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ADVANCES IN INFILTRATED WATER TREATMENT FOR DRINKING PURPOSES

The need to treat infiltrated water results not only from the sanitary recommendations for drinking water quality, but also from technological reasons. The hazards of pollution with nitrogen compounds and organic substances and the influence of these polluting species on water technology are emphasized. As far as the future trends are concerned, consideration should be given to the enhancement of iron and manganese removal by coagulation, decarbonization and catalytic filtration, as well as to the removal of nitrogen compounds during dry filtration and denitrification process. The following measures have been postulated: the application of sorption on activated carbon for the removal of organic compounds, the reduction of chlorine demand, and the maintenance of the biological stability of water to prevent recontamination during transport in the water-pipe network.

1. INTRODUCTION

It is a fairly frequent practice to classify infiltrated water into the category of groundwater, and consequently to regard it as a safe source (in sanitary terms) of municipal water supply. The treatment trains proposed for infiltrated water are often reduced to physical processes (aeration, filtration) and optional disinfection, i.e., to the procedures typically used when treating groundwater. In engineering, however, groundwater is not necessarily easy to treat and often requires the application of developed technological systems. Such are, e.g., the ground- and infiltrated waters in the Tarnobrzeg region (because of an unstable physicochemical composition), those in the regions of Nowy Korczyn and Busko (because of very high concentrations of iron compounds), or the infiltrated water taken in for the needs of the Opole supply system (also because of very high concentrations of iron compounds). They all require coagulation as a unit process in the treatment train.

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2. QUALITY OF INFILTRATED WATER

In the majority of instances, there are not very many differences in the basic parameters between infiltrated water and groundwater. Both contain gaseous pollutants (e.g., hydrogen sulphide, carbon dioxide) and dissolved polluting species (iron and manganese compounds). Owing to the inflow of surface waters, which infiltrate into the groundwater, the overall mineralization of the infiltrated water is lower than that of the groundwater, but the pH is generally higher, and in some cases may even exceed 7.0. Infiltrated waters are not always deoxidized; they often display oxygen concentrations as high as 2.0 g O_2/m^3. Their physicochemical composition follows a seasonal pattern, but these variations are very small.

The presence of pollutants, which are typical of surface waters, as well as their concentrations in the infiltrated water depend on the type of the infiltration applied (natural, artificial) and on the level of surface water pollution. Organic substances (measured, e.g., in terms of permanganate COD), which are viewed as characteristic of infiltrated water, can be determined even if they occur at low concentrations. This does not always correlate with the total organic carbon (TOC) content, but certainly affects the choice of the treatment train. In the infiltrated water taken in for the municipality of Wrocław – with COD values ranging between 1.7 and 3.5 g O_2/m^3 – TOC concentration normally varies from 2.3 to 6.0 g C/m^3 [1].

Another problem dealt with when treating infiltrated water is the presence of nitrogen compounds. Here, the infiltration method applied plays an important role. When use is made of bank infiltration, the level of surface water pollution with ammonia nitrogen contributes noticeably to the concentration of this species in the infiltrated water. For example, as a result of water infiltration from the river Ołobok, the concentration of ammonia nitrogen in the wells of the water intake approached 2.0 g NH_3/m^3 [2]. This is not the case where artificial infiltration involving basins is applied. Artificial infiltration often promotes biological oxidation of ammonia nitrogen to nitrate nitrogen followed by the reduction of nitrate nitrogen to gaseous nitrogen or nitric oxides. And this is a natural method of removing nitrogen compounds from the aquatic environment.

Excess concentrations of nitrates are seldom found in infiltrated water, but there may occur episodes of increased nitrate concentrations due to the migration of these compounds from point sources (e.g. inappropriate storage of fertilizers, lack of an insulating layer to protect the aquifer, excess fertilization with nitrogen compounds).

3. REQUIRED REMOVAL OF POLLUTANTS FROM INFILTRATED WATER IN THE LIGHT OF SANITARY REGULATIONS

The need to remove the polluting species present in the infiltrated water is driven by the legal regulations governing the quality of potable water. Under these regula-

tions, iron and manganese content must be reduced to the admissible levels defined by the WHO, which have changed in the past 50 years from 0.5 g Fe/m^3 to 0.1 g Fe/m^3 (with some intervals when 1.0 g Fe/m^3 was the admissible value) for iron compounds, and from 0.1 g Mn/m^3 to 0.05 g Mn/m^3 for manganese compounds [3]. Under the regulations issued by the Polish Ministry of Health on November 19, 2002, the following concentrations were defined as permissible in drinking water: 0.2 g Fe/m^3 for iron compounds, 0.05 g Mn/m^3 for manganese compounds, 0.5 g NH_3/m^3 for ammonia nitrogen (in the case of nonchlorinated water, even a concentration as high as 1.5 g NH_3/m^3 is acceptable), 50 g NO_3^-/m^3 for nitrates, 0.5 g NO_2^-/m^3 for nitrites, and 5.0 g O_2/m^3 for organic compounds expressed as permanganate COD. Thus, according to these sanitary regulations, it is advisable to remove ammonia nitrogen from infiltrated water at times. The admissible concentrations of nitrates in infiltrated water have not been exceeded so far; or maybe nitrates containing waters are prevented from entering the supply system.

Sanitary regulations also emphasize the need of maintaining the carbonate–calcium equilibrium in order to prevent water-pipe network corrosion and encrustation.

4. INFILTRATED WATER TREATMENT

A conventional treatment train for infiltrated water includes aeration, rapid filtration and disinfection. This method worked as long as the admissible concentration of iron compounds and manganese compounds in treated water amounted to 0.5 g Fe/m^3 and 0.1 g Mn/m^3, respectively. The water quality desired was achieved in the course of rapid filtration, after the filter bed had been ripened with respect to iron and manganese oxides. But the presence of ammonia nitrogen (even at concentrations allowed for potable water), or an insufficient removal of hydrogen sulphide during aeration disturbs the treatment process in general, and manganese removal in particular. Such disturbances were reduced by including chemical oxidation in the treatment train, with potassium permanganate as the oxidizing agent, which was replaced by chlorine in the 1960s and 1970s. And again in the late 1990s, after thorough analysis of the disadvantages inherent in chlorination, preference was given to the application of potassium permanganate. However, with the admissible concentrations of iron and manganese compounds for treated water, which are in force now (0.2 g Fe/m^3 and 0.05 g Mn/m^3, respectively), it is generally necessary to modify the water treatment technology. Aeration and filtration will yield water of the desired parameters if the following conditions are fulfilled: reduced compounds are absent, the filter bed is sufficiently deep (1.5 m), and the filtration rate does not exceed 5 m/h.

The presence of ammonia nitrogen (even at concentrations approaching 0.2 g N/m^3) may disturb the removal of manganese, especially in the second half of the filtration cycle [4]. When infiltrated waters are to be treated for municipal supply, it is advis-

able to take into account not only their readiness for iron and manganese removal, but also their biological stability, because if the latter is lacking, recontamination may occur [5]. Biological stability can be maintained by inhibiting the growth of mixotrophic organisms. Such inhibition may be achieved by decreasing the concentration of biodegradable dissolved organic carbon (BDOC) below 300 mg C/m^3 in chlorinated water and below 30 mg C/m^3 in non-chlorinated water or by applying sufficiently high doses of disinfectants. Of the final disinfectants, chlorine and chlorine compounds are most frequently applied, with chlorine dioxide as the most popular in recent times [6]. The dose recommended for chlorine dioxide does not exceed 0.4 g Cl_2/m^3, since higher doses create favourable conditions for the formation of hazardous chlorine compounds, chlorites and chlorates. Whenever use is made of chlorine as a disinfecting agent, this leads to the formation of chlorination by-products, which have been criticized for a long time.

The demand of the disinfectant depends on whether or not reduced compounds (specifically ammonia nitrogen) and organic matter (TOC, DOC) are present in the water to be treated. This holds also for the organic substances that are difficult to assimilate biologically, because during oxidation they may be converted into easily assimilable compounds (AOC), thus stimulating the growth of undesirable microorganisms. These findings imply that an advanced treatment of infiltrated water requires the removal not only of the aggressive carbon dioxide, hydrogen sulphide, iron and manganese compounds, but also of organic matter (which should be reduced to TOC values below 2.0 g C/m^3) and ammonia nitrogen (which has to occur at concentrations lower than 0.1 g N/m^3), although relevant sanitary regulations are less rigorous. The admissible TOC content has not been defined either in Polish or EU Standards. The allowable concentration of organic pollutants (expressed as COD), which must not exceed 5.0 g O_2/m^3, indicates that the TOC content in the water is high. The infiltrated water taken in by the waterworks of Wrocław for municipal supply in some instances displayed TOC concentrations as high as 6.0 g C/m^3 at a comparatively low COD level [1]. Thus, it is necessary to extend the conventional treatment train for infiltrated water by including additional unit processes that would not only enhance the removal of iron and manganese compounds but also reduce the concentrations of TOC and ammonia nitrogen.

5. ENHANCING THE EFFICIENCY OF INFILTRATED WATER TREATMENT

Iron and manganese removal can be enhanced by coagulation. If the concentration of iron compounds is comparatively low (up to about 5.0 g Fe/m^3), coagulation may be performed in the filter bed [1], with 5.0 g/m^3 (or lower) doses of alum or iron hydrolyzing salts as coagulants, preferentially ferric chloride. This allows the iron con-

centration in the treated infiltrated water to be kept at 0.2 g Fe/m^3 (or below that value), when use is made of a 1.5 m deep ripened sand filter and a filtration rate of up to 5.0 m/h. However, a satisfactory removal of iron compounds is concomitant with the deterioration in the efficiency of manganese removal. This drawback was overcome with a cationic polyelectrolyte-aided coagulation process, using 1.3–1.6 g/m^3 doses of Magnafloc LT31 and the same filtration rate. Promising results were also obtained with a combination of coagulant and polyelectrolyte: ferric chloride (1.5 g/m^3) and Magnafloc LT31 (up to 1.0 g/m^3).

When the concentration of iron compounds in the water to be treated is high, coagulation must be carried out as a separate unit process following aeration. Under such conditions, preference is given to sludge blanket coagulation, which utilizes the iron compounds partly precipitated during pH adjustment to 8.5 with lime or sodium hydroxide. The ferric hydroxide precipitated in this way exerts a coagulating effect upon the other (not precipitated and persisting in the water) iron and manganese compounds. If the coagulation effects are poor, the use of alum coagulants is recommended.

There is a process (although not fully appreciated) which well applies to the treatment of infiltrated waters (and also groundwaters), especially those with a proneness to precipitate calcium carbonates, namely lime softening (decarbonization) [7]. The lack of interest in using it comes from the need to decrease the pH following its application. The sanitary regulations that are in force now allow water pH levels of up to 9.5, and this eliminates the need of pH adjustment (recarbonation). Decarbonization can be carried out using the sludge-blanket technology. The decarbonization process promotes not only a reduction in temporary hardness, but also an efficient removal of iron and manganese compounds.

Enhanced removal of iron and manganese from water solutions can be achieved with rapid filtration in a pyrolusite bed [7]. Pyrolusite beds provide a high efficiency of manganese removal even in the presence of ammonia nitrogen, and make it possible to rise the filtration rate to 15 m/h. If use is made of a pyrolusite bed, it is advisable to decrease the iron content as a prior step, especially when the raw water displays high concentrations of iron compounds. In that particular case, two-stage filtration seems to be better suited. The first stage is designed for complete or partial removal of iron compounds on a sand bed. The second stage is to provide removal of manganese and residual iron compounds and reduction in ammonia nitrogen concentration on a pyrolusite bed. Using catalytic beds (pyrolusite) is advantageous in that this eliminates the need for chemical treatment (particularly oxidation) and enables a high treatment efficiency to be achieved with high filtration rates.

The inclusion of dry filtration in the treatment train for infiltrated and groundwater also deserves consideration [8]. However, if use is made of the dry filtration process, the concentration of iron compounds in the water to be filtered must be reduced to the value of approximately 1.0 g Fe/m^3 in a prior step. In the course of dry filtration, am-

monia nitrogen content decreases as a result of nitrification, and this promotes the removal of manganese compounds. Dry filtration can be carried out either with a sand bed of a grain size ranging between 1.0 and 2.0 mm, or with an active carbon bed of a grain size from 1.0 to 3.0 mm and a depth varying from 1.5 to 2.0 m. The technological efficiency of the dry filter bed depends on the amount of oxygen which enters the water during air supply (in co- or countercurrent) to the filter, and on the aeration process in the initial part of the treatment train. When the dry filtration process involves an active carbon bed, satisfactory treatment effect can be achieved owing to the natural oxygenation of the water during spray irrigation above the bed. With a spray irrigation height of 1.0 m, the optimal filtration rate amounts to 2.0 m/h. Such conditions not only favour nitrification, which leads to the reduction in ammonia nitrogen concentration, but they also promote a reduction in the organic matter content.

So far, whenever the concentration of nitrates exceeded 50 g NO_3^-/m^3, the water has been regarded as unfit for drinking purposes. The development of the technology for the removal of nitrates has changed this approach. Nitrates can be efficiently removed from the water via biological reduction, i.e. denitrification, and the requisites for achieving this can be itemized as follows: maintenance of anaerobic conditions, application of appropriate aids (e.g. hydrogen or organics (ethanol, acetic acid), depending on the type of denitrification), and presence of phosphates. Bacteria are cultured in immobilized beds (sand, ceramic aggregate or polystyrene foam, active carbon). The reactor is operated with up or down flow of water at a filtration rate of up to 10 m/h. Following completion of the denitrification process, it is advisable to aerate the water for the removal of gases (hydrogen, nitrogen, carbon dioxide) and for oxygen supply, as well as to include filtration (preferentially a two-stage process involving an active carbon bed at the second stage) for iron and manganese removal, and for the removal of nonutilized substrates.

The content of organic substances and nitrogen compounds can be efficiently reduced when sand filtration (with a ripened bed) is followed by carbon filtration (with a biologically active carbon bed). In the course of carbon filter operation, it is possible to enhance bacterial growth and thus provide favourable conditions for the transformation or retention of nonbiodegradable compounds and for the nitrification of ammonia nitrogen in the carbon bed. The processes that occur in the active carbon bed can be further enhanced by applying oxidation (preferably with ozone) as a prior step to carbon filtration. However, the inclusion of the ozonation process has the inherent disadvantage of increasing considerably the overall water treatment costs and promoting the occurrence of bromates in the water of coastal areas.

6. CONCLUSIONS

The physicochemical characteristics of infiltrated water depends on the type of infiltration. With artificial infiltration, the composition of the taken-in water does not

very much differ from that of the groundwater. During natural infiltration, however, a considerable portion of the polluting species penetrates from surface water to the infiltrated water. This holds particularly for organic matter and nitrogen compounds. Making decision on the treatment of infiltrated water should be supported not only by thorough considerations of the desired water quality (in terms of sanitary regulations), but also by technological considerations which, in some instances, substantiate the inclusion of sorption and the removal of nitrogen compounds in the treatment train.

It is a common practice to treat infiltrated water by conventional technological trains, but then the application of deep filter beds and low filtration rates is recommended. The inclusion of pyrolusite filter beds in the water treatment train yields high treatment efficiencies even in the presence of reduced compounds and with a high filtration rate. The process of iron and manganese removal can be enhanced by introducing coagulation as a unit process in the treatment train. To develop the treatment of infiltrated water it is advisable to consider the inclusion of the lime softening process.

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ZAAWANSOWANE METODY OCZYSZCZANIA WÓD INFILTRACYJNYCH
DLA ZAOPATRZENIA W WODĘ PRZEZNACZONĄ DO SPOŻYCIA

Konieczność oczyszczania wód infiltracyjnych w układach technologicznych wynika nie tylko z przepisów sanitarnych, dotyczących jakości wody przeznaczonej do spożycia, ale również ze względów technologicznych. Omówiono zanieczyszczenia wód infiltracyjnych związkami azotowymi i organiczny-

mi oraz ich wpływ na technologię oczyszczania wody. W kierunkach rozwoju układów technologicznych oczyszczania wód infiltracyjnych wskazano na intensyfikację procesów odżelaziania i odmanganiania wody przez stosowanie koagulacji, dekarbonizacji, filtracji na złożach katalitycznych, a także usuwanie związków azotowych podczas filtracji suchej i w reaktorach denitryfikacyjnych. Podkreślono konieczność stosowania procesu sorpcji na węglu aktywnym do usuwania związków organicznych celem obniżenia zapotrzebowania wody na chlor, który jest niezbędny do utrzymania biologicznej stabilności wody, zabezpieczającej ją przed wtórnym zanieczyszczeniem w sieci wodociągowej.