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Improving the efficiency of bag filters using the Intensiv-Filter expert system

This article addresses the optimisation of bag filters with the aim of reducing their lifecycle cost (LCC). Energy consumption, mainly driven by fan motors and by the consumption of compressed air, represents the largest portion of the LCC of a bag filter. Today, improved jet-pulse cleaning systems enable the use of very long filter bags, which leads to a reduction of both investment and operating costs. A systematic analysis of the process parameter 'air tank pressure' was carried out for bag lengths up to 12m. The results are summarised in a decision matrix, which allows the cement producer to decide about the maximum possible bag length in filter upgrades, as well as for new installations.

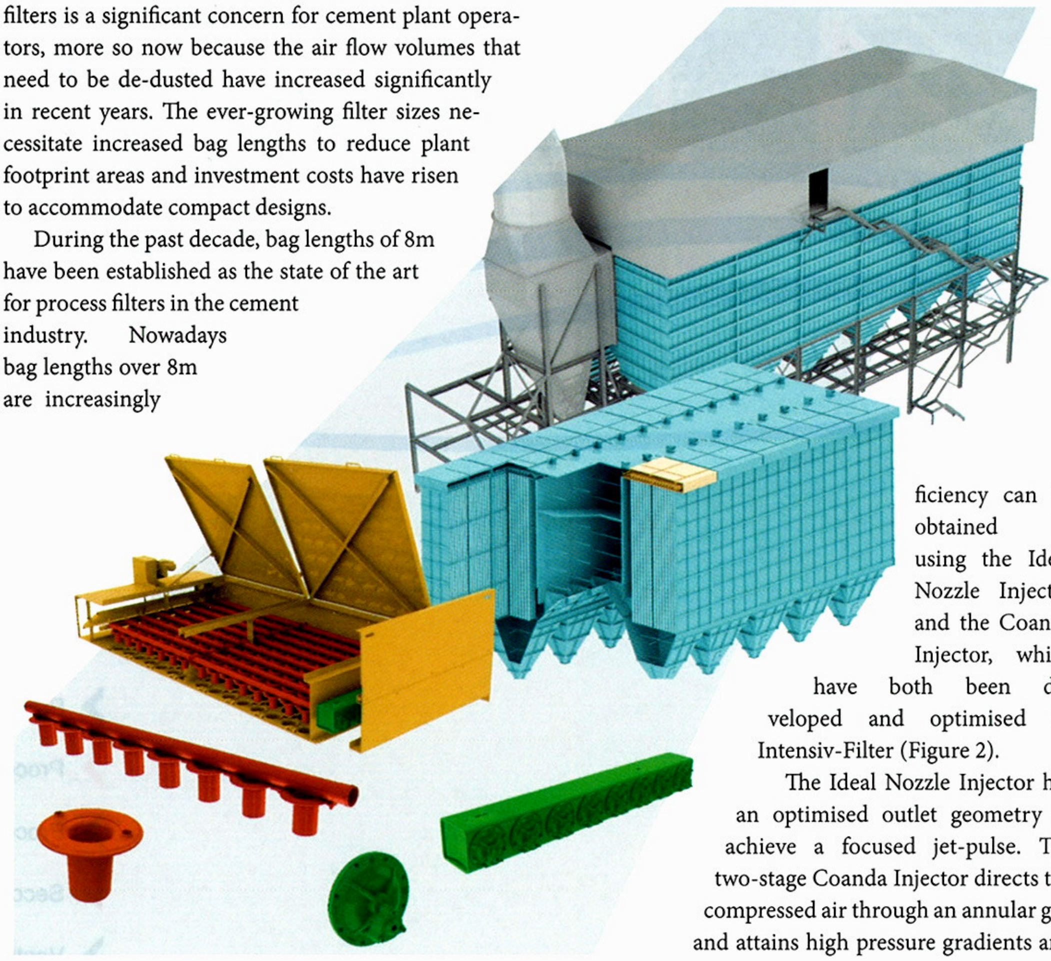
Introduction

In the cement industry, the lifecycle cost (LCC) of production equipment is becoming a more and more prominent cost consideration. The raw meal, coal, clinker and cement de-dusting and product separation as well as off gas cleaning is now carried out by modern jet-pulse bag filters. Energy consumption, mainly driven by fan motors and the consumption of compressed air, is the biggest portion of the LCC of a bag filter.

The minimisation of energy consumption in bag filters is a significant concern for cement plant operators, more so now because the air flow volumes that need to be de-dusted have increased significantly in recent years. The ever-growing filter sizes necessitate increased bag lengths to reduce plant footprint areas and investment costs have risen to accommodate compact designs.

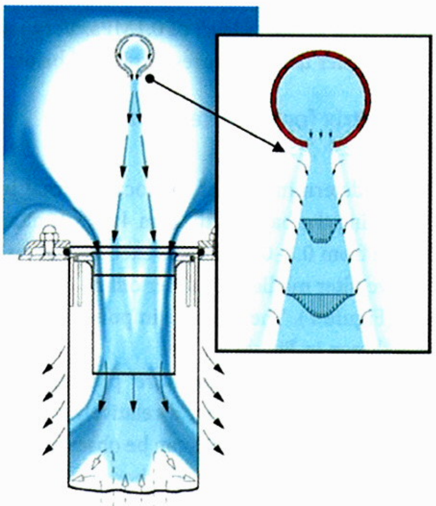
During the past decade, bag lengths of 8m have been established as the state of the art for process filters in the cement industry. Nowadays bag lengths over 8m are increasingly being considered in new projects. Figure 1 shows the modular process filter series ProJet mega® which covers gas flow volume rates up to over 2 million m³/h in one baghouse installation.[1]

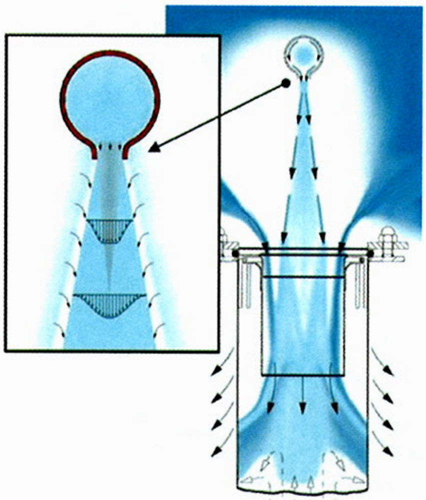
The installed injector technology and the operating mode (online or offline cleaning) plays a key role when it comes to very long filter bags and several injector types can be used. Conventional injectors are more or less simple holes in a steel tube, which are located above the bags. Significantly increased cleaning efficiency can be obtained by using the Ideal Nozzle Injector and the Coanda Injector, which have both been developed and optimised by Intensiv-Filter (Figure 2).

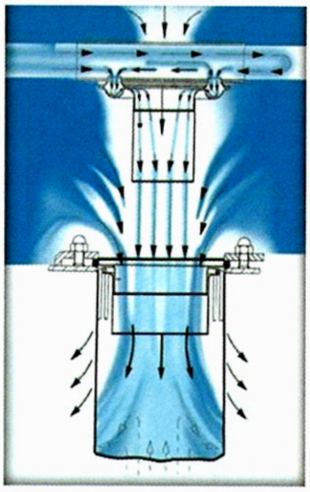


Right - Figure 1: The ProJet mega® modular process filter series, which can cover gas flow volume rates up to over 2 million m³/h in one baghouse installation.[1]

The Ideal Nozzle Injector has an optimised outlet geometry to achieve a focused jet-pulse. The two-stage Coanda Injector directs the compressed air through an annular gap and attains high pressure gradients and







Above left - Figure 2a: Hole type nozzle with inlet nozzle.

Above centre - Figure 2b: Ideal nozzle with inlet nozzle.

Above - Figure 2c: Coanda injector with inlet nozzle.

acceleration forces at the filter bag and a high amount of secondary air.[2]

Decision matrix

Experimental set-up: The excess pressure inside the bag is decisive for the cleaning efficiency of filter bags.[3] High-frequency pressure transducers were used to determine the internal bag pressure with high accuracy and signal resolution (Figure 3). The recorded overpressure plot is shown in Figure 4. According to the literature, two parameters can be correlated to the cleaning efficiency of a filter bag.[4]

1. The maximum peak overpressure (P_{max}).

2. The pressure impulse (p_D), defined as the surface integral between time t_1 and t_2, indicating the beginning and the end of a local overpressure.

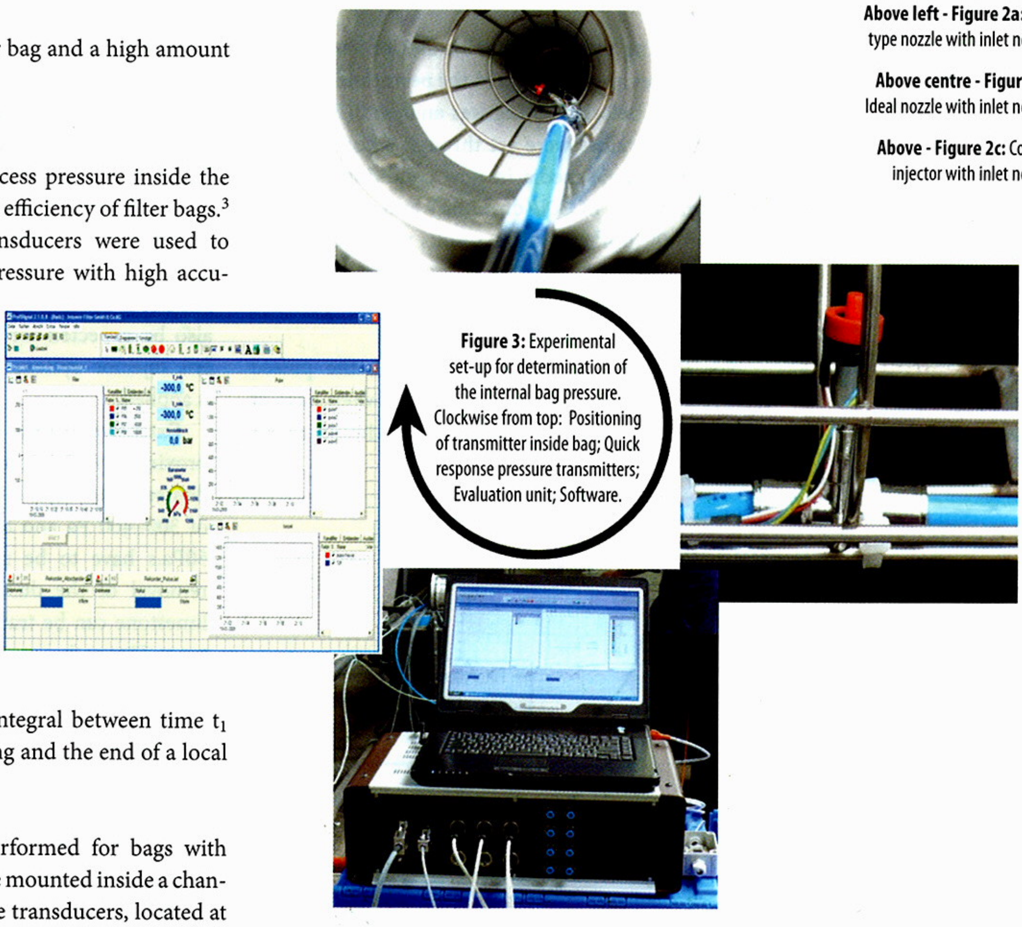
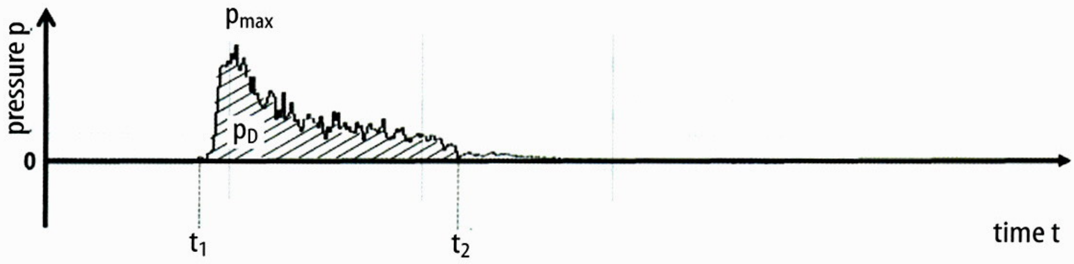


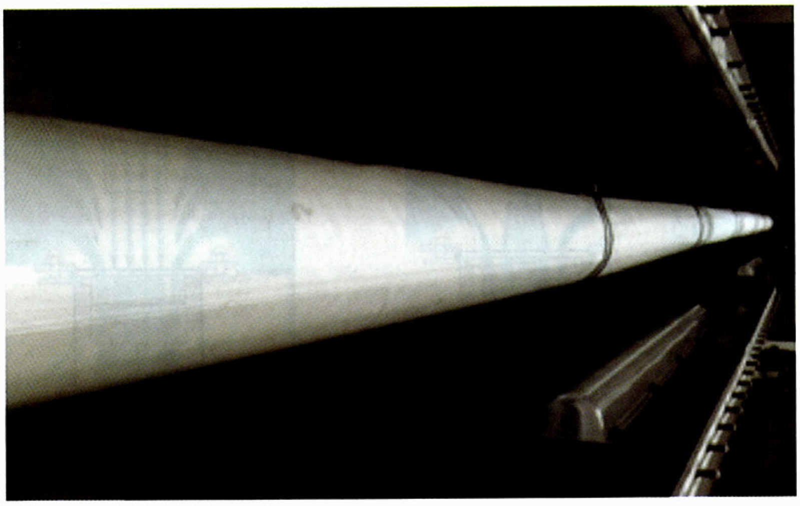
Figure 3: Experimental set-up for determination of the internal bag pressure. Clockwise from top: Positioning of transmitter inside bag; Quick response pressure transmitters; Evaluation unit; Software.

The measurements are performed for bags with lengths of up to 12m, which are mounted inside a channel (Figure 5). Several pressure transducers, located at different positions along the bag length, transfer the signal to a data logger with 1ms clock frequency.

In order to represent the permeability of the dust-loaded bag (just before cleaning) adequate, specially prepared filter media with reduced air permeability are used for the tests. The air permeability according to DIN EN ISO 9237 (volume of air (l)), which is passed in one minute through one squared decimeter of filter medium at a pressure difference of 200Pa)[5] was set at 5l/(dm^2.min). This value of the selected representative filter media for the parameter studies equals the air permeability of a filter bag in clinker, cement and kiln / raw meal mill applications before cleaning.



Left - Figure 4: Typical pressure progression curve inside the filter bag at a local position.

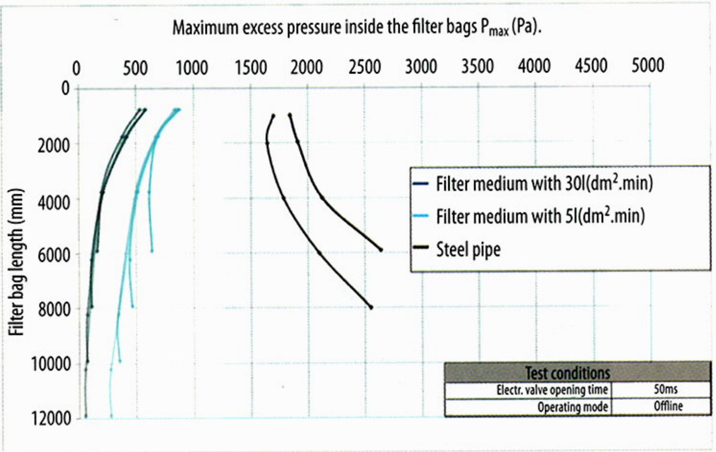


Above - Figure 5: The view into the test bench for testing very long filter bags.

Test results

Before starting the parameter studies of varying the tank pressures, the influence of the permeability of the bag at status before cleaning was analysed (Figure 6). The extreme values were set through a conventional ePTFE membrane media in new condition, with an air permeability of 30l/(dm²․min) and a solid steel pipe with 0l/(dm²․min). The results were carried out in offline operation mode (zero flow through the bags during cleaning) at constant cleaning tank pressure of 0.1MPa.

Below - Figure 6: Maximum internal bag pressure (P_{max}) for filter media with different air permeability and 0.1MPa tank pressure.

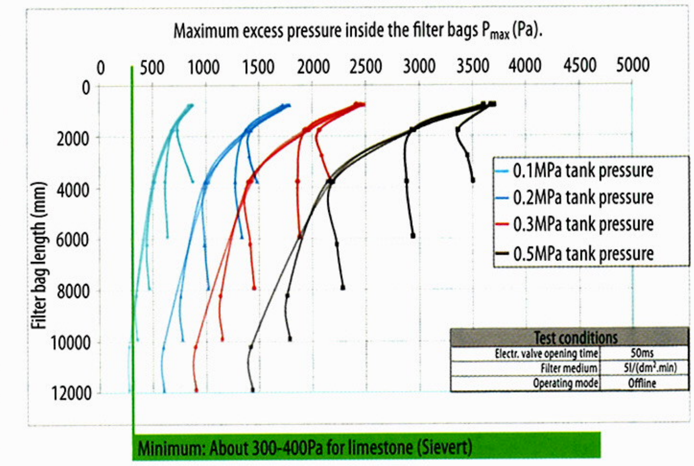


For the high air permeability level, the pulsed air disappears more or less completely when bags of 12m lengths are used. The obtained maximum excess pressure values are too low to achieve sufficient cleaning.

The opposite behaviour can be observed when the steel pipe is used. The jet pulse creates, even at a very low tank pressure level, very high internal bag pressures, which increase with the bag length.

The selected representative filter bag of 5l/(dm²․min) shows the well known behaviour with slightly decreasing overpressure over the length. Bag lengths up to 8m are in principle cleanable in offline operating mode even at the very low tank pressure level of 0.1MPa. Very long bags require higher tank pressures, explained below.

Right - Figure 7: Decision matrix for the layout of bag filters up to 12m bag lengths and offline operating mode - Decisive parameter: Maximum overpressure inside the bag.



Decision matrix for the selection of filter bags

Experimental determination of the local internal bag pressure, varying the bag length from 4m to 12m and tank pressure from 0.1-0.5MPa was executed with the representative filter media and under offline operating conditions (Figure 7). The pressure impulse inside the filter bag is shown in Figure 8.

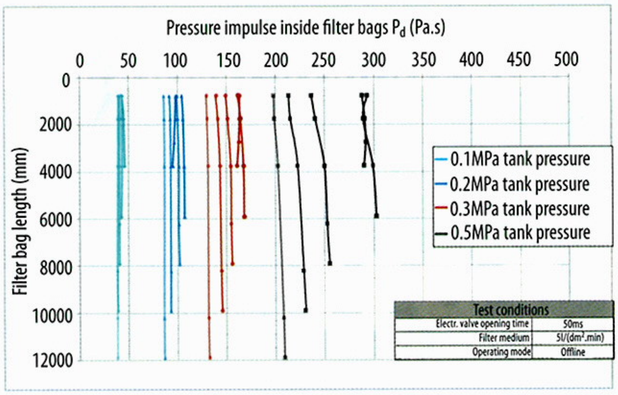
Whereas the maximum pressure predominately decreases along the bag length, a relatively constant pressure impulse over the length can be observed. This can be explained with the different shape of the pressure profile over the length.

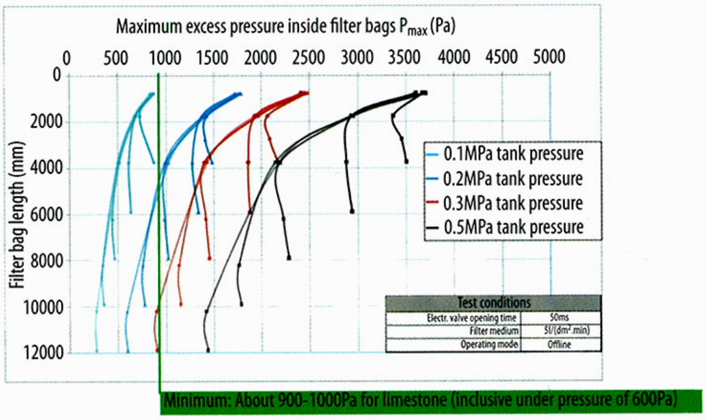
Close to the inlet we have high maximum pressure values and a short time interval with positive pressure. With increased bag lengths the maximum pressure values will decrease, but the time interval with positive pressure increases, resulting in a constant area below the pressure curve over time (Figure 4) and thus a constant pressure impulse over length.

Because the pressure impulse is seen as the predominant factor for bag cleaning efficiency, one conclusion is that a homogeneous cleaning effect can also be expected for 12m-long filter bags if a modern injector system and a sufficient tank pressure is applied.

Extensive studies in a pilot plant with an approximately 2m-long bag using limestone have demonstrated that a minimum internal bag pressure of 300–400 Pa and a minimum pressure impulse of 50Pa.s have to be reached to ensure the effective removal of the dust cakes.[3] The characteristics of limestone can be transferred to a wide range of dust types. Hence these minimum values can be applied for uncritical, well-agglomerating dusts.

With this knowledge, Figure 7 can be used as a decision matrix for the layout of bag filters of up to 12m in the cement industry. A security factor to cover influences of real dust properties may be added to the 300-400Pa limit. With that, for example, a 12m bag can be operated without any anticipated problems with a modern injector (tests are executed with Intensiv Ideal





Above - Figure 8: Decision matrix for the layout of bag filters up to 12m in length and offline operating mode - Decisive parameter: Pressure impulse inside the bag.

Above right - Figure 9: Decision matrix for the layout of bag filters up to 12m in length and online operating mode - Decisive parameter: Maximum overpressure inside the bag.

Nozzle Injector, 50ms pulse time, 6.35cm (2.5inch) diaphragm valve, 50l tank volume) at 0.2MPa tank pressure and offline operating conditions.

Figure 7 can be also used for comparative purposes, for example if the operation of one filter type and application (e.g. a kiln / raw meal mill process filter) is running offline with a 0.15MPa tank pressure and 8m bags without any problems, one can expect to have trouble-free operation with a 10m bag and 0.2MPa or with a 12m bag and 0.25MPa.

The obtained decision matrix can be also used to predict the required bag overpressure when the filter is operated at online operating conditions. The pressure difference caused by the main flow through the filter media has to be added to the mentioned 300-400Pa minimum overpressure in this case.

Figure 9 shows one example at a differential pressure of 600Pa. It can be clearly seen that very long bags combined with online operation are also within the bounds of possibility. Of course, higher tank pressures have to be applied, which is possible, because 0.6MPa is very common in the industry.

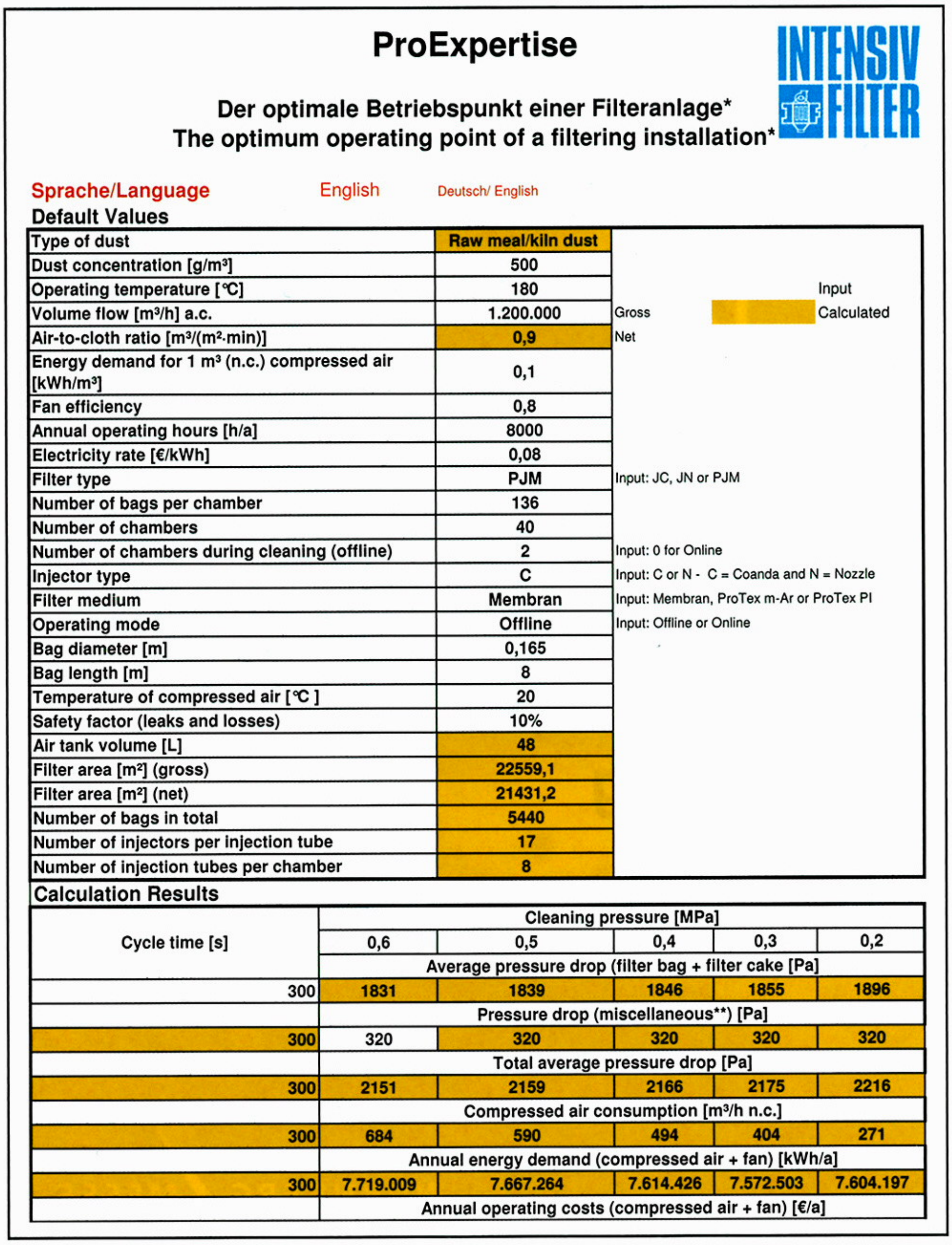
Determination of the optimum cycle time using the filter expert system

The optimum operating point of a bag filter depends on the geometrical parameters of the filter such as the filter surface, bag length, design of the raw and clean gas chambers, flaps and ducting as well as on the process parameters such as volume flow, raw gas concentration and temperature. Intensiv-Filter has developed the filter expert system ProExpertise, which predicts the optimum operating point for different geometrical and process parameters.

The main result is the optimum cycle time and the resulting annual operating costs, which include the electrical power for the fan drive as well as for the supply of the compressed air for jet-pulse cleaning.

Figure 10 shows the input / output interface of the filter expert system. As a case study, a high dust kiln-/raw meal filter is used, with data before optimisation (e.g. membrane filterbags and 300s cycle time). Process parameters can be entered in directly, as well as the geometrical data of the different modular Intensiv-Filter systems. In addition, the evaluation of bag filters from other manufacturers is possible if the tank volume and geometrical data such as the number of blow pipes per tank, injectors per blow pipe and size of the bags are known.

The calculation scheme of ProExpertise is based on the well known filter equations for cake filtration.[3] The required filter resistances



ProExpertise

INTENSIV FILTER

Der optimale Betriebspunkt einer Filteranlage*
The optimum operating point of a filtering installation*

Sprache/Language English Deutsch/ English

Default Values

Type of dust	Raw meal/kiln dust	
Dust concentration [g/m³]	500	
Operating temperature [°C]	180	Input
Volume flow [m³/h] a.c.	1.200.000	Gross ▨ Calculated
Air-to-cloth ratio [m³/(m²·min)]	0,9	Net
Energy demand for 1 m³ (n.c.) compressed air [kWh/m³]	0,1	
Fan efficiency	0,8	
Annual operating hours [h/a]	8000	
Electricity rate [€/kWh]	0,08	
Filter type	PJM	Input: JC, JN or PJM
Number of bags per chamber	136	
Number of chambers	40	
Number of chambers during cleaning (offline)	2	Input: 0 for Online
Injector type	C	Input: C or N - C = Coanda and N = Nozzle
Filter medium	Membran	Input: Membran, ProTex m-Ar or ProTex PI
Operating mode	Offline	Input: Offline or Online
Bag diameter [m]	0,165	
Bag length [m]	8	
Temperature of compressed air [°C]	20	
Safety factor (leaks and losses)	10%	
Air tank volume [L]	48	
Filter area [m²] (gross)	22559,1	
Filter area [m²] (net)	21431,2	
Number of bags in total	5440	
Number of injectors per injection tube	17	
Number of injection tubes per chamber	8	

Calculation Results

Cycle time [s]	Cleaning pressure [MPa]				
	0,6	0,5	0,4	0,3	0,2
	Average pressure drop (filter bag + filter cake [Pa]				
300	1831	1839	1846	1855	1896
	Pressure drop (miscellaneous**) [Pa]				
300	320	320	320	320	320
	Total average pressure drop [Pa]				
300	2151	2159	2166	2175	2216
	Compressed air consumption [m³/h n.c.]				
300	684	590	494	404	271
	Annual energy demand (compressed air + fan) [kWh/a]				
300	7.719.009	7.667.264	7.614.426	7.572.503	7.604.197
	Annual operating costs (compressed air + fan) [€/a]				

are determined by laboratory and pilot plant testing for different filter media and for different grades of mineral dust. VDI 3926, type 1 flat sheet testing is used to determine specific filter cake resistance of three different dust grades:

1. Pural Sb (Al_2O_3), is the normative filter testing dust, which represents a critical, non-agglomerating case with high tendency to penetrate through filter media.

2. Kiln/raw meal mill dust is taken from the product discharge of a process filter in a cement plant, representing kiln and full (without pre-separator) raw meal mill de-dusting.

3. Cement of 5900 Blaine.

Pilot plant test runs (10 x 4m-long bags) are used to determine the residual pressure drop (equivalent to the filter media resistance directly after cleaning) of several bag filter media. As the residual pressure loss is also a function of the applied cleaning power, different tank pressures of 0.1–0.6MPa are also considered. Again, all test of the results for the filter bag directly after jet-pulse cleaning are taken after a complete ageing procedure, to ensure quasi-stationary test conditions. The results are taken for the following different filter media types: [6-7]

1. Standard Polyester (PES) needle felt as a reference.

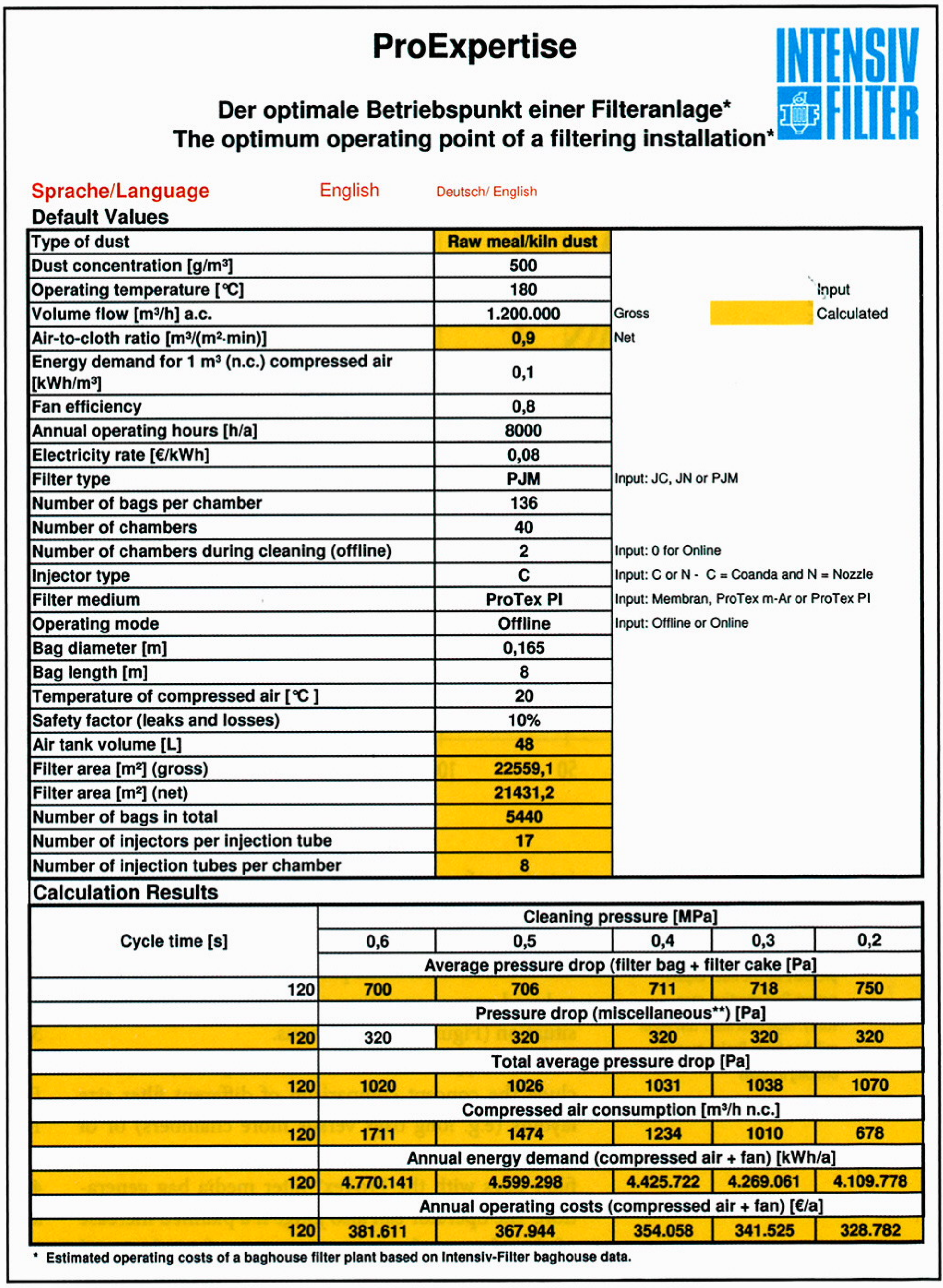
2. ePTFE Membrane laminated on a glass scrim.

3. ProTex® PES, a special microfibre needle felt with reduced differential pressure in operation.

4. ProTex® m-Ar, a special meta-Aramid (Nomex) microfibre needle felt quality with reduced differential pressure in operation.

5. ProTex® PI, a special Polyimid (P84) microfibre needle felt quality with reduced differential pressure in operation.

The results of the calculation are then expressed both in tabular and graphical forms. Figure 11 shows the operating costs for the above-mentioned kiln / raw meal mill application. At very short cycle times, the consumption of compressed air is predominant, leading to increased operating costs. After passing the minimum value (optimum operating point) the operating costs continue to grow, because of the increased cake resistance and thus fan motor power consumption.



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Filter area [m²] (net)	21431,2	
Number of bags in total	5440	
Number of injectors per injection tube	17	
Number of injection tubes per chamber	8	

Calculation Results

Cycle time [s]	Cleaning pressure [MPa]				
	0,6	0,5	0,4	0,3	0,2
	Average pressure drop (filter bag + filter cake [Pa]				
120	700	706	711	718	750
	Pressure drop (miscellaneous**) [Pa]				
120	320	320	320	320	320
	Total average pressure drop [Pa]				
120	1020	1026	1031	1038	1070
	Compressed air consumption [m³/h n.c.]				
120	1711	1474	1234	1010	678
	Annual energy demand (compressed air + fan) [kWh/a]				
120	4.770.141	4.599.298	4.425.722	4.269.061	4.109.778
	Annual operating costs (compressed air + fan) [€/a]				
120	381.611	367.944	354.058	341.525	328.782

* Estimated operating costs of a baghouse filter plant based on Intensiv-Filter baghouse data.

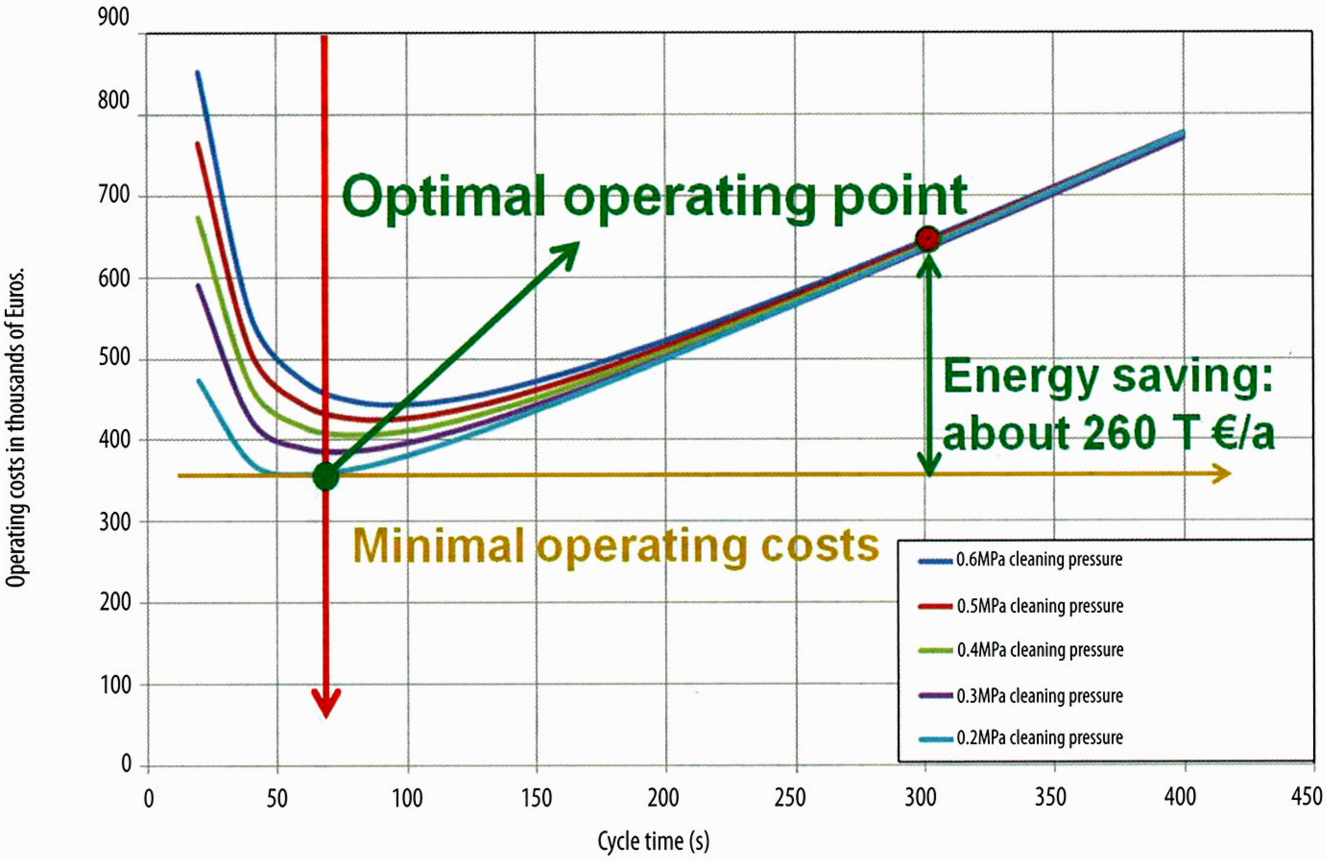
Above - Figure 12: The input / output interfaces of the filter expert system ProExpertise after optimisation.

Low values of the tank pressure tend to give lower operational costs and, due to the minor importance of the pressurised air consumption compared to fan motor power, an optimum operating point at lower cycle times. But there is a limitation caused by insufficient cleaning (patchy cleaning) at very low cleaning impulses.

The high dust application shown here, gives a very low cycle time as the optimum option, because the energy demand is determined by the high resistance of the fast growing filter cake. The picture changes completely if a low dust application is calculated.

The case study shows, that a setting of the cycle time away from the optimum, which is not unusual in the field, easily creates annual cost differences of Euro100,000. This potential can be used immediately in the cement sector, if the fan motor is frequency converter controlled, which is the case for nearly all cement process filters. Figure 12 shows the input/output

Left - Figure 10: The input / output interface of the filter expert system ProExpertise. Conditions: High dust kiln / raw meal bag filter, ProJet mega, 8m bag lengths.



Above - Figure 11: Prediction of the optimum cycle time as a function of the applied air tank pressure by the filter expert system ProExpertise, case study: high dust kiln / raw meal mill bag filter, ProJet mega®, 8m bag lengths

interface after optimisation. The cycle time was adjusted down to 120s and the filter media was changed over to the more energy efficient grade ProTex PI. The reduced differential pressure and the significantly reduced annual operating cost compared to the initial situation (Figure 10) are obvious.

Other applications of the filter expert systems include the concept comparison of different filter size layouts (e.g. long bags versus more chambers) or of upgrade options such as the replacement of standard filter bags with the ProTex® filter media bag generation. The operator can also judge if a planned increase of the plant performance (in terms of product and flow volume rate) can still be handled with the existing filtering installation or not. The assessment of increased operating costs (e.g. in the case of volume flow increase) versus required investment costs for a filter upgrade is also well supported by the programme.

Summary

ProExpertise is a tool that enables cement plant engineers to execute parameter studies in order to find the potential improvements in electrical energy consumption for existing and proposed bag filter systems. The expert system focuses on costs related to fan motor energy and compressed air. The next expansion stage will include costs of depreciation, service and bag replacement for full filtering installations.

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