Advances in Fiber Technology for High Performance Filtration

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(▼ indicates advancement of the PowerPoint presentation)

Slide 2

We have a problem. And the problem is not that the projector has malfunctioned. The problem starts with the fact that more and more people want more and more cars and books and computers and beer and boats and t-shirts and on and on and on. And as we gear up to meet this demand, we all need more and more energy. Energy that, in large part, will be produced by burning coal. And as we burn more and more and more coal, the problem we face is that this is not the way you want your lungs to look.

Slide 3

This is why coal-fired power plants are fitted with filtration units to remove most of the particulates from the exhaust gases. This filtration process is my focus today, in particular as it relates to new technology to improve both the cost and the performance of coal-fired power plant exhaust gas filtration, and to ultimately do a better job of keeping the black stuff out of our lungs.

Slide 4

This first diagram shows how a single bag filter is arrayed, with a wire structure to support the bag and to prevent collapse of the bag during reverse-flow cleaning cycles. ▼Here we can see a photo of a filter bag with its wire support. A large array of these bags is typically assembled in a ▼single baghouse section, as is seen in this view of the bottom of a baghouse installation.

Slide 5

As you might imagine, filtering the exhaust from a coal fired power plant is more challenging than that of a household vacuum cleaner. ▼First, of course, the air is hot. The filter medium must withstand continuous use temperatures of 350ºF for a number of years . Even though it's rarely seen in actual practice, these bags may see up to 375 to 400º at process spikes. ▼When the exhaust gas cools, it may drop close to the dew point of the gases. If the gas is carrying sulfur from the burned coal, this may allow for the formation of sulfuric acid on the bag surfaces. ▼On top of that, the hot gas stream can be laden with ▼nitric acid, mercury, and halogen ions. Also, hydrolytic effects can be exacerbated on the filter media.

The coal combustion product particles that are to be captured by the baghouse as filter cakes on the surface of the filter bags can be as small as sub-micron particles but are typically larger than 2.5 microns in diameter. After the filter becomes fully loaded, rather than discarding and replacing the filter bag, ▼the bag is pulsed by a reverse jet of air and the filtrate is dislodged and collected at the bottom of the baghouse for disposal. This "pulse jet" cleaning process is repeated many 10's of thousands of times over the life of a bag while in use.

So the filter medium must have exceptional physical properties along with resistance to heat as well as to corrosive chemicals. In some cases the filter bag must be able to withstand the formation of a hole in the filter bag if it is hit by a spark. And with all of these requirements, the filter bag must be constructed so as to efficiently filter combustion process particles from the air and then release them quickly during the pulse jet cleaning process.

Slide 6

The typical filter bag for these applications is a ▼needlepunched fabric of 16 ounces per square yard and is▼ tightly needled to control thickness, permeability, and Mullen burst strength. ▼The fabric may include an inserted scrim that can improve dimensional stability, which can be important in achieving the multiple cleaning cycles typically demanded before a bag is replaced. ▼The fabric may also have a membrane of expanded PTFE laminated to the upstream surface to limit penetration of the particles into the depth of the fabric, making the fabric easier to clean.

Slide 7

Some high performance fibers used in baghouse fabric filters are shown here. Teflon has the highest performance properties, but because of its extremely high cost, is only used where nothing else will work. The materials are listed in order of descending cost, so of course glass is used wherever conditions will permit its use. But for coal-fired power generation, glass' poor acid resistance is insufficient in most cases, and the other fibers shown do not have, by themselves, the proper combination of chemical and thermal resistance at a low enough price to add significant value in large scale applications.

Slide 8

▼The first problem with many of these high performance fiber offerings is their value or price to performance ratio. For example, meta-aramid fiber prices are lower than most other baghouse filter fibers, but they do not have good chemical resistance to the acids that we know will be in the off-gas stream in coal combustion. ▼The second problem is availability. The processes for making many aramid-based polymers and fibers is complex and costly, and so global capacity is somewhat limited. The fiber spinning process involves the use of solvents that makes it difficult for new production facilities to get environmental approvals. ▼Finally, new proposed air purity legislation such as $PM_{2.5}$ will require better filtration of particles as low as 2.5 microns aerodynamic diameter, which will require more baghouse installations and drive increases in fiber demand, further affecting the current availability of many of these specific fibers.

What's needed is a lower-cost material that has sufficient heat and chemical resistance.

<u>Slide 9</u>

The material of choice for coal-fired baghouse fabric filter applications is a filter medium made with fibers of polyphenylene sulfide, or PPS. PPS starts out with an automatic cost advantage because the polymer cost is significantly lower than aramids. On top of that, PPS is a thermoplastic that can be spun into fibers using a less costly melt extrusion process. So PPS fibers are typically available at a significant cost savings over other high performance fibers. ▼

PPS is available in fiber form, and new fiber spinning capacity does not require the same level of regulatory review that solvent-spun fiber plants do. ▼ On the other hand, current global PPS polymer capacity is not sufficient to meet demand, so there are availability problems with PPS as well. A little later, I'll introduce one new way we've devised to alleviate this problem.

Can PPS fibers deliver improved filtration efficiency over other high performance fibers? You might not initially think so, ▼but I'll soon describe new technology that we believe will allow the increased filtration efficiency of smaller particles that may help replace laminated membranes and their use.

<u>Slide 10</u>

To get a better look at how PPS can achieve some of these technological advances, let's take a look at the polymer. This is the chemical structure of the PPS monomer.

<u>Slide 11</u>

And here are some of its characteristic properties. ▼Baghouse fabric filters require good tenacity to keep their shape and structure during repeated cleaning cycles, and PPS fibers can be made with plenty to spare, typically with tenacities around 4 grams per denier.

▼If properly heat-set, PPS fibers can have essentially negligible shrinkage, which is particularly important to for maintaining designed fabric porosity and dimensions in a high temperature environment. Shrinkage can typically be kept below 2% at temperatures as high as 180ºC.

▼PPS is inherently flame resistant, with an LOI of 34%, which is even higher than that of meta-aramids. This does not mean that PPS is as flame resistant as aramids in every respect, because aramids will not melt, while PPS will. But this is one of those areas where aramid fabrics can be over-engineered for the application, because baghouse fabric filters in coal-fired power plants do not commonly face the risk of fire. So PPS' flame resistance is a necessary safety factor in the case of an unexpected fire, but the flame resistance of aramids is not necessary because live flames are not part of the day-to-day environment of the application.

In asphalt plant baghouses, where live sparks are common, PPS can melt away and leave a hole that destroys the effectiveness of the filter, so in these plants, aramids are still the fiber of choice over PPS fibers. But that's an area we're working on, and we may have something to report in that area by next year.

▼ Finally, one characteristic property of PPS that unlocks most of its advantages over aramids is its thermoplasticity. Because aramid fibers must be spun in a solvent-based process, there are practical limits to the sizes and shapes of the fibers that can be made. It should be noted that this is a limitation for all of the other baghouse fibers besides aramids, as well. Thermoplastics, though, can be made into fibers using a melt-spinning process, which is not only less costly, as I mentioned earlier, but is also much more versatile.

<u>Slide 12</u>

This chart illustrates just how well-suited PPS is for baghouse fabric filtration in regard to its heat resistance. Because the power plant baghouse gases are hot and wet, we've looked at the strength loss of three candidate fibers in a 160ºC autoclave for up to 144 days. Polyester fibers will actually withstand baghouse temperatures fairly well if the heat is dry, and they're so much cheaper than either PPS or aramids that they might well be used in the application if not for their susceptibility to hydrolysis. What may come as a bit of a surprise, though, is that meta aramids are also susceptible to hydrolytic decomposition, though obviously to a lesser degree than polyesters. But if you have a choice (and you do), it's clear that PPS provides better performance in this regard, even before you consider the lower price.

<u>Slide 13</u>

Here we see that PPS is also superior to meta-aramid fibers in maintaining strength in sulfuric acid environments. Sulfuric acid is shown here because it's the most important corrosive chemical in coal-fired power plant baghouses. But PPS also exhibits excellent resistance to most other corrosive liquids, including other acids, bases, inorganic solutions, hydrocarbons, and organic solvents, even at elevated temperatures.

But this chart and the previous one point out that PPS' properties are actually superior to those of meta-aramid fibers in the two most critical areas for the application of filtering coal-fired power plant exhaust gases.

<u>Slide 14</u>

I mentioned earlier that PPS derives significant advantages over other high performance fibers used in baghouse fabric filters from its ability to be made into fibers via a melt-spinning process. One thing that's easily done in a melt spinning process but impractical in other fiber processes is the creation of fibers with non-round cross sections.

▼Probably the most common shaped cross section made by melt-spinning processes is the trilobal fiber, which is a common shape among nylon and other melt-spun carpet fibers. The advantage of a trilobal cross section in baghouse filters is that it provides increased surface area, and as a result it thereby provides more effective filtration, and may produce superior results with fine-particle filtration.

▼An even more articulated, if less common cross section is this one, known as the 4DG cross section. It was originally developed in polyester for the purpose of moving moisture through capillary wicking. In PPS, this cross section is even more effective than a trilobal cross section in air filtration applications. A significant advantage of this cross section is that eddy currents create natural reservoirs for particles inside the fibers' grooves, where the filter can be loaded to a significant extent without ever blocking any of the fabric's pores and increasing the filter's pressure drop.

In the case of baghouse filters in series with electrostatic precipitators, PPS 4DG fiber may have an advantage over typical round cross-section coarse PPS fibers. The additional surface area of the 4DG cross-section will insure high particle removal efficiency while at the same time insuring that the permeability of the fabric filter remains open enough to control opacity and pressure drop at the same time.

▼And going the opposite direction, this ribbon cross section fiber would also be marginally better than a round cross section in terms of its surface area, but it is showing even greater promise in providing a fabric surface that resists particle penetration into the depth of the fabric, thereby mitigating the need for a PTFE laminate.

<u>Slide 15</u>

Here's another advantage that melt-spinning offers over the solution-spinning process used to make other baghouse fibers. Purpose-built melt-spinning processes can produce bicomponent fibers, or fibers coextruded with two polymers in each fiber. The fiber cross section shown here has a core of polyester surrounded by a sheath of PPS. The polyester in the core dramatically reduces the materials cost of the fiber, and thus the eventual fiber price. Meanwhile, the PPS sheath protects the polyester core from the harsh environment of the baghouse, so the polyester is not destroyed.

Note that in addition to extending the cost advantage that PPS enjoys over most other fibers, this new technology, developed just in the last 12 months, also addresses the problem of polymer availability. A fiber comprising 50% polyester in the core allows twice the number of bag filters to be made from any fixed quantity of PPS polymer.

Polyester/PPS sheath/core fibers like these are being tested in baghouse fabric filters today and show promise for many applications.

Slide 16

Here's another fiber cross section that can be made using bicomponent spinning technology. This is a fiber with a hollow core, and with alternating wedges of PPS and polyester arranged around the core. How on earth could something like this be useful in baghouse filtration?

The usefulness comes from the fact that this kind of cross section is designed for the alternating wedges to be produced as a single fiber for the sake of throughputs and handling efficiencies, thereby keeping costs low, but to split apart into individual microfibers after being made into a fabric. If the polyester component is replaced with another high performance resin type, the resultant fiber can be processed into a microdenier cap that contains fibers that will split into subdenier fibers (similar to meltblown diameters) and can replace the need to laminate expanded PTFE membranes onto the filter fabric surface to control particle penetration.

Slide 17

So if we make a filter felt from a 3 denier fiber like this, ▼after the needling is done, the individual segments separate into 16 discrete microfibers averaging less than two tenths of a denier each.

Slide 18

When we first introduced improved PPS fibers as an advantage over conventional materials for baghouse fabric filtration in coal-fired power plants a few slides ago, ▼it was already clear that PPS offered a cost advantage over incumbent fibers. But now you know how bicomponent fiber spinning technology can improve that cost and performance (value) advantage even further.

There was some uncertainty about the availability of PPS polymer, ▼but it should be clear now that bicomponent technology can also extend the availability of even limited supplies of PPS polymer.

And it was unclear then that PPS could offer any advantage over incumbent fibers in improving the filtration of smaller particles, ▼but of course I've just shown you how microfibers, as well as shaped fiber cross sections can do things that can't be done with conventional fibers to address this very problem.

Ultimately, this all adds up to the conclusion that novel PPS fibers offer compelling advantages in our efforts to solve the▼bigger problem I set forth at the beginning of the presentation.

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