Romanian Journal of Ecology & Environmental Chemistry, 3(2), 2021
https://doi.org/10.21698/rjeec.2021.214

Options to improve the coagulation process operation in a drinking water treatment plant. Case study

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Received:	Accepted:	Published:
28.09.2021	10.12.2021	17.12.2021

Abstract
Aluminum salts are widely used across Romania in surface water treatment as coagulants. It is well-known that the efficiency of these coagulants has a complex dependency on the nature of the raw water, being affected by temperature, pH and suspended solids. The objective of this case study was to compare the coagulation - flocculation efficiency process of raw water from the Bega River, at low temperature and turbidity, taking into account the use of alternative coagulating agents such as alum, poly aluminum chloride (PAC) and their mixing in 1:1 ratio. The raw water samples were treated using "Jar test" procedure, comparable with the current plant conditions at Timisoara Waterworks and taking into account possible operational improvements. For the mixture method applied in which was combined alum and PAC in 1:1 mixing ratio were achieved lower concentrations in aluminum residual, TOC and turbidity.

Keywords: *coagulation, drinking water treatment, alum, polyaluminum chloride solution, alternative coagulants*

INTRODUCTION

The drinking water treatment plant has to comply and operate in accordance with international water quality guidelines and national standards. It is necessary to continuously monitor both the quality of the raw water and the water produced by the drinking water treatment plant, in order to guarantee a high quality of drinking water. In addition, raw water quality is subject to changes, with seasonal effects (temperature, turbidity) or long-term trends (salt content).

An alternative to improve the treatment technology of surface water for drinking purpose is to increase the efficiency of coagulation - flocculation process.

A wide variety of aluminium salts exist for use as coagulants in coagulation - flocculation processes in surface water treatment, in order to reduce organic matter, colour, turbidity and microorganism levels and to remove the suspended solids from raw water [1]. It is well known that the efficiency of these coagulants depends on the nature of the raw water. The temperature, the pH and especially the specific proportions of organic, inorganic and biological particles that constitute the suspended solids affect the coagulation-flocculation process performance. In addition, to improve process performance and efficiency, various combinations of coagulants have been studied and can be applied, but the performance of the coagulation-flocculation process again depends on the quality of the raw water. [2]. Practically, no systematic and rigorous criteria can be applied for all drinking water treatment facilities. In fact the coagulant selection must be addressed by each plant according to its own operation conditions [3].

Aluminium sulphate (alum) is the most popular mention coagulant used in water treatment. As part of advanced technologies, today some water companies tend to use alternative coagulants, based on

pre-hydrolysed forms of aluminium, more effective than the traditional coagulants, as alum in many cases [4].
The cost of these coagulants in general varies, but the complex forms of poly aluminium chloride solution (PAC) usually cost much higher as alum [5]. In order to reduce the cost, operators often use alum in cases when raw water is easily treatable.
The temperature of surface water can be lower than 5 ºC for about 2 months in winter and the engineers and technicians are concerned about the low coagulation efficiency in a cold environment. In this functional context, the complex forms, like PAC, most used in winter, when the raw water is cold and difficult to treat, the chemical reactions being slower, give a very good solution. [6].
In the last few decades the literature reported advances in analytical approach, measuring technology and these have made it possible for researchers to understand many aspects regarding the performance of the coagulation process [7]. On the other hand, were established a health-based guideline for the presence of aluminium in drinking water. Therefore, water treatment plants using aluminium- based coagulants should optimize their operations to reduce residual aluminium levels in treated water as a precautionary measure [8-10]. The optimized use of PAC and other enhanced coagulants normally maximize pathogen removals, minimize residual aluminium and produce low turbidity and sludge content in the clarified water, than alum does.
The objective of this case study was to compare the coagulation-flocculation process efficiency of water from Bega River at low temperature (1-4 °C) and turbidity (3-10 NTU). In the study were taked into account the aluminium sulphate (widely used), the poly aluminium chloride solution (PAC) - a complex, dynamic mixture of positively charged poly-nuclear aluminium species (which is provisory used) and combination of them in 1:1 mixing ratio. So, in this case study, according to the literature, different coagulants available were evaluated to be use in water treatment, in order to demonstrate that the process operation of drinking water treatment facilities can be improved through alternating coagulants usage.

EXPERIMENTAL PART

Raw water

The raw water samples was collected from Bega River, the water source which supply the Bega Treatment Plant in Timisoara, Romania.

Jar tests

Coagulation and flocculation optimisation are generally considered at the laboratory scale, using a Jar test apparatus and procedure. This well-established process optimisation technique allows a rapid assessment of key variables (e.g. coagulant dose, pH, mixing speed and flocculation time). Jar tests experiments were performed using Jar test equipment manufactured by Velp Scientifica (Model FC6S, Italy), characterized by an electronic speed control with an independent speed settable for each place (six posts), aimed to optimise the result of settling reducing chemical consumption [11]. The selected applied procedures for experimental series consisted to rapidly mix the solution for 2 min at a velocity gradient (G1) of 86.05 s^{-1} (150 rpm) and then slowly mix the solution at G2= 12.7 s^{-1} (45 rpm) for 15 min, and settling for 30 min (which compares to current plant conditions at the Timisoara Waterworks). Coagulants dosage was measured by a calibrated pipette (Multipette stream Electronic hand dispenser, Eppendorf, Germany), coagulant (Al) dosage was expressed in milligrams per liter as Al in this study. Tests were carried out on 0.8 L water samples at outdoor temperature (5±1 °C). Treated water samples were taken after settling for later analysis; all experiments were repeated at least three times to assure the reproducibility of experimental results [11,12].

Analytical methods

For 30 min after settling, supernatants were collected to measure residual turbidity using a turbidimeter (model Hach 2100N, USA). Total organic carbon (TOC) was determined using a TOC

Analyzer (model TOC-V CPH, Shimadzu, Germany). The UV_{254} and colour were measured by a spectrophotometer (model Pharo 300, Merck, Germany). Dissolved Al concentrations were measured after sample filtration through 0.45 µm membrane, respectively, using Spectroquant kits for Aluminium test (Merck, Germany). The pH and conductivity were determined on a laboratory multi-parameter analyser (model Consort C863, Consort, Belgium) [11,12].
Scanning electron microscope (SEM) coupled with a X-ray energy-dispersion detector (EDAX) was performed with a instrument type Inspect S (Fei Company, Netherlands). Finally, after settling of samples, a drop of each sample was disposited on a metal substrate and left overnight to dry. The apparatus works in a low vacuum, at an acceleration voltages of 25 kV.

Description of commercial PAC product
The utilised PAC coagulant was a commercial product provided as liquid polyaluminum chloride, an aqueous solution of PAC with the general formula $Al_n(OH)_mCl_{3n-m}$, a product fulfilling the requirements of ONorm EN 883 (chemicals used for treatment of water aimed to human consumption) type 1 of 2004. PAC solution (colourless to pale yellow, clear to slightly cloudy liquid) is completely soluble in water. Its use requires less alkalinity adjustment than most coagulants because of its basicity [11]. The guaranteed values in the product specification are show in the Table 1.

Table 1. The characteristics of PAC solution

	Content of Al (%)	pH	Density (kg/dm^3, 20°C)	Chloride (%)	Basicity (%)	Dynamic viscosity (mPas, 20°C)
PAC	5.20	2.5	1.23	12.5	65	20

RESULTS AND DISCUSSION

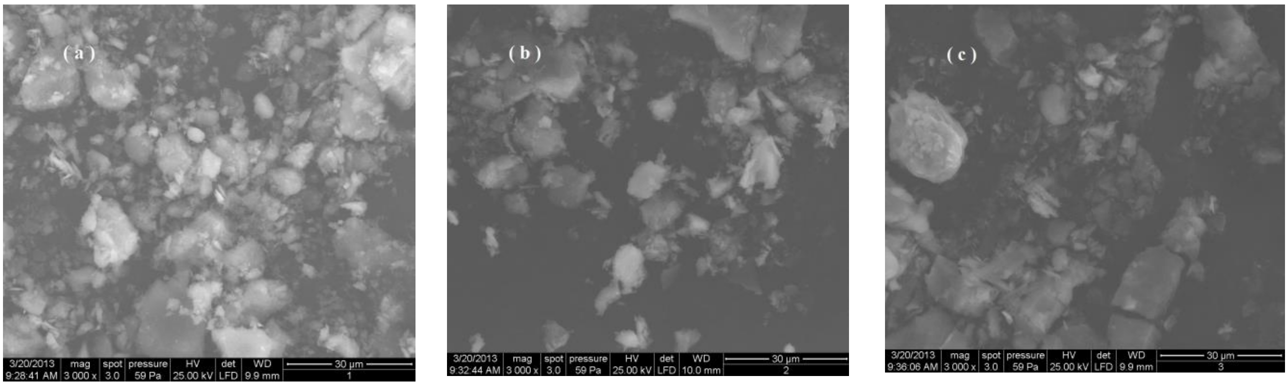
According to the literature, the presence of aluminum residual in drinking water presents possible risks for human health. In this case study was investigated the use of alternative coagulating agents such as alum and PAC, aluminum-based coagulants.
They are already used individually, is also implemented their alternative use in coagulation-flocculation process in Timisoara Waterworks, but require further studies concerning their technical, economic and environmental impacts.
Using poly aluminum chloride as a coagulant of raw water from the Bega River higher operational costs were obtained than using alum; however, it offers a higher satisfaction to the consumer. Significant performance and economic improvements can be achieved by periodically alternating coagulant usage in response to daily (and seasonal) fluctuations.
Their selection (between each other) is dependent on the raw water characteristics (pH, temperature, and alkalinity, organic and inorganic content). Laboratory-scale and pilot tests are required to select the best coagulant to use in any conditions [13].
According to the water treatments standards, to compare the coagulation-flocculation process efficiency when the Bega River water has low temperature (1-4 °C) and turbidity (3-10 NTU), was used the Jar test procedure [12]. Therefore, taking into account the alum (widely used) and the polyaluminium chloride solution (PAC - which is provisory used), the Bega raw water samples were treated with alum, PAC and combining them in 1:1 mixing ratio (alum+PAC) as coagulants. In the selected procedures applied, comparable with the current plant conditions at the Timisoara Waterworks, six water samples were always treated and controlled simultaneously in the apparatus. The dose range of the applied coagulant was the same to that used in alum of Timisoara Waterworks, for all three alternatives compared [11, 14-16].
The controlled water quality parameters, for the raw and the treated water samples, were: turbidity which conceive suspended solids content (the data are expressed in nephelometric turbidity units, i.e. in NTU); UV-absorbency measured al λ=254 nm (expressed as absorbency cm^{-1}) to characterize the concentration changes of organic compounds; total organic carbon (TOC) to emphasize the removal of NOM, expressed as mg C/L; and the dissolved (Al_{diz}) concentrations. The measurements

were accomplished after sample filtration through 0.45µm membrane. Temperature, pH and specific conductivity data of water samples were also checked during the experiments [11].
Water quality parameters of raw water and treated water with alum, PAC and alum+PAC as coagulants, after coagulation/flocculation process and 30-min sedimentation, are presented in Table 2 (representative data, selected from a set of experiments).

Table 2. Water quality parameters of raw water and treated water with different coagulants

Parameter (unit)	Raw water	Alum	PAC	Alum + PAC
Turbidity (NTU)	5.12	2.89	1.70	2.0
Dosage (mg Al/L)	-	1.42	0.85	1.42
pH	7.85	7.33	7.68	7.51
Temperature (°C)	3.6	3.6	3.6	3.6
Total organic carbon (mg C/L)	3.43	2.86	2.58	2.68
Conductivity (µS/cm)	187.3	193.1	191.9	202
UV_{254} (cm^{-1})	0.026	0.024	0.016	0.022
Residual Aluminium (mg/L)	-	0.18	0.11	0.16
Colour (HU)	11.4	4.7	4.6	4.4

By combining alum and PAC most of the parameters for the treated water improved, but with a small increase in residual aluminium compared to the other two coagulants used, which can be attributed to the alum in the mixture. The pH of the treated water when alum was combined with PAC was reduced more than for PAC alone, but not that much as for alum. In respect to colour, PAC did not reduce this parameter as much as alum and the combination of alum + PAC did.



a) b) c)

Fig. 1. SEM images of flocs obtained with different coagulants: (a) alum, (b) PAC, (c) alum + PAC

Figure 1 shows SEM images of the flocs formed with each coagulant. In case of the water which was treated with alum the flocs where present in a greater number but smaller in dimension which probably made them lighter and increased there floating ability.
Compared to alum, the flocs for PAC and the combination of PAC with alum are bigger and heavier and will settle much faster and easier in the settling step.
Combining alum and PAC did show potential for treating water with low turbidity and temperature which would prove useful in winter when alum alone would not be able to reduce the turbidity sufficiently.
Also using PAC alone is more costly than using it mixed with alum which makes this method also very attractive from an economical point of view.
The PACs exhibit a superior coagulation performance compared with the conventional nonpolymerized coagulants [17]. Their advantages are attributed to: (a) high concentration of polymeric species, (b) wider working pH range, (c) lower sensitivity to low water temperature, (d)

lower dose requirements for achieving equivalent performance with the conventional coagulants, (e) lower residual metal-ion concentration, and (f) lower sludge production [5, 7, 8, 17-19].
In particular, in other studies were reported that pre-polymerized coagulants PAC have a superior efficiency in the removal of NOM, turbidity and colour, as well as of algal-derived organic matter, than the conventional coagulants [11, 14, 20-22].

CONCLUSIONS

The conclusions are established fact on the results of this case study with respect to operational improvements. In addition, a perspective is done on future work for the implementation in drinking water treatment plant.
In summary:

- ✓ A comparative investigation of the Bega water treatment efficiencies using several coagulants (a PAC commercial product, classical alum and combinations of them) was carried out.
- ✓ 2. Using polyaluminium chloride as a coagulant in drinking water treatment offer a higher satisfaction to the consumers than using alum, despite the higher operating costs involved.
- ✓ 3. By simultaneously treating of the surface raw water with alum and PAC, an effective coagulant is practically formed, which can be applied in drinking water treatment.
- ✓ 4. For the mixture method applied in which was combined alum and PAC were achieved lower concentrations in aluminium residual, TOC and turbidity.

Future studies on the Pilot Plant are needed to check and correct this obtained results, in order to set up the necessary mathematical models to be implemented in the SCADA programme used today in the Bega drinking water treatment plant.

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Citation: Pacala, A., Samonid, M.L., Murariu, B., Options to improve the coagulation process operation in a drinking water treatment plant. Case study, *Rom. J. Ecol. Environ. Chem*., **2021**, 3, no.2, pp. 114-119.