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TECHNOLOGICAL ASPECTS OF SLUDGE BLANKET COAGULATION

Physicochemical parameters of the sludge blanket process were analyzed. The effects of the sludge blanket flocculation, volume flocculation and surface flocculation processes were compared. The effect of the hydraulic parameters on the sludge blanket efficiency was also investigated.

NOTATIONS

α — exponent,
ε — porosity of sludge blanket,
ϱ_s — flock density,
ϱ — water density,
ν — kinematic viscosity,
a — radius of particle,
$\bar{a}$ — critical radius of particle which settles according to Stokes' law,
C — flock volume concentration,
g — acceleration of gravity,
u_0 — particle sedimentation velocity,
u — flow velocity in fluid bed.

1. INTRODUCTION

The application of the sludge blanket in water treatment processes dates back to the end of the nineteenth century, but the real development in the design of clarifiers has taken place since 1940. Although the general idea of the process is now well known, nevertheless its adequate and complete theoretical description does not exist yet. The process of sludge blanket flocculation should be considered from technological and hydraulic aspects.

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Taking into consideration the mechanism of sludge blanket coagulation alone, this process can be classified among a volume coagulation. This is not so when the hydraulic phenomena associated with the process are considered. In this particular case, sludge blanket coagulation shows an affinity to the process of surface coagulation which occurs in a porous medium. Hence, it can be seen that sludge blanket coagulation is an intermediate process between volume coagulation and surface coagulation. It seems therefore reasonable to compare the effects obtained in either of the two processes.

2. REMOVAL EFFICIENCY

The effectiveness of the coagulation process was estimated in terms of the physical and chemical parameters which characterize the process irrespective of the water to be treated and the coagulation method employed. These parameters are as follows: type and dose of coagulant, temperature and pH of the water, electrokinetic potential, and intensity of mixing expressed by the velocity gradient of fluid motion.

2.1. TYPES OF COAGULANTS

Water coagulation is usually conducted with hydrolysing salts of aluminium and iron as coagulants. Surface waters being generally coagulated with alum, the treatment effects are referred to this compound. Iron salts used as coagulants are less effective in coloured matter removal and are quite good in permanganate COD reduction. Degrees of turbidity removal achieved with alum or iron salts as coagulants are comparable. That is why the study of the coagulation process chiefly concerned turbidity removal.

The investigations included the effect of coagulant dose on turbidity removal and on the amount of residual ions of the hydrolyzed coagulants (Al^{+3} or Fe^{+3}) [7]. It has been found that if the coagulant dose (alum or ferric chloride) increases, so does the efficiency of turbidity removal. When ferric chloride is employed as a coagulant, the turbidity removal efficiency increases until the optimum value of the coagulant dose has been achieved, thereupon it does not increase any more. The amount of residual iron in the effluent decreases with the increasing coagulant dose. Residual aluminium increases, especially when the flow velocity in the sludge blanket is increased. It is interesting to observe that as the coagulant dose increases, the ease with which flocks enter the filter decreases, and that the concentration of aluminium in the flocks is increased.

In conventional method of volume coagulation the concentration of iron in the effluent is usually higher than that of aluminium. The advantage of sludge blanket coagulation is that it requires smaller coagulant doses. Thus, the treatment of the river Odra water by the sludge blanket procedure involved an alum dose by some 40% lower than that required in the conventional system [1]. Similar effects were obtained by coagulation in the filter bed. It is worth noting that in this case the filter run takes a considerably shorter time than in filtration process preceded by sludge blanket coagulation.

2.2. TEMPERATURE AND pH OF THE WATER

The experiments performed with the river Odra water coagulated in a conventional system have substantiated the strong relationship between optimum pH and temperature [2]. The results show that the optimum pH decreases with the increasing water temperature (the rise of temperature from 274.5 K to 295.5 K gave the optimum pH dropped from 6.3 to 5.2). The optimum pH not only strongly influences the treatment efficiency, but also brings about a decrease in coagulant dosage and reduces the concentration of aluminium in the effluent to trace amounts.

The relationship between pH and treatment efficiency remains valid in sludge blanket coagulation. The optimum pH of the river Odra water coagulated via this route was the same as in conventional coagulation. The application of the optimum pH extends substantially the duration of the filter run (fig. 1). As shown by other investigators [7], at pH kept on an optimum level turbidity removal is improved and residual concentrations of metals constituting the coagulant and remaining in the effluent decrease. The optimum pH for alum ranges between 6.5 and 7.0, whereas that for ferric chloride varies from 5.0 to 6.5.

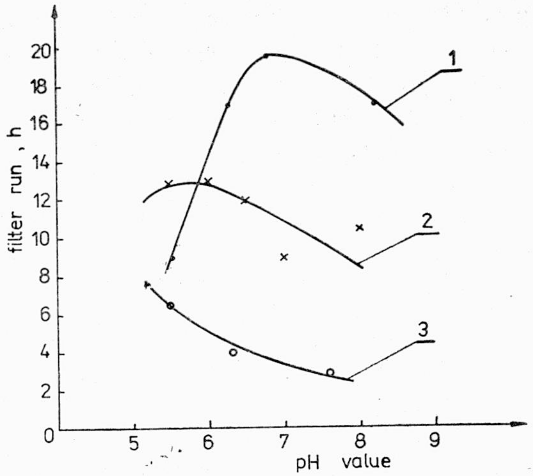

Fig. 1. Filter run vs. pH of water

1 — sludge blanket coagulation and filtration according to [7], *2* — sludge blanket coagulation and filtration according to [1], *3* — coagulation in the sand filter [5]

Rys. 1. Cykl filtracyjny w zależności od pH wody

1 — koagulacja w osadzie zawieszonym i filtracja według [7], *2* — koagulacja w osadzie zawieszonym i filtracja według [1], *3* — koagulacja w złożu piaskowym [5]

2.3. ELECTROKINETIC POTENTIAL

The values of the zeta-potential for the coagulation of polluted water are given in table. As can be seen from this table, the value of electrokinetic potential for the sludge blanket ranges between the zeta-potential values determined for volume- and surface-coagulation being always higher than for volume coagulation. This means that the required degree of destabilization of the colloidal systems may be less and that the coagulant dose to be employed can be smaller than in conventional coagulation. The higher degree of destabilization required in conventional systems can be attributed to the desorption process initiated by the increased velocity gradients in the flocculation tanks. In stabilized filter beds, it is the sorption process that influences the flocculation effects. This is indicated by the flocculation efficiency achieved at a higher zeta-potential and a higher velocity gradient in the porous medium.

Table

Optimum electrokinetic potential for the removal of turbidity, coloured matter and permanganate COD

Optymalny potencjał elektrokinetyczny usuwania mętności, barwy i utlenialności

Pollutant	Volume coagulation	Sludge blanket	Surface coagulation
Turbidity	−10 mV	−16.0 mV	−17.0 to −18.5 mV
Colour	−5 mV	−10.0 mV	—
Permanganate COD	−5 mV	−10.0 mV	−14.0 mV

2.4. VELOCITY GRADIENT

The optimum velocity gradients in the coagulation process involving hydrolysing coagulants vary from 20 to 60 s^{-1} (fig. 2). As sludge blanket coagulation is conducted in conjunction with a sedimentation process, the optimum velocity gradients are lower and amount to several s^{-1} [4] (fig. 2). This is an indication that the hydraulic conditions in sludge blanket flocculation are favourable throughout the process.

Flocculation in filter beds proceeds at different velocity gradients which vary with each change of the filtering medium. They range between 100 and 500 s^{-1} or 15 and 300 s^{-1} for sand beds or double-media filters, respectively [5] (fig. 2).

The analysis of the velocity gradients shows that the flocculation conditions in the sludge blanket differ both from those employed in conventional coagulation in flocculation tanks and those employed in surface coagulation in filter beds.

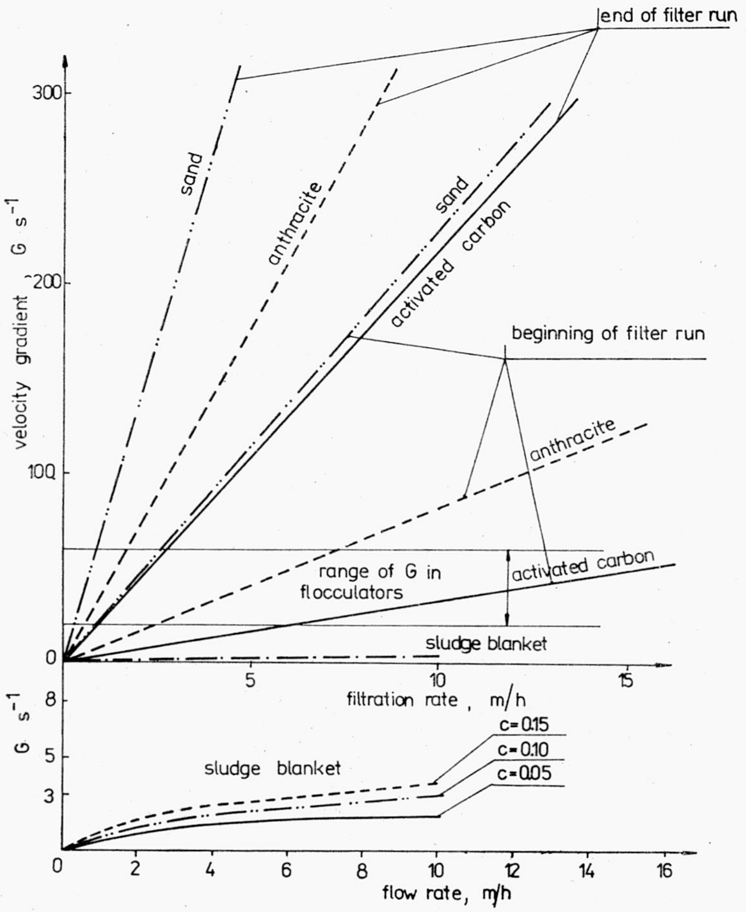

Fig. 2. Velocity gradient of fluid motion in the coagulation process

Rys. 2. Gradient prędkości ruchu cieczy w procesie koagulacji

3. HYDRAULICS OF THE SLUDGE BLANKET

The operation of the sludge blanket is based on the hydrodynamics of fluidized beds which includes separation of phases, mass transfer, mixing conditions, and the structure of the sludge blanket, depending on the water flow conditions. The structural properties of the sludge are described by the coefficient of cohesion k which is a function of flow velocity and water content in the sludge [6]. The suitability of the sludge structure is determined by a coefficient of cohesion between 1.2 and 1.5 m/h. This parameter — as well as an appropriate depth of the sludge layer — has a great influence on the filtration process which follows the coagulation process in the treatment system. The investigation results show that as the depth of the sludge layer increases, so does the duration of the filter run [1]. It is also of interest to mention that the optimum sludge depth employed in engineering practice ranges between 2 and 2.5 m. Velocity gradient and water content are almost constant throughout the sludge layer. As shown by the analysis of the velocity gradient, a 2.0 to 2.5 m deep sludge blanket yields a high removal efficiency (>99%) provided that the volume concentration of the sludge is kept constant at a level of 0.15. If the volume concentration is less, the removal efficiency will decrease even though the sludge depth remains unchanged [4] (fig. 3).

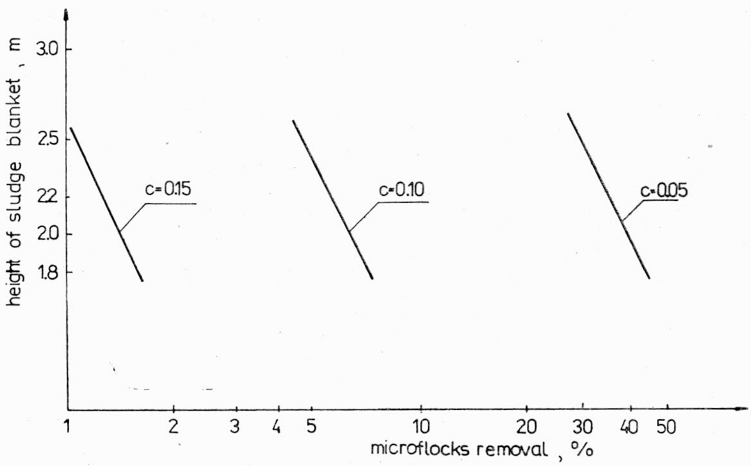

Fig. 3. Particle removals in the sludge blanket

Rys. 3. Usuwanie cząstek w osadzie zawieszonym

The efficiency of the sludge blanket is substantially influenced by the flow velocity of water. The optimum flow velocities are coagulant-dependent and take the following values: 0.6 to 1.3 mm/s, 1.2 to 2.5 mm/s, and 0.8 to 2.0 mm/s for alum, alum combined with activated silica, and chlorinated ferric sulphate, respectively [8]. As shown by the experimental results obtained by the authors of this report the optimum flow velocites tend towards the lower values of the velocity ranges given above.

The hydraulics of the sludge blanket was studied using the example of the Bóbr water treatment involving flow velocities of 0.5 to 10 m/h [3]. The coefficient of cohesion varied from 0.98 to 1.15 m/h.

The effect of temperature on flow velocity was determined from the equations characterizing the fluidized bed [8]

$$u = u_0 \varepsilon^a. \tag{1}$$

The velocity at the beginning of fluidization (which is described by Allen as the sedimentation velocity of a single flock) takes the form

$$u_0 = \frac{1}{2}\left(\frac{\varrho_s-\varrho}{\varrho}g\right)^{2/3}\frac{a-\frac{2}{5}\bar{a}}{\nu^{1/3}}. \tag{2}$$

Hence, the effect of temperature on flow velocity is associated with the change in the viscosity of the water. Thus,

$$\frac{u_1}{u_2} = \left(\frac{\nu_2}{\nu_1}\right)^{1/3}. \tag{3}$$

The effect of flock density on flow velocity at the same temperature is given by

$$\frac{u_1}{u_2} = \left(\frac{\varrho_1-\varrho}{\varrho_2-\varrho}\right)^{2/3}. \tag{4}$$

In the temperature range of 273 to 293 K the velocity ratio varies from 0.825 to 1.0. This means that the flow velocity in the sludge blanket at 273 K decreases by 17.5%. To compensate for the difference in the efficiency of the clarifiers it is necessary that the flock density be in agreement with the relationship

$$\left(\frac{\varrho_{s_1}-\varrho}{\varrho_{s_2}-\varrho}\right)^{2/3} = 1.2, \tag{5}$$

(which holds for temperatures between 273 and 293 K).

As shown by this relationship, it is necessary to increase the flock density ϱ_1 in the water at 273 K by employing polyelectrolytes, so that this density be higher than the density of flocks settling at 293 K.

4. CONCLUSIONS

1. Both removal efficiency and the optimum pH range substantiate the usability of iron salts (rather than alum) as a coagulant in sludge blanket coagulation.
2. Zeta-potential measurements permit a partial explanation o fthe mechanism governing the phenomena that occur during coagulation and results of the method employed.
3. The values of velocity gradients indicate that the flocculation conditions differ from one coagulation method to another.
4. The sludge layer depth for the treatment efficiency required can be calculated from the relationships described by the velocity gradient.
5. Based on the relationships characterizing the fluidized bed the influence of water temperature on the clarifier capacity at unchanged quality of raw water can be established.
6. The decreasing capacity of the clarifiers at low water temperatures may be compensated by increasing the flock density with polyelectrolytes.

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TECHNOLOGICZNE ASPEKTY KOAGULACJI W OSADZIE ZAWIESZONYM

Analizowano fizykochemiczne parametry procesu koagulacji w osadzie zawieszonym. Efekty koagulacji w osadzie zawieszonym porównano z konwencjonalnym procesem koagulacji objętościowej i powierzchniowej. Badano również wpływ parametrów hydraulicznych na sprawność koagulacji w osadzie zawieszonym.

TECHNOLOGISCHE ASPEKTE DER KOAGULATION IM SCHLAMMSCHWEBEBETT

Im Bericht werden die physikalisch-chemischen Parameter des Fällungsprozesses im Schwebeschlamm analysiert. Die Effekte wurden mit dem konventionellen Prozeß der Volumen- und Oberflächenkoagulation verglichen. Untersucht wurde auch der Einfluß der hydraulischen Parameter auf die Leistung der Koagulation im Schlammschwebebett.

ТЕХНОЛОГИЧЕСКИЕ АСПЕКТЫ КОАГУЛЯЦИИ ВО ВЗВЕШЕННОМ ОСАДКЕ

В работе проанализированы физикохимические параметры процесса коагуляции во взвешенном осадке. Эффект коагуляции во взвещенном осадке сопоставлен с традиционным процессом объёмной и поверхностной коагуляции. Исследовалось также влияние гидравлических параметров на выход коагуляции во взвешенном осадке.