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DIRECT FILTRATION APPLIED
TO INFILTRATION WATER TREATMENT

The quality of infiltration water was assessed and the effects of the treatment process which involved coagulation in the rapid filter bed were discussed. The optimum filtration rate was established and the treatment effects were related to the type of the coagulant and polyelectrolyte used. The experimental study substantiated the usefulness of the cation polyelectrolyte Magnafloc LT31which can be applied as a sole coagulant or in combination with ferric chloride. In this way, it was possible to reduce the coagulant dose without deteriorating the water treatment effect in the 24-hour filtration cycle.

1. INTRODUCTION

Direct filtration is of utility only if the pollution level in the water to be treated is low. Conventional coagulation was found to be useless under such circumstances, because the coagulant portions applied were much higher than it might have been inferred from the low content of pollutants. Yet, there is one factor limiting the use of direct filtration, namely the specific deposit in the filter bed with respect to the porosity of the filter bed. The purpose of direct filtration of infiltrated water was to achieve the results of sweeping treatment.

2. METHODS

The experiments were carried out with infiltration water samples collected at the Waterworks of Wrocław after the flood of July 1997 [1]. Water aeration was applied in a full-scale system at a hydraulic load of 60 m^3/m^2h. The filtration process was studied using aerated water samples and a through-flow system of 100 mm diameter filters. The sand filter beds were characterized by an effective size $d_{10} = 0.8$ mm and

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a uniformity coefficient $U = 1.5$. The sand bed depth amounted to 1.0 m and 1.5 m. The coagulation process was carried out with hydrolyzing coagulants (alum, ferric chloride) dosed in portions ranging from 2.5 to 10.0 g/m^3 and was aided by the polyelectrolyte Magnafloc LT31 (with sanitary certificate allowing use for potable water treatment; the doses involved varied from 1.3 to 5.2 g/m^3). Filtration rate ranged between 5 and 10 m/h. Water quality parameters were determined according to Polish standards.

3. WATER QUALITY

In July 1997, the aquifers of Wrocław were flooded with polluted riverine water (from the Odra and the Oława). During flood the infiltration water intake was out of operation, and flood-related investigations in the aquifer area were started. They showed that the vegetation of the area investigated, which was adapted to seasonal submersion, noticeably reduced the adverse effect of the flood water on the parameters of the topsoil layer. After the high water had receded, no substantial changes were found in the topsoil chemistry [2]. The belts of reeds and sedge planted in the Oława valley substantiated their utility in the period of the flood, as they trapped most of the settleable solids carried by the water, thus protecting the aquifer against silting up. The turbulent flow of the high water produced a kind of air cushion, which considerably reduced water infiltration into the soil and, also, migration of pollutants. Analysis of soil revealed the occurrence of aerobic mesofauna, and the air cushion was found to have acted as a natural barrier protecting the infiltration water from excess pollution [2]. The quality of raw water following the flood period is shown in the table [1].

Table

Quality of raw water

Parameter, unit	Range of values
Colour, g Pt/m^3	10–40
Turbidity, NTU	5–30
pH	5.9–7.3
Alkalinity, val/m^3	2.3–2.9
Aggressive carbon dioxide, g CO_2/m^3	13.2–30.8
COD (permanganate), g O_2/m^3	1.7–3.5
TOC, g C/m^3	2.3–6.0
Dissolved oxygen, g O_2/m^3	1.2–6.4
Dissolved solids, g/m^3	350–450
Ammonia, g N/m^3	0.65–6.35
Total iron, g Fe/m^3	0.65–6.35
Manganese, g Mn/m^3	0.5–0.7

Analysis of water samples revealed a considerable variability of some basic physicochemical parameters. Thus, ammonia nitrogen occurred at much higher concentrations in winter than in the other seasons [1]. The samples displayed increased levels of coloured matter, turbidity and organics. Generally, the infiltration water under study is of medium hardness and moderate mineralization, with increased turbidity and colour, as well as with a considerable content of iron and manganese compounds. Elevated concentrations of organic matter (including TOC), together with humic substances, are indicative of the presence of THM precursors [1].

From the parameters of the infiltration water it may be inferred that an effective iron and manganese removal, the restoration of carbonate–calcium equilibrium, as well as a thorough disinfection will provide the water quality desired. This quality can be further upgraded by decreasing ammonia nitrogen, colour intensity and COD to lower levels than those recommended for potable and household water (thus making it meet the health standards). Expressed in numbers, this means a level of ≤ 5 g Pt/m^3; ≤ 1 NTU; ≤ 3 g O_2/m^3, and ≤ 2.0 g C/m^3 for coloured matter, turbidity, COD and TOC, respectively. Water of such parameters prevents formation of side products during disinfection and makes it possible to decrease the required dose of disinfectants. It should be added that the removal of iron compounds to the value of 0.2 g Fe/m^3 noticeably reduces encrustation of water pipes.

4. RESULTS

Conventional water treatment trains include aeration, which is to oxidize bivalent iron compounds, as well as to desorb aggressive carbon dioxide, thus reducing the corrosive effect of the water. Unlike groundwater, the raw water to be taken in had an oxygen content varying from 1.2 to 6.4 g O_2/m^3, and the saturation of oxygen ranging between 12 and 44% (34% on an average). As a result of aeration, oxygen content and oxygen saturation increased noticeably, amounting to 9.5–12.0 g O_2/m^3 and 80–100% (87% on an average), respectively. Thus, in terms of oxygenation, the efficiency of the aeration process should be regarded as very high. But the conversion of Fe(II) to Fe(III) in the course of aeration was found to be low. Our investigations showed that, following the completion of the aeration process, Fe(II) content in the water approached 14% (an amount which did not inhibit iron removal). This finding should be attributed to the presence of oxygen in raw water, which favoured oxidation of at least a certain portion of iron compounds.

The removal of aggressive carbon dioxide by aeration considerably reduced the corrosive effect of the water. In the course of the aeration process, the level of aggressive carbon dioxide decreased from 15 g CO_2/m^3 to 3.2 g CO_2/m^3 on an average, which corresponded to a removal efficiency of about 80%. The corrosive tendency was analysed by examining the calcium carbonate saturation index and the Strohecker

index [1]. In the course of aeration, the values of both the parameters decreased from 3.12 to 0.23 and from 1.1 to 0.67, respectively. And this indicates that the taken-in water, which has a comparatively high corrosive effect, displays a low or moderate aggressiveness as a result of aeration. This finding implies that the water has the ability to dissolve calcium carbonate and that it calls for pH adjustment.

Figure 1 gathers the results of iron and manganese removal with no chemical aid. Thus, filtration at a velocity of 5 m/h (following aeration as a prior step) yielded a decrease of iron compound concentrations to values below 0.5 g Fe/m^3, practically irrespective of the filter bed depth. Manganese compound removal was much more effective at a greater bed depth, yielding concentration values always below 0.1 g Mn/m^3. At a shallower bed depth, manganese concentrations persisting in the effluent noticeably exceeded 0.1 g Mn/m^3. The increase of the filtration rate to 10 m/h brought about a satisfactory efficiency of iron removal on both filters (< 0.5 g Fe/m^3), but the removal of manganese compounds was insufficient (> 0.1 g Mn/m^3).
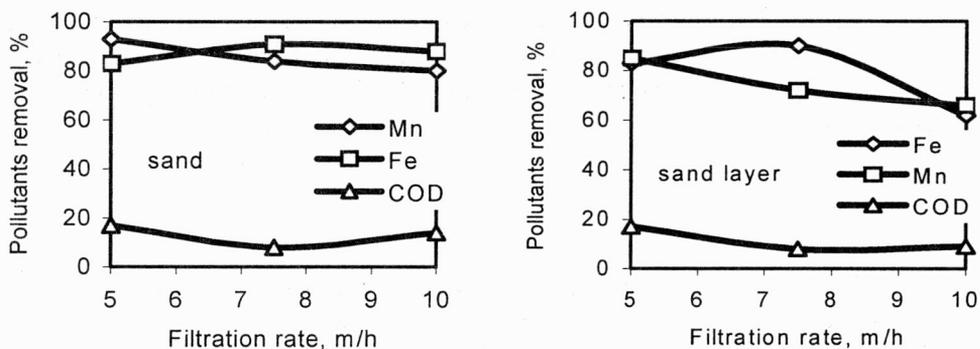

Fig. 1. Effect of raw water filtration

Iron and manganese removal aided by direct filtration with hydrolysing coagulants (alum or ferric chloride) in doses ranging from 2.5 to 10 g/m^3 and at a filtration rate falling between 5 and 10 m/h was investigated. Thus an alum dose of 5 g/m^3 brought about only a 50% efficiency of iron removal; the removal of manganese compounds was poor (manganese concentrations persisting in the effluent amounted up to 0.24 g Mn/m^3). The increase of the alum dose had no beneficial effect either on iron or manganese removal; it shortened dramatically the length of the filter run and decreased noticeably the filtrate quality [3].

Ferric chloride was found to be effective at a dose of 6 g/m^3 and a filtration rate of 5 m/h, yielding an iron removal efficiency of about 50%. The pattern of manganese removal throughout a major part of the filtration run was similar to the one when no coagulant aid was applied. The increase of the ferric chloride dose and of the filtration

rate caused decrease of the efficiency of manganese removal, but did not affect unfavourably the removal of iron compounds (the persisting concentration being equal to, or lower than 0.2 g Fe/m^3). There was, however, a noticeable shortening of the filtration run (to 10 h) [3].

Direct filtration involving hydrolyzing coagulants is not very effective. Higher removal efficiencies can be achieved when use is made of polyelectrolyte-aided coagulation. The contribution of polyelectrolyte aid to the efficiency of the treatment process was investigated using doses of 1.3 to 5.2 g/m^3 and filtration rates of 5 to 10 m/h. Filtration rates higher than 5.0 m/h were excluded, because the 24-hour filter run (which was possible to achieve) did not always provide the filtrate quality desired. The decision of eliminating filtration rates higher than 5.0 m/h was supported by the results of our study into filtration with no coagulants, which was carried out in order to determine the optimum bed depth and filtration rate. The removal of iron and manganese compounds as well as COD and TOC during direct filtration is given in figure 2.
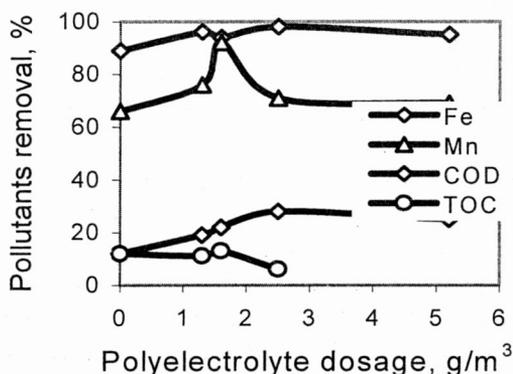

Fig. 2. Effect of water filtration with polyelectrolyte doses (filtration rate of 5 m/h)

The optimum (in terms of manganese removal) polyelectrolyte dose corresponding with the 5 m/h filtration rate was found to be that of 1.6 g/m^3. With this dose a 70-hour filtration cycle was achieved (figure 3), yielding residual concentrations of iron and manganese which averaged 0.11 g/m^3 and 0.05 g/m^3, respectively. Another advantage of applying the 1.6 g/m^3 polyelectrolyte dose is that the process of manganese removal was not disturbed even at increased ammonia nitrogen concentrations in the water (0.3 to 0.5 g N/m^3), which were always found to induce breakdown of manganese removal. With polyelectrolyte doses higher than 1.6 g/m^3 and filtration rates exceeding 5 m/h, the efficiency of manganese removal and the duration of the filtration cycle decreased noticeably. The range of efficient polyelectrolyte doses was found to be narrow, which is likely to inhibit the operation of the object filters.
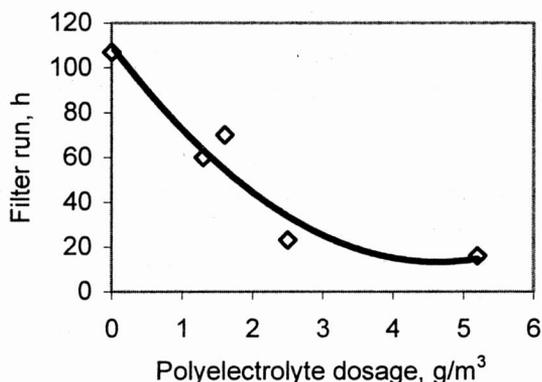
Fig. 3. Filtration run versus polyelectrolyte dose (filtration rate of 5 m/h)

The removal of iron and manganese compounds was paralleled by the decrease of turbidity, colour and COD (which was slightly greater at an increased bed depth). The increase of the filtration rate from 5 to 10 m/h did not noticeably worsen water quality. Thus, the decrease of COD was about several percent, turbidity ranged from 1 to 2 NTU, and coloured matter concentration was slightly elevated, varying from 20 to 25 g Pt/m^3. The reduction of coagulant doses (either alum or ferric chloride) had only a slight effect on the behaviour of the three parameters mentioned. Overdosing brought about a dramatic rise in turbidity and colour; there was a breakthrough of the filter bed, and this meant that turbidity rose to the level of 70 NTU.

The application of Magnafloc LT31 (a cation polyelectrolyte) accounted for the decrease of organic pollutants. Thus, at the filtration rate of 5 m/h, the efficiency of COD removal increased by 7–13% with 1.3–5.2 g/m^3 dose, respectively (figure 2). The variations of TOC did not substantiate these values. The efficiency of TOC removal by polyelectrolyte-aided filtration did not very much differ from the one achieved without polyelectrolyte aid. But the efficiency of COD removal was found to be influenced by the filtration rate [3]. The increase from 5 to 7.5 m/h resulted in the decrease of the efficiency of COD removal. TOC variations did not follow a pattern like this.

In water treatment process involving application of polyelectrolytes, the increase of the polyelectrolyte dose may not necessarily upgrade the quality of the water; on the contrary, it may lead to the clogging of the bed by large flocs, thus deteriorating the quality of the effluent and shortening the duration of the filter run. The efficiency of polyelectrolyte aid in the removal of pollutants from infiltration water demonstrated in this study manifested itself in the iron and manganese removal (with an optimum dose equal to 1.6 g/m^3) and the removal of the remaining pollutants (primarily COD up to 1.3 g/m^3) at the filtration rate of 5 m/h. Analysis of the efficiency of organic matter removal revealed a narrow range of effective polyelectrolyte doses for the treatment of the infiltration water investigated.

Since ferric chloride was effective in decreasing iron compound concentration in the water and Magnafloc LT31 provided effective removal of manganese compounds, we decided to apply a combination of the two coagulants. In this way, it was possible to reduce the optimum coagulant doses. Thus, a 1.5 g/m^3 dose of ferric chloride and a 0.9 g/m^3 dose of Magnafloc LT31 (applied separately above the filter bed) yielded the following: the concentration of iron and manganese compounds fell to the level of 0.1 g Fe/m^3 and 0.04–0.05 g Mn/m^3, respectively; TOC and COD decreased by 10 to 20%, respectively, whereas turbidity and colour were reduced by 50%, all without shortening the 34-hour filtration cycle.

The investigations have corroborated the utility of the ferric chloride coagulant with polyelectrolyte aid – Magnafloc LT31 – in the direct filtration process.

5. CONCLUSIONS

Infiltration water treatment via a train including aeration and filtration through riped beds provides water quality which does not meet relevant sanitary standards even if use is made of high-rate aeration systems which fail to yield complete oxidation of iron compounds. While the treatment train reduces considerably the corrosiveness of the water, it does not provide a stable carbonate–calcium equilibrium, so the treated water is classified as weakly aggressive.

The treatment effects can be upgraded by including coagulation as an additional step of the treatment train. It is advisable to apply the direct filtration process as this does not support the increase in the corrosive effect of the water. In our study, the application of hydrolyzing coagulants (up to 5 g/m^3) decreased the iron compound content even below 0.2 g Fe/m^3. The application of alum was abandoned because of the poor efficiency of manganese removal. Promising results were obtained with polyelectrolyte-aided coagulation (Magnafloc LT31 doses from 1.3 to 1.6 g/m^3) or with combined doses of ferric chloride and polyelectrolyte, which yielded good removal of iron and manganese compounds. The use of hydrolyzing coagulants or polyelectrolyte also increased the removal of coloured matter. Colour persisting in the effluent approached 10 g Pt/m^3. Turbidity removal was slightly poorer never falling below 1 NTU. The advantage of polyelectrolyte aid is that further increase of water corrosiveness could be prevented.

Filtration rate had to be maintained at 5 m/h and the depth of the filter bed at 1.5 m. Any increase of the filtration rate degraded the quality of the treated water, which could not be restored even with increased coagulant or flocculant doses. Coagulation carried out in the rapid-filter bed shortened the duration of the filtration cycle, but with appropriately established coagulant doses it was possible to preserve the 24-hour one. The increase of the polyelectrolyte dose brought about a faster head loss increment than did the increase of the coagulant dose.

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KOAGULACJA W ZŁOŻU FILTRACYJNYM
W OCZYSZCZANIU WÓD INFILTRACYJNYCH

Omówiono jakość wód infiltracyjnych z uwzględnieniem wpływu powodzi na ich skład. Przedstawiono efekty technologiczne oczyszczania wód infiltracyjnych w procesie filtracji, zależnie od prędkości filtracji i wysokości złoża filtracyjnego. Określono możliwości intensyfikacji procesu filtracji dzięki zastosowaniu koagulacji bezpośrednio w złożu filtracyjnym. Ustalono optymalne dawki niezbędnych chemikaliów oraz prędkość filtracji podczas 24-godzinnego cyklu filtracji.