Steffen Heidenreich
Pall Schumacher GmbH
Postfach 15 62,
D-74555 Crailsheim, Germany
Phone: + 49 7951 / 302 - 172
Fax: + 49 7951 / 302 - 280
e-mail: steffen.heidenreich@sut.com
(Primary Contact)

Walter Haag
Pall Schumacher GmbH
Postfach 15 62,
D-74555 Crailsheim, Germany
Phone: + 49 7951 / 302 - 151
Fax: + 49 7951 / 302 - 280
e-mail: walter.haag@sut.com

Astrid Walch
Pall Schumacher GmbH
Postfach 15 62,
D-74555 Crailsheim, Germany
Phone: + 49 7951 / 302 - 154
Fax: + 49 7951 / 302 - 280
e-mail: astrid.walch@sut.com

Bernd Scheibner
Pall Schumacher GmbH
Postfach 15 62,
D-74555 Crailsheim, Germany
Phone: + 49 7951 / 302 - 180
Fax: + 49 7951 / 302 - 280
e-mail: bernd.scheibner@sut.com

Robert Mai
Forschungszentrum Karlsruhe GmbH,
Institut für Technische Chemie,
Bereich Thermische Abfallbehandlung,
Postfach 36 40,
D-76021 Karlsruhe, Germany
Phone: + 49 7247 / 82 - 3146
Fax: + 49 7247 / 82 - 6549
e-mail: robert.mai@itc-tab.fzk.de

Hans Leibold
Forschungszentrum Karlsruhe GmbH,
Institut für Technische Chemie,
Bereich Thermische Abfallbehandlung,
Postfach 36 40,
D-76021 Karlsruhe, Germany
Phone: + 49 7247 / 82 - 31 46
Fax: + 49 7247 / 82 - 6549
e-mail: hans.leibold@itc-tab.fzk.de

Helmut Seifert
Forschungszentrum Karlsruhe GmbH,
Institut für Technische Chemie,
Bereich Thermische Abfallbehandlung,
Postfach 36 40,
D-76021 Karlsruhe, Germany
Phone: + 49 7247 / 82 - 2655
Fax: + 49 7247 / 82 - 4373
e-mail: helmut.seifert@itc-tab.fzk.de

Ceramic Hot Gas Filter with Integrated Failsafe System

Keywords: Hot gas filtration, ceramic filter, filter element cleaning, pulse cleaning, failsafe system, safety filter

Introduction

Filtration at high temperatures is a technology which is applied in many processes. Hot gas filters are key parts to prevent gas turbines from damage in advanced coal-fired power plants, such as pressurized fluidized-bed combustion and integrated gasification combined cycle processes. In refineries hot gas filters are used to recover the catalyst from fluid catalytic cracking units for fulfilling stringent environmental demands. Some further examples for the successful use of hot gas filters are: product recovery in the production of ceramic powders, pigments or nanoparticles, the cleaning of syngas from biomass and waste pyrolysis or gasification and the cleaning of flue gases from radio-active waste incineration. Ceramic filters are well proved for hot gas filtration because of their excellent thermal and chemical stability as well as their high filtration efficiency and their long-term durability. Filtration at very high temperatures and pressures as well as under chemical aggressive conditions is possible when using ceramic filter elements.

One potential risk of ceramic filter elements is that they can break under high mechanical stresses which can occur when problems in the operation of the process arise. Under normal operating conditions and correctly mounted filter elements the risk of a candle failure is close to zero. But a candle failure cannot be absolutely avoided, especially in case of troubles. To overcome the potential risk of an unscheduled cost-intensive shut-down of the process a failsafe system for ceramic filters is required. In conventional filter systems jet pulses are used to clean the filter elements. The integration of a failsafe system in the clean gas side is very difficult in case that a jet pulse cleaning system is used. If a failsafe system would be integrated between the jet pulse cleaning system and the filter candle the cleaning intensity would be dramatically decreased. Furthermore, using a jet pulse cleaning system problems arise when high contents of very fine particles and sticky particles are filtered. Such particles cause clogging and an increase of the pressure drop of the filter since the cleaning intensities of the jet pulses are too low to detach the particles completely from the surface of the filter elements.

Objective

In order to integrate a failsafe system and to improve the cleaning intensity a new cleaning method was recently developed, the CPP (coupled pressure pulse) cleaning (Heidenreich et al. 2001). For the CPP method the cleaning system is directly coupled with the filter candles. One feature of this new technique is that the cleaning gas pressure exceeds the system pressure only by 0.05 to 0.1 MPa, whereas in case of conventional jet pulse systems two times the system pressure (at least 0.6 MPa) is standard. The key advantage of the coupled pressure pulse cleaning is that a safety filter for each filter candle can be integrated in the clean gas side of the filter. Thus, a candle failure is not longer a serious problem. The integrated safety filter enables the operation of the filter system also in case a filter candle breaks. This increases the availability of the filter and prevents an unscheduled costly shut-down of the system.
In this paper the design of the ceramic filter with the failsafe system and the CPP cleaning will be described. The new developed safety filter elements, their pressure drop and their filtration

and clogging behavior will be shown. Tests of single system components, of the whole filter system and first experiences of operating this system will be reported.

Description of the CPP-Recleaning Technique

The principle of the CPP cleaning technique is shown in comparison with the conventional jet pulse cleaning in Figure 1.

In case of jet pulse cleaning a blow pipe is located in a defined distance above the head of the filter candle. The blow pipe is connected to a pressurized back-pulse gas reservoir. Normal back-pulse gas pressures are between 0.5 to 1 MPa for a filter system operated at atmospheric pressure. For high pressure applications, for example a pressurized coal combustion, the cleaning gas pressure for jet pulse recleaning should be twice as high as the system pressure. For recleaning the back-pulse gas streams into the filter candle and the kinetic energy of the free jet is transfer into static pressure. The over pressure inside the candle results in the recleaning of the candle. The over pressure and correspondingly the cleaning intensity is determined by the flow velocity of the jet at the outlet of the blow pipe, the mass flow rate of the jet, and the geometry of the blowback system. The flow velocity of the jet is limited to sonic speed.

The CPP cleaning system is based on the direct coupling of the back-pulse gas reservoir and the filter candle. One can imaging the CPP system as an extreme case of a jet pulse system: reducing the distance of the blow pipe to the filter element to zero and simultaneously increasing the inner blow pipe diameter to the inner diameter of the filter candle lead to the direct coupling of the blowback system and the filter candle. The connecting duct between the back-pulse gas reservoir and the filter candle has to be porous so that the filtrated gas can flow through. In case of a candle failure the porous duct acts as a safety filter.

The direct coupling of the blow-back gas reservoir and each filter candle in technical systems is difficult. For this reason technical systems are built up in a modified way. The principle set-up of a hot gas filter with CPP recleaning system is shown in Figure 2. The filter vessel is divided into a raw gas and a clean gas side by a tube sheet where the filter elements are fixed. The gas enters the filter by the raw gas inlet and flows through the filter candles to the clean gas outlet. The filter elements are split into groups by dividing the clean gas area into several cells. The different groups are sequentially cleaned on-line. In contrast to the conventional jet pulse cleaning the CPP cleaning system is directly coupled with the filter candles. During filtration the cleaning system is separated from the clean gas room by the recleaning valve. By opening this valve the pressure inside the clean gas room and the filter candles is fast increased for a short time. This fast increase of the pressure results in a high cleaning intensity. In order to attain the fast increase of the pressure the recleaning duct and valve have to be well dimensioned.

The cleaning gas pressure required by the CPP cleaning is considerably lower than the pressure required by the conventional jet pulse cleaning. The cleaning gas pressure has to be only 0.05 to 0.1 MPa higher than the system pressure to achieve cleaning intensities which are higher than those achieved by jet pulse cleaning. In order to build up the pressure in the clean gas room and in the filter candles without losing cleaning gas through the clean gas outlet a special system component, the so called hydraulic switch, is installed in the clean gas outlet. The function of the hydraulic switch is characterised by its flow resistance. For laminar flow as in case of filtration the flow resistance of the switch is very low. During the cleaning the flow is turbulent and the resistance of the switch is high.

The CPP cleaning system offers the possibility to add an individual safety filter for each filter candle, as shown in Figure 2. First the gas passes the filter candle and then the subsequent safety filter before it reaches the clean gas room. In case a filter candle breaks the safety filter has to separate the dust particles with high efficiency to ensure that the clean gas dust concentration does not exceed the given limiting value. The safety filter has a deep-bed characteristic so that it is clogged. Cleaning of the safety filter is not desired because this would result in an increased loss of cleaning gas and a reduced cleaning intensitiy for the filter candles still intact. During normal operating without failure the safety filter must have a low pressure drop.

Hot gas filter system

A prototype hot gas filter with CPP cleaning system was built up as part of the pyrolysis pilot plant “PYDRA” at the Karlsruhe Research Centre. Figure 3 shows the head of this filter unit. The single components of this prototype of CPP cleaning system, such as hydraulic switch, cleaning valve, fixation of the safety filter, are well designed for the operating conditions. The design of the hydraulic switch has to fulfil two requirements: i) a low pressure drop ii) a low loss of cleaning gas. The requirement of the cleaning valve is that it opens very fast and a high mass flow rate of cleaning gas is fast reached.

The filter is equipped with rigid ceramic filter candles (DIA-SCHUMALITH T 10-20) with a length of 1500 mm, an outer diameter of 60 mm and an inner diameter of 40 mm. The filter candles are arranged in two groups of three candles each. A newly developed individual safety filter is integrated between each filter candle and the clean gas room. The filter is designed for the operating temperature of the pyrolysis process of 550 °C. The operating flow rate is about 140 m^3/h. This corresponds to a filtration velocity of 2.3 cm/s. Nitrogen is used as cleaning gas. The supply tank and the cleaning duct are heated to 400 °C. Thus, the risk of condensation of gas components is reduced.

Filtration Trials

Before operating the filter system with pyrolysis gas we performed some series of stand-alone tests with the system. The reason for the stand-alone experiments was to evaluate the performance of the CPP recleaning system under defined conditions. In order to simulate a dust with a sticky and critical dust behaviour a special model dust was used. This model dust was a mixture of 80 wt.% of glass, 7 wt.% of sodium chloride, and 13 wt.% of calcium chloride. The chlorides are mixed in such a ratio to form an eutetic salt mixture. Thus, softening of the dust at a defined temperature is attained. Here the eutetic salt mixture had a melting temperature of 500 °C. The softening temperature can be adjusted by varying the mixing ratio and using different chlorides (Mai et al. 2000).

Figure 4 shows the pressure drop of the filter system operating with the model test dust at 525 °C. By operating the filter system at a temperature above the melting point of the eutetic salt mixture a sticky dust with critical cleaning behaviour was simulated. The back-pulse gas pressure was only 0.1 MPa above the system pressure, which in this case was atmospheric. A stable filtration cycle was achieved using the CPP cleaning system, even with the difficulty to filter, sticky dust.

The performance of the system was also investigated in case of a candle failure. A candle failure was simulated by removing one filter candle. The system was operated at 525 °C and the test dust with the melting point at 500 °C was used. Figure 5 shows the pressure drop for the start-up phase of the filter system. The pressure drop curve indicates that the safety filter clogs fast and remains clogged because of its depth filtration characteristic. A stable filtration was achieved using the critical model dust. This demonstrates that the newly developed individual safety filters were successfully integrated into the filter system.

The initial pressure drop of the system was higher than in case of normal operation. This is due to the fact that the filter area was reduced and the face velocity at the intact candles increased correspondingly. From the pressure drop curve it can be very well distinguished when the cluster with the broken candle and when the cluster with the intact candles is cleaned. If the cluster with the broken candle is cleaned, a lower decrease of the pressure drop is attained as compared to the cleaning of the cluster with the intact candles.

Comparison of cleaning intensities of jet pulse and CPP at a cluster of 18 filter candles

The cleaning intensities which can be achieved with a conventional jet pulse and the new CPP system were investigated by measuring the back-pulse pressures inside new filter candles. The measurements were performed at a cluster of 18 filter elements. We used a conventional jet pulse system with a venturi-ejector and a very fast opening recleaning valve, which needs about 30 ms for a full opening of the valve. The backpulse gas pressure was varied between 0.3 to 0.7 MPa. The measured back-pulse pressures inside the filter candles are shown in Figure 6. Additionally, back-pulse pressures measured for the CPP cleaning system are shown. A backpulse pressure of only 0.1 MPa is required for the CPP system to achieve the same pressure inside the filter candles as with the jet pulse system at a back-pulse gas pressure of 0.7 MPa. By increasing the backpulse gas pressure from 0.1 MPa to 0.2 MPa the pressure inside the filter candles and correspondingly the recleaning intensity is more than doubled. The CPP offers a high flexibility in adjusting the recleaning intensity by increasing the backpulse gas pressure. High cleaning intensities can be achieved by the CPP system. In contrast the cleaning intensity which can be achieved by the jet pulse system is significantly lower and limited. Increasing the backpulse gas pressure from 0.5 to 0.7 MPa results only in a low increase of the pressure inside the candle and correspondingly of the cleaning intensity.

Figure 7 shows a comparison of two different backpulse valve types both with the same nominal diameter used for the CPP system. The backpulse pressure which is achieved inside the filter candles depends on the characteristic of the recleaning valve. Thus, it is necessary to use a fast and geometrically optimised recleaning valve. But even for the valve typ 2 with the lower performance the cleaning intensities which are achieved are significantly higher than those achieved with the jet pulse system.

Performance of the safety filter

The CPP system offers the possibility to install an individual safety filter above each primary filter candle. This safety filter has to fulfil several requirements. In case of normal filtration it should have a low pressure drop. The length of the safety filter should be much smaller than those of the filter candle. This results in a higher face velocity. In case of a candle failure the safety filter should have a low particle penetration. Furthermore, it should be quickly clogged.

Safety filters with depth filtration characteristic were developed and optimized in some steps. The pressure drop of the safety filter in case of filtration has been reduced to 10 percent of the initial pressure drop of the filter candle. The performance of the safety filters was investigated in some laboratory experiments. In a test rig equipped with six candles the breakage of one candle was simulated. Figure 8 shows a view of the six safety filters. The one above the broken candle shows a dust cake on the inner side. The outer side is free from dust. Only a low amount of dust has penetrated in the structure of the safety filter. The filter and the dust inside were prepared and analysed by scanning electron microscopy. Figure 9 illustrates the cross-section of the safety filter with the upstream face above. The three pictures on the right show details at different positions with higher magnification. These figures indicates the clogging behaviour of the safety filter. The dust penetrates only a small distance into the matrix and clogs the pore channels up to a depth of about 2 mm.

The collection efficiency of the safety filter was investigated using a very fine dust with a median of the number particle size distribution of 0.25 µm. The particle concentration in the raw and the clean gas was measured with an optical particle counter. In Figure 10 the penetration of particles is shown as a function of the operation time. The safety filter was recleaned after each 30 minutes by a CPP system. The safety filter shows a very high collection efficiency. The collection efficiency increases with the operation time. This indicates that the filter cloggs more and more. After each recleaning cycle a short increase of the dust penetration can be detected. But this increase becomes shorter with increasing operation time and drops very quick to a low penetration value. This indicates also a clogging of the filter structure with increasing operation time. After six recleaning cycles which corresponds to an operation time of 3 hours the collection efficiency of the safety filter is comparable with that of the primary filter candle. In fact with the safety filter a high collection efficiency of 99.9999 to 99.99999 percent is achieved for this very fine dust used in the experiment. The development of high efficient safety filters was successfully performed.

Conclusions

The CPP (coupled pressure pulse) cleaning technique, which was developed in a co-operation between the Karlsruhe Research Centre and Pall Schumacher, has significant advantages compared to conventional jet pulse cleaning. High cleaning intensities are achieved with the CPP technique. Due to this fact stable filtration is obtained even for critical, sticky dusts. Furthermore, as a result of the high cleaning intensity the residual pressure drop of the system is low. Hence, filtration cycle or filtration velocity can be increased which reduces operating or investment costs. The CPP cleaning technique requires a cleaning gas pressure which exceeds the system pressure by only 0.05 to 0,1 MPa. This also reduces investment and operating costs, especially in case of pressurized applications.

Moreover, the CPP cleaning method offers the possibility to integrate an individual safety filter for each filter candle. The safety filters developed have low pressure drop and clog fast. A stable and safe operation of the newly designed filter system is obtained in case of candle failures. This has been demonstrated for the filtration of a sticky model dust. An unscheduled costly shutdown of the process caused by candle failures is no longer a problem using this promising new filter with integrated failsafe system.

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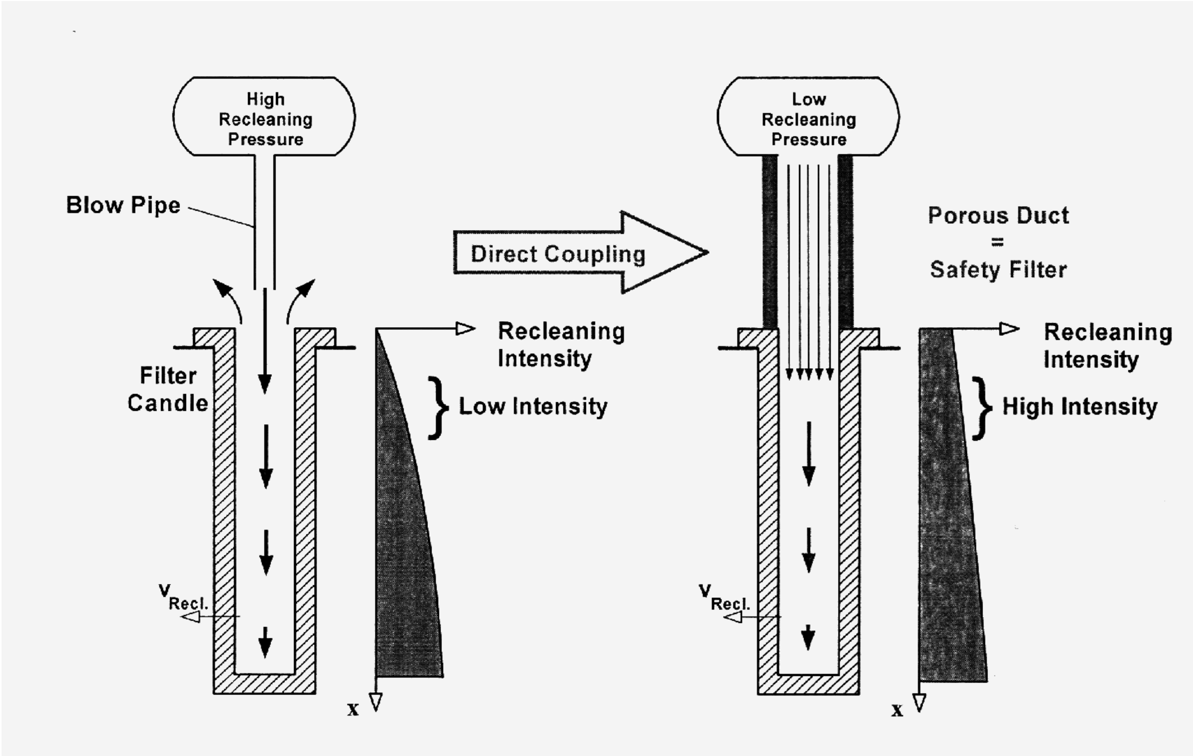

Fig. 1 Comparison of the principle of conventional jet pulse and CPP recleaning

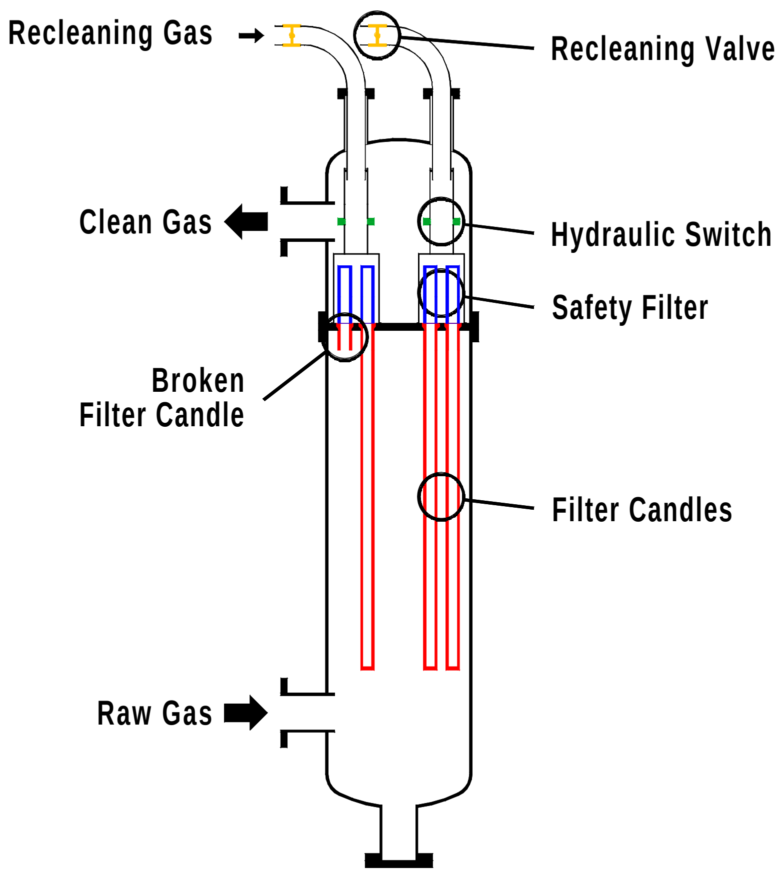

Fig. 2 Scheme of a hot gas filter with CPP cleaning system

Fig. 3 View of the filter of the pyrolysis pilot plant at the Karlsruhe Research Centre

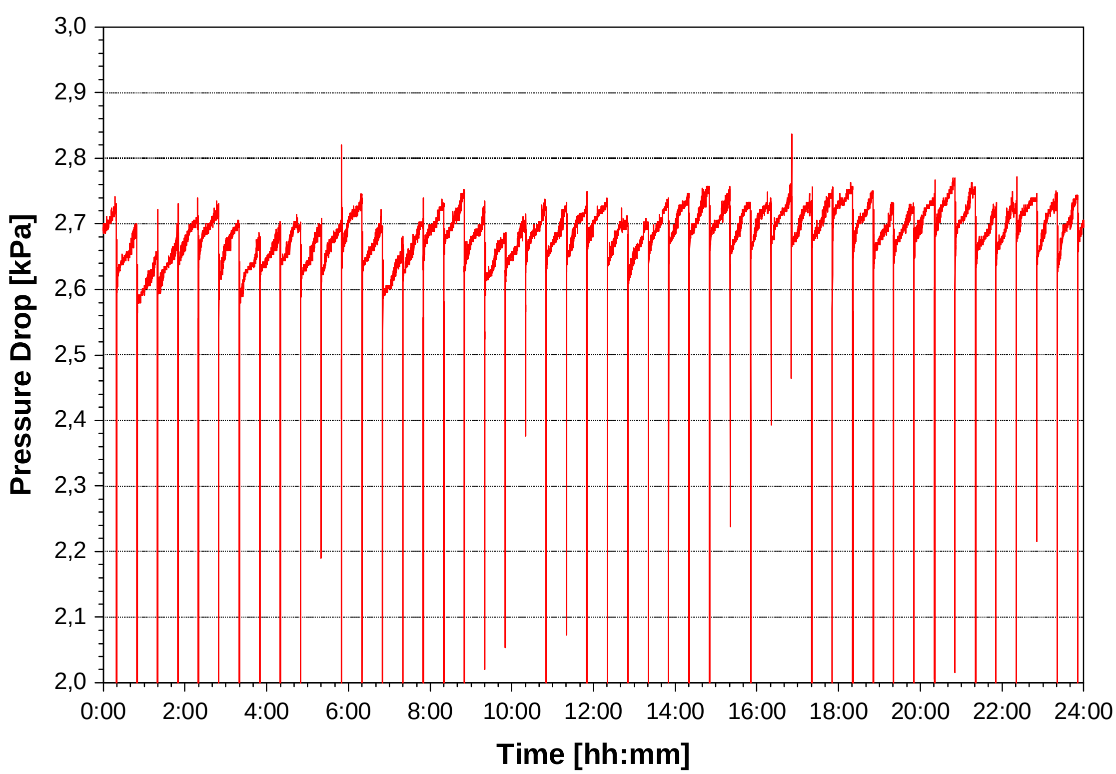

Fig. 4 Pressure drop of filter system operated with sticky test dust at 525 °C. Back-pulse gas pressure was 0.1 MPa above system pressure.

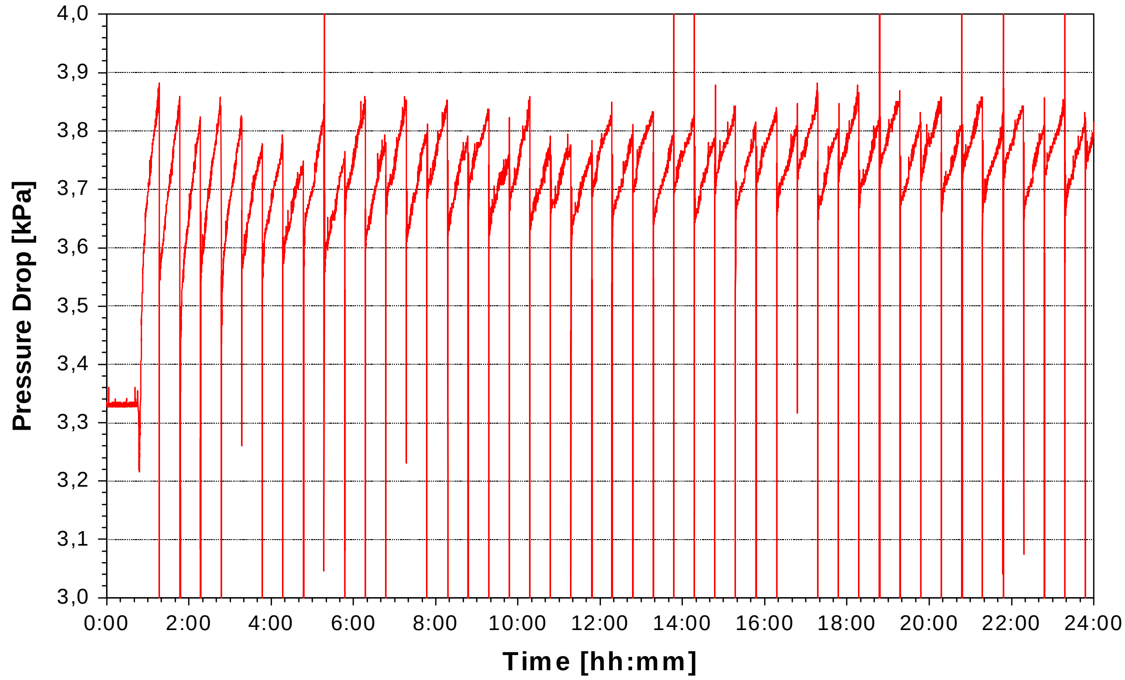

Fig. 5 Pressure drop of filter system in case of a candle failure operated with sticky dust at 525 °C. Back-pulse gas pressure was 0.1 MPa above system pressure.

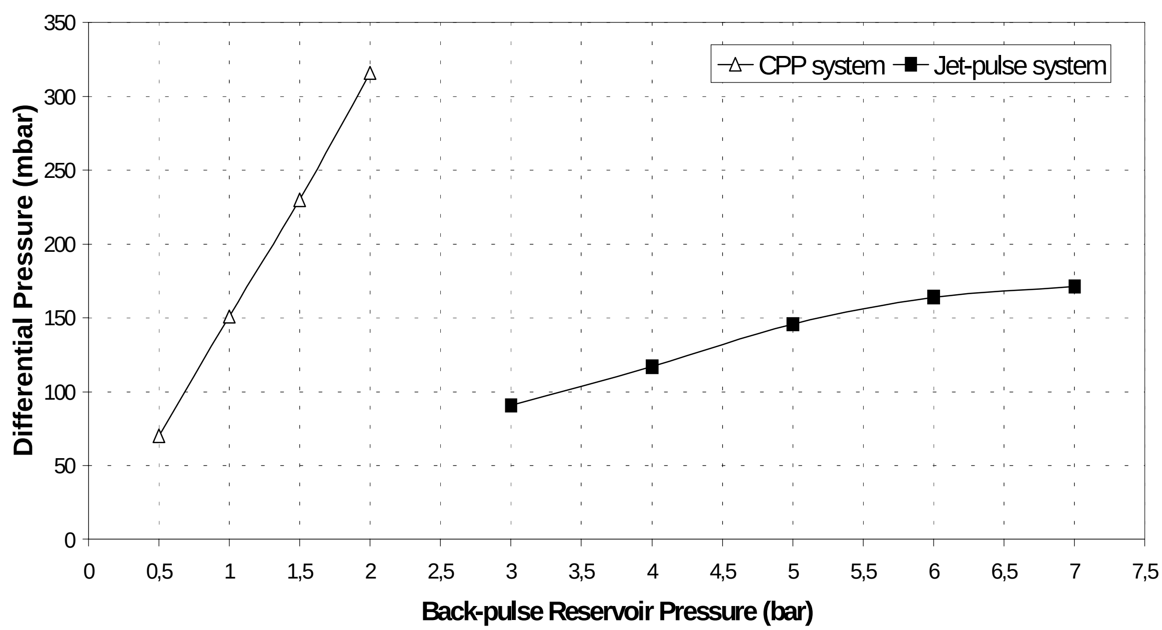

Fig. 6 Comparison of back-pulse pressure inside new filter candles of a cluster of 18 filter elements between CPP and jet pulse cleaning system.

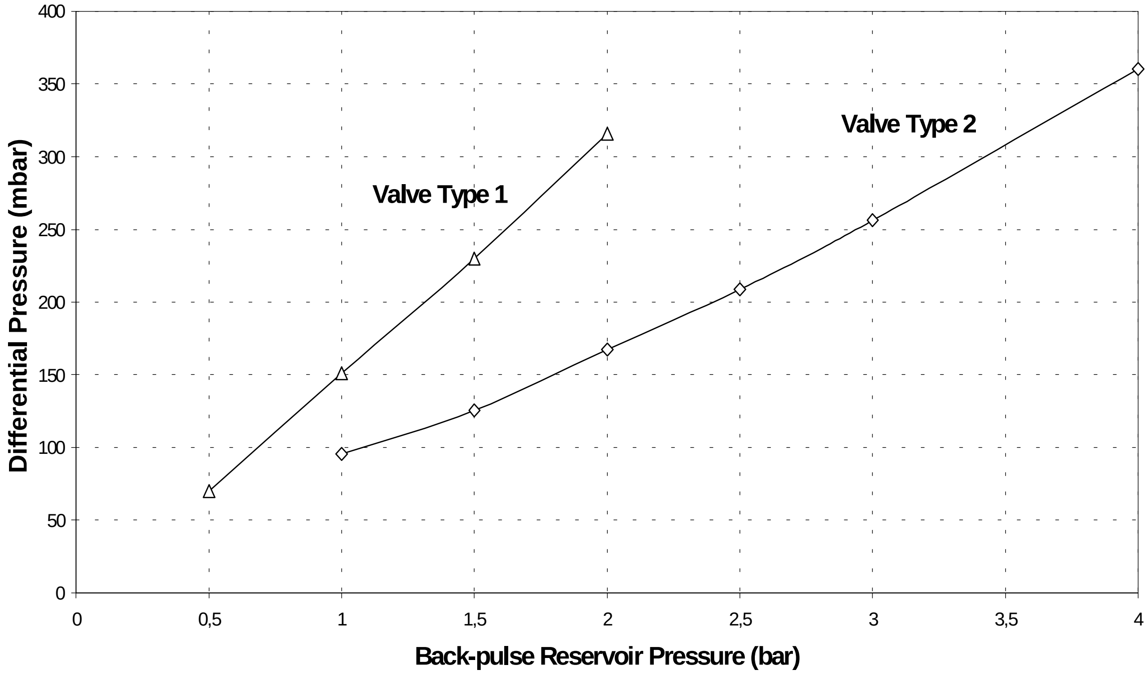

Fig. 7 Comparison of two different backpulse valve types both with the same nominal diameter. Back-pulse pressure inside new filter candles of a cluster of 18 filter elements was measured.

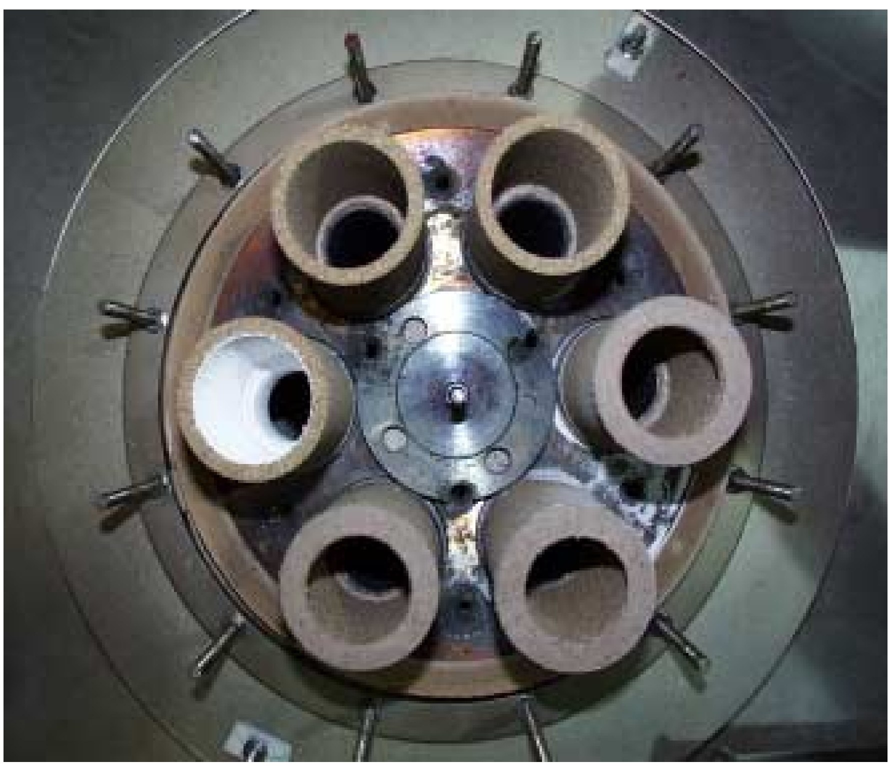

Fig. 8 View on safety filters tested in laboratory experiment in case of failure of one candle.

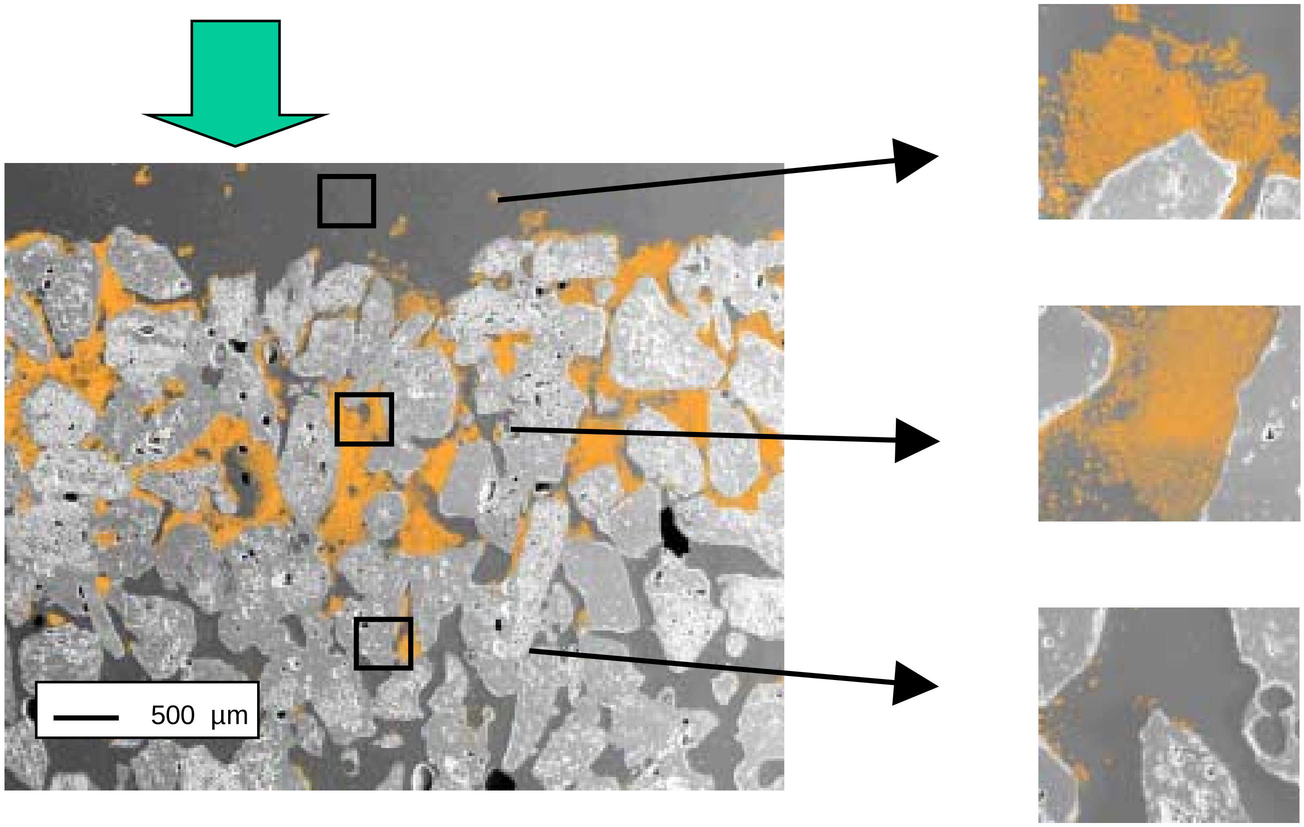

Fig. 9 Electron microscopy of the texture a safety filter in case of a candle failure.

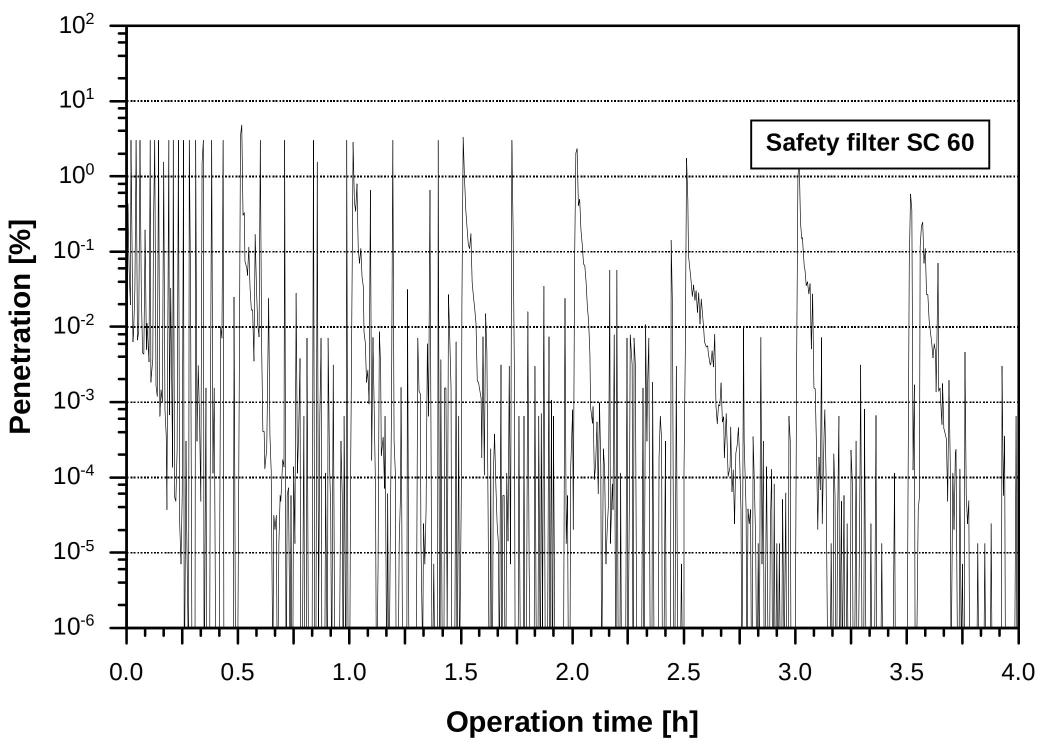

Fig. 10 Collection efficiency of the safety filter.