

A PRACTICAL GUIDE TO FILTER MEDIA FAILURE ANALYSIS

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ABSTRACT

Filter bag replacement can be one of the largest operating expenses for a baghouse system. Selecting a filter media on price alone can be costly. A low priced media with short bag life could actually be more expensive over the lifetime of a system.

Analysis of filter bag failures often reveals system problems that are easy to correct. Using knowledge of filtration material properties, alternatives can be specified that are more compatible with operating conditions. Combining laboratory findings with field operating data, it is possible to find a solution that outperforms the current baghouse configuration. While bag life and filter media cost determine bag replacement expense, improved filter media performance (lower emissions, higher airflow, etc.) can also have a large impact on the total system operating cost.

This paper examines the problems and solutions found during laboratory filter bag analysis. The solution may be changing to a high performance filter media. In other cases, system conditions create problems that greatly limit the performance of the media. Lost production from an unscheduled shutdown can greatly exceed the cost of filter media and labor to replace it. Attention to operation and periodic checks of the filter media provide opportunities for significant cost savings.

INTRODUCTION

Forensic analysis of used filter bags can bring to light many aspects of a filter's performance. These residual characteristics are in response to the system design and operating conditions. Determination of these characteristics is of paramount importance and can be aided by understanding and asking the following questions:

- 1) Why perform filter analysis?
- 2) What are the modes of failure?
- 3) What tests can be done to evaluate the condition of the filter?
- 4) What tests can be done to evaluate the characteristics of the dust?

Why perform filter analysis?

Filter analysis is performed for many reasons, including failure analysis, trouble shooting system operations, or for a routine checkup to determine the remaining life of the filter. Comparisons with competitive materials and guarantee issues are additional reasons for filter analysis.

What are the modes of failure?

Typically, there are five modes of failure to consider when analyzing filter media. These modes are mechanical strength/wear, chemical degradation, thermal degradation, dust penetration/media blinding, and incorrect design. They address performance of the filter against material, product, and application design specifications.

What tests can be done to and assess the condition of the filter?

To fully address the five failure modes, an evaluation of the filter condition and properties should be performed. These evaluations take place by sampling the used filter and performing an array of specific tests. Sampling of an unused filter is also recommended to establish a benchmark for comparison.

Inspection of the failure at the site of operation is preferred, but when inconvenient, a laboratory analysis must suffice. Visual analysis during this inspection often reveals the most useful information.

The pieces of the puzzle that must be assembled include permeability, material strength, visual/microscopic analysis, particulate capture efficiency, system performance data, temperature of the gas stream, and the properties of the dust being collected.

Permeability Testing:

Permeability, as defined by the Frazier Number, is the volumetric flow rate, measured in cubic feet per minute (cfm), through a square foot of filter media at a pressure differential

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of 0.5" water gauge (w.g.). The unit of measure is written as $\text{cfm}/\text{ft}^2 @ 0.5" \text{ w.g.}$.

This measurement is performed on the filter in the "as-received" condition and after various cleaning steps. The first measurement is taken with minimal disturbance of the remaining dust cake.

Additional measurements are taken of the filtration surface after the sample is lightly snapped and also after being lightly brushed to simulate a cleaning cycle. A large increase in permeability after these steps indicates that the filter is releasing dust effectively. The front surface is then vacuumed to further remove particulate and determine the extent of the filter's permeability recovery. The backside (clean side) of the filter is vacuumed as the final step. An increase in the permeability indicates dust contamination. As a point of reference, a material with a permeability below $1 \text{ cfm}/\text{ft}^2$ at 0.5" w.g. is considered blinded.

Mullen Burst Strength Test:

The Mullen Burst Strength Test is a measure of the two-dimensional, or planar, strength of the media, measured in pounds per square inch. The sample is securely clamped over a rubber diaphragm. The diaphragm is steadily pressurized with fluid until it expands to the point where it breaks through the media. The corresponding pressure of the fluid within the diaphragm at the point when the media ruptures is recorded as the strength. The effects on the filter from mechanical, chemical, or thermal stress are determined.

Tensile Strength Test:

The Tensile Strength Test is a measure of the directional strength of the media, measured in pounds per square inch. The sample is secured in the testing machine and is pulled apart to the point of failure. A resultant load/displacement curve is developed which is then compared to new material for residual property characteristic.

Microscopy:

Visual analysis of a filter sample is often aided by the use of a light microscope. Determining the particulate interaction with the filter surface, in addition to observing the failure site is often critical in solving filter performance issues. Scanning electron microscopy (SEM) is also very helpful when investigating particulate and filter fiber surface morphology. Evidence of abrasion, chemical, and thermal effects is often enhanced during this analysis.

Efficiency:

Particulate capture efficiency is an additional test that results in a filter performance characteristic. A fractional efficiency characteristic curve is generated which describes the ability of a filter to capture particles of differing sizes as a function of gas stream and filter morphology.

The filter media is mounted in a special chamber and subjected to a challenge aerosol. Air streams are sampled to determine concentration upstream and downstream of the

test chamber. The efficiency is determined by the difference between these concentrations.

Additional Tests:

There are additional analytical tests that may be helpful in determining the residual characteristic of filter media. These include chemical analysis, thermal gravimetric analysis (TGA), differential scanning calorimetry (DSC), and energy dispersive spectroscopy (EDS).

Thermal Gravimetric Analysis (TGA), is an analytical technique that involves heating a sample and measuring the weight change as the sample begins to decompose and volatilize. By using a thermobalance, TGA provides a continuous record of weight change for a sample exposed to a controlled temperature environment. Test samples may be heated or cooled at a pre-selected rate or isothermally maintained at a fixed temperature.

Whenever a material undergoes a crystalline phase transition such as melting, crystallization, sublimation, or when a material reacts chemically, energy in the form of heat is either absorbed or given off. Differential Scanning Calorimetry (DSC) is used to determine the enthalpy of these processes, as well as the heat capacity and thermal emissivity of solid samples. This analytical technique measures the differential heat flow required to maintain a sample and an inert reference at the same temperature. As a sample is heated and begins to melt, it absorbs heat more quickly than the reference and a differential heat flow is created between the two chambers.

Energy Dispersive Spectrometry (EDS) provides a one to ten-micron depth surface analysis of the elemental composition of a sample in a SEM chamber. X-rays are used to detect characteristics of individual elements, which are generated when electrons bombard the sample. A silicon detector, located in the SEM specimen chamber, collects the x-ray signals. This analytical test method is used to identify particulate contaminants, corrosive products, or unknown substances. EDS can evaluate composition as a function of position on the surface of the sample. This information is mapped on a photograph of the area being analyzed. Chemical bonding information is not available from EDS and the analysis is not sensitive to elements lower in atomic number than 9 (Fluorine).

What tests can be done to evaluate the characteristics of the dust?

It is usually necessary to obtain the characteristics of the dust that is being filtered. A measurement of the bulk density, particle size distribution, and morphology along with elemental composition is needed to fully understand potential effects.

Bulk Density:

Bulk density is a weight per unit volume measurement, which is expressed in grams per cubic centimeter or in pounds per cubic foot. The object of the analysis is to determine the bulk or apparent density of a dust. This data can then be used for the diagnosis of reentrainment or aid in fabric filter design.

Particle Size:

This test is used to determine the range of particle sizes present in a dust sample. The results are presented in terms of particle size versus cumulative percentage of total weight or volume. When plotted on a logprobability graph, the mass-mean diameter can be determined. This is a characteristic parameter of the dust that can be used to predict filter performance in applications where similar dusts are being used.

TEST SUMMARY

In summary, the answers to these questions lead to discoveries that explain many of the reasons a filter fails to meet expectations. Inferior performance includes a high pressure drop, an increase in resistance to flow, poor mechanical characteristics, and unacceptable particulate emissions. All of these lead to an under-performing filter and result in shorter than desired life.

In order for this type of analysis and resultant discovery to be fully utilized, a careful evaluation of the filter and filtration system needs to be performed. Once the system has been characterized, a system optimization analysis can begin.

SYSTEM CONTRIBUTIONS

Space requirements, baghouse selection, and filter media cleaning methods require serious consideration for optimal performance in new systems. Operational contributions to the performance of a filter media include batch or continuous processing, air-to-cloth ratio, gas stream temperature, humidity, and composition of dust. Balancing production requirements with emission regulation and planned outages also have a profound impact on the performance of the system.

The following case study provides an example where this analytical method was used to solve a filter media problem.

CASE STUDY

This example is a 52 MW co-generation facility operating a boiler baghouse. This boiler uses wood waste and plant sludge as fuel.

Baghouse Design and Critical Parameters:

Manufacturer:	Standard Havens
No. of modules:	9
No. of bags/module:	210
Total no. of bags:	3,990
Bag size (nominal):	6.25" dia. x 174" long
Bag material:	14 oz/yd ² duo-density NOMEX® felt
Total cloth area:	90,668 ft ²
Design airflow:	320,000 acfm (normal) 360,000 acfm (max.)
Temperature:	334°F (normal) 375°F (max.)

Air-to-cloth ratio:	3.66/1 (gross) 4.09/1 (net)
Cages:	12-wire 304 stainless steel 8" horizontal ring spacing 3" integral venturi
Pulse pressure:	68 psig (at the header)
Cleaning:	Continuous off-line pulsing a single row
Expected ΔP:	7"-9" H ₂ O
Maximum emissions:	0.008 gr /dscf, PM10
Maximum opacity:	20%

Boiler Information/Operation:

The boiler is a duel reciprocating grate type. The first grate is stationary being fixed at a 47° angle. This grate is used as a fuel preheater/dryer to allow for lower combustion temperatures at the second reciprocating grate. Lower burning temperature, coupled with a 20% aqueous injection via a steam carrier, is used to reduce NO_x emissions. The unit burns wood waste and plant sludge. Fuel moisture rates can be as high as 60%. Fuel and gas stream SO₂ levels are low at < 1.1% (by weight) and < 50 ppm, respectively. Fuel and gas stream Cl levels are low at < 1.3% (by weight) and < 1,100 ppm, respectively.

Operating History:

Performance results were mixed. After system startup, tests confirmed that permitted emission and opacity levels were being met. However, shortly after startup, the temperature levels increased beyond the maximum recommended temperature of aramid fibers (425°F) and the bags started to fail. It was believed the high temperature caused the failures. The bags became brittle and were easily torn by hand. New aramid filter bags were installed and, after about one year of service, performance tests indicated emissions and opacity levels were acceptable, but close to maximum permitted levels. The pressure drop was at the upper end of acceptable levels, running at approximately 10-11" H₂O. The analysis began when the filter bags started to fail after approximately one year of service. The initial design operating conditions suggested that the current filter media was close to its performance limits with regard to the combination of temperature and moisture.

Filter Bag Analysis:

A representative filter bag was removed from service for examination. The bag was covered with a light layer of dust. The appearance of the felt was considerably darker than an unused aramid fiber felt filter bag. The inside of the bag contained approximately 400 ml of particulate comprised of iron oxide flakes, media used for sand blasting, and residual dust from the process. The bag could easily be torn by hand in both the machine and cross-machine directions.



Figure 1: Cross-section of filter at 25x magnification

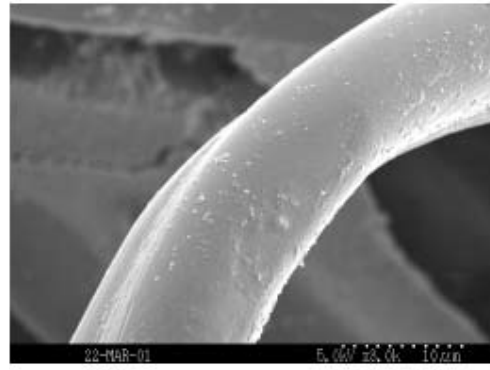


Figure 4: Surface morphology of new fiber At 3,000x magnification

Microscopic analysis of the cross-section of the filter bag at 25x, is presented as Figure 1. Localized regions of dust penetration were revealed on the backside of the filter media.

The individual fiber surface morphology was viewed using scanning electron microscopy at 3,000x and 7,500x magnification. Severe surface degradation is shown in Figures 2 and 3 as rough, scale-like demarcations. Representative photomicrographs of unaffected aramid fibers are presented as a benchmark in Figures 4 and 5, revealing a smooth fiber surface. This type of degradation is consistent with damage caused by hydrolysis.

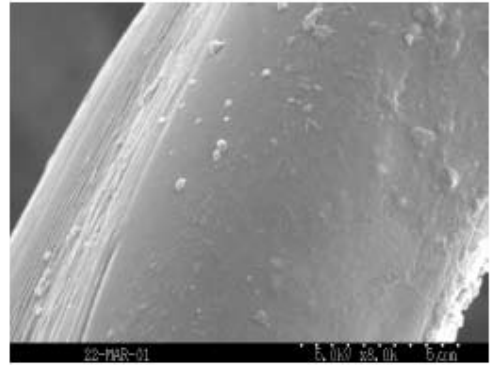


Figure 5: Surface morphology of new fiber at 7,500x magnification



Figure 2: Surface morphology of used fiber at 3,000x magnification

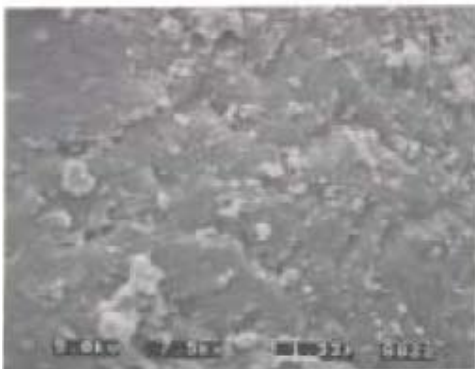


Figure 3: Surface morphology of used fiber at 7,500x magnification

Referencing the graph presented as Figure 6, it was predicted that the aramid felt bags in this application would have a service life of approximately one year. The baghouse operating temperature and percent moisture levels were 325°F and 25%, respectively. This was consistent with the service life encountered in this application.

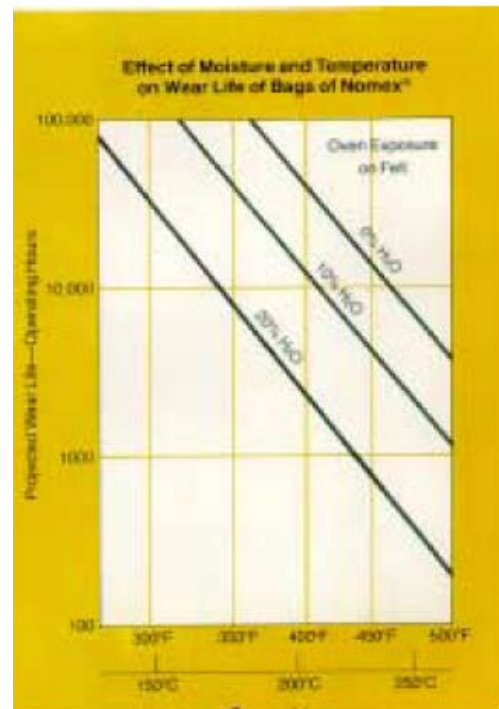


Figure 6: Effect of moisture and temperature on wear life of NOMEX® aramid felt

The SO₂ levels were relatively low (less than 50 ppm on a monthly average). A pH of 3 was measured for the dust. Based on the gas stream and dust analysis, there was a potential for acid attack of the aramid fibers. The effect of temperature and SO₂ concentration on the strength of aramid felt filter bags is shown as Figure 7.

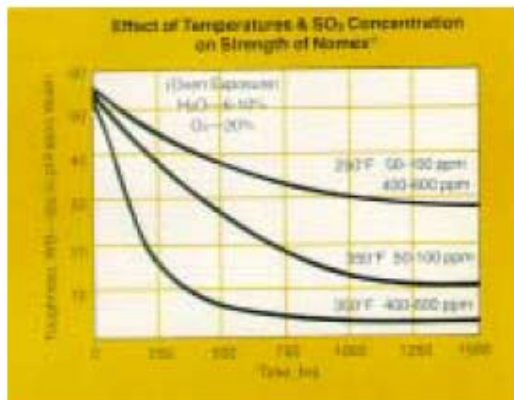


Figure 7: Effect of temperature and SO₂ concentration on strength of NOMEX®

Permeability and Mullen Burst data, presented as Table 1, was gathered on the used filter bag at the top, middle, and bottom regions.

Permeability Data (cfm/ft ² @ 0.5" H ₂ O)			
	Top	Middle	Bottom
As Received	1.9	3.2	6.4
Lightly Snapped	2.1	5.0	7.8
Lightly Brushed	N/A	N/A	N/A
Vacuum Front Surface	3.0	6.7	10.5
Vacuum Back Surface	4.4	7.7	11.4
New Rating	30	30	30
Mullen Burst Strength (psi)			
	Top	Middle	Bottom
As Received	200	155	155
New Rating	425	425	425

Table 1

CONCLUSION

In conclusion, the aramid filter was found to have reached the end of its useful life due to the application temperature, moisture, and operating conditions present.

The fuel used contributed as much as 60% moisture to the gas stream. The filter was determined to have failed due to hydrolysis, possibly accelerated by low levels of SO₂.

Aramid Fiber and Hydrolysis:

Aramid fibers possess very good chemical resistance compared to other fibers, especially in the 150-180°C (300-350°F) range. Aramid felt filters are also among the most abrasion resistant. In dust collection applications, the ability of the filter to resist abrasion damage from the support cage, the gas stream, and particulate is important. Table 2 shows the chemical and abrasion resistance of a number of fibers typically used in filtration.

Fabric	Max. Cont. Temp	Acid Resistance	Alkali Resistance	Flex Abrasion Resistance
Cotton	180°F	Poor	Good	Very Good
	200°F	Excellent	Excellent	Very Good
Polyester	275°F	Good	Good	Very Good
RYTON®	375°F	Good	Very Good	Very Good
NOMEX® (aramid)	400°F	Poor to fair	Excellent	Excellent
TEFLON®	450°F	Excellent	Excellent	Fair
Glass felt	500°F	Good	Fair	Fair
Woven fiberglass	500°F	Fair to good	Fair to good	Fair
P-84	500°F	Fair	Fair	Good
SUPERFLEX® fabric	500°F	Very Good	Fair to good	Excellent

Table 2: Fabric Selection Chart

The weak link for the aramid fiber is a susceptibility to hydrolysis and acid attack in applications with moisture at temperatures above 150°C (300°F). Hydrolysis is defined as “a chemical reaction in which water reacts with another substance to form two or more new substances.” If there are acids present in the gas stream, the chemical reaction will be catalyzed and damage to the aramid fiber will occur faster. For aramid, the reaction is shown as:

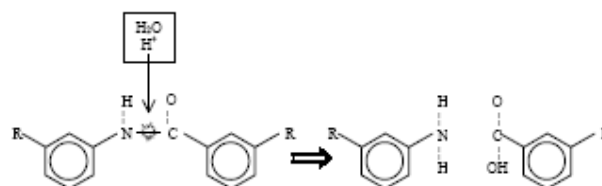


Figure 8: Chemical equation for hydrolysis reaction of aramid

When hydrolysis occurs, the molecular chains of the aramid fiber are broken, thus decreasing the mechanical strength of the felt. A filter that has been hydrolyzed will appear darker in color and be less flexible than a new, unused filter.

SOLUTION

The solution presented and accepted was the use of SUPERFLEX® fabric filter bags. SUPERFLEX® filter bags have GORE-TEX® membrane as the filtration surface and use a patented combination of fluoropolymer and fiberglass fibers to improve flex fatigue resistance. To date, the filters have lasted 3- 1/2 years without a single failure. The system pressure drop has been reduced from 10-1/2" H₂O to 7-1/2" H₂O. The maximum allowable emissions of 0.008 gr/dscf have been met. Savings on maintenance, plant air, and fan energy are being realized.

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