Issue 04/2010, Page 89 to 92

SPECIAL PRINT

VGB PowerTech

International Journal for Electricity and Heat Generation

# Filtration with High-efficiency Fibres in Coal-fired Boiler Applications

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# Filtration with High-efficiency Fibres in Coal-fired Boiler Applications

*Florin Popovici*

***Kurzfassung***

**Filtration mit Hochleistungsfasern in kohlegefeuerten Anlagen**

*Moderne Filtermedien basieren auf Polymerfasermaterialien. Die Auswahl erfolgt einerseits nach den chemischen Eigenschaften des Grundmaterials und andererseits ist die Filtrationsleistung hinsichtlich erzielbarer Emissionswerte ein wesentliches Kriterium. Composite Materialien – sogenannte Fasermischungen vereinen bei geeigneter Kombination die positiven Eigenschaften der Grundmaterialien. Die Filtrationseigenschaften von multilobal geformten P84 (Polyimid) Fasern und trilobalen Procon (PPS – Polyphenylensulfid) Fasern werden mit runden Standardfasern aus PPS gegenübergestellt. Eine Evaluierung der theoretischen Überlegungen erfolgt in einem eigens dafür konzipierten Teststand, der eine Untersuchung der Filterschläuche direkt in der Anlage erlaubt. Da die für den Test vorgesehenen Filterschläuche in der Anlage eingebaut sind, erfahren sie die gleiche Staubbeaufschlagung und chemische Atmosphäre wie die anderen Filtermedien der Anlage. Weiters wird auf Alterungsmechanismen von Filtermaterialien eingegangen.*

*Der derzeitige Stand der Technik hinsichtlich Konstruktion und Faserauswahl von Filtermedien wird mit Beispielen aus Kraftwerksanlagen aus Südafrika gezeigt. Der Schlauchfilter hat dort lange Tradition und somit liegt eine lange Einsatzerfahrung mit verschiedenen Materialien aus Polyacrylnitril (PAN), Polyphenylensulfid (PPS) und P84 (Polyimid) vor.*

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## General

During the past few years coal consumption in power plants has seen a significant growth and it is expected that for the next decade the coal demand will increase at an even higher rate. Most of the growth in coal use arises in China and India. Former Eastern Block countries will also see a high coal demand during the next years. While the coal demand will continue to rise, the maximum required particulate emission levels are expected to be reduced to values lower than 20 mg/Nm$^3$. In many instances the use of a single coal source is no more a viable strategy and coal-fired plants require access to different coal sources. With each type of coal, after the combustion process, the resulting gases and fly ashes have different properties in terms of chemical constituents and particle size distribution. This requires an emission control technology operating consistently within the regulatory emission limits for a wide range of process parameters. In the case of Fabric Filter Plants (FFPs), the filtration material design and the selection of fibres are of critical importance. The fibres mechanical, chemical and filtration properties associated with the process parameters need particular attention. The most common type of filter material used in coal-fired boiler bag houses is based on a needle felt composition. Fibres like PPS (Polyphenylenesulphide), PI (P84-Polyimide), PTFE (Polytetrafluoretilene) and PAN (Polyacrylnitrile) are used individually or in specific combinations to form the needle felt.

## Needle Felt Materials

A needle felt comprises of a base material or support scrim upon which a web or batt of fibres is bonded by means of a needling process. The batt consists of one or more layers of fibre orientated randomly into open batt, where the fibres are arranged in both horizontal directions. A batt can be applied to one or both sides of the support material (scrim). By blending fibres with good chemical resistance (i.e. PTFE) with fibres characterised by better filtration properties (i.e. PI) we can achieve a stable filter media leading to low particulate emissions. An extra layer of fine fibres characterised by a high surface area could also be added onto the filtration side in order to prevent the penetration of fine dust particles into the needle felt leading to excessive filter bags cleaning. The bag cleaning applies a mechanical stress onto the bag material and has a direct effect on the bag life. The higher the cleaning rate the lower the bag life. The most common types of needle felts are shown in Figure 1.

## Dust Cake Filtration

The needle felt bags have to be pre-coated with special materials before they are put in

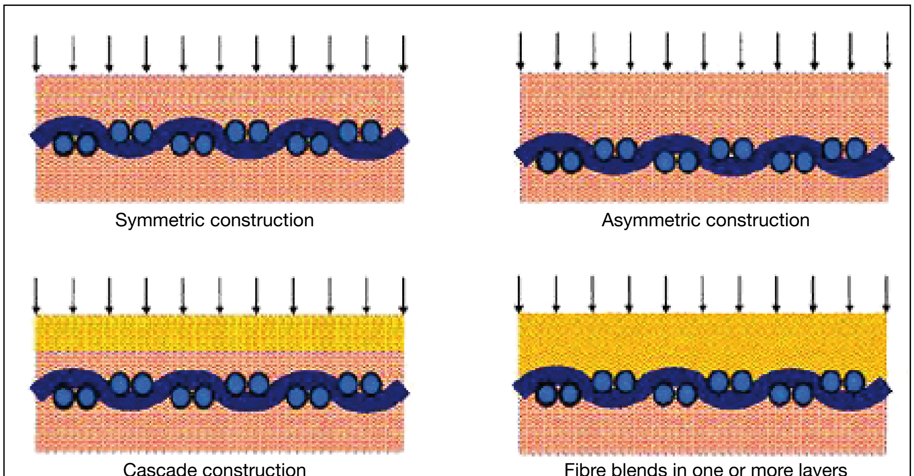



*Figure 1. Needlefelt constructions.*

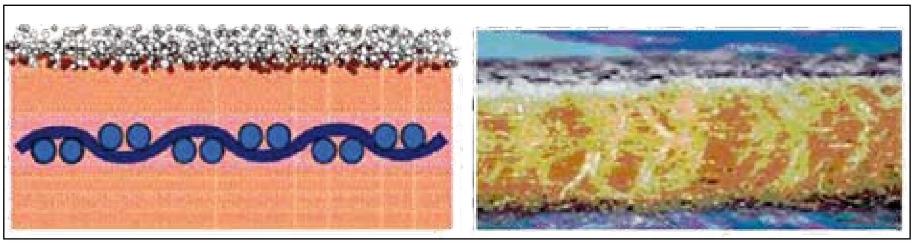


*Figure 2. Stable dust cake – schematic and picture.*

normal operation. The main reason for pre-coating is the formation of dust cake which, actually, takes over filtration. This dust layer is named "permanent dust cake". The main role of needle felt fibres in combination with the pre-coating material is to form a stable and porous permanent dust cake. The most common pre-coating materials used in coal-fired boiler bag houses are calcium hydroxide and calcium carbonate. The fly ash accumulates onto the permanent dust cake and it is removed at regular intervals by the cleaning system in relation to the pressure drop across the FFP or a time controller. The fly ash removed by the cleaning system is named "removable dust cake". A non-stable permanent dust cake will lead to the blinding of the needle felt with dust particles penetrating between the fibres in the depth of the material. Some of the dust particles cross the whole needle felt and are released during pulsing creating the so-called "pulsing puff". Figure 2 shows a schematic and a figure of a filter material cross section taken from a clean needle felt with stable permanent dust cake (surface filtration). The filtration process consists of two phases; the formation of the permanent dust cake or pre-coating of bags and the filtration by the permanent dust cake.

## High-filtration Efficiency Fibres

It was realised that, in addition to fibre fineness, the cross section of the fibre plays a crucial role in improving the filtration properties of a needle felt. A fine round fibre of 1.7 dtex has a larger surface area than a 2.2 dtex round fibre and a fine multi-lobal fibre (1.7 dtex) has an even higher surface area than the 1.7 dtex fine round fibre. The higher the surface area, the smaller the pores between the fibres and the higher pores total surface. The trajectory of a dust particle while travelling across the filtration material is also more complex. Figure 3 shows the relative surface area of different titre round, irregular multi-lobbed and regular tri-lobbed fibres.

## Filtration Mechanisms – Round versus Irregular Multi-lobal Fibres

It is well documented that irregular multi-lobal fibre-based needle felts like P84 (PI) have much higher filtration efficiencies if compared to round fibres based filter materials. A study was performed, with assistance from the Technical University of Vienna, to understand the details and exact reasons for the lower particulate emissions and pressure drop across bag houses provided with P84 based needle felt materials. By comparing the projected diameter of two types of fibres with the same titre (weight related to length) we can notice that the irregular multi-lobbed P84 fibre has a 30 % larger projected diameter than the round fibre. During the needle felt manufacturing process the fibres are entangled in a fleece or web which is then needle-punched and compacted to form the filter material. In the final product the fibres will lay on top of each other forming a porous and compact material. The felt resulting from the irregular multi-lobbed P84 fibres is more porous than the felt produced with round fibres. A flow simulation was performed for both types of fibres. The results of the Computational Fluid Dynamic (CFD) model presented in Figure 4 show the presence of low velocity areas. The fine dust particles will accumulate in the low velocity areas, actually, charging the fibres and, implicitly, the filter material. Due to the irregularity of the P84 fibre cross section, the filter material charged with dust maintains a high porosity, because the dust collected between the fibre lobs is not in the way of the flow lines (Figure 5). So P84 based needle felts are able to fulfil even lowest emission standards. The particulate emission levels are related to the design features of the FFP and the titre of the P84 fibres. The lowest emission is achieved with a P84 fibre titre of 0.6 dtex. In summary, the filtration theory with multi-lobal fires is the following:

- The felt constructed from multi-lobal fine fibres has a high surface area, thus, it is irregular and porous.
- The dust separates in the low velocity zones of the multi-lobal fibres forming the permanent dust cake.

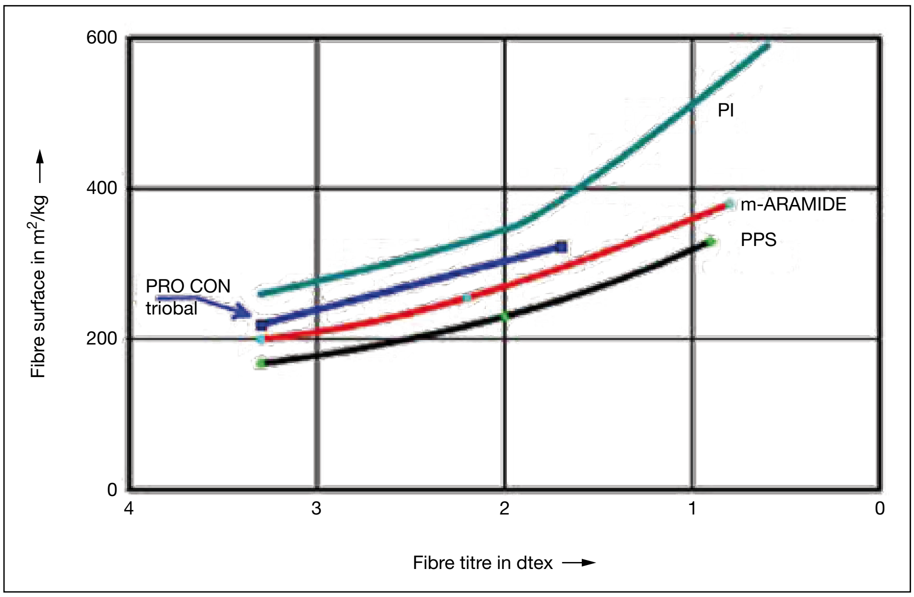



*Figure 3. Fibre surface versus fibre titre (size).*

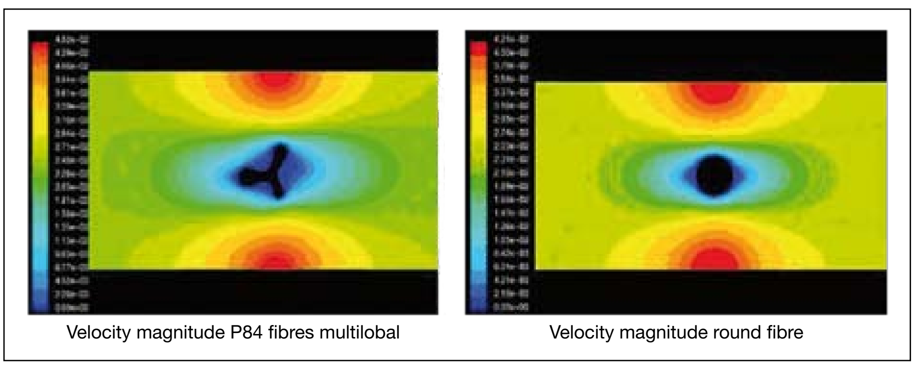



*Figure 4. CFD model – low velocity areas in light blue color.*

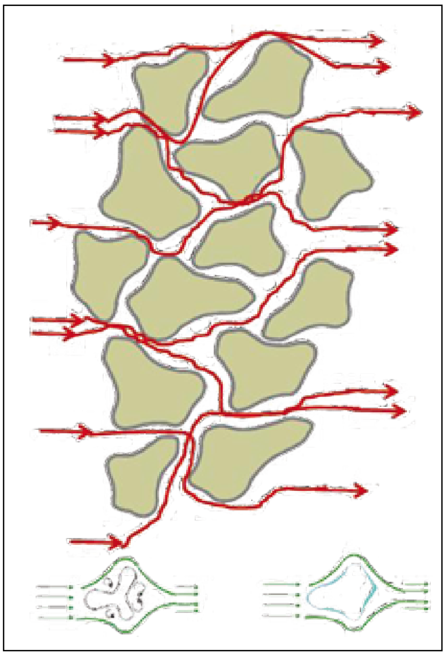


*Figure 5. Flow lines through the dust cake.*

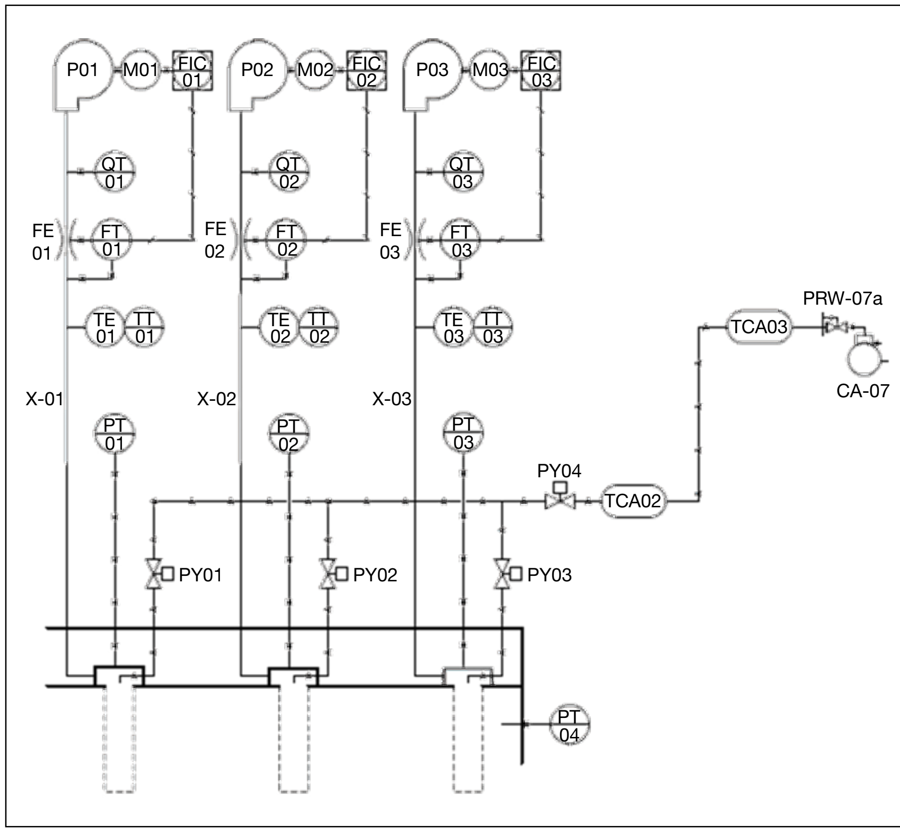



*Figure 6. EVONIK filtration test rig schematic.*

– The structure of the filter media is transferred to the permanent dust cake and the dust cake formed by multi-lobal fibres is irregular and porous. The flow-lines are affected to a lesser extent if compared to the round fibres dust cake.
– The dust cake formed by multi-lobal fibres is stable during the bag cleaning phase.
– Multi-lobal felts can collect finer dust particles than felts based on similar titre round fibres.

## Performance Test of Filter Material in an Industrial-size Test Rig

The Evonik Filtration Test Rig (FTR) was developed for evaluating filtration and chemical resistance properties of three different bag filters. This could assist with the selection of a superior or a more cost effective type of filter bag for a specific coal-fired boiler bag house application. The FTR comprises of three main components: platform with suction fans, instrumentation and control, inspection window adaptor and tube plate bag covers. The FTR schematic is shown in Figure 6. We tested three types of bags in South Africa, Johannesburg at the African Explosives Limited coal-fired boiler bag house. At this plant, one fluidised bed boiler supplies steam for various processes. The associated pulse jet bag house is provided with eight compartments. The normal bag house flue gas inlet temperature is between 150 °C and 180 °C and the flue gas dust loading is about 30 g/Nm$^3$. Each of the tested bags had a PPS scrim and the inner batt constructed out of 2.2 dtex PPS fibres but with different filtration surfaces: bag 1 has 1.3 dtex PPS round fibres, bag 2 has a blend of P84 1.7 dtex multi-lobal with Procon PPS 1.7 dtex tri-lobal and bag 3 has Procon PPS 1.7 dtex tri-lobal. The test was performed at constant flow and identical ΔP set points. The criterion for comparison was the pulsing rate required to control the ΔP within the set range. The results are presented in Figure 7 and indicate that the bag based on the blend of multi-lobal and tri-lobal fibres had a 60 % lower pulsing rate than the bag based on fine round fibres. It is interesting to mention that although the set ΔP range was exactly the same for each bag; the multi-lobal/tri-lobal bag had a lower average ΔP than the round fibre bag. This is explained by the fact that, after cleaning, the pressure differential through the bag was dropping at much lower levels due to the porosity of the permanent dust cake. The bag based on tri-lobal fibres had better filtration properties than the round fibre bag and inferior to the multi-lobal/tri-lobal bag. The number of pulses influences directly the bag life, as each pulse represents a me-

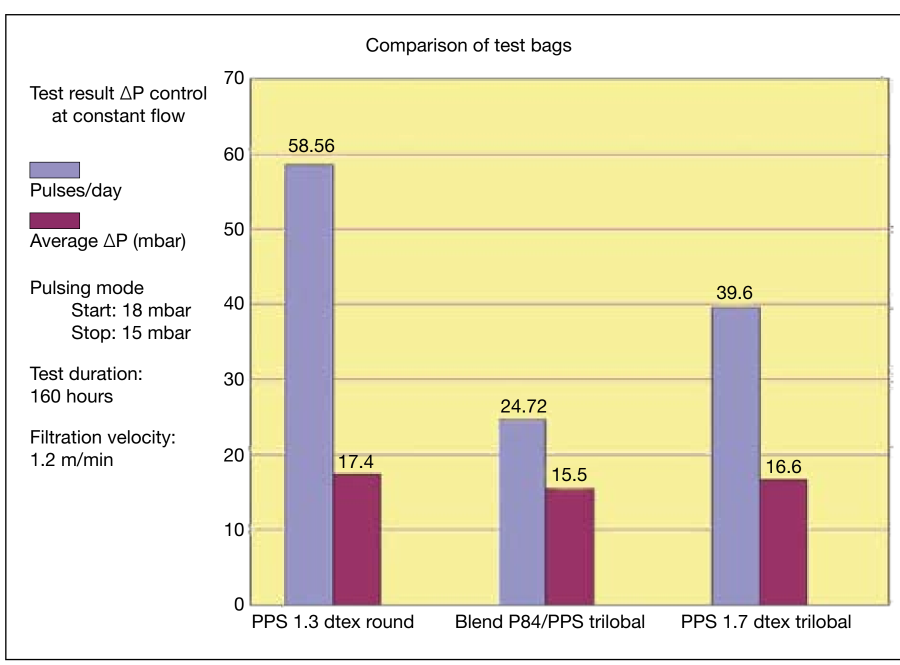



*Figure 7. Filtration Test Rig (FTR) results.*

*Table 1. Technical specification of the AEL utility (South Africa) boiler bag house.*

| | |
|---|---|
| Boiler: | Fluidised bed boiler – Babcock |
| Filter material: | Procon/(PTFE)/P84 multi-lobal + Procon tri-lobal |
| Type of cleaning: | Pulse jet – off line |
| Flow: | 63 $m^3/s$ |
| Temperature: | 150 to 180 °C |
| Acid dew point: | 140 °C |
| Filtration face velocity: | 1.044 m/min |
| Filtration face velocity (n-1): | 1.19 m/min with one cell isolated |
| $H_2O$: | up to 7 vol. % |
| $O_2$: | 9.0 to 14 vol. % |
| $SO_x$: | 200 to 300 $mg/Nm^3$ |
| $NO_2$: | < 5 $mg/Nm^3$ |
| Cleaning of economiser tubes: | Acoustic cleaning |
| Air attemperation: | Yes |
| Particulate emission: | 5 $mg/m^3$ (after bag change) |
| Guarantee: | < 30 $mg/m^3$ |

chanical stress for the filter material, thus the bags pulsed less will have a longer life in operation. The superior performance of the multi-lobal fibre based bag filters is also proven by actual performance of such bags in bag houses around the world.

## Chemical Resistance of PAN, PPS, P84 and PTFE

The filter bags operating life is also related to the resistance of their fibres to the operating environment. Each fibre has its limitations in terms of operating temperature, oxidation and filtration properties. Therefore, in many cases, a composite material will have better properties than the filter media based on individual fibres. For example, PPS fibres have a high acidic resistance but P84 shows a much better filtration performance. So for specific applications, a material based on a blend of PPS and P84 fibres will show a much better overall performance than materials based on the individual PPS fibres. In addition, if the operating temperature is over 180 ˚C, a felt based on a PPS and P84 with a PTFE scrim could be the winning solution. The PTFE fibres have poor filtration properties; therefore, for high-temperature applications a material based on a blend of PTFE and P84 is desired. PAN-based materials could also be used in coal-fired boiler bag houses but in these cases the bag houses have to be equipped with gas temperature control systems. These are mainly dampers allowing ambient air to flood the bag house inlet duct. PAN materials can operate continuously at maximum 130 ˚C. Particular attention is to be paid to the temperature stratification in the bag house inlet duct in order to avoid hot or cold spots in the bag house. It is known that, especially, the Ljungstrom air heaters create a significant temperature gradient in the air heater gas exit duct. A well designed gas temperature control system can overcome the temperature stratification if it is based on individual control loops (thermocouple/cooling damper) for each significant gas temperature path.

## Bag Filter Plant References: Eskom South Africa

Eskom, the main utility in South Africa, is operating some of the largest coal-fired power plants provided with bag houses in the world. Two of them are equipped with bag houses based on PAN bag filter needle felt materials: Majuba Power Station, 6 units (3 x 715 MW and 3 x 685 MW) and Hendrina Power Station 3 units (10 x 200 MW). Three boilers at Duvha Power Station were equipped initially with PAN type bags but the material was damaged by acidic gases and all sets of bags were replaced, eventually, with a material based on a PPS & P84 blend. At Majuba, the initial sets of bags were based on pure PAN fibres and later the specification was changed to a blend of PAN and P84, which rendered a better performance. Eskom has specified the bag house filter media for the new power plants Medupi (8 x 800) and Kusile (8 x 800) based on the latest Majuba felt; a blend of PAN & P84. The other bag house power plants in Eskom have bag filter materials made out of a blend of PPS & P84: Camden (8 x 200 MW), Grootvlei (3 x 200 MW), Duvha (3 x 600 MW), Arnot (6 x 350MW) and Hendrina (2 x 300 MW). Two other boilers at Hendrina have plain PPS bags.

## AEL South Africa – Fluidised Bed Boiler Bag House

The filter material for the AEL South Africa bag house was based on woven fibre glass bags and the life achieved was about one year of operation with particulate emissions in excess of 300 $mg/Nm^3$. The high particulate emissions created significant abrasion in the duct work and onto the suction fan blades to the extent that the fan had to be replaced once per year. The filter material specification was changed to a needle felt based on a PTFE scrim with a Procon (PPS) inner batt and a surface batt formed by a blend of irregular multi-lobal P84 1.7 dtex with Procon tri-lobal PPS 1.7 dtex fibres. The life achieved by the new set of bags is six years up to date and the bag replacement is planned for early next year.

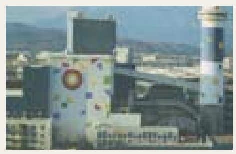
The technical specification of the AEL utility boiler bag house is listed in Table 1. □

# Convincing facts - P84 and Procon references

## Fly ash collection for coal fired boilers.

Coal fired power station South Africa

Coal fired boiler Canada



Coal fired boiler Slovenia

Coal fired boiler Czech Republic

### Chemistry at Work:

Being resistant to most chemcial substances Procon PPS can operate under harsh environment. This is necessary as the operation of the filter is sometimes below the acidic dew point. The temperature stability of 200 °C offers a wide flexibility of the operating mode and allows a certain buffer in case of preheater malfunction.

### Flexibility in operating conditions:

Bag filters equipped with P84-Procon blended filter bags are highly flexible whenever the coal supply is changed and biomass is used as secondary fuel to subsidize part of the main fuel. In addition sudden changes in the operating mode with regards to boiler load and CO generation can be managed with the filter media.

### In summary P84-Procon blends offer these advantages:

- high chemical stability
- high temperature stability up to 200 °C
- suitable for co-fired boilers
- superior filtration performance
- low pressure drop
- cost effective solution

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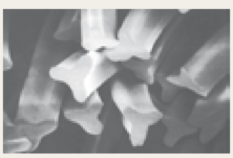
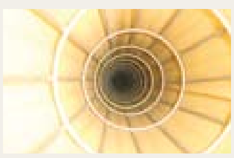


Procon fibre with trilobal cross section

Illustration of a P84-Procon blended needle felt



View inside a P84 based filter bag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