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GENERAL TRENDS IN WATER TREATMENT TECHNOLOGY AT THE TURN OF THE MILLENIUM: INFILTRATION WATER TREATMENT IN WROCŁAW

The developments in the technology of water treatment in Poland in the past century have been investigated and examplified by the waterworks of Wrocław. A particular consideration is given to advanced water treatment processes. Another sequence of biological processes is proposed for the treatment train applied.

1. INTRODUCTION

Civilization is concomitant with a variety of comforts the modern world can offer. And this includes high-quality water supply under an appropriate pressure and in the desired amount at any time of day. Needless to say that only central water-supply systems are able to provide such services. Twenty-five years ago in Poland only large municipalities benefited from central water supply, which was not made available to the inhabitants of small towns or villages. Moreover, municipal water was supplied from the intakes providing low-quality water in the majority of instances.

Nowadays, high quality has become a key issue also in Polish water supply systems. It is no longer sufficient to meet the admissible concentrations of bacteria, viruses and physicochemical water pollutants. More and more users insist not only on decreasing the values of those parameters much below the allowable levels, but also on enriching the water, for example, with magnesium.

In Poland, the problem of water intake and treatment and the problem of wastewater treatment have been approached separately. The decision-makers have not been aware of how these two problems are interrelated. As a matter of fact, the interrelation is not very clear at first glance, because water intake and treatment are mostly carried out in one region, and wastewater treatment in another region. Our recent reform of the administration system seems to favour a joint approach to the water/wastewater

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treatment problem not only on an individual scale in particular industrial plants, but also on a larger scale in countries, towns, cities and industrialized urban agglomerations.

In the nineteen-seventies, there was a noticeable development of surface water and groundwater treatment technologies. The predicted quality of raw water was low, and such predictions were then justified because of the continuing degradation of aquatic environment – not only surface water was polluted; pollution also increased in groundwater which had always been regarded as safe in terms of bacteriological and physicochemical composition and therefore recommended for municipal intake.

Uncontrolled pollution and contamination of groundwater resources (accounted for a variety of industries, non-sanitary landfills and agriculture) led to the abandonment of some groundwater intakes which had served the municipal supply system, and the nearby settlements had to draw water from emergency supply units. Even though it may seem that water treatment and wastewater treatment have hardly anything in common, the two processes should be regarded as complementary.

Before 1970, there was a tendency to develop water treatment systems, and little consideration being given to wastewater treatment, so the number of available wastewater treatment plants was insufficient. The water treatment train made use of in those days was extended by including water renovation. The inclusion of the process was justified because water of the first-class purity was lacking, so it was necessary to take water of the second-class, or even of the third-class purity, especially in areas with a serious water deficiency (due to the presence of heavy industry or watersheds).

Decision-makers were aware of the necessity of advanced wastewater treatment, which included removal of carbon compounds and biogens, but because of the permanent lack of funds they managed to construct only some of the intended modern objects. There were also suggestions that the wastewater treatment plants under design conditions should provide removal of carbon compounds only in order to enable construction of twice as many wastewater treatment plants at the same cost, thus decreasing noticeably the pollution of the recipient streams (primarily that of the surface waters).

2. WATER POLLUTANTS AND THEIR REMOVAL

Treated wastewaters entering the recipient carry organic pollutants (of which 50% are resistant to biochemical degradation), inorganic substances and microorganisms (bacteria and viruses). Water polluted with inorganic substances includes increased concentrations of chlorides, sulphates, nitrogen compounds, phosphorus compounds and heavy metals. Organic pollutants referred to as COD and TOC do not create serious problems. Far more grave is the environmental threat posed by micropollutants in general and by refraction compounds in particular. Environmental scientists and egineers were not aware of this threat until after new and more advanced analytical methods had been implemented.

Of the micropollutants present in the water to be treated, heavy metals and their organic complexes, radionuclides and asbestos create serious hazards. Heavy metals, for example, are non-degradable substances, dangerous because of their bioaccumulation. Also polycyclic aromatic hydrocarbons (PAHs), which proved to be of a carcinogenic nature, and growth of algae, which are capable of transporting viruses, PAHs, heavy metals and radionuclides through the treatment system into drinking water, may present certain hazards for us. So far, the said micropollutants have not been troublesome from the technological point of view because of their concentrations, which hardly ever exceed the admissible values for tap water.

Nowadays, the most serious problem to cope with in water treatment is the removal of nitrogen compounds. The ever increasing concentrations of nitrates and nitrites are accounted for by two major factors – unreasonable use of fertilizers and ill-managed wastewater treatment, especially in rural areas.

In the early 1970s, the water being treated was conventionally chlorinated. Such a disinfection method was applied until the implementation of advanced analytical methods made it clear that the trihalomethanes (THMs) produced as a result of chlorination are likely to be carcinogenic substances.

Although these days in Poland more and more water supply systems are being built in rural areas, the quality of the water supplied to the farms is still far from being acceptable. But in general, the sanitary conditions in Polish villages are expected to improve noticeably. In urban areas, where water supply and sewerage systems have long been in service, the inhabitants continue to insist on upgrading the quality of the water produced by the treatment plants. Such demands trigger the development of new technologies or the improvement of those in use.

At the turn of the millennium the following concepts are being considered in Poland:

- Coagulation, which is an important part of the treatment train for surface water, should be a multi-stage process. If the process involves many stages, it will be possible to utilize the coagulants rationally, according to the actual concentrations of pollutants, and to decrease the required doses of chemicals. Direct coagulation in the filter bed is made use of in sweeping treatment of groundwater in order to decrease the concentrations of residual iron, coloured matter and turbidity to the values of ≤ 0.1 g Fe/m^3, ≤ 5 g Pt/m^3 and 1 g/m^3, respectively. Sweeping treatment allows a considerable reduction of the disinfectant dose and, consequently, a noticeable improvement of organoleptic properties, which will meet with public approval.

- Sweeping treatment involves oxidation, which implies the application of sorption, but the need of including sorption into the treatment train does not necessarily mean that oxidation must also be included. There is a continuing tendency to abandon chlorine as an oxidizing agent, because the by-products forming in the course of the oxidation reaction have health implications for human organisms. There is also a tendency to replace chlorine with chlorine dioxide for the purpose of disinfection.

• For the need of ammonia nitrogen removal, nitrification is introduced as part of the treatment train. Nitrification is carried out on dry filters, as well as on biologically activated filters (BAF). The mechanism of the process consists in that a bacterial flora forms in the filter bed, which operates under varying hydraulic conditions, but always in an aerobic environment. The bacterial flora is responsible for the biological oxidation of ammonia nitrogen to nitrate nitrogen. An original Polish technology of dry filtration through the activated carbon bed has been successfully implemented on an industrial scale in the brown-coal mine of Konin [1], [2], which also produces water for municipal supply. But ammonia nitrogen can also be removed by filtration through a pyrolusite bed, which is known to enhance the efficiency of groundwater treatment. Another method of nitrogen compound removal is selective ion exchange on a ptylolite bed and on ionic-exchange resins for ammonia nitrogen and nitrate nitrogen, respectively. The anion-exchange resins required for nitrate removal have all attestations needed and are marketed in Poland. Nitrate nitrogen removal by biological reduction in the course of the denitrification process, which has found wide acceptance elsewhere, in Poland is still under study (at an advanced stage by now).

• Processes involving biological treatment (infiltration or slow filtration), which used to be applied to the treatment of comparatively clean water at the beginning of the treatment train (prior to chemical processes), are now introduced after complete physicochemical treatment to provide what is known as after-treatment.

• When the water to be treated is of a high temporary hardness, the treatment train may incorporate decarbonization, and also partial demineralization when such a need exists. Decarbonization (which has been in use for the treatment of industrial water) is of help in eliminating water aggressiveness [3].

• The need of magnesium enrichment is unobjectionable, especially for soft water, because magnesium is available to the human organism through oral intake. Magnesium enrichment calls for an additional stage of filtration – through a dolomite bed [4], and this is concomitant with some changes in the technology of aggressiveness removal.

• To obtain an ultra-clean water it is advisable to combine conventional treatment with appropriate membrane techniques and ion-exchange processes.

3. INFILTRATION WATER TREATMENT IN THE WATERWORKS OF WROCŁAW

The changes in the technology of water treatment shown are examplified by one of the waterworks of Wrocław. The object of interest has a capacity of 10,000 m^3/d. In periods of water deficiency in the city, the capacity of the waterworks exceeded 100,000 m^3/d. Nowadays, the object works again with a capacity of 10,000 m^3/d.

The treatment train for infiltration water, made use of for nearly a century, involves aeration, lime treatment, filtration and disinfection. In the 1960s and 1970s, infiltration water was combined with surface water to make up the existing deficit.

Consequently, the treatment train was extended by the inclusion of sludge blanket coagulation, which was carried out after aeration, prior to the filtration process. The waterworks of Wrocław were first in Poland to apply ozonation before final chlorine disinfection. These days, the ozonation system is being retrofitted, and attempts are made to change the site of ozone dosage. The water fluorization setup is temporarily under operation and works efficiently.

Nowadays, only infiltration water is taken in. The infiltration water utilized for municipal supply is characterized by a moderate hardness and mineralization and by increased levels of coloured matter, turbidity, iron compounds and manganese compounds. There were also detected the increased concentrations of organic pollutants, especially of TOC. The presence of humic substances is indicative of the potentiality for THM formation. The presence of phosphates exerts a stabilizing effect on the pollutants, thus inhibiting the treatment process. The composition of the taken-in infiltration water indicates that the removal of iron and manganese compounds – although indispensable – is not as important as the decrease of organic matter concentration [5], in order to achieve the desired water quality.

The improvement of the treatment train includes aeration, filtration and disinfection. The retrofitted aeration system (multiple-tray aerator of a hydraulic loading ranging between 60 and 80 m^3/m^2h) provides an oxygen amount which is sufficient to oxidize iron compounds and to reduce a high efficiency of aggressive CO_2. Filtration of aerated water through gravity sand beds yields satisfactory treatment effects and provides water of the quality demanded by the Clean Water Act (issued 4th May, 1990 by the Minister of Public Health and Social Welfare), which means 0.5 g Fe/m^3 (these values seldom being exceeded) and 0.1 g Mn/m^3. However, to meet the standards established in relevant EU Directives it is necessary to include coagulation as a unit process in the treatment train applied. The volume coagulation process, which is in use now, should be replaced by direct filtration, i.e. coagulation in the filter bed. The advantages of using direct filtration can be itemized as follows: water aggressiveness does not increase (in contrast to volume coagulation where aggressiveness increases considerably), there is potentiality for a noticeable reduction of coagulant doses and sludge volume with a concomitant increase of sludge thickening efficiency. Considering the process of manganese removal in the filter bed, the rate of water filtration must not be higher than 5 m/h. Direct filtration involving hydrolyzing coagulants in amounts of up to 5 g/m^3 brings about a considerable decrease in the concentrations of iron compounds ($\leq$0.1 g Fe/m^3). Of the coagulants examined, the polyelectrolyte Magnafloc LT31 (with attestation of applicability to potable water production) was found to be most effective. With Magnafloc LT31 doses ranging between 1.5 and 2.0 g/m^3, or with a combination of Magnafloc and ferric chloride dosed in the proportion of 1.5 g $FeCl_3/m^3$ and (up to) 1.0 g $LT31/m^3$, the concentrations of iron compounds and manganese compounds dropped below 0.1 g Fe/m^3 and 0.1 g Mn/m^3, respectively.

The efficiency of the treatment train proposed was substantiated by the results of bacteriological and genotoxicity examinations which confirmed the high quality of the water in sanitary terms. In most instances no mutagenic or carcinogenic pollutants were found in the samples. The mutagenicity factor was below 2.0, i.e. it varied within the admissible limits. The application of chlorine, even in very small doses, as a disinfecting agent deteriorated the organoleptic properties of the water treated.

The use of chlorine dioxide instead of chlorine for the purpose of disinfection has raised objections. Chlorine dioxide is preferable when the TOC of the water to be disinfected falls below 2.0 g C/m^3. Under such conditions, it may be expected that the chlorine dioxide dose required will not exceed 0.5 g ClO_2/m^3 and that the formation of toxic chlorites will be inhibited. However, the water obtained according to the proposed treatment train often displays increased TOC concentrations, in some instances even up to 3.5 g C/m^3. The result is that the appropriate chlorine dioxide doses cause formation of excess quantities of chlorites.

TOC concentrations can be brought down below 2.0 g C/m^3 by supplementing the treatment train with sorption on activated carbon. But the sorption process must be completed either with ozone oxidation or with upgrading the taken-in water in order to obtain the first-class purity.

The waterworks of Wrocław were able to upgrade the quality of potable water without changing the treatment train. They reduced the chlorine dioxide dose to 0.5–0.6 g ClO_2/m^3, at which only trace amounts of chlorites are formed (the increased demand for an oxidizing agent being still covered by chlorine). As a result, the taste and smell of tap water have been noticeably improved.

4. CONCLUSIONS

• In the past centrury, the technology of water treatment has been subject to changes. New processes have been designed and new devices have been developed, particularly for the removal of nitrogen compounds. The unit processes (both biological and chemical) of the treatment train have changed their sequence of occurrence.

• The quality of the treated infiltration water meets the Clean Water Standards issued by the Ministry of Public Health and Social Welfare for drinking and household uses. However, to comply with relevant EU standards it is necessary to upgrade the quality of the water produced by the waterworks of Wrocław, and this calls for an advanced treatment train. The extent to which the treatment train should be changed will depend on the quality of the taken-in water.

• Advanced treatment methods will make it possible to eliminate chlorine as a disinfecting agent by replacing it with chlorine dioxide, which will upgrade the organoleptic properties of the treated water to make the water quality meet with public approval.

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KIERUNKI W TECHNOLOGII OCZYSZCZANIA WODY U SCHYŁKU TYSIĄCLECIA: OCZYSZCZANIE WÓD INFILTRACYJNYCH WE WROCŁAWIU

Opisano aktualne kierunki w technologii oczyszczania wody uwzględniające usuwanie nowych zanieczyszczeń, szczególnie związków azotowych. Wykazano celowość stosowania koagulacji bezpośrednio w złożu filtracyjnym. Wskazano na możliwość zmiany kolejności procesów biologicznych w ciągu technologicznym. Na tle omawianych zmian przeanalizowano zmiany w technologii oczyszczania wody infiltracyjnej we Wrocławiu.