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# SCHUMACHER HOT GAS FILTER LONG-TERM OPERATING EXPERIENCE in the NUON POWER BUGGENUM IGCC POWER PLANT

**Keywords:** Hot gas filtration, ceramic filterelements, IGCC, coal gasification

## 1. Introduction

Coal is a main source of primary energy for power generation and it will remain indispensable in the future. In order to increase the efficiency and to meet environmental challenges new advanced coal-fired power systems were developed starting in the beginning of the 1990s. One of these efficient and clean technologies is the Integrated Gasification Combined Cycle (IGCC) process.

## 2. Description of current Hot Gas Filtration Process Conditions at NUON POWER Buggenum

In Buggenum in the Netherlands one of the world's largest coal gasification plant for electricity generation, a 253 MWe IGCC power plant, was built and started-up in 1994. Since 1998, after a demonstration period of three years, the plant has been used as a full commercial electricity generating unit. Since October 2001 the installation is owned by NUON.
As illustrated in Fig.1 NUON is one of the largest energy and water companies in the Netherlands.
Using the SHELL process, pulverised coal is gasified at 1500° C and a pressure of 28 bar using pure oxygen. The gas is cleaned after passing a gas cooler. Larger fly-ash particles are collected in a cyclone and the finer ones in a subsequent ceramic hot gas filter.
Using wet gas cleaning, gaseous pollutants such as chlorides are removed. After desulphurisation the gas is saturated with water and fed into the gas turbine and burned. A principal flow schematic of the IGCC – unit is illustrated in Fig. 2.
The ceramic filter unit of the IGCC plant at Buggenum, designed and manufactured by PALL SCHUMACHER, was installed in 1992. The filter is equipped with 864 DIA- SCHUMALITH filter candles. The filter candles are arranged in 18 groups of 48 elements each. The filter is operated at a temperature between 250 and 285 °C and a pressure of about 26 bar. The nominal gas mass flow is about 107 kg/s (volume flow rate 30,000 $m^3$/h.; $\rho$ = 12,8 kg/m3). The dust concentration varies between 0.1 and 0.5 kg/s.

## 3. Description of construction of PALL SCHUMACHER Hot Gas Filter and used Filter Candles

The Hot Gas Filter unit has been completely engineered and delivered by PALL SCHUMACHER. The scope of supply comprised the filter vessel with all internals including tube sheet , ceramic filter elements, grid and raw gas distribution system.
Also, the pressurized blow back tank including fast acting blow back valves of coaxial type was engineered and delivered by PALL SCHUMACHER.
The Hot Gas Filter design is based on the PALL SCHUMACHER modular tube sheet configuration. A single master tube sheet contains 18 smaller modular tube sheets. Each modular tube sheet is equipped with a venturi head for enhanced blow back pressure during the cleaning cycle. The Venturi-design enables simultaneous cleaning of 48 filter elements with one reverse pulse which reduces the number of jet-pulse valves to an economical minimum. The hot Gas Filter itself is approximately 17 meters high with an inner diameter of 4.2 meters and an empty weight of approximately 90 metric tons. The typical construction of the PALL SCHUMACHER Hot Gas Filter design including main parts is shown in Fig. 3.
The DIA – SCHUMALITH ceramic filter elements are manufactured at PALL SCHUMACHER in Crailsheim / Germany. All DIA – SCHUMALITH filter elements are based on ceramically bonded silicon carbide. The macroporous silicon carbide matrix functions as a rigid , stable structure supporting the membrane which acts as the actual barrier filter. This membrane consists of Mullite grains and has a thickness of about 100 – 200 µm with a pore size of about 10 µm.
Since start-up, the type of filter elements used has changed due to new and improved developments by PALL SCHUMACHER. The most significant change has been made by replacing DIA – SCHUMALITH F- 40 by DIA –SCHUMALITH 10-20 filter elements in 1997. Main advantages of the exchange were an improved filtration efficiency caused by reduction of the membrane pore size from appr. 15 to 10 µm, better cleaning of the elements based on a smoother outside surface, and a reduction of the element wall thickness from 15 to 10 mm. The residual pressure drop, on a long-term basis, is significantly lower for DIA – SCHUMALITH 10-20 compared to DIA – SCHUMALITH F- 40.
Simultaneous with these advantageous changes in filter elements, improved filter elementfixturing has been achieved through the installation of a bottom retaining grid. The advantage of the grid is prevention of element deflection thereby increasing the robustness of the total filter element fixture system. The current element fixturing system, with grid, is shown in Fig. 4 in the attachment.

## 4. Overview last 4 operating runs PALL SCHUMACHER Filter at NUON POWER

This section provides an overview of the last 4 runs of the gasifier and filter at NUON POWER showing results regarding time of exposure of elements. As filter elements have been examined by PALL SCHUMACHER laboratories on a regular basis after being in use, some results of these candle investigations and therefore resulting conclusions are also added. Runtime is defined as the time between 2 planned ceramic filter element exchanges.
Fig 5. contains a summary of the last 4 runs and describes in detail which type of element has been used incl. the exposure time of the filter elements in current and former runs.

Run 1 and run 2 were made with new sets of elements, which have not been used in former runs. In run 3 all installed elements have been in use in previous runs 1 + 2 . In current run 4, the majority already performed for 10,555 hours in run 1.
The relatively high initial filter resistance of 0,7 in run 3 is based on the fact that 816 filter elements used in run 2 have not been exchanged for operational run 3. However the low initial filter resistance of 0,4 in run 4 can be attributed to the fact that 720 elements were off-line cleaned prior to reinstallation and additional 144 filter elements were in service for the first time.
In run 3, exposure times for the elements of more than 13.700 operating hours was achieved and it is expected that for run 4 element exposure time will clearly exceed 16.000 operating hours. The comparision of run 1 to run 3 with regard to the availability of the Hot Gas Filter unit in hours / month results in an increase of more than 21 % which can be interpreted as an improvement of the operating reliability of the hot gas filter unit.
Based on an agreement between NUON POWER and PALL SCHUMACHER some selected elements are examined at PALL SCHUMACHER laboratories for pressure drop, destructive 4-point bending test, O-ring strength, TOF – test and cleaning procedures as well as SEM analysis after having been in service in the Hot Gas Filter unit. The results of these typical tests are shown in Fig. 6. The data is for examined elements from run 1, after elements having been exposed to syngas athmosphere for 10.555 hours. This represents one of the longest runtimes up to now. From the results of these different performed tests the conclusion be drawn that even after this long exposure time to syngas atmosphere, the properties of the tested elements are quite close to those related to new unused elements. Clear evidence of superior retaining efficiency of the DIA – membrane is shown in Fig. 7. The 400 X magnification shows that dust particles were retained on top of the membrane and a support structure completely free of dust particles.

## 5. Dimensionless Filterresistance as main criteria for evaluation of filter performance

In order to evaluate the performance of the hot gas filter unit and the ceramic filter elements NUON POWER developed a special investigation method. The value to be determined for performance evaluation of hot gas filter unit is the „filter resistance factor“. The filter resistance factor is a dimensionless figure and depends mainly from the relevant delta p across the filter unit, systempressure, systemtemperature and gas mass flow.
For calculation of filter resistance factor relevant system data received from various measuring points in the process are set in proportion to defined reference data.
The filter resistance factor is about 0,4 when using new ceramic filter elements and only slightly higher in case of using cleaned elements. During operation, the filter resistance factor is usually in the range of 0,6 to 0,8. Filter resistance exceeding the value of 0,9 for a long period of time could be a criteria for taking the unit out of service and exchanging or cleaning the ceramic filter elements. The filter resistance factor depends also on the type of coal used and from syngas quantity, which can be interpreted in that way that an increase in syngas quantity will always lead to an increase in delta p across the filter but not inevitable to an increase of filter resistance factor.

This correlation can be seen in Fig. 8. The graph depicts the original measured data of delta p , filter resistance and syngasquantity for the period of time from 10th to 17th of May 2002. Due to the fact that NUON POWER is a commercial running IGCC – unit, it is necessary to increase or lower the gasifier capacity and the therefore resulting amount of syngas periodically in order to fullfill customer needs for power supply.
During these fluctuations in syngas flow rate it is anticipated that filter resistance factor of hot gas filter will not exceed optimal range of 0,6 to 0,8, even for very high syngasquantities close to 100 kg/s.
The development of filter resistance over the complete runtime is given in Fig. 9 and Fig. 10 were these figures are presented for operational run 2 and operational run 4 of the hot gas filter unit at NUON POWER Buggenum.
During operation of the Hot Gas Filter unit the input data for filter resistance factor are measured and calculated every two minutes. Resulting hourly and daily average data are presented in this diagramm.
It is important for the operation of the Hot Gas Filter unit that even under conditions close to full load syngasquantity (appr. 100 kg/s) which can appear over the total runtime the two dependent criterions delta – p and filterresistance, will not exceed given limiting values. At NUON POWER Buggenum these values are delta – p < 0,5 bar and filterresistance < 0,9.
As shown in the curves of Fig. 9. and 10., this criteria could be reliably achieved for operational run 2 and 4. Furthermore, it is typical that based on the long term filter element behavior with regard to delta – p development the increase of filter resistance factor in the first months after starting a new operational run is relatively rapid into the range between 0,6 – 0,8 but after reaching this range it tends to remain continously in this desired operating range. This behavior can be interpreted as a result of a reliable and powerfull working, well designed, conventional Venturi blow-back system. Also the gradual feed of biomass into the gasifier started in 2001 did not lead to any measurable effects or influences to Hot Gas Filter unit performance.

## 6. Summary and Conclusions

The filter is successfully in operation for the last 5 years for about 25.000 operating hours without any measurable dust load on clean gas side and without any filter element blocking.
Different ceramic filter element types have been used. The close cooperation between PALL SCHUMACHER and NUON POWER Buggenum has resulted in the development of a final, well performing, version.
Offline cleaning method of the filter elements offers the advantage for NUON to save expenditures for new sets of filter elements.
Additionally, the construction of filter and filter element has been continously improved to perform to customers needs.
The ceramic filter element lifetime is improved to more than 10.000 operating hours and the current set of elements has been in continuous operation for more than 15.000 hours.
The lifetime of the elements and the delta p development is sufficient to fullfill NUON's needs to operate the filter unit for 2 years of uninterrupted operation.
There is no need for a previously undertaken yearly filter overhaul. Therefore, the availability of the total filter plant is tremendously increased.

The latest figures for Total Plant Availability reported by NUON Power for the period of time 1.1.2002 to 12.5.2002 indicate a Total IGCC - Power Plant availability of 94 % and unplanned shutdowns of only 0,2 %. The availability of the Gasifier – Syngascooler – Hot Gas Filter unit for the same period of time has been reported with 92 % with unplanned shutdowns of only 0,3 %.
The longest reported uninterrupted in-service-time of the Gasifier – Syngascooler – Hot Gas Filter unit was achieved during operational run 4 and reached the outstanding performance of 2675 hours. These represents more than 3,5 months of continuous operation.
Based on the present results obtained from the Hot Gas Filter unit it is expected that the new challenges at NUON POWER will be succesfully and reliably achieved by means of the PALL SCHUMACHER Hot Gas Filter unit.

These challenges are:

- extension of operational runtime from 1,5 to 2 years
- Biomass – cogasification of chicken litter, sewage sludge, milled wood and paper pulp from 30 % (weight) in 2003 up to 50% (weight) in 2005

The most important factor from NUON POWER's point of view is that the reliability of the filter and the used ceramic filter elements has been demonstrated to support full commercial operation of the plant.


Fig. 1. View of the 230 MW NUON POWER Plant in Buggenum / Netherlands

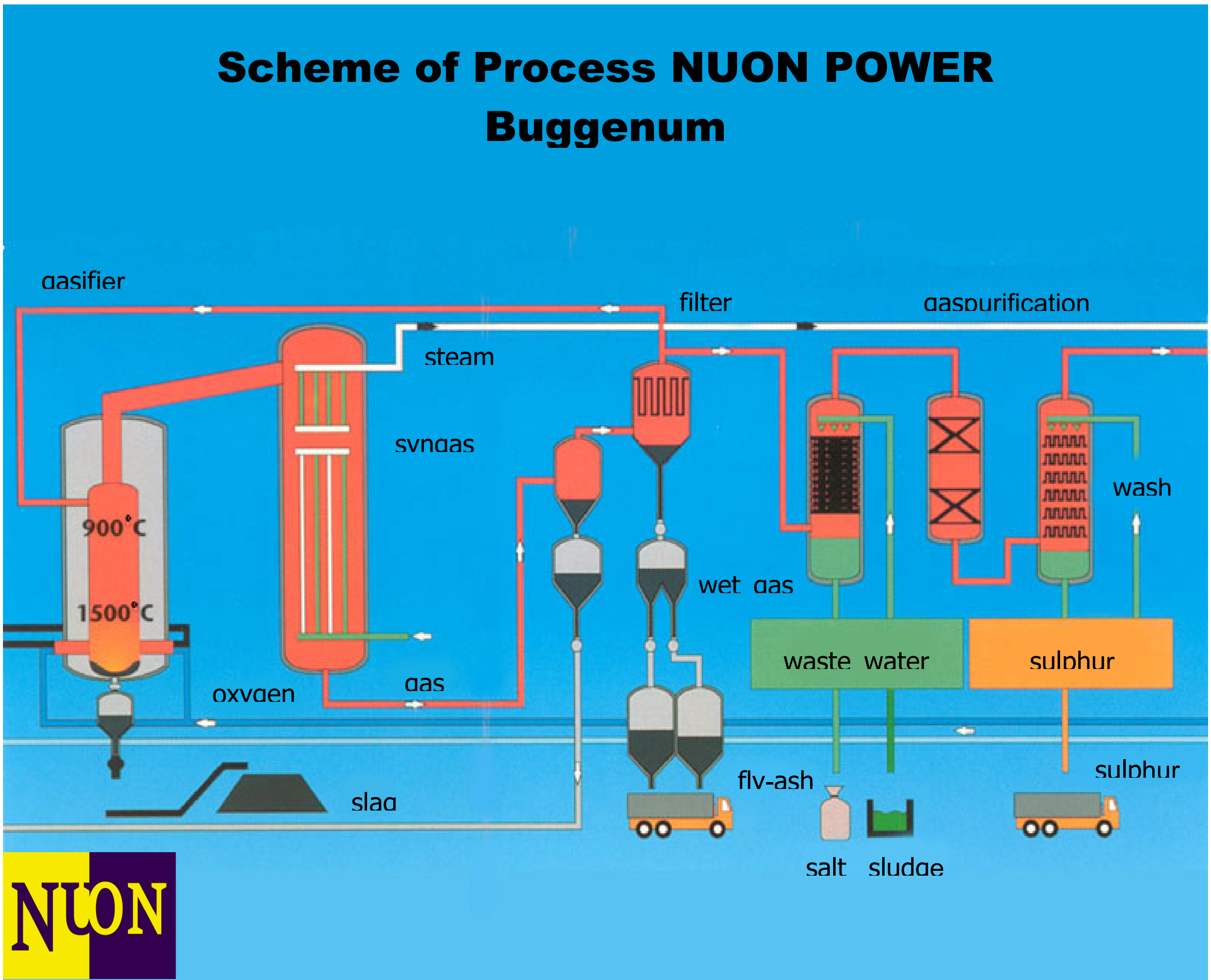


Fig. 2. Simplified Process scheme NUON POWER Buggenum Plant

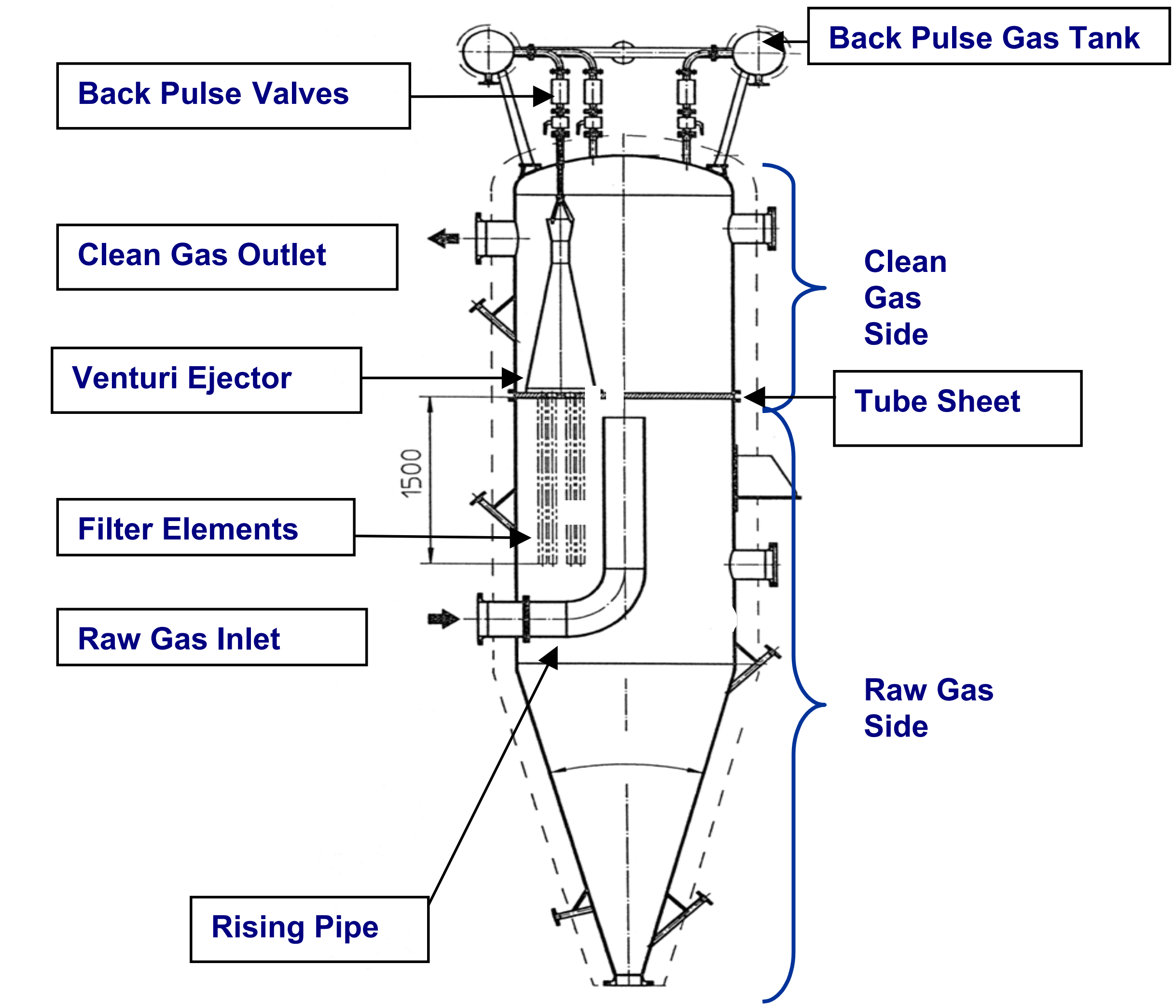


Fig. 3. Typical PALL SCHUMACHER Hot Gas Filter design in principal

Fig. 4. Filter element fixation system with bottom grid

| run | runtime | No of elements | Type of element | Exposure time in former run (in hours) | Exposure time in run (in hours) | Filterresistance begin / end |
|---|---|---|---|---|---|---|
| 1 | 1.5.1997 to 1.5.1999 | 864 | DSL 10-20, glued | n.a. | 10.555 | 0,4 / 0,8 |
| 2 | 1.5.1999 to 1.11.2000 | 864 | DSL 10-20, pinhole | n.a. | 7.785 | 0,4 / 0,7 |
| 3 | 1.11.2000 to 2.5.2001 | 816 | DSL 10-20, pinhole | 7.785 (run 2) | 3.192 | 0,7 / 0,83 |
| 3 | 1.11.2000 to 2.5.2001 | 48 | DSL 10-20, glued | 10.555 ( run 1) | 3.192 | 0,7 / 0,83 |
| 4 | Since 1.7.2001 | 720 | DSL 10-20, glued | 10.555 ( run 1) | > 5.000 | 0,4 / n.a. |
| 4 | Since 1.7.2001 | 144 | DSL 10-20, glued | n.a. | > 5.000 | 0,4 / n.a. |

Fig. 5. Runtime, used elements and exposure time with filterresistance last four operating runs at NUON POWER Buggenum

| No. of the element | Unit | 1 | 2 | 3 | 4 | Reference |
|---|---|---|---|---|---|---|
| Material - with glued fixation cylinder | | DSL 10-20 | DSL 10-20 | DSL 10-20 | DSL 10-20 | DSL 10-20 |
| Code-No. | | 305 H (?) /195 | 306 H / ? | 305 H / ? | 305 H / 217 | 305 H |
| Dimensions (dense end was cut before examination) | mm | 60/40*1500 | 60/40*1500 | 60/40*1500 | 60/40*1500 | 60/40*1500 |
| Differential pressure at 250 m/h - as received | mbar | 170 | 185 | 195 | 175 | new: 20 - 30 mbar |
| Differential pressure at 250 m/h - after cleaning with pressurized air | mbar | 145 | 125 | 155 | 155 | |
| Differential pressure at 250 m/h - after washing and cleaning with soft brush | mbar | 32 | 41 | 41 | 38 | |
| Differential pressure at 250 m/h - after backflushing with water from inside to outside | mbar | 39 | 45 | 45 | 44 | new: 20 - 30 mbar |
| Time of flight (TOF) | µs | 290 | 296 | 304 | 305 | appr. 290 |
| 4-point bending strength | MPa | 16,5 | 14,3 | 15,5 | 13,8 | -- |
| O-ring strength | MPa | 29,6 | 28,7 | 26,3 | 25,9 | appr. 35 |
| C-ring strength compression | MPa | 23,0 | 20,0 | 19,3 | 20,5 | appr. 27 |
| Youngs modulus | GPa | 49,5 | 49,0 | 45,4 | -- | appr. 49 |

Fig. 6. Results of typical physical examinations performed on used elements from NUON POWER Buggenum

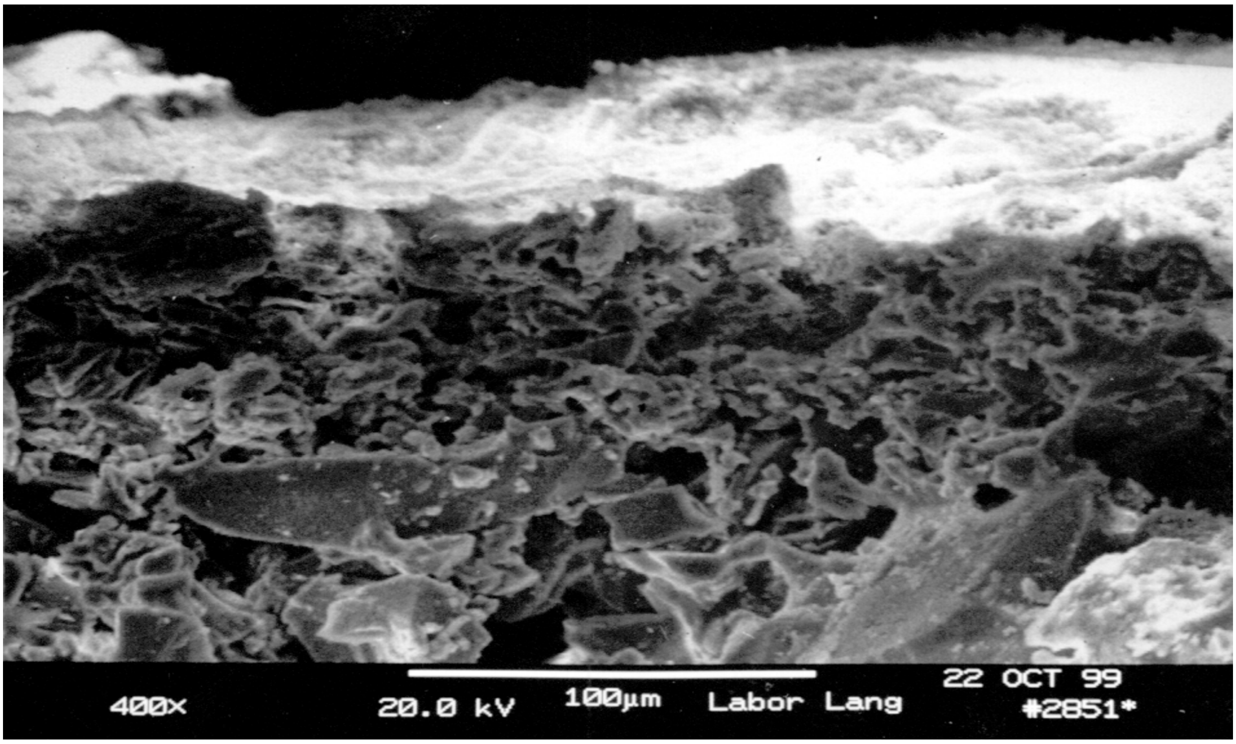


Fig. 7. Photo No. 2851 (400x) filter elements as received showing dust on membrane and support structure completely free of particles

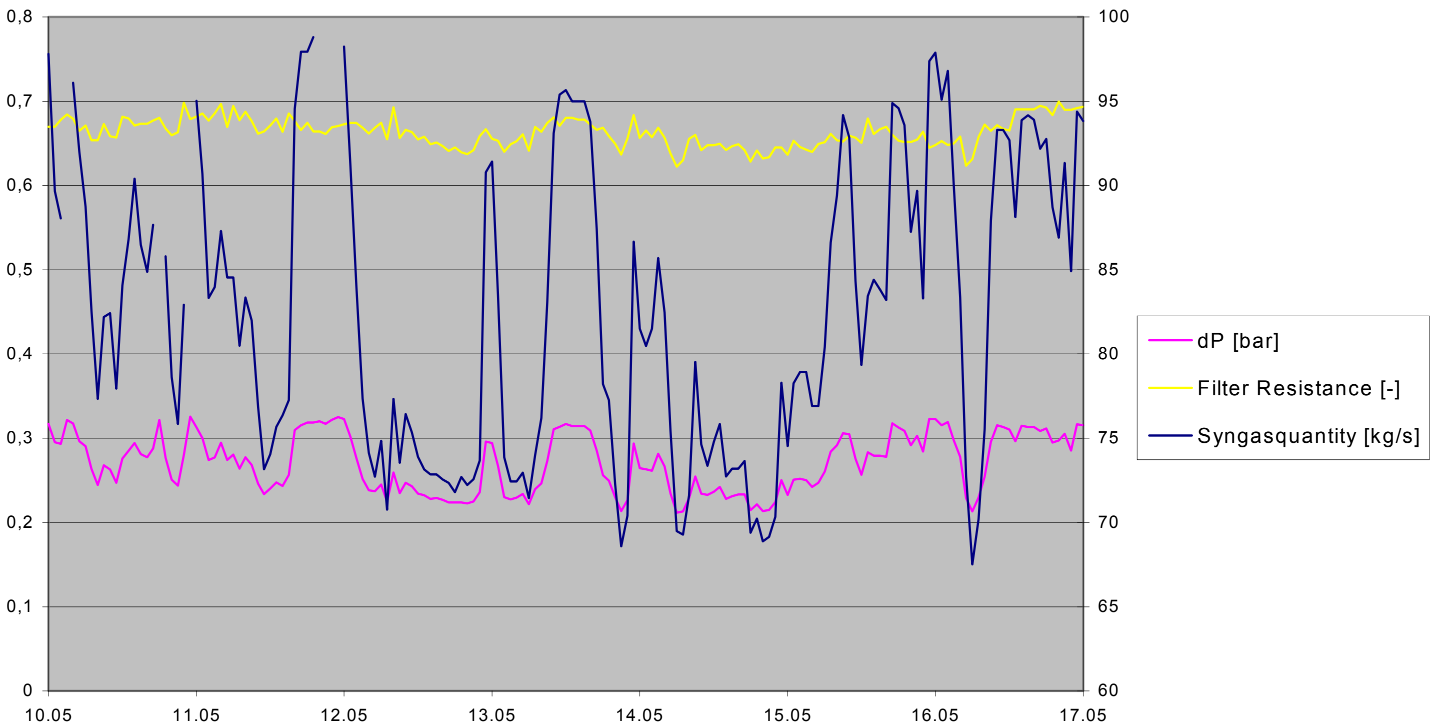


Fig. 8. Development of delta p and filter resistance depending on syngas quantity

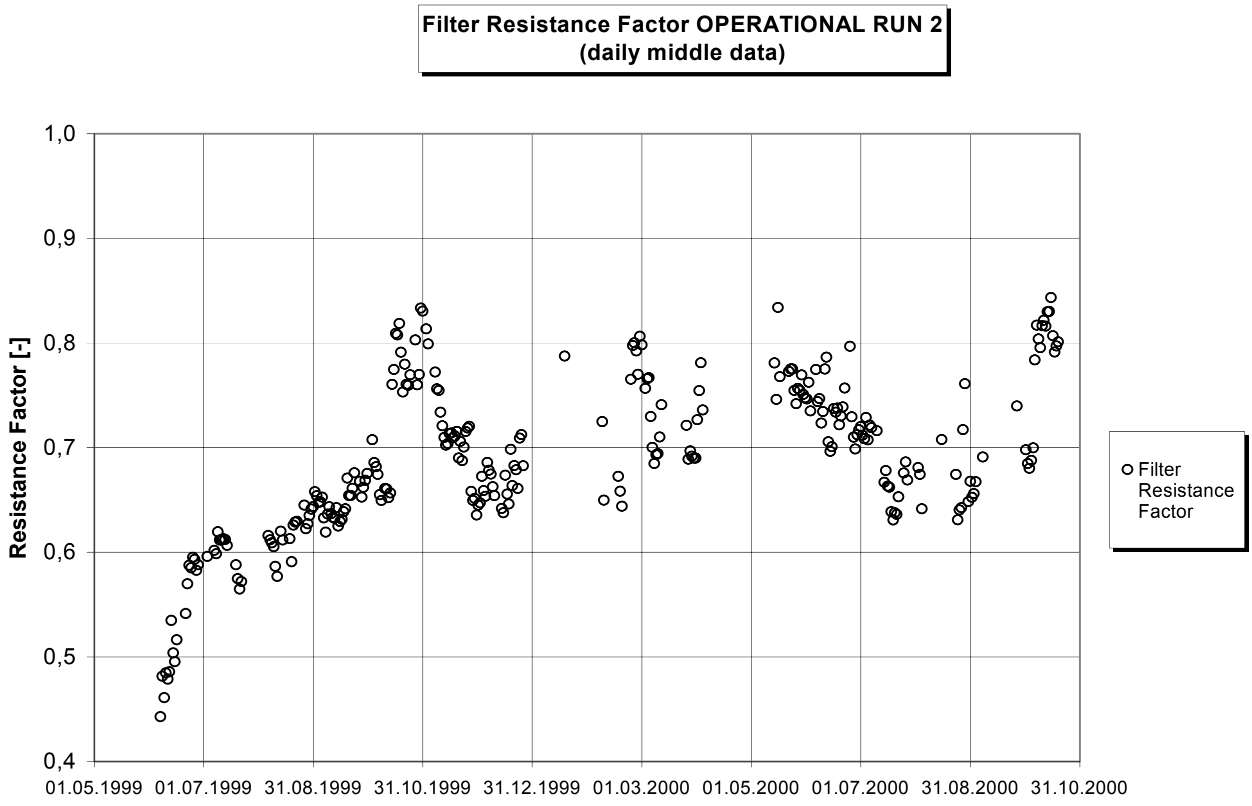


Fig. 9. Development of filter resistance for OPERATIONAL RUN 2

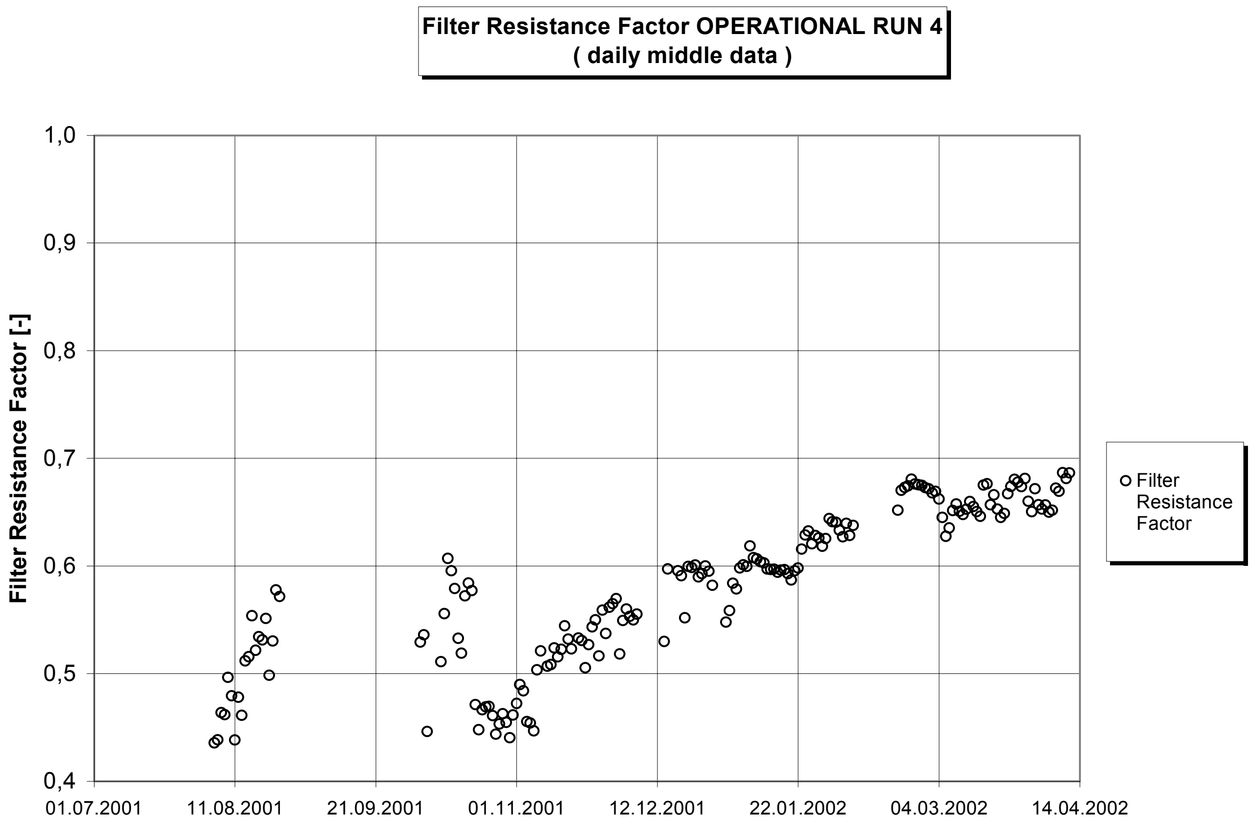


Fig. 10. Development of filter resistance for OPERATIONAL RUN 4