

## **Auto-abstract**

### **on the achievements of scientific and research activities as well as teaching and organizational work**

#### **1. First and last name**

**Rafał Tytus Bray**

#### **2. Awarded diplomas and academic degrees**

- 1990     Obtaining the Master of Science degree in Environmental Engineering Department in the field of Sanitary Engineering at the Hydrotechnical Faculty at the Gdansk University of Technology (actually: the Faculty of Civil and Environmental Engineering). Master's degree in sanitary engineering, specialization: Water supply and sewage and waste treatment.
- 2000     Obtaining the Doctor degree of technical sciences in environmental engineering with a specialization in water and wastewater technology at the Faculty of Hydraulic and Environmental Engineering, Gdansk University of Technology (actually: the Faculty of Civil and Environmental Engineering), the title of the doctoral thesis: „ The role of physio-chemical and biological processes in manganese and ammonia nitrogen removal from groundwater”.

#### **3. Employment history in research institutes**

- 1989-2000     Assistant in Gdansk University of Technology, Hydrotechnical Faculty (actually: the Faculty of Civil and Environmental Engineering), Department of Water and Wastewater Technology.
- 1999-2000     Lecturer in Gdansk University of Technology, Environmental Engineering Faculty (actually: the Faculty of Civil and Environmental Engineering), Department of Water and Wastewater Technology.
- 2000-2015     Assistant Professor in Gdansk University of Technology, the Faculty of Civil and Environmental Engineering, Department of Water and Wastewater Technology.
- 2015-till now     Senior Lecturer in Gdansk University of Technology, the Faculty of Civil and Environmental Engineering, Department of Water and Wastewater Technology.
- 2006-2008     Lecturer in Higher School of Environment in Bydgoszcz (contract work)

**4. Identification of an achievement resulting from article 16, section 2 of the act on academic degrees and titles and about degrees and titles in the field of fine arts of march 14, 2003 (Dz.U. [Journal of Laws] No. 65, Item 595, as amended)**

**a) Title of the achievement**

A series of publications related thematically:

**Processes in removing manganese, ammonia and arsenic from groundwater and options for their simultaneous removal**

**b) Publications which are the part of scientific achievement**

**Scientific publications in the Journal Citation Reports (JCR)**

1. Olańczuk-Neyman K., Częścik P., Łasińska E., **Bray R.**: Evaluation of effectivity of selected filter beds for iron and manganese removal. W: Water Science and Technology: Water Supply Vol 1 No2 pp 159-165, IWA Publishing 2001. Punktacja MNiSW: brak, IF: brak (Publikacja JCR/WoS)

*My percentage is estimated at 30%*

2. **Bray R.**, Olańczuk-Neyman K.: Wpływ warunków ciśnieniowej filtracji na przebieg biologicznego usuwania azotu amonowego z wody w procesie nityfikacji. Przemysł Chemiczny. - T. 87, nr 5 (2008), s. 420-422. Punktacja MNiSW:15, IF:0,254 (Publikacja JCR/WoS)

*My percentage is estimated at 90%*

3. **Bray R.**: Usuwanie arsenu z wody podziemnej w procesie zintegrowanym - koagulacja/mikrofiltracja. Ochrona Środowiska. -Vol. 35., nr. 4 (2013), s.33-37. Punktacja MNiSW:15, IF:0,619 (Publikacja JCR/WoS)

*Independent publication, participation 100%*

4. **Bray R.**, Fitobór K.: Wykorzystanie PIX 112 do usuwania jonów arsenu z wody podziemnej w procesie koagulacji powierzchniowej w złożu filtru piaskowo-piroluzytowego. Ochrona Środowiska. -Vol. 38, nr.2 (2016), s.45-48 Punktacja MNiSW:15, IF:0,425 (2015r.) (Publikacja JCR/WoS)

*My percentage is estimated at 75%*

5. **Bray R.**, Fitobór K.: Sizes of iron hydroxide particles formed during ferric coagulation processes. Desalination and Water Treatment. Vol. 64 (2017), pp 419-424. Punktacja MNiSW:20, IF:1,272 (2015r.) (Publikacja JCR/WoS)

*My percentage is estimated at 75%*

**Scientific publications in international or national journals other than those contained in the database referred to in art. A:**

6. Olańczuk-Neyman K., **Bray R.**: Przebieg wpracowywania kwarcowych złóż filtracyjnych przeznaczonych do usuwania manganu i azotu amonowego z wód podziemnych. VI Międzynarodowa Konferencja, XVIII Krajowa Konferencja "Zaopatrzenie w wodę, jakość i ochrona wód". Poznań, Polska, 2004 r. t.1 s. 483-491. Punktacja MNiSW:brak, IF:brak

*My percentage is estimated at 90%*

7. **Bray R.**: Rola mikroorganizmów przy wpracowywaniu kwarcowych złóż odmanganiających. W: II Kongres Inżynierii Środowiska : Tom 1 / red. L. Pawłowski, M.R. Dudzińska, A. Pawłowski. - Lublin : PAN, Komit. Inż. Środow., 2005. - s. 155-162. - Monografie Komitetu Inżynierii Środowiska PAN ; vol. 32 Punktacja MNiSW:brak, IF:brak

*Independent publication, participation 100%*

8. **Bray R.**, Łasińska E.: Treatment of high-quality groundwater by means of one-stage filtration on active filtration beds. Polish Journal of Environmental Studies. - Vol. 16, nr 2A (Suplement), pt. 2 (2007), s. 234-238. Punktacja MNiSW:brak, IF:brak

*My percentage is estimated at 90%*

9. **Bray R.**, Olańczuk-Neyman K., Sokołowska A.: The influence of oscillatory low pressure on bacteria number in groundwater supplied to distribution system// Polish Journal of Environmental Studies. -Vol. 16., nr. nr 2A (Suplement), pt. 2 (2007), s.217-220. Punktacja MNiSW:brak, IF:brak

*My percentage is estimated at 70%*

10. **Bray R.**: Removal of ammonia nitrogen from groundwater during nitrification processes using pressure filters. Monografie Komitetu Inżynierii Środowiska PAN, 2010, vol. 64, s. 35-43. Punktacja MNiSW:5, IF: brak

*Independent publication, participation 100%*

**My total participation in the publications included in the achievement:**

- in the publications JCR/WoS - 74%
- in all publications - 82%

Total IF – 2,57

Total number of points MNiSW – 74

Taking into account your own share – 63,75

**c) discussion of the above mentioned research work aim and the results achieved with the presentation of their possible use**

Underground waters are the best source of water supply for the population. Despite their high quality, most of these waters contain pollutants at concentrations higher than those permitted and require purification. In Poland the most common groundwater pollutants are iron, manganese and ammonium nitrogen. Less common are other pollutants, such as arsenic. In addition, underground waters rarely contain excessive permissible concentrations for one type of pollutant, thus two or more undesirable admixtures usually have to be removed from water. Various processes are applied in treatment of groundwater, the most common being the physical and chemical oxidation of iron and manganese; and biological - mainly nitrification of ammonium nitrogen. Much less often used are the processes of coagulation or chemical precipitation, based on dosage of reagents into the water. The common feature of physical-chemical oxidation and biological nitrification processes is their "natural course", i.e. without the support of chemical reagents and the fact that they largely take place in filtration beds. This plays a decisive role in their progress and efficiency of removal. Also in the case of coagulation, individual processes very often occur in filter beds, as in surface coagulation, for example. As a result, most of the groundwater treatment processes occur in filter beds, due to the interactions between the pollutants being removed from water and the compounds or microorganisms present on the surface of the filter bed grains.

Despite decades of experience and still-evolving knowledge of the processes occurring in groundwater treatment, there is still no definitive determination or complete control of the individual processes responsible for the removal of particular pollutants. As a consequence, this translates into errors in design of underground water treatment plants, in particular improper selection of process parameters or improper use of equipment.

The nature of manganese removal from underground water processes is not yet fully understood. In particular, there is no certainty as to the importance of the biological processes involving manganese-oxidizing bacteria, identified in the filter beds. In most cases, the removal of manganese compounds is based on physio-chemical catalytic oxidation processes, with the manganese(IV) oxides present in the filter bed. It cannot be ruled out, however, that biological processes may play a more important role in the initial exploitation of filters, e.g. during processing, when active manganese oxides have not yet accumulated. There is also no sufficient knowledge as to the effectiveness of the new filter materials proposed for use in removal of manganese in contractors' bids for water treatment plants. Such beds are often used without prior verification and are offered as much better and more efficient than traditional quartz deposits.

The basic way of removing ammonia from water is biological nitrification of ammonium nitrogen to nitric nitrogen(V). The most important factors affecting the course of the nitrification process are: concentration of oxygen dissolved in water, temperature, concentration and changes in concentration of ammonium nitrogen, reaction, alkalinity, presence of organic and toxic substances and filtration rate and type of filter material. This broad group of factors also often includes pressure, with a prevailing belief that biological processes, including nitrification, are more effective at pressures closer to atmospheric levels, present in gravity filtration (open). An increase in pressure is a detrimental factor. The available literature, however, provides no results of studies determining the influence of pressurized working conditions on the nitrification process.

Another not fully determined issue is the ability to remove many contaminants simultaneously (in the same type of devices). The traditional approach separates the processes leading to the removal of individual pollutants by, for example, two-stage filtration, because each of the removed pollutants requiring distinct, specific properties of the filter material. For example, in manganese removal, the presence of active, higher catalytic manganese oxides is required in the bed, and the biological removal of ammonia requires the formation within the bed of a biological membrane, populated by nitrifying bacteria of first and second phase. In literature, attention is also often directed to factors that interfere with the removal of manganese, such as the presence of elevated iron concentrations or ammonia in the treated water. Thus, questions arise concerning the possibility of simultaneous removal of manganese with iron, ammonia or other impurities such as arsenic. In the latter case, the problem may be quite complex, as the removal of arsenic requires dosage of considerable quantities of iron compounds into the water and optimally occurs at low water pH levels, both of which factors are unfavorable in removal of manganese.

New measuring devices have also been introduced, enabling to perform tests that previously had to be performed with less precise methods. A laser granulometer was used to measure the particle size resulting from coagulation / co-precipitation of arsenic using iron coagulants. The use of laser granulometer allowed measurements to be made not only with great accuracy, but above all in real time, which was previously practically impossible.

It was therefore considered appropriate to carry out research regarding the following issues:

- the role of microorganisms in the processing of quartz manganese-removal beds.
- the importance of materials and filtration layers in the removal of manganese from groundwater in active deposits.
- influence of filtration pressure conditions on the course of biological removal of ammonium nitrogen from water in the nitrification process.
- removal of arsenic from groundwater and the possibility of its simultaneous removal with manganese.
- particle size of iron hydroxide (III) formed by coagulation/co-precipitation of arsenic using iron coagulants.
- the possibility of simultaneous removal of manganese with iron, ammonia or arsenic.

### **The role of microorganisms in the processing of quartz manganese-removal beds and possibility of simultaneous integrating filter beds during processes of removal of ammonia and manganese**

*[These issues were discussed in publications 4.2.6; 4.2.7]*

The basic method of removing manganese from groundwater is aeration and filtration through active catalytic beds. Removal of manganese from water involves the oxidation of dissolved Mn(II) ions to insoluble higher oxides (e.g.  $\text{MnO}_2 \cdot \text{H}_2\text{O}$ ). However, for this process to occur at a pH close to that naturally present in groundwater, the presence of oxidized manganese  $\text{MnO}_x$  forms is required ( $x \leq 2$ ) (catalyzing the oxidation reaction of manganese).

The formation of a catalytic layer of higher manganese oxides (processing of quartz bed) is obtained by filtration of aerated water containing manganese. At the same time, the sand grains are gradually covered with a coating containing manganese oxides.

The performed research was a continuation of research carried out in the years 1996-2000, as part of a dissertation. It was determined then that manganese oxidation bacteria did not play a significant role in the manganese removal (in spite of the presence of these bacteria in the bed) in the activated beds, i.e. the manganese oxide coated catalytic active layer. These beds removed manganese at high performance levels, stable over time, despite the inhibition of manganese oxidative bacteria activity. It was therefore considered that the dominant process was the physico-chemical catalytic oxidation by manganese oxides. Certain observations, however, indicated that microorganisms may play a greater role in the filtering period. It has been observed, inter alia, that the drainage system with active microflora filters was covered by a black coating, most likely  $MnO_2$ , while an installation containing the inhibited bacteria remained "clean".

The purpose of the study was to determine the significance of manganese oxidizing bacteria during the period of processing of new quartz beds, i.e., in the process of formation of a catalytic layer of higher manganese oxides.

It has been assumed that in the initial filtration period (when the bed grains are not yet coated with manganese oxides), the role of the "catalyst" of Mn(II) to Mn(IV) oxidation can be played by manganese bacteria (manganese-oxidizing), developing in the bed, naturally occurring in filtered water. These bacteria oxidize bivalent manganese to tetravalent manganese and deposit the generated manganese oxides most often outside the cell membrane. The manganese oxide layer produced within the bed in this way will gradually take over catalytic-sorption functions.

The research was carried out at the "Letniki" sewage treatment station near Elbląg, using natural underground waters, after pre-treatment in the first stage filters, where water was cleansed primarily of iron and partially of manganese and ammonium. The research consisted of comparing the course of processing parallel working filters, filled with fresh, sterile quartz sand. Some of these filters had inhibited growth of microorganisms (by introducing ultraviolet-disinfected water into the filters and by using periodic heating of the filter beds), while in the remaining filters the microflora developed naturally and without disturbances. Microbiological studies have shown that microfiltration beds without inhibited flora development have been naturally colonized by a microflora of heterotrophic bacteria (including manganese oxidative bacteria) and autotrophic nitrifying bacteria, phases I and II. The filter beds with inhibited growth of microorganisms were also inhabited by heterotrophic bacteria, the number of which was comparable to the number of bacteria in beds without inhibited development of microflora. However, there were no manganese oxidative bacteria or nitrifying bacteria in these beds.

In the two series of tests performed on all filter beds with uninhibited development of microorganisms, the beds were processed, which took about 8 weeks. After processing, the concentration of manganese in the filter outflow was about 0.02 mg/l (with an average of 0.79 - 0.98 mgMn/l before filtering) and its elimination efficiency was greater than 95-98%. Apart from manganese, ammonium nitrate was also effectively removed (over 90% to concentrations below 0.1 mgN/l, with an average of 0.61 to 0.95 mgN/l before filtering the filters) and iron. The processing of filtration beds, i.e. deposition of manganese oxide on sand grains, was also confirmed by the results of tests of the chemical composition of the filter beds and observations of their appearance. The content of manganese in the filter bed

increased three or four times every two weeks, and after 8 weeks of filtration, at the time of full efficiency of manganese removal, was on average 0.9 mgMn/g of bed, which, in conversion to MnO<sub>2</sub>, equals 1.42 mg/g of bed (that is manganese dioxide content by weight constituted about 0.14% of total bed mass). At the end of the study (after 15 weeks) the content of manganese in the upper layers of the beds was already 12.8-16 mgMn/g of bed, which means about 2.0-2.5% MnO<sub>2</sub> in the bed. Initially, manganese dioxide was deposited uniformly throughout the bed height, and later mostly in the upper part of the bed, as confirmed by observations and photographic documentation of the filter beds. The height of the beds had also increased, on average by about 10% (from about 72 cm at the beginning to about 80 cm at the end of the study). Assuming that manganese dioxide was deposited mainly in the upper layers of the beds, the increase in grain volume could be as high as 20-30%. These results, together with a 2.5% increase in the mass of beds, indicate that the structure and porosity of manganese oxide deposits in beds are considerably expanded.

The processes in filters with inhibited bacterial activity had a completely different course. Despite a four-month filtration, none of these deposits had been processed, nor did the manganese removal efficiency improve. Throughout the whole study period, the efficiency of manganese removal in these beds was very low and most of the measurements did not exceed 5-10% and the concentration of manganese in water after filtering was often the same as prior to filtering. The content of manganese in the filter beds during four months of filtration increased only to 0.015-0.106 mgMn/g of the bed, which, calculated to MnO<sub>2</sub>, represents only about 0.002-0.017% of the bed weight. These numbers are between 120 and 600 times smaller than in beds inhabited by manganese oxidizing bacteria. The appearance of the beds has also remained practically unchanged (quartz sand grains along the whole bed height had remained clear). Only the efficiency of iron removal was the same as that of the beds with inhibited development of microorganisms.

This confirms the assumed hypothesis that microorganisms inhabiting filtration beds, mainly manganese oxidizing bacteria, play an essential role in the processing of quartz manganese removal beds. At the same time, the lack of suitable microflora, or lack of opportunities for its development, may be a cause for failure in the processing of the manganese removal filtration beds.

Another issue, related to the specific composition of the investigated groundwater, was the impact of high concentrations of ammonia on the processing of manganese removal filtration beds and the possibility of simultaneous processing of filters in the process of manganese and ammonia removal. Literature has repeatedly stressed the negative impact of ammonia on the removal of manganese from groundwater. The limit of ammonia concentration above which the process of removal can be significantly inhibited is usually assumed as 0,7 mgNH<sub>3</sub>/l. This issue is important, because higher concentrations of ammonia are present in about one third of total groundwater in our country and often coexist with manganese.

Studies have shown that all filters without inhibited microbial activity have been processed, both in manganese removal and nitrification processes. As in the case of manganese, the processing of nitrification filters took about 8 weeks. After this period, the ammonia removal efficiency was over 90% and its concentration in the filter did not exceed 0.1 mgN/l (with an average of 0.61 - 0.95 mgN/l prior to filtering). The removal of ammonia was accompanied by production of nitric nitrogen, which was on average lesser than the amount of ammonium nitrogen removed. The oxygen consumption was lower than the stoichiometric requirement relating to the amount of ammonia removed, it was close however

to the stoichiometric oxygen requirement for the amount of nitric nitrogen produced during that time. These results indicate the colonization of the filter beds by nitrifying bacteria, with the beds being inhabited simultaneously by bacteria of I and II nitrification phase. Characteristic here is the high convergence and similarity of the course of the filter processing during the processed of manganese removal and nitrification. This is confirmed by previous observations indicating the co-operation of the manganese removal and nitrification processes. Nitrites can utilize manganese oxides that are deposited in the bed, which, thanks to developed surfaces and sorption properties in relation to ammonium nitrogen, create better conditions for the development of nitrifying bacteria. The beneficial effect of nitrification on the process of manganese removal may be the reduction in the concentrations of ammonium nitrogen in the filtered water. However, observations do not confirm this, indicating instead that manganese was removed mainly in the upper layers of the filter bed, where the concentration of ammonium nitrogen was the biggest, irrespective of the course of the nitrification process. Another explanation for the beneficial effect of the nitrification process on the biological processing of manganese removal filters may be that autotrophic nitrifying bacteria and their metabolites, developing in the filter bed, may be an essential source of organic carbon for the heterotrophic manganese bacteria.

Results of the research were cited in academic textbook "Oczyszczanie wody. Podstawy teoretyczne i technologiczne, procesy i urządzenia", Kowal A.L., Świdorska-Bróż M., Wydawnictwo Naukowe PWN, Warszawa 2007, p. 425.

### **Significance of materials and filtration layers in removal of manganese from groundwater in active filtering beds and possibilities for simultaneous removal of iron and manganese in single-stage filtration**

*[These issues were discussed in publications 4.2.1; 4.2.8]*

The purpose of the research was:

- the comparison of manganese removal efficiency of different filter materials, in single and multi-layered beds,
- determination of the sequence of processes leading to the removal of iron and manganese and the locations of removal of these components in multi-layer filters,
- determination of the importance of individual layers and filter materials in the removal of iron and manganese,
- the possibility of simultaneous removal of iron and manganese from water in single-stage filtration.

The studies were carried out at the intakes of groundwater: "Sieradzka" in Gdynia and in Głobino, which supplies water to the city of Słupsk, using natural underground water from quaternary formations with elevated iron and manganese concentrations (Sieradzka 0.2 - 2.0 mgFe/l, 0.08 - 0.18 mg Mn/l, Głobino 0.06 - 0.60 mgFe/l, 0.04 - 0.22 mgMn/l). The studies took long enough (2.5 and 4 months) to allow the observation of changes in the properties of utilized filter beds, resulting from deposition of compounds, mainly iron and manganese. The research was conducted on a relatively large scale, using technical equipment utilized in small, industrial water treatment plants. Various filter materials and beds were used as filter

fillers: single-layer quartz sand, double-layer quartz sand and pyrolusite, double-layer quartz sand and Hydrolyte-Mn and triple-layer: anthracite, quartz sand and pyrolusite.

Studies have shown that not all active filter media facilitate the removal of manganese from groundwater with high efficiency. The synthetic Hydrolyte-Mn filter material, coated with a manganese oxide layer, required processing, and for the first two months of filtration it practically did not remove manganese. It was only after two and a half months that the concentration of manganese in the filter dropped below 0.05 mg/l. Substantial effects of manganese removal were obtained by using pyrolusite (natural mineral containing manganese dioxide). From the first days of filtration, at both water intakes, manganese was removed with high efficiency and its concentration in the filter outflow was lower than 0.05 mg/l in most of measurements. However, significant changes in efficiency were observed, and manganese concentrations in the filter outflow were periodically higher than 0.05 mg/l, acceptable for drinking water. Studies have shown that quartz beds with naturally produced catalytic coatings were no worse in terms of efficiency of removing manganese than pyrolusite beds. In quartz beds, after processing, the obtained manganese removal efficiency was very stable and very high - depending on the intake, more than 90% or 80% and its concentration in treated water, in the vast majority of samples, did not exceed 0.02 mg/l. The only disadvantage of quartz deposits was the need for their processing, which in case of filtration of water from the "Sieradzka" intake took almost a month. However, this period can be significantly shortened, by using an admixture of a processed filter bed, freshly taken from manganese removal filters. In the Głobino study, the quartz filter implemented in this way has been processed in less than three weeks. All tested filter beds removed iron with similar efficiency, with concentrations in the filter outflow not exceeding 0.05 mg/l (average of 0.02).

At the end of the study at Głobino, after about four months of filtration, two measurements of filtration effects were performed along the depth of the filter beds. These measurements have shown that the removal of iron and manganese was similar for all tested filter materials: quartz, quartz-pyrolusite and anthracite-quartz-pyrolusite. In each of the beds, I have observed a clear stratification of processes: firstly, at the top of the beds, iron was removed and then, when the concentration of iron dropped to about 0.05-0.1 mg/l, manganese began to be removed (from the depth of approx. 10-25 cm, and for beds with an anthracite layer - from approx. 35 cm). It was characteristic that in all examined filters, single, three- and three-layer, manganese was removed (up to the level observed in the outflow of the filter) in the quartz sand layer, and the pyrolusite layer below did not matter in this case. It is likely that the pyrolusite layer was more important in the removal of manganese in the initial filtration period when the quartz sand layer was not yet covered by active manganese oxides. In each of the beds, the concentrations of iron and manganese approaching those measured at the filtered outflows were already stable at a depth of about 40-50 cm from the surface of the beds and, in each case, above the layer of pyrolusite. In case of a 3-layer (quartz-pyrolusite-anthracite) bed filter, the majority of iron was removed in the anthracite layer and the manganese was only removed in the quartz sand layer.

**The effect of pressurized filtration conditions on the course of biological removal of ammonium nitrate from water by nitrification**

*[These issues are discussed in 4.2.2; 4.2.9; 4.2.10]*

The purpose of the study was to determine the effect of pressurized filtration conditions and periodic rapid pressure changes on the course of biological nitrification of ammonium nitrogen with nitrification bacteria occupying the filter bed.

The study was conducted in two stages. First, studies were conducted to determine the effect of elevated and variable pressure on bacteria developing in pipeline water. Next, the effects of elevated and variable pressure on the course of the nitrification process in the filter bed were investigated. Tests were conducted under controlled laboratory conditions, followed by field tests, applying the fractional-technical scale that better reflect the conditions at the water treatment stations. The filters, both in laboratory and field studies, were filled with a filter bed taken from fast gravity filters of the second degree from ZPW "Ząbrowo" near Elbląg, where the nitrification process was running at high efficiency.

The results of the preliminary laboratory tests on the effect of increased and variable pressure on bacteria developing in pipeline water indicated that a constant pressure of 0.6 MPa (in pressure filters) had no significant effect on the total number of bacteria in the water (including mainly heterotrophic bacteria). There was no statistically significant difference in the total number of bacteria after 96 hours of incubation in water samples subjected to a constant pressure of 0.6 MPa, as compared to the control sample. Microscopic images of the control sample (open) and the sample subjected to constant high pressure were similar. Both were predominantly composed of clusters of at least a dozen or so bacterial cells, with a smaller number of single cells. Also, the number of colony forming units (JKT), calculated using the culture method in open and pressure samples was comparable. Significant influences on the number of bacteria in water were, however, exerted by rapid pressure changes in the range of 0 to 0.6 MPa, which resulted in a 40% reduction in the total number of bacteria compared to the control sample (calculated using direct counting using the DAPI epifluorescence microscope). In addition, variable pressure caused a breakup of bacterial clusters and release of individual cells (which was visible in microscopic observations). As a result, there was an almost double observable increase in the number of JKT, calculated by the cultural method.

Thus, the results of studies indicated that a constant pressure of 0.6 MPa had no significant effect on the total number of bacteria. On the other hand, elevated pressure (0.6 MPa) and frequent changes in pressure resulted in a 40% decrease in the total number of bacteria, which could indicate damage to more sensitive cells and cause the bacteria to break up and release individual cells.

In laboratory studies on the effect of elevated and variable pressure on the course of nitrification processes in the filter bed, filtering water alternately in pressurized and open conditions has shown that nitrification processes can proceed smoothly at pressures up to 0.8 MPa. It was also shown that pressure changes, irrespective of the direction of these changes, practically did not interfere with nitrification processes. Nitrification processes occurred with the same high efficiency in both open and pressurized filtration and the concentration of ammonium nitrogen was kept at a very low level of approximately 0,1 mgN-NH<sub>4</sub><sup>+</sup>/l (at 0.8 to 1.0 mgN/l in raw water). Removal of ammonia from water was accompanied by a proportional increase in nitrate concentration (V) indicating the course of both the first and the second nitrification phase.

This was confirmed by field studies, during which nitrification processes occurred at with high efficiency at pressures of 0.4 MPa and frequent and rapid decompressions. Removal of ammonia and changes in concentrations of nitrates(III) and nitrates(V) in filtered water occurred similarly to gravity filtration carried out in parallel. It has been observed, however, that after adding more than a doubled dosage of ammonium nitrate to raw water, all filters, both pressure and gravity, required adaptation to elevated ammonia nitrogen concentrations (not related to the increase in pressure, as it was also related to the gravitational filter). The gravitational filter was the quickest to adapt, it took about one month. In the case of pressure filters, this process lasted for a dozen or so days and during the processing, the effects of ammonia removal on the pressure filters were worse than on the pressure filter. This indicates that, in the case of pressure filters, the adaptation of biocenosis (processing) to the elevated concentration of ammonia in water is slower than in the case of gravity filtration. It is probable that, under increased pressure conditions, the growth of nitrification bacteria biomass was slower than in open conditions. Suggested possible causes for slower growth of nitrification bacteria in pressure filters were: the need for bacteria to adapt to elevated pressures; lower oxygen saturation in pressure filters at unchanged concentrations of oxygen dissolved in water (laboratory tests have shown a systematic, slightly larger, on average by 0,1 mgO<sub>2</sub>/mgN-NH<sub>4</sub><sup>+</sup>, oxygen consumption in open filtration). The cause could also have been an intensified elusion of nitrification bacteria during the rinsing of pressure filters (decompression of pressure filters, prior to their rinsing, resulted in disintegration of the nitrifying bacteria clusters, as a result of which they were removed more intensely during rinsing than during the rinsing of the gravity filter). Some researchers also indicate that microorganisms in the logarithmic growth phase are more susceptible to damage caused by increased pressure than in the stationary phase. After the processing of filters, the nitrification process, both in the gravitational filter and in the pressure filters, has displayed similar high efficiency, over 80%.

It has been a certain surprise to observe that higher levels of nitrification were achieved on a pressure filter undergoing frequent decompressions, than on a second pressure filter, under constant pressure. This may indicate that frequent pressure changes cause an increase in the packing of the filter bed grains, which may translate into an increase in the efficiency of the nitrification process. Changes in the structure of the biological membrane due to frequent pressure changes also cannot be ruled out; break-ups of nitrifying bacteria clusters or biological membranes (as observed in laboratory tests), enabled better access to bacterial substrates located in the deeper layers of the biological membrane.

In laboratory tests, a significant amount of oxygen usage was observed, calculated into ammonium nitrogen, from 4,38 to 7,32 mgO<sub>2</sub>/mgN-NH<sub>4</sub><sup>+</sup> (average of 5,8 mgO<sub>2</sub>/mgN-NH<sub>4</sub><sup>+</sup>). In most of the measurements it was higher than the stoichiometric oxygen requirement in the nitrification process (4,57 mgO<sub>2</sub>/mgN-NH<sub>4</sub><sup>+</sup>), as well as than the experimentally observed, both in my earlier studies and in the findings of other authors (usually smaller than stoichiometric values). At the time of the highest oxygen consumption, a negative increase in nitrate(III) concentration was observed in the filter outflow, up to 1,2 mgNO<sub>2</sub>/l (more than twice the acceptable norm for drinking water). Such high oxygen demand and decrease in the treatment effects indicated that it was consumed in processes other than nitrification, most likely in biological decomposition of organic matter by heterotrophs. The main, primary source of organic carbon necessary for the intensive development of heterotrophic bacteria could in this case be the products of metabolism of nitrifying bacteria and their dead biomass. Negligent filter flushing during laboratory tests was possibly conducive to the growth of the biofilm. The biological nature of processes related to oxygen consumption, including the

oxidation of accumulation of organic matter, was indicated by the variable, with respect to nitrification processes, course of oxygen demand patterns over time, resembling various growth phases of bacterial cultures, depending on the accumulation and depletion of nutrients.

A similar phenomena of much higher oxygen consumption, which cannot be explained by the stoichiometric consumption by the nitrification process nor the composition of the filtered water, were observed at several water treatment stations in the Pomeranian voivodship. In some cases, almost twice the standard stoichiometric oxygen consumption in the nitrification process was observed, and the concentrations of oxygen after filtering sometimes dropped to less than 1,0 mgO<sub>2</sub>/l. At these facilities, in spite of relatively small concentrations of ammonia in filtered water (about 1 mgN-NH<sub>4</sub><sup>+</sup>), inhibited nitrification and insufficient ammonia removal from water were observed.

Thus, it should be recognized that the rinsing of biological filters, in which nitrification processes are used for water treatment (although it may cause temporary disturbances in the removal of ammonia), is not only beneficial in the long run, but necessary for their proper functioning. It allows the removal of excess biological membranes from the filters, including heterotrophic bacteria competing with nitrifying bacteria for oxygen, nutrients, and favorable location in the biological membrane. This is particularly important in the case of II stage filtration, where the length of the filtration cycle can be considerably extended, for hydraulic reasons.

### **Removal of arsenic from groundwater and the possibility of its simultaneous removal with manganese**

*[These issues were discussed in publications 4.2.3; 4.2.4]*

Arsenic is relatively rare in groundwater intakes. Concentrations of this element in excess of permissible norms were found in about 7% of water intakes in Poland. However, due to its high toxicity, arsenic concentrations in drinking water are strictly observed, and most often the sanitary services would not issue even a temporary approval for introduction of water with excess arsenic concentrations into the water-supply pipelines. At the same time, most of the groundwater in our country contains excess levels of iron and manganese, so when the presence of arsenic is detected in water, the need to remove iron and manganese together with this element is very probable to follow. The combination of these processes could prove difficult or even impossible, as literature indicates that, irrespective of methods, arsenic can effectively be removed at a low water pH levels, optimally between 4.0 and 6.0 while manganese, even when using active catalytic beds, requires pH levels above 6.5 and often above 7.0.

Coagulation/co-precipitation of arsenic with iron ions is a known method of removing arsenic compounds from both ground- and surface- waters. In this method, iron (III) compounds, most commonly FeCl<sub>3</sub> or Fe<sub>2</sub>(SO<sub>4</sub>)<sub>3</sub>, are added into the water and then the water is filtered. As with other methods of arsenic removal, also in this case many authors stress that the degree of arsenic removal using a given iron dose increases with decreasing pH water levels. The highest removal efficiency of arsenic is obtained at pH = 4 ÷ 6, where iron (III) hydroxide forms positively charged colloids, which promotes the adsorption of arsenic anions on the surface of flocs. The method in itself guarantees simultaneous removal of iron from the water, as well as arsenic. However, in case of necessity of lowering the water pH, it may prevent simultaneous removal of manganese in the same devices.

The purpose of the study was to prove that simultaneous removal of arsenic and manganese from groundwater is possible.

The study was carried out using natural underground waters, taken from quaternary deposits in the Kashubian Lake District in the Pomeranian Voivodship, where the concentrations of arsenic were 33-46 µg/l. In addition, waters were characterized by excess manganese (0.67 - 0.87 mg/l) and iron (0.152 - 0.297 mg/l) concentrations. The water reaction was slightly alkaline (pH 7.74). Due to the presence in the water intake - in addition to arsenic compounds - of excess iron and manganese concentrations, it has been assumed that the suitable method of removal of arsenic ions will be coagulation using iron compounds and filtration. Traditional filtration (by granular beds) was compared with membrane filtration. The study consisted of dosing iron sulfate (III) (iron coagulant PIX 112) into the water, followed by its aeration and filtration in a pressure system. A double-layer - quartz-pyrolusite - bed was used to fill the filter, 1.20 m high (quartz sand - 0.80 m and pyrolusite - 0.40 m). The use of the pyrolusite layer was dictated by the need to remove excess manganese from the water. Microfiltration tubular membranes (type XP 201/04/SIN, made of PVDF, with a cutoff limit of 400 kDa), manufactured by ITT Membranes, were used for membrane filtration. The total area of the membrane was 0,80 m<sup>2</sup>.

Aeration and filtration through a quartz-pyrolusite bed (without coagulant dosage) allowed for a reduction of the amount of arsenic compounds by almost 40% and its concentration in the filter was 21 µgAs/l. Moreover, as expected, iron and manganese were almost completely removed, their contents of after filtration decreased to trace values. The relatively good effect of arsenic removal can be attributed to co-precipitation with iron, naturally occurring in the water intake, its adsorption to previously deposited iron compounds in the filter bed, and adsorption of arsenate ions by the pyrolusite layer (the major component of pyrolusite is manganese dioxide, with arsenate-adsorption properties). Also the removal of manganese ions from the filtered water should be attributed to the layer of pyrolusite present in the filter bed, which removes manganese in the catalytic-sorption processes.

The dosage of iron sulfate (III) into the water intake, prior to aeration and filtration, has significantly improved the removal efficiency of arsenic ions and has reduced arsenic concentrations to levels lower than the acceptable standard in water intended for human consumption. Even at doses slightly exceeding 2.0 mgFe/l, the efficiency of the process was 78% and the concentration of arsenic in the filter decreased to 7.6 µgAs/l. Further increases in coagulant dosages (up to 9.7 mgFe/l) resulted in an only slightly improved efficiency of arsenic removal, up to 5.1 µgAs/l at the highest dose of coagulant. The concentration of the iron compounds in the filter increased with the dose of coagulant, but remained below the acceptable limit throughout the range of doses. This means that, during the process of filtration, most of the iron compounds, both the dosed ones and the ones naturally occurring in water, were removed from water. Even better results were obtained in the removal of manganese, the concentration of which after filtration was consistently maintained at a very low level, well below the permissible levels (although a gradual increase in manganese concentration in the filtrate was observed, proportional to the coagulant dose). The deterioration of the manganese removal effects was most probably a result of lowering the pH of water and the increasing concentration of manganese in water prior to filtration, as the coagulant dose was increased.

Using microfiltration without coagulation, a significant decrease in arsenic concentration was achieved by approximately 55-67%, from 33 - 40 µgAs/l in raw water to 13 - 14.8 µgAs/l in the permeate. In addition, all the analyzed water properties had also

improved, including manganese, with a retention factor of 36 to 47%. The resulting high degree of arsenic retention for microfiltration in itself is difficult to explain, as the pore size of the microfilm membrane is much larger than the dissolved arsenic compound molecules. It is possible that the effect of high arsenic retention was a sum of effects: retention of solid or colloidal arsenic particles and co-precipitation of iron compounds naturally occurring in treated water. After introducing iron sulphate (III) into the water, prior to microfiltration, the arsenic removal efficiency increased to 76% and its concentration decreased below the levels acceptable for drinking water standards, at a dosage of 2.1 mgFe/l. As with surface coagulation, a further increase in coagulant dosage (up to 18.8 mgFe/l) had only slightly improved the removal of arsenic, with the lowest concentration of 5.3 µgAs/l obtained at a dose of 9.7 mgFe/l (retention 86%). The concentration of iron in the permeate over the entire range of coagulant doses used was maintained at trace levels, lower than those in the conventional filtration. Manganese, the concentration of which in the permeate increased proportionally to the coagulant dose, behaved differently, with a dosage of 2.0 mgFe/l the concentration of manganese in the permeate was already higher than its concentration in raw water (the source of manganese, besides the water intake, was also the coagulant solution). The loss of effectiveness of manganese removal during coagulant dosage could be due to the decrease in water pH combined with increased coagulant doses, which dropped to 7.12 at the highest dose (from 7.74 in raw water).

Comparing in parallel studies, the efficiency of removal of arsenic ions from water in an integrated coagulation/microfiltration system was similar to that obtained in surface coagulation. Both processes allowed the concentration of arsenic to be reduced to a level corresponding to the requirements for drinking water at relatively low doses of coagulant, slightly above 2.0 mg Fe/l, without the need for additional chemical modification of the water composition, in particular with the natural, slightly alkaline pH of water. The concentration of arsenic was lower after coagulation and surface filtration, and the iron concentrations were lower after membrane filtration. In addition, in favor of surface coagulation, manganese can be removed by applying a layer of pyrolusite to the filter bed, while with coagulation and microfiltration, manganese is not removed.

Based on the research, a small water purification plant with a maximum capacity of 1,5 m<sup>3</sup>/h was built in 2013. According to the initial assumptions, a typical technological line and devices used for iron and manganese removal from underground waters (aeration and filtration through an anthracite-quartz-pyrolusite bed) were put in place, supported by iron coagulant dosage. This station is under constant supervision by the Author and its exploitation was the next stage of research. Full-scale technical experiences not only confirmed the results of the pilot studies, but were actually much better. At the time of operation, using coagulant doses initially in the range of 2.2 ÷ 2.5 mgFe/l and then lowered to 1.6 ÷ 2.0 mgFe/l, the concentration of arsenic in purified water was 2.1 ÷ 6.4 mgAs/l, and the removal efficiency was usually higher than 90%. High removal efficiency of iron and manganese compounds has also been obtained, with concentrations in treated water well below the permissible limits. In addition to the high efficiency of arsenic removal, equally important was manganese removal, at a constant level, the whole time of operation - we've had some fears that, with longer filtration of water with high iron concentrations, the catalytic properties of the pyrolusite layer could be lost due to deposition of iron compounds on the surface of its grains.

Results of the research proved the thesis that simultaneous removal of arsenic and manganese from groundwater is possible, using coagulation with iron salts when pH>7 and traditional filtration through multilayers filter bed with catalytic filter layer.

### **Particle size of iron hydroxide (III) formed by coagulation / co-precipitation of arsenic with iron coagulants**

*[These issues are discussed in 4.2.5]*

After the coagulation process, the resulting slurry should be removed from water. In traditional systems, it is done by means of fast filtration, often preceded by sedimentation and, in hybrid systems, by membrane filtration. In case of ultrafiltration and microfiltration, the dominant mechanism for the separation of particles present in water is the sieve mechanism. In this case, the separation of substance is based on physical sifting and the process efficiency depends on the porosity of the membrane and the size of the removed particles. In order to achieve satisfactory separation performance levels, it is necessary to ensure that the particle size removed from the water is greater than the pore size of the membrane. In addition, the presence in water of particles comparable in size to the pore dimensions of the membrane may lead to irreversible blocking of the membranes. This process is one of the main factors limiting the use of membrane techniques in practice. In this case, knowledge of particle size arising from the coagulation/flocculation process should be one of the basic criteria for selection of the separation technique (e.g. type and size of the membrane pores) and flocculation period. In literature, when discussing the advantages of integrated coagulation membrane filtration systems, it is generally emphasized that this process does not require a flocculation phase and that 2-10  $\mu\text{m}$  flocs are sufficient to achieve high process efficiency, which can be achieved in a rapid mixing phase of up to 20 s.

The purpose of the study was to determine size of the particles created during coagulation process and prove that in the case of coagulation integrated with membrane or conventional filtration, flocculation time might have significant impact on the process effectiveness.

Measurements related to a situation where iron coagulants are dispensed into water to remove heavy metals, e.g. arsenic, and treated water contains only small amounts of colloidal substances. The resulting coagulant particles are built almost exclusively of iron hydroxide (III). The flocculation process was carried out using pipeline water to which the PIX 112 iron coagulant (the same one used in arsenic removal studies) was dosed at doses of 2.0; 4.0; 7.0 and 10.0 mgFe/l. The process was carried out at a temperature of 8.5-9.5°C, imitating the conditions of groundwater treatment. Fast mixing lasted 30 seconds and slow mixing (17 rpm) lasted 40 minutes. The measurements of particle sizes generated by the flocculation process were performed "on-line", using the Mastersizer Hydro 2000MU laser diffraction analyzer from Malvern Instruments Ltd. To perform the measurements during slow mixing, it was necessary to modify the test bench and to forego the mixing system integrated with the analyzer, as it was causing a break-up of the forming flocs.

The results showed that the coagulant dose (and consequently the initial iron concentration (III)) was the primary factor determining the course of the flocculation process and the size of the ferrous hydroxide flocs. The rate at which the flocs grew in size increased with increasing doses of coagulant. In the first seconds after dispensing the coagulant, the smallest particles with sizes of 0.02 to 0.5  $\mu\text{m}$  (depending on the dose) had begun to show in the solution, showing the transition of iron into an undissolved form (iron hydroxide(III)). In the next 17-33 seconds, for all coagulant doses, a flocs size of > 1  $\mu\text{m}$  was formed in the water, with a remainder of smaller particles still present in the solution. Then there was a constant increase in flocs size to about 250-260  $\mu\text{m}$  (with an average size of d50) (regardless of the coagulant dose). The process then remained in a fixed state, during which the

disintegration of the flocs equaled their agglomeration. The rates of growth of the flocs size and the time after which flocs reached the maximum size were dependent on the iron sulfate (III) dosage. As the dose of coagulant increased, the flocks increased their size faster and reached their maximum size quicker. For the doses used (2,0 - 10,0 mgFe/l), this time was between 15 and 40 minutes. For a dose of 4.0 mgFe/l, the time was about 30 minutes and for a dose of 10 mgFe/l, about 15 minutes. Only at a dose of 2.0 mgFe/l, in spite of over 40 minutes of mixing, the flocs did not reach maximum sizes and their growth was still observed.

Particle measurements performed using a laser granulometer can be helpful in optimizing the flocculation process and designing the reaction/slow mixing chambers. In the course of studies, it was determined that the higher the dose of coagulant, the shorter the stoppage time should be in this type of devices. For the applied doses of iron sulphate (III), this time was from 15 to over 40 minutes.

From the point of view of separation of the post-coagulation particles, both in the conventional and membrane filtration processes, the most important thing is not the large size of particles, but the presence and the amount of the smallest particles. The obtained results showed that during flocculation, irrespective of the formation of larger agglomerates, the smallest particles could remain in water for a long time. They corresponded to the particle size arising in the first seconds after coagulant dosing (smaller than 1.0  $\mu\text{m}$  and often less than 0.1  $\mu\text{m}$ ). This process lasted from tens of seconds to several minutes and was dependent on the dose of coagulant. The smaller the dose, the longer the retention time of the smallest particles. For higher doses, 7.0 and 10 mgFe/l, particle sizes smaller than 1.0  $\mu\text{m}$  were maintained for no longer than 1.0 minute. On the other hand, for 2.0 mgFe/l, particles smaller than 1.0  $\mu\text{m}$  were gone after about 7.0 minutes. Although the percentage of fine particles was not large (1-10% of all particles), the presence of such particles could lead to irreversible blocking of both microfiltration membranes and ultrafiltration membranes with the largest pore diameters.

The conducted studies have shown that when using conventional or membrane filtration (MF or UF), the flocculation time may have an important impact on the resulting retention effects of the post-coagulative particles and that for low doses of coagulants, the slow mixing time should not be shorter than a few (6-7) minutes.

### **The most important achievements that result from the research:**

- Microorganisms inhabiting the filter beds, especially manganese oxidizing bacteria, are essential in the process of quartz manganese removal beds (formation of active manganese oxide coatings on the surface of the filter grain grains). At the same time, the lack of suitable microflora, or lack of opportunities for its development, may cause a failure in processing of manganese removal filtration beds.
- The full efficiency of manganese removal from groundwater in filter beds was obtained with the manganese dioxide content in the bed at a level of 1.42 mg / g on average and its content at about 0.14% of the total bed weight. A naturally produced manganese oxide layer displays a significantly expanded structure and porosity.
- Elevated concentrations of ammonium nitrogen (up to about 1.0-1.5 mgNH<sub>3</sub>/l) do not inhibit the processing of a manganese removal filtration bed. The bed was processing simultaneously in both processes: biological-catalytic manganese removal and

biological nitrification of ammonium nitrogen. This may indicate a synergy between the processes of manganese removal and nitrification.

- Using active filter beds made from natural manganese minerals (pyrolusite) facilitates high efficiency of manganese removal. The most important advantage of these filter beds is the lack of necessity for processing. However, not all active filter media allow the removal of manganese from groundwater with high efficiency.
- Quartz beds with naturally produced catalytic layers are on par with pyrolusite beds in terms of manganese removal. The only downside of quartz beds is the need for a few weeks' worth of processing. However, this period can be considerably shortened, by a few-percent admixture of a processed filtration bed, freshly taken from manganese removal filters.
- Underground waters exceeding the permissible concentrations of iron and manganese can be purified by aeration and single-stage filtration. A clear stratification of processes has been demonstrated: firstly, at the top of the bed, iron was removed, and then, when the concentration of iron decreased to about 0.05-0.1 mg / l, manganese began to be removed.
- The presence of a pyrolusite layer in the filter bed does not necessarily mean that the manganese is removed in this layer. In the processed beds, manganese was removed (up to the level observed in the outflow of the filter) in the quartz sand layer. The pyrolusite layer present below did not matter in this case. The pyrolusite layer was of importance in removing manganese only in the initial filtration period, when the quartz sand layer was not yet covered by active manganese oxides.
- Nitrification processes have been shown to be effective at pressures up to 0.8 MPa. It was also pointed out that pressure changes, irrespective of their direction, caused practically no disturbances in the course of nitrification.
- In the case of pressure filters, the adaptation of biocenosis (processing) to higher concentrations of ammonium nitrate in filtrated water is slower than in case of gravity filtration (elevated pressure causes slower growth of nitrifying bacteria, as compared to gravity filtration).
- Rinsing of biological filters, where nitrification processes are used for water treatment, despite temporary disturbances in the removal of ammonia, is a necessary process for their proper operation, in the long run. It allows the removal of excessive biological membranes from the filters, including heterotrophic bacteria competing with nitrifying bacteria for oxygen, nutrients, and favorable location in the biological membrane. This is particularly important in the case of second stage filtration, where the length of the filtration cycle can be considerably extended for hydraulic reasons.
- High efficiency of arsenic removal with iron sulphate (III) and conventional filtration or microfiltration has been demonstrated for relatively low coagulant dosages and without a need for additional chemical modification of the water composition (especially at natural, slightly alkaline pH of water).
- It is possible to simultaneously remove arsenic and manganese from groundwater using iron salts coagulation at  $\text{pH} > 7$  and traditional filtration through a multilayer bed with a catalytic bed layer.

- Particle size measurements made using a laser granulometer may be helpful in optimizing the flocculation process and in design of reaction / slow mixing chambers. It was found that a higher dose of coagulant reduced the stoppage time in these devices.
- The coagulant dose was the primary determinant of the flocculation process and the size of the ferric hydroxide (III) flocs. The rate at which the flocs grew in size increased with the increasing dosage of coagulant.
- During flocculation (regardless of the formation of larger agglomerates), also the finest particles remained in the water for a long time, corresponding to the size of particles forming in the first seconds after coagulant dosage (smaller than 1.0  $\mu\text{m}$  and even less than 0.1  $\mu\text{m}$ ). This process lasted from tens of seconds to several minutes and was dependent on the dose of coagulant. The smaller the dose, the longer the retention time of the smallest particles.
- With usage of conventional and membrane filtration (MF or UF), the flocculation time may have a significant effect on the retention efficiency of the post-coagulative particles. Especially for small doses of coagulants, the slow mixing time should not be less than a few (6-7) minutes.

### **The possibility of using the results**

Knowledge obtained thanks to the results of research may be used in design and utilisation of water treatment plants in which groundwater is purified, especially groundwater with heightened content of manganese, ammonia, and arsenic.

Recognising the character of the manganese removal filters integrating process, and first and foremost, knowledge that it may be a biological process, is significant in filters utilisation. Primarily, all actions that may hinder development of bacteria oxidising manganese should be avoided during the filter bed integrating period. Particularly, water containing bactericidal substances, such as e.g. water disinfectants or potassium permanganate, which is often used for manganese removal, cannot be put into the filters. This regards both filtered water and water used for rinsing of filters. Biological creation time of filters may be shortened as well by using few percent concentration of a fresh filter bed taken from manganese removal filters.

While designing water treatment plants, in which ammonia will be removed in nitrification process, pressure equipment may be used as often as open equipment. Choice of the equipment should be determined on the basis of other parameters of treated water (e.g. alkalinity, or presence of free carbon dioxide). In the case of degree II filters, in which the nitrification process takes place, filters should be rinsed more often than mere hydraulics requires. Significant extending of filtration process may lead to excess development of biological membrane, including heterotrophic bacteria, which in turn may disturb nitrification processes.

In the case of groundwater in which apart from manganese there is iron or ammonia (up to about 1,0-1,5  $\text{mgNH}_3/\text{l}$ ), purification is possible during one-step filtration. It is also possible to remove arsenic and manganese during one-step filtration by gradually adding iron coagulant into the water and using groundwater purification devices (aerators and filters). This means simplifying of process lines and decreasing of investment costs.

Particles size measurements taken using laser granulometer might be used in reaction/flocculation chambers design. It was proved that when using membrane and conventional filtration, flocculation time might have significant impact on post-coagulation particles intercepting effectiveness. For small doses of coagulants, flocculation time should not be shorter than few minutes, since during that time particles of dimensions smaller than 1,0 or even 0,1  $\mu\text{m}$  still float in the water.

## **5. Description of other scientific and research achievements**

### **a) Before receiving the doctor degree**

In 1984, I began my studies at the Gdańsk University of Technology at the Faculty of Hydraulic Engineering (presently the Faculty of Civil and Environmental Engineering). In 1990 under the supervision of doc. Stanisław Bachanek, I defended my master thesis entitled: "Technological project of industrial sewage plant of Technical Agriculture Services Companies".

I had begun my work as an assistant in 1989, even before my graduation, at the Faculty of Hydraulic Engineering (presently the Faculty of Civil and Environmental Engineering) at the Department of Water and Wastewater Technologies. In 1991, I took part in a five-month military training of cadet reserve at the Military Officer Training College in Wrocław. In 1992, at the Gdansk University of Technology, I completed a two-semester Postgraduate Study in Teaching and Pedagogical Improvement of Academic Teachers. Following that, in 1992-1993, I completed the Polish-Danish Postgraduate Environmental Protection Study "Wastewater Treatment in Constructed Wetlands". In the years 1993-1994, at the Faculty of Management and Economics of Gdansk University of Technology, I completed a postgraduate course "Managing a company in market conditions".

My first research work after securing my employment at the university concerned biological removal of phosphorus from biologically purified wastewater. Under the direction of Professor Irena Kulik-Kuziemska I conducted research on the use of algae in removal of high concentrations of phosphates from municipal sewage, after biological treatment processes. I studied the effect of retention time, temperature (within the 4.5 to 25°C range) and light intensity (30-8000 lx) on phosphorus elimination. Various ways of separating suspended algae from purified wastewater have also been investigated. Studies have shown that the use of algae allows the removal of phosphorus from purified wastewater to concentrations below 1.0 mgPO<sub>4</sub>/l. However, in the climate conditions prevalent in our country, such effects can only be obtained during the summer. In the remaining period the effects would be much worse and in the winter, almost non-existent. The main factors influencing the decrease in effects in the autumn-winter period were low sunlight intensity and shorter access times to natural sunlight, with the temperature of sewage playing a lesser role. The problem was also the separation of biomass of algae from purified wastewater. The use of sedimentation was ineffective to this end.

Quite soon my interests turned towards purification of groundwater. Around 1993, I joined the research led by professor Krystyna Olańczuk-Neyman and associate professor Jerzy Prejzner, concerning removal of manganese and ammonium nitrate from groundwater. These issues have also become the subject of my dissertation, "The role of physico-chemical and biological processes in the elimination of manganese and ammonium nitrate from groundwater", which I carried out under the advice of Professor Krystyna Olańczuk-Neyman, and which I defended on January 21, 2000. The purpose of my dissertation was to determine the nature of the processes involved and the importance of biological and physico-chemical processes taking place during the removal of manganese and ammonium nitrate from groundwater in the second stage of filtration on processed sand beds. I reviewed the literature on these issues and conducted my own research on a laboratory scale, model scale, and full technical scale. In all my experimental works, I used natural underground water after I degree of filtration with significant content of manganese and ammonium nitrate.

Studies have shown the suitability of processed quartz sand for removal of high concentrations of manganese and ammonium nitrate from groundwater. The second stage of filtration achieved very good effects of elimination of manganese and ammonium nitrogen, and the concentrations of both components practically did not exceed the limit values for drinking water and household use, at very high concentrations of these components in water fed to filters (manganese from 0.2 to 0.9 mg/l, ammonium nitrate from 0.2 to 1.9 mgN-NH<sub>4</sub><sup>+</sup>/l).

It was found that the removal of manganese on the processed sand bed occurred on physio-chemical basis (sorption and catalytic oxidation with MnO<sub>2</sub>), but no direct oxidation of manganese sedimentation bacteria was observed (the possibility of biological elimination processes of this component cannot be ruled out). It is also impossible to exclude the important role of these bacteria during the processing of fresh sand beds, in the process of forming a catalytic layer of manganese oxides. The physio-chemical nature of the processes leading to the elimination of manganese in the studied, processed sand beds was supported by:

- unchanged, high manganese elimination effects after inhibiting the activity of bacteria occupying the bed,
- unchanged, high removal effects of manganese at periodic low dissolved oxygen content (even at 0.5 mgO<sub>2</sub>/l) – it can be assumed that manganese removal during this time occurred mainly by sorption and catalytic oxidation,
- deterioration of manganese elimination effects after a longer (about 4 days) filtration of water with low oxygen content (less than 2 mgO<sub>2</sub>/l), i.e. loss of sorption-catalytic properties of the bed - indicating that Mn(III) oxidation to Mn(IV) occurred involving the oxygen dissolved in water.

Removal of ammonium nitrogen was carried out by biological and physio-chemical means, mainly phase I and II nitrification and sorption / ion exchange of ammonium nitrogen. These processes occurred simultaneously, and the contribution of individual processes to the removal of ammonium nitrogen during filtration was variable and depended on the composition of the filtered water (primarily oxygen and ammonium nitrogen content). At low oxygen concentrations, the processes of sorption / ion exchange of ammonium nitrogen dominated, their contribution lessening in favor of the nitrification process, as oxygen concentration increased. The nitrification process was sensitive to changes in the concentration of ammonium nitrogen in the filtered water, which was manifested by the periodic inhibition of nitrites and nitrates production. This was probably due to the need to adapt the biocenosis to new conditions. The adaptation period caused by the change in the concentration of ammonium nitrogen lasted from a dozen or so hours to a dozen or so days.

It should be added that the obtained results were used in the 1996-1998 modernization of the "Letniki" water treatment plant with a capacity of about 15,000 m<sup>3</sup>/day, producing water for the Central Żuławy Water Supply. The modernization was performed in order to replace the existing one-stage filtration with two-stage filtration. The existing stations, particularly filters and pumps, were kept. Thanks to modernization, the treated water fully complies with the current requirements of water intended for consumption. The station is still in operation, with the construction of a new treatment plant starting in 2017, where a technology compatible with the technology of my co-design will be used.

## **b) After receiving the doctor degree**

My research interests after obtaining my PhD degree can be categorized into three basic areas:

- disinfection and treatment of biologically purified municipal waste water,
- biological and chemical stability of water entering the water supply network,
- application of low-pressure membrane processes in water treatment and wastewater treatment.

### **Disinfection and treatment of biologically purified municipal waste water**

*[These issues were discussed in publications A.1, E.6, E.7, E.11, E.18]*

In the treatment of urban waste water, the microbiological risk posed by purified waste water discharged into the environment is increasingly being addressed. In the light of data from the literature, municipal sewage treatment plants can be classified as serious environmental emitters of microbiological contamination, including human pathogens, viruses, bacteria and protozoa. Raw municipal wastewater contains numerous pathogenic microorganisms, opportunistic and also antibiotic-resistant, including multiple-treatment resistant, mainly of intestinal origin. Despite a very high (over 99%) reduction in the number of bacteria in wastewater in the purification process, the effluent from wastewater treatment plants still contains 104 to 106/100 ml of indicator fecal coliform bacteria.

Between 2007 and 2010 I was a co-contractor in a EU EEA Grants E007/P01/2007/01/85 financed project – “New methods of emission reduction of selected pollutants and application of by-products from sewage treatment plants”. In this project, I was responsible for the preparation of research stations and conduction of research, mainly on the use of membrane processes and ultraviolet rays in disinfection and purification of treated municipal waste water from the sewage treatment plants "Wschód" in Gdańsk and "Dębogórze" in Gdynia. I had continued these studies, mainly in the area of application of UV rays for disinfection of sewage, in the following years. As a result, numerous scientific papers have been written, which I have co-authored; published in scientific journals, and presented at international and national conferences. I was also co-author of the book "Sewage disinfection", edited by Krystyna Olańczuk-Neyman and Bernard Quant, published in the "Seidel-Przywecki" Publishing House in 2015.

Studies on the application of low-pressure membrane processes - ultrafiltration and microfiltration - in the disinfection of treated municipal wastewater were conducted with treated sewage from the mechanical and biological sewage treatment plants "Wschód" in Gdańsk and "Dębogórze" in Gdynia. Membrane filtration was carried out using tubular membranes with a total area of 0.80 m<sup>2</sup>. The study utilized mass-produced FP 200 ultrafiltration membranes made of PVDF, with 200 kDa separation, and XP 201/04/SIN microfiltration membranes made of PVDF, with a 400 kDa separation, by ITT Membranes. The membrane module was supplied by a continuously purified sewage system, using both dead-end flow and cross-flow. Membrane filtration was performed at 0.3 and 0.5 MPa transmembrane pressure. In selected research batches, the purified wastewater, prior to introduction into the membrane system, was additionally filtered through a conventional filter filled with quartz gravel.

The results showed that both ultrafiltration and microfiltration are effective methods of municipal disinfection of purified wastewater. The number of indicator bacteria decreased by 3-5 orders of magnitude, and in the permeate, the number of fecal coliforms did not exceed 20 JTK/l at UF and 200 JTK/l at MF and the numbers of fecal streptococcus did not exceed 5 JTK/l and 10 JTK/l respectively. These effects were obtained irrespective of the bacterial counts in the purified wastewater prior to membrane filtration that ranged from  $1.0 \times 10^5$  to  $3.0 \times 10^5$  JTK/l for coliform bacteria and for fecal streptococcus from  $8.9 \times 10^4$  to  $4.8 \times 10^5$  JTK/l. The high elimination of indicator bacteria in wastewater purified by microfiltration and ultrafiltration processes was accompanied by significant changes in its physicochemical quality. The best results were obtained for two indicators: turbidity and total phosphorus, which in the vast majority of measurements were removed from the purified sewage almost completely. The turbidity of the permeate, irrespective of the turbidity of the wastewater entering the system (ranging from 1.77 to 5.35 NTU) and the ultrafiltration method and parameters, did not exceed 0.02 NTU. The overall phosphorus retention ratio during ultrafiltration was 95% on average and its concentration in the permeate did not exceed 0.13 mg/l, with over 2/3 of the measurements being less than 0.01 mg/l. Microfiltration resulted in slightly decreased, but still very high phosphorus removal - retention rate was 49.4% on average and total permeate phosphorus concentration was not greater than 0.2 mgP/l, (with almost half of the measurements being lower than 0.1 mg/l). Average effects were obtained with respect to the COD, the retention coefficient of which was 38.9% for ultrafiltration and 17.2% for microfiltration, and the COD value of the permeate did not exceed 32 mgO<sub>2</sub>/l (33.9-60.2 mgO<sub>2</sub>/l in sewage supplied to the system). BZT<sub>5</sub> was characterized by a very high variability in removal efficiency in the ultrafiltration process, which ranged from 0 to 92.9%, on average 47.3%. Total nitrogen was removed to a small extent, with an average retention factor of just 7.3% for UF and 10.3% for MF; in half of samples it was not removed at all.

Pre-filtration performed before conventional membrane filtration on a gravel bed filter, although significantly improving the quality of wastewater fed into the membrane system, did not improve the quality of the permeate. There is no observable relationship between the length of the filter cycle (150 to 360 minutes) and the pressure and quality. For longer filter cycles, using microfiltration for indicator bacteria, coloration and UV absorbance, however, there was a noticeable deterioration of the effects at the end of the filter cycle. The composition and concentration of the individual permeate components (with the exception of general nitrogen) did not depend on the quality of the purified wastewater supplied to the system. Lack of any dependence was observed primarily for those components that were removed in the ultrafiltration process with both high and medium efficiencies (suspension, turbidity, total phosphorus, COD, BZT<sub>5</sub>). The exception was general nitrogen, the concentration of which in the permeate increased as its concentration in the sewage fed to the system increased. This indicates that the quality of the permeate and the degree of removal of individual wastewater components was determined primarily by the form of their presence in wastewater. It has been observed that components, the concentration of which correlated with the amount of slurry in the effluent from the treatment plant, were better removed from the wastewater by ultrafiltration than components where no such correlation was found.

Research was also carried out, applying fractional-technical scale, regarding disinfection of treated wastewater using UV radiation. These studies, as in case of use of membrane filtration, were carried out with waste water purified in the sewage treatment plants "Wschód" in Gdańsk and "Dębogórze" in Gdynia. The study utilized a device equipped with a 33 W low-pressure radiator emitting radiation at a wavelength of 254 nm. The study was conducted at a variable radiation dose ranging from about 5 to nearly 100 mJ/cm<sup>2</sup>.

Disinfection was performed on biologically purified effluents collected directly after the final settling tanks and sewage after additional treatment with the use of filtration through quartz sand filters. The results show very high efficiency of disinfection of wastewater using UV rays. The reduction of the number of bacteria came to 4 orders of magnitude. It was observed that fecal coliforms were more susceptible to UV radiation than fecal streptococci. To reduce the number of fecal coliforms to less than 1000 JTK/100ml, a UV dose of  $<10 \text{ mJ/cm}^2$  is needed, and to achieve a similar effect for fecal streptococci, the dose needs to be twice as high. The use of pre-treatment of waste water by filtration has resulted in the same disinfection effects at a lower radiation dose of 20 to 50%. The reduction of fecal coliform count to less than 1000 JKT/100ml was achieved at a dose of  $5 \text{ mJ/cm}^2$ .

In the years 2014 - 2015, research was carried out at the sewage treatment plant in Jastrzębia Góra, where the first (in Poland) equipment for disinfection of treated wastewater with UV rays was installed on a full technical scale. Results of these studies were presented during the Congress of Environmental Engineering in Lublin in 2016. Currently the maximum sewage flow at the treatment plant is  $5170 \text{ m}^3/\text{d}$ . The UV device for disinfection of purified waste water consisting of 12 low pressure radiators, with a total output of 6.0 kW, was mounted in a special covered canal after the final settling tanks. The unit had adjustable power in the range of 31 to 100% of nominal value. The nominal UV dose for which the device was selected was  $11 \text{ mJ/cm}^2$ . However, during the autumn-winter-spring period, with the smallest flow of waste water, the UV dose was higher, with most measurements not exceeding  $22 \text{ mJ/cm}^2$ . The purity of the treated wastewater, which is the basic quality parameter for UV disinfection, was 49 to 62.5%. There was a clear dependence of transmittance on the flow of waste water. The assumed radiation dose of  $11 \text{ mJ/cm}^2$  ensures a reduction in mesophilic bacteria at 80% (80-95%). The mean bacterial elimination efficiency (calculated on the basis of the mean number of bacteria before and after the disinfection for the entire study period) was 93.6% for mesophilic bacteria. There was a noticeable effect of sewage flow on the effectiveness of disinfection, with a decrease in the effectiveness of disinfection as the flow was increased. For the lowest flows below  $100 \text{ m}^3/\text{h}$ , the disinfection performance was higher in 95-97% than 99% in most measurements, while for the highest flows above  $240 \text{ m}^3/\text{h}$ , the disinfection efficiency did not exceed 90%, and in most parameters, it was within the range of 80-85%.

### **Biological and chemical stability of water entering the water supply network**

*[These issues were discussed in publications A.2, E.4, E.9, E.21, E.23, E.33]*

The primary task of supply systems of water intended for human consumption, apart from meeting the quantitative and qualitative requirements, is to minimize the risk of deterioration in water quality. Water purification technologies should ensure, within the water treatment system (WTS), a controlled occurrence of all possible physicochemical and biological processes that can take place in treated water. The creation of conditions for these processes in the water supply network excludes the possibility of influencing their course, and the resulting products accumulate in the form of mineral deposits and biofilm, or pass along with the water to the end receivers.

In 2004, I had analyzed 79 randomly selected rural public waterworks in the Pomeranian Voivodeship, of about 740 such facilities in the whole voivodship. The vast majority of analyzed water pipelines (about 90%) supplied up to 1500 inhabitants and the

water production did not exceed 350 m<sup>3</sup>/day. Only about 17% of the total water supply, throughout the studied period, fully met the quality requirements for water intended for human consumption. In the remaining waterworks, permanent or periodic breaches of between 1 and 6 parameters were recorded at the same time, in most cases breaching no more than 3 parameters at the same time. Iron, manganese and turbidity were the most often exceeded parameters, and the problems with these parameters concerned about ¾ of water supply. Relatively common were also high levels of ammonia, oxidation and coloration, these indicators concerned approximately 31%, 28% and 16% waterworks respectively. Approximately 15% of the water supply periodically exceeded bacteriological limits, including coliform bacteria. Such frequent and significant exceedances of the limit values of basic water quality parameters can be explained by the fact that the studies covered the years 2000-2004, i.e. a period immediately after the introduction in 2000 of significantly higher requirements for drinking water, which were not met immediately.

I had also conducted a study on the impact of the applied water treatment technology on the microbiological and chemical stability of groundwater entering the water supply network. The research was carried out in Gdańsk, Gdynia, Kwidzyn and Malbork and concerned both waters untreated prior to introduction into the water supply network as well as treated waters. In case of ground waters characterized by good microbiological quality, no final disinfection was applied. The water intakes contained elevated concentrations of iron and manganese, and the treatment technology was based on aeration and pressure filtration on processed quartz sand beds. In spite of lack of disinfection, there was no exceedance of the limit values for heterotrophic bacteria in the water supply system, and their number only slightly increased with increasing distances from the treatment plant.

Studies on the microbiological quality of groundwater undergoing final disinfection were carried out for two water treatment plants and the water supply system in Kwidzyn. The groundwater supplying both treatment plants contained excess iron, manganese and one of the intakes also contained ammonium nitrate. In the first station, the treatment technology was based on traditional aeration and single stage open filtration. The second facility utilized aeration in open reactors filled with bio-plastic (Kaldnes) pellets inhabited by a biological membrane and two-stage filtration on open DynaSand filters. At both stations, water after treatment was disinfected with ClO<sub>2</sub>. At both treatment stations in the water after treatment, an increase in the number of heterotrophic and denitrifying bacteria was observed. Despite the use of disinfection, the overall increase in the number of bacteria in the water supply network has also been observed at increasing distances from the facilities.

Studies have also been carried out on the effect of mixing water from two different aquifers (purified quaternary formation water and cretaceous formation water) on the chemical and biological stability of water. The quaternary water was purified using aeration and two-stage filtration. On the first-degree filters (anthracite-sand beds), most of the admixtures were removed, mainly iron and ammonium nitrite (in the nitrification process) and most of the manganese. Secondary filters (pyrolusite-sand beds, activated during sodium hypochlorite flushing), the remaining manganese was removed. The treated water fully complied with requirements for drinking water, and was characterized by high hardness. Subterranean water, taken from cretaceous formations, was characterized by low carbonate hardness, the iron content was close to the permissible value, and ammonium nitrite was slightly exceeded. In addition, significant excesses of permissible fluoride (up to 3.0 mgF/l) and boron (up to 1.5 mg/l) levels were observed. Quaternary and cretaceous waters were mixed at a 2:1 ratio so that, after mixing, the contents of all water components met the conditions for water intended for human consumption.

An original research methodology has been developed, making it possible to compare the ability of the studied waters for sediment precipitation. To this end, the absorbance of the ultraviolet rays and visible light passing through the sediment layer depositing on the inner walls of the tubes was measured, through which the test water flowed constantly for more than three months. It was considered that the amount of absorbance and its change over time would be an indirect indicator of the amount of sedimentation.

The study results had shown that both quaternary water after treatment processes and untreated cretaceous water were characterized by high chemical and microbiological stability. The absorption of light by the precipitate on the walls of the tube, both in the ultraviolet (300 ÷ 310 nm) range and the visible light (385 ÷ 395 nm) range, remained at a very low level throughout the study, indicating a small amount of sediment accumulating on inner tube walls. Mixing of purified quaternary water with cretaceous water resulted in a significant reduction in water stability, leading to formation of a sludge layer. The absorption of light by the deposits accumulating on the walls of the tube, through which the mixed water flowed, was increasing much faster than that of quaternary and cretaceous water, both in the ultraviolet and visible light ranges. In addition, after about 80 days of study, a noticeable quickening of the increase in absorbance was observed, which could indicate acceleration of the sludge growth. The spectral characteristics have also changed, which may indicate a change in the composition and structure of the sediment. Most probably, earlier, mostly mineral compounds were accumulated, forming a more homogeneous and compact sediment structure, for example due to the carbonate-calcium imbalance that results from mixing of waters with different physio-chemical compositions. Later on, probably on a mineral skeleton, a biological membrane with a more varied thickness and a spongy structure began to form, producing differentiated absorbance results.

The acceleration of sedimentation can also be explained by catalytic action of previously sedimented mineral compounds, such as iron or manganese. A rapid increase in sedimentation intensity, observed from the 80th day of the study, regardless of the nature of the process (biological or chemical - catalytic), indicates interaction between the water components and the sediment layer, which significantly accelerates sediment formation. Accelerated growth of microorganisms in mixed water has been confirmed by microbiological tests. After seven days of incubation at 10°C, similar to typically occurring in groundwater, all of the samples tested showed a clear increase in the total number of bacteria, with the largest (over 3-fold) increase in the number of bacteria recorded in mixed water. The probable reason for the greatest increase in the number of bacteria in mixed water was the improvement of nutrient conditions for the bacterial flora originating from various waters, and in particular the enrichment of the barren cretaceous water environment with organic substances derived from quaternary water and the supply of missing biogens (mainly ammonium nitrogen) to bacteria present in purified quaternary water.

The conducted research has shown that the treatment processes applied in the studied groundwater treatment stations effectively protect the biological stability of water distributed in not overly extended water supply networks. On the other hand, mixing water from different aquifers, even when all of them are high-quality and are biologically and chemically stable, can cause disturbances in the stability of mixed water, resulting in deterioration of its quality, precipitation, biofilm formation and secondary microbial growth in water supply networks. In addition, the sediment deposited on the walls of water pipes, acting on the water components, can significantly accelerate the formation of sediment.

## **Application of low-pressure membrane processes in water treatment and waste-water treatment**

The use of membrane techniques is not a completely separate research topic and is related to the scientific achievements discussed earlier, but it is an important part of my research interests. I became interested in membrane techniques in 2001, when I participated in the Membrane School, "Membranes and Membrane Techniques in Environmental Engineering", organized by the Faculty of Environmental Engineering and Energetics, Silesian University of Technology. Since 2010, I regularly participate in Scientific Conferences "Membranes and Membrane Processes in Environmental Protection", also organized by the Faculty of Environmental Engineering and Energy, Silesian University of Technology. At these conferences, I have delivered five papers on membrane techniques [L.1, L.3, L.5, L.7, L.8, L.10]. In particular, I am interested in low-pressure membrane processes used independently in disinfection and treatment of purified wastewater and in systems integrated with conventional coagulation in groundwater treatment. In total, I have published nine articles devoted to membrane techniques [B.3, B.5, E.3, E.5, E.6, E.7, E.12, E.31]. I have also discussed these issues at three seminars organized by the Kemipol Company from Police.

In addition to the above-mentioned studies on the use of microfiltration and ultrafiltration in the disinfection and treatment of biologically treated municipal effluents and the discussed ultrafiltration in the removal of arsenic from groundwater, I have also conducted research on the application of microfiltration integrated with coagulation for the purification of colored groundwater. These studies, carried out on a fractional - technical scale with the use of natural underground water with high coloration (47-49 mgPt/l) and excess iron and manganese concentrations, had shown that treatment of this type of water in an integrated system - coagulation with iron coagulants with microfiltration, allowed for reduction of coloration as well as iron removal. Almost half the color reduction was achieved at a coagulant dose of 3.7 mgFe/l, and increase of dosages resulted in further increases in color reduction to a maximum of 77%, using a high coagulant dose of 16.5 mgFe/l. The color reduction was accompanied, albeit to a lesser extent, by the reduction in UV absorbance and oxidation. However, the process was ineffective for manganese, the concentration of which in the permeate remained unchanged. It was also found that pre-aeration of raw water had an essential, beneficial influence on the course of the process. While good color and iron reduction effects were obtained for aerated water, for non-aerated water the color reductions effects were noticeably worse and the iron concentration increased after the process, in direct proportion to the coagulant dose, which also increased the color of the treated water.

## **6. Information on didactic, organizational and scientific activities and cooperation and popularization of science**

I have been continuously teaching classes at the Faculty of Civil and Environmental Engineering at the Gdańsk University of Technology in the Department of Water and Wastewater Technologies since 1990, to the present day. Initially, until the year 2000, I conducted laboratory exercises, auditorium exercises and project exercises as an assistant and since 2000, I had also been lecturing, at full-time and part-time studies, in subjects:

- Water technology (in the field of water and wastewater technology) - lectures and laboratory exercises,
- Water treatment plants - lectures, design exercises, auditorium exercises,

- Water treatment equipment - lectures, design exercises, auditorium exercises,
- General chemistry - auditorium exercises and laboratory exercises,

Since 2002 I have been a thesis advisor in about 40 master's theses and engineering theses and reviewer of about 40 theses. In the years 2001-2006 I was the tutor of the year in the field of Environmental Engineering, full-time studies. I am also an assistant advisor in the doctoral dissertation of M.Sc. Eng. Karolina Fitobór "Treated rainwater as a source of water for household purposes". From 2002 to 2005, I was the Dean's Representative in the Point System Committee. Simultaneously, I was also a Representative of the Faculty in the Disciplinary Commission for Students for the term 2002-2005 and in 2008-2012 I was disciplinary spokesman for the students of the Gdańsk University of Technology.

In the years 2006-2008 I also conducted lectures and exercises at extramural engineering studies in the subject "Water Treatment" at the Higher School of Environment in Bydgoszcz. I was also the supervisor of four engineering diploma theses at that educational institution.

In cooperation with the Gdańsk Water Foundation, in the years 2006-2008, I was co-organizer of two training seminars on "Optimization of iron, manganese and ammonium nitrogen removal from groundwater - theory and technological research" and "Underground water treatment, physio-chemical and biological methods of removal of iron, manganese and ammonium nitrogen". I also participated in several other training seminars organized by this Foundation. Within the frame of my popularization activities, I have also participated in four seminars organized by the Kemipol Company, where I delivered papers related to my research activities, mainly concerning the use of coagulants in the treatment of groundwater.

During my professional career, I have had the opportunity to use my knowledge in practice, providing opinions and expert evaluations and participating in expert teams in economic projects related to the modernization and expansion of water supply infrastructure in our country, especially in the construction or modernization of water treatment plants. This work offered me, on the one hand, the opportunity to apply the acquired theoretical knowledge in practice, as well as allowing me to acquire new practical experiences that I constantly use in didactic, expert and scientific work. In my work, I have also often applied the results of my own scientific research on the treatment of groundwater. The most important projects I participated in were the Gdańsk Water and Sewerage Infrastructure Project, which was implemented in Gdansk's Water and Sewerage Infrastructure in 2008 - 2011, where I participated as a consultant and technological advisor in the modernization and construction of six water treatment plants in Gdańsk ("Osowa", "Pręgowo", "Zaspa Wodna", "Dolina Radości", "Lipce" and "Zakoniczyn").

Prior to this, in 2005, I have prepared opinions on the concepts of modernization of these objects. In the years 2010-2013 I had participated in the project "Comprehensive solution for water and sewage management for the City of Wałcz", where I was the author of the modernization concept and the author of the technological part of the functional-appropriable program for modernization of the "Podgórna" water treatment facility, and then I acted as an expert and consultant in the realization of this investment until the commissioning of the new facility for use in 2013. I also acted as consultant / technology expert in building a swimming pool for the Junior High School in Kosakowo (in the years 2012-2015) and in the years 2014-2016, I was a consultant / key expert, water treatment technology specialist for the construction of the new Water Treatment Station no. 1 in Mińsk Mazowiecki. In all these projects, my tasks included reviewing technological documentation for all design phases,

including initial designs, construction, implementation, participation in consultations with the procurer and the contractor, verification of necessity reports and negotiation protocols, verification of material applications and participation in final acceptances. In many cases, my involvement was not solely limited to the fields of project or document review, but also involved creative solving of technical and technological problems and proposing alternative solutions that were often used and implemented. In addition, I am the author or co-author of over twenty technical opinions and expert evaluations concerning mostly water treatment plants in our country. I had also prepared an opinion, in 2015, as a court expert for the Poznań Regional Court (Leszno District Offices, XII Civil Division in Leszno).

For my work, I was honored in 2000 by the President of the Polish Republic with the Bronze Cross of Merit. I have received three team awards and one individual award from the Rector of Gdańsk University of Technology for outstanding achievements in scientific and organizational work. In 2015, I have received an especially important award - the "Roman" statuette of gratitude - awarded by "Bogdan Jański's Fundacja Burego Misia".

