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LIQUID COAGULANTS IN WATER TREATMENT TECHNOLOGY

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Abstract. In recent years the Tallinn Drinking Water Treatment Plant has tested two liquid coagulants – ferric sulphate and alum sulphate. With raw water from Lake Ülemiste alum sulphate gave much better results. The aim of this research was to compare the impact of different coagulants on the characteristics of Estonian natural waters and to establish the possibility of dissolution of toxic metals from the coagulants used.

Key words: natural water, coagulation, colour, turbidity, soluble metal ions, removal.

INTRODUCTION

Although numerous methods exist for improving the quality of drinking water a classical water treatment method – coagulation – is and probably will stay in use in the future. Coagulation is a well-studied process, which enables to reduce the turbidity and colour of natural water, influencing at the same time its pH value, chemical oxygen demand (COD), and other properties.

The basic prerequisite for a successful coagulation is an optimum dosage of the coagulant. At the same time the quality of the source of drinking water, including its seasonal changes caused by weather conditions, have to be taken into consideration. The optimum dosage guarantees efficient water clarification and a high quality of drinking water. At the same time failureless functioning of the purification equipment will be ensured.

In recent years researchers from Tallinn Technical University have studied problems connected with coagulation in the treatment of both natural and waste water [1, 2]. This subject is topical due to water purification problems in Tallinn as well as in other areas of Estonia. Alum and ferric coagulants were used to study the coagulation of water from Lake Ülemiste, the Pirita and Pärnu rivers, and several artesian wells in Estonia.

The suitability of drinking water with regard to its chemical composition is determined by the content of toxic (health damaging) components and components influencing the organoleptic qualities (scent, taste, colour, turbidity) of water. An important toxic component in water is aluminium. Its permissible concentration according to the Estonian standard EVS 663 [3] is 0.2 mg/dm^3. Iron is one of the components influencing organoleptic qualities of water. Its permissible concentration ranges from 0.1 to 1.0 mg/dm^3 for different classes of drinking water according to EVS 663.

A wrong dosage of alum, iron, or mixed coagulants may be a reason of impermissible amounts of soluble iron and aluminium in drinking water. The problem is particularly acute in case of iron pollution because it is "visible" (water can be yellowish or brownish) and therefore causes more emotions among customers than "invisible" aluminium pollution.

Chemical coagulation in water treatment is aimed at destabilizing suspended contaminants to make the particles contact and agglomerate and form flocs that settle to the bottom of the solution. The efficiency of coagulation in removing turbidity depends on the type of colloids in suspension; the temperature, pH, and chemical composition of the water; the type and dosage of the coagulants; and the degree and time of mixing provided for chemical dispersion and flocculation.

Abundant information is available in literature on the coagulation mechanism and the chemistry of coagulant–water solutions. It has been established that metal cations, such as Al^{3+} and Fe^{3+}, are hydrated in water and are present as aquocomplexes [4]. Hydroxometal complexes are formed in water and are readily adsorbed at interfaces, whereas simple aquometal ions are not adsorbed. The formation of different aquocomplexes depends on the pH of water, and their solubility is of great importance in the coagulation process because soluble alum or ferric compounds are impermissible in drinking water, as mentioned above. In general, the efficiency of ferric and alum coagulants is similar when they are compared on a molar basis.

The chemistry of dual Al–Fe coagulants can be much more complex than that of single ones. Complexing and competition between the two coagulants may reduce their effectiveness or the zone of coagulation, or vice versa, the mixed coagulants may have a larger coagulation zone than either coagulant separately. No discernible improvement in the coagulating ability of the dual coagulant over the single ones occurs.

The main purpose of the investigation was to assess the influence of liquid coagulants, such as aluminium sulphate and ferric sulphate, on the properties of natural water; to find out differences in the behaviour of two aluminium sulphate liquid coagulants (ALS and UTK) produced in different ways; to determine optimum doses of different coagulants for different waters; to find out the concentration of Al^{3+} ions in water treated with coagulants; and to compare the influence of different coagulation regimes on the results of the experiment. Below the results of investigations carried out in 1994–97 are reported.

EXPERIMENTAL

The main properties and period of investigation of different water samples from Lake Ülemiste, the Pirita and Pärnu rivers, and some artesian wells are presented in Table 1 and the characteristics of the coagulants in Table 2. The water of Lake Ülemiste, the main source of drinking water of the city of Tallinn, was investigated during the longest period of time.

Table 1

Characteristics of the studied waters

Sampling place	Sampling time	Colour, degree (mg Pt/l)	Turbidity, TE/F	pH	Alkalinity, mg-eq/l	COD, mg O_2 /l	Iron, total, mg/l
Lake Ülemiste	03.94–03.97	40–70*	1.5–6.4, 13	7.49–8.1	1.8–4.3	10.8–15.3	0.11
Pirita River	11.95	90	–	8.35	3.8	23.1	1.5
Pärnu River	10.95–11.95	85	–	7.89	4.5	14.94	0.32
Artesian wells in Pärnu	10.95–11.95	15.5–17.5	–	7.78–7.96	7.45–7.65	12.42–13.32	0.08
Artesian well at Vastseliina	10.96	111–330	33–46	7.8–8.0	4.0–5.0	1.9–5.0	6.6–7.6
Artesian wells at Vääna-Jõesuu	03.97	20–31*	13 TU	7.21–8.26	5.4–6.0	–	–

* designates values obtained at wavelength 436 nm, other values were obtained at wavelength 315 nm;
– not determined.

Table 2

Characteristics of the coagulants studied

Characteristic	Coagulant		
	ALS/UTK	PIX	K-110
Density of solution, g/cm^3	1.32–1.34	1.56	solid
Viscosity, mPa·s, 25 °C	15–25	33.0	solid
Active matter:			
Al/Fe, %	4.2/–	–/12	5.45/6.58
Al_2O_3/Fe_2O_3, %	7.9–8.3/–	–/17.1	10.3/9.4
Σ Al_2O_3, %	8.3	10.9*	16.3*
pH	1.8–2.2	<1	2.0 (solution of 1%)

* Fe^{3+} was calculated conditionally as Al^{3+}.

Among the coagulants the main attention was devoted to two different liquid aluminium sulphate coagulants. One of them is produced by AS Kemivesi and the other was developed at Tallinn Technical University (called respectively ALS and UTK). To compare the influence of aluminium sulphate on different kinds of raw water samples, two more coagulants were tested: iron(III)sulphate liquid-formed coagulant (PIX) from AS Kemivesi and a solid dual Al–Fe coagulant made from Estonian glauconite (K-110) developed at Tallinn Technical University.

To characterize different water samples, colour, turbidity, pH, alkalinity, and COD were chosen as parameters. These are easy to determine and are common, well-known quality indicators.

Laboratory coagulation jar tests were carried out using mixing equipment Flocculator (Kemira Kemivesi), which enables to process simultaneously six 1 litre samples of water. It is also possible to vary the mixing–flocculating–settling cycle in a large range of time and rotational frequencies, as it can be seen in Table 3.

Table 3

Duration of coagulation processes

Process	Regime		
	1	2	3
Mixing, 400 rpm	10 s	120 s	60 s
Flocculating, 20 rpm	10 min	5 min	20 min
Settling	15 min	30 min	120 min

To determine colour, turbidity, and soluble metal ions, such as Al^{3+} and Fe^{3+}, a photometer NANOCOLOR 300D was used. In our earlier investigations also other equipment has been used [1, 2]. In the present study colour was determined at wavelength 436 nm and expressed as mg Pt/l, earlier at wavelength 315 nm. For this reason the results of determination are not directly comparable: the figures obtained at wavelength 436 tend to be bigger.

Turbidity was determined respectively at wavelengths 620 and 530 nm. It is expressed by formazine standard in mg/l or TE/F (turbidity unit).

Soluble Al^{3+} ion was determined with the Eriochrome cyanine R-method at wavelength 540 nm and Fe^{3+} ion with 1,10-phenanthroline at 470 nm.

COD was determined as usual with potassium permanganate in an acidic solution. Alkalinity was determined by titration with hydrochloric acid [5].

RESULTS

The characteristics of the tested water samples varied within a large range (Table 1). As shown above, many possibilities exist for comparing the influence of different coagulants on different waters before and after coagulation. We chose colour and turbidity, which are the most common quality parameters. Optimum doses of different coagulants can be found in Figs. 1 and 2 as the minimum values on the coagulation curves. For Lake Ülemiste, the optimum doses of liquid aluminium coagulants ALS and UTK were almost the same: 11–13 mg Al^{3+}/l, but the reduction of colour was different. For the solid dual coagulant K-110 the optimum dose was 18 mg Al^{3+}/l.

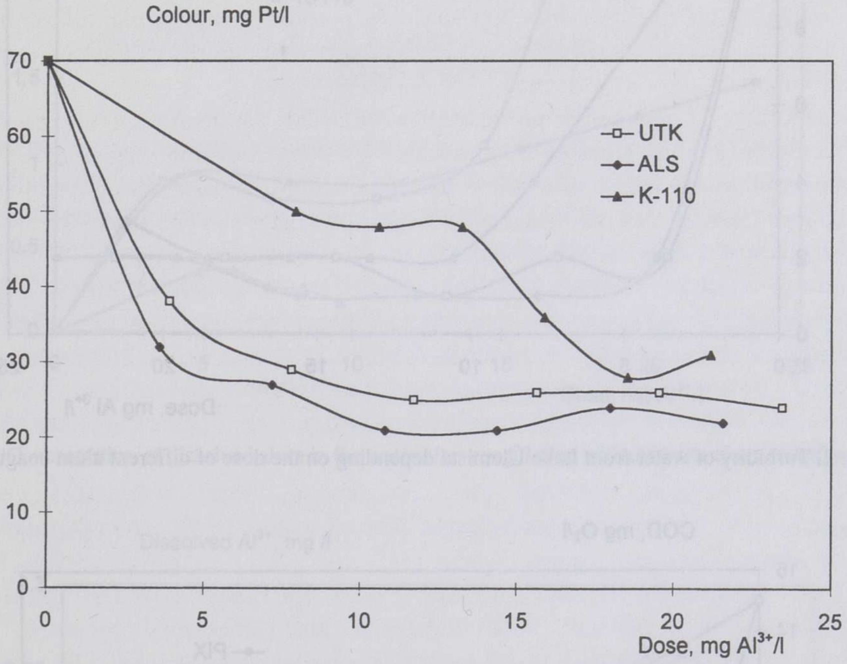

Fig. 1. Colour of water from Lake Ülemiste depending on the dose of different alum coagulants.

As expected, the quality of the raw water sample was the main factor influencing the coagulation process. For the Pärnu region the optimum dose of the coagulant ALS for the removal of colour was about 20 mg Al^{3+}/l; however, the optimum dose of the ferric coagulant PIX is nearly twice as big – about 41.5 mg Fe^{3+}/l. As an illustration, the COD reduction of water from the Pärnu River with ALS and PIX is given in Fig. 3. The optimum doses for the water of the Pirita River are about 30 mg Al^{3+}/l and 62 mg Fe^{3+}/l. There are some kinds of water, for example, from Vastseliina, which cannot be coagulated without flocculants because of their high turbidity and colloidal iron content. With Fennopol-type flocculants the coagulation process proceeded successfully. Special attention was paid to the solubility of metal ions in water. Figure 4 demonstrates that the solubility of Al^{3+} is somewhat higher when liquid coagulants are used than in case of the solid dual coagulant K-110. However, it is too early to generalize these results because of the insufficiency of data.

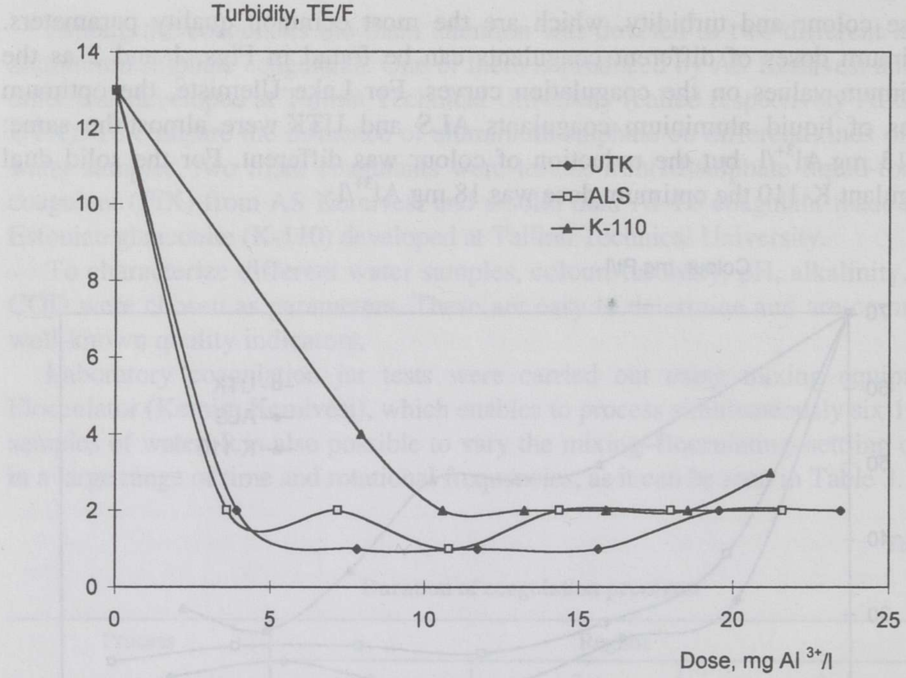

Fig. 2. Turbidity of water from Lake Ülemiste depending on the dose of different alum coagulants.

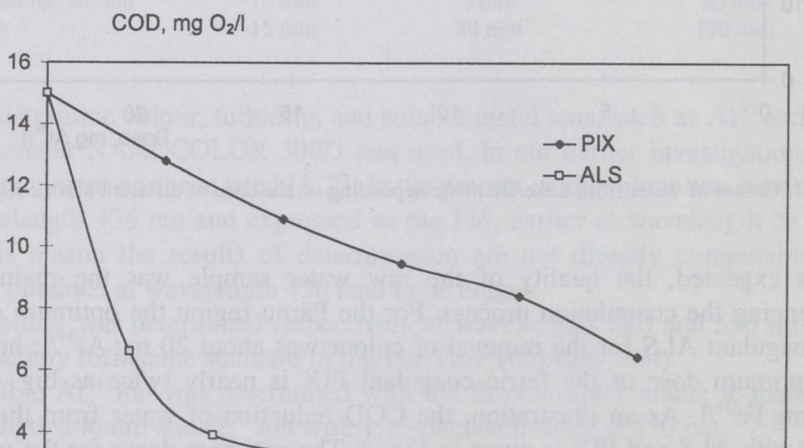

Fig. 3. Chemical oxygen demand (COD) of water from the Pärnu River depending on the dose of different coagulants.

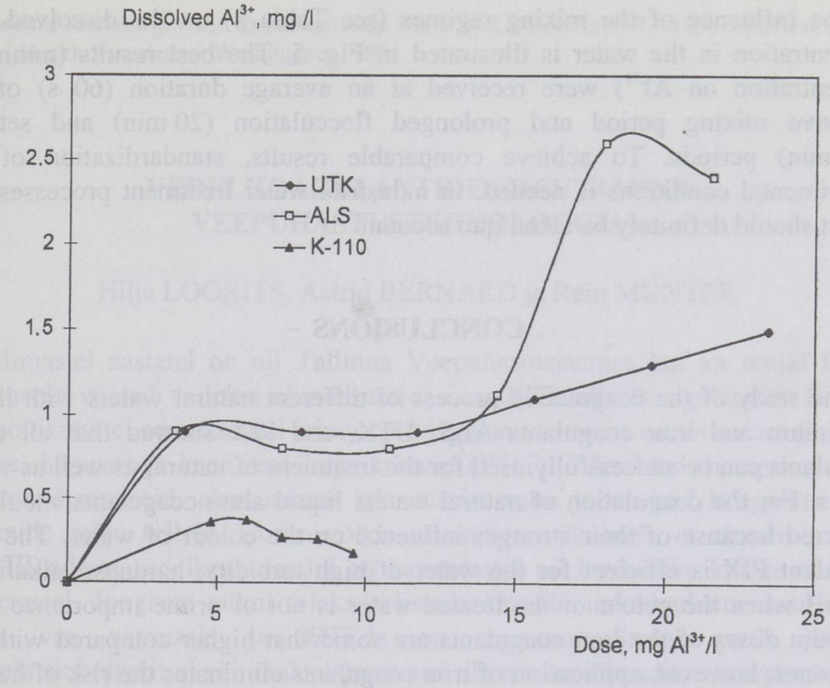

Fig. 4. Concentration of dissolved alum in the water after coagulation with different alum coagulants.

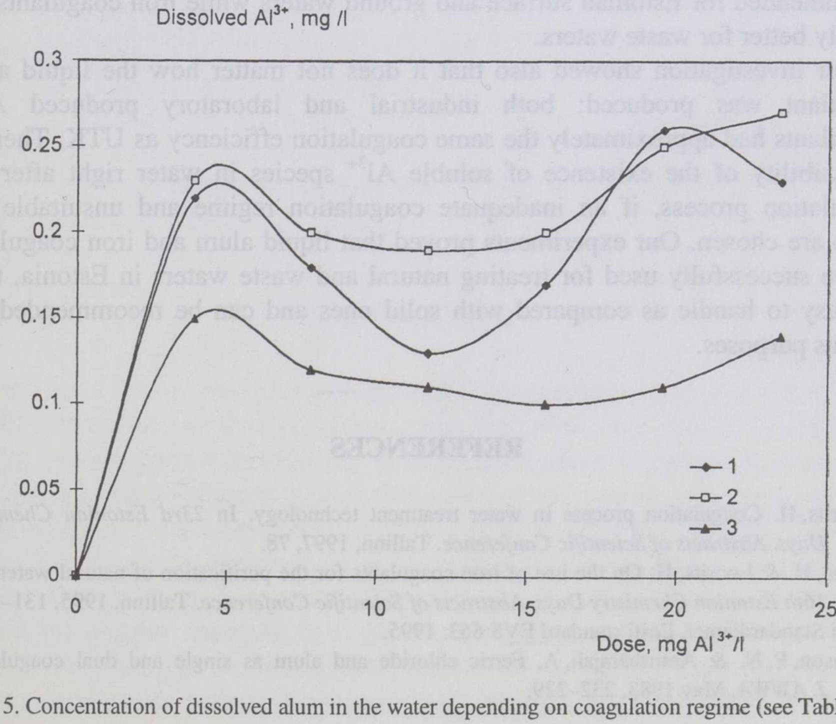

Fig. 5. Concentration of dissolved alum in the water depending on coagulation regime (see Table 3).

The influence of the mixing regimes (see Table 3) on the dissolved Al^{3+} concentration in the water is illustrated in Fig. 5. The best results (minimum concentration on Al^{3+}) were received at an average duration (60 s) of the intensive mixing period and prolonged flocculation (20 min) and settling (120 min) periods. To achieve comparable results, standardization of the experimental conditions is needed. In industrial water treatment processes this aspect should definitely be taken into account.

CONCLUSIONS

The study of the coagulation process of different natural waters with liquid aluminium and iron coagulants ALS, UTK, and PIX showed that all these coagulants can be successfully used for the treatment of natural as well as waste waters. For the coagulation of natural waters liquid alum coagulants should be preferred because of their stronger influence on the colour of water. The iron coagulant PIX is efficient for the water of high turbidity, hardness, alkalinity, and pH when the colour of the treated water is not of prime importance. The optimum doses of the iron coagulants are somewhat higher compared with the alum ones; however, application of iron coagulants eliminates the risk of having soluble aluminium species in the treated water.

Our experiments ensured that, in general, alum coagulants can be recommended for Estonian surface and ground waters while iron coagulants are usually better for waste waters.

Our investigation showed also that it does not matter how the liquid alum coagulant was produced: both industrial and laboratory produced ALS coagulants had approximately the same coagulation efficiency as UTK. There is a possibility of the existence of soluble Al^{3+} species in water right after the coagulation process, if an inadequate coagulation regime and unsuitable pH limits are chosen. Our experiments proved that liquid alum and iron coagulants can be successfully used for treating natural and waste waters in Estonia, they are easy to handle as compared with solid ones and can be recommended for various purposes.

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VEDELKOAGULANTIDE KASUTAMINE VEEPUHASTUSTEHNOLOOGIAS

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Viimastel aastatel on nii Tallinna Veepuhastusjaamas kui ka mujal Eestis kasutusele võetud vedelad alumiinium- ja raud(III)sulfaatkoagulandid. Koagulatsioonikatsetel on määratud erinevate koagulantide toime vee omadustele, nagu värvus, hägusus ja keemiline hapnikutarve (KHT). Võrreldud on optimaalseid koagulandiannuseid, alumiiniumi lahustumist vette ja uuritud koagulatsioonirežiimide mõju sellele. Uurimistööde tulemustest järeldub, et alumiinium- ja raud(III)sulfaat vedelkoagulandid on kasutatavad nii looduslike kui ka heitvete töötlemisel. Joogivee puhul tuleks eelistada alumiiniumkoagulante, sest nende toime vee värvusele ja KHT-le on tugevam. Samas peab jälgima koagulatsioonirežiimi vältimaks lahustunud alumiiniumühendite sattumist vette.