ASME AG-1 SECTION FK RADIAL FLOW HEPA FILTERS; REQUIREMENTS AND COSIDERATIONS

Andrew Stillo
Camfil USA, Inc

ABSTRACT

Radial Flow, High Efficiency Particulate Air (HEPA) Filters have seen very limited use, in large-scale ventilation systems in the US nuclear industry, due to a lack experience and codification required by users. They have seen implementation in other applications such as glove boxes and other specialty equipment used in a laboratory setting. The first large-scale ventilation application, this filter configuration has been utilized, was the Sellafield fuel reprocessing facility. This facility is located in the UK and run by the Nuclear Decommissioning Authority formally British Nuclear Fuels Ltd (BNFL). This facility uses in excess of 300 filter installations [1]. Subsequently, they have also been applied at the Advanced Mixed Waste Treatment Project (AMWTP) at Idaho National Laboratory (INL). Two of the primary benefits this filter configurations offers are ease of remote handling in hot-zones and ease of disposal.

In 2008, the Committee on Nuclear Air and Gas Treatment (CONAGT) published code section FK [2] "Special HEPA Filters". This code section originally included, axial flow odd sized rectangular filters, axial flow round filters, and duct connected axial flow filters along with radial flow filters. A subsequent revision to this code section removed the duct connected axial flow filters due to technical concerns. ASME AG-1 Code section FK [2] requires that filters, manufactured in accordance with this code section, must meet specific material, design and performance requirements. These requirements mirror those originally established in ASME Code Section FC [2] titled "HEPA Filters". Although this approach seemed reasonable at the time, it has become evident that some of the design requirements may have limitations not originally considered.

As a result of recent publications, related to the performance issues associated with this style filter, a review of the design requirements along with their effect on the performance of this filter type is warranted.

INTRODUCTION

The potential use of radial flow HEPA filters, in both passive and active ventilation systems, is a vital component in the protection of personnel and the environment. They perform a critical function in the containment of radioactive materials within the ventilation system or facility. These filters are manufactured and qualified in accordance with the American Society of Mechanical Engineers (ASME) AG-1 Code on

Nuclear Air and Gas Treatment section FK [2]. The basic configuration of this HEPA filter type is depicted in figure 1.

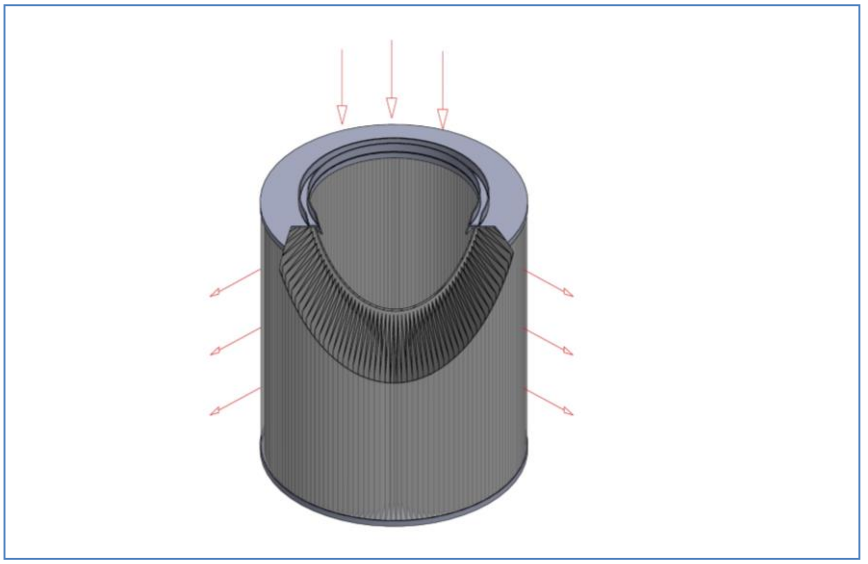

Figure 1. Configuration of a radial flow filter

During the early stages of writing ASME AG-1 Code section FK [2], it was decided to utilize much of the existing ASME AG-1 Code section FC [2] as a basis. This greatly simplified the creation of a significant portion of the content and structure of the code section; however, unanticipated issues with some of the design requirements warrant further consideration.

REVIEW OF AVAILABLE TESTING

It has become evident, based on more recent studies of both commercial and prototype radial-flow HEPA filter design [3][4][5], that there should be some concern related to some of the design requirements that may result in premature failure of the filter medium. One of these studies [4] provided a performance comparison of dimple pleat (embossed media) vs. ribbon separator pack styles used in existing radial flow filter designs. This study shows two different dimple pleat style filters. They are described as safe change and remote change designed for the Hanford Tank Waste Treatment and Immobilization Plant in Hanford, WA. The difference between these two styles is slight differences in the diameter and end cap design. The filters were loaded with three different particulates. In addition, they were also exposed to the following two sets of environmental conditions;

1. Inlet air controlled to 40-50% relative humidity (RH) / 21.2˚C (70˚F). Test until max pressure drop of 12442 Pa (50 in. w.c.) and/or failure is reached (ambient conditions).

2. Inlet air controlled to 40-50% RH / 21.2˚C (70˚F) until filter reaches 4 in. w.g., then add air at 74-77˚C and 95-100% RH for maximum duration. Test until max pressure drop and/or failure is reached (elevated environmental conditions).

The particulates utilized in this study [4] were carbon black, Arizona road dust and Alumina. The particle size distribution of these aerosols is shown in figure 2.

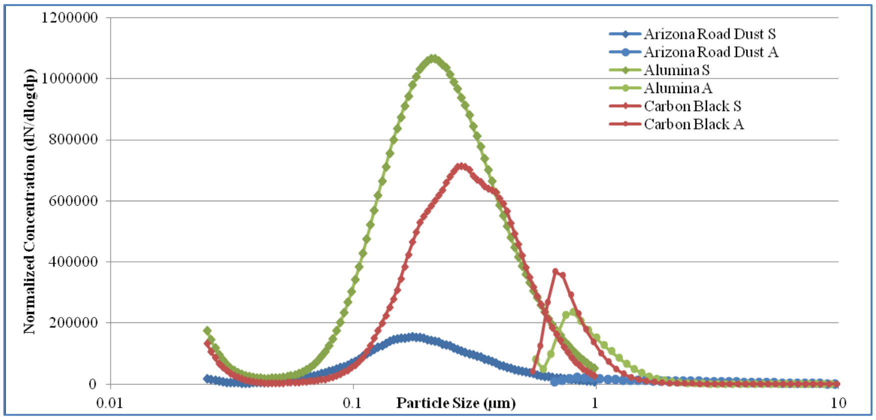

Figure 2. Particle size distributions for the three aerosols used to evaluate the performance of dimple pleat and ribbon separator radial flow filters [4]

The loading performance of the dimple pleat and ribbon separator filters, when loaded with Alumina under ambient conditions, is depicted in the loading comparison curves shown in Figure 3.

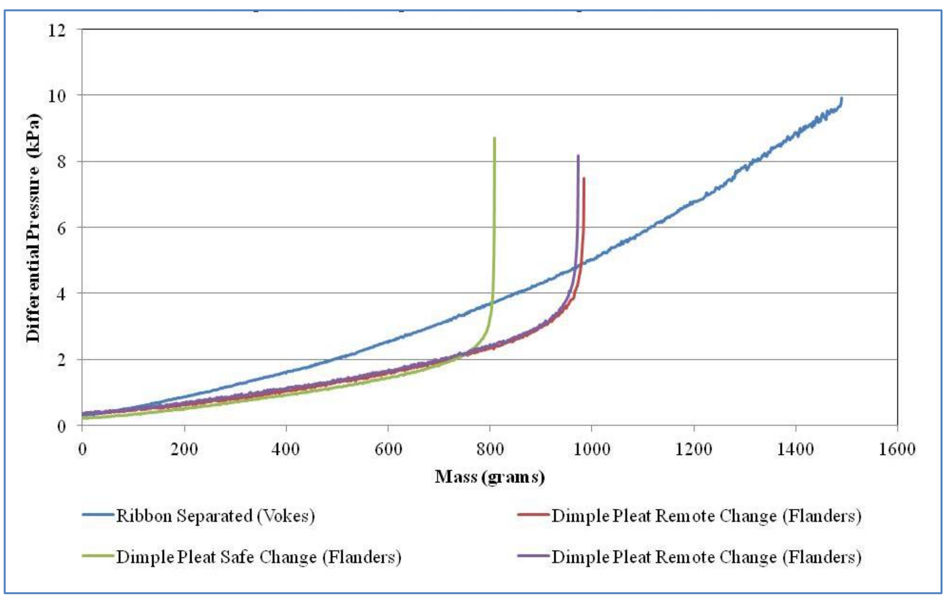

Figure 3. Plot of Alumina mass loading curves for ribbon separator and dimple pleat packs under ambient conditions [4]

A key conclusion, based on the resulting ambient condition loading curves, was that the rapid change in the slope of the dimple pleat loading curves indicates a change in filter pack geometry. It was observed, by visual inspection of the media pack at different stages of loading, that the space between adjacent pleats was reducing due to media deflection (ballooning) and dimple collapse as shown in figure 4. This type of behavior was not observed in the media ribbon separator filters. Additionally, it was noted that the rapid increase in pressure drop would only allow a 30-minute response time for facility operators to take action and reduce the airflow and prevent physical failure of the filter. The ribbon media separator filter demonstrated what is considered a normal expected loading curve.

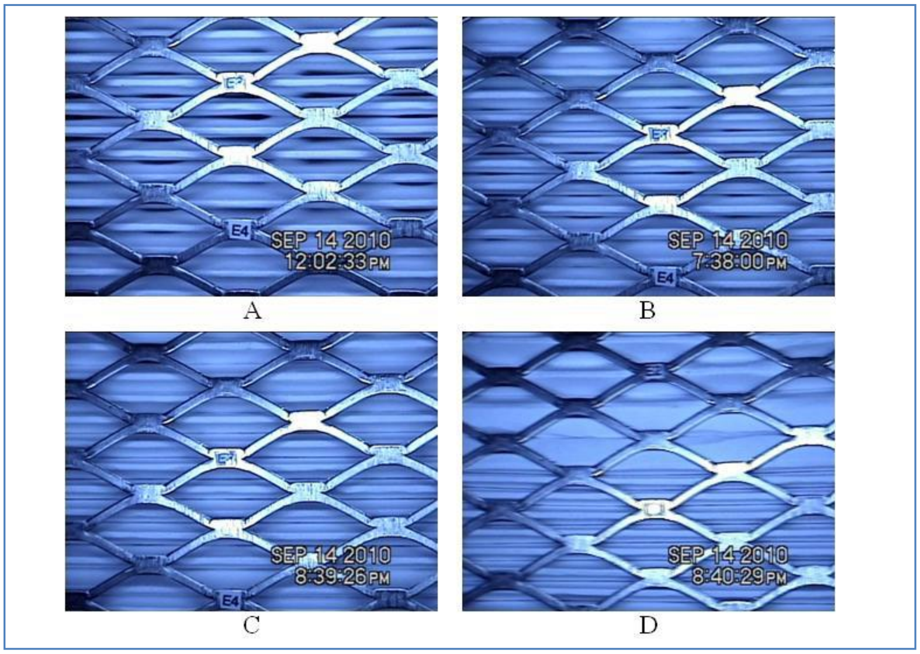

Figure 4. Photograph of dimple pleat pack at increased levels of loading (A-lowest to D highest)

The filters were then evaluated at elevated RH and temperature conditions after initial preloading of the filter to 1000 Pa (4 in w.c.). These conditions yielded differential pressure vs. time plots as shown in figure 5 for dimple pleat filters and figure 6 for ribbon separator filters.

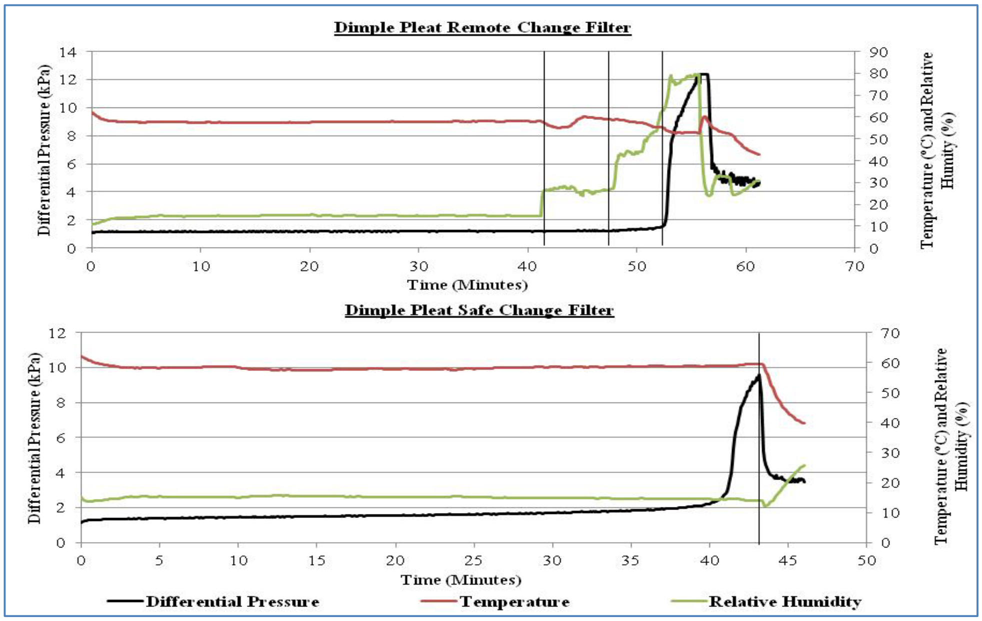

Figure 5. Plots of loading curves for dimple pleat filters tested under elevated conditions after loading to 1000 Pa (4 in. w.c.) [4]

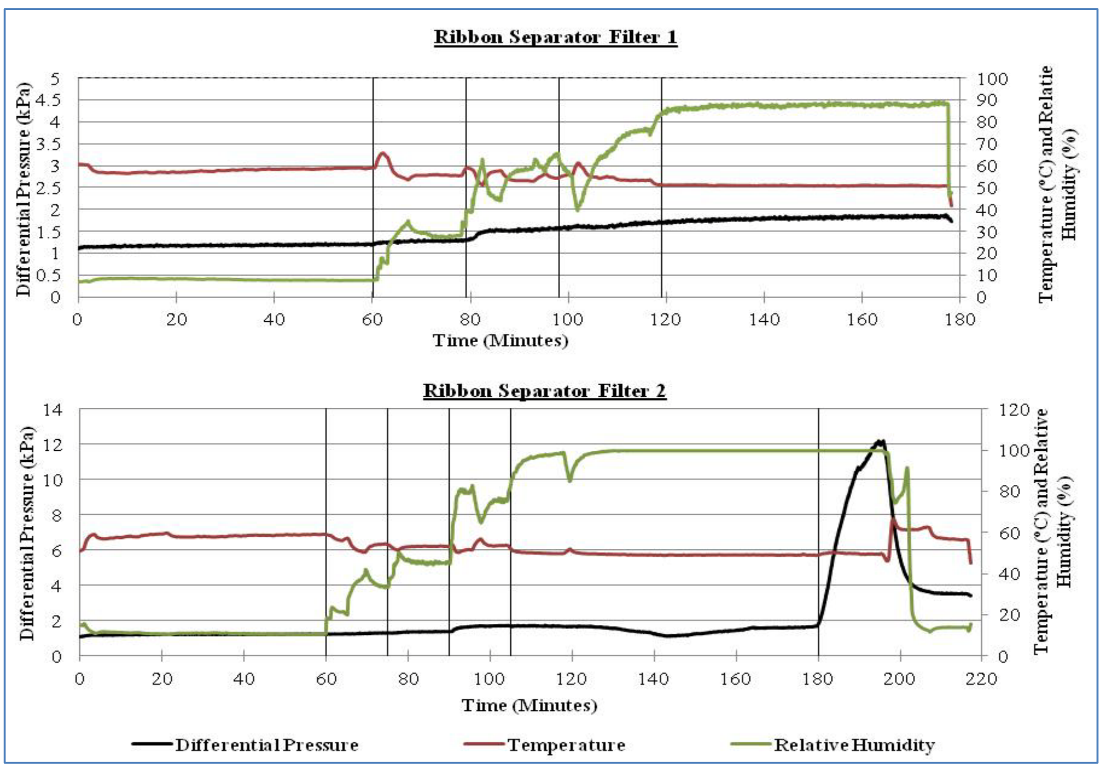

Figure 6. Plots of loading curves for ribbon separator filters tested under elevated conditions after loading to 1000 Pa (4 in. w.c.) [4]

Under these conditions, considered less severe than the resistance to pressure qualification test specified in the AG-1 Code [2], the dimple pleat separator filters tested experienced catastrophic pack rupture. In one case, this failure occurred prior to any increase in RH. The dimple pleat pack ruptures can be seen in Figure 5 when a rapid increase in filter pressure drop occurs followed by a rapid decrease in pressure drop. Photographs of these ruptures are depicted in figure 7. In comparison, the ribbon media separator filter both performed well after the increase in temperature and RH. One of the two ribbon media separator filters was then exposed to direct water spray after exposure to the elevated conditions for approximately 2 hrs. The rate of water spray utilized was 2.27 LPM (0.5 GPM). The filter pressure drop climbed rapidly, upon introduction of the water spray, until pack rupture within approximately 15 minutes. This is demonstrated in the bottom chart in figure 6 where rapid increases in pressure drop starting at 180 minutes is followed by a rapid decrease in pressure drop. Photographs of the resulting ruptures are depicted in figure 8.

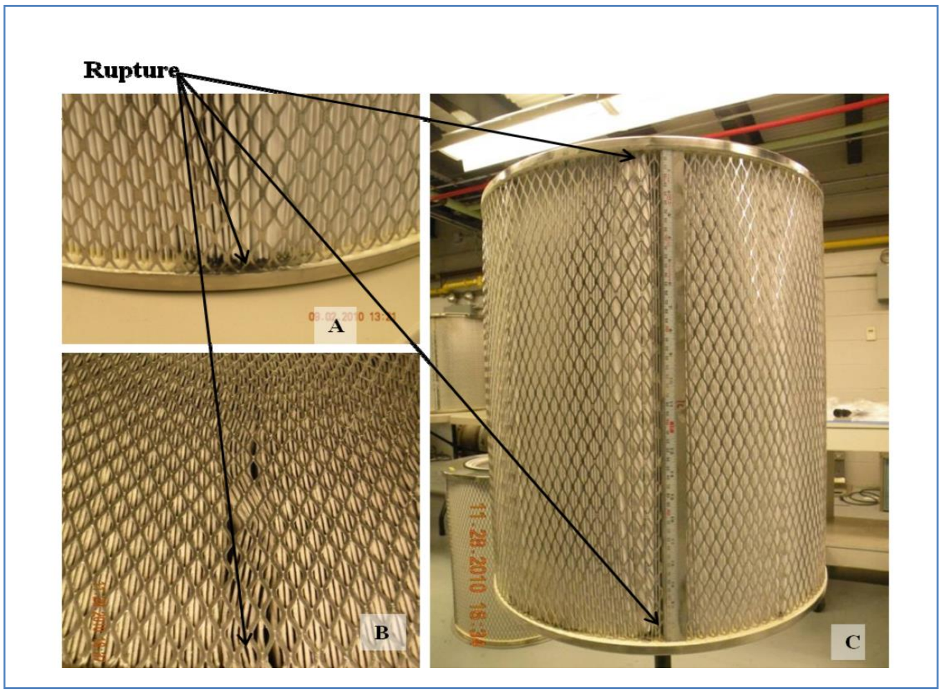

Fig. 7. Photographs of dimple pleat separator pack ruptures.

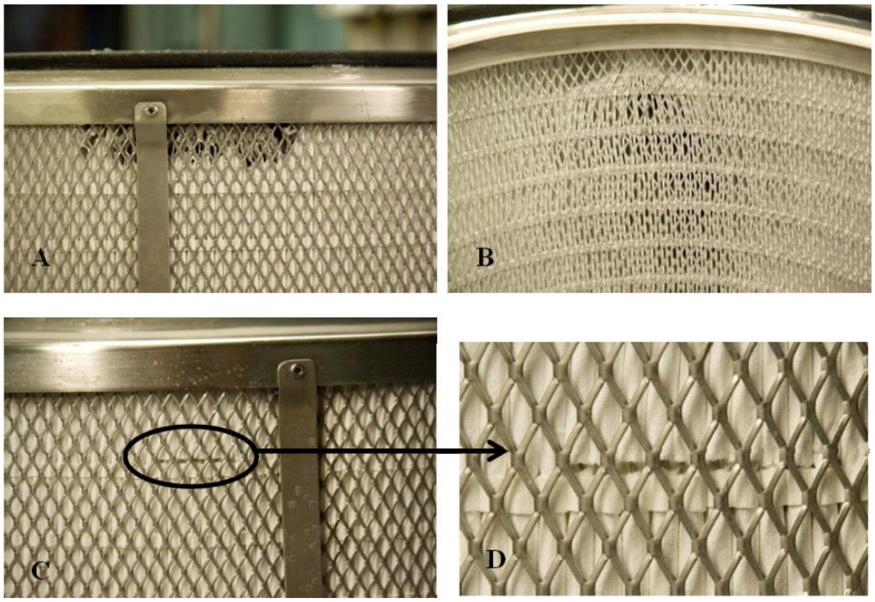

Fig. 8. Photographs of media ribbon separator pack ruptures.

Clearly, the radial flow filter pack type utilized, is a critical design requirement that has a direct impact on the lifecycle performance of a radial flow filter. It has been shown that one of the pack types tested [3][4][5] are likely to experience premature catastrophic failure when exposed to slightly elevated environmental conditions. The other pack type experienced rapid failure after direct water spray exposure similar to the resistance to pressure test specified in ASME AG-1 section FK-5140.

REVIEW OF ALLOWABLE PACK TYPES

Nuclear grade radial flow HEPA filters, designed and qualified in accordance the section FK of the AG-1 Code [2] are constructed using one of 4 specific pack types. The pack types are defined as;

(a) Type A filter packs: Made by folding the media to the required depth. The folded filter media is separated and supported with corrugated separators. (See figure 9 below for a photograph of a Type A filter pack).

(b) Type B filter packs: Made from a series of flat panels of pleated filter media, which are assembled in a V form. Pleats are separated and supported by ribbons of glass fiber media or noncombustible threads bonded to the filter media. (See figure 9 below for a photograph of a Type B filter pack).

(c) Type C filters packs: Made by corrugating or embossing a continuous sheet of filter media and folding the media to the required depth to make the filter pack. (See figure 9 below for photographs of a Type C filter packs).

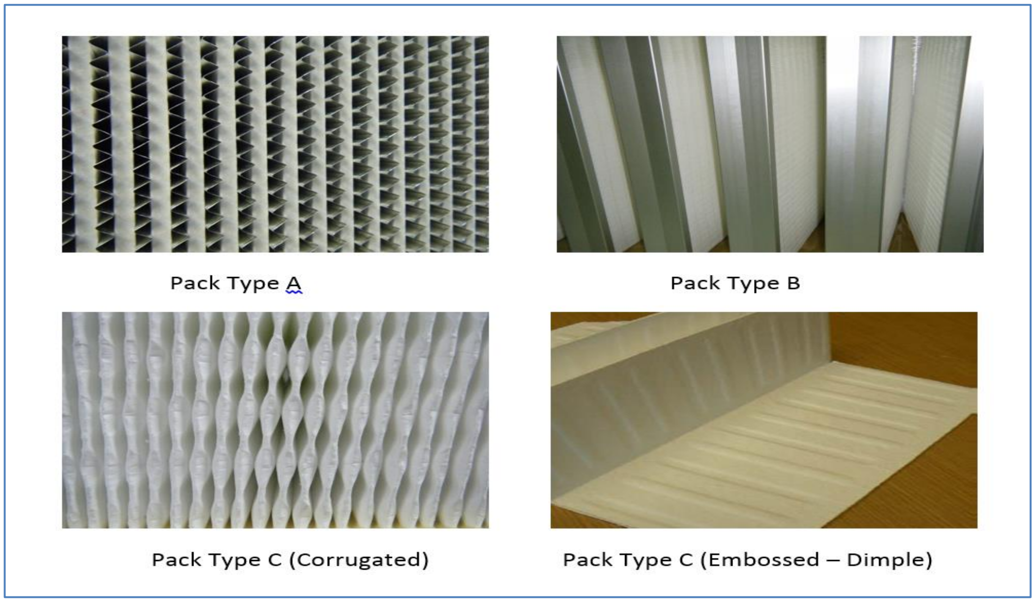

Fig. 9. Photographs of pack types A, B and C as defined in ASME AG-1 section FK [2].

(d) Type D filter packs: Made by folding the media to the required depth. The folded filter media shall be separated and supported by ribbons of glass fiber media or noncombustible threads, glued to the filter media. (See figure 10 below for photographs of a Type D filter packs).

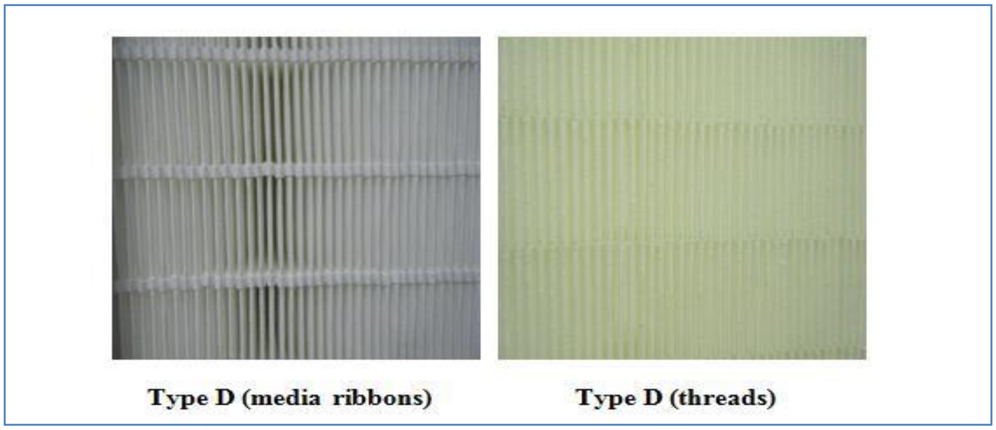

Fig. 10. Photographs of pack type D as defined in ASME AG-1 section FC.

PLEAT PACK CONSTRUCTION CONSIDERATIONS

For purposes of this continued discussion, pack types A & B will be ignored as they are unlikely to be applied to a radial flow filter design. With that in mind, each remaining pack construction has perceived benefits and weaknesses when applied to a radial flow filter design. Let's review these benefits and weaknesses and if applicable, consider how they may affect the robustness of the filter pack.

(a) <u>Pack type C</u> (corrugated or embossed media):

i. <u>Benefits:</u> The use of the media itself, to provide the separation between pleats, eliminates additional components in the manufacture of the filter. This can lower the initial cost of the filter. Additionally, the elimination of a material used as a separator reduces other potential issues associated with acidic environments.

ii. <u>Weaknesses:</u> When using this pack type, the robustness of the pack is highly dependent on applying some pack compression, since there is no bonding pleat to pleat. When assembling this pack type, in a radial flow configuration, the amount of pack compression achievable is very limited resulting in a relatively unstable pack. Consequently, the pack will not respond as a single structure. Individual pleats can act independently to increased pressure drop or other flow dynamics. Additionally, when this construction is subjected to adverse environmental conditions, including elevated temperature, RH and/or direct water exposure, the media is likely to soften/weaken over time causing the corrugation or embossing (dimples) to compress or collapse. When this occurs, a rapid increase in pressure drop is likely to occur. Another potential issue is the dimple spacing. The radial flow filter prototype designs tested [4] had a dimple spacing estimated at approximately 35-40mm (1-3/8 to 1-9/16 in). This wide spacing can contribute to the rapid pressure drop increase, due to deflection of the media between the "support" dimples, as the filter is loaded or exposed to elevated environmental conditions.

(b) <u>Pack type D</u> (with thread separator):

i. <u>Benefits:</u> This construction results in a highly stable pack since it relies on the thread being bonded to the media and itself, and not compression. As a result, the pack responds as a single structure so individual pleats can't respond to changing conditions independently.

ii. <u>Weaknesses:</u> One potential weakness is the ability to pass the spot flame qualification test. This type of construction has passed the spot flame requirement, when utilized in a Type B pack construction. Additionally, the ability of the thread material and adhesive to withstand acidic environments needs to be validated.

(c) <u>Pack type D</u> (with ribbons of glass fiber media separator):

i. <u>Benefits:</u> The use of the media itself, in the form of a ribbon to provide the separation between pleats, eliminates an additional material, used as a separator, and reduces other potential issues when exposed to acidic environments.

ii. <u>Weaknesses:</u> Like the dimple corrugated or embossed (dimple) pleat configuration, the robustness of the pack is dependent on applying some pack compression, since there is no bonding pleat to pleat. When assembling this pack type, in a radial flow configuration, the amount of pack compression achievable is very limited resulting in a relatively unstable pack. Additionally, when this construction is subjected to adverse environmental conditions, specifically direct water exposure, the media will soften/weaken quickly reducing any existing pack compression. This results in the likelihood of pleat flutter and displacement that further weakens and can result in distortion and/or tearing of the medium. The ability, of the adhesive utilized to bond the media ribbon to the media surface, to withstand acidic environments may need to be validated.

OTHER CONSTRUCTION CONSIDERATIONS:

The pack type utilized in the construction of a radial flow filter is a key factor concerning the robustness of the filter design. Other factors, contributing to the robustness of the filter, are the pack depth and general lack of filter pack support due to grille spacing.

a) Pack Depth: Packs utilized in radial flow filters use reduced pack depths compared to traditional deep pleat filters. A stress model shows that a reduction is pack depth yields a proportional increase in the maximum stress in the filter medium [6]. This coupled with no pack compression and a lack of pleat to pleat bonding is likely to intensify the stress within the medium.
b) Grille Spacing: One current design also includes a space between the pleated media pack and grille. This serves to protect media from direct contact with the grille to avoid potential abrasion damage. As a result, the grille provides no structural support to the filter pack allowing greater media deflection and increased stress.

CONCLUSIONS:

It is clear, based on the results of recent testing and the discussions above, current radial flow filter designs may lack the robustness required for many applications. This is likely the result of a combination of factors including but not limited to a lack of pack compression, no pleat to pleat bonding, distance between pleat spacers, reduced pack height and no downstream pack support. Data on a representative radial flow filter, using thread separator technology, is lacking. The use of a thread separator pack should eliminate issues associated with loosening packs when loaded or exposure to elevated environmental conditions. The use of minimal space, between the downstream side of the pack and the grille, should also be considered for pack support. Work is ongoing to develop an optimized radial flow filter configuration using thread separator technology. Once complete, it is expected that identical testing will be performed allowing a direct comparison of all three pack types.

REFERENCES:

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2. ASME AG-1-2015 “Code on Nuclear Air and Gas Treatment”, pp 457-485.
3. P. Griffin, M. Parsons and C. Waggoner, “Results from Evaluation of Representative ASME AG-1 Section FK Radial Flow Dimple Pleated HEPA Filters Under Elevated Conditions”, Proceedings of the 2012 Waste Management Symposia Session 10 titled “Filtration Issues for Waste Treatment”.
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6. C.I. Ricketts and P.R. Smith, “A Model for the Stresses in the Filter Medium of Deep-Pleat, HEPA-Filter Packs and its Practical Applications”. Proceedings of the 28th Nuclear Air Cleaning Conference.