Deciding Which Pulse Jet Filter Media Choice is Best for Your Utility Coal Fired Boiler Application

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Disclaimer

The reader should be aware that any design recommendations, quantitative parameters defined, operating modes and/or maintenance rules suggested, are only meant to provide general guidelines or approaches to design. There are virtually dozens of different specific hardware designs and hundreds of industrial applications; thus when one wishes to design, select or operate a control system, the information presented in this presentation can only serve as a general understanding of the approach. Detailed design, selection and operation requires empirical knowledge and experience specifically suited for the application of interest. If the user lacks this empirical information it is then necessary to obtain it from the equipment vendors, industry colleagues, consultants, and/or pilot plant operation.

What Will Be Covered?

- Design: Key Issues
- Pulse Jet Cleaning Parameters
- Design Considerations and Trade-Offs
- Fabric Selection Considerations
- The Membrane Option
- Standard Fabric Tests, Time v. Temp Study
- Causes of Premature Bag Failure
- Case Studies of Each Fabric Type
- Review and Conclusions

Design: Key Issues

- Full process description affecting inlet gas (Vol., Temp., Chem., dust loading – high, low & normal)
- Baghouse specs (G/C, flow distribution)
- Bag Spec - devil in the details (e.g. shrinkage)

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PULSE JET CLEANING - PARAMETERS

Energy Source:	Low, Intermediate & High Pressure Compressed Air
Typ. Cleaning Initiation:	Timed or ΔP ΔP Trigger Typ. 5.0 - 7.0 in. H_2O Cleaning Activated If > 72 hrs.
Motion:	Air Bubble Travels Down Bag Bag Distends From Cage
Mode:	On-Stream: One Row/Pulse Off-Stream: One Compartment
Bags:	4½ - 6″ Diameter 8′ - 32′ Length
Bag Support:	1, 2 and 3 Piece Cages ¼″ - ½″ Pinch

PULSE JET CLEANING SYSTEM DESIGN

Typical Design Parameters	HP/LV[1]	IP/IV[2]	LP/HV[3]
Bag/Cage Cross Section	Circle	Circle	Oval
Bag Diameter (or equiv.), inches	4.5 - 6	5	5
Bag Length (on-line cleaning), feet	14 - 32	20 - 28	20 - 30
Tank Pressure, psig	40 - 100	15 - 35	7.5 - 12.5
Entrained Gas/Pulse Air Ratio	6 - 7	1 - 2	-
Pulse Valve Diameter, inches	1-½ to 3	4	6, 8, 10 or 12
Pulse Manifold (pipe) Diameter, inches	1-½ to 2-½	4	Tapered Duct
Pulse Orifice Size (nozzle), inches	3/8 to 3/4	3/4 to 1	Slots = 1/2 x 4

[1] High pressure/low volume (HP/LV)
[2] Intermediate pressure/intermediate volume (IP/IV)
[3] Low pressure/high volume (LP/HV)

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Design Considerations & Trade-Offs

- Provide Required Filtration
- Obtain Optimum Bag Life
- Provide Required Cleaning Capability
- Distribute Gas & Dust Equally
- Provide Effective Dust Removal From Collector

N.B.

Lower G/C gives longer bag life & lower ΔP (trade-off capital vs. operating cost)

Good design & PM retains design cleaning frequency (low)

Longer Bag Life

Design:
Fabric Filter Categories

- Capacity
- Filtering Temperature
- Operating Duty

Needs Dictated By Specific Application

- Cleaning Method
- Filter Media
- Filtering Gas Flow Direction

Options

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Design: Fabric Selection Considerations

Gas Stream

- Temperature
- Moisture
- Chemistry
- Dust Loading

Dust Characterization

- Abrasiveness
- Stickiness
- Explosiveness
- Flammability

Fabric

- Filtration Performance
- Temperature Max
- Release Properties
- Pressure Drop
- Life/Durability
- Costs

Other

- Scrim
- Coatings/Treatment
- Hardware
- Blends

Fabric Selection Chart

Fabric	Max Continuous Temp	Surge Temp.	Acid Resistance	Fluoride Resistance	Alkali Resistance	Flex Abrasion Resistance	Relative Cost*
Cotton	180 °F	200 °F	Poor	Poor	Good	Very Good	0.3
Wool	200 °F	230 °F	Good	--	Poor	Fair	--
Polypropylene	200 °F	200 °F	Excellent	Poor	Excellent	Very Good	0.4
Acrylic	265 °F	284 °F	--	--	Fair	Good	0.4
Polyester	275 °F	300 °F	Fair	Poor to Fair	Fair	Very Good	0.4
Basofil®/ Melamine	375 °F	-- °F	Good	--	Excellent	--	--
PPS	375 °F	425 °F	Good	Good	Very Good	Very Good	1.0
Nomex®/ Aramid	400 °F	425 °F	Poor to Fair	Good	Good	Excellent	0.9
P-84®/ Polyimide	400 °F	500 °F	Fair	Fair to Good	Fair	Good	1.6
Teflon®/PTFE	450 °F	500 °F	Excellent	Excellent	Excellent	Fair	4.7
Glass Felt	500 °F	550 °F	Good	Poor	Fair	Fair	1.6
Woven Fiberglass	500 °F	-- °F	Fair to Good	Poor	Fair to Good	Fair	0.7

*Relative Cost – PPS Pulse Jet Bag 5”∅ x 10’ Long

Cost Considerations

- Current pricing per bag, 33' long by 5" diameter:
  - PPS Felt ~ $81-90
  - P-84 Felt ~ $143-158
  - WFG/Membrane ~ $73-81

Fabric Selection Process

All Fabric Options

Key Decision Factors

- Filtration & Temperature

Remaining Options

Other Decision Factors

- Purchase Price & Bag Life & Pressure Drop

Cost Analysis

Final Selection

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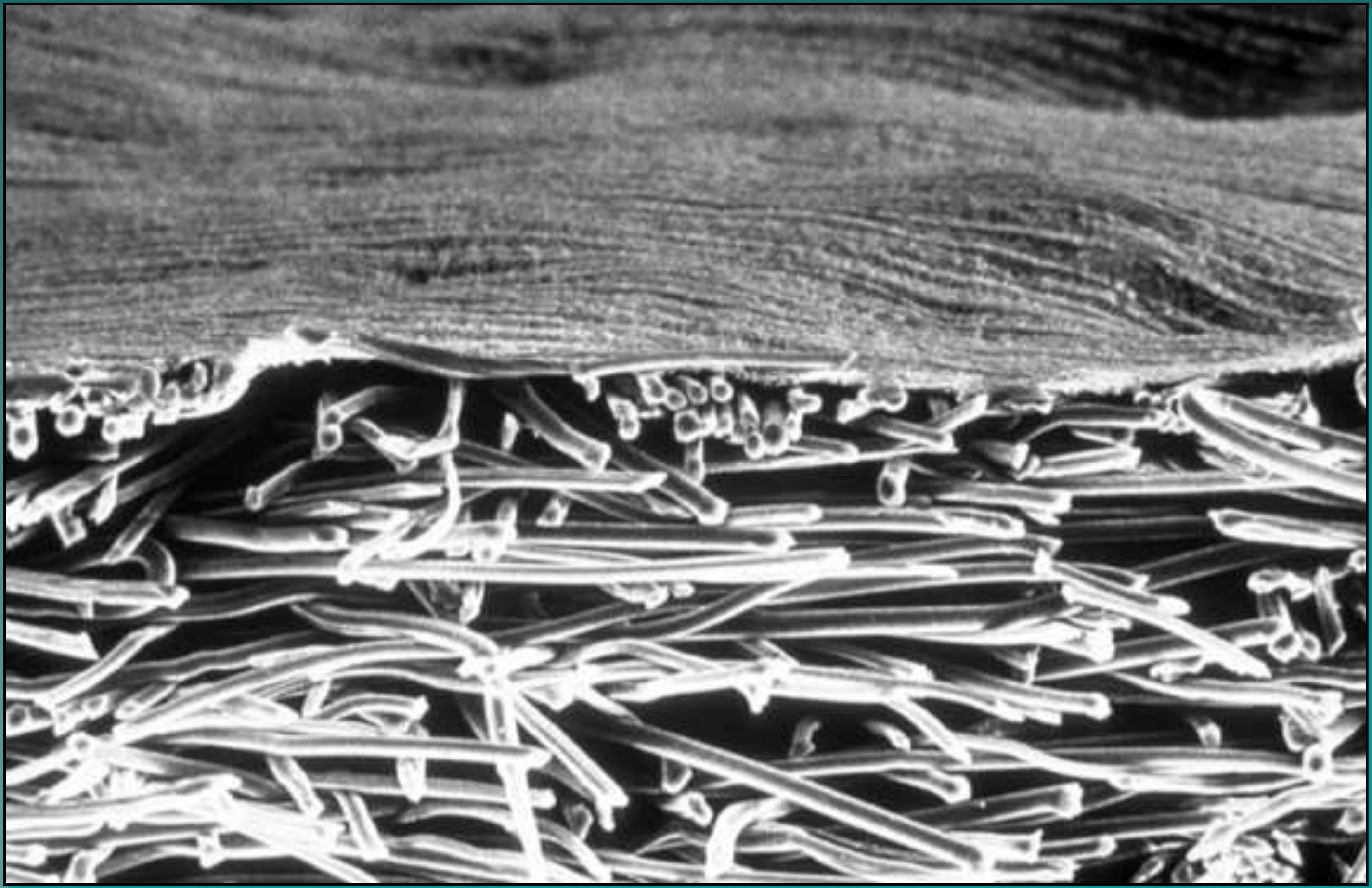
The Membrane Option

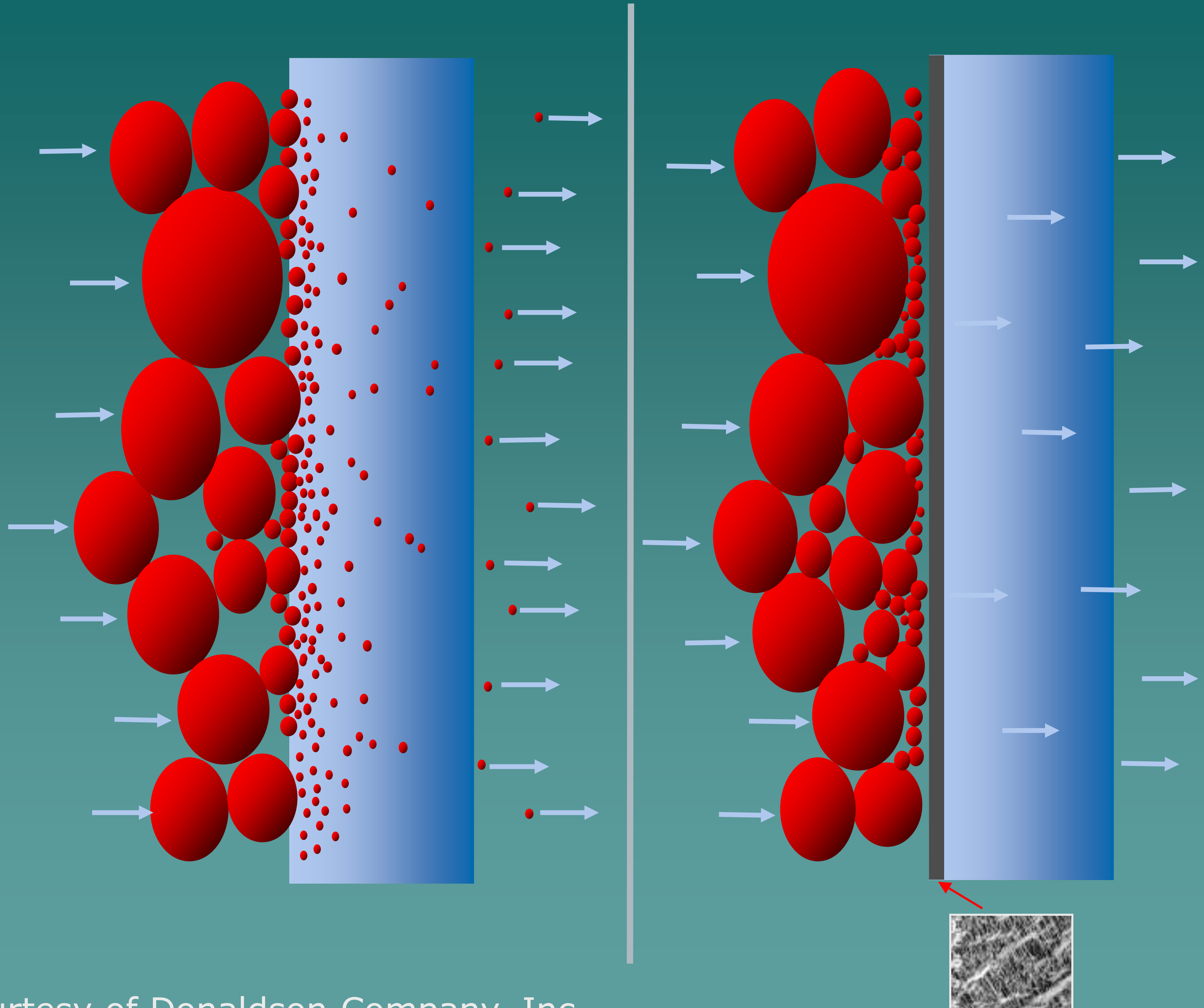
- How does it work?
- Why choose it?

ePTFE MEMBRANE/POLYESTER FELT



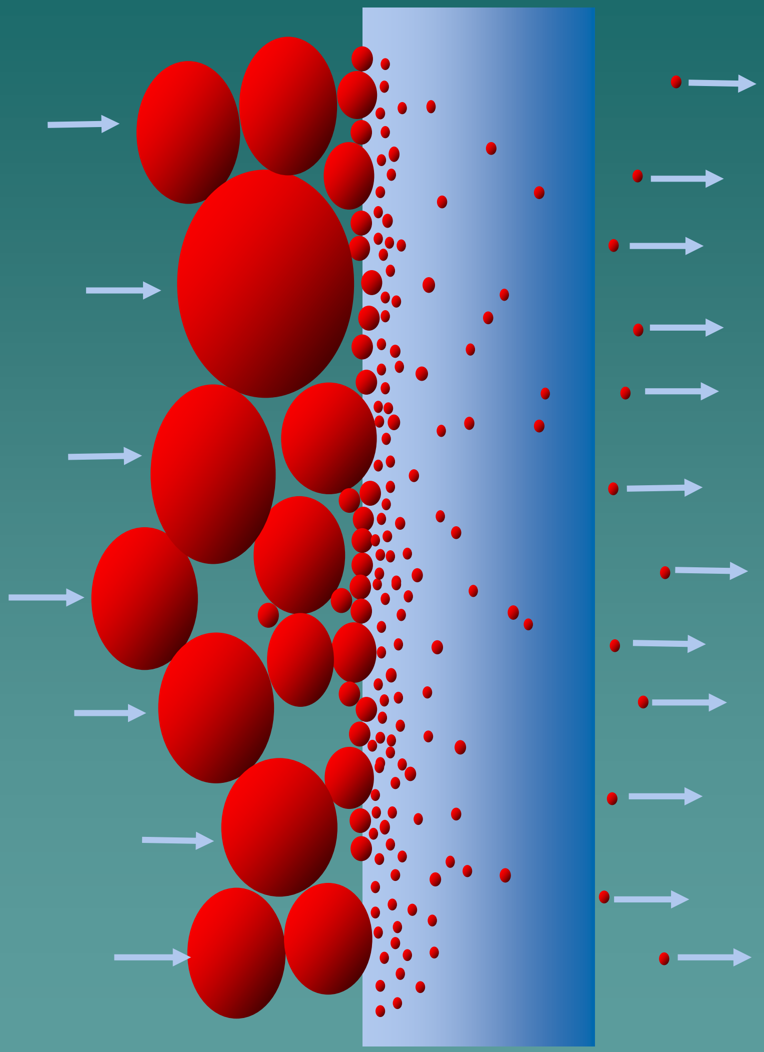
Courtesy of W.L. Gore & Associates

DEPTH FILTRATION - SURFACE FILTRATION



Courtesy of Donaldson Company, Inc.

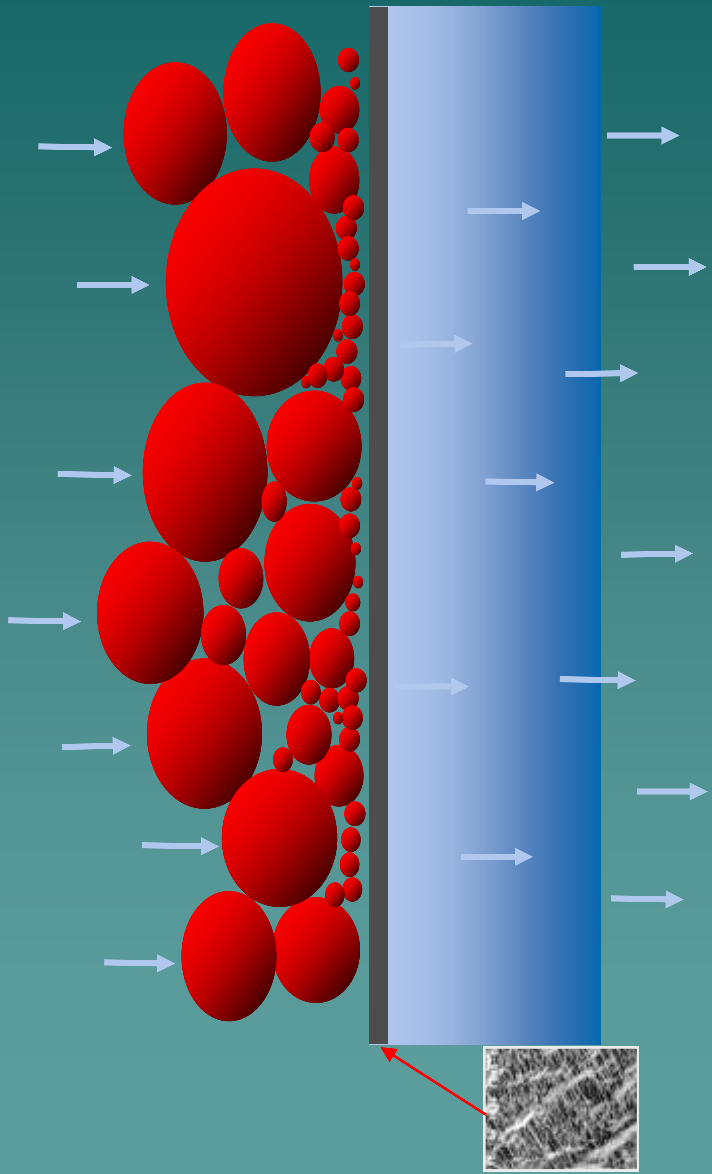
Depth Filtration



- Efficiency relies on cake formation
- Dust cake restricts airflow
- Requires high cleaning energy which imparts mechanical stresses
- Fine particles migrate into media causing abrasion damage
- Leads to blinding - High pressure drop

Courtesy of Donaldson Company, Inc.

Surface Filtration



- Acts as primary dust cake, no pre-coat required
- Inhibits particle migration
- Low cake formation allows for reduced cleaning therefore less mechanical stresses
- Higher cleaning efficiency gives higher constant airflow
- Excellent cake release - Low pressure drop

Courtesy of Donaldson Company, Inc.

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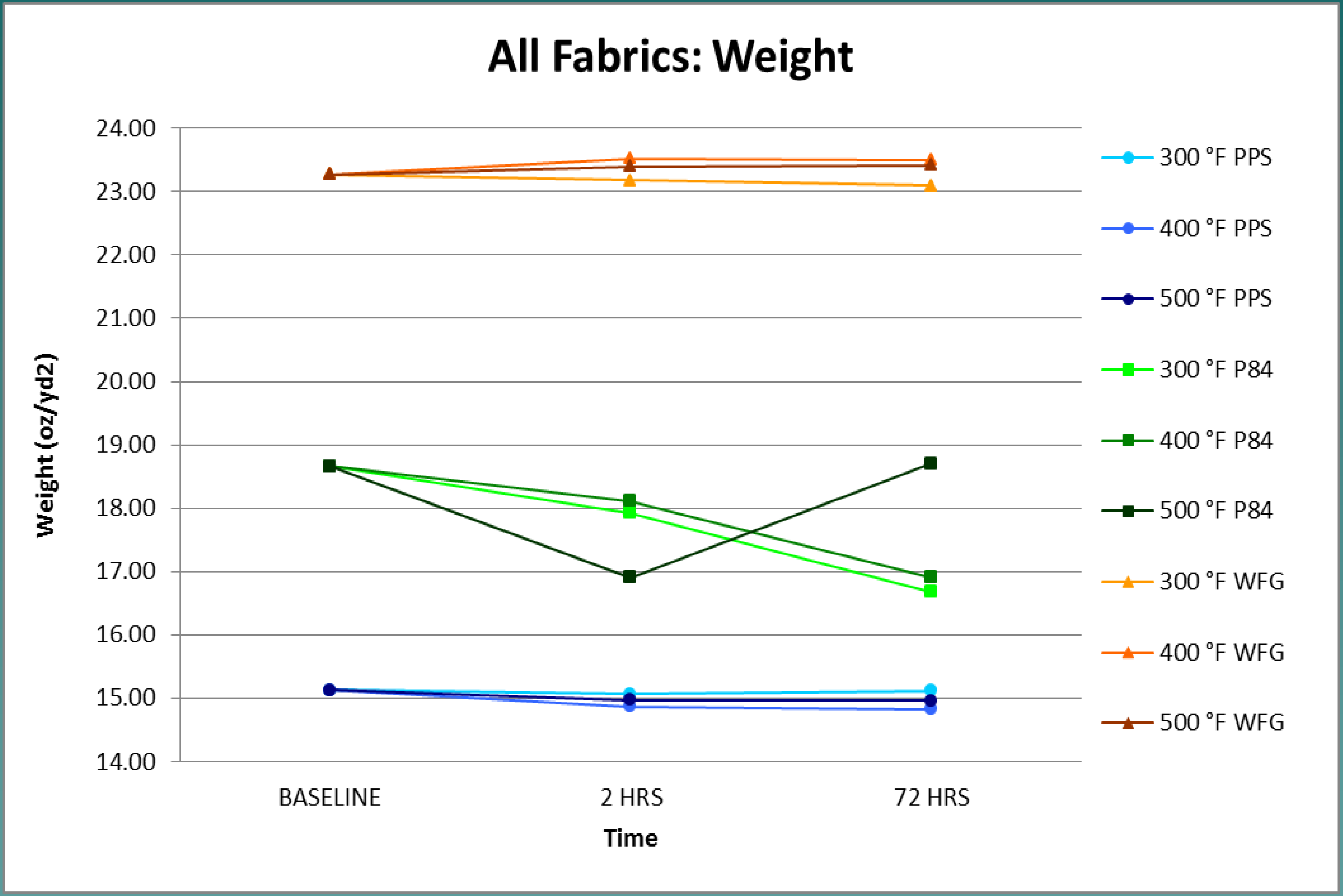
Standard Fabric Tests

Test	**Method**
Weight	ASTM D3776
Thickness	ASTM D1777
Count	ASTM D3775
Permeability	ASTM D737
Tensile Strength	ASTM D5035
Mullen Burst	ASTM D3786
MIT Flex	ASTM D2176
Organic Content	ASTM D578
Water Repellency	ASTM D2721
Yarn Weight	ASTM D578
Yarn Twist	ASTM D578
Filtration Performance	ASTM D6830
Surface Resistance	STM 11.11
Volume Resistance	STM 11.12
Two-Point Resistance	STM 11.13

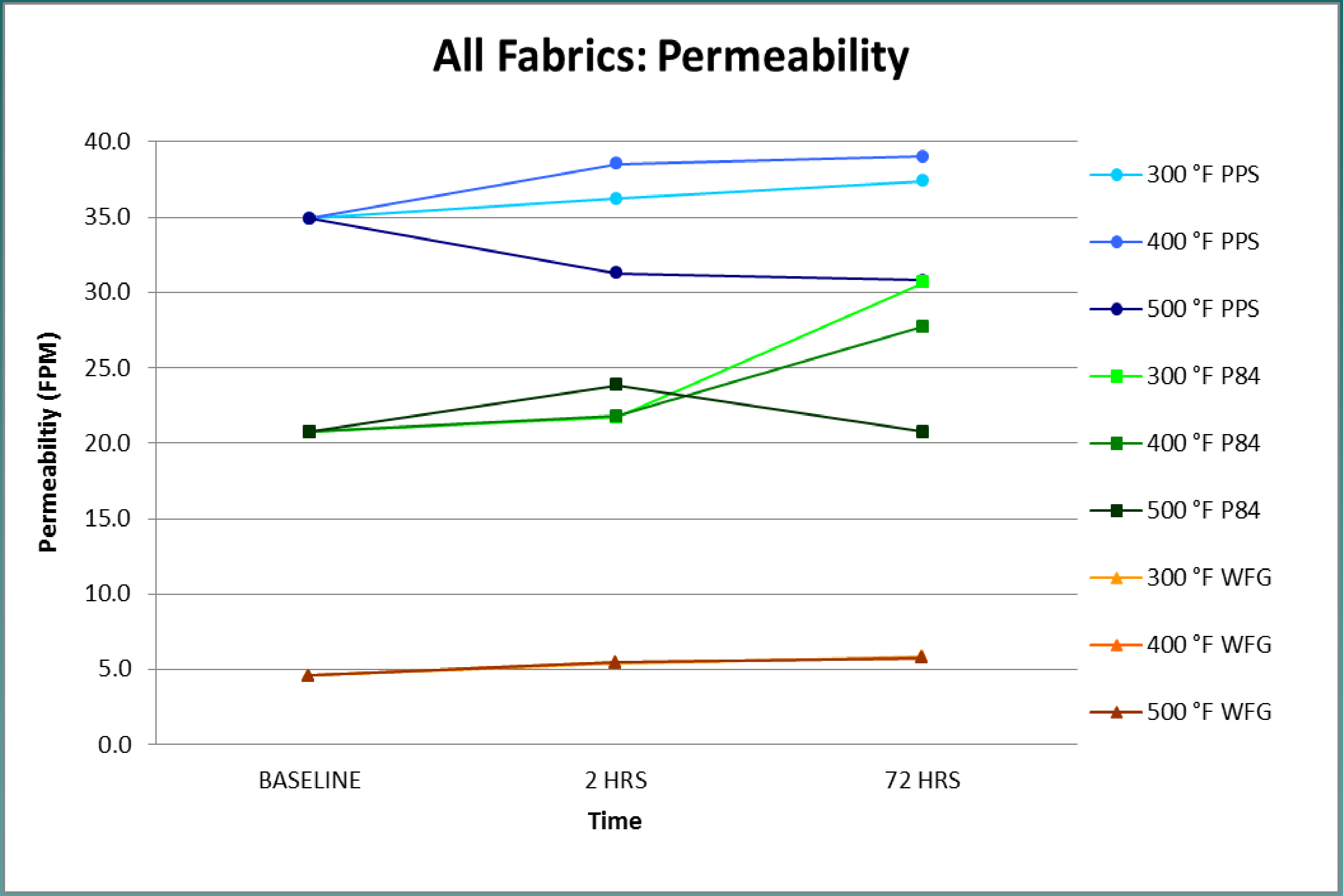
Time v. Temp Summary Graph



Permeability Test Method

- Frazier Permeability apparatus is used to determine air handling capability of filter media.
- Includes capability to measure air flow over a wide (0-20” w.g.) differential pressure.
- Ambient to 400 °F temperature range.
- Non-destructive manner.

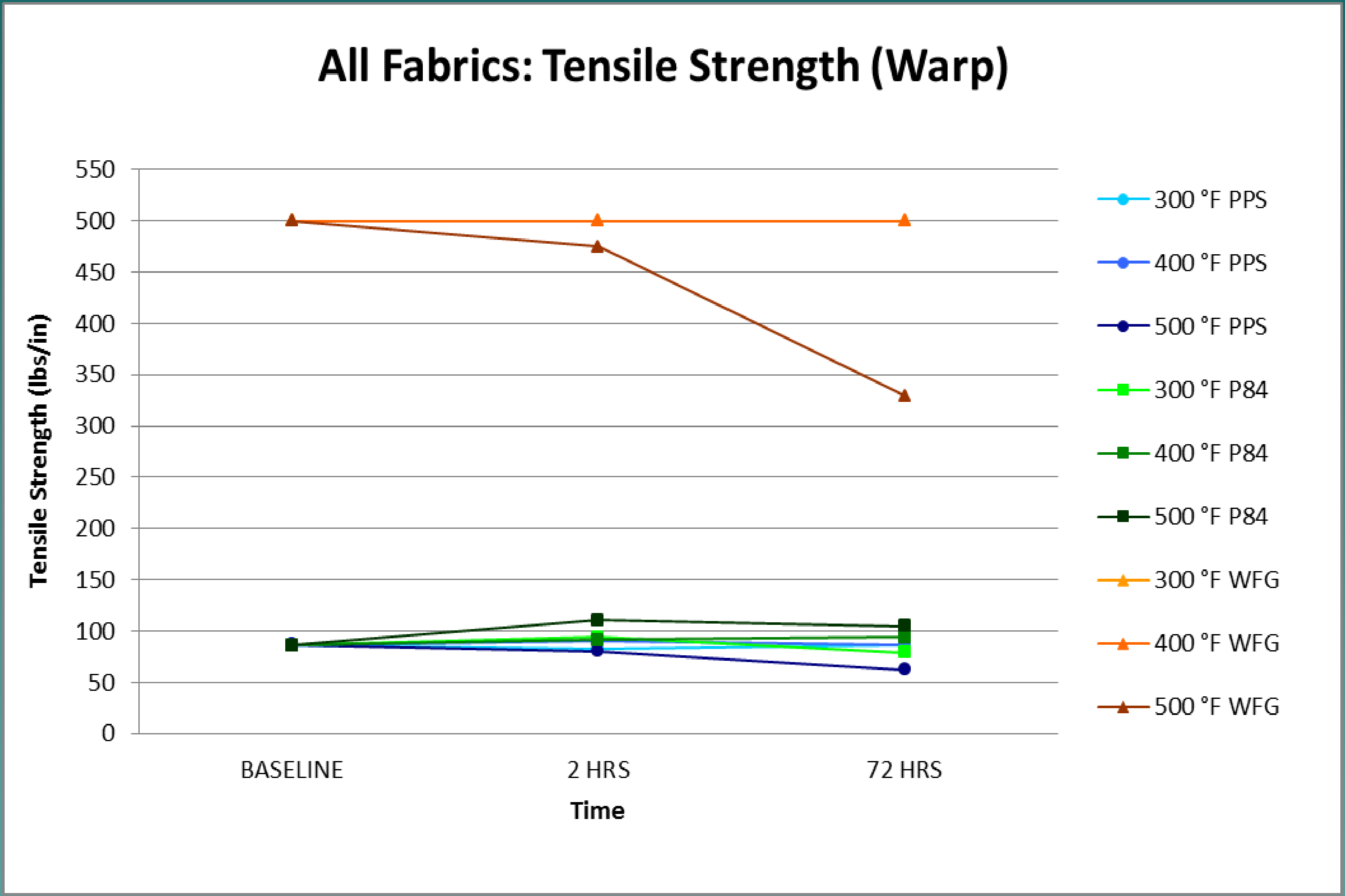
Time v. Temp. Summary Graph



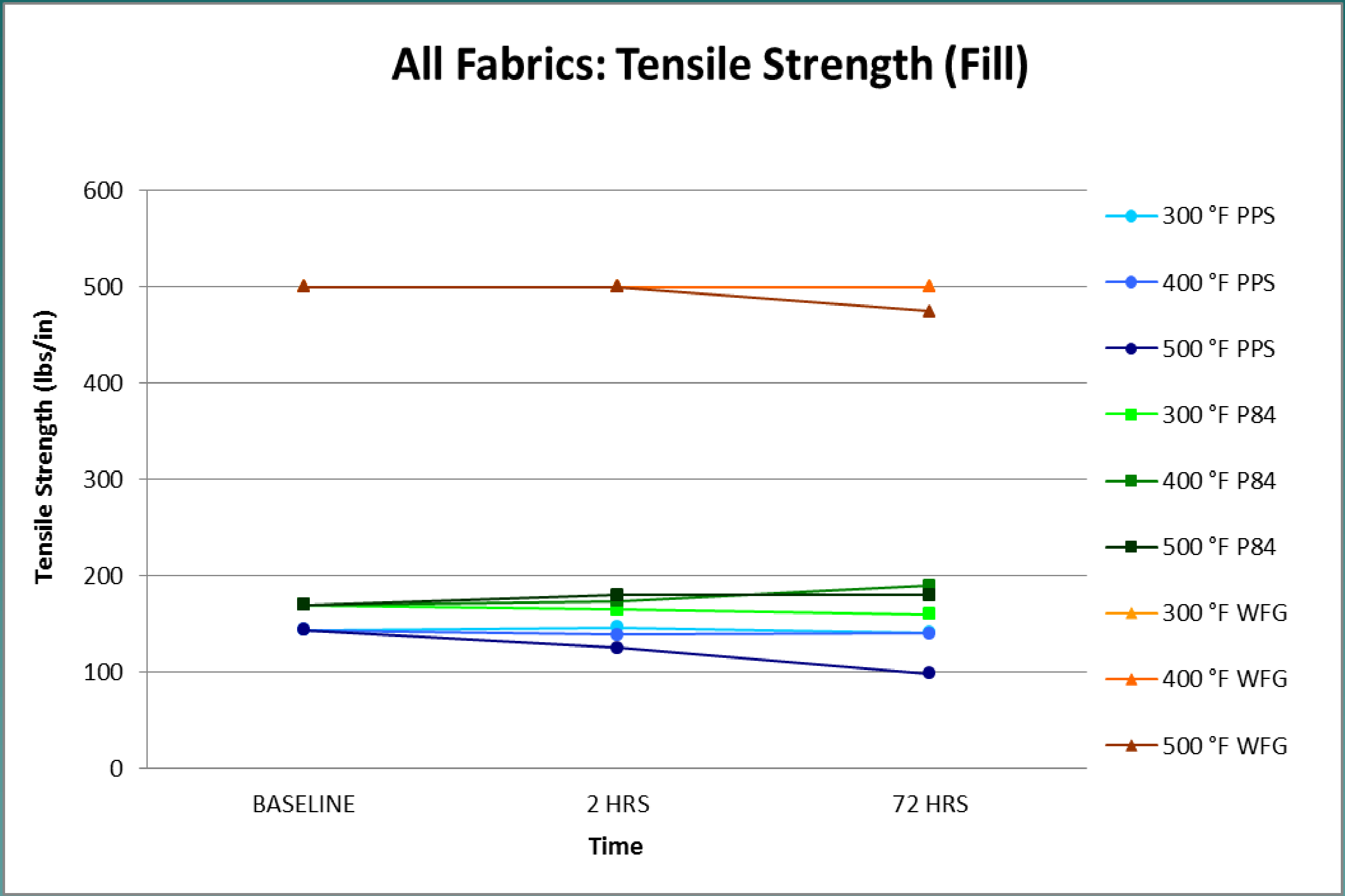
Tensile Test Method

- Provides stretch, elongation, and tear data for fabrics.
- Measures relative strength of warp and filling yarns in fabric samples.

Time v. Temp. Summary Graph



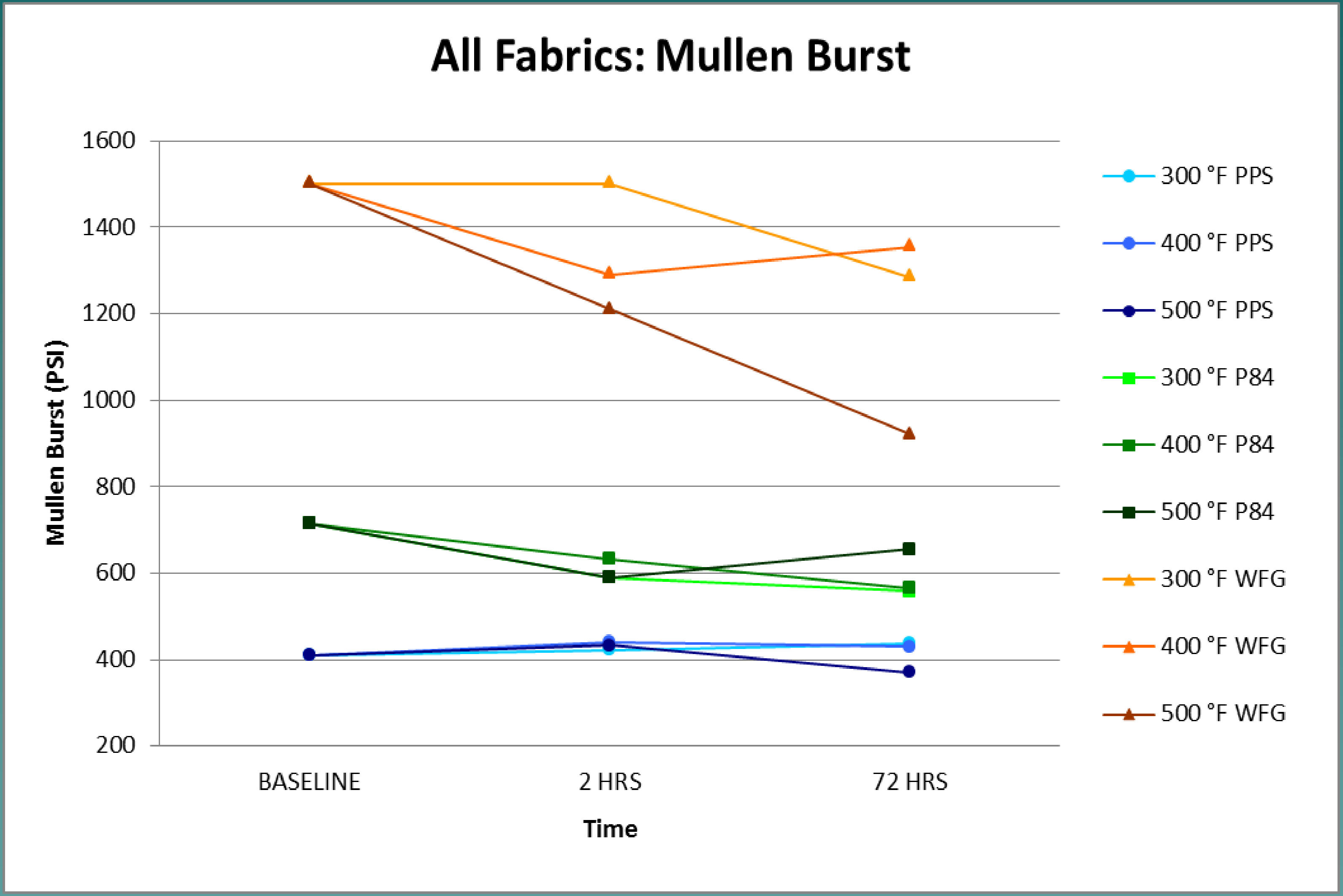
Time v. Temp. Summary Graph



Mullen Burst Test Method

- Shows the relative total strength of fabrics to withstand severe pulsing or pressure.
- Fabric strength is measured by determining the difference between the total pressure required to rupture the specimen and the pressure required to inflate an expandable diaphragm.

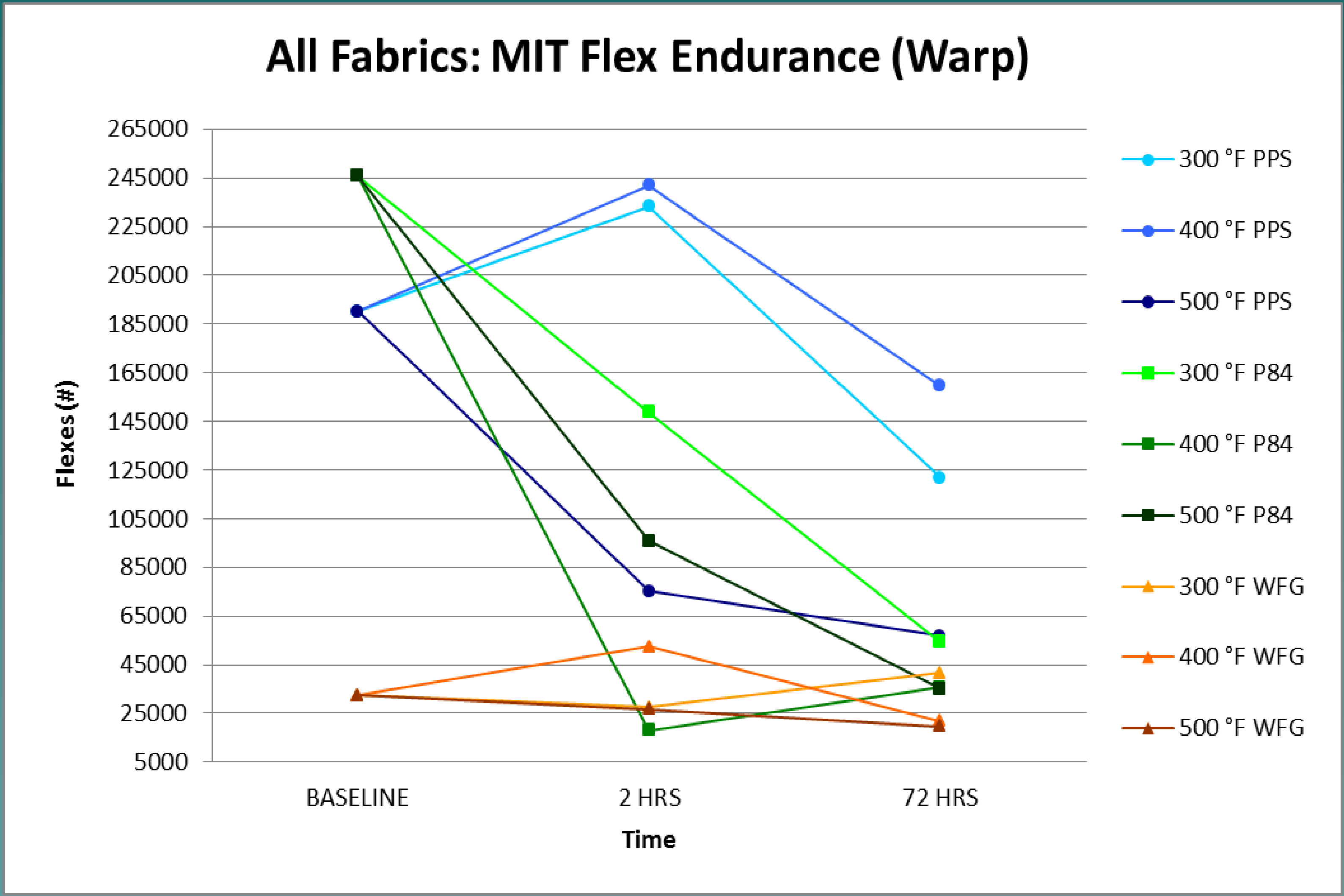
Time v. Temp. Summary Graph



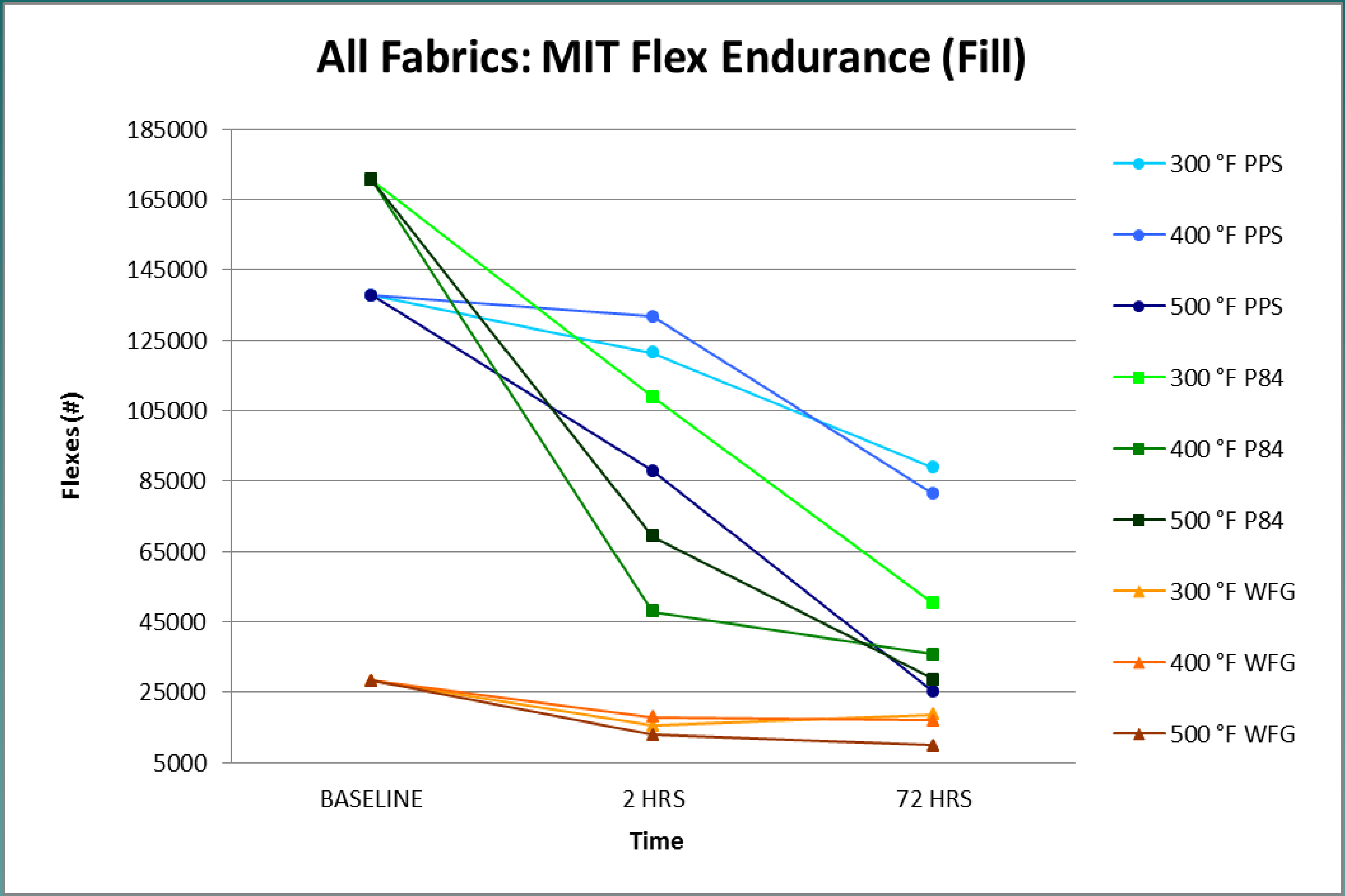
M.I.T. Flex Endurance Test

- Primarily measures relative value of fiberglass fabric weaves and finishes to withstand self abrasion from flexing by measuring the number of flex cycles necessary to break a fabric sample.

Time v. Temp. Summary Graph



Time v. Temp. Summary Graph

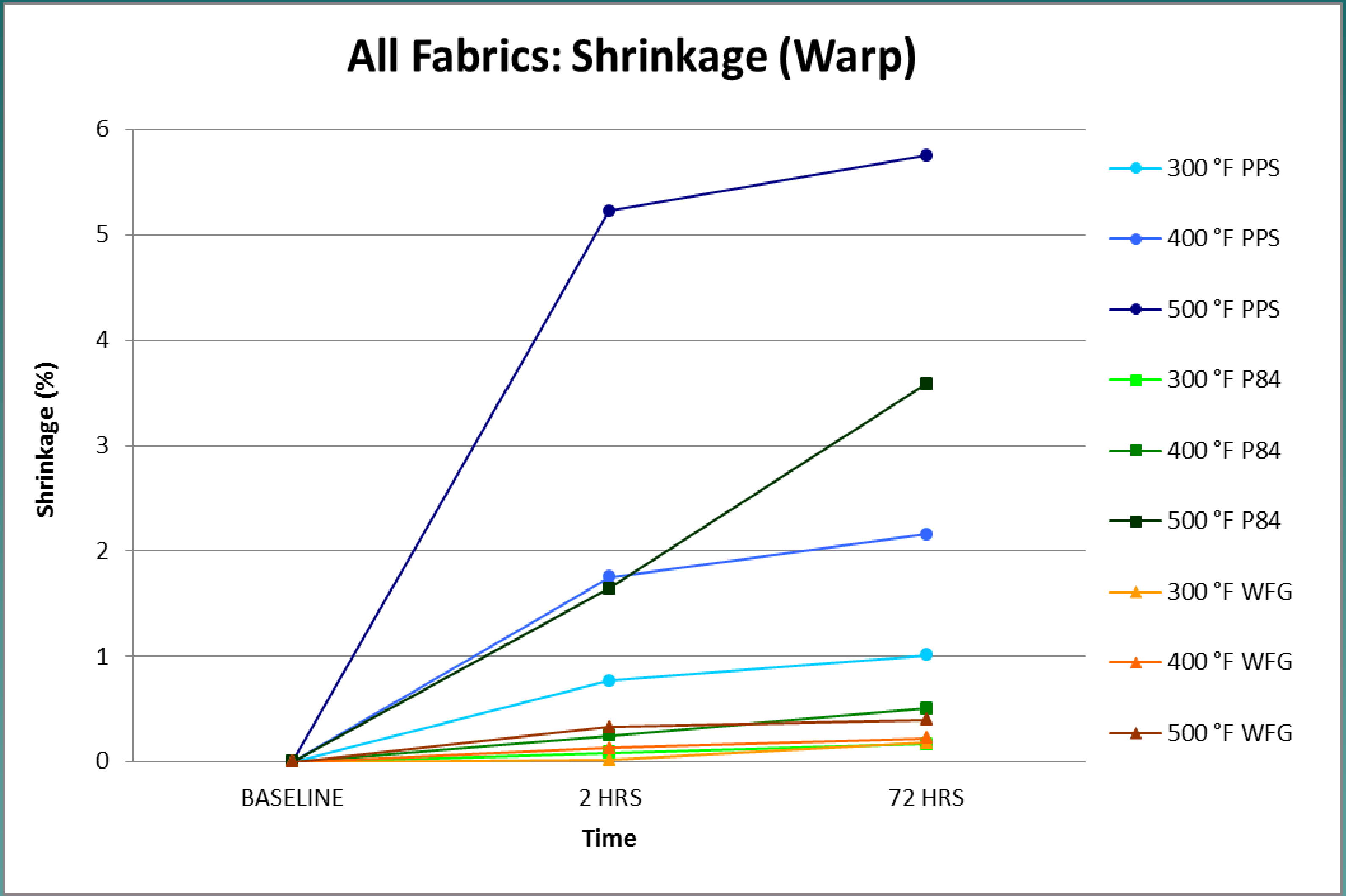


Shrinkage Test Method

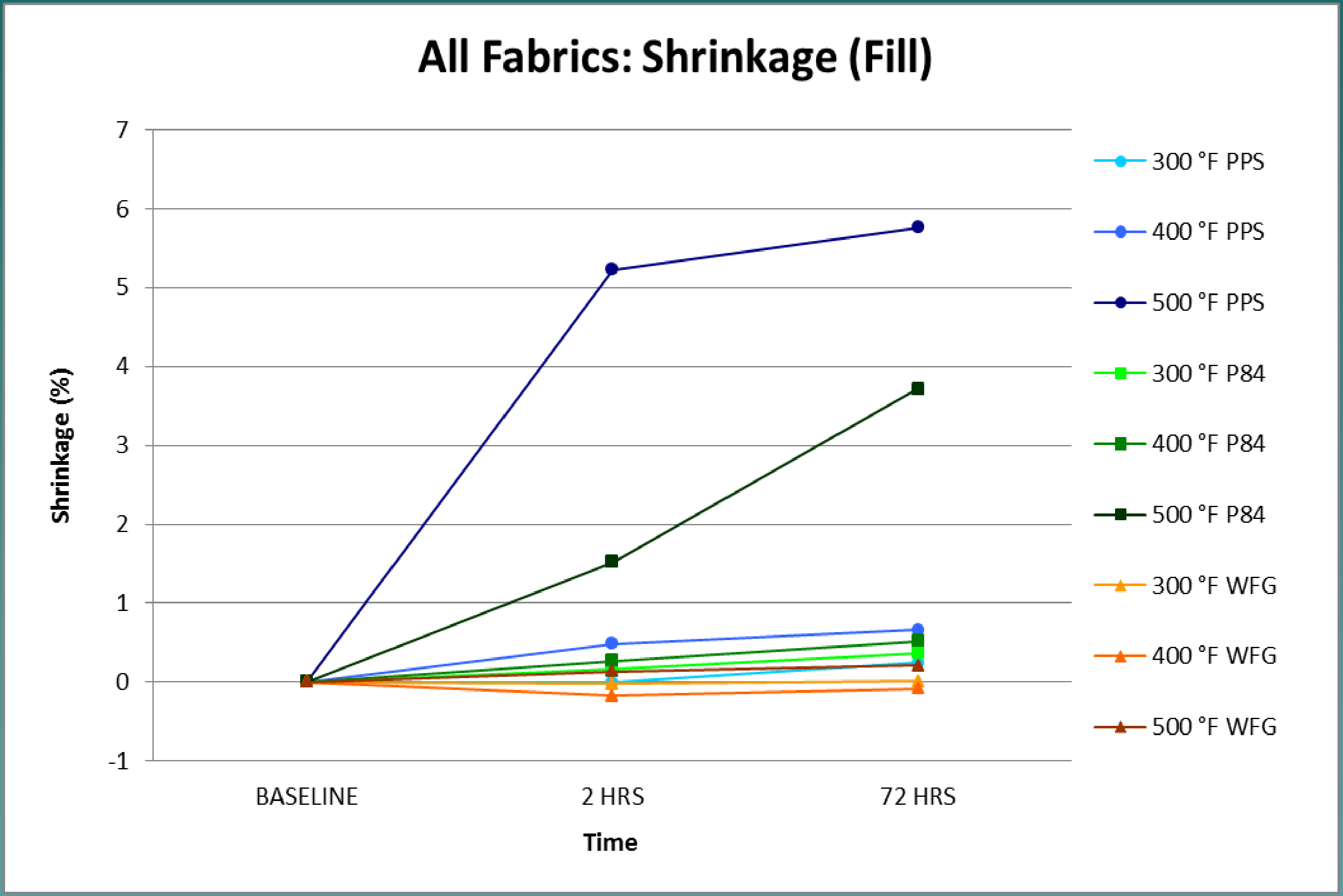
- Measures percent of fabric shrinkage after exposure to specific heat.
- Fabric shrinkage is measured using calipers in multiple areas which are marked on the fabric sample before heat exposure.
- Both the warp and fill direction shrinkages are measured.

http://www.thermoscientific.com/ecomm/servlet/productsdetail_11152___11962945_-1

Time v. Temp. Summary Graph



Time v. Temp. Summary Graph



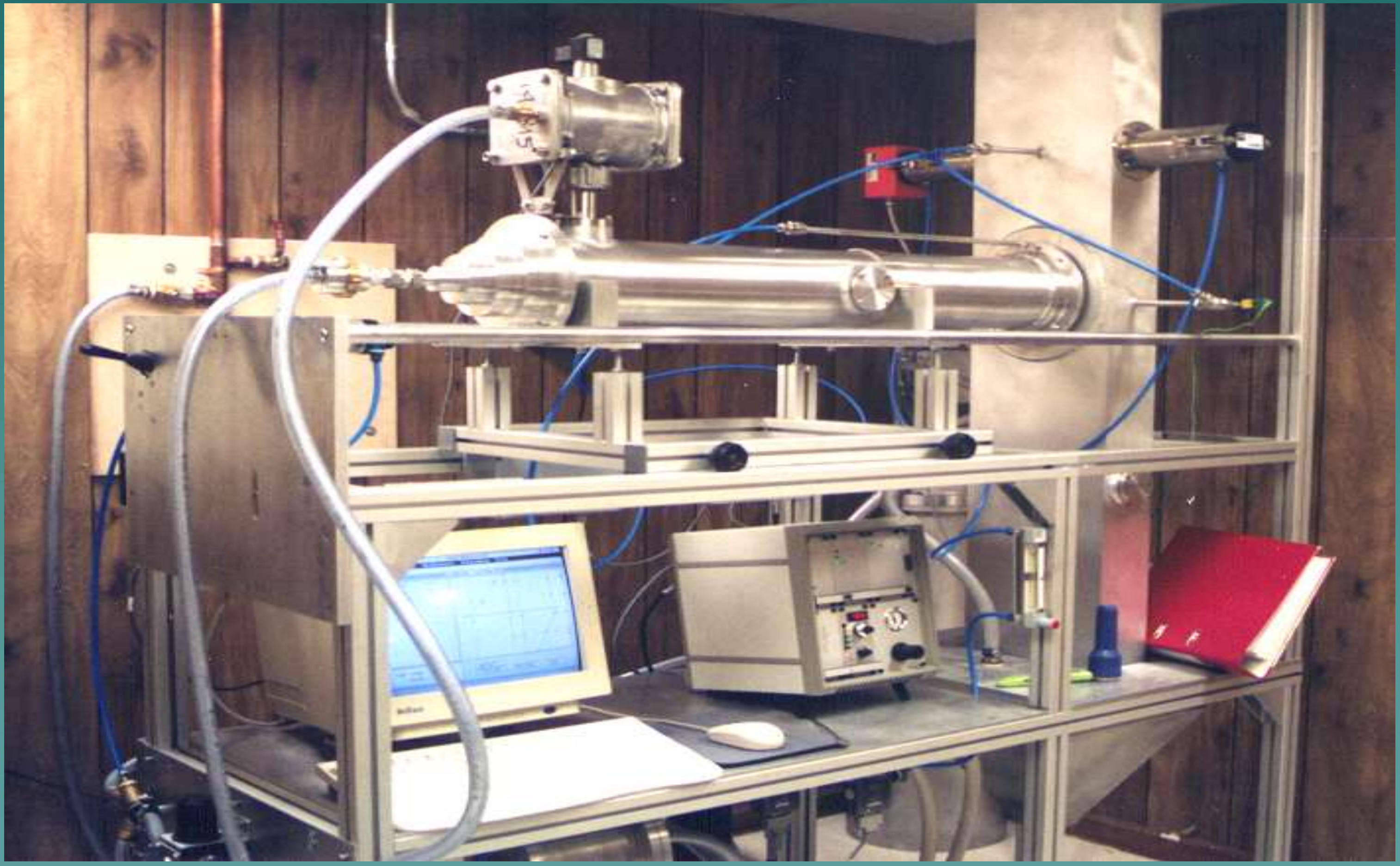
Time v. Temperature Study Summary of Results

SUMMARY OF TEST RESULTS

ALL FABRICS (PPS, P84, WFG)

	TEST PERFORMED		BASELINE	300 °F AFTER 2 HRS	300 °F AFTER 72 HRS	400 °F AFTER 2 HRS	400 °F AFTER 72 HRS	500 °F AFTER 2 HRS	500 °F AFTER 72 HRS
	WEIGHT, oz/yd²								
PPS			15.13	15.06	15.11	14.87	14.83	14.97	14.96
P84			18.66	17.92	16.68	18.11	16.91	16.90	18.71
WFG			23.28	23.18	23.10	23.52	23.50	23.40	23.42
	PERMEABILITY, fpm								
PPS			34.9	36.2	37.4	38.6	39.0	31.3	30.8
P84			20.8	21.7	30.7	21.8	27.8	23.9	20.8
WFG			4.6	5.4	5.9	5.5	5.8	5.5	5.8
	SHRINKAGE-%								
PPS		WARP	-	0.77	1.01	1.75	2.16	8.79	8.91
		FILL	-	-0.01	0.25	0.49	0.66	5.23	5.75
P84		WARP	-	0.08	0.17	0.25	0.51	1.65	3.58
		FILL	-	0.16	0.37	0.27	0.52	1.52	3.71
WFG		WARP	-	0.02	0.18	0.13	0.23	0.33	0.40
		FILL	-	-0.02	0.01	-0.17	-0.08	0.14	0.21
	MULLEN BURST, psi								
PPS			410	423	438	440	430	433	370
P84			715	590	558	633	565	590	655
WFG			1500	1500	1285	1290	1355	1210	920
	TENSILE STRENGTH, lbs/in								
PPS		WARP	87	83	87	90	87	81	63
		FILL	144	147	142	140	141	126	99
P84		WARP	86	94	79	92	94	111	105
		FILL	170	166	161	174	190	180	181
WFG		WARP	500	500	500	500	500	475	329
		FILL	500	500	500	500	500	500	475
	MIT FLEX, # flexes								
PPS		WARP	190220	233252	121986	241888	159490	75224	56949
		FILL	137731	121278	88662	131724	81249	87791	25023
P84		WARP	102267	198072	54316	17948	35810	95863	35148
		FILL	314043	59618	50048	34308	35639	80773	28664
WFG		WARP	32566	19802	41749	27550	21896	26778	19556
		FILL	28282	23177	18545	15429	16943	12839	9915

ETS Filtration Performance Test Apparatus



Breakout Table of Test Results Summary

	Fabric Type		
Parameter:	PPS Felt	P-84 Felt	Woven Fiberglass w/ ePTFE Membrane
Outlet PM 2.5 Particle Concentration, gr/dscf	0.0000669	0.0000482	0.0000007
Number of Pulses	179	168	108
Residual Pressure Drop, Performance Test Period, inches w.g.	1.04	0.94	1.05
Removal Efficiency % (PM 2.5)*	99.99879	99.99911	99.99999

$$* \frac{\text{(Dust Concentration *0.5287)-PM 2.5 Outlet Concentration}}{\text{Dust Concentration * 0.5287}} *100$$

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Premature Bag Failure: Factors Effecting Bag Life

- Design and Manufacturer
- Installation
- Gas Flow
- Gas Temperature
- Gas Acidity
- Dust Loading & Particle Size
- Cleaning Intensity/Frequency/Duration
- Bag Tension
- Adjacent Bag Life

Premature Bag Failure: Causes

- Mechanical
  - Dust Abrasion
  - Over Cleaning
  - Bag Tension
  - Adjacent Bag
- Thermal
  - Excessive Temperature
  - Dew Point
- Chemical
  - Acids
  - Alkalies
  - Condensation (Organics, Acids, Water)

Premature Bag Failure: Typical Causes of Pulse Jet Bag Failures

- Dust on "clean side" – accelerates bag-to-cage wear
- High velocity dust abrasion - Bottom of bag
- Chemical attack from flue gas contaminants coupled with acid dew point excursions
- Bag-to-cage abrasion - Bad fit, poor design, damaged cage
- Bag-to-bag abrasion - Too close, bent cages, high can velocity
- Mechanical abrasion in top 1/3 of bag - misaligned Venturi or pulse pipe
- Process upset conditions - Fabric temperature capability exceeded; particulate is introduced to blind or attack the fabric

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Premature Bag Failure: Case Study 1 – Pulse Jet Bag

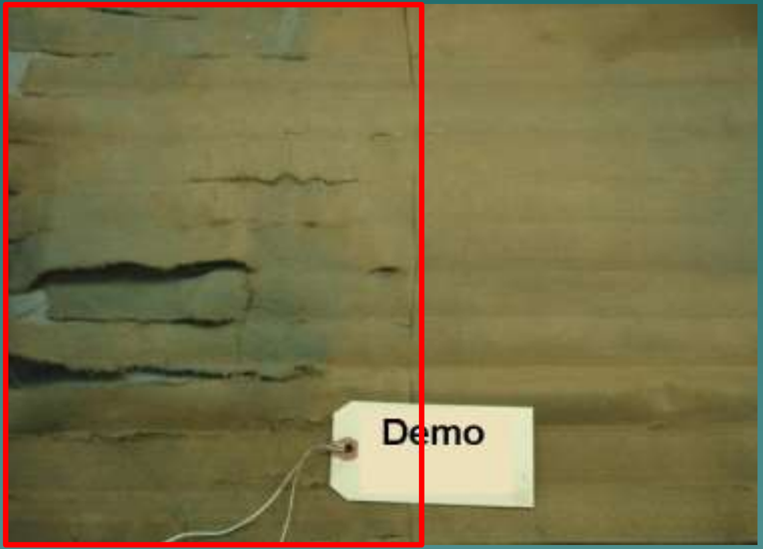
Case 1:
10 bags tested, CFB, PPS Felt

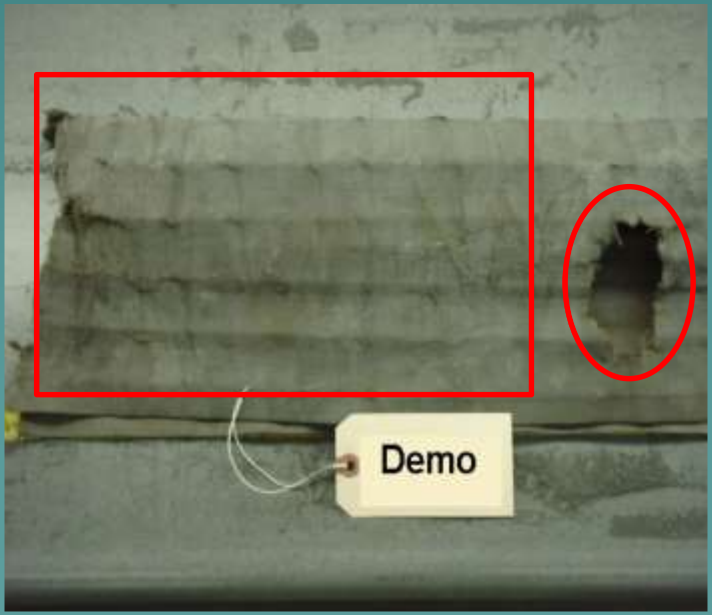
Results:
Multiple holes and abrasions particularly along vertical cage lines at bag top, fabric easily torn by hand, rust flakes on the non-collection sides of the bags, welded seam failure on all bags

Conclusions:
pH values ranged from acidic to alkaline, bag failures possibly due to a combination of thermal and chemical attack

Premature Bag Failure Case 1 Photos – Pulse Jet

Bag failure along vertical cage lines (non-collection side view)





Areas of abraded and degraded fabric

Premature Bag Failure: Case Study 2 – Pulse Jet Bag

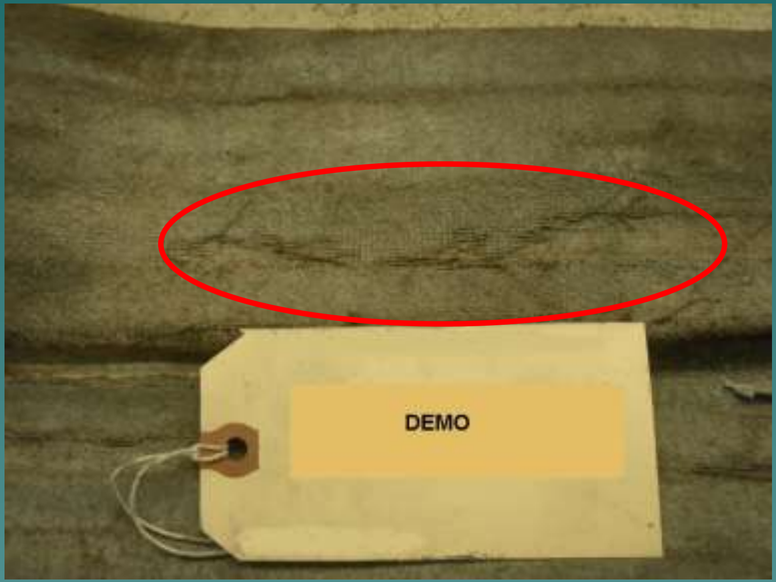
Case 2:
15 bags tested, CFB, P-84Felt

Results:
Multiple holes in bags, fabric failure around the top cuff seam, pearling of dust, discoloration of non-collection side fabric,

Conclusions:
Poor to moderate strength retention and low pH values indicate chemical attack possibly complicated by thermal attack. Pearling of the dust cake suggests moisture in the baghouse.

Premature Bag Failure
Case 2 Photos – Pulse Jet

View of degraded fabric on bag body. (collection side)



View of all holes along or in between cage lines from non-collection side

Premature Bag Failure: Case Study 3 – Pulse Jet Bag

Case 3:
1 bag tested, CFB, Woven Fiberglass w/ePTFE membrane

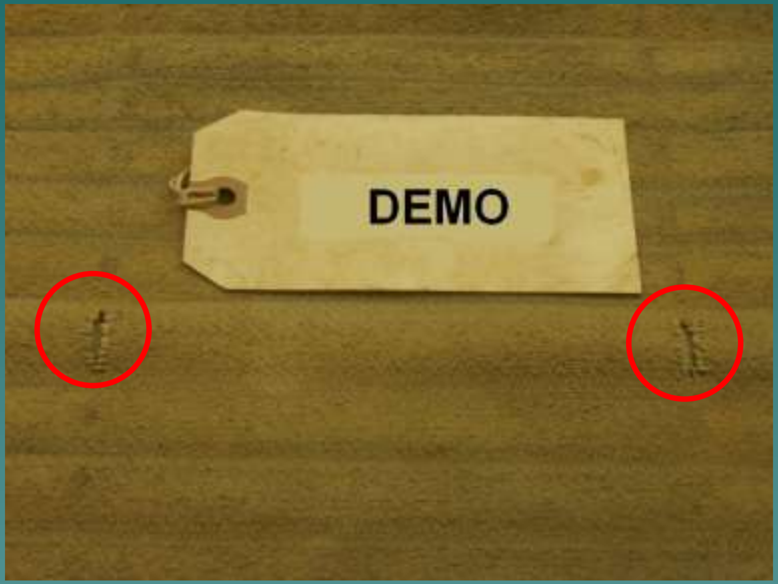
Results:
Holes on horizontal ring spacers, abrasions on collection side, fill direction flexes low, "clean side" dust present

Conclusions:
Physical damage consistent with bag-to-cage abrasion

Possible causes - excessive cleaning of bags, dust or rust on cage rings, improper bag-to-cage fit

Premature Bag Failure: Case 3 Photos – Pulse Jet

Holes at horizontal ring spacers in middle of bag (non-collection side)



View of holes at horizontal ring spacers from collection side

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Review and Conclusions

- Maximize Bag Life & Minimize ΔP
- Proper Design & Detailed Specification (Rec. Low G/C)
- Sufficient QA/QC Program (Risk/Reward)
- Installation Inspection & Correction
- PM & Responsive Maintenance ASAP
- "Keep Clean Side Clean"
- Bag Set Monitoring Program and Key Data Collection & Review
- Operate Within Design Ranges (Especially Bag Cleaning Cycle)

Overview of Test Results

WEIGHT,
oz/yd^2

Average values exhibited very little change after heat exposure.

- PPS, 15 oz/yd^2
- P84, 17-18 oz/yd^2
- WFG, 22-23 oz/yd^2

Overview of Test Results

PERMEABILITY,
fpm

- PPS, Increased >4 @ 400 °F (72 hrs), Decreased >4 @ 500 °F (72 hours)
- P-84, Increased >7 @ 300 °F and 400 °F (72 hours)
- WFG, Most stable, 4-6

Overview of Test Results

TENSILE STRENGTH (WARP),
lbs/in

@ 500 °F (72 hrs)

- PPS, Dropped 24 lbs/inch
- P84, Gained 19 lbs/inch
- WFG, Decreased >171 lbs/inch

Overview of Test Results

TENSILE STRENGTH (FILL),
lbs/in

@ 500 °F (72 hrs)

- PPS, Dropped 45 lbs/inch
- P84, Gained 11 lbs/inch
- WFG, Dropped >25 lbs/inch

Overview of Test Results

MULLEN BURST,
psi

- PPS, Stable
- P84, Dropped >150 @ 300 °F & 400 °F (72 hrs)
- WFG, Dropped >500 @ 500 °F (72 hours)

Overview of Test Results

MIT FLEX (WARP),
flexes

- PPS, >190,000 to start, Highest after 300 °F and 400 °F (2 hours)
- P84, Highest baseline but falls the most
- WFG, Lowest baseline but most stable

Overview of Test Results

MIT FLEX (FILL), # flexes

- PPS, Falls from >135,000 to <90,000 @ 300 °F and 400 °F (72 hours), Falls to 25,000 @ 500 °F (72 hours)
- P84, Highest baseline but falls the most
- WFG, Dropped >18,000 @ 500 °F (72 hrs)

Overview of Test Results

SHRINKAGE (WARP), %

- PPS, Worst especially @ 500 °F (72 hrs), 8.9
- P84, <1 @ 400 °F (72 hrs), 3.6 @ 500 °F (72 hrs)
- WFG, Stable <1

Overview of Test Results

SHRINKAGE (FILL), %

- PPS, Worst especially @ 500 °F (72 hrs), 5.8
- P84, <1 @ 400 °F (72 hrs), 3.7 @ 500 °F (72 hrs)
- WFG, Stable <1

Relative Bag Performance Conclusions

- Filtration performance of P84 and PPS Felt similar and very good.
- Filtration performance of WFG/Membrane excellent.
- Other study* shows membrane out-performs traditional felts.
- Bag Life
  - PPS Felt, can exceed 5 years
  - P-84 Felt, can exceed 2½ years
  - WFG/Membrane, dependent on multiple factor
- Cost of Bags
  - P-84, commands a premium (1.7)
  - WFG/Membrane, (.8)
- Ultimate decision is a function of site specific inlet definition and cage design.

Future Efforts

- Lab testing provides a public, initial data set
- It is a work in progress (e.g. acid flex testing
- Hope it will be useful to others and that they will add to it
- Need for site specific pilot plant comparisons

THANK YOU FOR LISTENING

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*<u>**The Technical Suitability & Limitations of PPS Filter Media When Utilized in Utility Boiler Baghouses**</u>
<u>Christina Clark, Terry Williamson, Jeff Smith, John D. McKenna. MEGA Symposium in Baltimore, MD, August 2012.</u>
http://www.etsi-inc.com/Publications%20Page.htm

Questions?