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Impact of backwashing procedures on deep bed filtration productivity in drinking water treatment

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A B S T R A C T

Backwash procedures for deep bed filters were evaluated and compared by means of a new integrated approach based on productivity. For this, different backwash procedures were experimentally evaluated by using a pilot plant for direct filtration. A standard backwash mode as applied in practice served as a reference and effluent turbidity was used as the criterion for filter run termination. The backwash water volumes needed, duration of the filter-to-waste period, time out of operation, total volume discharged and filter run-time were determined and used to calculate average filtration velocity and average productivity.

Results for filter run-times, filter backwash volumes, and filter-to-waste volumes showed considerable differences between the backwash procedures. Thus, backwash procedures with additional clear flushing phases were characterised by an increased need for backwash water. However, this additional water consumption could not be compensated by savings during filter ripening. Compared to the reference backwash procedure, filter run-times were longer for both single-media and dual-media filters when air scour and air/water flush were optimised with respect to flow rates and the proportion of air and water. This means that drinking water production time is longer and less water is needed for filter bed cleaning. Also, backwashing with additional clear flushing phases resulted in longer filter run-times before turbidity breakthrough.

However, regarding the productivity of the filtration process, it was shown that it was almost the same for all of the backwash procedures investigated in this study. Due to this unexpected finding, the relationships between filter bed cleaning, filter ripening and filtration performance were considered and important conclusions and new approaches for process optimisation and resource savings were derived.

1. Introduction

In drinking water treatment, for more than one hundred years, deep-bed filtration has been one of the most commonly used processes for solid–liquid separation of particulate and aggregated material. Over time, research has focused on improving filtration plant design, optimising the filtration process, analysing the mechanisms and the possibilities of modelling the filtration process. However, filter backwash and its impact on the filtration process have received considerably less attention in the research.

From the 1960s to the 1980s the main research activities aimed to improve the basic understanding of backwashing processes with the objective of fluidising the filter bed sufficiently and long enough to remove deposited material (Camp et al., 1971; Amirtharajah and Cleasby, 1972; Cleasby et al.,

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1977; Valencia and Cleasby, 1979). Research in this period aimed at increasing filter run-time by decreasing head loss and improving filter effluent quality (Qureshi, 1982), preventing the formation of mud balls (Camp et al., 1971; Qureshi, 1982), understanding temperature effects (Kawamura, 1975b; Valencia and Cleasby, 1979), and at optimally designing and operating filtration plants (Kawamura, 1975a, 1999, b, c; Quaye, 1987; Kawamura, 1999).

Due to investigations by Amirtharajah (1993), based on a theory developed earlier (Amirtharajah, 1984), it was found that water alone backwashing was inadequate. High-rate water wash alone, as traditionally applied in the United States, was considered to be a weak cleaning process and, therefore, the improvement of cleaning efficiency by the integration of air scour was proposed. For optimum removal of particles, the conditions for a concurrent air and water flow should be such that collapse-pulsing occurs (Amirtharajah, 1993). Investigations by Fitzpatrick (1993) provided visual proof that collapse-pulsing gives the best filter bed cleaning due to the high shear forces resulting from a high degree of filter bed agitation. Chipps et al. (1995) recommended a combination of air and water, at the sub-fluidising rate, as effective for filter backwash to ensure best filtration performance.

In numerous literature studies, the prediction of filter bed expansion, as well as of minimum fluidisation velocity, has been of great relevance. Amirtharajah (1971) modelled the mechanism responsible for particle detachment from the filter grains on the basis of a macroscopic energy balance from which an optimal bed expansion could be determined that provides maximum hydrodynamic shear forces. According to this theory, the optimum bed expansion is 80–100% for filter sand which is rather high and not economical for application in practice. However, it was shown in experimental full-scale studies by Johnson and Cleasby (1966) that optimal filter bed cleaning was obtained with an expansion of 16–18%. These results do not necessarily contradict the model calculations since the shear-porosity-curve on the basis of Amirtharajah's equations is relatively flat with a slightly pronounced maximum. Similar conclusions emerged from investigations by Moll (1988), which resulted in optimal shear force effects at 90% filter bed expansion. However, it was found that at 10% of filter bed expansion, 93% of maximum shear forces still remain, which is enough for sufficient cleaning of a quartz sand filter bed. Due to additional experiments, Moll (1990) suggested a maximum cleaning efficiency at a filter bed expansion of 25%, however, without economic proof.

The importance of the minimum fluidising velocity, as an extremely useful parameter to investigate and optimise filter backwashing processes, was emphasised by Amirtharajah and Cleasby (1972). They also pointed out the difficulties involved in the exact definition of this parameter. Valencia and Cleasby (1979) discussed different approaches to calculate optimal backwashing velocities for filter media grains of different sizes. On the basis of equations derived by Narsimhan (1965) and Ergun (1952) and later adapted by Wen and Yu (1966a, b), equations to calculate sufficient backwash rates were established by Moll (1978, 1980) that could be applied to both sand filters and other filter media. The experiments performed by Moll confirmed the choice of the effective grain diameter d_k as decisive for an exact determination of the optimal backwash rate. Experimental results by Cleasby and Fan (1981) agreed with predictions using the model of Wen and Yu (1966a) when d_{90} was substituted for d_{eq}, the grain diameter of a sphere of equal volume (Qureshi, 1982). Another model for the prediction of fluidisation was proposed by Muslu (1987) in which the minimum fluidisation rate was expressed as a function of porosity, density and sphericity.

In the 1970s and 1980s, research started to focus on the initial period of poor filtrate quality, after filter backwash in particular, as for example the investigations by Harris (1970), O'Melia and Ali (1978), Amirtharajah (1978), Amirtharajah and Wetstein (1980), Francois and Van Haute (1985) and Cranston and Amirtharajah (1987). The low quality of filter effluent immediately after filter backwash had received little attention for a long time because it had been common practice previously to take samples for quality control from the clean water tank and not directly at the filter outlet. Due to mixing, the short-time deterioration of filtrate quality could not be proven thus. Moreover, new insights into the initial degradation of effluent quality could be gained by using new particle and turbidity measuring technology capable of online operation. Amirtharajah (1985) extensively investigated the initial as well as the backwash phase of the deep bed filtration process. His experiments resulted in the descriptions of the two peak characteristics of initial effluent quality as a consequence of backwash water remnants that are still within and above the filter media. On the basis of these investigations, three phases of initial degradation could be identified. The filtrate right after starting the filtration process mainly consists of clean water remnants from backwashing that remained in the under-drain region of the filter. The next phase is associated with the increasing impact of backwash remnant particles remaining in the pore water and in the filter box above the filter media. The following phase is affected by influent and remnant particles that cannot adequately be retained by the filter media due to still insufficient filter ripening with respect to the fact that already deposited particles act as additional collectors.

Since this period of poor filtrate quality could also be associated with an increased passage of potentially pathogenic micro-organisms as, for example, observed by Logsdon et al. (1985), Rose (1988) and LeChevallier et al. (1991), attempts to reduce the magnitude and duration of the filter ripening period were intensified. The investigations cited motivated designers to return to the common earlier practice to discharge filter effluent until filtrate quality reaches the desired standards. Yapijakis (1982) suggested the addition of polyelectrolytes to the backwash water to reduce the initial turbidity period and the peak. Suthaker et al. (1998) investigated the impact of the initial filtration rate on the filter ripening sequence and suggested the selection of a suitable filtration rate for ripening. Another approach to improve initial filtrate quality was proposed by Colton et al. (1996). They investigated the optimisation potential of collapse-pulsing as a backwash procedure and a slow start mode for the filtration process and were able to demonstrate a decreased passage, by more than half, of particles with a size ranging from 2 to 5 μm. These attempts were resumed by Amburgey (2002) and Amburgey et al. (2003, 2004) by providing an attempt to adapt the backwash process. To avoid a filter-to-