

입상여과에서 입자물질의 탈리

Particle Detachment in Granular Media Filtration

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Abstract

Particle breakthrough can occur by either the breakoff of previously captured particles (or flocs) or the direct passage of some influent particles through the filter. Filtration experiments were performed in a laboratory-scale filter using spherical glass beads with a diameter of 0.55 mm as collectors. A single type of particle suspension (Min-U-Sil 5, nearly pure SiO_2) and three different destabilization methods (pH control, alum and polymer destabilization) were utilized. The operating conditions were similar to those of standard media filtration practice: a filtration velocity of 5 m/h. To assess the possibility of particle detachment during the normal filtration, a hydraulic shock load (20% increase of flow rate) was applied after 4 hours of normal filtration. The magnitude of particle detachment was proportional to the particle size for non-Brownian particles. At the same time, less favorable particles, i.e., particles with larger surface charge, were easily detached during the hydraulic shock load. Therefore, proper particle destabilization before filtration is crucial for maximum particle removal as well as minimum particle breakthrough.

Key words: filtration, particle detachment, zeta potential distribution, particle size distribution

주제어: 여과, 입자물질탈리, 제타전위분포, 입자크기분포

1. INTRODUCTION

Filtered water with a turbidity of 0.1 NTU is considered safe for drinking purposes (Hatukai et al., 1997). Even at this low turbidity, the water can contain hundreds of particles per milliliter. It has been shown that

most of the failures to meet turbidity criteria were due to initial breakthrough immediately after a backwash and later breakthrough after a long period of filtration in which adequate removal was achieved (McTigue et al., 1998).

The fundamental mechanisms of the detachment process are not as well studied as the mechanisms of

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attachment. In the past, researchers have investigated particle detachment processes in terms of macroscopic parameters such as effluent concentration. Only recently have researchers investigated particle detachment from a fundamental approach, i.e., consideration of short range forces such as Born repulsion and hydration forces.

Amirtharajah and his colleagues (Ahmad and Amirtharajah, 1998; Raveendran and Amirtharajah, 1995) did extensive investigations on particle detachment during filter backwashing. Though they confined their theoretical and experimental framework to filter backwashing, the same ideas can be applied to particle detachment during granular media filtration. They viewed the detachment process as occurring in two steps: detachment and transport. The chemistry of the system affects some colloidal interactions so that detachment can be viewed as a physicochemically dominated process, while transport is mostly a physical process (Raveendran and Amirtharajah, 1995).

As particles are removed from the suspension and captured on the collector, they tend to accumulate in a variety of geometric configurations. If the overall filtration velocity remains constant, then the fluid velocity within the pores will increase as particles accumulate in the pores. These increasing velocities will result in increasing drag forces on the deposited particles. Eventually the drag forces reach a magnitude equal to the adhesive forces, and after that point, particles are detached (Amirtharajah, 1988; Adin and Rebhun, 1987).

Bai and Tien (1996) tried to investigate the influence of flow shear shock on particle detachment by introducing following equation.

$$F_n = F'_f - F_s = k'_f \frac{6(1 - \epsilon_0)Hd_p}{d_c 12 \delta_o^2} - 2.551 \times 3\pi\mu \frac{A_s d_p^2 v}{d_c \epsilon_o - \sigma}$$

where F_n is net tangential force; F'_f is frictional force against sliding; F_s is hydrodynamic shear force; k'_f is constant; H is Hamaker constant; δ_o is surface-to-surface

separation distance between a particle and a collector. They concluded that if $F_n \geq 0$, then there is no particle detachment, whereas if $F_n < 0$, then there is a sliding of the deposited particle and, subsequently, its detachment. Bai and Tien (1996) postulated that F_n would be dependent on particle and collector diameter, flow rate, and hydraulic gradient in a filter bed layer.

As a suspension passes through the filter, some particles attach to the media or to previously-retained particles, but others remain in suspension, depending on their physicochemical characteristics. At the same time, some of the previously-captured particles are detached either as individual particles or flocs.

Many researchers have investigated various aspects of particle detachment (breakthrough) with limited success, yet nobody has investigated physicochemical differences of detached particles and non-attached particles in terms of the zeta potential distribution (ZPD) as well as particle size distribution (PSD) of particles. These differences were experimentally investigated during this research.

2. EXPERIMENTAL METHODS

A schematic diagram of the experimental filtration system utilized in this research is presented in Fig. 1. A clear acrylic laboratory-scale filter column was used. This column has an inner diameter of 3.8 cm and a maximum media depth of 14.2 cm. During this research, the filter media depth was fixed at 10 cm.

Various experiments have been implemented to investigate particle detachment in porous media filtration. Studies have been conducted in a laboratory-scale filter using spherical glass beads as the media under several conditions of relatively simple solution chemistry. A single type of particle suspension (Min-U-Sil 5) and three different destabilization methods (pH control, alum and polymer destabilization) were utilized. The operating conditions were similar to those of standard media filtration practice: a filtration velocity of 5 m/h and media diameter of 0.55 mm. Particle size and zeta potential of particles were measured by Coulter Counter (Coulter

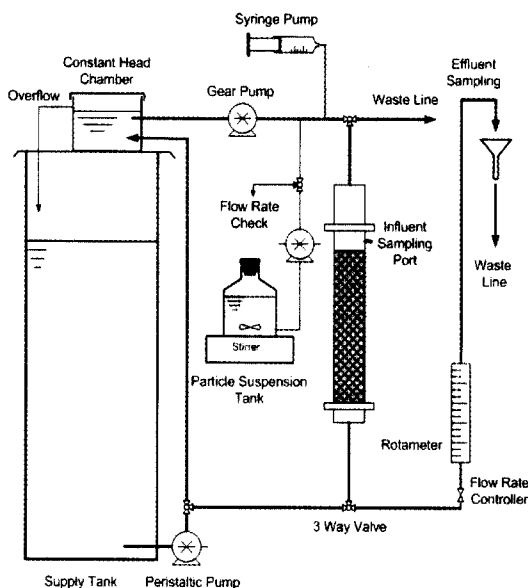


Fig. 1. Schematic of experimental filtration system (not to scale).

Multisizer, Coulter Electronics Inc.) and Zetaphoremeter IV (CAD, France), respectively. A more detailed explanation on experimental methods can be found elsewhere (Kim, 2004).

3. RESULTS

To assess the possibility of particle detachment a hydraulic shock load was applied after 4 hours ($20 \text{ m}^3/\text{m}^2$ cumulative hydraulic loading (CHL)) of normal filtration. The solids concentration remaining during the entire 5 hour filtration experiments ($26.6 \text{ m}^3/\text{m}^2$ CHL) at pH 4.0 is shown in Fig. 2. After 4 hours of normal filtration processes, the flow rate was increased 20%, i.e., from 5 m/h to 6 m/h. To exclude any influence of influent particles, the hydraulic shock load was applied $0.42 \text{ m}^3/\text{m}^2$ CHL after the particle suspension line was closed. As $0.33 \text{ m}^3/\text{m}^2$ CHL was needed for thorough flushing of the filter volume, $0.42 \text{ m}^3/\text{m}^2$ CHL was thought to be enough to have particle-free influent.

After the hydraulic shock was applied, the PSD was analyzed to investigate the influence of the hydraulic shock load on PSD with time. The particle number

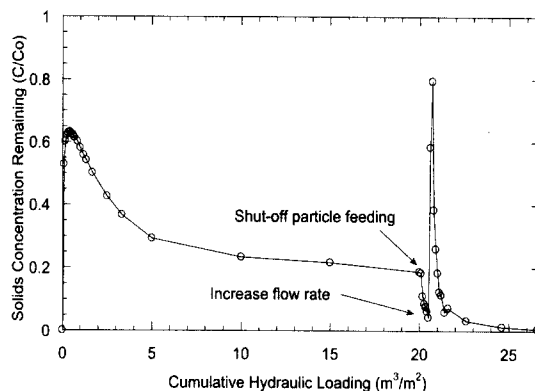


Fig. 2. Solids concentration remaining (C/C_0) during the whole experiment (5 hours) at pH 4.0.

fraction percentages among four size ranges for the influent and effluent after hydraulic shock loading are shown in Fig. 3, where S-0 min and S-1 min represent samples taken from 0 to 1 minute and 1 to 2 minutes, respectively, after the hydraulic shock load was applied. It was shown that relative magnitude of particle detachment under hydraulic shock load was proportional to the particle size, i.e., larger particles are more easily detached when the effluent particle size fraction was normalized by that of the influent. These findings are similar to that of Bai and Tien (2000), who noticed that larger particles are more liable to be detached than smaller particles due to their large surface area.

Particle detachment on the basis of particle number concentration during the hydraulic shock load at pHs 3.0, and 5.0 is shown in Fig. 4. This graph confirms that larger particles are more liable to be detached than smaller particles during the hydraulic shock load. From this figure, it can also be assumed that more severe particle detachment happened right after the hydraulic shock load application, but its magnitude gradually decreased with time. On the other hand, at pH 5.0, particles in the $4.0\text{-}5.0 \mu\text{m}$ size range group showed slightly less increase of particle number than the $3.0\text{-}4.0 \mu\text{m}$ group did as shown in Fig. 4(B). It can be assumed that some of the large particles were not a single particle but a floc, and during the hydraulic shock load some of the larger flocs may have broken into separate particles, so that the number of the

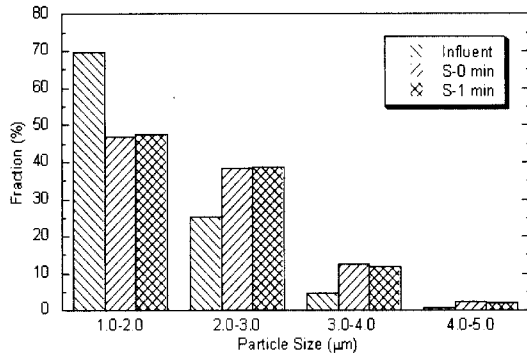


Fig. 3. Particle size fraction percentages at pH 3.0 (number base) during the hydraulic shock load application.

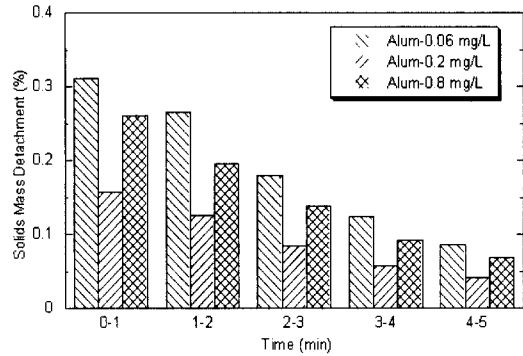


Fig. 5. Solids mass detachment during the hydraulic shock load application at alum destabilization.

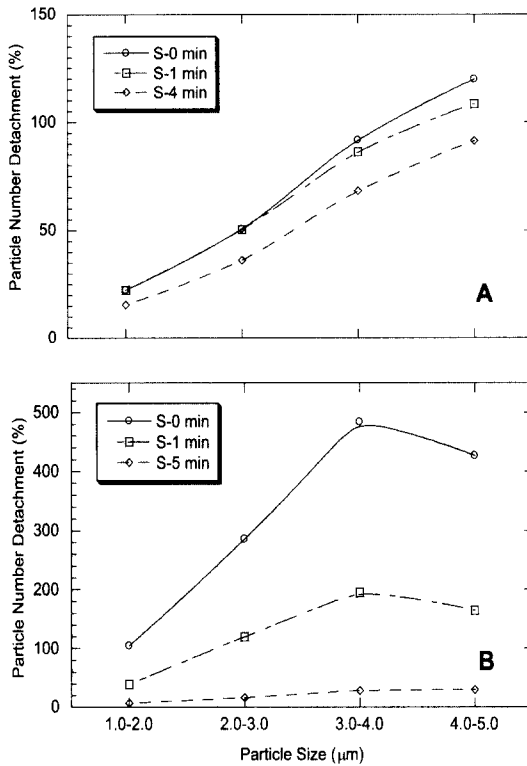


Fig. 4. Particle number detachment during the hydraulic shock load application at pHs 3.0 (A) and 5.0 (B) (normalized by influent PSD).

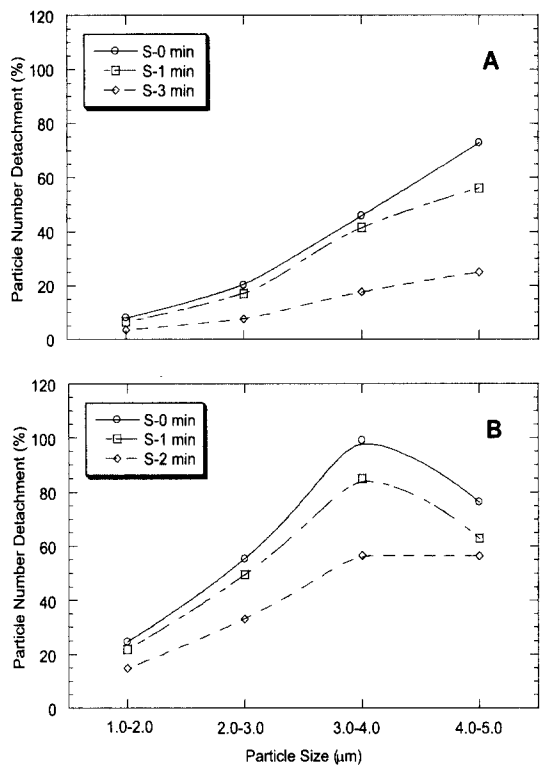


Fig. 6. Particle number detachment during the hydraulic shock load application at alum dose of 0.2 mg/L (A) and 0.06 mg/L (B).

larger particles decreased.

The solids mass detached under the hydraulic shock load with alum destabilization is shown in Fig. 5. Though more mass was removed at the optimum dose (0.2 mg/L),

less particle detachment occurred. This phenomenon can be assumed to be related to the floc strength. It can be assumed that the magnitude of particle detachment is inversely proportional to the floc strength, assuming the

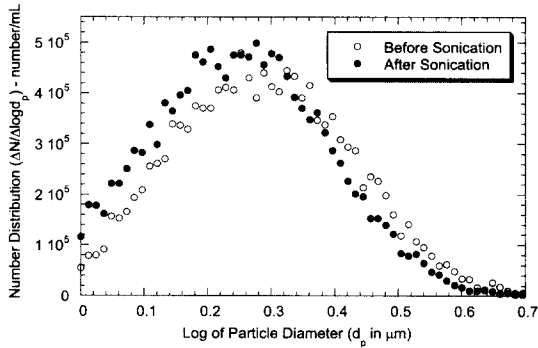


Fig. 7. PSD of sample before sonication and after sonication at alum dose of 0.2 mg/L (sample of S-0 min., duration-10 min.).

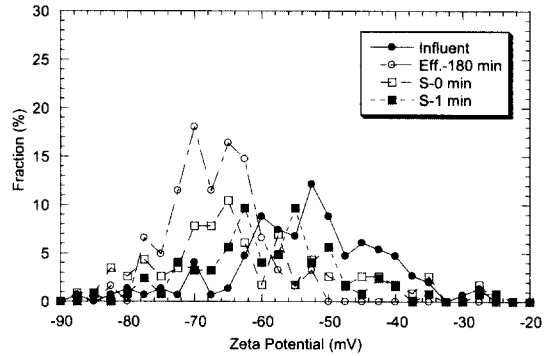


Fig. 9. ZPDs of Min-U-Sil 5 during the hydraulic shock load application at polymer dose of 0.001 mg/L.

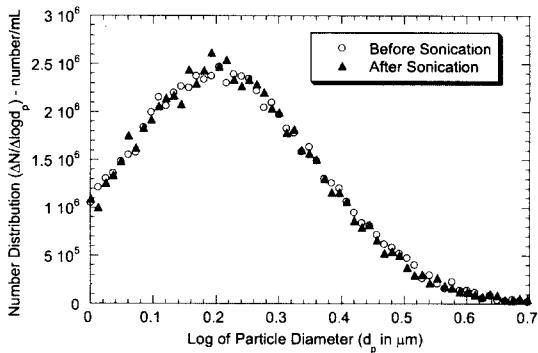


Fig. 8. PSD of influent at alum destabilization before sonication and after sonication.

same mass has been accumulated during the filtration.

The particle number detached at optimum dose (0.2 mg/L) and below optimum alum dose (0.06 mg/L) during the hydraulic shock load is shown in Fig. 6. It was normalized by the influent PSD. Though particle detachment generally increased with the increase of particle size as shown in Fig. 6(A), less particle detachment was noticed at the biggest particle size range (4.0-5.0 μm) in comparison to the 3.0-4.0 μm range as shown in Fig 6(B). It can be assumed that during the hydraulic shock load, bigger particles were broken into smaller individual particles or flocs.

To investigate whether large particles in the effluent during the hydraulic shock load were individual particles or flocs made up of two or more particles, ultrasonication

of the particles was conducted in a small bath (Branson Model: 13-22-4, CT). Fig. 7 shows the PSD of the S-0 min sample during the hydraulic shock load at alum dose of 0.2 mg/L before and after sonication. This graph shows that the PSD after 10 minutes of sonication significantly shifted to left (smaller particles), which suggests that larger particles were broken into smaller separate particles. From this graph, it can be deduced that flocs can be broken into several smaller particles when the higher shear field of the hydraulic shock load was applied.

One of the possibilities of this shift can be the possibility of the break-up of Min-U-Sil 5 particles themselves. However, there is no significant difference between the PSD of the influent before and after sonication, as shown in Fig. 8, which means that unflocculated Min-U-Sil 5 particles did not break up during the sonication.

ZPDs of the effluent during the hydraulic shock load at the polymer dose of 0.001 mg/L (below optimum) are shown in Fig. 9. Compared to the ZPD of Eff.-180 min (that was far to the left of the influent), S-0 min and S-1 min were between the influent and effluent at 180 minutes (i.e. Eff.-180 min). It can be deduced that the zeta potentials (absolute values) of detached particles during the hydraulic shock load were higher than those of the influent but less than those of the effluent.

From this figure, several things can be deduced. First, less negative (more destabilized) particles were well

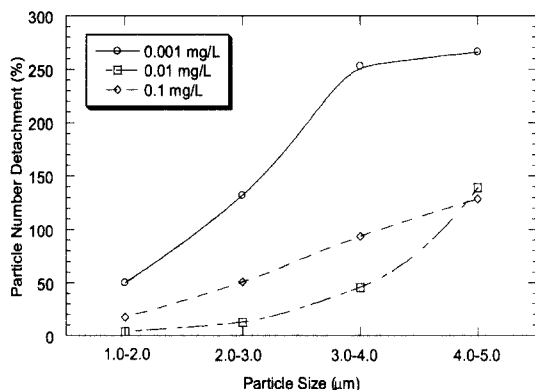


Fig. 10. Particle number detachment right after hydraulic shock load application (S-0 min.) at different polymer doses.

attached during the normal filtration, because the ZPDs of S-0 min and S-1 min were less negative than the ZPD of Eff.-180 min. Second, the ZPDs of the effluent during the hydraulic shock load were still more negative than that of the influent, which means weakly held particles were more easily detached than were the strongly attached particles. Third, when the ZPDs of S-0 min, S-1 min, and S-2 min (graph is not shown) are compared, it is seen that the mean zeta potential slightly moved from more to less negative, which means more weakly held particles were detached right after the hydraulic shock load.

The particle number detached at S-0 minutes under the three different polymer doses (i.e., optimum dose (0.01 mg/L), below optimum dose (0.001 mg/L), above optimum dose (0.1 mg/L)) is presented in Fig. 10. From this graph, it can be deduced that particle detachment can be a function of particle size: bigger particles can be more easily detached than smaller particles. At the same time, the slope of the graph can be a function of floc strength. When the floc strength is small (e.g., polymer dose of 0.001 mg/L), then the shape of graph can be convex, while if the floc strength (e.g., polymer dose of 0.01 mg/L) is high, then its shape would be concave. If the floc strength is intermediate, then its slope would be linear.

Another observation can be made from Fig. 10. If floc strength is high, then although floc detachment may happen at a certain depth in a real WTP, detached particles can be reattached at subsequent filter depth

(assuming that the filter depth is sufficient, because particle transport efficiency increases with increasing particle size for non-Brownian particles). Therefore, it is very important to ensure proper charge destabilization for the following reasons. First, proper charge destabilization can maximize particle removal efficiency. Second, it can minimize particle detachment. Third, when particle detachment occurs, it can maximize particle reattachment deeper in the filter.

4. SUMMARY AND CONCLUSIONS

The major observations based on these filtration experiments using three different destabilization methods are stated below.

1. More severe particle detachment was noticed when the influent zeta potential was high. It can be assumed that if the zeta potential of the influent is high (absolute value base), then the attraction force is small, which means flocs are liable to be detached.

2. When the hydraulic shock load was applied, the magnitude of particle detachment (when the effluent PSD was normalized by the influent PSD) was proportional to the particle size at all three chemical conditions. This phenomenon can be caused by larger particles' greater surface area.

3. In some cases, when the influent zeta potential was too high, the magnitude of detachment (when the effluent PSD was normalized by the influent PSD) of larger particles (e.g., 4.0-5.0 μm) was smaller than that of smaller particles (e.g., 3.0-4.0 μm). It can be assumed that in this case, bigger particles were broken into small individual particles because the attachment force of flocs was weak.

4. The shape of the curve between the magnitude of particle detachment and particle size depends on floc strength and may be concave, linear, or convex: if the floc strength is large, then the slope can be concave; if it is small then the shape can be convex; finally, if it is intermediate, then the slope can be linear.

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