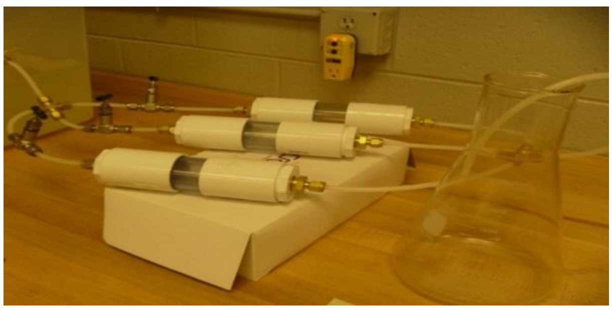

Fig. 4: Flask and 3 cylinders with valves and filter papers inside

4. Experimental analysis and evaluation

4.1. Running experiment

In running the experiment, the flask with certain amount of ashes and particles inside was connected to the air compressor through a tube. The air compressor was first turned on to compress air and drive it through the flask to absorb the ashes and particles. Afterwards the compressed and polluted air entered the container and was trapped by the filter medium according to the Bernoulli principle. The cleaned air then passed through the tube and the remaining particles were captured by the filter papers. Finally, the filtered air was disposed into the environment through an outlet. In order to investigate the effects of viscosity of the filter media on the performance of the designed system, four different media with zero, low, medium, and high viscosity were separately used for this experimental validation and the results were compared. In our study, water was chosen as the basic filter media and its viscosity were altered by adding different amount of polyethylene glycol, an in noxious polyether compound which can effectively change the viscosity of a large volume of water with only small dosage.

Viscosity of the water was indicated through its kinematic viscosity, which was measured using a Cannon-Fenske Routine Viscometer. In determining the viscosity, efflux time for meniscus to pass from "C" to "E" Fig. 5 was firstly measured and the kinematic viscosity was calculated by multiplying the efflux time and the viscometer constant. Polyethylene glycol ($HO-CH_2-(CH_2-O-CH_2)_n-CH_2-OH$) is a compound with many applications in manufacturing. It was selected in this study for changing the viscosity of the filter media because it can enhance the reaction between the molecules in the solution and some types of force such as hydrogen bond that exists between the molecules in the solution would enhance the capability of the solution in capturing the particulates. The effects of the polyethylene glycol and other chemical compounds in improving the filter media's particle trapping capacity through changing the media's viscosity will be further investigated in future study.

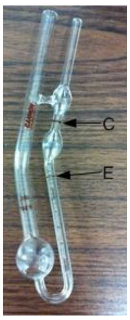

Fig. 5: Viscosity measurement using Cannon-Fenske Viscometer

The water with kinematic viscosity of 100cSt, 200cSt, and 300cSt was used for low, medium and high viscosity level, respectively. This is because that through our experiments, it was observed that when the kinematic viscosity was higher than 300cSt the mixing liquid would lose most of its fluidity. On the other side, the mixing liquid didn't show much difference in capturing the particulates from the water when its kinetic viscosity was lower than 100cSt. The 100cSt filter medium was obtained from a 22mg/ml polyethylene glycol-water solution, the 200cSt filter medium from a 35mg/ml solution, and the 300cSt filter medium from a 48mg/ml solution.

4.2. Analysis of experimental results

The experiments were kept running for 30 minutes and the weight of the input particulates and the particulates captured by the filter medium were measured every ten minutes to demonstrate the efficiency of the developed system and the capacity of the filter media with different viscosities in removing the suspending particles. The ashes and particles trapped by the filter media were measured by subtracting the particles filtered by the filter papers (measured from the filter papers) and the remaining particles collected at the outlet from the amount of particles that entered the system. Tables 1 to 4 compare the performance of the filter media with different viscosities in removing the particles and ashes from the airflow as time increases. The capacity of the filter media with different viscosities in capturing the suspending particulates are compared and plotted in Fig. 6 and their efficiency were compared in Fig. 7. After the experiments, it was found that most particles were trapped by the filter medium and located on the bottom of the container, and only a few particles were captured by the filter paper, which was observed and measured in UL Lafayette's microscopy center, as shown in Fig. 8. Eventually, the particles captured on the bottom of the container and on the filter papers were safely disposed. Fig. 9 shows the entire experiment system.

Table 1: Capacity of the developed system in removing particles from incoming airflow, filter media is water (no viscosity)

Time	10 min	20 min	30 min	60 min
Input particulates	0.056 kg	0.102 kg	0.165 kg	0.320 kg
Captured particulates	0.042 kg	0.074 kg	0.116 kg	0.189 kg
Efficiency	75%	72.5%	70.3%	59.1%

Table 2: Capacity of the developed system in removing particles from incoming airflow, viscosity of filter media = 100cSt (low level)

Time	10 min	20 min	30 min	60 min
Input particulates	0.054 kg	0.107 kg	0.163 kg	0.323 kg
Captured particulates	0.046 kg	0.092 kg	0.139 kg	0.271 kg
Efficiency	85.2%	85.8%	85.3%	83.9%

Table 3: Capacity of developed system in removing particles from incoming airflow, filter media viscosity = 200cSt (medium level)

Time	10 min	20 min	30 min	60 min
Input particulates	0.055 kg	0.107 kg	0.160 kg	0.323 kg
Captured particulates	0.051 kg	0.098 kg	0.147 kg	0.294 kg
Efficiency	92.7%	92.0%	91.9%	91.0%

Table 4: Capacity of developed system in removing particles from incoming airflow, viscosity of filter media = 300cSt (high level)

Time	10 min	20 min	30 min	60 min
Input particulates	0.054 kg	0.108 kg	0.162 kg	0.322 kg
Captured particulates	0.053 kg	0.105 kg	0.158 kg	0.312 kg
Efficiency	97.2%	97.2%	97.2%	96.9%

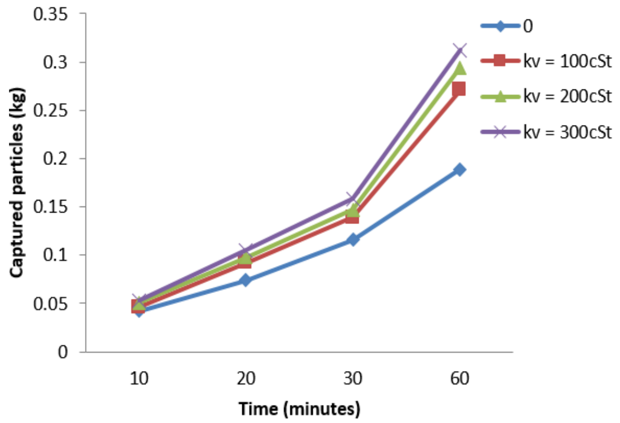

Fig. 6: Capacity of filter media with different viscosities in removing the particles

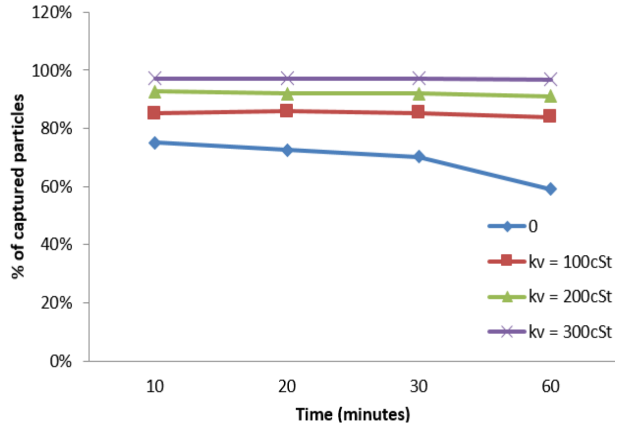

Fig. 7: Efficiency of filter media with different viscosities in removing the particles

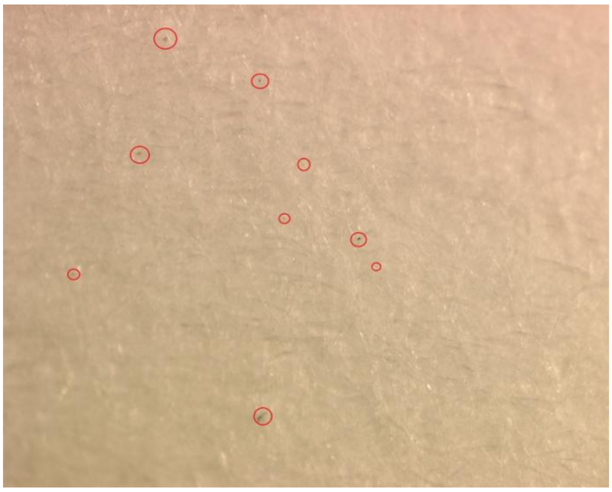

Fig. 8: Particles captured by the filter paper

Fig. 9: Particulate control system for experimental validation

4.3. Discussions

From Tables 1 to 4 and Figs. 7 and 8, it can be found that increasing viscosity of the filter media will evidently enhance the particulate trapping capacity and efficiency of the developed system. However, if we continue to add polyethylene glycol into the liquid to improve its viscosity, the filter media will lose most of its fluidity, which will badly reduce the system's particle trapping capacity. Another issue need to be concerned is the cost, adding chemical compounds such as polyethylene glycol to the water will definitely improve its viscosity thereby enhancing its particle trapping capacity, but the cost of building such a particulate control system will also rise because of the addition of those chemical compounds. From the experiments, it was also observed that as the time increased, the efficiency of the developed system in capturing the particulates would slightly decrease. Such decrease was more conceivable when the filter media was water. This is because that water will be saturated when too many particulates flow into it, which will reduce its capacity in capturing more particles. Meanwhile, the incoming particles will bring electrons into the water and the accumulation of electrons will change property of the water therefore reducing its ability of absorbing the particles. Here the efficiency is determined as the percentage of the weight of captured particulates and that of the total incoming particulates.

5. CFD simulation

After experimental validation, this particulate control system was modeled and the experiments were simulated using commercial CFD software, ANSYS fluent. ANSYS fluent is a powerful CFD software package for modeling the behavior of fluids and has been extensively used for hydropower system design [16-18] and validation of phase particle entrapment [19]. Fig. 10 sketches the CFD container-air-fluid-particle model, where the elements were created through low-medium quality mesh with a bottom-up approach so as to achieve a high accuracy while save most of the computing time.

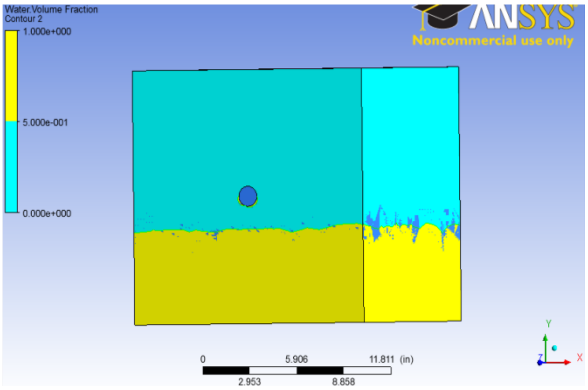

Fig. 10: Computational model for the container filled with water, air, and particles

In the CFD model, the container was modeled with the solid element, the air and filter media were modeled with fluid element. Quadrilateral dominant meshing method was used to reduce the skewness and improve the quality of the mesh. Mesh refinement was performed around the inlet conduit edges in order to correctly capture the fast-changed results in that area. After meshing process, the entire model contains 2255 elements (cells) and 2394 nodes. The ashes were classified as inert particles and the distribution range of diameters for the particles was defined as the Rosin-Rammler-logarithmic distribution model with a spread of 3.5. The discrete random walk model was chosen for stochastic tracking of the particle dispersion.

During the simulation, the ashes entered the container at a speed of 0.01m/s, whose material properties are listed in Table 1. Eulerian model provided in the software was selected as the primary multiphase model and solutions were calculated based on averaging of Navier-Stokes equations over the volume including the arbitrarily suspended bubbles and the continuous phase. It was assumed that the liquid was filled up to 2/3 of the container initially, whose viscosity was defined as 0, 100, 200, and 300cSt, separately. Air flow was then introduced into this system using compiled user define function (UDF) to establish a fully developed velocity profile at the inlet as follows,

$$v = -\frac{3}{2}\bar{v}\left[1-\left(\frac{y_r}{r}\right)^2\right] \quad (1)$$

The average speed of air flow was 3, 4.5, and 6 m/s at the inlet. Since multiphase flow is intrinsically an unsteady state, simulations had to be carried out in transient framework. A UDF was employed to specify variable time steps through the iteration process in a way that it started with a time step of 0.00001 seconds and gradually increased to 0.01 seconds at flow time of 10 seconds. After simulation, the CFD results were compared with the experimental data and a good agreement was achieved in explaining the effects of viscosity of the filter medium on its efficiency in absorbing particles. As shown from Figs. 11 to 13, as viscosity increases, the bubble size increases, and therefore the absorption efficiency of the filter medium increases too. The distribution of particles obtained from CFD simulations also agreed with that observed from the experiments. As shown in Figs. 14 to 16, during the filtering process, small particles tend to deposit near side wall, while larger particles will deposit around the bottom center of the container.

A fine mesh model with 7243 cells and 7558 nodes was constructed and applied for the same simulations to investigate the sensitivity of the simulation results to the mesh strategy. The results obtained from the fine mesh model are very close to those yielded from the coarse mesh model: the differences in the volume fractions of air at the suction head with different viscosity predicted by the coarse and fine mesh are within 5%. The distribution modes of particle resident time generated from both models are also close to each other. Thus, it is verified that the results obtained from the coarse mesh model (2255 cells and 2394 nodes) are reliable.

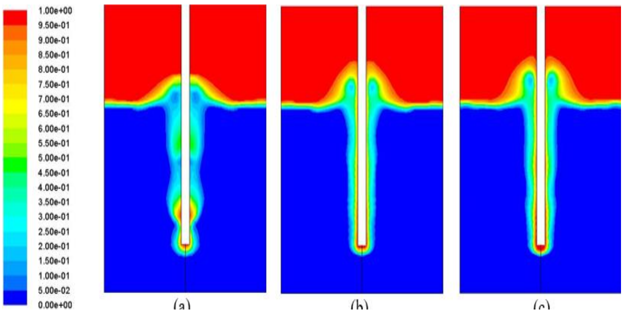

Fig. 11: Volume fraction of air (liquid viscosity of 100 cSt) (a) air inlet velocity of 3m/sec (b) air inlet velocity of 4.5m/sec (c) air inlet velocity of 6m/sec

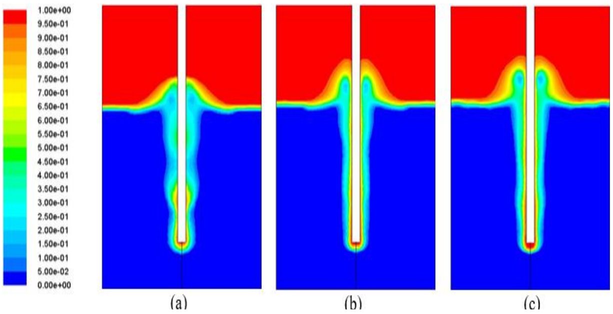

Fig. 12: Volume fraction of air (liquid viscosity of 200 cSt) (a) air inlet velocity of 3m/sec (b) air inlet velocity of 4.5m/sec (c) air inlet velocity of 6m/sec

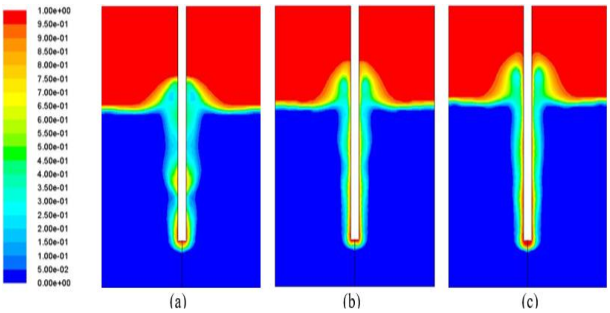

Fig. 13: Volume fraction of air (liquid viscosity of 300 cSt) (a) air inlet velocity of 3m/sec (b) air inlet velocity of 4.5m/sec (c) air inlet velocity of 6m/sec

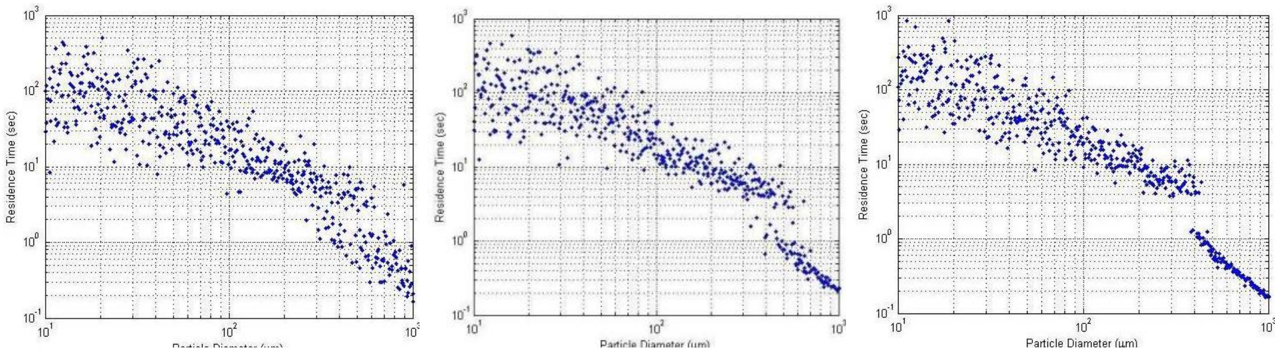

Fig. 14: Distribution of particle resident time vs. diameter of particles (liquid viscosity of 100 cSt) (a) air inlet velocity of 3m/sec (b) air inlet velocity of 4.5m/sec (c) air inlet velocity of 6m/sec

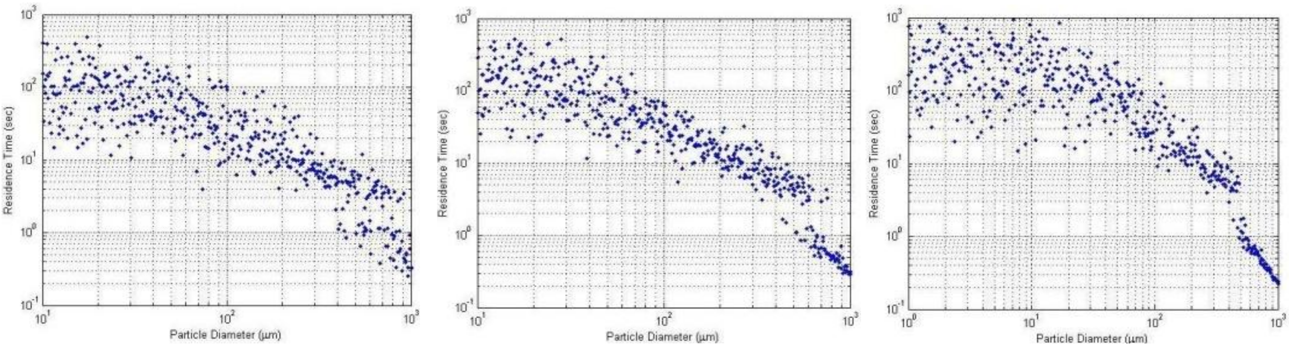

Fig. 15: Distribution of particle resident time vs. diameter of particles (liquid viscosity of 200 cSt) (a) air inlet velocity of 3m/sec (b) air inlet velocity of 4.5m/sec (c) air inlet velocity of 6m/sec

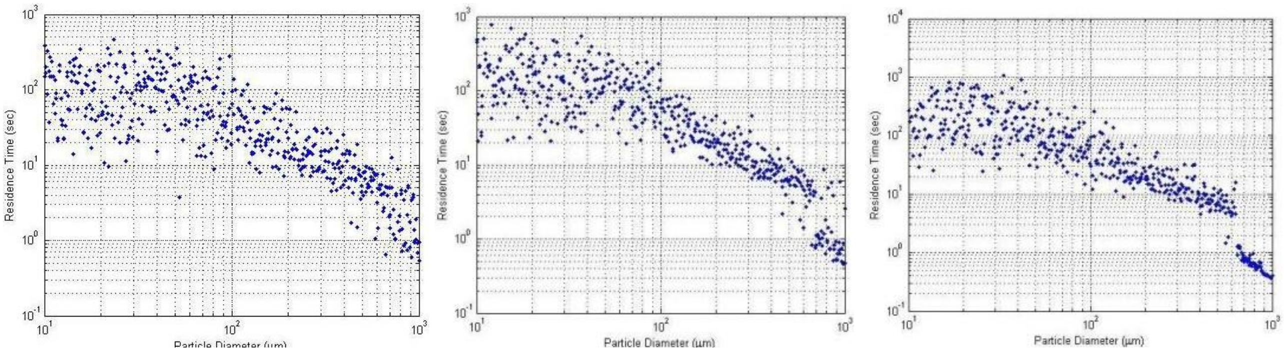

Fig. 16: Distribution of particle resident time vs. diameter of particles (liquid viscosity of 300 cSt) (a) air inlet velocity of 3m/sec (b) air inlet velocity of 4.5m/sec (c) air inlet velocity of 6m/sec

6. Suggestions

The experimental results are satisfying; however, it was found from the experiment that the presented system can be improved in following facts:

- First, it was found the 12V air compressor used for the experiment is not powerful enough. It is planned to use a high power pump to effectively and massively compress the air and drive it into the particulate control system. The using of the high power pump will significantly reduce the experimental time.
- In the future, abrasive particles will be used for the experiment to test tolerance of the developed system to the abrasive properties of particles. The capability of processing abrasive particles will be a unique merit of this system, with which the system can be applied in spacecraft, workstation, and other planetary structures to remove the abrasive particles such as lunar surface dust.
- Further investigation will be conducted to study the efficiency of the system in removing and disposing particles of different size and optimize the design accordingly. Our ultimate goal is to develop a flexible particulate control system that can efficiently process particles of a wide range (from 5 to 1000μm).
- Containers with different shapes and dimensions will be evaluated through this experiment in order to find the optimal shape and size of the container so as to achieve the best particle removal capability, and to make the developed system applicable for different occasions.
- The presented manufacturing and experimental techniques will be combined with computational and analytical techniques in the future for further optimizations and developments, such as extend its lifetime, minimize the operation cost, and commercialization, etc.

7. Advantages of the design

Based on the experimental results, it was found that compare to existing particulate control systems the developed prototype offers following unique merits.

- The developed system represents a simple and robust technology to cleanly remove particles suspended in air while avoiding dispersing them in the environment.
- The system is very flexible, its size can be scaled up and down, and the filter medium inside can be easily switched so as to be applicable on different occasions.
- The system can be easily built with a very low cost. The developed particulate system only includes a plastic container, three valves, filter papers, filter liquid, and tubes, whose overall cost does not exceed $10.
- The performance of this system and its efficiency in air cleaning can be easily evaluated by measuring the weight of the trapped and filtered particles.
- Because of its flexibility, the proposed system can be interfaced with or made compatible with many types of particles, for example, mitigating the amount of particles entrained in smoke or even mitigating the effect of an unpleasant odor.

Due to the aforementioned advantages, the designed prototype has a broad applicability in industry and therefore possesses strong prospects for commercialization. In aerospace and space engineering, particulate matter suspended in the habitable cabin atmosphere is a challenge for all phases of crewed lunar surface exploration missions. The particulate control system built in this project can be applied to efficiently and safely remove and dispose the particulate matter originating from sources internal to the habitable cabin and from lunar surface dust intrusion in the cabin environment. In automotive industry, the present particulate management technology can be used to develop filter systems to work in-line with the vehicle or habitat ventilation system. In that regard, the designed prototype can be modified into a portable device to decouple the filtration system from the vehicle's ventilation system.

Meanwhile, the designed system and presented particle transfer technology can also be applied in any civil industries where materials, because of potential hazard, contamination, general cleanliness or other reasons, must be processed in a manner that exposure to the outside must be minimized or eliminated. Such industries include, but are not limited to, chemical and pharmaceutical production, fossil fuel power plant operations, ore processing, HVAC industry, and environmental protection.

8. Conclusions

In this project, a particulate control system is designed based on the Bernoulli principle and prototyped for experimental validation. The capacity and efficiency of the developed system in removing the particulates from the airflow were verified through a series of experiments. From the experimental results, it was found that the particulate trapping efficiency and capacity of such system could be apparently improved by increasing the filter media's viscosity. It is suggested that an optimal viscosity has to be selected for the filter media to achieve decent particulate trapping capacity at an appropriate cost without affecting the media's fluidity. It was also deduced that the system's efficiency in removing the particles would slightly decrease as the experimental time increased. Such decrement was more detectable when the filter media's viscosity was close to zero, such as water. This is because that the low-viscosity filter media will be saturated when too many particulates flow into it, which will reduce its capacity in capturing more particles.

Meanwhile, the incoming particles will bring electrons into the media and the accumulation of electrons will change property of the media therefore reducing its ability of absorbing the particles. All the experimental results were validated through CFD simulations. In the future, the present system can be extensively optimized and developed to be able to efficiently and safely process a wide range of particles with different size and properties and be applicable for different occasions. For example, the system can implement an ideal filter medium with optimum permeability and porosity, which can be a walnut shell medium wet with a fluid or a polymer filter medium with micro size permeability. Moreover, the particulate control system can include a micro fibrous support and a nano fibrous facial layer or use many-layer nano fibrous filters combined with a single micro fibrous backing to make it more profitable from the quality factor standpoint in the improvement phase. In summary, due to its low cost, portable size, and high flexibility, the developed system has bright prospects for commercialization and has the potential to benefit many industries.

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