Boron removal from the water with chemical precipitation methods

Iwona Skoczko

Department of Technology in Environmental Engineering, Faculty of Civil and Environmental Science,
Bialystok University of Technology, Wiejska 45E, Białystok 15-351, Poland, email: i.skoczko@pb.edu.pl (I. Skoczko)

ABSTRACT

Boron is a common element in the nature. Its concentration in the water depends mainly on the geochemical character of the catchment area and anthropogenic sources (artificial fertilizers, processing and exploitation of minerals, leaching from fly ash, landfills, geothermal water, and industrial wastewater) which are a major threat of water pollution with boron. Moreover it is an element that so far has been random, taking into account its influence on the human body. The maximum dose of boron that can be absorbed without harming the human body is 1.0 mg B per kg of human body weight. Significantly exceeding these values causes harmful side effects. It was the reason to conduct research on boron removal from water with popular methods of water treatment commonly using at urban water treatment stations. There were applied methods of coagulation and chemical precipitation using aluminum sulfate [$AL_2(SO_4)_3$], calcium hydroxide $Ca(OH)_2$ (Low Lime Process and High Lime Process), iron (III) chlorosulfate, and polyaluminum chloride (III). The experiments were carried out using laboratory reactors, where coagulants were added in different doses. As part of tests, analyses of contamination in raw and purified water were carried out and included: pH, color, turbidity, alkalinity, chemical oxygen demand-Mn, Ca, Mg, and boron. On the basis of the conducted research, it was found that effective boron removal is possible with the use of lime precipitation at a high pH range. The other tested methods were less effective.

Keywords: Boron; Coagulation; Precipitation; Water treatment

1. Introduction

Boron is a common element in nature. It is present in all elements of the environment from the atmosphere through the biosphere, hydrosphere to the lithosphere. Boron occurs in the environment mainly in the form of boric acid (H_3BO_3) and borate ions. Natural sources of boron include oceans and seas, volcanic eruptions, rocks, and the earth's crust (boron constitutes 3%–10% of its composition). Boric acid and borate ions are used in the production of borosilicate glass (glass fiber, glass, frits, and enamel), soap and detergents, fire retardants. Boron compounds are found in mild antiseptics, antidepressants, pesticides, and agricultural fertilizers. It is also used in medicine for cancer treatment and cosmetology [1–3].

In the natural water, most often boron occurs in the form of undissociated boric acid in a molecular form. This depends mainly on the pH of water [3]. The influence of pH on the degree of dissociation of boric acid is shown graphically in Fig. 1.

At low pH, boric acid in molecular form does not undergo hydration, and at higher pH, it is transformed into a borate ion. In a neutral environment (pH = 7–8), boric acid in molecular form is the dominant form of boron (99.3% at pH = 7 and 93.2% at pH = 8) [1,4].

In the natural water, boron occurs at a concentration between 0.01 and 5 mg/L. The amount of boron in freshwater depends mainly on the geochemical character of the catchment area, the distance from the sea, and the amount of industrial and municipal wastewater discharged to the receiver. Boron in groundwater is present as a result of leaching of rocks and soils. It enters surface waters as a result of human activity, mainly due to the use of artificial fertilizers
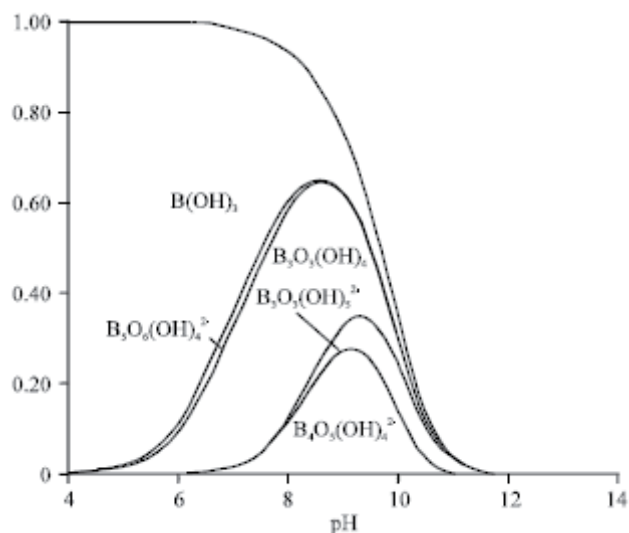
Fig. 1. Changing of borate ions species depending water pH [4].

and plant protection products with an admixture of borate ions, processing, and exploitation of boron-containing minerals, fly ashes, and geothermal waters. In addition, high boron concentration enters the aquatic environment along with leachate from landfills and wastewater from the glass and metallurgical production [4,5].

Boron in sufficient quantities has a beneficial effect on living organisms, including human beings. Boron influences the proper bone structure prevents osteoporosis and arthritis. Moreover, it has a beneficial effect on brain cell activity, calcium and magnesium metabolism, and the immune system [1]. However, its higher concentration may cause toxic effects. The lethal dose of boron for a human is about 17 g, but even at 4 g, there are undesirable effects. Excessive amount of boron disrupts brain function, causing depression and anxiety. It can lead to kidney disease, a reduction in hemoglobin or digestive disorders [3].

In accordance with the Regulation of the Polish Minister of Environment of 21 July 2016 on the method of classification of surface water bodies and environmental quality standards for priority substances, boron limit concentrations depend on the water quality class [2,7,8]. In the case of surface water in classes III, IV, and V, there is no established boron concentration limit. However, in I and II class the concentration of boron cannot exceed 2.0 mg/L B. For groundwater, the limit values are significantly lower. For I class the permissible concentration is 0.5 mg/L and for class V no limit values are set. Wolska and Bryjak [7] report that excessive amounts of boron are removed from commercially used water by electrocoagulation, ion exchange, reverse osmosis (RO), and electrodialysis.

Conventional water treatment processes do not let to remove boron to acceptable concentration, and advanced methods have to be considered to decrease its level in the water. According to literature data (presented in Table 1) cation exchange and pressure membrane methods, that is, RO may enable its permitted amount in water, but such methods are used mostly for industrial water production.

In the literature, no information was found on boron removal using "point of entry" or "point of use" for water treatment system installed in an individual source line ahead of any or all of the building's taps, faucets, or other dedicated outlets used to dispense water for drinking, cooking or bathing, including urban water treatment plants.

Boron is an element that has so far been random, taking into account its influence on the human body. In the available literature, it is difficult to find information on the possibility of boron removal from drinking water using common and popular methods of water treatment. In view of the above, research has been carried out to eliminate excessive amounts of boron from infiltration groundwater prepared for the purpose of drinking water.

Table 1
Literature review on the removal of boron from the water

Process	Concentration (mg/L)	pH	Effect (%)	References
Coagulation	3	5–8	25	[9]
	2	7–8	20–65	Author's own research
Sodium aluminate	1.7	nd	90	[10]
Softening	10	nd	15–25	[9]
Electrocoagulation	2	nd	95	[11]
Metal oxides	0.5–1.2	nd	40–90	[9]
Adsorption	2.5–5	8–9	60	[12]
Ion exchange	2	5–8	90	[13]
Filtration	0.5	5–7	5	[14,15]
Chemical precipitation	2	9	45–60	Author's own research
		11	20–40	
RO	1	5–7	25–50	[16,9]
RO	2.3–4	>9.5	95	[17]
Electrodialysis	1–3	9–10.5	40–80	[18]
RO desalination	5–5.1	>10	43–96	[19,20]

Nd, no data.

2. Methods

Research was carried out as laboratory tests to remove boron from the infiltration groundwater used as raw water. Natural infiltration groundwater containing excessive amounts of boron was used. Water was taken from a deep well-located about 50 m underground. Pollution parameters for raw water are presented in Table 2. For experiments on boron removal, there were applied methods of coagulation and chemical boron precipitation using: aluminum sulfate [$AL_2(SO_4)_3$], calcium hydroxide $Ca(OH)_2$ (Low Lime Process—LLP and High Lime Process–HLP), iron (III) chlorosulfate (IC), and polyaluminum chloride (III; PACl). The mentioned agents were applied as 95% pure reagent-grade chemicals recommended by Nicolai [9] and Dabrowska [22]. The doses of the tested preparations were calculated on the basis of color and turbidity values of raw water using the following Eqs. (1) and (2):

$$D_1 = \alpha\sqrt{B}\,\text{g/L} \tag{1}$$

$$D_2 = \beta\sqrt{M}\,\text{g/L} \tag{2}$$

α, β–conversion factors depending on the type of precipitant, B–watercolor, mg/L; M–water turbidity, NTU.

Among the calculated doses D_1 and D_2 for individual precipitating preparation, the higher value was adopted for the study.

Lime precipitation was applied with $Ca(OH)_2$ solution. It was used in a low dose at pH about 9.5–10 (LLP) and a high dose at pH about 11–12 (HLP). In order to precipitate boron at the required pH, $Ca(OH)_2$ was added to water in doses: LLP = 0.25 g/L, HLP = 2 g/L.

The experiments were carried out with the use of five laboratory glass reactors (separately for every tested coagulant) with a volume of 1 L, filled with the raw water. Tested coagulants were added to reactors in the calculated doses: PACl = 0.5 g/L, $AL_2(SO_4)_3$ = 1 g/L, IC = 0.7 g/L, $Ca(OH)_2$–LLP = 0.5 g/L, HLP = 2 g/L. Used doses were average for turbidity/color calculation according to Eqs. (1) and (2) for every one of the examined experiment series. After the coagulant dosing, rapid mixing with a magnetic stirrer was carried out for 1 min with the rate of 115 s^{-1} and then slow mixing for 40 min with a magnetic stirrer with a rate of 25 s^{-1}. After this time, the samples were sedimented for 30 min and then filtered through a cellulose filter. The investigations were carried out in three cycles, with five repeating series in each cycle. The paper presents the averaged results obtained in each cycle of experiments.

Analyses of contamination of raw and purified water included: pH, color, turbidity, alkalinity, (COD) chemical oxygen demand-Mn, Ca, Mg, and boron. Boron concentration was determined by atomic absorption with flame atomization. There were used dilutions of tested water solution containing boron. Dilution ratio was 1 (part of polluted water):1,000 (part of distilled water). Atomic Absorption Spectrometer Thermo Scientific iCE3500 were used (Thermo Fisher Scientific, Poland). A hollow cathode boron lamp was operated at 20 mA. Measurements were carried out at the main and secondary atomic lines for boron at 249.773 and 249.677 nm lines with a 0.2 nm slit bandwidth. A deuterium lamp was used to correct for background absorption. The obtained results were subjected to statistical analysis. Averaged values for each series, standard deviation (SD) and standard error (SE) were calculated.

3. Results and discussion

The averaged test results obtained for all tested pollution indicators in particular research series are presented in Table 2, while their statistical elaboration is presented in Table 3. Fig. 2 shows averaged boron concentration in water probes before and after coagulation with aluminum

Table 2
The averaged test results obtained for all the tested pollution indicators in particular research series

		I cycle					II cycle					III cycle				
	Raw water	LLP	HLP	$Al_2(SO_4)_3$	PACl	IC	LLP	HLP	$Al_2(SO_4)_3$	PACl	IC	LLP	HLP	$Al_2(SO_4)_3$	PACl	IC
Color (mgPt /L)	20	24	35	45	40	621	8	62	61	35	964	24	35	45	40	520
Turbidity (NTU)	1.7	0.63	3.92	6.85	4.95	7.24	0.35	8.5	4.9	4.20	121	3.45	0.8	6	5.61	1.8
pH	7.85	10.05	11.49	7.7	7.55	7.15	7	7.01	5	7.38	5	8	8	7	7.25	7
COD-Mn (mgO$_2$/L)	7	3.1	0.5	5.5	6.1	4	2	3	6.5	5.8	3	2.5	3	7	5.5	3.5
Boron (mg/L)	2.0	0.884	0.821	0.742	1.599	2.133	0.89	1.626	1.772	1.564	1.868	1.1	1.4	1.63	1.655	2.09
Alkalinity (mgCaCO$_3$/L)	205	350	550	130	150	175	350	600	100	140	150	400	550	120	50	150
Ca (mg CaCO$_3$/L)	124	720	1350	96	88	103	966	1750	104	98	121	864	1545	92	77	83
Mg (mg CaCO$_3$/L)	77	21	10	41	44	48	34	21	45	45	51	25	9	30	32	34

Table 3
Analyzed boron concentration showed in statistical elaboration

Cycle	Raw water	LLP	HLP	$Al_2(SO_4)_3$	IC	PACl
I	2,0	0.884	0.821	0.742	1.999	1.599
II		0.89	1.626	1.772	1.868	1.564
III		1.1	1.4	1.63	1.998	1.665
	Average	0.96	1.28	1.38	1.995	1.742
	Median	0.89	1.4	1.63	1.868	1.765
	Standard deviation	0.12	0.42	0.56	0.073	0.139
	Standard error	0.09	0.31	0.43	0.042	0.08
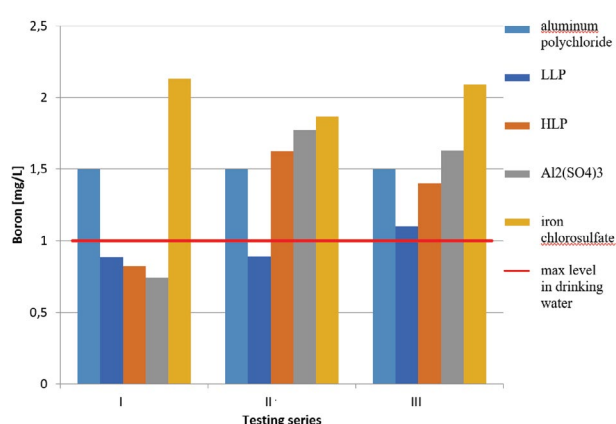
Fig. 2. Boron concentration range in individual series.

Fig. 3. Boron concentration in raw and treated water.
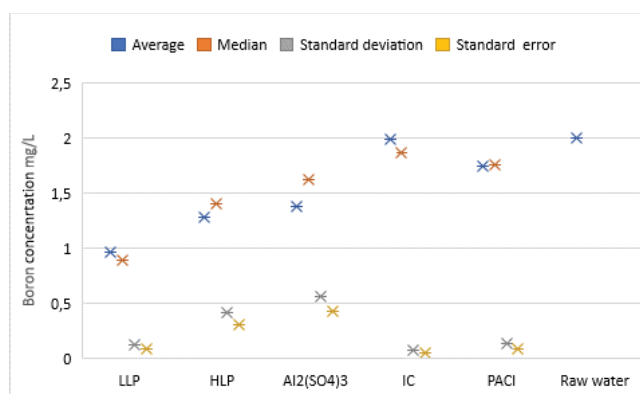
Fig. 4. Statistical evaluation of born concentration.

sulfate $AL_2(SO_4)_3$, iron (III) chlorosulfate IC, PACl (III) as well as before and after precipitation with calcium hydroxide $Ca(OH)_2$—LLP and HLP.

Boron's concentration, as an element which may affect human health, should be reduced in drinking water as well as in the water to be used for irrigation. In accordance with the Drinking Water Directive 98/83/EC and the Regulation of the Polish Minister of Health of 7 December 2017 (Journal of Laws 2017 item 2294), the concentration of boron in drinking water should not exceed 1 mg/L [8,23]. Moreover, due to the potential treat health effect of boron on human beings, the WHO)[24] provided a requirement for the boron concentration in drinking water at less than 0.5 mg/L. This limit value was achieved in the first cycle of tests using $Ca(OH)_2$ for both LLP and HLP. Concentration below 1 mg/L was also obtained thanks to coagulation with $Al_2(SO_4)_3$. The highest concentrations of boron (2.133 mg/L) in water treated by the process of coagulation were observed after coagulation with iron (III) chlorosulfate. IC coagulation caused precipitation of $Fe(OH)_3$ flocs which may adsorb boron. In the presented study, $Fe(OH)_3$ flocs sedimented slowly and were not effectively separated on filtration, what resulted in an increase in boron concentrations in the treated water. On the other hand, the lowest concentration (0.821 mg/L) noticed for LLP and HLP precipitation. Experimental methods included repeated series and cycles of water tests and that is why the part of experiments was also basic statistical terms elaboration including average value, SD and SE (Table 3, Figs. 3 and 4).
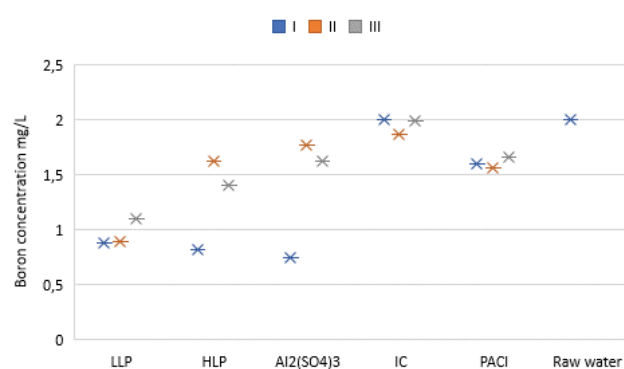
SD explains how far the boron concentration values obtained in the tests are spread around the average. SD of the analysed parameters ranged from 0.073 for IC to 0.56 for PACl coagulation. SE was the SD for average boron concentration reached in tests. It was used to determine how a given value can differ in different measurements of the same phenomenon, that is, to indicate how the sample average estimates the average from each series and each cycle of study. As presented in Table 2, the largest deviation and SE was obtained with aluminum sulfate coagulation and the smallest with IC coagulation. In conducted research SE was used to determine confidence intervals for the average boron concentration. The SE values ranged from 0.042 for PACl to 0.43 for aluminum

sulfate. Both the SD and SE for the samples were negligible what proves the repetitiveness of results and the validation of the research. Yilmaz et al. [11] also investigated born removal from water solution. They compared electrocoagulation and chemical coagulation. Comparison was possible because of the same dose of coagulant for electrocoagulation and chemical coagulation processes. Boron removal was higher with electrocoagulation process. In addition, scientists noticed that chemical coagulation has any effect for boron removal from boron-containing solution. Own investigation does not support Yilmaz's conclusions. It was proven boron may be efficiently removed from water solution with LLP, HLP, and $Al_2(SO_4)_3$ to the required level for drinking water [24]. On the other hand, the boron removal efficiency was lower by lower pH due to competition between H_3O^- ions from hydrolysis and the positively charged ions from $Al(OH)_3$. Such phenomenon also observed Danis and Huang [25]. They proved that in constant condition chemical coagulation at pH 8 and coagulant dose of 0.8 mol let reach 72% removal of boron for 10 mg/L of its initial concentration. It allowed to get <3 mg/L in purified water. It confirms that contaminants removal by precipitation methods is very advantageous for drinking water treatment.

Many authors [21,26–31] prove that chemical coagulation and precipitation processes help to remove from the water organic compounds, color, and turbidity. Such dependence was noticed in own research too. Turbidity was the most effectively rejected parameter, form about 2 NTU in raw water to 0.35 for LLP precipitation. Organic substances, as COD, were also separated from the water using coagulation and precipitation, where the best method was LLP and HLP too. Tested chemical coagulation and precipitation methods may be efficient for its rejection from the water. On the basis of the conducted studies it was observed that the watercolor decreased in the second cycle for HLP and in the third cycle for LLP and HLP. The color significantly increased in treated water coagulated with iron (III) chlorosulfate compared to raw water. The average value of color in the samples ranged from 8 mg Pt /L for LLP to 964 mg Pt /L for IC. Turbidity was another of the studied indicators. Legal regulations state that it should be at the level acceptable to the consumer and recommend its value in drinking water below 1 NTU. Such turbidity value was exceeded after $Al_2(SO_4)_3$ and IC coagulation in each of the studied cycles. Moreover, the turbidity value increased after HLP, IC, and PACl coagulation, whereas after LLP coagulation the turbidity concentration decreased in the first and second research cycles. According to Table 2, the highest turbidity removal effect was obtained for LLP coagulation and the lowest for $Al_2(SO_4)_3$ coagulation. It was also pointed out that the results of the HLP coagulation are significantly uneven and not repeatable. The watercolor acceptable by the consumers was obtained after coagulation with a high dose and a low dose of lime in the third and second cycle of the process. Dąbrowska [22], conducting extensive research on water coagulation with aluminum salts, proved that better effects of reducing pollution parameters can be obtained at neutral and slightly acidic pH. Higher pH did not improve the purification effect. On the other hand, Ramphal and Sybiya [27] conducted targeted experiments with coagulation on color and turbidity removal as well as evaluating the kinetics of these pollution removals at similar pH. They

noticed that the largest floc size and floc growth rate should result in the lowest residual turbidity and color. However, this was not observed as the lowest residual turbidity and color corresponded to the lowest average steady-state ratio and aggregation rate. Other coagulants as polyaluminum ferric chloride, polyferrous sulfate, and polyferric chloride were investigated by Verma et al. [28]. Scientists proved that such coagulants were found to be more effective and suggested for water decolorization. Aluminum and iron polysalts were also tested is presented in this manuscript results. But their mode of action is not completely understood. Such dependence describes Jinming [29]. According to his opinion alternative coagulants, based on pre-hydrolyzed forms of aluminum and iron, are more effective than the traditional additives in many cases, especially with regard to the role of charge neutralization and hydroxide precipitation. The analyzed results in this study are compatible with those of Malakootian and Fatehizadeh [30]. According to their results, the highest removal was related to the highest dose of coagulant and highest pH using lime precipitation. Coro and Laha [31] used the method of lime precipitation for the removal of color from underground water. They observed that increasing pH to above 11 the color of filtered water was reduced to <15 mg/L. While conducting own research, it was pointed out that after the process of coagulation the turbidity was much lower and pH and alkalinity significantly decreased in water. The lowest values of alkalinity (and highest pH) were observed for LLP and HLP coagulation and the highest values of alkalinity (and lowest pH)—for IC coagulation. The average value of alkalinity ranged from 33.36 mg $CaCO_3$/L during LLP coagulation to 141.77 mg $CaCO_3$/L with IC coagulation.

COD is an important parameter of coagulation and chemical precipitation efficiency. It was noticed that after the coagulation process the COD values decreased for most of the used precipitating preparations [except $Al_2(SO_4)_3$ coagulation]. It was observed that the highest COD value was determined for $Al_2(SO_4)_3$ coagulation and it was 7 mg/L, while the lowest—0.5 mg/L for HLP. The average COD value ranged from 2.17 to 6.33 mg/L. For coagulation with HLP, $Al_2(SO_4)_3$, IC, and PACl, COD values changed with the boron concentration. Jonathan et al. [32] observed that there is limited research data relating to the removal of organic contaminants using coagulation. They investigated the potential of new types of precipitants and coagulants and noticed the coagulation-based hybrid processes which can remove trace organic contaminants from water. The data analyzed in their study regarding removal efficiency suggests that, even for the significantly hydrophobic compounds, hydrophobicity is not the sole factor governing the removal of trace organic contaminants by coagulation. Mingquan et al. [33] investigated the mechanism of natural organic matter removal by coagulation is using coagulant Polyaluminum Chloride (PACl), compared with $AlCl_3$. They noticed that after the coagulant dosing, aluminum ion hydrolyzed quite quickly, formed larger polymer and then precipitated. The process based on pH condition. The reached benefit was complex aggregation and settlement. Vaezi et al. [34] optimized coagulation with ferric chloride and checked COD removal. They used coagulants from the same group as the author of this manuscript. Considerable increases in COD removal were observed for

most of the samples. The results indicated that can be developed a modified coagulation process without the need to increase the amount of coagulant.

Mechanism of boron removal includes its separate forms in nature. In the environment, boron is present in the form of boric acid, borate or borosilicate. It accepts hydroxide ion (OH–) from water and releases a proton into the water solution. The concentration of boron can change in the natural waters in a variety of ways [3]. Schubert [35] writes that boron can be adsorbed by soil and sediments. Adsorption–desorption reactions are significant mechanism influencing boron concentration in water. The greatest adsorption is generally observed at pH 7.5–9.0. Faigon and Hefer [6] found out that boric acid and borates exist in the form of $B(OH)_3$ in dilute aqueous solution below pH 7. Above pH 10, the metaborate anion $[B(OH)_4^-]$ becomes the main element in solution. Between 6 and 11 pH and concentrations higher than 0.025 mol/L, water-soluble polyborate ions in forms $B_3O_3(OH)_4^-$, $B_4O_5(OH)_4^-$, and $B_5O_6(OH)_4^-$ are generated. The chemical and toxicological properties of borax pentahydrate ($Na_2B_4O_7 \cdot 5H_2O$), borax ($Na_2B_4O_7 \cdot 10H_2O$), boric acid, and other borate ions are expected to be similar on a molar boron equivalent basis when dissolved in water or biological fluids at the same pH and low concentration [1–7,35]. According to Yan et al. [36] changes in coagulants species and charge of the target compound can result due to variation in pH of the liquid media. It was proved by Zhao et al. [37] as well. Self-aggregations of the aromatic and hydrophobic functional groups can occur under acidic pH, while adsorption onto flocs and subsequent removal through flocculation may occur under alkaline pH. However, certain compounds may show negligible removal by coagulation over a wide range of pH. Pernitsky and Edzwald [38] tested water pH and alkalinity in the coagulation process too. They noticed PACl basicity should be matched to raw water alkalinity so that coagulation pH is as close as possible to the pH of minimum solubility of the coagulant. The solids separation process used for treatment was also found to be important for coagulant selection. Raw waters coagulated with PACl containing sulfate were found to have the best settling characteristics but showed the highest head-loss rates in direct applications [2]. Own study let to explain boron removal efficiency dependence on pH. The reached results show that boron rejection increases with increasing pH and reaches a maximum between pH 8–10 [$AL_2(SO_4)_3$ and LLP process] and decreases with further increase in pH (HLP). The maximum removal occurs at a pH equivalent to the dissociation constant (pKa) of boric acid, ~8.5. At below pH 7.0, $B(OH)_3^0$ predominated and reduction effect is lower (IC, PaCl). As the pH increases, the $B(OH)_4^-$ concentration increases too. The amount of precipitated boron ions in flocs and sediments increased rapidly. Next, an increase of pH resulted in additional OH– concentration relative $B(OH)_4^-$, and boron removal effect decreased rapidly due to the competition of OH– for the adsorption sites [39]. Parks and Edwards [3] also noticed the removal of boron from 1.2 to 0.16 mg/L was accomplished using aluminum sulfate at a dosage of 1,125 mg/L, at a pH of 12. Other pH-dependable process is softening and it may be considered as a process for partial boron removal. It concerns on the precipitation of Ca and Mg salts at alkaline water pH. According to the literature, the calcium concentration can be reduced from that of near saturation calcium sulfate to saturation calcium carbonate. Magnesium is precipitated as a hydroxide. For lime softening, the pH needs to exceed high level (pH > 8.5) to precipitate calcium carbonate. Magnesium precipitation in a form of hydroxide sediments, requires a pH of over 10.2. For lime soda softening, the same criteria should be applied. This method let reach a calcium hardness of <70 mg/L as $CaCO_3$, and magnesium hardness of <70 mg/L as $CaCO_3$ and a substantially reduced alkalinity [35]. Such dependence was observed during own study. Mg concentration decreased significantly from 77 mg/L in the raw water to about 20 mg/L in water after LLP and HLP precipitation. On the other hand, Ca concentration changed from about 77 mg/L to over 700 mg/L for LLP and over than 1,300 mg/L for HLP. However, chemical coagulation with $Al_2(SO_4)_3$ reduced its concentration to about 80 mg/L and with PaCl—to about 100 mg/L. Nonetheless, these reactions were not parallel with boron rejection.

The conducted research and reached results demonstrate that chemical coagulation and precipitation methods might be important methods for the treatment of water containing boron [40]. Presented study is significantly important because boron concentration changes fluently in the environment and even without more stringent legal regulations, its removal from different water sources will be necessary in the near future. Taking into consideration that the world's freshwater sources dwindling, additional attention could be turn to more polluted and saline water as a supply of drinking water, where average boron concentration reaches over 5 mg/L. Such boron concentration may affect human health. Its removal is essential if this water comes to individual domestic systems or is be used for plant irrigation. Likewise, in reuse and recharge applications of freshwater, boron can accumulate to troublesome levels. Presented in the manuscript popular method are used at most urban water treatment plants producing drinking water. The importance of conducted research bold such factors as low operational cost of coagulation and lime precipitation which may be considered as an additional benefit to increase in boron removal.

4. Conclusions

- Boron removal by the method lime precipitation as well as chemical coagulation is very advantageous for drinking water treatment technology. The boron concentration allowed by the legal regulations (below 1 mg/L) was obtained in the first cycle of experiments with LLP, HLP, and $Al_2(SO_4)_3$ coagulation and in the second cycle with LLP.
- The less effective coagulant was iron (III) chlorosulfate (IC). The boron concentration in water after coagulation only slightly decreased in comparison with raw water from 2 to 1.88 mg/L. There were two series when B concentration increased about 10% more than in the raw water. That was caused by $Fe(OH)_3$ flocs in the water which absorbed boron.
- The best results in boron removal were achieved by lime precipitation as LLP. The average efficiency of boron ion removal was between 40% and 60%. Mechanism of boron removal let to achieve better results with pH between 8.5 and 10, which was ensured for experiments with LLP.

- Chemical coagulation with $Al_2(SO_4)_3$ let to remove boron forms from the water in over 50% in the first research series from 2 mg/L in the raw water to 0.7 mg/L In the following cycles the concentration of boron in the treated water increased to about 1.6 and 1.7 mg/L and the effect of boron removal was lower.
- On the basis of the conducted research it was found conventional water treatment processes (coagulation, precipitation, sedimentation, and filtration) do not remove boron to an appreciable extent, and possible special methods have to be employed to remove it to concentrations lower than WHO recommendations of 0.5 mg/L.

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