

Study of the process of activation of aluminum sulfate coagulant solutions during filtration on rapid filters

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Abstract— This study focuses on the treatment of drinking water with activated aluminium sulphate solutions at rapid filters. Experimental investigations were conducted to assess the impact of activated aluminium sulphate solutions on the duration of the protective effect of filter loading and the time taken to reach the maximum allowable head loss. The prediction of drinking water treatment efficacy using activated aluminium sulphate solutions is outlined and compared with experimental data.

Keywords— Coagulation, filtration, drinking water treatment, activated coagulant solutions, intensification of water treatment processes.

I. INTRODUCTION

In the technological process of water purification filtration is performed on fast filters with granular loading after coagulation and preliminary sedimentation of clarified water [1-4]. Of the known theories of the process of water purification by filtration the greatest recognition was given to the theory of D.M. Mintz [1], according to which the process of clarification of the filtered suspension can be considered as the sum result of two oppositely directed processes: adhesion of retained particles to the macrosurface under the action of adhesion forces and detachment of previously adhered particles under the influence of hydrodynamic forces of the flow, and their transfer to the next layers of loading (suffusion). Water clarification in each elementary loading layer occurs as long as the intensity of particle adhesion exceeds the intensity of particle detachment. As the sludge accumulates, the particle detachment rate increases. In water purification, the filtering process is interesting in the stage where particle adhesion prevails over particle detachment. The relationship between the adhesion forces and the hydrodynamic forces arising from the movement of water can be written as an inequality.

$$\frac{A\delta}{f(l)} \gg 3\pi\delta\eta V_n, \quad (1)$$

where A is adhesion constant of two substances (Hamaker's constant), δ is adhesive particle size, $f(l)$ is a value depending on the shape of particles and the distance between them, η is water viscosity, V_n is component of the flow velocity normal to the particle surface.

The left side of the equation characterises the adhesion forces, while the right side characterises the hydrodynamic conditions.

Particle detachment under the influence of water flow occurs when the detachment force F_d is able to overcome the adhesion force F_{ad} and the mass of particles P , i.e.,

$$F_d \geq \mu \cdot (F_{ad} + P), \quad (2)$$

where μ is the coefficient of friction.

If $F_{ad} \gg P$, then $F_d \geq \mu \cdot F_{ad}$. The force of the flow impact on the particle depends on the density and viscosity of the medium, the particle diameter, the flow velocity and the conditions of flow around the adhering particles.

According to [4, 5], the criterion of the optimum filtering mode is the ratio between the duration of the protective effect of the loading t_l and the time of filter operation until the maximum head loss t_h is reached. In technological and economic terms, the best mode is the one in which $t_l = t_h$. Nevertheless, from the point of view of sanitary reliability it is advisable to take the value

$t_l : t_h > 1$, as in this case during the whole filter cycle the high quality of filtrate is guaranteed and the degree of sanitary reliability of facilities is increased.

In this paper, the solution of the problem is to study the process of drinking water purification at rapid filters using activated solution of aluminium sulphate coagulant. The latter allows to reduce the consumption of reagents, improve the quality of water purification, increase the productivity of treatment facilities, reduce the cost of drinking water [6-9].

II. EXPERIMENTAL

The main methodological aspects of the conducted research are given in [10-12]. The scheme of the laboratory installation, which allows to carry out research

on intensification of the process of water filtration with the use of activated coagulant solution is shown in Fig. 1.

The installation consists of two glass columns with diameter 100mm and height 1000mm, filled with quartz sand $d=0.5-1.2\text{mm}$, $d_{eq}=0.7-0.8\text{mm}$, height 800mm. Filtering is carried out from top to bottom, filtering speed does not exceed 6-8m/h.

When performing research, water treated with reagents - activated (6) and ordinary (7), was fed into stabilisation tanks (4), then to filtration columns (1). Washing loading was carried out with tap water for 7 minutes with the intensity of 10 l/s m^2 [10, 13].

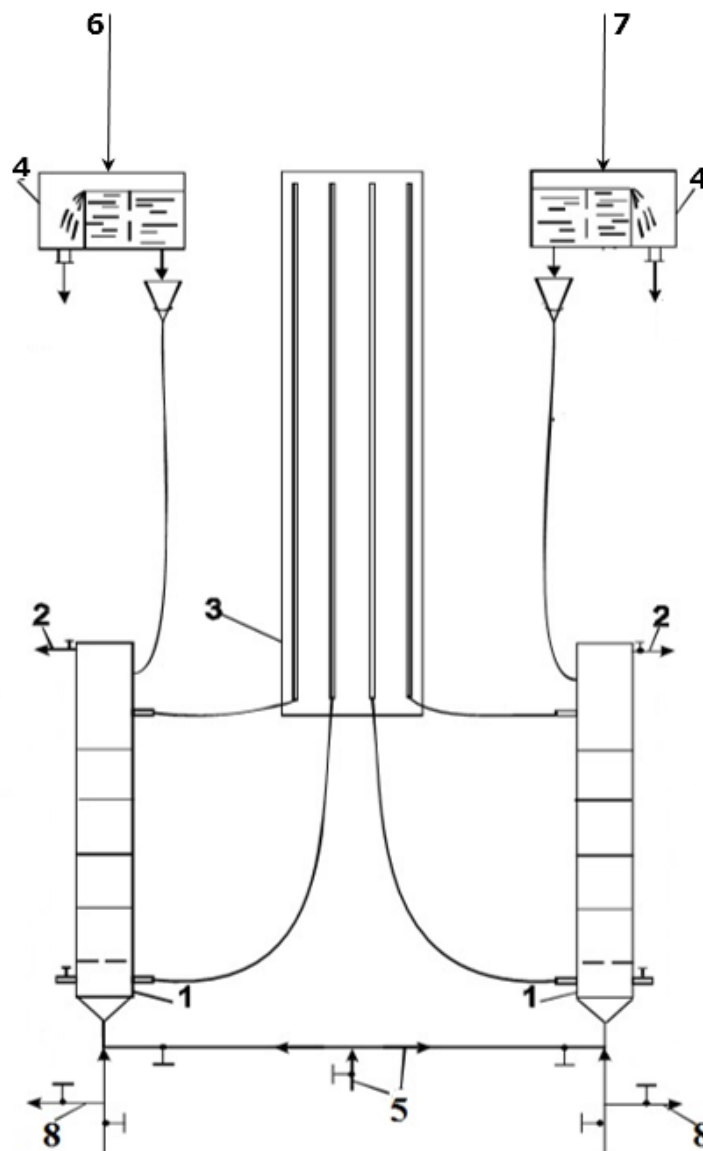


Fig. 1 Scheme of laboratory installation

- 1-filtering column; 2-drainage of wash water; 3-piezometric panel; 4-stabilising tanks; 5-delivery of wash water;
6-delivery of water treated with activated reagent solution; 7-delivery of water treated with ordinary reagent solution;
8-discharge of water into the reserve tank.

The results of the research are summarised in Table 1.

Table 1. Effect of water treatment with activated sulphate coagulant solution aluminium sulfate on duration of protective effect of filter loading (t_l) and time of achievement of maximum allowable head loss (t_h)

No. of experiment series	Duration of protective effect of filter loading (t_l , min) during water treatment:		Time to reach the maximum allowable head loss (t_h , min) during water treatment:		Efficiency of changing filter parameters, %	
	conventional solution coagulant	activated coagulant solution	conventional solution coagulant	activated coagulant solution	t_l	t_h
I	375 (6 h 15 min)	475 (7 h 55 min)	465 (7 h 45 min)	585 (9 h 45 min)		
II	350 (5 h 50 min)	485 (8 h 05 min)	480 (8 h 00 min)	580 (9 h 40 min)		
III	365 (6 h 05 min)	475 (7 h 55 min)	450 (7 h 30 min)	595 (9 h 55 min)		
IV	345 (5 h 45 min)	470 (7 h 50 min)	445 (7 h 25 min)	585 (9 h 45 min)		
V	360 (6 h 00 min)	475 (7 h 55 min)	485 (8 h 05 min)	585 (9 h 45 min)		
VI	370 (6 h 10 min)	490 (8 h 10 min)	455 (7 h 35 min)	575 (9 h 35 min)		
VII	365 (6 h 05 min)	475 (7 h 55 min)	450 (7 h 30 min)	580 (9 h 40 min)		
mean value	361 (6 h 01 min)	477 (7 h 57 min)	461 (7 h 41 min)	584 (9 h 44 min)	+32,1	+26,6

III. RESULT AND DISCUSSION

A mathematical model predicting the efficacy of clarifying water using activated aluminium sulphate coagulant solution was developed based on research.

In creating a mathematical model for processes with continuous production characteristics like water treatment facilities, an essential objective is maintaining a technologically sound water purification mode under optimal magnetic-electric activation conditions of aluminium sulphate solution.

A mathematical model was constructed through a full factorial experiment with three factors at two variation levels - 2^3 [14, 15].

The mathematical models were created for low turbidity coloured water and for water with high suspended solids content of low colour. Characterisation of these types of water is given in [10]. Effective parameters for activating aluminium sulphate coagulant solution based on qualitative parameters of clarified water are also included in the study.

The following are accepted as the main factors affecting water clarification when using activated coagulant solution:

– for low turbidity coloured waters:

- chromaticity, C, deg;
- reagent dose, D, mg/dm³;

- water temperature, T, °C.

– for water with high suspended solids content and low colour:

- suspended solids content, S, mg/dm³;

- reagent dose, D, mg/dm³;

- water temperature, T, °C.

Functional dependences of the effect of natural water purification under effective modes of coagulant solution activation are as follows:

- for low turbidity coloured waters:

$$E = f(C, D, T) \text{ or } Y = f(X_1, X_2, X_3) \quad (3)$$

where Y is the effect of natural water treatment, C=X₁, D=X₂, T=X₃.

– for water with high suspended solids and low colour:

$$E = f(S, D, T) \text{ or } Y = f(X_1, X_2, X_3), \quad (4)$$

where Y is the effect of natural water treatment, S=X₁, D=X₂, T=X₃.

In general, the functional dependence described by equations (3 and 4) is as follows:

$$Y = b_0X_0 + b_1X_1 + b_2X_2 + b_3X_3 + b_{12}X_1X_2 + b_{13}X_1X_3 + b_{23}X_2X_3 + b_{123}X_1X_2X_3 \quad (5)$$

where b₀, b₁, b₂, b₃, b₁₂, b₁₃, b₂₃, b₁₂₃ are regression coefficients.

It should be noted that the degree of accuracy of the mathematical model is determined by the range of variation of factors: for each *i*-th factor X_{*i0*} – the basic level of the factor is set; X_{*i*max}, X_{*i*min} – the upper and lower levels of the *i*-th factor, which are taken during the research; ΔX_{*i*} – variation interval equal to

$$\Delta X_i = \frac{X_{i\max} - X_{i\min}}{2}, i = 1 \dots k \quad (6)$$

During the experiment we used coded values of factor levels. In this case, the main level was taken equal to zero, the upper level is +1, and the lower level is -1. Coding is carried out according to the formula:

$$\bar{X}_i = \frac{X_i - X_{i0}}{\Delta X_i}, i = 1 \dots k \quad (7)$$

The parameters for designing an experiment using low turbidity coloured water and water with a high concentration of suspended solids and low chromaticity are furnished in Table 2.

Table 2 - Experiment planning conditions

Factors		Levels of variation			Variation interval
Name	Code view	-1	0	+1	
Low turbidity coloured water (coagulant - aluminium sulphate)					
Colour, deg	X ₁	35	65	95	30
Reagent dose, mg/dm ³ ;	X ₂	6,25	12,50	18,75	6,25
Water temperature, °C	X ₃	3	12	21	9
Waters with high suspended solids content and low chromaticity (coagulant - aluminium sulphate)					
Suspended substances, mg/dm ³	X ₁	70	105	140	35
Reagent dose, mg/dm ³	X ₂	6,25	12,50	18,75	6,25
Water temperature, °C	X ₃	3	12	21	9

After describing the process of water purification and investigating the use of activated aluminium sulphate coagulant solution, the resulting relationship between the natural water clarification effect and coagulant dosage can be expressed as follows:

- for low turbidity coloured waters:

$$E = 80.96 + 0.58C + 0.879T - 0.709DT \quad (8)$$

- for water with high suspended solids content and low chromaticity:

$$E = 97.36 - 0.303S + 0.44D + 0.348ST \quad (9)$$

Figures 2 and 3 show the comparison of experimental and calculated data in determining the effect

of water clarification when using activated coagulant solution:

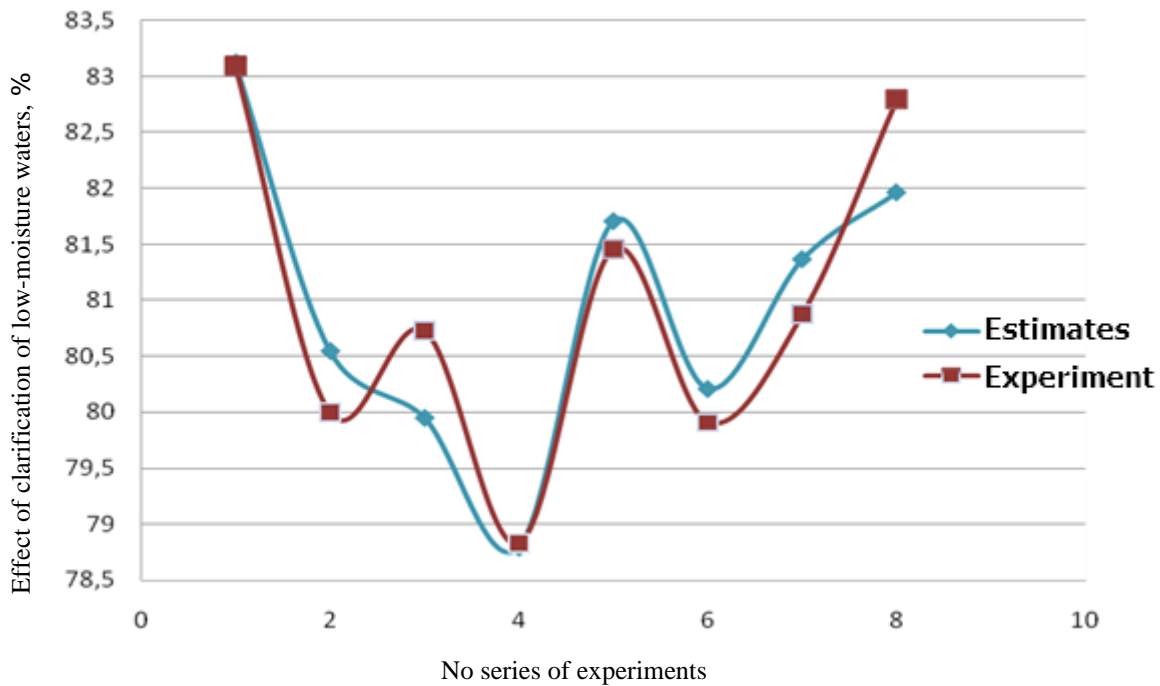


Fig. 2 Comparison of experimental and calculated data in determining the effect of clarification of low turbid coloured waters when using activated solution

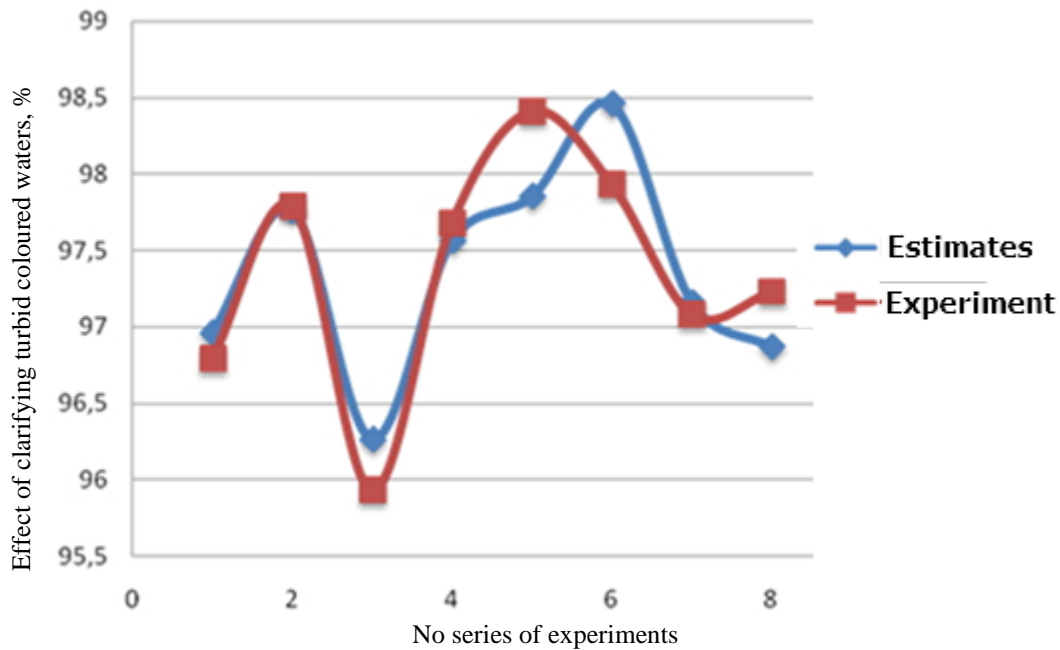


Fig. 3 Comparison of experimental and calculated data in determining the effect of clarification of water with increased suspended solids content and low colour at application of activated aluminium sulphate solution

The received mathematical dependences of the effect of natural water clarification at application of the activated aluminium sulphate solution describe the investigated process completely enough that allows to draw a conclusion about possibility of use of dependences

in technological calculations of work of treatment facilities and substantiation of application of the activated coagulant solution for intensification of the process of water clarification at water treatment facilities.

IV. CONCLUSION

Low turbidity water with increased suspended solids content and low chromaticity can be used in technological calculations for the design of water treatment facilities. It fully describes the process under study.

During the research, it was found that employing activated solutions of aluminium sulphate coagulant can diminish the estimated doses by an average of 25-30%, elevate the filters' capability by an average of 40%, and reduce the remaining aluminium residue in clarified water by an average of 45-50%. This subsequently enhances the environmental protection measures for drinking water. Simultaneously, the duration of water treatment with activated aluminium sulphate coagulant solution strengthens the water filtration process. The average duration of the protective effect of loading, as well as the time to attain maximum head loss, increases by approximately 21-32%.

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