Long-Term Performance of a Mist Collector

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ABSTRACT

The performance of a three-stage mist collector has been investigated through parallel tests in the laboratory and at a transmission plant over the course of one year. Collection efficiency, loading, and pressure drop were measured repeatedly over time for the entire collector and for each of its three component stages. The first-stage, metal mesh filter maintained constant performance over the year, both in the lab and in the plant. The second-stage, pocket filter decreased substantially in efficiency over time, particularly for sub-micrometer droplets; this decrease paralleled an increase in pressure drop and loading. The third-stage, 95% DOP filter maintained high efficiency and low pressure drop in the lab; however, the corresponding filter in the plant decreased in efficiency as loading and pressure drop increased. These data suggest how well mist collectors perform under ideal as well as practical conditions, and can help establish maintenance guidelines that keep performance high.

INTRODUCTION

Researchers at the University of North Carolina have been investigating the performance of collectors that remove mists produced by metal machining operations. Initially, a standard test procedure was developed to relate removal efficiency and droplet diameter for each stage of a collector and the collector as a whole when challenged with three types of metalworking fluid mist.[(1)] Ten commercially available mist collectors were evaluated to identify the most promising component technologies.[(2)] As limited data were resolved for both maintenance requirements and collector performance, a longer-term study was initiated with two identical collectors that performed well in the initial tests; one prototype was evaluated in the laboratory at UNC and the other at a Ford transmission plant.

The objectives of this work were: (1) to identify the relationship between removal efficiency and droplet diameter for each of the three stages in the prototype collector, as well as the collector as a whole, when challenged with a straight oil mist over time in the laboratory; (2) to determine how filter loading, filter pressure drop, and the relationship between droplet collection efficiency and droplet diameter change with time; and (3) to confirm the lab results with parallel tests conducted at the transmission plant.

METHODS

Prototype Collectors

Two prototype collectors were sized by their manufacturer to process 1000 cfm of air. Each unit contained three filters: a metal mesh filter, a pocket filter, and a 95% DOP filter, arranged vertically in series. The metal mesh filters were 50.2 by 50.2 by 9.2 cm thick and consisted of ribbon-like strands averaging 1.14 mm in width and 0.08 mm in thickness. The pocket filters were suspended from rods and clamped to the collector housing. Each pocket filter was comprised of ten pockets made from glass fibers that averaged 3.2 μm in diameter; the total filter surface area for the pocket filter was 12.1 m^2. The 95% DOP filters were composed of glass fibers with average diameter of 3.1 μm. In the lab collector, this filter contained 80 pleats that were each 20.3 cm deep to give a total collection area of 18.2 m^2. At the plant, the 95% DOP filter contained 74 pleats that were 26.7 cm deep, to give a total collection area of 21.3 m^2.

Test Set-Up

Figure 1 presents schematic sketches of the two collectors as placed in their respective test set-ups. Tests were conducted weekly in the laboratory and monthly at the plant to evaluate collector and component efficiency for removing droplets of hobbing oil, a straight oil composed [(3)] of organics ranging from C_{13} to C_{30}. In the laboratory, a six-jet nebulizer was used to generate a mist concentration that was introduced into the airflow alternately at points upstream (Position 2) and downstream (Position 1) of the collector. Droplets

produced by the nebulizer were counted using an Aerosizer, an instrument that counts and measures droplets aerodynamically. Droplet count data were sorted into 21 size intervals that ranged from 0.25 to 6.3 μm in diameter. To ensure that any count differences observed between the positions were not caused by subtle shifts in the mist generation rate, the nebulizer was moved between the positions in a 2-1-2-1-2-1-2-1-2 pattern, with the nebulizer in operation the entire time. Separate Aerosizer measurements were taken with the nebulizer in each of these nine positions.

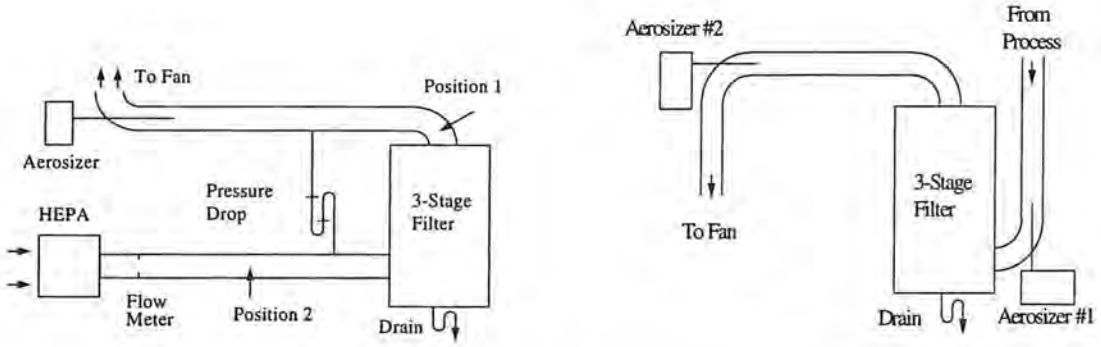

Figure 1. Schematic sketches of the test set-up in the laboratory at UNC (left) and at the plant (right).

In the laboratory, weekly efficiency tests were run on the housing alone, housing and metal mesh filter, housing and pocket filter, housing and 95% DOP filter, and the housing with all three filters installed. Prior to the start of each weekly test, all filters were removed and weighed; the amount of fluid that had entered and drained through the system was also determined by weighing the nebulizer and catch in the drain bucket. Pressure drops across the collector and each individual component were measured. On the days between tests, the filters in the lab were exposed to high concentrations of hobbing oil mist (35 mg/m^3) introduced continuously into the air stream at Position 2 by a 40-jet conditioning nebulizer.

In the plant, mist was generated by two hobbing machines located 11.3 m upstream of the collector. Each hobbing machine sheared nearly 40 g of metal from a blank die every 30 seconds and contributed dust and smoke particles to the hobbing oil mist. Monthly trips were made to the plant to establish collector performance. As in the lab, all filters were removed and weighed. Pressure drops across the collector and each component in the collector were also measured. Sets of ten efficiency measurements were made for particles from 0.25 to 6.3 μm in diameter by simultaneously measuring mist concentrations upstream and downstream of the collector using two Aerosizers. Ten-measurement sets were made for the housing alone, for the housing plus the first stage, housing plus first and second stages, and housing with all three stages installed. To eliminate any bias due to differences between the two Aerosizers, the instruments were then interchanged and another complete round of efficiency measurements was made.

The data from both test sites were analyzed to determine penetration vs. droplet diameter for each component of the collector and for the complete collector with all filters installed. Similarly, data from both tests sites were plotted to determine how filter loadings and pressure drops changed over time.

RESULTS

Mist Removal Efficiency

Plots of collection efficiency against droplet diameter are shown in Figures 2, 3, and 4 for the metal mesh filters, pocket filters, and 95% DOP filters, respectively, in the laboratory (left) and at the plant (right). For each figure, data are presented for weeks 1, 4, 13, 26, and 51 or 52. Figure 2 shows that the efficiencies of the metal mesh filter at both locations were nearly identical and remained constant for the duration of the study. At both sites this first stage filter collected essentially all droplets larger than 5 μm in diameter, but was ineffective for droplets smaller than 1.5 μm.

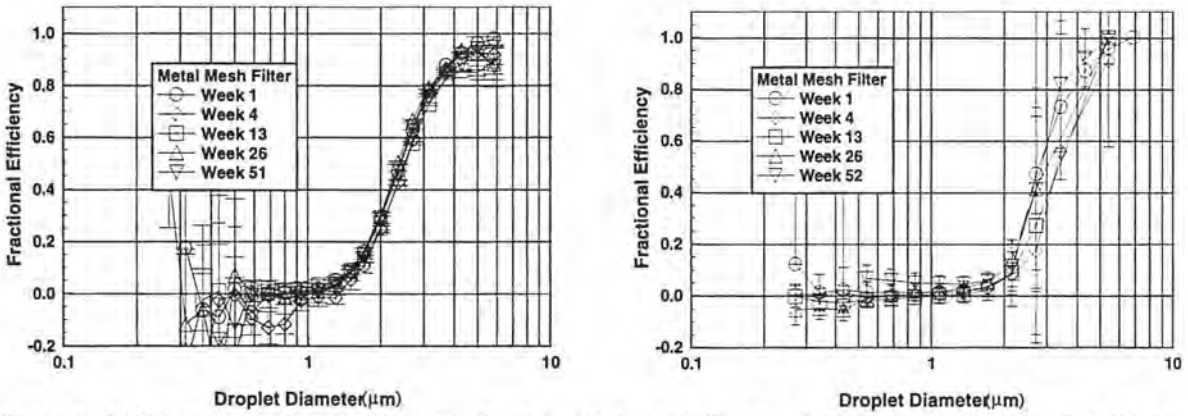

Figure 2. Efficiency vs. droplet diameter for the metal mesh filter in the laboratory (left) and at the plant (right) at 1, 4, 13, 26, and 51 or 52 weeks.

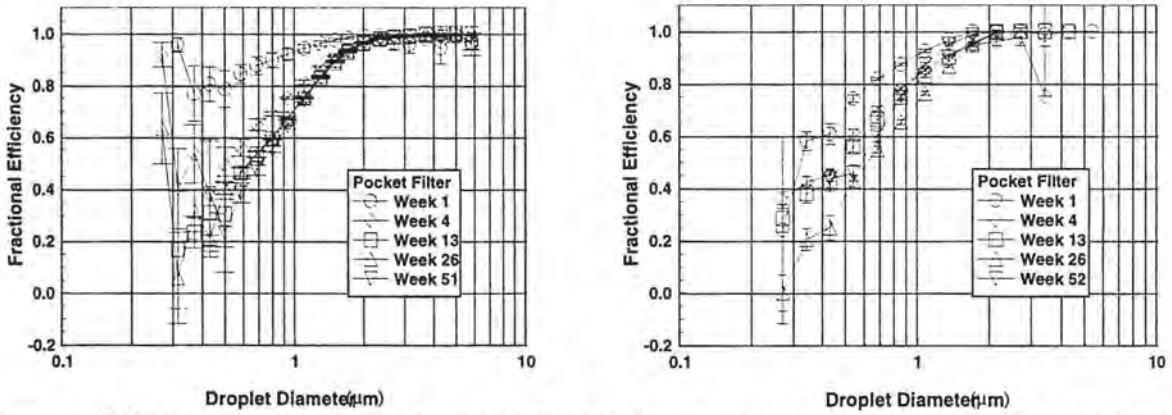

Figure 3. Efficiency vs. droplet size for the pocket filter in the laboratory (left) and at the plant (right) when new and at 4, 13, 26, and 51 or 52 weeks.

Figure 3 shows that at both sites, the efficiency of the pocket filter decreased rapidly over the first month for droplets smaller than 1 µm. The pocket filter in the lab then continued at steady efficiency until the final months of the study, when its efficiency deteriorated further. In the lab, efficiency for 0.5 µm droplets declined from 80% when new to 40% at 26 weeks and to less than 25% at one year. At the plant the decrease in efficiency leveled off at 26 weeks, where it remained through one year of testing. In the plant, efficiency for a 0.5 µm droplet dropped from 70% when the pocket filter was new to 40% at 26 week and 45% at one year. Although the efficiency of filters that collect solid particles generally increases with use[4], the efficiency of filters that collect liquid droplets such as those used here have been found to decrease with use.[5,6,7]

Figure 4 shows that the performance of the 95% DOP filters in the lab and plant were quite different. In the lab, the overall efficiency of the 95% DOP filter remained high, although a slight decrease occurred for droplets less than 0.6 µm. However, at the plant, the efficiency of the 95% DOP filter decreased steadily with time, especially for sub-micron droplets. At the plant, efficiency for a 0.5 µm droplet decreased from 100% when new to 88% at 26 weeks and 80% after one year.

Component Loading

Figure 5 shows the increase in weights of component stages for the prototype collectors in the lab and at the plant. At both sites, the weight of the metal mesh filter did not change appreciably with time. The loading on the pocket filter at both locations experienced a substantial increase at first, became steady, then declined slightly in the latter months. The steady-state loading carried by the pocket filter was about the same, 14 pounds, in both the lab and the plant. In the lab collector, the loading on the third-stage 95% DOP filter held constant for six months, then increased, perhaps reflecting the decrease in efficiency of the second-stage pocket filter, which allowed more mist to reach the third stage. At the plant, the 95% DOP filter displayed a fairly steady increase in weight throughout the duration of the tests.

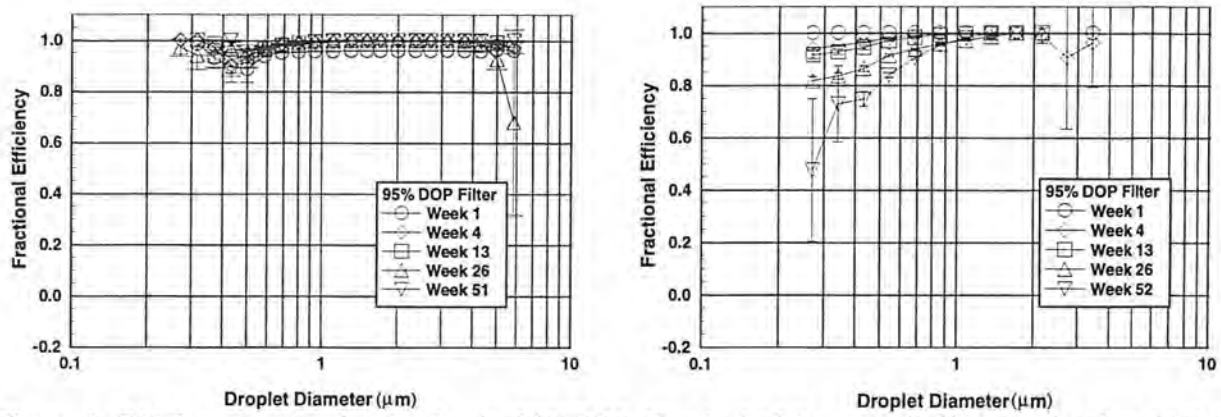

Figure 4. Efficiency vs. droplet size for the 95% DOP filter in the laboratory (left) and at the plant (right) when new and at 4, 13, 26, and 51 or 52 weeks.

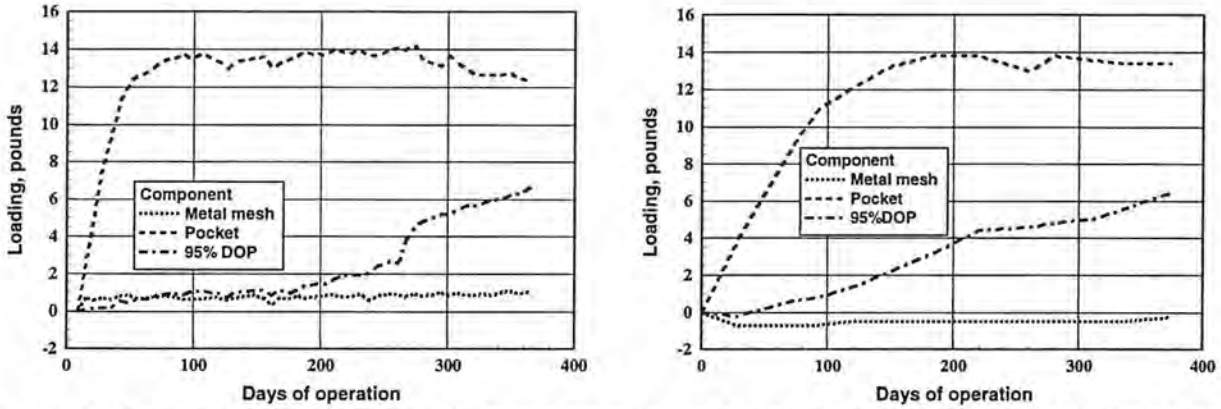

Figure 5. Component weight gain for the prototype collector in the laboratory (left) and at the plant (right).

Pressure Drop

Figure 6 presents pressure drop data against day of test for each component for the collectors in the lab and at the plant. Pressure drop for the complete collector increased by 1.4 in. H_2O in the lab and by 7.0 in. H_2O at the plant during the year's tests. In the lab, the pressure drops across the housing, metal mesh filter, and the 95% DOP filter were fairly constant; the pocket filter experienced the greatest increase. In the plant, the pressure drop data paralleled the lab data until the last several months, when pressure drop across the pocket and 95% DOP filters increased substantially. Surprisingly, pressure drops across the pocket filter did not track the substantial increases in filter loading at either the lab or the plant as shown in Figure 5.

During the last few months of the study, a large concrete floor at the plant was demolished and removed. Figure 6 shows that pressure drop across the pocket and 95% DOP filters at the plant increased substantially during the time that this demolition occurred. Although dust produced by this demolition did not substantially affect filter loadings as shown in Figure 5, the small size of the dust particles that collected on the pocket and 95% DOP filters during this time may have affected the specific resistance of the dust/mist deposit in such a way that pressure drop increased more than expected.

CONCLUSIONS

The conclusions reached in this work are specific to the design of the collectors and their internal components, the test fluid (hobbing oil), and the test conditions investigated here. Further work is under way to evaluate similar mist collectors under other operating conditions.

The three-stage collectors tested in the lab and in the plant both provided good collection efficiency for mist droplets of all sizes over the course of the year's tests. After one year of operation, the efficiency of both collectors remained high, even on submicrometer particles.

The largest component of pressure drop in both collectors was the housing itself. Pressure drop across the housing should be minimized by careful design to minimize energy costs.

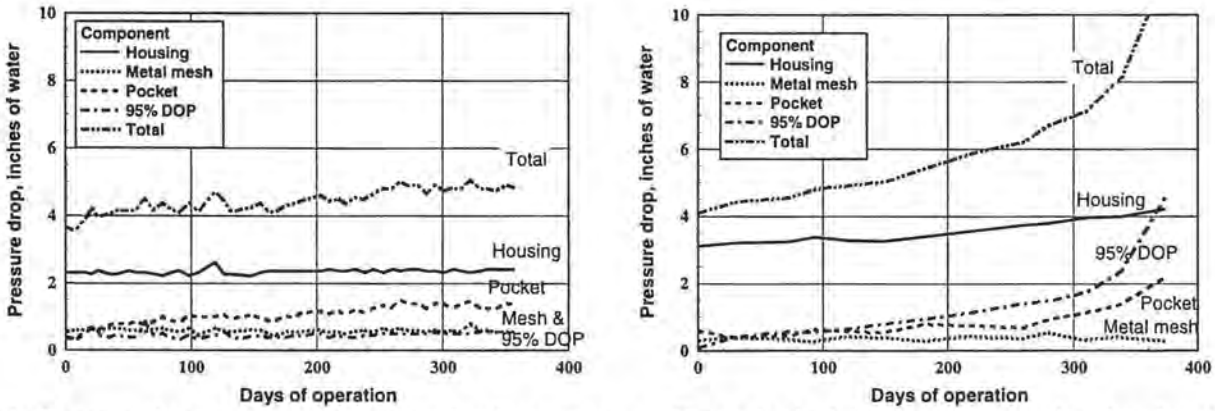

Figure 6. Pressure drop vs. day of operation for the prototype collector in the laboratory (left) and at the plant (right).

The first-stage, metal mesh filter used in this study has a lifetime of more than one year. At both test locations, this filter operated at constant efficiency with stable pressure drop, no weight gain, and no evidence of physical deterioration. These findings suggest the desirability of developing a first-stage filter that has higher efficiency, to provide even better protection of the collection stages downstream.

The efficiencies of the second-stage, pocket filters decreased with time as liquid loaded onto the filters. Pressure drop across the pocket filter in the lab, which was exposed to hobbing oil mist alone, was not an obvious indicator of the correct time to replace this filter. For the pocket filter in the lab, pressure drop increased only slightly, whereas efficiency decreased substantially over the course of the year's tests. Pressure drop across the pocket filter in the plant, which was exposed to smoke, heat, and dust particles from the process, as well as mist, provided a better gauge for filter replacement. For the pocket filter in the plant, pressure drop generally increased as efficiency decreased. For both the pocket filter in the lab and the pocket filter in the plant, filter lifetime under the conditions of these tests was about nine months. At this point, pressure drop across the pocket filter in the plant was about 1.7 inches of water.

The 95% DOP filter in the laboratory, which was exposed to mist alone, maintained high collection efficiency over the course of these tests. However, the performance of the corresponding filter at the plant, which was exposed to smoke and dust particles from the process as well as mist, deteriorated after 10 months of operation, as evidenced by its poor efficiency for submicron particles and increased pressure drop. Replacement of the 95% DOP filter is recommended when the pressure drop across this filter exceeds 2.0 inches of water. The decrease in efficiency for the 95% DOP filter with use suggests that a more efficient final filter may be necessary if emissions from the collector must be minimized.

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For your convenience, the following example citation is the correct way to cite a paper published in this volume as Bibliographical Reference:

> Moore, J.S., M. Christensen, R. Wilson, D. Nash, and B. Shelton: *Mycobacterial Contamination of Metal Removal Fluids and Potential Abatement Strategies.* Metalworking Fluids Symposium II. The Industrial Metalworking Environment: Assessment and Control of Metal Removal Fluids. September 1997. Detroit, MI ***Symposium Proceedings***. The American Automobile Manufacturers Association, 1998, pp.266-274.

PUBLISHER'S INFORMATION

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The reader will notice a variety of nomenclature differences among authors when referring to these fluids which were the subject of the Symposium and of this volume. Indeed, even the Symposium title reflected some of this variation: "*Metalworking* Fluids Symposium II," and "The Industrial Metalworking Environment: Assessment and Control of *Metal Removal* Fluids." Lest we add to the confusion, our use of the term *metalworking* in the title "Metalworking Fluids Symposium II" was a conscious decision based on nothing more than to maintain continuity with the title from the first Symposium. It was for that reason that "Assessment and Control of Metal Removal Fluids" was added in recognition of, and to call attention to the fact that the vast majority of research and data to date has been generated on a subset or class of metalworking fluids known as **metal removal fluids**. In addition to metal removal fluids, the very general term 'metalworking' fluids also encompasses the large and general classes of *metal protecting* fluids, *metal forming* fluids, and *metal treating* fluids. Besides functional differences between metalworking fluid classes, there are substantial compositional differences both between and within classes. So while it is somewhat sloppy though quite common and generally harmless to use generic terms such as metalworking fluids, or machining fluids, or coolants, the reader should be well aware of these important distinctions and that in virtually all instances where there is a connection with purported health effects, the person is really referring to that subclass of metalworking fluids known as *metal removal fluids*.

ISBN 1-893348-00-8

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