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EXPERIMENTAL RESEARCH INTO DEPTH FILTRATION OF POLYDISPERSED SUSPENSION

Numerous laboratory experiments and theoretical studies of depth filtration have been carried out by various researchers over the last hundred years, but no satisfactory, complete and practical mathematical model has yet been proposed. Little is therefore known about attachment efficiency and there are few practical methods of measuring and describing the size and shape of suspension particles. A laser particle size distribution measuring technique applied during laboratory and full-scale experiments (according to theory) proved that suspension particle diameter has a major impact on removal efficiency. The results revealed the importance of other parameters such as surface potential, particle shape and surface microstructure.

1. INTRODUCTION

Over the past century, numerous theoretical studies and laboratory experiments have been carried out in order to understand and describe the depth filtration process [2], [6]. Some observations [1], [9] report a sudden improvement of particle removal efficiency during the initial filtration phase followed by stabilization until a critical point is reached, whereafter efficiency begins to decline. Others [5] report systematic deterioration of efficiency during the filtration cycle or that it remains constant throughout.

Analysis of existing analytical equations [10], [11] shows that most recognised phenomena accompanying filtration depend on particle size. Along with increases in particle size we observe a clear increase in the predominance of interception and sedimentation in the transport of particles to the area where adhesion forces are exerted. Adhesion forces are still poorly recognized, though there is no doubt that particle sizes also have a considerable influence on them. The London–van der Waals force grows with increasing particle size. On the other hand, we also usually observe a reacting electrokinetic double layer force. Moreover, particle size has a considerable effect on hydrodynamic forces related to local wall shear stress acting tangentially to

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the surface. Frictional force increases simultaneously with increasing particle size. Many studies [3], [4], [7]–[9] also suggest that the size of suspension particles influences the morphology of deposit being formed on filter bed grains, which in turn affects the capacity of the suspension to retain subsequent particles flowing through.

2. LABORATORY SET-UP

The laboratory experiments were carried out in the set-up including a filtration column and inflow system. The raw water suspension arriving at the filter during the experiments was prepared in a one cubic-metre radial tank made of stainless steel. The tank was equipped with a hydraulic mixing system to protect it against suspension particle sedimentation. The raw suspension was pumped to the overflow tank maintaining constant inflow to the column. The three-metre-high filtration column was filled with sand medium to a height of eighty centimetres with stratification as presented in table 1. Closing slowly the outflow valve at the end of the backwash cycle ensured similar sand stratification at the beginning of the filtration runs.

Table 1

Filtration media grain size

Grain size	Weight percentage
0.4 mm – 0.5 mm	10 %
0.5 mm – 0.63 mm	19 %
0.63 mm – 0.8 mm	31 %
0.8 mm – 1.0 mm	36 %
1.0 mm – 1.25 mm	4 %

The particle size distribution was measured using a Malvern laser diffraction instrument based on the Mie theory

The raw suspension was modelled in the tank using silica powder Sipernat 310 and Sipernat 820 A produced by Degussa. The particle size distributions of the silica powders are presented in figure 1, while the chemical composition and BET specific surface area are presented in table 2. The suspension concentration of the inflow obtained in all the experiments was 150 milligrams per 1 dm^3. The filtration velocity was maintained at a constant 5.4 metres per hour, and measured temperature was 19.5 °C.

Zeta potential was measured with a Malvern Zetasizer. The zeta potentials of the sand grain, Sipernat 310 particles and Sipernat 820 A particles were (–37 mV), (–27 mV), (–42 mV) respectively in dematerialised water and (–24mV), (–15mV) and (–28 mV) in water used during laboratory experiments. Conductance of the filtered water was 0.43 mS/cm, with a pH of 8.3.

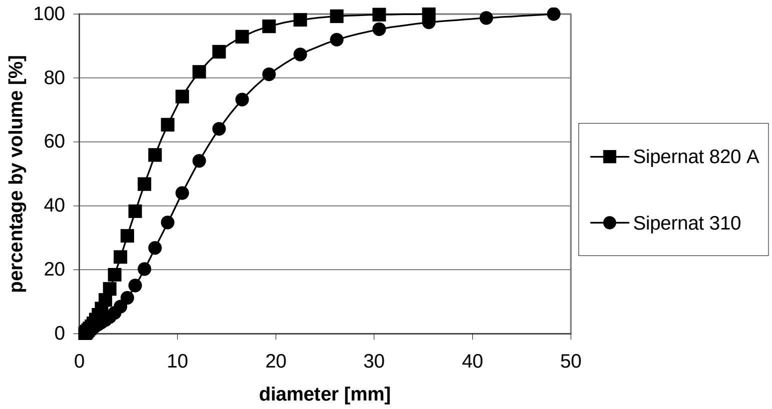

Fig. 1. Particle size distribution of inflow suspensions

Table 2

Chemical composition

Powder	Chemical composition	Specific surface BET [m^2/g]
Sipernat 820A	82% SiO_2; 9.5% Al_2O_3; 8% Na_2O, 0.03% Fe_2O_3; 0.4 % SO_3	90
Sipernat 310	99% SiO_2; 0.5% Na_2O; 0,02 Fe_2O_3; 0.3 % SO_3	750

3. WATER PLANT

The full-scale experiments were carried out in one of Kraków's water treatment plants on the Dłubnia River. The plant uses conventional technologies such as coagulation, flocculation, sedimentation and filtration. Water from the river is continuously coagulated with aluminium sulphate, and suspension after flocculation is settled in horizontal tanks and enters ten rapid sand filters. The pH of the water flowing through the filter averaged 8.5, conductance amounted to 0.73 mS/cm and temperature to 11 °C . Unfortunately, suspension concentration at the outflow from the filter was lower than the minimum level suggested by the producer, so samples were settled and decanted before measurement.

4. EXPERIMENTAL RESEARCH

Most reports in reference material [1], [9] describe a three-stage depth filtration process. In the first stage, the efficiency of particle removal improved considerably, whereafter it remained constant until reaching a critical point. In the last stage, particle removal efficiency began to deteriorate. The first two stages were clearly visible during laboratory experiments (figure 2) using a suspension based on Sipernat 310 granulate. During experimental research in a water treatment plant (figure 3) the filtration process proved to be much the same, except that in full-scale experiments efficiency increased gradually from the very beginning. Absence of sudden improvement in efficiency at the initial stage may be a result of many years' filter bed operation in the water treatment plant, which meant that the bed was covered with a thin layer of biological film, even after backwashing.

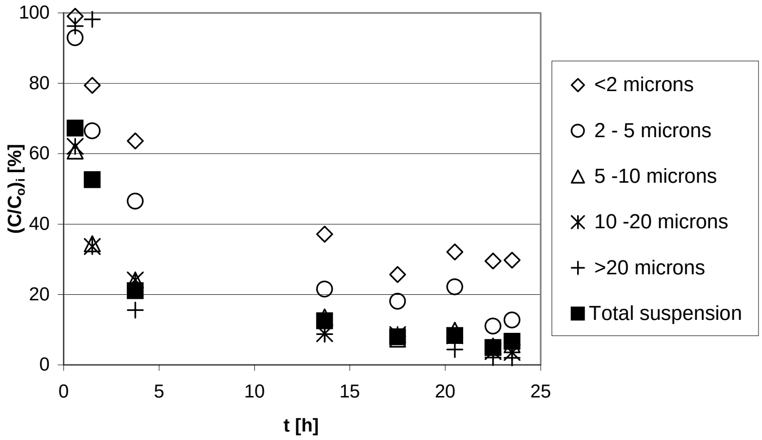

Fig. 2. Variation of relative concentrations of each size fraction and total suspension during laboratory experiments (by volume) – Sipernat 310

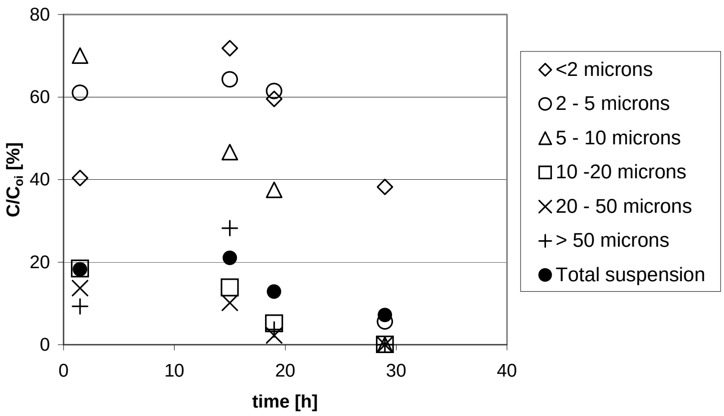

Fig. 3. Variation of relative concentration of each size fraction and total suspension during full-scale experiments in water treatment plant (by volume)

Figures 2 and 3 show the progress of removal efficiency not only for filtered total suspension, but also for the certain-size particles constituting its components. As expected, larger particle removal efficiency was generally much better than removal efficiency for smaller particles. Interception and the gravity effect on particle removal may explain this. The considerable increase in the efficiency of all-size particle removal in the initial phase can be easily explained in terms of the superior capacity of deposit consisting of retained particles to remove suspended particles subsequently flowing through than the retaining capacity of sand grains after backwashing. Undoubtedly, these properties were obtained by flocculation on full commercial scale, and by the use of Sipernat 310 particles during laboratory experiments, which have a surface potential value relatively close to zero and a relatively well-developed surface structure. On the other hand, filter bed porosity gradually decreased during filtration. As a result, flow velocity inside the filter bed pores increased, and this resulted in increasing shear stresses. This may explain slower improvement of efficiency in the second filtration phase. During both experimental tests, increase in the efficiency of thicker particle removal was still slightly higher than for finer particles, although head loss reached maximum acceptable values, as shown in figure 2 and figure 3. This was due to decreasing porosity, which causes both increase of shear stresses and improvement of conditions of interception, which is a dominant phenomenon in the removal of thicker particles. During the experiments, particle size distribution at the outflow from the filter was considerably different than that in inflowing water – what is more, it changed during the run. Therefore, filtration efficiency measured on the basis of nephelometric turbidity progressed decisively differently than that when measured on the basis of the volume of total suspended solids as presented in figure 2 and figure 3. This was analysed in [12].

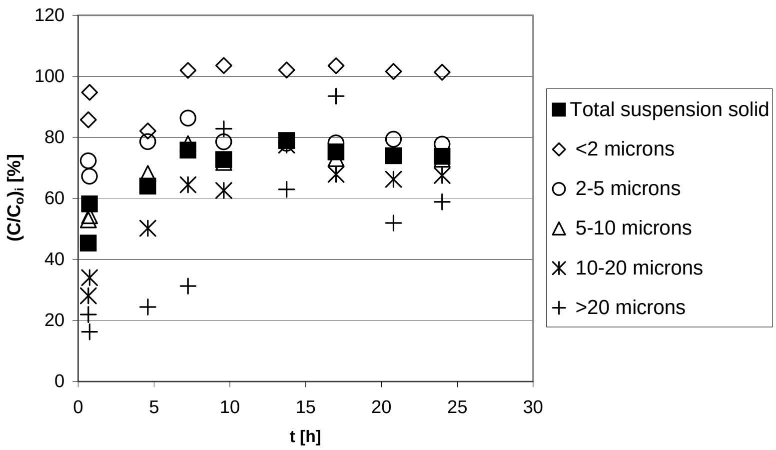

Fig. 4. Variation of relative concentration of each size fraction and total suspension during laboratory experiments (by volume) – Sipernat 820A

In the same laboratory filtration conditions as in the case of the Sipernat 310 experiments, the change in removal efficiency for Sipernat 820 A suspension particles proceeded in a completely different manner. Instead of improvement, particle removal efficiency gradually deteriorated from the very beginning, as shown in figure 4. Initial removal efficiency for particles dispersed in the suspension was approximately 55% – it was therefore close to initial removal efficiency for Sipernat 310 suspension particles as shown in figure 2. However, in subsequent filtration stages, efficiency deteriorated instead of improving. In particular, we could see a decrease in removal efficiency for thicker particles. Throughout the filtration process, removal efficiency for particles smaller than 2 microns remained at its lowest level. There is no question that the Sipernat 820 A granulate particles dispersed in suspension were responsible for deteriorating efficiency, as all other parameters remained unchanged. The properties of deposit consisting of retained particles and formed on filter bed grains regarding the capture of particles flowing through must have been similar or even worse than the properties of filter bed grains after backwashing. Sipernat 820 A particles were smaller than Sipernat 310 particles, as shown in figure 1. Some opinions presented in reference material [4], [8], [9] suggest that deposit consisting of small particles is less efficient in removing particles flowing through than deposit containing thicker particles, due to its more compact morphology. Therefore, this phenomenon could bring about a degree of improvement of efficiency in first granulate removal, and deterioration of the other. Undoubtedly, the distinctly lower zeta potential of the Sipernat 820 A particles as compared to that of the Sipernat 310 particles resulted in the occurrence of greater "double layer" repulsive forces between flowing through and previously retained Sipernat 820 particles than between Sipernat 310 particles. The lack of a tendency to coagulate and form aggregates, additionally verified by particle size measurements, confirms the high stability of Sipernat 820 A granulate suspension, unlike Sipernat 310 granulate suspension. Moreover, the low efficiency of deposit consisting of Sipernat 820 A particles in removing subsequent particles flowing through the filter bed was probably due to the smooth surface structure characterized by low porosity. This is indicated by information from the manufacturer that BET specific surface for Sipernat 820 A particles is low compared to that of Sipernat 310 granulate particles. If these properties occur in deposit consisting of Sipernat 820 A particles, shear stresses increasing during filtration could result in a decrease in removal efficiency, particularly for large particles.

A very low increase in head loss was the consequence of low removal efficiency for Sipernat 820 A suspensions. After one day head loss grew from 24 cm to only ca. 28 cm. In the same period and in much the same filtration conditions, the substantially higher removal efficiency of Sipernat 310 suspensions resulted in an increase in total head loss in the filter bed from 24 cm to ca. 140 cm, while the head loss increase in both experiments was very similar for identical volumes of particles retained in the filter bed. The only difference was that the same volume of particles was retained after

5.5 hours of filtering a suspension consisting of Sipernat 310 granulate as that retained after approximately 25 hours of filtering the Sipernat 820 A granulate suspension.

5. CONCLUSIONS

The experiments reveal that particle size has a considerable effect on the efficiency and progress of the depth filtration process. In relation to individual particles and their sum, this efficiency changes during filtration. The experiments prove that this progress can be extremely different for suspension particles from the same size ranges but with different properties, in spite of their seemingly similar chemical composition (in both cases, the dispersed particles were silicon compounds). It was necessary to identify differences in their surface structure, in the varying quantitative share of thicker particles, and in surface potential measured indirectly using zeta potential. Improvement of efficiency during the filtration process is of course more typical of filtration used in water treatment and sewage treatment, since it is usually carried out in unstable conditions, that is at zeta potential close to zero. This was demonstrated by full-scale experiments in a water treatment plant. On the other hand, the tests carried out in the water treatment plant showed no sudden improvement during the initial period, due to many years of filter bed operation.

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EKSPERYMENTALNE BADANIA FILTRÓW POSPIESZNYCH DO UZDATNIANIA WODY Z UWZGLĘDNIENIEM NIEJEDNORODNOŚCI ZAWIESINY

Filtracja pospieszna jest jednym z podstawowych procesów wykorzystywanych w oczyszczaniu wody i ścieków. Istnieje szereg modeli teoretycznych próbujących opisać jej przebieg. Niestety, do dziś nie opracowano uniwersalnego modelu, który dałoby się zastosować w dowolnych warunkach. Jednym z głównych tego powodów jest trudna do jednoznacznego opisania zawiesina. Wyniki przeprowadzonych badań eksperymentalnych w laboratorium i w zakładzie uzdatniania wody ukazują znaczący wpływ wielkości cząstek na efektywność ich usuwania oraz odmienny przebieg ich filtracji. Badania wykazały również wpływ innych parametrów charakteryzujących zawiesinę. Efektywność usuwania cząstek o podobnych wielkościach, ale różnych potencjałach powierzchniowych oraz kształcie i mikrostrukturze powierzchniowej, początkowo dość podobna, w trakcie filtracji zmieniała się całkowicie.