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# Lab-scale research of water treatment with use of water glass and nanoiron

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## ABSTRACT

The article describes the partial outputs of the research focusing on alternative procedures and agents for water treatment. In this case, the possibilities are shown of using water glass and nanoiron as agents for removing heavy metals and nutrients from the water. In particular, laboratory experiments are presented simulating the processes of removing chromium and phosphorus from water. The purpose of the experiments was to show the efficiency of mentioned alternative agents when removing the pollution mentioned. The laboratory experiment was conceived as a series of jar tests as standard procedure used in connection with the control and optimisation of the coagulation process. Laboratory processes were carried out with model water whose main component was raw water from a surface water source enriched with a previously given concentration of selected pollution – chromium and phosphorus. During the experiments, the dependence was determined of the removal of the given pollution on the dose of the agent and simultaneous search for the optimal dose while applying water glass and/or nanoiron as innovative agents.

*Keywords:* Drinking water; Jar test; Removal of metals; Water glass; Nanoiron; Water treatment

## 1. Introduction

The presented paper focuses on the treatment of the properties of surface water above all in the indicators that do not present such usual pollution. The objective was to obtain drinking water of the best possible quality, and this can be achieved if attention is also focused on less common pollutants. Today the treatment of water from surface water sources commonly incorporates physical and chemical processes involving coagulation and subsequent separation. The structures of technological lines described as conventional guarantee suitable physical, chemical, organoleptic and microbiological properties of drinking water parameters in accordance with the requirements of valid legislation. An important part of the raw water treatment process is the formation of a suspension resulting in the destabilisation of adverse impurities and their subsequent aggregation. These aggregates will subsequently be removed from the water by separating procedures in the next step of treatment. The suspension formation process depends on a whole series of factors, which include physical and chemical factors. The type and dose of destabilising agent is important for the optimal formation of the suspension, then pH and the type and amount of pollutants in the treated water are equally important. In the next step, it is important to choose a suitable mixing rate, time and distribution. The mixing process needs to be optimised to the stated criteria to achieve the most effective removal of impurities from water.

As is known, the coagulation and separating process includes the following equipment: dosage of chemicals (coagulant, agent for changing pH), homogenising element and flocculation basin, degree of separation (sedimentation tank, filters, etc.), sludge management and technology work. The coagulating agents used in present conditions are still to

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a great degree iron and aluminium salts, in the conditions of the Czech Republic but also elsewhere in the world, most of all aluminium sulphate [1], iron(III) sulphate, iron(III) chloride and polyaluminium chloride. The coagulation process is part of conventional water treatment and is traditionally used to improve the removal of colloidal and finely suspended particles. Other pollution can also be removed under specific conditions [2].

The coagulation process is traditionally used to remove solid colloidal type of components from treated water. Coagulants make some soluble components (such as natural organic matter, hydrophobic synthetic organic components) insoluble and during coagulation produced by metal hydroxides due to the addition of iron or aluminium salts can absorb other pollutants [3].

In some cases, in some areas, it is necessary to use treatment processes resulting in the effective removal of specific substances. We often face a requirement for the elimination of metals [4] such as arsenic [5], nickel, chromium, radioactive substances such as uranium or other substances such as phosphorus. Various pollutants occur in waters in different aggregation, valence and in different forms (organic vs. inorganic, soluble vs. insoluble, etc.). These substances should be removed from water due to their toxicity, radioactivity [17], or due to their effect on the nutrient cycle in waters [2].

The Enhanced Surface Water Treatment Rule [6] requires water treatment tools to increase the removal amount of natural organic matter from the water. One of the possible approaches is to "increase" the performance of existing coagulation processes by increasing coagulant doses, change of the type of coagulant or reduction of pH coagulation. Some new U.S. EPA rules requiring change in water treatment can actually speed up degradation of the infrastructure. Concerns are also growing that these changes in treatment could cause the degradation of elements of the infrastructure facilities of water supply systems. A survey of the impacts of enhanced coagulation on 275 water treatment facilities in the United States showed that in 24% of facilities some form of infrastructure degradation has been observed [7].

Hence, it is considered necessary to devote attention to increase the separating efficiency of treatment processes by using new agents. The described research focused on determining the efficiency of the removal of chromium and phosphorus from water during its treatment using processes with unconventional agents – water glass and nanoiron. Experiments using water glass are described in the following text.

The main goal of this research was to found the curve of effectiveness of removal of selected pollutants from water – chromium and phosphorus. Chromium occurs very rarely in natural water, rather originating from anthropogenic activities such as some industrial plants or wastewater treatment plants [2]. In addition, phosphorus in natural waters comes from anthropogenic activity [2,11], such as application of agricultural fertilizers and others. As innovative reagents, the water glass and nanoiron were used to remove these pollutants.

### 1.1. Water glass

Soluble silicates are the main group of synthetic chemicals. Only commodity acids and alkalis exceed them in the volume of production. They are known as water glass and represent a group of highly universal compounds. Given their many suitable properties they are used in many varied applications and in industry. Silicon from water glass transforms quickly into biologically active orthosilicic acid (soluble silicate). Important areas of application are household detergents, production of cellulose and paper, stabilisation of soil and various industrial sectors. It is estimated that about 88,000–121,000 tons of $SiO_2$ is produced annually. This amount represents only a small fraction (<2%) of the expected total amount of soluble silicates transported by rivers into oceans. It is for this reason that significant negative effects are not expected on water ecosystems [8].

Water glass is a colourless, transparent, vitreous substance commercially available in the form of powder or as a transparent, viscous aqueous solution. In terms of chemistry this concerns sodium silicate, potassium silicate or a combination of both. The raw materials for the production of silicates are quartz sand (or other sources rich in silicon dioxide), alkali carbonates such as sodium carbonate ($Na_2CO_3$) or potassium carbonate ($K_2CO_3$) and alkali metal hydroxides (NaOH, KOH, LiOH, etc.). The greatest part of the produced volume representing approximately 90% of the total production of soluble silicates is contained as sodium silicate in the form of granules, aqueous solution, hydrothermal liquid, powder or crystals. The soluble (alkali) silicates are produced as sodium, potassium, lithium or in various combinations. This is a combination of silicon dioxide with alkali metals in differing ratio. Soluble silicates do not follow a definite stoichiometric formula and a specific chemical formula or molecular mass cannot be assigned to them [9].

Released into the environment, pH and concentrations lead to dynamic polymerisation–depolymerisation balance with speciation and various mono-, oligo- and polymeric anions and amorphous silicon dioxide. All soluble silicates are moderately to highly soluble in water and virtually insoluble in organic solvents. This means that lipophilic decomposition is unlikely. As soon as soluble silicates get into the hydrosphere they dilute and quickly depolymerise. Subsequently, these molecules cannot be distinguished from natural soluble silicon dioxide. It is interesting that silicates do not contribute to chemical or biological consumption of oxygen in a water course. Silicates are ever-present in the environment, in foods and drinking water, have been used in various applications for decades. No adverse system effects have ever been reported caused by their application. Acute, subacute and chronic toxicity is very low. Soluble silicates are not carcinogenic, mutagenic and do not produce reproductive toxins [6,9].

### 1.2. Nanoiron

Currently, there are various materials available for removing heavy metals [4] from underground water, including active carbon, carbon nanotubes, bentonite and zero-valent iron [12]. All of these substances are capable of transforming toxic substances into non-toxic and/or absorb toxic substances based on ion exchange, ion coagulation and adsorption. The size of the iron nanoparticles ranges between 0.4 and 1,000 μm; however, the majority of the particles are 50–60 μm. This size is considered an effective adsorbent and an ideal technology for in situ remediation of groundwater [14,16] contaminated with heavy metals. Zero-valence iron was used in North America in groundwater remediation for over a decade and its use greatly reduced the amount of chlorinated organic compounds. The use of elementary iron as a reduction medium is now coming to the forefront of interest due to its low cost of operation and maintenance. Additionally, it is easy to obtain and has both good efficiency and the ability to degrade impurities [13,17,19].

The use of nanoparticles of zero-valent iron for in situ reduction of contaminants is an example of reductive abiotic remediation methods. The use of nanoiron is a remediation method useful for a wide range of contaminants [15,19], from simple cations and anions to complex organic halogenated compounds. In terms of inorganic matters, heavy metals are of particular interest, including chromium, arsenic and uranium. Another group includes reducible anions, such as phosphates, nitrates and sulphates. The widest use of nanoiron is currently found in chlorine removal of organic compounds, particularly chlorinated ethenes, as well as polychlorinated biphenyls and other halogenated compounds [16].

The preparation of nanoparticles of zero-valent iron is usually performed using one of two methods. The first is a heat treatment, using a mixture of iron oxide with carbon or quicklime powder. The second method is a reduction of melted iron using reduction transformations of the melted metal into zero-valent iron, thanks to the process of chemical reduction. The characteristic feature of material, thus produced, is its ability to remove pollution from groundwater.

### *1.3. Degradation of polluting substances*

The uses of zero-valent iron for cleaning waste water were studied [14] in greater depth than its use in the case of drinking water. However, the exact mechanism of how iron degrades these contaminants is not entirely understood. Upon reaction, a molecule of reacting iron may achieve a solid surface and subsequently connect in a location that may either be reactive or non-reactive. There may also be a competition between the dissolved substance of the reactant and certain other dissolved matter in the available space. Reactive sides refer to bonds disrupted by the molecules of the dissolved reactant (meaning a chemical reaction), while non-reactive sides are those with only sorption interaction, where the molecule of the dissolved substance remains untouched.

The zero-valent iron Fe(0) was studied in detail in regard to removing heavy metals such as chromium and arsenic. These degradation mechanisms are based on the transformation of a toxic form into non-toxic, or on the adsorption on the surface of iron depending upon the type of heavy metal. The removal of chromium is based on the transformation of six-valent chromium Cr(VI), which is a strong oxidant and potential carcinogen, into a three-valent chromium Cr(III), which is less dangerous, less soluble in water and bonds with solid materials. The reduction of Cr(VI) using Fe(0) produces iron ion Fe(III) and chromium ion Cr(III). Chromium Cr(III) and can be removed using coagulation or with the use of hydroxide in mixed condition into Fe(III) and Cr(III).

The removal of arsenic with zero-valent iron does not include reduction of the metal form, it only regards surface complexes. First, iron hydroxide (active phase) must be formed on the surface of the particles in order for arsenic to be bonded to this material under oxidation conditions. The effectiveness of the removal depends upon the surface or type of iron used and improves over time, perhaps due to a large sorption surface resulting from the corrosion of the iron and adsorption or coagulation of the iron oxide. As(III) and As(V) may therefore be removed from a water solution using Fe(0) [13,15,16,19].

## 2. Methodology

The procedure known as the jar optimisation test was selected when carrying out laboratory experiments simulating the removal of selected pollution for the purpose of testing the efficiency of the given process.

### *2.1. Jar test*

Using the jar test [10,11] carried out in laboratory conditions, the course was modelled of the process of the removal of chromium and phosphorus using water glass as the main agent. The model jar test usually serves to optimise the operating parameters of the operated treatment plants, to check and evaluate the operation of treatment plants and to optimise the proposed parameters of newly built treatment plants. In the case of the carried out research, there were optimal conditions of the removal of the described pollution.

By using the jar test, it is possible to optimise the multi-parameter treatment process, such as the amount and type of agent for destabilisation, amount and type of agent for pre-preparation, intensity and time of slow mixing, amount and type of auxiliary aggregate agents, and also the agent's opening point.

During the described research only a dose of the agent was optimised, in this case water glass and nanoiron. The mixing conditions are based on previous experiments with aluminium sulphate as a reagent for turbidity removal. No other auxiliary agent for pre-preparation was used.

The procedure of the jar test can be selected in full or to a limited extent depending on the purpose of the test. In order to carry out the jar test in full extent, the procedure is as follows:

- Optimisation of the dose of destabilising agent or agent for pre-preparation during selected mixing conditions.
- Optimisation of the quick mixing conditions follows after the determination of the optimal dose according to the previous point.
- Optimisation of slow mixing conditions.
- Re-optimisation of the destabilisation conditions at determined quick and slow mixing according to points 2 and 3.

If it is considered using auxiliary aggregate agents, optimise at the optimal dose according to point 4 and the given conditions of quick and slow mixing, conditions of the application of auxiliary aggregate agents, that is, amount and opening.

During the research, a jar test was carried out using two agents – water glass and nanoiron. Previously, the full optimized experiments with the aluminium sulphate were done, while the knowledge of the optimal conditions using this agent was applied in the laboratory experiments with water glass and nanoiron. A jar test was carried out to a limited extent for both sets of experiments (water glass and nanoiron), that is, the dose of agent was only optimised, and other parameters were set from previous tests with aluminium sulphate.

During the jar test, a pre-selected amount of agent was dosed to the same volumes of model raw water. A set of six identical samples of 1 L of model raw water was always used in the experiments. Furthermore, such conditions of the model process were set to create a separable suspension. Here we mean setting the optimal values of the intensity and mixing time and the subsequent sedimentation time from previous experiments with aluminium sulphate. The mixing conditions were set as follows: quick mixing for two minutes at a blade rotation rate of 150 rpm and then slow mixing for 20 min at a blade rotation rate of 40 rpm. The sedimentation time after mixing was always selected as lasting for 60 min.

### 2.2. Raw water

Model raw water was used during the research experiments. This was prepared from water taken from a surface source and reference solutions containing known concentrations of selected pollutants. As raw water, the water taken from the Brno water reservoir was used for the research tasks. The obtained water was continuously slowly mixed until the water was used for the experiments.

Afterwards, this water was enriched with the specific concentration of the pollutants mentioned. For every pollutant, model water was prepared separately. The chromium concentration was dosed into the model water so that its value would be approximately double the limit set by legislation for drinking water which is 50 μg/L in the Czech Republic [2,4,10]. In the case of phosphorus, no limit value has been set in the relevant decree. Therefore, the applied value was taken from updated note to the decree. This note sets the value at 1–2 mg/L.

Finally, the trivalent chromium concentration value was set at 0.0994 mg/L and the phosphorus (meaning total) was set at 1.98 mg/L by the use of standard solution (see below). Both the concentrations of chromium and phosphorus were verified by the spectrophotometer analysis. The value of pH was kept at 7.5. Turbidity in the raw water varied between 4.3 and 5.8 NTU and average temperature of water during the research was about 20°C.

The entire procedure of laboratory experiments can be summed up in the following several steps:

- Homogenization of raw water
- Preparing of samples of raw water
- Dosing of agents
- Quick mixing
- Slow mixing
- Sedimentation
- Analyses of turbidity and concentrations

The experiments were always carried out separately for turbidity and individual monitored pollutants, while each experiment was repeated at least three times. The results presented below are average values from repeated measurements.

### 2.3. Tools and equipment

During the laboratory experiments, standard equipment was used for the jar test, specifically a multi-digit mixing column with regulation of paddle mixer rotations, a 1,250 mL reactive cylindrical vessel, sampling pipettes, turbidimeter, etc.

In the laboratory experiments, chemicals were used as agents for treatment processes such as water glass (density 1,420 kg/m$^3$, $Na_2O$ 10.24%, $SiO_2$ 29.50%), nanoiron (Nanofer 25) and aluminium sulphate as well agents for pH treatment (calcium hydroxide, sulphuric acid).

For the simulation of water pollution, standard chromium trivalent and phosphorus (as $PO_4^{3-}$) solutions were used. Concentration of chromium solution was 50 mg/L and phosphorus 1,000 mg/L. The process of removing chromium and phosphorus from the water was simulated under laboratory conditions using standard equipment – mixing columns.

## 3. Results

### 3.1. Water glass

The main attention is focused on the results of the research experiments using water glass as the main agent for the removal of chromium and phosphorus from the water. Trivalent chromium, as a representative heavy metal, was selected as the monitored pollution and total phosphorus as a representative nutrient. The level of turbidity removal was also monitored and the results were compared with a conventional coagulant.

Seventeen different doses of sodium water glass were tested to obtain the necessary amount of data. The doses ranged from 42.6 to 710 mg of water glass to 1 L of prepared model water. The model water was always homogenised for about 2 min before the start of the tests. Once the experiments, whose methodology was described below, were carried out, the results were recorded, that is, the residual concentration of pollutants and turbidity at the stated doses of water glass as shown in Figs. 1 and 2.

The residual values of the monitored concentrations of pollutants in the water samples were compared with the initial concentrations and converted to the efficiency expressed in percentages (Table 1). Figs. 3–5 show the efficiency of removal depending on the water glass dose in the case of turbidity and for chromium and phosphorus.

### 3.2. Nanoiron

The goals of this work were similar to the case of sodium silicate, that is, to establish efficiency curves for the removal of three-valent chromium and phosphorus from model water. Sludge measurement was again used as a supportive criterion. Given the high initial values of turbidity, the aim was also to establish the curve of turbidity decrease over time at the given dosage of nanoiron. The last partial goal of the laboratory experiments was to identify whether turbidity caused by the dosages of nanoiron could be removed by adding aluminium sulphate to the reaction vessel after the reaction of nanoiron with the pollutants.

Tests using six different dosages of the Nanofer 25 product were carried out in the first part of these laboratory experiments with nanoiron. Dosages were selected within the

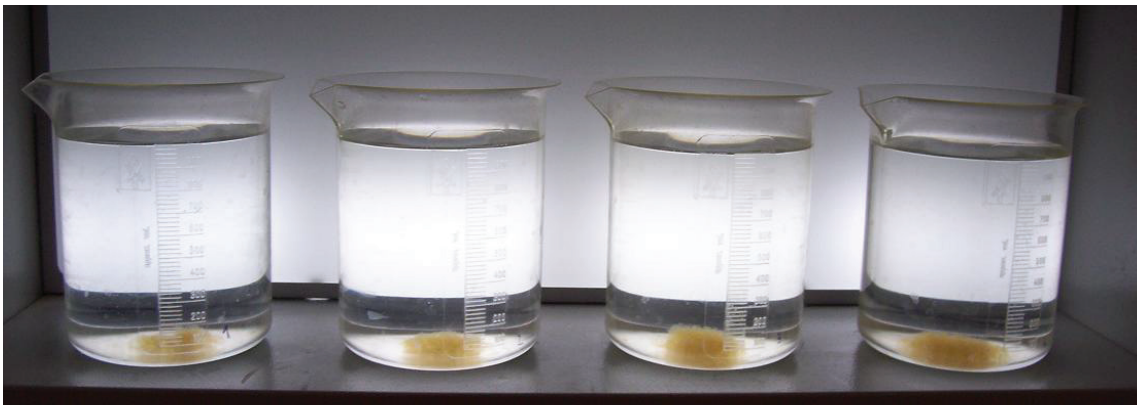

Fig. 1. Sedimentation when dosing water glass, doses from the left 326 to 433 mg per 1 L of model water.

Fig. 2. Creation of flocs after the dosing of water glass, slow mixing stage.

Table 1
Results of the experiments depending on the water glass dose

| Sample | Dose Water glass (mg) | Turbidity NTU | Concentration | |
|---|---|---|---|---|
| | | | Chromium (mg/L) | Phosphorus (mg/L) |
| 1 | 42.6 | 1.84 | 0.0292 | 1.710 |
| 2 | 78.1 | 1.64 | 0.0289 | 1.720 |
| 3 | 113.6 | 1.79 | 0.0338 | 1.730 |
| 4 | 149.1 | 1.76 | 0.0336 | 1.720 |
| 5 | 184.6 | 1.80 | 0.0322 | 1.720 |
| 6 | 220.1 | 1.59 | 0.0262 | 1.650 |
| 7 | 255.6 | 1.73 | 0.0216 | 1.690 |
| 8 | 291.1 | 0.45 | 0.0038 | 1.110 |
| 9 | 326.6 | 0.45 | 0.0025 | 1.030 |
| 10 | 362.1 | 0.36 | 0.0027 | 0.855 |
| 11 | 397.6 | 0.37 | 0.0026 | 0.759 |
| 12 | 433.1 | 0.32 | 0.0024 | 0.677 |
| 13 | 468.6 | 0.33 | 0.0023 | 0.570 |
| 14 | 504.1 | 0.32 | 0.0018 | 0.445 |
| 15 | 539.6 | 0.32 | 0.0018 | 0.112 |
| 16 | 575.1 | 0.32 | 0.0018 | 0.426 |
| 17 | 710.0 | 0.32 | 0.0023 | 0.641 |

range from 0.5 to 5 mg per 1 L of model water, which is based on the required usage range of reactive $Fe^0$ in the values from 0.10 to 1.00 g. A homogenization of content in a plastic barrel took place prior to the experiments. The homogenization was performed by shaking the plastic barrel containing the model water for approximately 2 min.

The curve of turbidity reduction over time at the given nanoiron dosage of 3.0 mg/L was researched in the next phase regarding the possibility of using nanoiron for drinking water treatment. Only the turbidity value was measured over the course of these experiments and the results are shown in Fig. 5. The longest time period during which sedimentation took place was 24 h. By this time, the contents of the reaction vessel were visually clear; however, the measured turbidity value reached 8.28 NTU (Table 2).

## 4. Discussion and conclusions

Tests carried out on the model water, which contained significantly increased concentrations of chromium and phosphorus, about twice as much as permitted by legislative limits for drinking water (valid in the Czech Republic), showed the ability of the water glass to significantly reduce the concentrations of these pollutants in the treated water. Besides chromium and phosphorus, the model water was marked in content with a certain share of natural turbidity and its removal was also monitored during the experiments. To a certain extent, the water glass can be considered an innovative agent used to treat water while applying standard technological procedures, that is, known from the processes of coagulation. During the carried out experiments, it was clearly shown that this agent is marked for its ability to reduce three different types of pollution – turbidity and the concentration of chromium and phosphorus.

A significant value found during the experiments is a water glass dose of 291.1 mg/L of model water. At water glass doses below 284.0 mg, the values of residual concentrations of Cr(III) were in lineal hundredths of milligrams per litre,

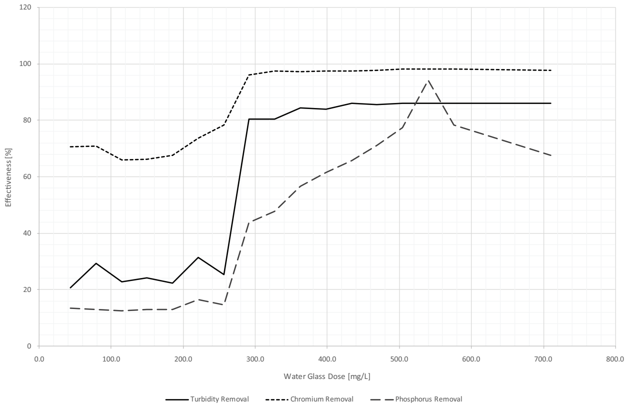

Fig. 3. Dependence of removal effectiveness on a water glass dose.

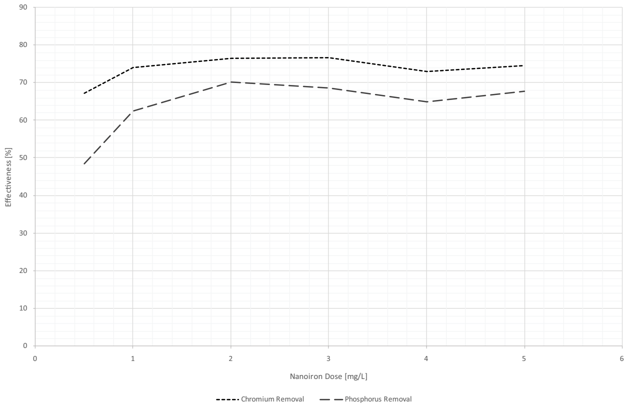

Fig. 4. Dependence of removal effectiveness on a nanoiron dose.

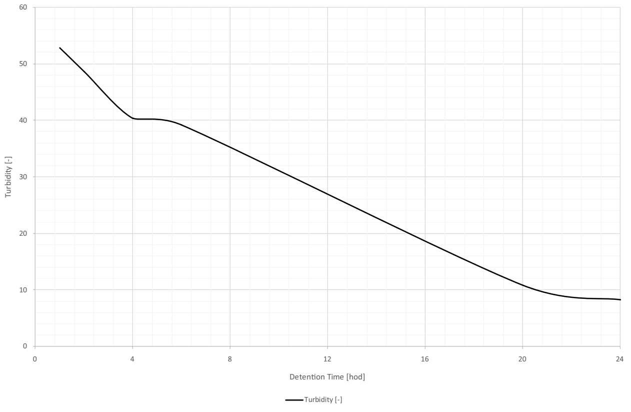

Fig. 5. The development of turbidity over time with dosages of nanoiron.

more precisely from 0.02 to 0.04 mg/L and the values of residual concentrations of phosphorus were about 1.70 mg/L.

At doses above 284.0 mg of water glass, there was a lineal fall of the residual concentration of chromium and of the residual concentration of phosphorus an approximate lineal fall right down to a dose of 504.1 mg of water glass. The next dose of 539.6 mg of water glass lead to the lowest measured residual concentration of phosphorus, at a further increase of the water glass dose the residual concentration of phosphorus increased again linearly.

The residual concentration of trivalent chromium at water glass doses above 284.0 mg/L of the model water was almost constant; therefore, in terms of the removal of chromium from water containing about 0.100 mg/L of chromium the dosage of water glass in concentrations above 355.0 mg/L of treated water is uneconomical.

Pollution is reduced by being trapped in the form of beige coloured flocs with the application of sodium water glass. Individual flocs begin to appear during the slow mixing stage and their number and size are in proportion to the dosed amount of water glass. Before the cut-off, the flocs appear in a low number and are very small, after crossing the cut-off concentration of water glass in the model water their number rises significantly and their size is about 2 mm in diameter. During the sedimentation stage of the laboratory tests, these formed flocs sedimented on the bottom of the used reaction vessel. At the end of the sedimentation stage flocs could be seen settled in heaps at the bottom of the reaction vessel and the model water was clear.

By applying the sodium water glass, it was possible during the laboratory tests to achieve a maximum degree of the removal of turbidity of 86.21%. Using the trivalent chromium, it was possible to achieve a reduction of residual concentration of 98.19%, which is almost complete removal of trivalent chromium from the model water. In the case of the phosphorus, the maximum achieved degree of removal was 94.34% using a dose of 539.6 mg of sodium water glass in 1 L of model water. The achieved results are significantly below the limit values required by valid legislation for drinking water therefore in view of the safety of the used water glass it is possible to recommend the use of this method of removing trivalent chromium and phosphorus from drinking water.

The water glass represents a very good alternative to the already established treatment processes in the removal of chromium and phosphorus. The efficiency of the process obviously and expectedly depends on the dose of agent applied. However, if we look at the course of dependence, it is necessary to notice an altogether different course for individual agents and individual forms of pollution.

A different course of the efficiency curve in the case of the chromium and phosphorus can be noticed in further monitored pollutants in the case of treatment using the water glass. In the case of chromium, the results of removal are better already from the application of a certain dose, while for the phosphorus the optimum, a sort of turning point, can be found but with a further increase of the dose its efficiency falls.

The subject for further discussion and research is the effect of water glass on the subsequent separation processes. Above all it will be interesting to monitor the suspension created by the water glass in a filter bed and its effect on the operating parameters of the filters.

Nanoiron was included in the experiment as one of the possible alternative agents for the specific pollution of raw water in drinking water treatment. In the case of nanoiron, the reduction of pollutant substances took place through bonding these substances to the reactive surface of nanoparticles. Dosages of nanoiron from 0.10 g $Fe^0$ to 1.00 g $Fe^0$ per 1 L of model water were applied.

Table 2
Measured values of nanoiron dosages

| Sample | Dose | | Turbidity NTU | Concentration | |
|---|---|---|---|---|---|
| | Nanoiron (g) | Fe (g) | | Chromium (mg/L) | Phosphorus (mg/L) |
| 1 | 0.50 | 0.10 | 14.7 | 0.0326 | 1.020 |
| 2 | 1.00 | 0.20 | 26.9 | 0.0258 | 0.743 |
| 3 | 2.00 | 0.40 | 34.3 | 0.0233 | 0.591 |
| 4 | 3.00 | 0.60 | 52.8 | 0.0232 | 0.622 |
| 5 | 4.00 | 0.80 | 58.4 | 0.0269 | 0.694 |
| 6 | 5.00 | 1.00 | 60.8 | 0.0253 | 0.638 |

The reaction had an entirely smooth course. Upon completion of the reaction, a compact black sediment formed at the bottom of the reaction vessel, containing reacted nanoiron with bonded three-valent chromium and phosphorus. There were tiny brown droplets of impurities on the walls of the vessel. The sediment volume on the bottom of the 1-L reaction vessel was approximately 25 mL. All dosages achieved reductions in the amount of pollutant substances below the levels required by current legislation in regard to drinking water.

A problem with turbidity caused by the suspended nanoparticles of iron was found during the laboratory experiments focused on the removal of chromium and phosphorus, preventing further use of such treated water for the production of drinking water. This could be considered the main disadvantage of using nanoiron in water treatment. The turbidity value increased linearly along with the dosage of nanoiron.

For this reason, the research was further developed with several additional experiments in which the sedimentation phase was prolonged. Its goal was to establish the necessary time period after which water treated with nanoiron could be further used for the production of drinking water from the perspective of turbidity. In response to the established turbidity value, a series of experiments was performed aiming to answer the question of how long after the dosage of nanoiron the turbidity value decreases sufficiently for thus treated water to be available for further treatment into drinking water.

Turbidity was monitored over the course of sedimentation lasting 1, 2, 4, 6, 20 and 24 h. Over the course of this period, at the dosage of 0.60 g $Fe^0$/L of model water, the initial turbidity of 52.80 NTU decreased to 8.28 NTU after 24 h. Although this experiment proved the decrease of turbidity over time, the measured value is still high for further use for drinking water purposes. For this reason, another series of experiments was launched, identifying the use of liquid aluminium sulphate for the removal of turbidity caused by dosages of nanoiron.

During establishing possible removal of the turbidity caused by dosages of nanoiron using liquid aluminium sulphate, nanoiron was added in an amount corresponding to the dosage of zero-valent iron of 0.60 g/L. The dosage of aluminium sulphate was varied. Results indicate that the measured value of turbidity linearly decreased with increasing dosages of aluminium sulphate. This holds true up to the dosage of 0.500 mL/L of aluminium sulphate, as further turbidity decrease was very gradual and slow. The lowest value of remaining turbidity was measured at the maximum dosage of aluminium sulphate, 3.00 mg/L model water. A decrease of turbidity value took place from 70.80 to 15.00 NTU. The level of reduction of turbidity caused by nanoiron using aluminium sulphate is not sufficient for the further production of drinking water.

These days, nanoparticles of zero-valent iron are quite commonly used for remediation of soil polluted with heavy metals. Additionally, nanoiron is used in the removal of pollutants from industrial waste water, although there is no detailed information available regarding its use for drinking water treatment. Therefore, the goal was to establish the efficiency of removing specific selected pollution from model water and defining the necessary dosages of the agent.

The ability of elementary iron nanoparticles to reduce remnant concentrations of chromium and phosphorus contained in the water was confirmed during the laboratory experiments. The concentration of three-valent chromium was reduced, using this agent, from the value of 0.0939–0.0232 mg/L, representing a reduction by 75.29%. In the case of phosphorus, the maximum measured reduction was 69.85%, which in total numbers meant a decrease from 1.960 to 0.591 mg/L.

The problematic removal of turbidity caused by suspended nanoiron could prove considerable for using nanoiron to treat drinking water and it is apparent that further research is required in regard to establishing suitable subsequent separation processes. However, sufficient reductions of concentration of monitored pollutants were achieved by treating water with nanoiron.

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