Looking for the minimum efficiency of fibrous air filters during their service life

11th World Filtration Congress & Exhibition

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April 16 - 20, 2012 – Graz – Austria

Abstract Book

WFC 11
11th WORLD FILTRATION CONGRESS
APRIL 16 – 20, 2012 · GRAZ – AUSTRIA

WFC11

11th World Filtration Congress

Abstract Book

CONTENT VOLUME I

Conference Dates:
April 16 – 20, 2012

Venue:
Messe Congress Graz · Messeplatz 1 · 8010 Graz · Austria

hosted by
GÖCH – Austrian Chemical Society
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WFC11 Congress Organizing Secretariat:
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Abstract Book ISBN 978-3-941655-04-1
USB-Stick ISBN 978-3-941655-05-8

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LOOKING FOR THE MINIMUM EFFICIENCY OF FIBROUS AIR FILTERS DURING THEIR SERVICE LIFE

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ABSTRACT

Electret fibrous filter media achieve high efficiencies while maintaining low air flow resistance by incorporating electrostatic charges on their fibers. However, captured ultrafine particles reduce electrostatic effects. Existing test methods specify preconditioning to detect the minimum efficiency by eliminating electrostatic effects. ASHRAE 52.2 exposes media to nanoparticle KCl aerosols. ISO/TS21220 and EN779 immerse media in isopropyl alcohol (IPA). These approaches have some problems:

- Nanoparticle generation is fairly complicated and needs to be kept under control;
- The structure of some media may be changed by liquid immersion;
- Soaking full scale air filters requires large amounts of IPA.

A new procedure, exposure to IPA vapor, has been shown to be effective. We summarize these studies and ISO/TC142 activities related to them.

KEYWORDS

Air Filters, Air Filter Media, Conditioning Agents, Intake Filters, Nonwovens, Filter Media Testing

1. Introduction

It has been broadly demonstrated that the electrostatic forces added to polymer fibers by creating electrets in them will improve their particle capture abilities without increasing the pressure drop in filter media formed from these fibers. Some filter operating conditions, however, have been shown to reduce or remove the electrostatic properties of electret fibers, causing a temporary or continuing loss of media particle-capture efficiency. Filtration applications require knowledge of the minimum efficiency provided by a filter (worst-case performance), rather than average or best-case performance. If no minimum efficiency is required, the air filter could theoretically be eliminated with no harm for the specific application. For this reason, experimenters and standards-writing committees have sought media treatments which eliminate electrostatic effects from filter media, while leaving the aerodynamic and diffusional effects unchanged. The choice of an agent to do this in a repeatable, reliable manner for all forms of electrified fibers is not simple. Such treatment could be a forced degradation of some media and not others, and therefore should be applied to all media before performance tests. It should be applicable to full-scale filters as well as media samples.

2. Media Discharging / Neutralization Methods

2.1 Discharging Mechanisms

There is little agreement on what physical mechanisms are at work when the electrostatic effects associated with an electret fiber are suppressed, even for a specific treatment form. These five general mechanisms have been proposed:

- Neutralization by ions of opposite sign;
- Screening by a layer of partially or highly conductive particles or liquid film;
- Dissolution of fiber surface layer by a solvent;
- Chemical reactions with fiber surface layer;
- Ionic conduction by a liquid coating.

The explanation of mechanisms is further complicated by the fact that some treatments have improved, rather than degraded, particle-capture efficiency, and even reduced pressure drops. A particle loading, for example, can sequentially decrease efficiency, then increase it, then decrease it again, as various particle structures develop on the fiber surfaces.

It is possible that one or more of these mechanisms is at work in a given treatment. A large variety of treatments have been reported. Biermann (1982), for example, tried some of each of the above methods.

2.2 Discharge by Particulate Loading

Several studies making use of aerosols to eliminate electrostatic effects have been published. Included in these are: ambient natural aerosol; soot and other carbon forms; Diesel engine exhaust fumes; aerosols of stearic acid, "oil", Di-octyl Sebacate (DOS), Di-Octyl Phthalate (DOP), and KCl micro- and nano-particles. Of these, media preconditioning with Diesel engine exhaust fumes and KCl nano-particles have been included in test codes, presumably because they have been demonstrated to be effective on a range of electret media, and are reasonably practical to implement.

2.3 Discharge by Liquid Immersion

Studies of discharging by immersion of electret media in liquids, or "rinsing", have produced mixed results. Pure water seems to have little discharging capability, but water with ionic additives (NaCl and acids) and surfactants did decrease efficiency markedly. The organic solvents hexane, heptane, iso-octane, benzene, toluene, and a methylethyl ketone + acetone mixture have been tried. Immersion in liquid isopropyl alcohol (IPA) has been studied extensively, and adopted as a discharging method for the EN779 filter test standard. The results of these tests indicate that to be effective, the liquid must wet the fibers, and be ionic. It is unclear to what extent fiber rearrangement – clumping – might explain some of the reduction in efficiency from immersion and drying of the media samples. Some studies have examined the fiber surfaces after discharge by immersion, using scanning electron microscope images, and found no evidence of surface changes.

2.4 Discharge by Exposure to Vapors

The effects of high relative humidity, with condensation of pure water vapor on electret fibers, appear to be limited. Vapors of organic liquids are altogether different. Electret media exposed to methylethyl ketone + acetone, and ethylbenzene vapors had decreased efficiency, and isopropyl alcohol (IPA) vapor has been shown to eliminate electrical charges even more effectively than liquid IPA. Again, ionic properties seem to be essential.

2.5 Discharging with Surfactants

As mentioned in section 2.3, surfactants can energize water to discharge electrets. Oddly, however, a mixture of surfactants with opposite polarities can be used to convert an uncharged polymer into an electret. The choice of a preconditioning agent must be made carefully to avoid unforeseen behavior.

3. Development of Test Procedures to Obtain Discharged Air Filters

During the last two decades committees writing air filtration test standards have struggled with how to standardize methods to obtain the mechanical efficiency of air filters independent of any electrostatic effects present. Since the beginning of the 1990s it was clear that the air filter efficiency improvement due to electrostatic forces on the charged fibers would in many cases drop off. The extent and rate of efficiency loss depends on many factors (particle size distribution and concentration, chemical composition of the particles caught on the fibers, system air flow rate, level of prefiltration, etc.). Some of these factors play a role still not completely clear and known. The properties of the filter media itself influence this behavior: the finer the fibers, the less significant the efficiency drop.

Ageing carried out during laboratory tests by clogging the filter with synthetic dust does not reflect at all the behavior of electrostatically charged (or other) filters during their actual service life. In fact efficiency during laboratory tests hardly ever decreases. Hence, the need to develop a specific procedure providing the minimum efficiency that a charged filter could reach during its actual operation. If and how to use the minimum efficiency value for classification purposes is beyond the scope of this paper.

The first official attempt of standardizing a procedure to measure the so-called “electrostatic enhancement factor” was made in 1996 by Working Group (WG) 1 of CEN/TC195 “Air filters for general air cleaning”. The procedure developed by CEN/TC195 was published as Annex A of EN779:2002 “Particulate Air Filters for General Ventilation - Determination of the filtration performance”. Annex A is normative, i.e. it shall always be carried out even if the measured efficiency after discharging is not taken into account in the classification system of EN779:2002. The 2011 version of EN779 does use this piece of information to set some minimum efficiency levels to be met by F7, F8 and F9 filter classes.

This part of the standard requires the user to obtain the completely discharged efficiency of the filter under test, or of a piece of filtering media making up the same filter. The suggested approach is to immerse a piece of filter media in isopropyl alcohol (IPA) for some time, after having measured its initial efficiency. The efficiency measurement must be repeated after 24 hours and the difference between the efficiency curves (with special attention to the 0.4 micrometer size) is assumed to be due to the complete inhibition of the electrostatic charge.

The description in EN779:2002 Annex A is rather loose because no specific procedure is prescribed: diesel fumes and detergents or surfactants in water are suggested along with IPA immersion. Moreover, any method which can provide the minimum efficiency is allowed. However, the standard does not define how to demonstrate that minimum efficiency has been reached. Laboratory experts know that by varying the air flow it is possible to determine whether the efficiency of the filter is still enhanced by electrostatic forces. However, subjective evaluation is not a reliable means for providing measured data of fundamental relevance in choosing air filters and governing such an important market.

To narrow the choice of the discharging method a comparison of discharge methods was carried out in 2003-04 by nine European laboratories. Full-size glassfiber filters and polymer-electret filters were checked for clean resistance and efficiency on 0.4 µm diameter DEHS particles before distribution.

The nine sets of glassfiber filters had 89.6 Pa average resistance, std. dev. = 4.3 Pa, and 56.8% average efficiency with std. dev = 1.7%. For the electret filters, average resistance was 126.6 Pa with std.dev = 2.9 Pa, average efficiency 78.6% with std.dev = 3.2%. The results of these tests are listed in Tables 1-4. The tables list the particle capture efficiencies on 0.4 µm diameter DEHS particles with media sample face velocities of 0.13 m/s and full-size (610x610mm) filter flows of 3400m^3/h.

Table 1 - Tests on Polymer Electret Media Samples

Treatment	Surfactant		Isopropyl Alcohol Immersion	
Lab	Untreated	Treated	Untreated	Treated
1	-	-	79	40
2	84	41	82	48
2	80	56	-	-
3	46*	43	48*	37
4	-	-	78	41
6	-	-	74	38
9	80	38	81	42

Table 2 - Tests on Polymer Electret Bag Filters

Treatment	Diesel Fumes		Surfactant		Isopropyl Alcohol Immersion	
Lab	Untreated	Treated	Untreated	Treated	Untreated	Treated
1	74	40	-	-	-	-
2	81	41	-	-	-	-
4	-	-	-	-	77	54
5	-	-	-	-	87	58
7	-	-	81	89	71	68
8	-	-	-	-	71	68

Table 3 - Tests on Glassfiber Media Samples

Treatment	Surfactant		Isopropyl Alcohol Immersion	
Lab	Untreated	Treated	Untreated	Treated
1	-	-	58	49
2	58	63	58	57
2	59	66	-	-
3	48*	60	53	46
4	-	-	62	55
6	-	-	54	45
9	64	63	53	59

Table 4 - Tests on Glassfiber Bag Filters

Treatment	Diesel Fumes		Surfactant		Isopropyl Alcohol Immersion	
Lab	Untreated	Treated	Untreated	Treated	Untreated	Treated
1	59	49	-	-	-	-
2	64	58	-	-	-	-
4	-	-	-	-	57	52
5	-	-	-	-	69	67
7	58	53	60	55	-	-
8	-	-	-	-	58	55

These tests indicated that surfactants could not completely discharge some types of media.
The Diesel fumes approach could be successfully implemented, but it was not possible to standardize the Diesel engine completely. The discharging procedure dictated using exhaust fumes “fresh” enough to contain many very small and sticky particles before they could agglomerate. This was a somewhat imprecise definition.
On the basis of these results, WG3 of ISO/TC 142 “Cleaning Equipment for Air and Other Gases” later wrote ISO/TS 21220:2009 “Particulate air filters for general ventilation – Determination of filtration performance”, which permits only the IPA immersion method for discharging the filter medium.
At the same time in the USA the ASHRAE 52.2-1999 test method was being revised to include a preconditioning step of the air filter under test by exposing it to KCl nanoparticles. The procedure is described in Addendum b (2008) to ASHRAE Standard 52.2-2007 “Method of Testing General Ventilation Air-Cleaning Devices for Removal Efficiency by Particle Size”. This approach has the advantage of better mimicing what actually happens to a filter in a real installation. However, the method is fairly difficult to implement and expensive to carry out. In addition, the actual air filter efficiency may happen to be lower than the efficiency measured after treating the air filter using KCl nanoparticles, i.e. the method does not provide the mechanical efficiency of the filter media.
In this work we would like to emphasize the activity of ISO working groups because important new contributions are being made by the experts belonging to them. The most recent efforts in getting the discharged efficiency of a filter have been made by WG9 of ISO/TC142, which is devoted at developing standards for gas turbine air intake applications. WG9 faced two limitations of the IPA immersion approach:

1) the mechanical properties of some media could be affected and its efficiency lowered for reasons other than the inhibition of the electrostatic charge;
2) the discharge of a piece of filter media is less desirable than the discharge of a full filter; the correct media velocity is hard to reproduce, and there is no guarantee that the sample of media being discharged is truly representing the actual filter media used to manufacture the full filter.

In May 2010, during the committee review of ISO/CD 29461-1 “Air Intake Filter Systems for Rotary Machinery - Part 1: Test Methods and Classification for Static Filter Elements”, the Japanese delegation for the first time suggested using treatment by means of IPA vapors, i.e. without immersing the piece of media in liquid IPA. Some results presented by the Japanese commenters were shortly after confirmed by experiments in China, Italy and USA.
This new approach was welcomed by WG9 because it provided the chance to overcome the two problems stated above about IPA immersion. A report from Cai

(2010) describes the procedure and compares its discharging ability with the immersion procedure described in Annex A to EN779 2002, using samples of an electret medium, a polydisperse DOP aerosol, and total light-scattering photometry for efficiency evaluation. These results are given in Table 5.

Table 5 - Efficiencies With IPA Vapor Exposures, Electret Filter and DOP Polydisperse Aerosol

Initial IPA Vapor Exposure								Subsequent Liquid Immersion	
Time, h	0.0	0.5	1.1	2.2	4.3	16	24	25	40
Average E,%	87.6	19.8	19.0	19.6	18.2	18.8	18.8	42.5	40.7
Uncertainty,%	0.8	0.8	0.4	1.0	0.4	0.3	0.5	3.6	2.9
Initial Liquid IPA Exposure								Subsequent Vapor Exposure	
Time, h	0.0	0.8	1.2	2.2	4.3	16	24	25	40
Average E,%	88.9	54.3	53.6	52.6	52.2	50.2	50.3	18.2	20.0
Uncertainty,%	0.3	3.7	3.7	3.1	3.5	3.7	4.2	0.5	0.5

One effect which is very difficult to explain is that after IPA vapor exposure has reduced efficiency substantially, immersion in liquid IPA restores some of the electrostatic enhancement. The reverse effect is also observed; when immersion in liquid IPA has reduced efficiency (but less effectively than by vapor exposure), exposure to IPA vapor reduces efficiency to approximately the same level as is obtained by vapor exposure alone. (Table 5).

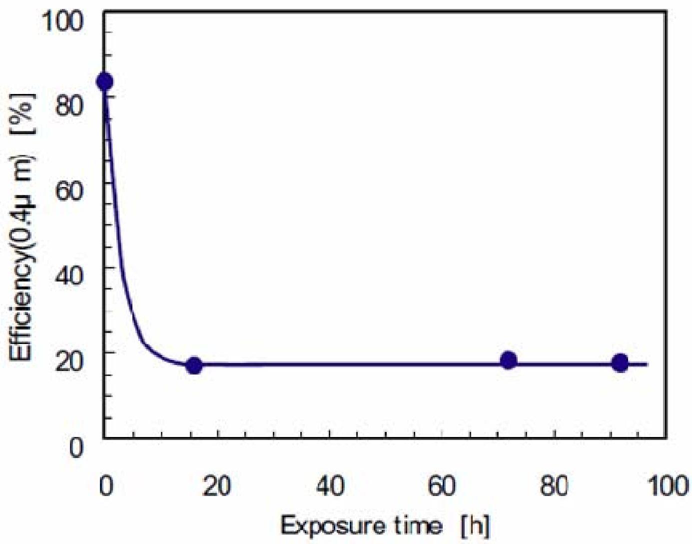

Figure 1 - Efficiency decay of electret fiber filter media from exposure to IPA vapor (Hayashi)

The Japanese report showed that exposure of electret media to IPA vapor caused a rapid reduction in efficiency for the first 5 hours, followed by a slower decline to a constant value at about 20 hours (Fig. 1). Thus one can expect complete discharge with a 1-day exposure, which is manageable as a test procedure.
The reports from Hayashi and Cai spurred WG9 of ISO/TC142 to organize tests

comparing IPA vapor treatment to liquid IPA immersion on samples of five media types.
Efficiency reductions (i.e. efficiency of the untreated media minus efficiency after treatment) on 0.4 µm diameter DEHS particles are listed in Table 6. Values in the table were read from bar charts in the report (Johansson, 2011). Each value represents an average of efficiency differences for four samples.

Table 6. Reduction in Efficiencies (%) from IPA Dipping and Vapor Exposure ISO/TC142/WG9 Interlaboratory Comparison

Medium	A Nom. Eff. = 50%		B Nom. Eff. = 46%		C Nom. Eff. = 77%		D Nom. Eff. = 62%		E Nom. Eff. = 86%	
Treatment	Dip	Vap	Dip	Vap	Dip	Vap	Dip	Vap	Dip	Vap
Lab 1	-	-	30	32	40	57	3	2	57	55
Lab 2	-3	-2	54*	36	32	51	9	3	44	47
Lab 3	-1	-2	49*	48*	60	65	14	-2	57	58
Lab 6	2	1	23	29	43	60	6	5	58	57
Lab 8	2	5	12	27	23	31	0	5	39	50
Lab 10	-13	0	28	31	43	42	3	0	50	52
Lab 11	2	1	27	34	38	58	3	0	58	59
Lab 12	0	1	31	37	43	51	5	3	52	53
Average	-1.4	0.1	32.0	34.4	40.6	51.8	5.5	2.3	52.1	53.9

Medium "A" was a pleatable glassfiber mat, "B" a pleatable polymer fiber mat, "C" a melt-blown polymer bag-filter medium, "D" a melt-blown glass bag-filter medium, and "E" a pleatable cellulosic mat.
Entries marked with (*) in Table 6 show reductions which are greater than the nominal efficiency of the samples. The explanation of this is shown in Table 7, which lists untreated media efficiencies read from charts similar to our Fig. 1. Measured initial efficiencies were sometimes substantially greater than nominal values.

Table 7. Initial Efficiencies of Media Samples Used in ISO/TC142/WG9 Interlaboratory Comparison

Medium	A Nom. Eff. = 50%		B Nom. Eff. = 46%		C Nom. Eff. = 77%		D Nom. Eff. = 62%		E Nom. Eff. = 86%	
Treatment	Dip	Vap	Dip	Vap	Dip	Vap	Dip	Vap	Dip	Vap
Lab 1	-	-	46	46	78	78	62	61	88	87
Lab 2	51	50	72	48	60	69	62	67	82	84
Lab 3	51	52	68	67	78	82	67	58	84	87
Lab 6	45	46	43	40	78	78	51	56	85	85
Lab 8	53	53	36	42	53	55	62	62	75	82
Lab 10	47	48	42	42	61	62	51	51	79	81
Lab 11	50	49	42	44	71	79	60	59	89	89
Lab 12:	55	55	42	43	75	73	58	60	86	86
Efficiency Variation Range	45 - 55	46 - 55	42 - 72	40 - 67	53 - 78	55 - 82	51 - 67	51 - 67	75 - 88	81 - 89

The ranges of untreated efficiencies on each sample set are at the bottom of the table. The actual measurement made is not efficiency, but penetration, (100%-E), which has even greater relative spreads in what should be equal values. Small samples of filter media are not uniform, and efficiency is not measured with the accuracy or repeatability we expect of temperatures, for example. Much of the error is probably due to the vagaries of the aerosol particle counters used.
The full scale filter approach looks possible but is still under study. One problem to be addressed is the stratification of IPA vapor that makes it difficult to perform an effective treatment on a filter placed in vertical position. Caution must be exercised also because the IPA vapors are an explosive mixture that, if ignited, could explode.

4. Conclusions

ISO/TC142 is a standards committee active in the filter testing area. It has recognized the need for a media test preconditioning method which can eliminate electrostatic effects in all filter media, while preserving media structure and leaving mechanical filtration and other media properties intact. The method should be practical for application to both flat media samples and full-scale filters. A method using a chamber which can expose a full-scale filter to vapors of isopropyl alcohol appears very promising, and is the subject of a current inter-laboratory study promoted by ISO TC 142, Working Group 9.

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