The Effect of Loading Dust Type on the Filtration Efficiency of Electrostatically-Charged Filters

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ABSTRACT

Ventilation filters composed of electrostatically-charged fibers, also referred to as electret filters, are know to have the potential to decrease in filtration efficiency with use. However, little data have been available on whether such decreases are seen in actual applications. ASHRAE (American Society of Heating and Refrigerating and Air-conditioning Engineers) is developing a new test method (draft ASHRAE 52.2P "Method of Testing General Ventilation Air-cleaning Devices for Removal Efficiency by Particle Size") that includes procedures intended to reveal if a filter's efficiency decreases with use. The work described in this paper had three purposes: 1) conduct tests to quantify the changes in filtration efficiency that electret filters undergo with actual use, 2) assess the adequacy of the draft ASHRAE 52.2P methodology to reveal these changes, and 3) if needed, develop a laboratory test method that more closely reveals these changes than is achieved with the draft ASHRAE 52.2P methodology.

Three types of electrostatically-charged filters were evaluated: a rigid cell filter charged via an electrodynamic spinning process, a pleated panel filter charged via a corona charging process, and a residential filter charged via a split-fiber process. The filtration efficiency measurements covered the 0.3 - 10 micrometer diameter size range. Exposures consisted of outdoor ambient air, in-home air, ASHRAE dust, ASHRAE dust without carbon black, and a submicrometer salt aerosol.

Results show that all the ambient and in-home exposed filters had substantial decreases in filtration efficiency. Laboratory tests using the draft ASHRAE 52.2P procedures did not reproduce these results well, often showing either little change or increases with loading rather than decreases. The submicrometer salt aerosol came closest to duplicating the outdoor and in-home aerosol exposure results, although the magnitude of the efficiency decrease was underestimated in some cases.

INTRODUCTION

ASHRAE has undertaken the development of a new fractional efficiency test method for ventilation filters: draft ASHRAE 52.2P "Method of Testing General Ventilation Air-Cleaning Devices for Removal Efficiency by Particle Size" [1]. The method involves measuring the initial and dust-loaded efficiency of filters over the particle diameter size range of 0.3 - 10 micrometer. One objective of the method is to determine the minimum efficiency of the filter over its lifetime, i.e., as dust accumulates on the filter. Typically, uncharged media filter will increase in efficiency with dust loading. However, for electrostatically-charged media (which are becoming increasingly common in ventilation filters), efficiency can decrease with dust loading.

One aspect of the new draft ASHRAE 52.2P method that differs from prior standards is the incorporation of a "conditioning" step. Traditionally, a filter's efficiency was measured in its initial condition and after dust loading to 25%, 50%, 75%, and 100% of final resistance (as in the ASHRAE 52.1 standard [2]). The conditioning step is an added procedure that comes between the initial efficiency measurement and the 25% dust loading step. The purpose of the conditioning step is to reveal decreases in filtration efficiency that a filter may undergo during the early stages of dust loading, i.e., before dust collection on the filter leads to increased filtration efficiency. Laboratory and field studies indicate that some electrostatically-charged filters may undergo substantial decreases in efficiency as they are exposed to aerosols [3,4,5,6].

In the draft ASHRAE 52.2P method, the conditioning step consists of challenging the filter with ASHRAE dust (a mixture of carbon black, cotton linters, and Arizona Road Dust) until either a pressure drop increase of 10 Pa is achieved or 30 gm of dust is fed; whichever comes first. Relative to the 25%, 50%, 75%, and 100% dust loading steps that follow, this is a very low dust challenge intended to simulate dust loading during the early stages of the filter's use.

The objective of this study was to determining the extent to which the draft ASHRAE 52.2P conditioning protocol, and modifications to that protocol, reproduce the reduction in efficiency that electret ventilation filters may undergo during the early stages of actual use.

METHODS

Three types of electrostatically-charged filters were evaluated: a high efficiency rigid cell filter charged via an electrodynamic spinning process (610 x 610 x 305 mm) operating at 0.71 m^3/s), a pleated panel filter charged via a corona charging process (610 x 610 x 50 mm operating at 0.71 m^3/s), and a residential filter charged via a split-fiber process (510 x 630 x 25 mm operating at 0.48 m^3/s). These filters were selected to include a range of filtration efficiencies and manufacturing processes.

The laboratory tests were conducted in RTI's ASHRAE 52.2 test duct. The test duct is designed to test full-size filters (typically 610 x 610 mm and 510 x 630 mm inch face dimensions) at flow rates from 0.22 to 1.4 m^3/s. The fractional filtration efficiency of the filters was measured following the initial efficiency procedures specified in draft ASHRAE 52.2P and involved generating a solid-phase potassium chloride challenge aerosol that spanned the size range from 0.3 - 10 micrometers. A high resolution optical particle counter was used to measure the upstream and downstream aerosol concentrations. Conditioning of the filter was conducted using ASHRAE dust (per the draft 52.2 method), using ASHRAE dust without carbon black, using 0-3 micrometer size fraction of Arizona Road Dust, and using a submicrometer salt aerosol. The dusts were dispersed using a standard ASHRAE dust feeder and followed the 50 Pa / 30 g criteria of the draft ASHRAE 52.2P method. The salt aerosol was generated by nebulizing a 1% aqueous solution of potassium chloride in a Laskin Nozzle operating with 3 nozzles at 350 kPa for 8 hours.

To provide a baseline for comparison, the filters were also exposed to outdoor ambient air and in-home air (for the residential filter only). The ambient exposures were conducted using portable ducts located in the outdoor-air intake plenum of an RTI office building. The plenum had fixed-position louvers and window screening to provide protection from precipitation and insects, but otherwise had free exposure to outdoor ambient air. Prior to exposure, the initial filtration efficiency of each of the three filters was measured in the laboratory test rig. The filters were then installed in the portable ducts and the ambient-air exposure initiated. The ducts were operated continuously (24 hrs per day) during the exposure period. At 2 week intervals, the filters were removed from the portable ducts and taken to the laboratory test facility where filtration efficiency was measured. The filters were then returned to the portable ducts to resume exposure to ambient air.

The in-home exposures were accomplished by having nine RTI employees use the filters in their home ventilation systems for various durations ranging from 2 weeks to 12 weeks. Unlike the ambient exposure filters, these filters were not pre-tested for their initial efficiency and were taken to the homes in their unopened plastic-wrap packaging. After installation in the ventilation system, the filters were returned to the test laboratory after completion of a single predetermined exposure period. To minimize possible disruption of dust deposits on the exposed filters, each participant was provided instructions on handling the filter and a carrying case to protect the filter when they brought the filter to the test lab. To establish an initial efficiency for comparison, new filters from the same lot (and from the same case of 12 filters) were tested at the same time as the in-home exposed filters were tested.

RESULTS

Results from the ambient exposure tests of the rigid-cell filter are shown in Figure 1. For this filter, substantial decreases in efficiency were observed after exposure. Figure 2 summarizes the results for the residential filter after use in home ventilation systems; again substantial decreases in efficiency are seen. Figures 3, and 4 show the results of laboratory tests for the initial efficiency and efficiency after performing a conditioning step with various dusts and with the sub-micrometer KCl salt.

For the residential filters the level or decreasing efficiency over the 3 - 10 micrometer range is often seen for lower efficiency filters and is attributed to particle bounce.

DISCUSSION

The ambient and in-home exposures showed decreases in efficiency with time for every filter. The draft ASHRAE 52.2P test method includes a conditioning step that is intended to reveal such decreases in the efficiency of electret media. These results clearly demonstrate the need for such a step in the test standard. However, except for showing a modest decrease at smaller particle sizes for the residential filter, the conditioning step showed primarily increases in efficiency for the filters.

Of the dusts and aerosols used for conditioning, only the submicrometer KCl showed a decrease for the high efficiency rigid cell filter; each of the other dusts only showed increases in efficiency for this filter. At smaller particle sizes, the submicrometer KCl aerosol also resulted in the greatest reduction in filtration efficiency for the other two filters and, overall, came closest to matching the ambient and in-home exposure results.

However, the submicrometer KCl aerosol, like the other dusts, did not reveal the decrease in efficiency at larger particle sizes. We attribute the lack of a decrease in efficiency at larger particle sizes to counteracting effects associated with particle collection on the filter fibers (e.g., dendritic deposits and suppression of particle bounce associated with particle deposits).

Further investigations of the conditioning procedures are needed to find means of better reproducing the decreased efficiencies observed after actual exposures. The use of submicrometer KCl particles improved the conditioning step over conditioning with ASHRAE dust, however, it still significantly underestimated the decrease the filters underwent when exposed to ambient and indoor aerosol.

It should be noted that this study did not attempt to distinguish between the effect that aerosol particle collection has on the observed reduction in filtration efficiency versus other possible factors such as temperature, humidity, and the simple passage of time. Testing is currently underway to evaluate these potential contributing factors.

ACKNOWLEDGMENT

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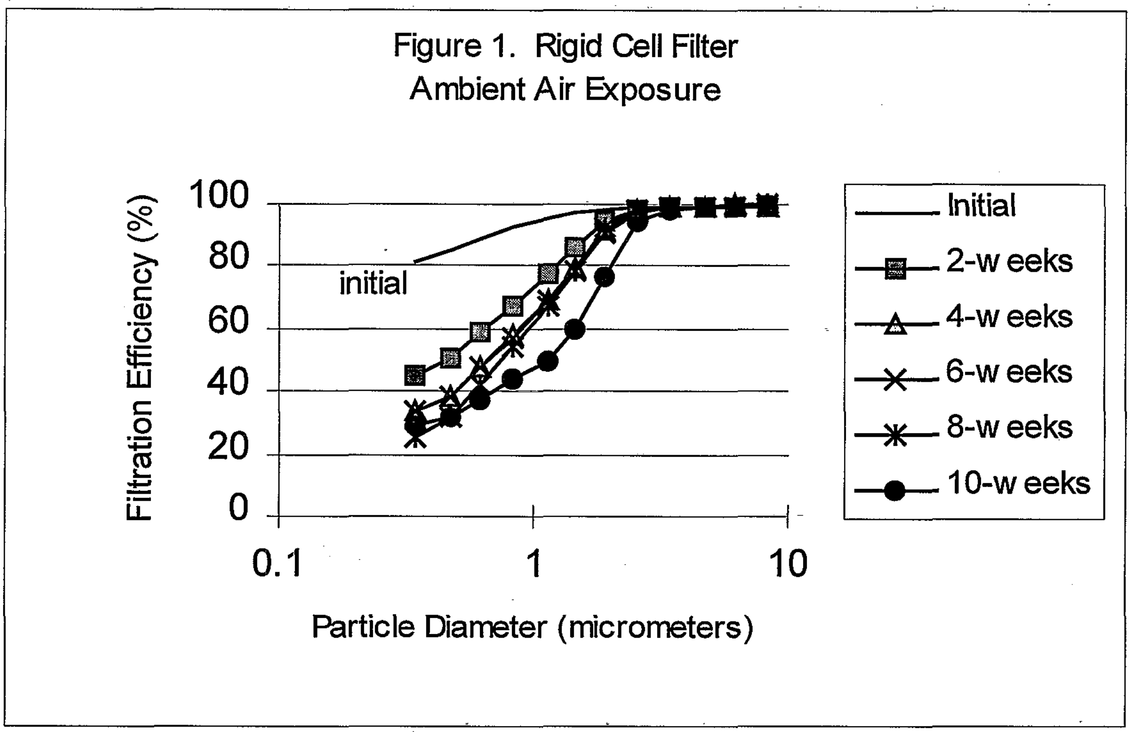

Figure 1. Rigid Cell Filter
Ambient Air Exposure
Filtration Efficiency (%)
100
80
60
40
20
0
initial
0.1
1
10
Particle Diameter (micrometers)
Initial
2-w eeks
4-w eeks
6-w eeks
8-w eeks
10-w eeks

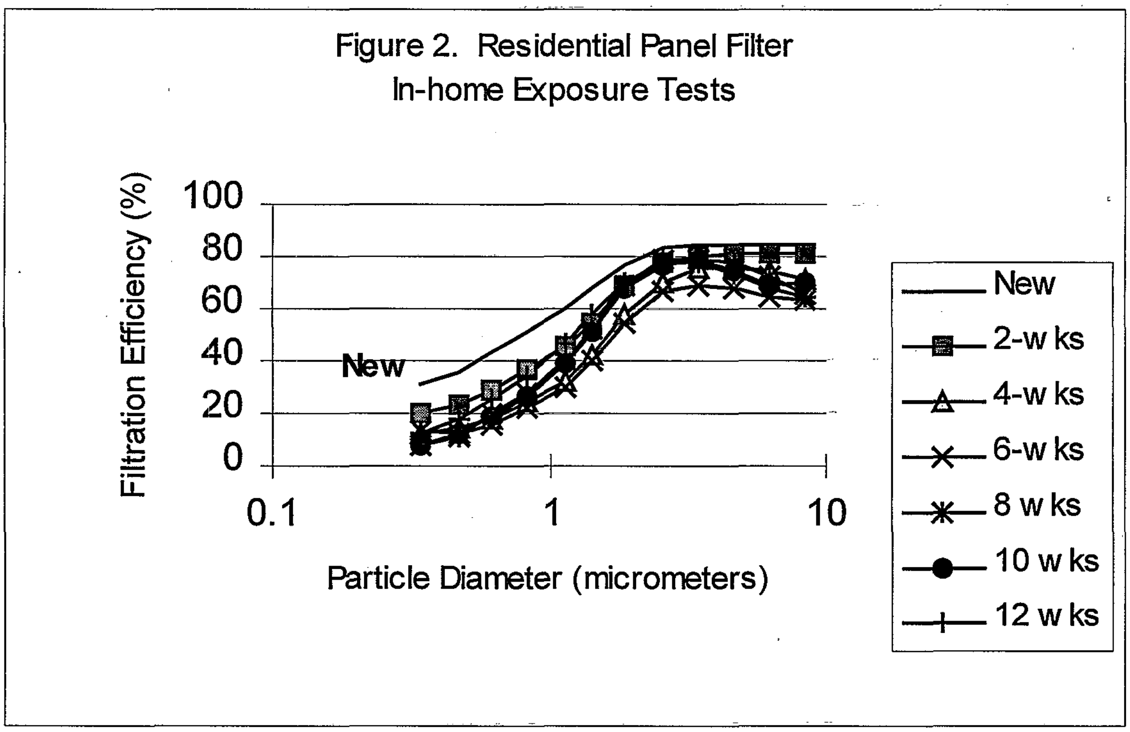

Figure 2. Residential Panel Filter
In-home Exposure Tests
Filtration Efficiency (%)
100
80
60
40
20
0
New
0.1
1
10
Particle Diameter (micrometers)
New
2-w ks
4-w ks
6-w ks
8 w ks
10 w ks
12 w ks

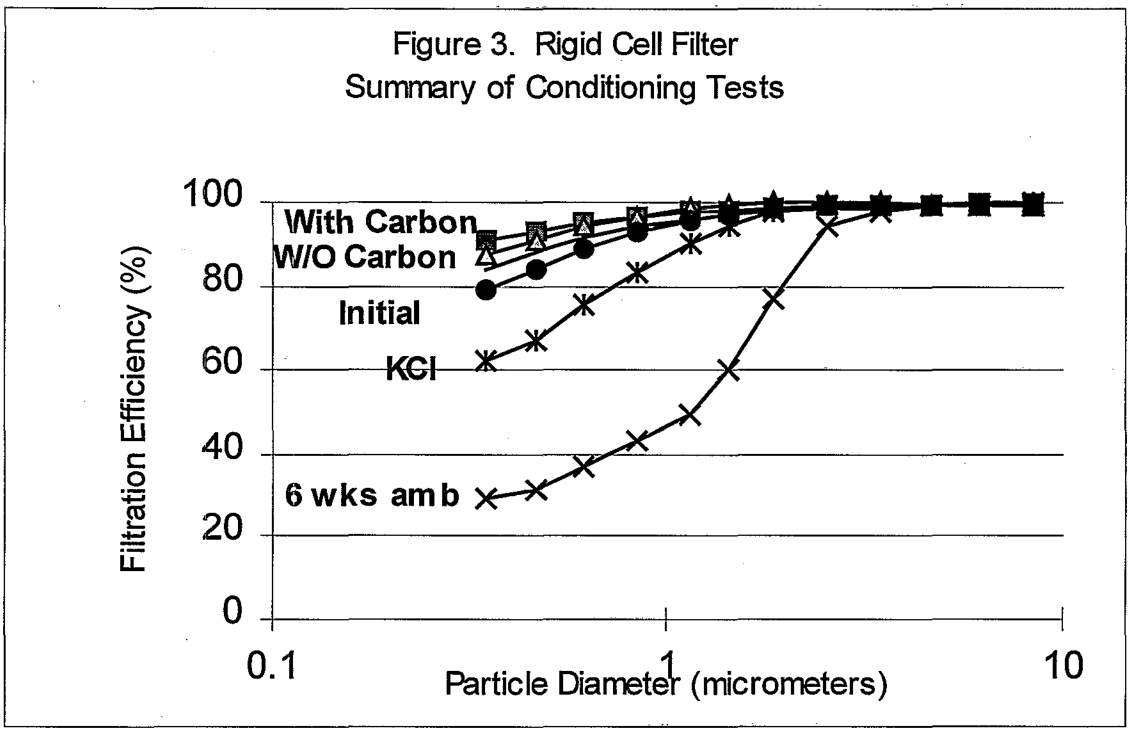
Figure 3. Rigid Cell Filter
Summary of Conditioning Tests
Filtration Efficiency (%)
100
80
60
40
20
0
With Carbon
W/O Carbon
Initial
KCl
6 wks amb
0.1
1
10
Particle Diameter (micrometers)

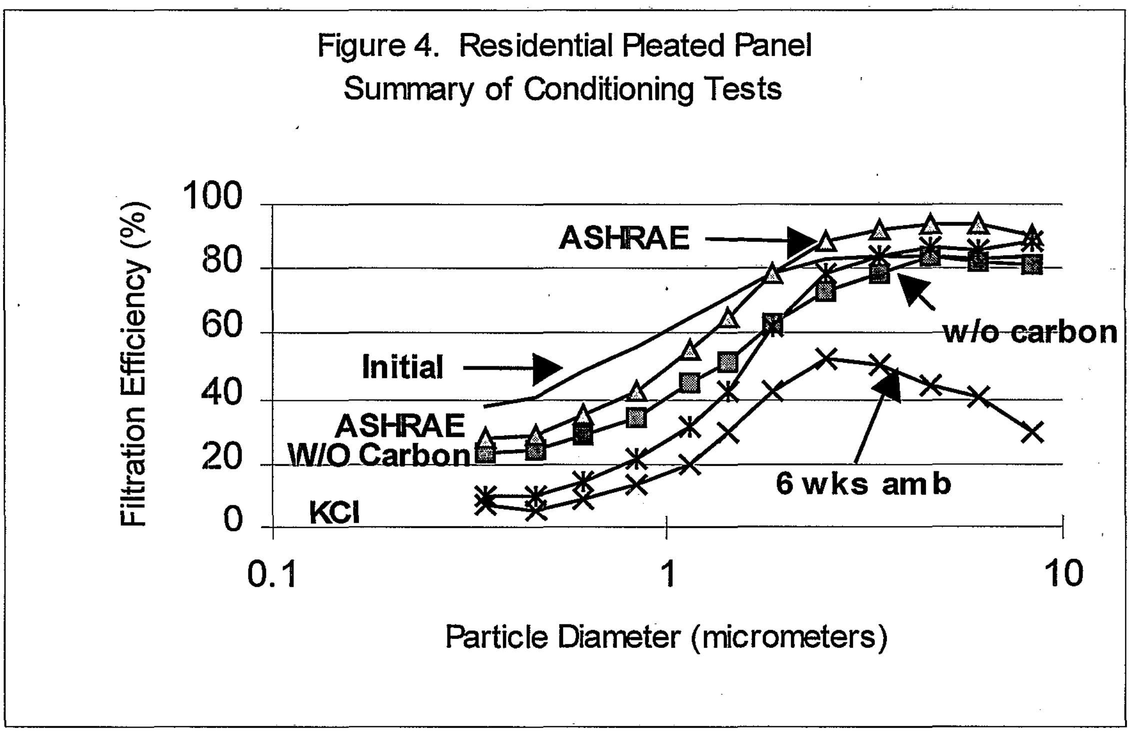
Figure 4. Residential Pleated Panel
Summary of Conditioning Tests
Filtration Efficiency (%)
100
80
60
40
20
0
ASHRAE
w/o carbon
Initial
ASHRAE
W/O Carbon
KCl
6 wks amb
0.1
1
10
Particle Diameter (micrometers)