Vietnam Journal of Science and Technology ***63*** *(2) (2025) 364-377*

doi.10.15625/2525-2518/18701

Composite reagents for water treatment based on natural alginates

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Received 25 August 2023; Accepted for publication 5 March 2025

Abstract. Compositions of composite reagents for water treatment based on inorganic coagulants and sodium alginate used as a flocculant have been developed. The dissolution time of coagulants based on aluminum compounds was established to be equal 0.2 - 0.4 min, the dissolution time of sodium alginate milled and fractionated on 0.25 mm sieves was determined to be 2.0 min. By controlling the dispersion degree of the composite reagent components, a consecutive release of the coagulant and flocculant (sodium alginate) into the treated water has been achieved. The process of mixing the reagents was shown to not affect the dispersion degree of the components and didn't prevent their consecutive release. An increase in the residual aluminum content was found when using $Al_2(SO_4)_3$ in the presence of sodium alginate. The effect has been eliminated by additional introduction of $CaCl_2$ into the composite reagent. The introduction of sodium alginate into composite reagents has been established to make it possible to increase the sedimentation rate of aggregates obtained by the hydrolysis of $Al_2(OH)_5Cl$ from 3.9×10^{-3} m/s to 17×10^{-3} m/s compared with the use of coagulant alone.

Keywords: water treatment, composite reagents, coagulants, flocculants, sodium alginate, magnetic particles.

Classification numbers: 1.5.2, 3.4.2.

1. INTRODUCTION

Today, flocculants of natural origin and their derivatives are widely used for the manufacture of composite reagents since this type of reagent is characterized by lower toxicity and is environmentally friendly. A number of works described the preparation of composite reagents based on aluminum sulfate (SA), aluminum polychlorides, and chitosan [1 - 4]. Mega *et al*. confirmed that adding chitosan to these reagents makes it possible to achieve the same degree of organic substance removal with a lower dose of coagulant [3]. Adding chitosan with high viscosity (500 mPa·s) to a highly basic polyaluminum chloride led to a decrease in turbidity, dissolved organic carbon content, and in the UV-absorption degree compared with the use of a coagulant alone [1]. The mechanism of chitosan action was shown to be similar to the action of synthetic cationic polyelectrolytes [2]. However, flocculation was observed only in the pH range where chitosan lost solubility and captured dispersed particles during precipitation, i.e., in an alkaline medium.

Shaylinda *et al*. obtained a composite coagulant based on poly iron (III) chloride and tapioca flour as a source of starch [5]. The resulting composition was used for wastewater treatment. As a result of using the developed composite reagent, a 95 % reduction in turbidity, a 94.6 % reduction in color and a 50.4 % reduction in chemical oxygen consumption was achieved. A composite reagent based on polyaluminum chloride, poly iron(III) chloride and a graft copolymer of starch with acrylamide and dimethyldiallylammonium chloride was used to treat model wastewater of the textile industry [6].

Lee *et al*. described the preparation of composite reagents SA – Aloe vera extract (ALAV) and magnesium sulfate – Aloe vera extract (MGAV) [7]. The efficiency of methylene blue dye removing from the model wastewater using the obtained composite reagents was studied. The degree of methylene blue removal with ALAV was shown to be equal 50 - 55 %, with MGAV it was 60 - 70 %.

A composite flocculant for portable water treatment containing poly aluminum - iron(III) chloride (PAFC) and microbial flocculant MBF-B16, obtained using the bacterium *Klebsiella variicola* B16, is described in [8]. Composite flocculant reduces the dose of inorganic coagulant by 56 - 72 %. Trial coagulation on kaolin model dispersions showed a higher turbidity removal efficiency using a composite flocculant in comparison with PAFC.

Sodium alginate is a polysaccharide of natural origin, consisting of D-mannuronic and L-guluronic acids residues (Fig. 1). It is also considered as an environmentally friendly alternative to synthetic flocculants. It is known to be used as a flocculant to remove dyes: rhodamine B, malachite green and methylene blue, etc. [9]. Sodium alginate in combination with aluminum chloride also showed its effectiveness in the deposition of latex dispersions [10]. In the treatment processes of waters containing humic acids, the introduction of sodium alginate in combination with the coagulant polyhyaluminum chloride made it possible to increase the floccules size and strength, as well as to increase the efficiency of humic acids removing in comparison with the use of a single coagulant [11]. However, the literature data does not contain information on the use of sodium alginate in composite reagents for water treatment.

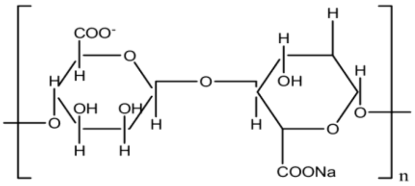


Figure 1. Structural formula of sodium alginate monomer units.

It should be noted that in most cases the use of natural flocculants does not allow achieving the same efficiency as when using synthetic reagents. The combination of traditional coagulants (aluminum sulfate and polyaluminum chloride) and natural reagents (sodium alginate) in the compositions, would reduce their toxicity and make them more environmentally friendly, along with maintaining the high efficiency of the composite reagent.

In this work, new composite reagents for the effective water pollutants removal were developed. The novelty of the proposed reagent lies in the fact that it is a mixture of a coagulant and a flocculant, which is added to contaminated water not in the form of solutions of these reagents, but in powder form. The scientific idea of the study is the simultaneous introduction of a coagulant and a flocculant, which will act sequentially due to different dissolution rates. A rapidly soluble coagulant based on a hydrolyzing aluminum salt forms a sol, the particles of which interact with the pollutants contained in the water and cause coagulation through neutralization or enmeshment mechanisms. The high-molecular flocculant, which has dissolved by this time, intensifies the process of particle enlargement, flocculation, and sedimentation. The composite reagent also contains magnetic nanoparticles Fe_3O_4, which affect the flocculation process and simplify the procedure for removing sediment formed as a result of sedimentation from the treated water. Ferromagnetic nanoparticles are commonly synthesized by co-precipitation of Fe(II) and Fe(III) salts in alkaline medium at a certain ratio. The Fe_3O_4 particles presence in coagulation aggregates will increase their sedimentation rate when an external magnetic field is applied. The advantage of using powder composite reagents is that there is no need to pre-dissolve the coagulant and flocculant and sequentially introduce their solutions into the water being treated.

The purpose of this research was to study the influence of the composition of the reagents based on aluminum-containing coagulants and natural alginates and the size of their particles on the properties of dispersions formed by introducing composite reagents into treated water.

2. EXPERIMENTAL

2.1. Chemicals

Aluminum sulfate (SA) was produced by Sigma-Aldrich, Germany. Polyaluminum chloride was commercial reagent manufactured by Ishimbay Specialized Chemical Plant of Catalysts LLC, Russian Federation. Sodium alginate granules purchased from Shandong Jiejing Group Ltd., China.

The chemical formulas, the Al_2O_3 content and the basicity of the used coagulants are shown in Table 1.

Table 1. Characteristics of the investigated coagulants.

Name of coagulant	Abbreviation	Formula	Active substance content (calculated as Al_2O_3), %	Basicity
Aluminum sulfate	SA	$Al_2(SO_4)_3 \cdot nH_2O$, n = (14 ÷ 18)	17 ± 2	0
Polyaluminum chloride “Brilliant 50”	B50	$Al_2(OH)_5Cl$	48 ± 4	2.5

2.2. Manufacturing of composite reagents

Sodium alginate granules were preliminarily ground in a Retsch ZM 200 ultracentrifugal mill (Retsch GmbH, Germany) equipped with a set of sieves with a mesh size of 0.08 to 1 mm. Then, the obtained samples disperse composition was determined by laser diffraction using a Master Sizer 3000 laser dispersity analyzer (Malvern Panalytical Ltd, UK). In the same way, a disperse composition of a powdered sodium alginate industrially manufactured sample (FoodChem Ltd., China) was determined.

To determine the optimal dispersity degree of the reagents, the obtained samples dissolution time was studied. Master Sizer 3000 laser dispersion analyzer with a Hydro MV wet dispersion unit was used for this purpose. Distilled water was a dispersion medium. To study the dissolution rate, a 100 mg sample of the studied coagulant or sodium alginate was introduced into the tank of the wet dispersion unit. The stirring velocity was 2500 rpm. At the same time, the undissolved particles volume concentration was measured every 30 s for 30 min. To analyze the results obtained, the dependence of the undissolved particles relative volume concentration c_t/c_0 on time t was plotted (c_t is the current volume concentration, c_0 is the initial volume concentration).

On the basis of industrial samples of coagulants SA and B50 and sodium alginate, milled and fractionated on sieves < 0.25 mm, composite reagents for water treatmant were prepared. The ratios of components B50 – sodium alginate were the following 4 : 1, 20 : 1 and 40 : 1, the ratios SA – sodium alginate: 8.8 : 1, 59 : 1 and 117 : 1. The ratios of the components were selected in such a way that the ratio of the coagulant active substance mass (calculated as Al_2O_3) to the sodium alginate mass for different coagulants was the same (the content of the active substance in SA and B50 is different). To prepare composite reagents, powdered coagulants were mixed step-by-step with pre-milled and fractionated sodium alginate samples. Then the disperse composition of the resulting composite reagents was studied using a laser dispersion analyzer Master Sizer 3000 with air dispersion module.

Synthesis of magnetic ultrafine particles. Magnetic ultrafine Fe_3O_4 particles synthesized by co-precipitation method of ferrous and ferric salts using ammonium hydroxide, followed by their stabilization using a mixture of triethanolamine and oleic acid [18]. The particle sizes and the specific surface area of magnetic nanoparticle were analyzed using a laser dispersion analyzer Master Sizer 3000 and the nitrogen adsorption-desorption method on a TriStar II 3020 instrument.

Studying the properties of coagulation aggregates. To study the physicochemical properties of coagulation aggregates, an aqueous solution of aluminum sulfate was used with the addition of 9 mmol/dm^3 of $KHCO_3$ and NaCl at pH 8.2 ± 0.2. A weighed portion of the composite reagent containing 71 mg of the coagulant active substance (calculated as Al_2O_3) was put into solution, and it was stirred for 0.5 min at 500 rpm followed by 1.5 min at 750 rpm. In this case, the hydrolysis of the coagulant proceeded, and the formation of aluminum hydroxide dispersion occurred. The particle size distribution, the external specific surface area, and the volume concentration of the formed aggregates were determined using a Master Sizer 3000 laser dispersion analyzer within 0.2–30 min after the introduction of the coagulant. pH was measured using a Thermo Orion 310 pH meter (Thermo Fisher Scientific Inc., USA). Based on the volume concentration values of the aluminum hydroxide dispersion obtained using a laser dispersion analyzer, the average density of particles ρ_p, formed as a result of the coagulant hydrolysis, was calculated.

For this, formula (1) was used, which was derived using the mathematical expressions given in [12] describing the coagulation aggregates volumetric weight:

$$\rho_p = \rho_w + \frac{m_s}{0{,}01\rho_s C_V V_{syst}}\left(\rho_s - \rho_w\right) \tag{1}$$

where ρ_w is the water density, under the experiment conditions (T = 293 K) ρ_w = 998.23 kg/m^3; m_s is the mass of hydroxide formed during the complete coagulant hydrolysis, the mass was calculated based on the coagulant dose; ρ_s is the aluminum hydroxide density, equal to 2424 kg/m^3 [13]; C_v is the particles volume concentration, vol. %; V_{syst} is the volume of the system under study, equals to 1 dm^3.

The sedimentation rate u was calculated using the formula given in [14]:

$$u = \frac{2g\left(\rho_p - \rho_w\right)\left(\frac{\langle d\rangle}{2}\right)^2}{9\eta} \tag{2}$$

where g = 9.81 m/s^2 is the acceleration of gravity; <d> is the average particle diameter determined using laser diffraction, μm; $\eta = 1.0050\cdot10^{-3}$ Pa · s is the water viscosity.

Residual aluminum was determined by the photometric method using the aluminon as photometric reagent.

3. RESULTS AND DISCUSSION

3.1. Particle size of ferromagnetic nanoparticles

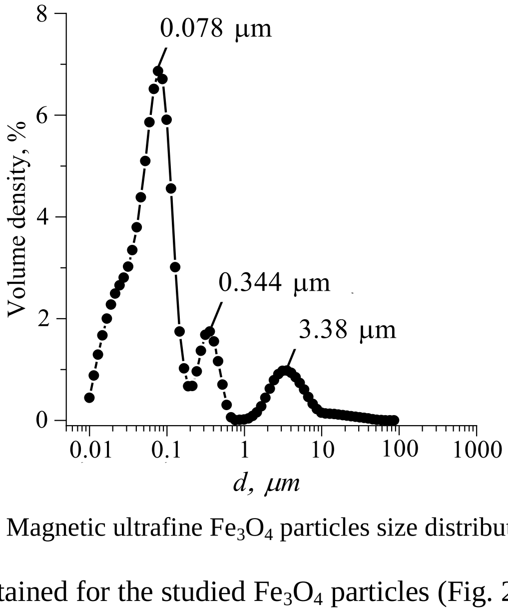
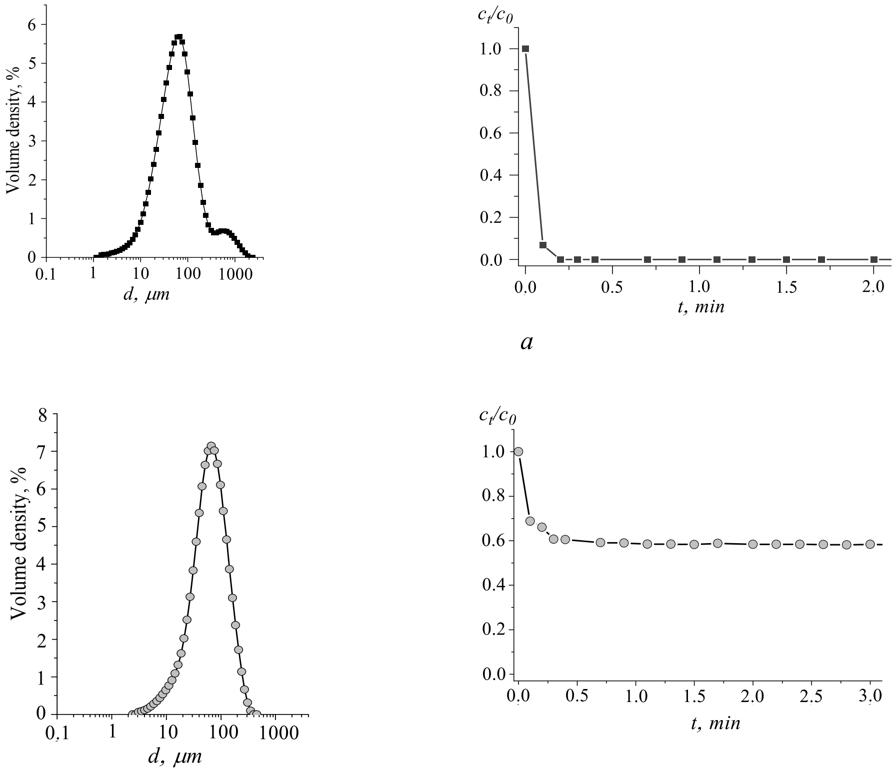


Figure 2. Magnetic ultrafine Fe_3O_4 particles size distribution.

The size distribution obtained for the studied Fe_3O_4 particles (Fig. 2) is characterized by the presence of three maxima for particle diameters of 0.078, 0.344, and 3.38 μm. This fact indicates the presence of the three most characteristic particle sizes, the bulk of the particles falling on particles of a colloidal dispersion degree (less than 1 μm). The average median particle size in this Fe_3O_4 sample is 0.098 ± 0.003 μm, with 10 wt. % particles have a size less than 0.052 ± 0.001 μm, 90 wt. % particles have size less than 3.9 ± 0.6 μm. These data, as well as the high value of the specific external surface area (67000 ± 3000 m^2/kg), indicate a high mass fraction of nanoparticles in the sample. Therefore, the sample can be used as magnetic ultrafine particles for the manufacture of composite reagents for water treatment.

3.2. Study of the dissolution time of components

According to literary sources, the time interval between the introduction of a coagulant and a flocculant should be at least 1 - 4 min [15, 16]. Consequently, the components of the composite reagents must be sequentially released into the treated water, and therefore the components dissolution time is necessary to be determined. The laser diffraction method was used to study the dissolution process of coagulants used for the composite reagents manufacture. During the experiment, the change in the particles volume concentration over time was studied.



a

b

a — SA; *b* — B50

Figure 3. The coagulant particles size distribution and the dependence of the undissolved particles relative volume concentration C_t/C_0 on time t during dissolution process.

Figure 3 illustrates dependences of the relative volume concentration of solid particles c_t/c_0 (which is the ratio of the current volumetric concentration c_t to the initial concentration c_0) on time t, as well as the particles size distribution of various coagulants. The data in Fig. 3 indicate that the process of SA dissolution took approximately 0.2 min, B50 - 0.4 min. The residual relative volume concentration c_t/c_0 of SA particles were reduced to zero. In the case of B50 the relative volume concentration of solid particles during the dissolution time decreased only to 0.6 and then did not change (Fig. 3, c). Thus, the B50 solution was established to contain undissolved particles. The results of a kinetics photometric study with ferron also indicate a high content of colloid aluminum hydroxocomplexes in B50 solution [17].

Sodium alginate granules were subjected to preliminary grinding followed by fractionation on sieves. The particle size distributions are presented in Fig. 4 and in Table 2.

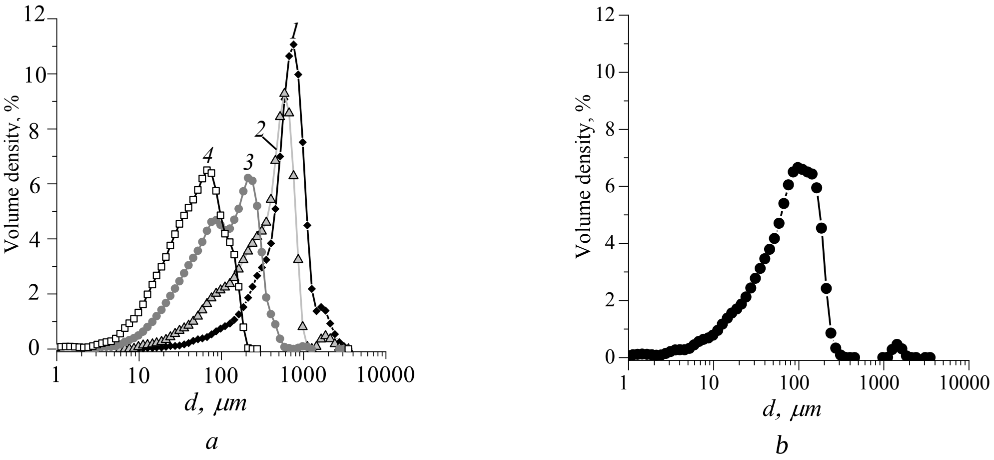


Figure 4. Sodium alginate particle size distribution: *a* – granules milled and fractionated on sieves of : 1 mm (1), 0.75 mm (2), 0.25 mm (3), and 0.08 mm (4); *b* – industrial powder sample.

According to the results obtained, the average sodium alginate particle size decreases from 680 ± 20 to 51.9 ± 0.2 μm with a decrease in the sieve mesh diameter from 1 mm to 0.08 mm. Along with a decrease in particle size, a regular increase in the value of their specific external surface area is observed. The largest particles size (D_v90) does not significantly exceed the size of the sieve cells. The particle size distribution parameters for industrial powdered sodium alginate are close to those of the sample fractionated on sieves with a mesh size of 0.25 mm.

Table 2. Parameters of sodium alginate particle size distributions*.

Sodium alginate samples	D_v10, μm	D_v50, μm	D_v90, μm	S_{ext}, m^2/kg
Milled granules < 1 mm	220 ± 30	680 ± 20	1300 ± 100	10 ± 1
< 0.75 mm	78 ± 7	400 ± 40	790 ± 60	21 ± 2
< 0.25 mm	24 ± 1	94 ± 3	241 ± 5	70 ± 2
< 0.08 mm	13.8 ± 0,3	51.9 ± 0,2	129 ± 2	133 ± 6
industrial powder sample	18 ± 1	83 ± 3	179 ± 3	107 ± 4

*10 % of particles are smaller than D_v10; D_v50 is medium particle size; 90 % of particles are smaller than D_v90; S_{ext} is specific external surface area.

To determine the optimal dispersity degree of sodium alginate, the obtained samples dissolution time was studied. The results obtained are presented in Fig. 5.

Based on the data obtained, the dissolution time was determined. It was determined as the time interval from the sample introduction until the moment when the value of the relative volume concentration c_t/c_0 did not exceed 0.05. The dissolution of coagulant powders has been established to occur in 0.2 - 0.4 min. Under ideal conditions, the difference in the dissolution duration of the coagulant and flocculant should be 1 - 2 min. According to the results obtained, the dissolution of sodium alginate samples fractionated on 1 mm and 0.75 mm sieves (Fig. 5, curves 1 and 2) occurs within 4.3 - 6.1 min. Consequently, the rate of their dissolution is insufficient for use in composite reagents.

The dissolution rate values of samples fractionated on 0.25 and 0.08 mm sieves practically coincide (Fig. 5, curves 3 and 4).

Their dissolution time is the same and equals 2.0 ± 0.2 min. Since it is technically more difficult to carry out grinding to sizes less than 0.08 mm and there is a risk of polymer destruction as a result of an increase in temperature during grinding, it is more advisable to use sodium alginate fractionated on sieves < 0.25 mm for the composite reagent manufacture. Industrial powdered sodium alginate and a sample fractionated on sieves < 0.25 mm have a similar dissolution time (2.8 ± 0.2 min) and the dissolution curve form (Fig. 5b). Therefore, the industrial sample can also be used for the composite reagents manufacture.

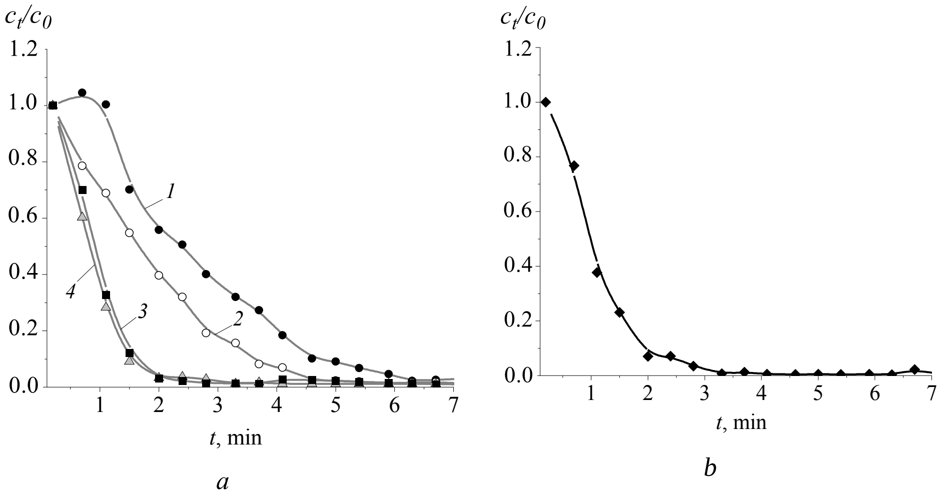


Figure 5. Dependence of the undissolved particles relative volume concentration c_t/c_0 on time t for sodium alginate samples with different dispersion degrees: *a* – granules milled and fractionated on sieves: 1 mm (*1*), 0.75 mm (*2*), 0.25 mm (*3*), 0.08 mm (*4*); *b* – industrial powder sample.

3.3. Influence of the components mixing process on their disperse composition

Table 3 shows the values of the particle size distribution parameters for composite reagents coagulant – flocculant with different components ratios in comparison with the components alone.

The data in Table 4 shows that the distribution parameters of composite reagents based on one coagulant are close, regardless of the content of the flocculant. Consequently, the mixing process does not have a significant effect on the disperse composition of the components, which makes it possible to control their dissolution rate in the process of water treatment.

Table 3. Particle size distribution parameters for composite reagents coagulant – flocculant and their components.

Sample	D_v10, µm	D_v50, µm	D_v90, µm	S_{ext}, m^2/kg
B50	23.2 ± 0.4	67 ± 1	160 ± 3	135 ± 2
Sodium alginate. milled < 0.25 mm	24 ± 1	94 ± 3	241 ± 5	70 ± 2
B50 – alginate 4 : 1	23.6 ± 0.2	68.3 ± 0.4	178 ± 5	131 ± 1
B50 – alginate 20 : 1	23.1 ± 0.2	62.3 ± 0.5	114 ± 2	141 ± 1
B50 – alginate 40 : 1	23.0 ± 0.1	61.1 ± 0.2	110 ± 1	144 ± 1
SA	17.5 ± 0.7	63 ± 5	238 ± 10	170 ±10
SA – alginate 8.8 : 1	22.0 ± 0.2	81 ± 1	200 ± 10	151 ± 3
SA – alginate 59 : 1	20.7 ± 0.2	80 ± 1	200 ± 20	153 ± 2
SA – alginate 117 : 1	21.7 ± 0.3	83 ± 1	200 ± 10	147 ± 4

3.4. Study of residual aluminum content

Also, a study was made of the residual aluminum content in water treated with the help of coagulants SA and B50 and composite reagents made on their basis. The residual aluminum content was determined by the photometric method using aluminon. The results are presented in Table 4.

Table 4. The content of residual aluminum in treated water.

Sample	Residual aluminum content. mg/dm^3
SA	0.50
SA + sodium alginate (59 : 1)	1.91
SA + sodium alginate (117 : 1)	1.26
SA + sodium alginate (59 : 1) + $CaCl_2$	0.14
B50	0.15
B50 + sodium alginate (20 : 1)	0.18

The use of a composite reagent of composition SA – sodium alginate has been established to lead to an increase in the residual aluminum content compared to the use of SA coagulant alone. At the same time, a decrease in the sodium alginate content in the composite reagent (transition from the SA – alginate ratio 59: 1 to 117: 1) causes a decrease in the concentration of residual aluminum from 1.91 to 1.26 mg/dm^3. In the case of coagulant B50, the use of a composite reagent does not lead to a significant increase in the residual aluminum content. It has been suggested that the increase in residual aluminum content when SA is used as a coagulant is due to the presence of sodium alginate. Sodium alginate was supposed to form soluble complexes with low molecular aluminum hydroxocomplexes present in SA solutions [17]. This is confirmed by the fact that when $CaCl_2$, which binds alginate into an insoluble compound, is introduced into the composite reagent, the content of residual aluminum decreases to a value close to that obtained using the B50 coagulant (up to 0.14 mg/dm^3). In B50 solutions, aluminum hydroxocomplexes with a high molecular mass predominate, as well as colloidal particles, which probably do not form stable complexes with sodium alginate macromolecules.

3.5. Study of coagulation aggregates parameters

Table 5 shows the size distributions parameters for aggregates obtained because of the hydrolysis of coagulants SA and B50 and composite reagents based on them.

Table 5. Characteristics of coagulation aggregates obtained by composite reagents hydrolysis*.

Dispersion	D_v10. µm	D_v50. µm	D_v90. µm	S_{ext}. m^2/kg	C_v. vol. %	ρ. kg/m^3	$u \cdot 10^3$. m/s
SA	90 ± 20	350 ± 30	660 ± 80	35 ± 4	0.17 ± 0.01	1036 ± 2	2.5 ± 0.5
SA - alginate	300 ± 20	820 ± 70	1600 ± 100	15 ± 2	0.9 ± 0.1	1005 ± 1	2.6 ± 0.5
SA - alginate - $CaCl_2$	210 ± 20	680 ± 70	1200 ± 80	18 ± 2	0.6 ± 0.1	1009 ± 2	2.7 ± 0.7
B50	530 ± 60	1530 ± 70	2600 ± 100	7 ± 1	2.1 ± 0.1	1013 ± 1	3.9 ± 0.4
B50 - alginate	290 ± 30	1540 ± 80	2600 ± 100	12 ± 1	0.5 ± 0.1	1011 ± 3	17 ± 4
B50 - alginate $CaCl_2$	170 ± 20	730 ± 70	1590 ± 80	19 ± 2	0.14 ± 0.04	1044 ± 1	13 ± 4

*Volume concentration C_v. average density ρ and sedimentation rate u.

The data in Table 5 show that the sizes of the coagulation aggregates formed by the composite reagent SA – alginate (59 : 1) are larger than those obtained by hydrolysis of individual SA. However. the aggregates density in the case of a composite reagent is reduced. which ultimately does not cause a significant change in the particle sedimentation rate. With the introduction of $CaCl_2$, the aggregates size decreases from 820 µm to 680 µm, however the sedimentation rate value retains as the same. The observed effect is explained by cross-linking of sodium alginate macromolecules with Ca^{2+} ions. As a result, the polymer shell of the particle becomes more compact, which is accompanied by a decrease in the aggregates size.

In the case of the composite reagent B50 – alginate 20 : 1, the presence of sodium alginate does not significantly affect the coagulation aggregates size, but their sedimentation rate increases from $3.9 \cdot 10^{-3}$ m/s to $17 \cdot 10^{-3}$ m/s. When $CaCl_2$ is added to the composite reagent, a decrease in the coagulation aggregates size and their sedimentation rate is observed. Thus, the use of the composite reagent B50 – sodium alginate leads to a significant increase in the sedimentation rate of coagulation aggregates in comparison with the use of other composite reagents and coagulants separately. At the same time, there is no increase in the residual aluminum content in treated water.

3.6. Influence of magnetic ultrafine particles on the parameters of coagulation aggregates.

Figure 6 shows the time dependences of the average size of coagulation aggregates obtained by hydrolysis of the composite reagents SA – sodium alginate and B50 – sodium alginate in the presence of Fe_3O_4 magnetic particles.

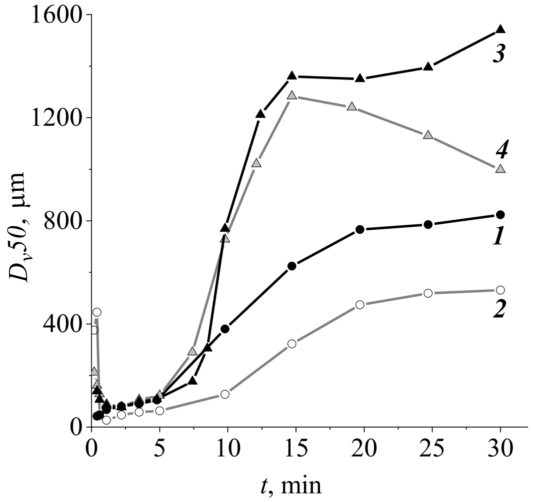


Figure 6. The dependence of the coagulation aggregates average diameter on time: 1 – SA – alginate; 2 – SA – alginate − Fe_3O_4; 3 – B50 – alginate. 4 – B50 – alginate − Fe_3O_4

Figure 6 shows the parameters of these aggregates at the time of 30 min. As follows from the data in Fig. 6 and Table 6, in the case of a composite reagent SA – sodium alginate, the aggregate growth kinetics curves have a similar shape in the presence of Fe_3O_4 magnetic particles and in their absence. At the same time, aggregates containing Fe_3O_4 particles are smaller and are also characterized by a lower volume concentration value c_v, which indicates compaction of the aggregates structure in the presence of magnetic particles.

Table 6. Characteristics of coagulation aggregates obtained by composite reagent hydrolysis.

Dispersion	D_v10. μm	D_v50. μm	D_v90. μm	S_{ext}. m^2/kg	c_v. vol. %
SA – alginate	300 ± 20	820 ± 70	1600 ± 100	15 ± 2	0.9 ± 0.1
SA – alginate – Fe_3O_4	180 ± 30	531 ± 60	1000 ± 80	22 ± 2	0.6 ± 0.1
B50 – alginate	290 ± 30	1540 ± 80	2600 ± 100	12 ± 1	0.5 ± 0.1
B50 – alginate – Fe_3O_4	211 ± 30	1000 ± 70	1850 ± 80	24 ± 2	0.12 ± 0.02

When using the composite reagent B50 – sodium alginate, the aggregate growth kinetics curves in the presence and in the absence of Fe_3O_4 magnetic particles coincide up to the time point of 15 min, then the aggregates size in presence of magnetic particles becomes smaller. Taking into account the sharp decrease in the aggregates volume concentration c_v from 0.5 to 0.12 vol. %, it can be assumed that they sedimentate, and some of the largest aggregates leave the device field of view. This indirectly indicates an increase in the aggregates sedimentation rate in the presence of magnetic nanoparticles. This factor is probably due to the change in the shape of the aggregates' growth kinetics curves.

4. CONCLUSION

Regulating the disperse composition of the composite reagent components has been established to make it possible to control their dissolution time and achieve the effect of sequential action of the reagents when they are simultaneously introduced into the treated water. It is more advisable to use sodium alginate with particle sizes < 0.25 mm to achieve the required dissolution time. It has been shown that the process of the reagents mixing does not have a significant effect on their disperse composition.

The introduction of sodium alginate in addition to aluminum sulfate leads to an increase in the size of the aggregates, but due to a decrease in their density, it does not significantly affect the sedimentation rate, which is a more important parameter from a practical point of view. As a result of combining sodium alginate and polyaluminum chloride B50 in a composite reagent, a significant increase in the coagulation aggregates sedimentation rate from $3.9 \cdot 10^{-3}$ m/s to $17 \cdot 10^{-3}$ m/s is observed. In this regard, the use of composite reagents based on polyaluminum chloride B50 and sodium alginate of the described disperse composition is more preferable

The introduction of magnetic ultrafine particles Fe_3O_4 into composite reagents creates the possibility of accelerating their separation from the treated water when exposed to an external magnetic field. At the same time, a change in the shape of the aggregates growth kinetic curves and a decrease in the particles volume concentration indicate that the presence of magnetic particles leads to compaction of the aggregates structure and an increase in their sedimentation rate even in the absence of a magnetic field.

Acknowledgements: The work was supported by the Belarusian Republican Foundation for Fundamental Research (grant № X21B-006) and by the Kurita Asia Research Grant (23Pvn029) provided by Kurita Water and Environment Foundation.

Authorship contribution: A.V. Zyhmant: investigation, formal analysis, data curation, writing – original draft. Minh Vu Xuan: investigation, formal analysis, data curation, writing – review & editing. D. D. Hrynshpan: conceptualization, formal analysis, data curation. T. A. Savitskaya: investigation, formal analysis, data curation. D. Lam Tran: conceptualization, supervision T. Lan Pham: conceptualization, writing – review & editing.

Competing interests: The authors have no competing interests to declare that are relevant to the content of this article.

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