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# Measurement of Local Frequencies of Filter Regeneration and their Effect on Successive Operating Cycles

Keywords: gas cleaning, rigid filter media, pulse regeneration, cycle time, filter regeneration

## Objectives and Approach

Stable operation, characterised by a succession of uniform filtration cycles with acceptable duration and pressure increase, remains a key issue in high temperature gas filtration. Ceramic filters are known to sometimes become instable. This is somehow related to "patchy cleaning", but cause-and-effect relationships have been difficult to identify. The objective of this contribution is to investigate incomplete regeneration patterns in detail, to try to classify them, and to identify relationships between the residual cake patterns and the form of successive filtration cycles. The work comprises both modelling and experiments at room temperature and high temperature conditions on ceramic media using quartz dust and bark ash.

## Theoretical Considerations

The computational work presented in this section is directed at calculating the pressure increase curve per cycle, from which cycle duration and residual pressure drop are derived, first for a single filter cycle at various degrees of regeneration, and then for a succession of cycles assuming different basic types of regeneration behaviour.

The model calculations are performed using a two-dimensional model introduced by Schmidt (Schmidt, 1995) and used in past publications for calculating the residual pressure drop of partially regenerated rigid filters (e.g. Dittler and Kasper, 1999) and the operational behaviour of partially regenerated filters as well (e.g. Dittler and Kasper, 1999). Figure 1 gives the geometrical arrangement of filter medium, dust cake, clean and raw gas for a partially regenerated filter medium after its first regeneration. The remaining dust cake has a uniform structure and therefore also a uniform height. Using this arrangement, pressure drop curves were calculated for different regeneration efficiencies at a filter face velocity of 5 cm/s. The specific resistance to flow of the dust cake was set to be $K_2$`= 120000 $s^{-1}$ and the resistance to flow of the filter medium was $K_1$`= 3000 Pa*s/m. The pressure drop curves obtained for different regeneration efficiencies are shown in figure 2. It can be seen, that the pressure drop increase gets steeper, the lower the regeneration efficiency becomes. This results in a reduction of filter cycle duration with decreasing regeneration efficiency. In case of only a single regenerated surface area the residual pressure drop also increases with decreasing regeneration efficiency (Dittler and Kasper, 1999). The results shown in figure 2 describe the pressure drop curve after removal of parts of a uniform dust layer. Therefore they describe the pressure drop curve in the second filtration cycle (after the first regeneration of the filter medium) theoretically.

In order to describe the transient development of filter cycle duration and residual pressure drop over a multitude of filtration cycles, two boundary cases of transient filter regeneration will be discussed. In the first case the filter medium is always regenerated at the same filter positions after every filtration cycle with a constant regeneration efficiency of f = 20%. In the second case the filter surface is regenerated also by 20%, but the positions in with the filter surface is regenerated are randomly distributed. Figure 3 shows the geometrical arrangements of both boundary cases of transient filter regeneration addressed. In case the filter element is always regenerated with a constant regeneration efficiency in the same positions the residual dust cake grows continuously as schematically shown in figure 4 (left). In case the 20% of the surface is regenerated randomly after every filtration cycle it is almost unlikely, that parts of the filter surface remain uncleaned after a certain number of filtration cycles.

Pressure drop curves calculated for both boundary cases of transient filter regeneration are shown in figure 4. In case the filter medium is always regenerated at the same positions the pressure drop curves change their character from cycle to cycle. They get steeper resulting in a reduction of filter cycle duration with increasing number of filtration cycles. The filtration process is instable over a multitude of filtration cycles in terms of development of filter cycle duration, but filter cycle duration reaches a constant level after a multitude of filtration cycles.

In case the filter is regenerated randomly with respect to the cleaned filter regions the pressure drop curves have the same shape. Therefore residual pressure drop and filter cycle duration remain at a constant level from the second filtration cycle onwards, resulting in a stable filter operation.

## Criteria for Stability of a Filtration Cycle – Definition of Successive Filtration Cycles

Defining stable filter operation and with this a successive filtration cycle through constant residual pressure drop after regeneration and constant filter cycle duration, different regeneration characteristics can be assigned to a stable or instable filter operation (Dittler, 2001):

- Stable filter operation
  In terms of the above definition stable filter operation occurs according to the model calculations performed and displayed schematically in figure 5 in case of:
  1. Completely regenerated filter surface
  2. Partially regenerated surface with randomly regenerated surface areas

- Instable filter operation
  Instable filter operation is the result of partially regenerated filter media as illustrated in figure 6 in case of:
  1. Partially regenerated filter surface – decreasing regeneration efficiency from cycle to cycle
  2. Partially regenerated filter surface – filter surface always regenerated at the same positions

In case the filter surface is always regenerated at the same positions from cycle to cycle filter cycle duration reaches a constant level after a large number of filter regenerations. This is due to the fact that the growing dust cake at positions the filter is never regenerated blocks the non-regenerated filter area. This is equivalent to a reduction of the effective filtration surface. Therefore filter cycle duration reaches a constant level after a large number of filter regenerations. As cycle duration can become very low, filter operation can become instable. From the definition of a constant cycle duration the process has to be regarded stable after a certain number of filtration cycles.

## Experimental Results

The theoretical results described in some detail in the sections above give useful hints for the interpretation of experimental results. The experiments described here were performed in lab scale filter test rigs using rigid ceramic filter media. Figure 7 gives measured pressure drop curves for two experiments carried out under different operational conditions. The left hand diagram presents pressure drop data obtained from an experiment carried out under ambient conditions using quartz dust (Dittler, 2001). The pressure drop curves displayed in the right hand diagram are measured under high temperature conditions using bark ash (Hemmer, 2002).

In both cases the filter cycle duration decreases with increasing number of filtration cycles, but the shapes of the pressure drop curves measured are different. In the left hand diagram the pressure drop curve of the first filtration cycle is not linear, which is due to dust cake compression observed in this experiment. In this diagram the pressure drop curves get steeper from cycle to cycle, whereas the slope of the pressure drop curves in the right hand diagram remains almost constant after a certain filtration time. These phenomena can be explained by the regeneration behaviour of the filter. In the experiment performed under ambient conditions the pressure drop curves measured are the result of changes in the local frequency of filter regeneration as described by Dittler et al. (Dittler et al., 2002) and Ferer et al. (Ferer et al., 2002).

The local frequency of regeneration can be measured by detecting the dust cake height before and after filter regeneration at each filter position over a number of filtration cycles. From the dust cake height data obtained (e.g. measured with an in situ measuring technique (Dittler et al., 1998)) the local frequency of filter regeneration can be gained (Dittler et al., 2002, Ferer et al., 2002)).

In case of the high temperature experiment the regeneration efficiency decreased from cycle to cycle, leading to a operational behaviour as described in the above sections (see figure 2).

## Conclusions

Partial filter regeneration produces characteristic shapes of pressure drop curves of a given cycle and can lead to a shortening of filter cycle duration. However, by discussing two theoretical boundary cases of transient filter regeneration it has been shown that partial filter regeneration alone is not sufficient to produce instability. Here it is necessary to look at the local frequencies of regeneration on the filter surface, in other words how often the cake at a give spot is removed over the course of a series of pulses (e.g. Dittler et al., 2002; Ferer et al., 2002). This frequency can be very different, depending on media, dust and operating conditions, despite a constant overall regeneration efficiency. Measured pressure drop curves can indicate the filter regeneration behaviour, as filter regeneration causes characteristic pressure drop curves.

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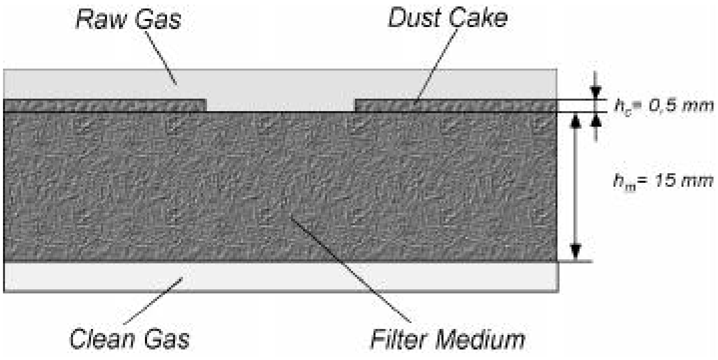

Figure 1: Geometrical arrangement of dust cake, filter medium, raw gas and clean gas after removal of parts of a uniform dust cake from the surface of the filter medium.

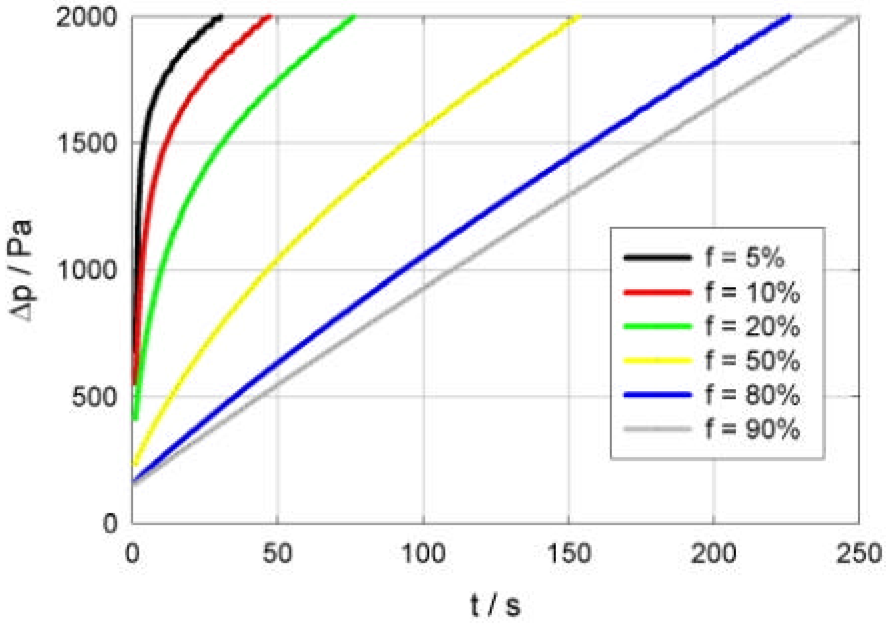

Figure 2: Pressure drop (Δp) vs. filtration time t for different regeneration efficiencies f.

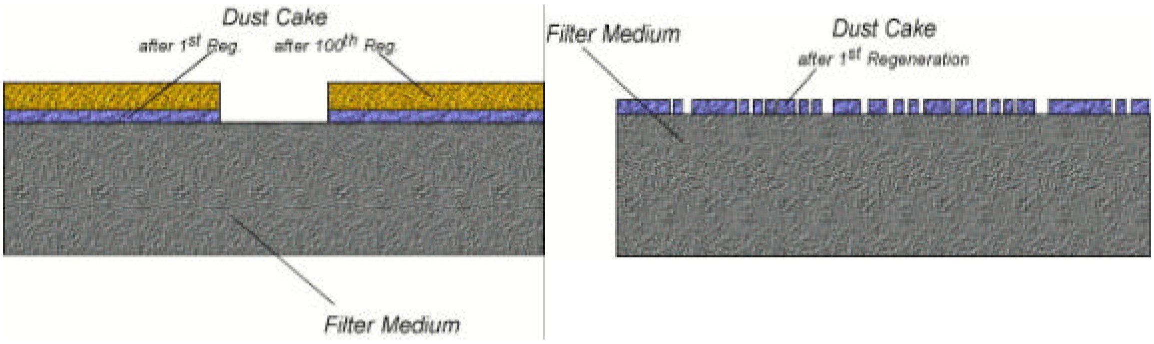

Figure 3: Geometrical arrangement of filter medium and dust cake in case of random filter regeneration (right) and regeneration of the filter medium in the same positions (left) at a regeneration efficiency of 20%.

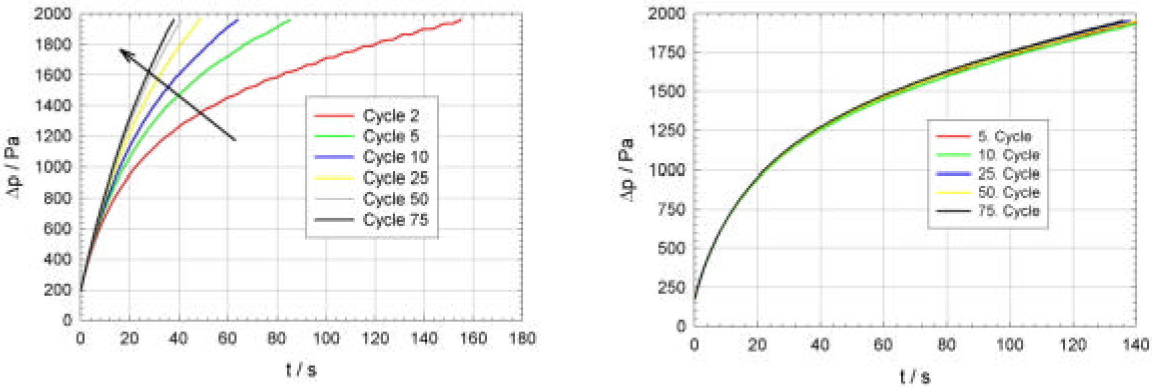

Figure 4: Calculated pressure drop curves for cycles #2, #5 .. #75 in case of random filter regeneration (right) and filter regeneration at the same positions (left) at a constant regeneration efficiency of f = 20%.

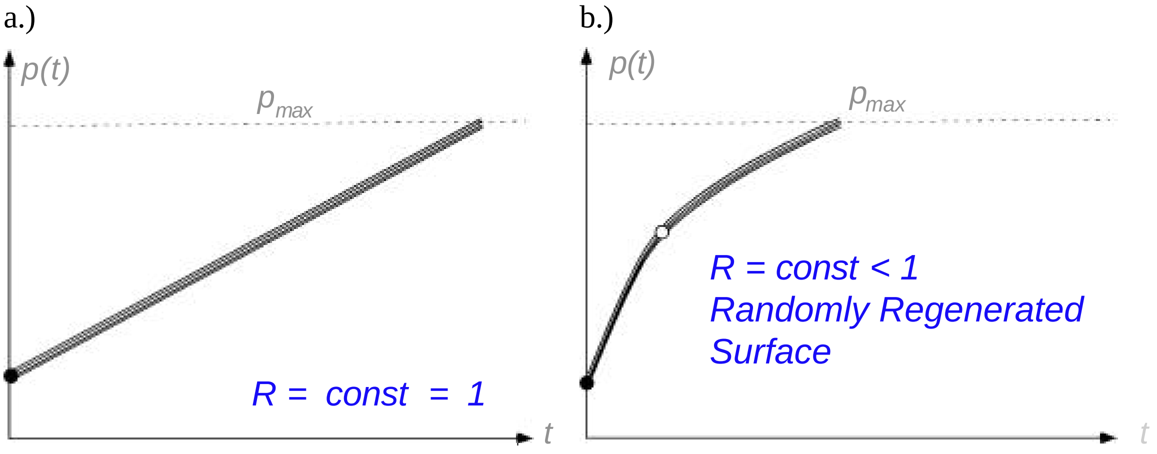

Figure 5: Illustration of stable filtration cycles (a) Completely regenerated filter medium and (b) randomly regenerated filter medium at constant regeneration efficiency.

a.) b.)

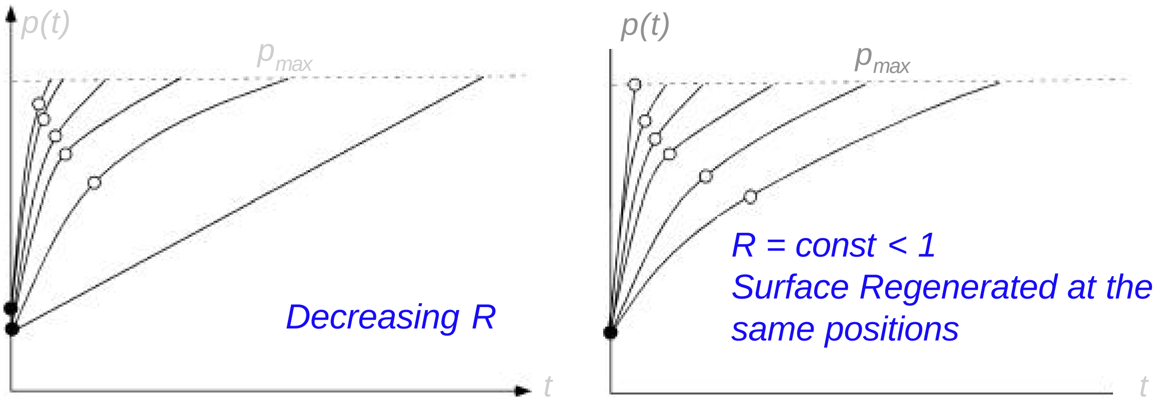

Figure 6: Illustration of instable filtration cycles in case of (a) decreasing regeneration efficiency and (b) surface regeneration at the same positions for a constant regeneration efficiency

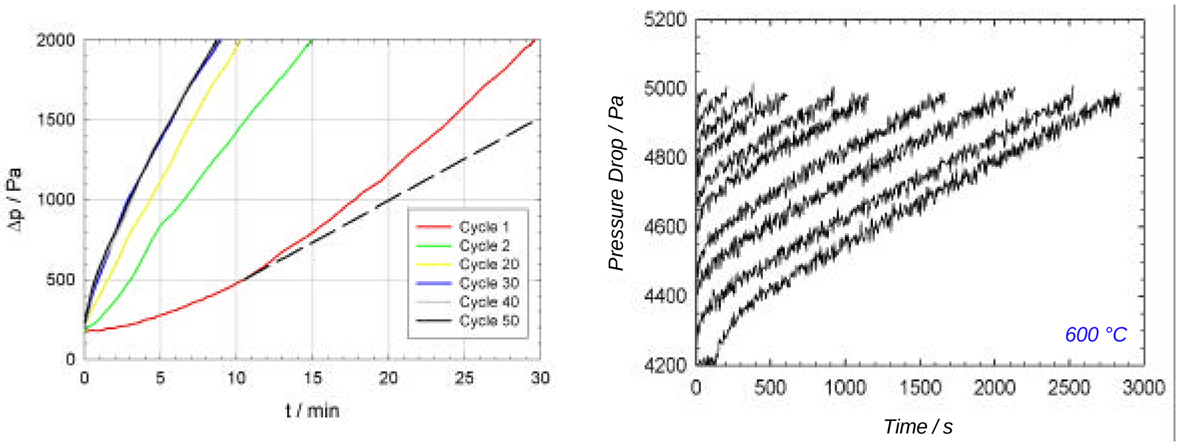

Figure 7: Measured pressure drop curves under ambient conditions (T = 20°C, quartz dust) (left) and hot gas conditions (T = 600°C, Bark ash) (right)