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TECHNOLOGICAL CRITERIA OF ALUM COAGULATION

The importance of some parameters of physicochemical phenomena occurring during coagulation process has been discussed, a special attention being given to flocculation. It has been shown that the process is controllable and that its optimization may be based on the proposed technological criteria.

LIST OF SYMBOLS

ε — porosity of beds,
ϱ_s, ϱ — density of filtration bed, density of water,
ζ — electrokinetic potential,
C_0, C — concentrations of pollutants in raw and treated water,
d — diameter of bed grains,
K — Kozen–Carmea's constant,
v — filtration velocity.

1. INTRODUCTION

The coagulation process consists of two phases, namely:

1. Destabilization of the colloidal dispersions of water impurities, conditioned by the kind and quantity of the coagulant dosage, as well as by electrokinetic potential of the particles.

2. Flocculation phase which depends essentially on the temperature and pH value of water, the electrokinetic potential as well as on the time and conditions of mixing.

The process efficiency depends on whether or not the flocculation process is conducted correctly. The investigations have shown the influence of physicochemical factors on the efficiency of volume coagulation and surface coagulation conducted in filter beds the latter being the extreme modification of the former.

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2. METHODS OF INVESTIGATIONS

Volumetric coagulation was conducted in jar test method. Flocculation time was 1200 s, pH value adjusted by using 0.1 n HCl or NaOH.

The influence of temperature on coagulation effects has been investigated. A constant temperature was kept by immersing the samples in thermostable bath. The mixing intensity was expressed by the velocity gradient of the liquid flow, which was determined from the measurement of rotational speed and size of stirrers as well as from the volume of the water samples.

In surface coagulation the influence of coagulant on the efficiency of the process was investigated depending on the filter bed, pH value and water temperature, using sand and sand-coal filters. They were characterized by the following parameters:

1. grain-size of sand: d_{10} — $0.7 \cdot 10^{-3}$m, d_{60} — $0.9 \cdot 10^{-3}$m;
grain-size of anthracite: d_{10} — $0.8 \cdot 10^{-3}$m, d_{60} — $1.1 \cdot 10^{-3}$m;
grain-size of activated carbon: d_{10} — $0.8 \cdot 10^{-3}$m, d_{60} — $0.95 \cdot 10^{-3}$m;
2. porosity: 0.35, 0.40 and 0.45, respectively.

The height of filter beds amounted to 0.9 m, in dual-media filters the sand layer was 0.6 m and the layer of anthracite or activated carbon — 0.3 m high. The filtration rate was 5 m/h. The mixing conditions in pure filtration beds were determined from the velocity gradient expressed by the formula [2]

$$G = \frac{1-\varepsilon}{\varepsilon^2} \frac{v}{d} \sqrt{\frac{\varrho_s - \varrho}{\varrho} K} .$$

To establish the values of the velocity gradient in polluted beds a filtration model has been assumed, in which the specific deposit, bed's porosity, grain-size and an equivalent filtration rate have been taken into account. The coagulation effects have been determined from the reductions of colour, turbidity and COD (permanganate value). These indicators have been determined according to the Polish standards.

The process was controlled, basing on the electrokinetic potential of colloidal particles. Electrokinetic potential has been determined from the measurement of electrophoretic mobility by electrophoresis. In surface coagulation filter run has been also investigated to determine the usability of beds for coagulation process. The raw water source was the Odra river the parameter of which varied in quality as follows: alkalinity — 100–125 g/m³ as $CaCO_3$, pH — 7.4–7.5, colour — 20–50 g/m³ Pt, turbidity — 15–50 g/m³, COD permanganate value — 11.2–16.2 g/m³ O_2. The mean electrokinetic potential of particles ranged from −22 to −30.5 mV.

3. EFFICIENCY OF COAGULATION PROCESS

3.1. COAGULANT DOSAGE

The required coagulant dosage depends on the method of coagulation. The efficiency of water purification in volume and surface coagulation are presented in fig. 1. The treatment effects in surface coagulation refer to the mean value obtained in the whole filter run.

From the comparison of the efficiency of water treatment, depending on the method applied, it follows that in surface coagulation the required dosages of coagulant are lower and that they assure a better quality of water. In volume coagulation the removal of impurities increased with the increasing the coagulant dosage, whereas in surface coagulation the turbidity removal increased with dosages ranging to 20 g/m^3 $Al_2(SO_4)_3 \cdot 18\ H_2O$ and was practically unchanged for the dosages ranging from 20 to 60 g/m^3, independently of the kind of bed.

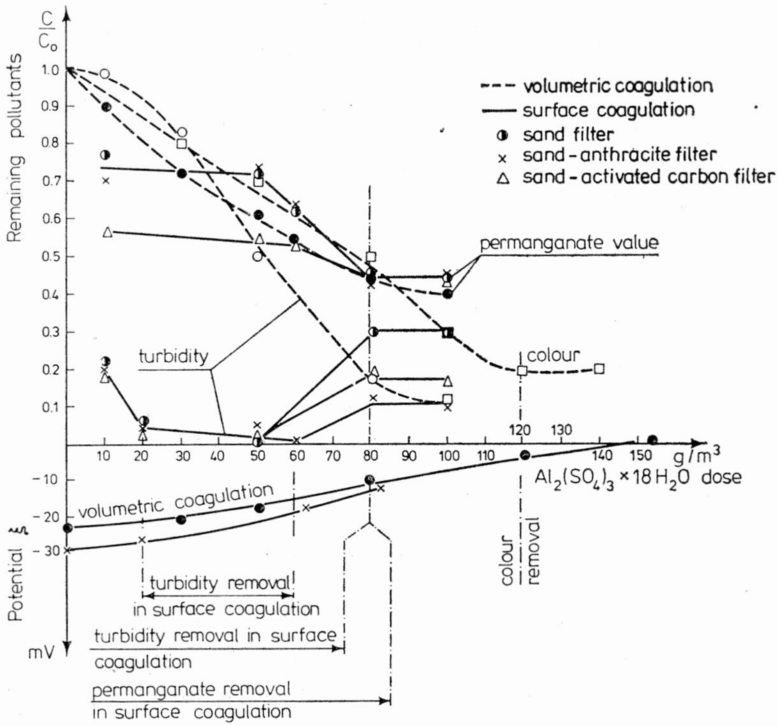

Fig. 1. The effect of coagulant dose on the coagulation efficiency and the value of electrokinetic potential

Rys. 1. Wpływ dawki koagulanta na efektywność koagulacji i wielkość potencjału elektrokinetycznego

The effect of filter bed media on the turbidity removal has been manifested at the coagulant dosages higher than 50–60 g/m^3. A reverse phenomenon has been observed in removal of compounds responsible for the COD. With the coagulant dosages higher than 80 g/m^3 the decrease of COD for the examined filtration beds and for volume coagulation was practically the same, whereas with lower dosages, especially below 50 g/m^3, the degree of the COD removal is higher for sand-carbon beds, if compared with sand and sand-anthracite beds as well as with volume coagulation. This proves that the sorptive ability of active carbon may be utilized with low coagulant dosage, whereas at higher doses of coagulant activated carbon performed the role of a filter medium.

For the sand and sand-anthracite beds the COD removal with the dose of 10 g/m^3 was better, compared with volume coagulation. This is due to the fact that the flocculation in filter beds at low doses of coagulant is more efficient, while volume flocculation is extremely weak.

The maximal doses of alum, at which the coagulation process may be conducted and established from the length of filter run, were the lowest for sand bed, somewhat higher for the sand-anthracite bed and the highest ones for the sand-carbon bed (fig. 2).

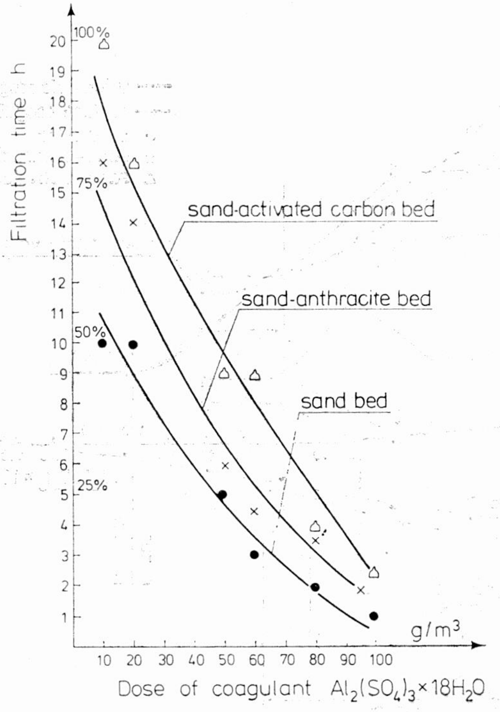

Fig. 2. Filtration time versus coagulant dose
Rys. 2. Zależność czasu filtracji od dawki koagulanta

Considering the quality of the filtrate the coagulant doses should not exceed 60 g/m^3 $Al_2(SO_4)_3 \cdot 18\ H_2O$. With this maximal dose of the coagulant the 8 hour filter run can be guaranteed exclusively in sand-coal bed. The sizes of coagulant doses are also related to the temperature and pH of water.

3.2. TEMPERATURE AND pH VALUE OF WATER

In volume coagulation with aluminium sulphate the efficiency of the process was conditioned by the pH value and temperature of water. It has been shown that lower treatment effects stated at low temperatures are due to a higher stability of colloids. This is related to the fact that at low temperatures the destabilization abilities of the coagulant are lower (fig. 3). The efficiency of the process was distinctly improved with the optimal pH value of water. The optimal pH being temperature dependent, decreased with the increasing temperature of water (fig. 3).

The optimal pH of water for the given temperature allows to obtain a better effect of treatment or to lower the doses of coagulant without deteriorating the quality of water (fig. 4).

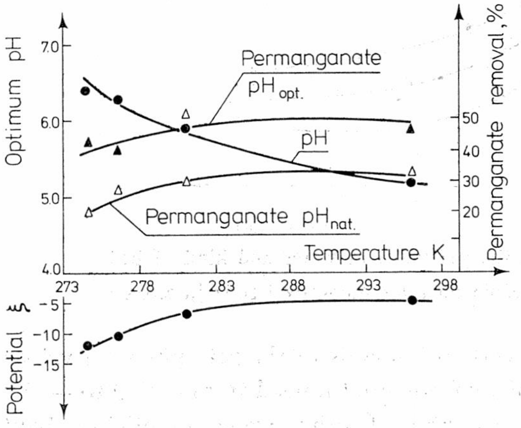

Fig. 3. The effect of temperature on the optimal pH value and destabilization of colloids

Rys. 3. Wpływ temperatury na wielkość odczynu optymalnego i destabilizację koloidów

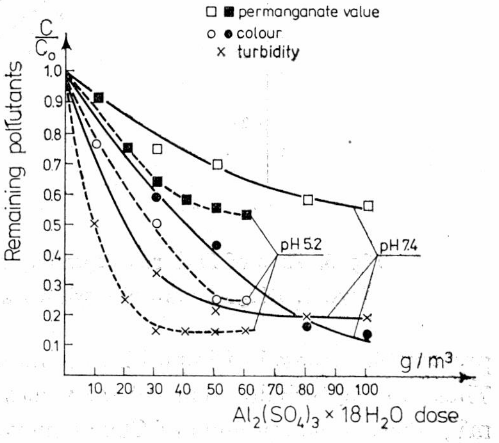

Fig. 4. Efficiency of water treatment at natural and optimal pH values

Rys. 4. Porównanie skuteczności oczyszczania wody przy pH naturalnym i optymalnym

In surface coagulation the temperature of water distinctly affected the course of the process in filter bed, having almost no influence on the treatment effects [4]. It has been stated, however, that the optimal pH results in the prolongation of the filter run (fig. 5).

3.3. ELECTROKINETIC POTENTIAL

The investigations conducted allowed to state the usability of the measurement of the zeta potential to the control of volume and surface coagulation.

It has been stated that the reduction of the stability of colloids with 50 g/m³ of aluminium sulphate was almost three times lower at the temperature of about 274 K than at temperatures exceeding 283 K (fig. 3). This phenomenon may explain the difficulties appearing during coagulation of water impurities at low temperatures, as well as the fact that to improve the treatment effects either polyelectrolytes or higher doses of coagulants or adjustment of pH value are applied. It has been shown that in volume coagulation with aluminium sulphate the turbidity was removed at the values of $\zeta \leqslant |-10.0|$ mV, and colour removal at $\zeta \leqslant |-5.0|$ mV (fig. 1). It has been also stated that in filtration

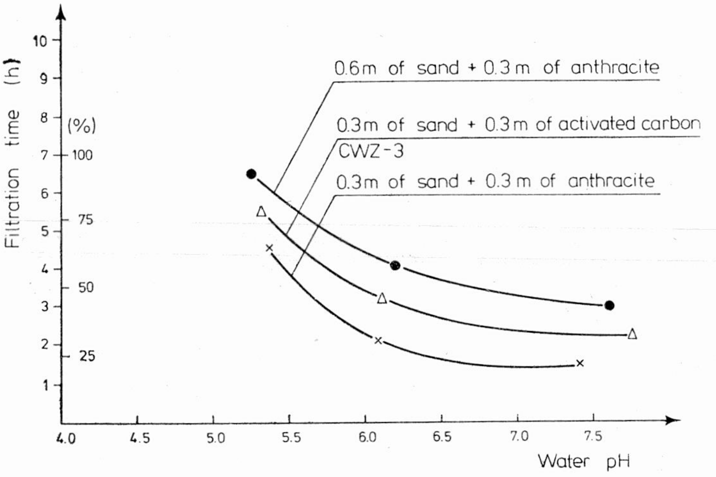

Fig. 5. Time of filter run depending on the pH value of water and kind of bed

Rys. 5. Długość cykli filtracyjnych zależnie od odczynu wody i rodzaju złoża

process the removal of impurities occurs in certain intervals of the zeta potential values Thus, for the turbidity removal the values of zeta potential ranged from —17.0 to —25.0 mV, whereas the optimum of COD removal was obtained with the zeta potential of about —14.5 mV (fig. 1). This is related to the application of lower doses of the coagulant in surface coagulation.

Zeta potential proved to be a helpful factor in the estimation of filter hydraulics. With the decreasing absolute values of the zeta potential the rate of head losses increased (fig. 6).

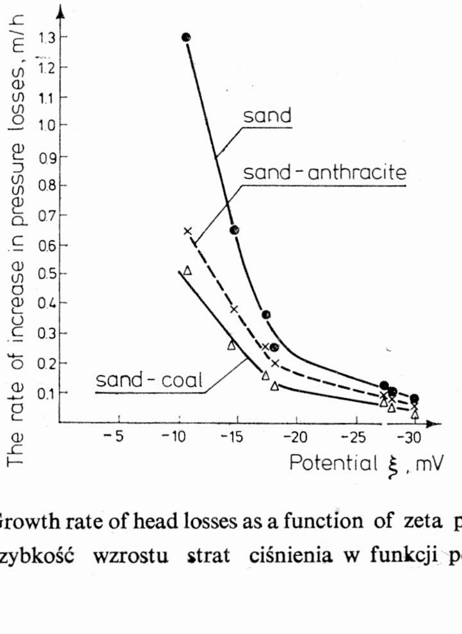

Fig. 6. Growth rate of head losses as a function of zeta potential

Rys. 6. Szybkość wzrostu strat ciśnienia w funkcji potencjału ζ

From the analysis of the growth rate of the head losses it follows that the optimum efficiency of the examined filter beds for alum coagulation appears at the ζ values up to -17.5 mV. At this value of ζ the turbidity was efficiently removed by the three kinds of examined beds, and COD by sand-coal beds. Because of a rapid increase of head loss at lower absolute values of the ζ potential, the doses of coagulant should be reduced to 50 g/m^3.

3.4. VELOCITY GRADIENT

For volume coagulation the optimal velocity gradient amounted to 20–60 s^{-1} (fig. 7). Negative effect of higher velocity gradients on volume flocculation can be partially compensated by applying higher doses of coagulant. In filtration process of the water being coagulated the determined velocity gradients were much higher and depended among others on the density of filter bed media as well as on the filtration time and ranged from 15 to 500 s^{-1} in filter run. Lower values refer to sand-coal bed, and the higher ones to the sand bed, proving that the flocculation conditions are better in double layer beds (fig. 8).

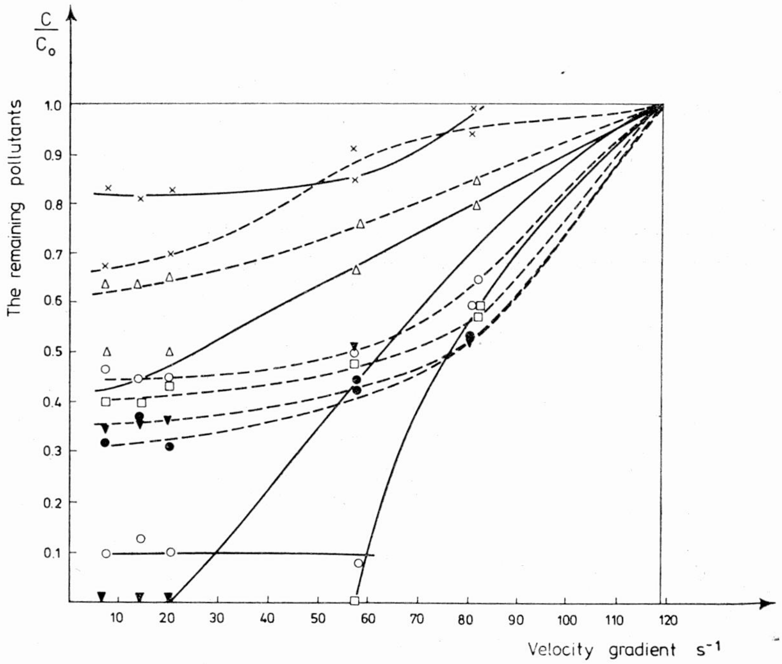

Fig. 7. Coagulation efficiency versus velocity gradient
– turbidity; – – – permanganate value; alum doses (g/m^3): × – 30, △ – 50, ○ – 80, □ – 100, ▼ – 120, ● – 150

Rys. 7. Skuteczność koagulacji zależnie od gradientu prędkości
– mętność; – – – utlenialność; dawki ałunu (g/m^3): × – 30, △ – 50, ○ – 80, □ – 100, ▼ – 120, ● – 150

The values of velocity gradient indicate that the flocks formed in surface coagulation differ in structure from those in volume coagulation, and that the application of multimedia beds and an apropriate filtration rate, depending on the density of filter medium, are fully justified in case of flocculation.

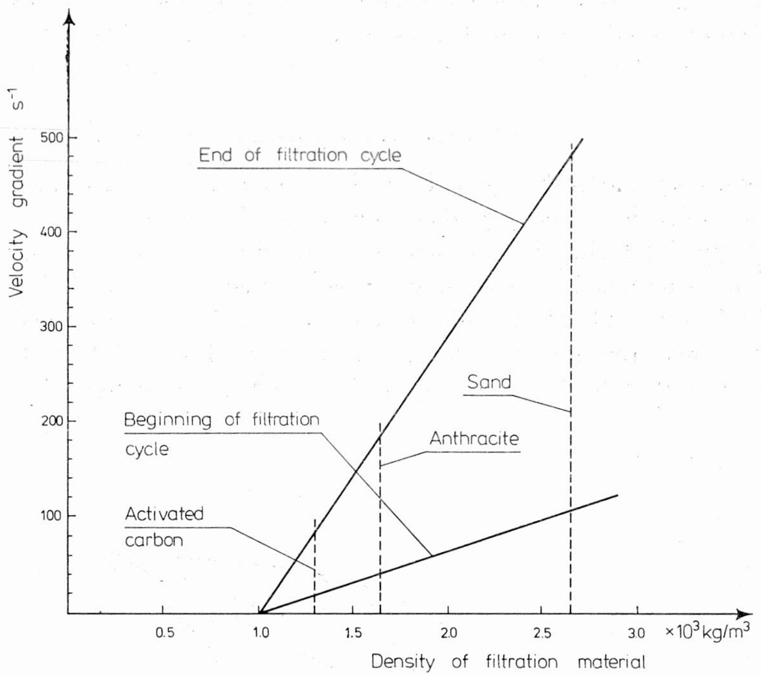

Fig. 8. Velocity gradient in filtration beds
Rys. 8. Gradient prędkości w złożach filtracyjnych

4. CONCLUSIONS

The conducted investigations allowed to state that the course of coagulation is conditioned by physicochemical parameters. It has been shown that impurities removal in volume coagulation occurs at the $\zeta < |-10.0|$ mV. To assure this value the doses of coagulant must increase with the decreasing temperature of water. The efficiency of this process may be improved by adjusting the pH to the optimal value which for the water from the Odra river varied from 6.3 to 5.2 for the temperature ranging within 274.5–295.5 K.

An appropriate course of flocculation is assured by the mixing process at the velocity gradients 20–60 s^{-1}. The same parameters, differing only in values, influence the efficiency of coagulation in filter beds. Thus, removal of water pollutants takes place for ζ ranging from -25.0 mV to -14.5 mV, the utilization of beds, determined by the process efficiency being more effective at higher absolute values of the zeta potential.

This conclusion has been confirmed by the analysis of the growth rate of the filtration head losses, from which it follows that the optimum efficiency of beds occurs at the ζ

reaching -17.0 mV. This value is obtained if the alum dose approaches 50 g/m^3. Coagulation in filter beds being conducted at relatively high values of the zeta potential low temperatures do not disturb the treatment effects, but only influence the time of filter run which can be increased by keeping the optimal pH of the water.

The length of the filter run is connected with the filtration rate, which is determined by flocculation gradient, depending on the filter media density — being higher for lighter beds. The values of velocity gradient indicate that the flocculation conditions in multimedia filters are more advantageous and speak for their utilization in direct coagulation filtration. Of the parameters discussed in the paper electrokinetic potential and velocity gradient should be recognized as the basic technological criteria, the pH of water connected with temperature being of a somewhat less importance.

By employing these criteria to control of coagulation process will assure its appropriate optimization.

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KRYTERIA TECHNOLOGICZNE PROCESU KOAGULACJI SIARCZANEM GLINOWYM

Przedstawiono znaczenie niektórych parametrów zjawisk fizyczno-chemicznych w procesie koagulacji siarczanem glinowym. Spośród omawianych parametrów za podstawowe kryteria technologiczne uznano potencjał elektrokinetyczny i gradient prędkości, a w następnej kolejności odczyn wody związany z temperaturą. Usuwanie zanieczyszczeń z wody zachodziło przy potencjale elektrokinetycznym $\zeta < |-10{,}0|$ mV dla koagulacji objętościowej i w zakresie $-25{,}0$ do $-14{,}5$ mV dla koagulacji w złożach filtracyjnych. Wysoką efektywność flokulacji w koagulacji objętościowej zapewniał gradient prędkości ruchu cieczy w zakresie 20–60 s^{-1}, a w procesie filtracji 15–500 s^{-1}. Gradient prędkości wskazuje na korzystniejsze warunki flokulacji w złożach wielowarstwowych, jak również uzasadnia stosowanie właściwej prędkości filtracji — wyższej dla złóż lżejszych.

Skuteczność koagulacji objętościowej zwiększała się przy zachowaniu optymalnego odczynu, którego wartość uzależniono od temperatury wody. W procesie prowadzonym w złożach filtracyjnych temperatura wpływała nie tyle na efekty oczyszczania, co na długość cyklu filtracji. Wydłużenie cyklu filtracji uzyskano przez zachowanie optymalnego pH.

Prowadzenie koagulacji w warunkach określonych wspomnianymi kryteriami zapewnia jej technologiczną optymalizację.

TECHNOLOGISCHE KRITERIEN DER KOAGULATION MIT ALUMINIUMSULFAT

Im Beitrag wird die Bedeutung der wichtigeren physikalischen und chemischen Faktoren der Koagulation erörtert. Grundlegend ist das elektrokinetische Potential, der Geschwindigkeitsgradient und die Reaktion pH, die (in gewissem Grad) temperaturabhängig ist.

Die normale Koagulation verläuft bei −10 mV, die Koagulation im Filterbett bei −25,0 bis −14,5 mV. Gute Flockung war bei Geschwindigkeitsgradienten zwischen 20–60 s^{-1} erreicht; im Filtrationsvorgang war sie bei 15–500 s^{-1} gesichert. Die Werte des Geschwindigkeitsgradienten weisen auf günstigere Flockungsverhältnisse in Mehrschichtfiltern, was auf höhere spezifische Filtrationsgeschwindigkeiten bei Bettschüttungen kleinerer Dichte zurückzuführen ist. Der Koagulationsverlauf ist pH-abhängig. Die Einhaltung der optimalen pH-Werte bei gegebenen Temperaturen verbessert zwar den Reinigungsgrad in Filtern nicht, verlängert aber deren Laufzeit.

Durch Einhaltung der o. besprochenen Bedingungen, ist die technologische Optimierung abgesichert

ТЕХНОЛОГИЧЕСКИЕ КРИТЕРИИ ПРОЦЕССА КОАГУЛЯЦИИ СУЛЬФАТОМ АЛЮМИНИЯ

Обсуждено значение некоторых параметров физико-химических явлений в процессе коагуляции сульфатом алюминия. Среди рассматриваемых параметров основными технологическими критериями признаны электрокинетический потенциал и градиент скорости, а в следующей очерёдности активная реакция воды, связанная с температурой. Удаление загрязнений из воды осуществлялось при электрокинетическом потенциале $\zeta < |-10,0|$ мВ для объёмной коагуляции в пределах −25,0 до −14,5 мВ для коагуляции в фильтрующих слоях. Высокую эффективность флокуляции в объёмной коагуляции обеспечивал градиент скорости движения жидкости в пределах 20–60 $с^{-1}$, а в процессе фильтрации 15–500 $с^{-1}$. Градиент скорости указывает на более благоприятные условия флокуляции в многослойных фильтрах, а также обосновывает применение соответствующей скорости фильтрации — высшей для более лёгких слоёв.

Эффективность объёмной коагуляции увеличивалась при сохранении оптимальной реакции, значение которой было обусловлено температурой воды. В процессе, проводимом в фильтрующих слоях температура влияла не столько на эффекты очистки, сколько на продолжительность цикла фильтрации. Удлинение цикла фильтрации было достигнуто сохранением оптимального pH.

Проведение коагуляции в условиях, определённых упомянутыми критериями обеспечивает её технологическую оптимизацию.