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THE EFFECT OF FLOCCULENT DOSAGE ONTO FLOCCULATION KINETICS

WPŁYW DAWKOWANIA FLOKULENTA NA KINETYKĘ FLOKULACJI

Abstract

The effect of flocculent dosage onto flocculation kinetics of kaolin slurry was investigated in baffled tank agitated by a Rushton turbine at given mixing intensity 168 W/m^3 and kaolin concentration 0,58 g/l. Created flocks were separated by sedimentation.

The tests have been carried out at the model wastewater (suspension of tap water and kaolin). The model wastewater was flocculated with organic flocculent Sokoflok 16A (solution 0,1% wt.). The simple semiempirical generalized correlation for flocculation kinetics proposed by Šulc (2003) and the simple semiempirical generalised correlation quantifying the effect of flocculation time and flocculent dosage onto flocculation proposed by Šulc, Ditl (2007) were used for data treatment.

Keywords: flocculation, mixing, turbidity, Rushton turbine, flocculation kinetics

Streszczenie

Wpływ dozowania flokulanta na kinetykę flokulacji gęstej zawiesiny kaolinu badano w mieszalniku zbiornikowym wyposażonym w przegrody i mieszadło turbinowe Rushtona dla mocy mieszania 168 W/m^3 i stężenia kaolinu 0,58 g/l. Wytworzone flokuły oddzielane były z zawiesiny na drodze sedymentacji.

Badania przeprowadzono wykorzystując ścieki modelowe otrzymane z wody wodociągowej i kaolinu. Wytrącanie prowadzono przy użyciu flokulanta Sokoflok 16A (roztwór 0,1%$_{mas}$). Do interpretacji procesu wykorzystano korelację zaproponowaną uprzednio przez Šulca (2003) i bardziej ogólną korelację Šulca i Ditla uwzględniającą czas dawkowania i wielkoś dawki flokulenta.

Słowa kluczowe: flokulacja, mieszanie, zmętnienie, turbina Rushtona, kinetyka flokulacji

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1. Introduction

Flocculation is one of the most important operations in solid–liquid separation processes in water supply and wastewater treatment. The purpose of flocculation is to transform fine particles into coarse aggregates – flocks that will eventually settle for achieving efficient separation. Flocculent dosage is very important parameter in drinking water treatment and wastewater treatment since one strongly affects operation cost of treatment and thus also benefit.

The aim is to determine the effect of flocculent dosage onto flocculation kinetics of kaolin slurry in baffled tank agitated by a Rushton turbine at given mixing intensity 168 W/m^3 and kaolin concentration 0,58 g/l.

2. Generalized correlation for flocculation

The turbidity measurement has been used and recommended for flocculation performance assessment in a routine control in the industry. Then the flocculation efficiency has been frequently expressed as the rate of turbidity removal

$$Z_e^*(t_F) = \frac{Z_e(t_F)}{Z_0} = \frac{Z_0 - Z_r(t_F)}{Z_0} = 1 - Z_r^*(t_F) \tag{1}$$

2.1. Generalized correlation for flocculation kinetics

Šulc [1] proposed generalized correlation for flocculation kinetics in an agitated tank that takes into account flock breaking as follows

$$\Delta Z_r^* = A^* \cdot (\Delta[nt_F]_{log}^*)^2 \tag{2}$$

$$\Delta Z_r^* = \frac{Z_r^* - Z_{r_{min}}^*}{Z_{r_{min}}^*} \tag{3}$$

$$\Delta\left[n \cdot t_F\right]_{log}^* = \frac{\log(nt_F) - \log([nt_F]_{min})}{\log([nt_F]_{min})} \tag{4}$$

The generalized correlation parameters $Z_r{}^*{}_{min}$, $[nt_F]_{min}$ and A^* depend generally on the flocculation process conditions such as mixing intensity, flocculent dosage, …).

2.2. Generalized correlation for flocculation quantifying the effect of flocculation time and flocculent dosage

Šulc, Ditl [2] proposed the simple semiempirical generalized correlation quantifying the effect of flocculation time and flocculent dosage onto flocculation at given mixing intensity in an agitated tank that takes into account flock breaking as follows

$$\Delta Z_r^* = A_{12}^* \cdot (\Delta[nt_F]_{log}^*)^2 + A_{22}^* \cdot \left(\Delta\left[\frac{D_F}{c_{C0}}\right]_{log}^*\right)^2 + B_{11}^* \cdot (\Delta[nt_F]_{log}^*) \cdot \left(\Delta\left[\frac{D_F}{c_{C0}}\right]_{log}^*\right) \tag{5}$$

$$\Delta Z_r^* = \frac{Z_r^* - Z_{r_{min(t,D)}}^*}{Z_{r_{min(t,D)}}^*} \tag{6}$$

$$\Delta\left[nt_F\right]^*_{log} = \frac{\log(nt_F) - \log([nt_F]_{min})}{\log([nt_F]_{min})} \tag{7}$$

$$\Delta\left[\frac{D_F}{c_{C0}}\right]^*_{log} = \frac{\log(D_F / c_{C0}) - \log((D_F / c_{C0})_{min})}{\log((D_F / c_{C0})_{min})} \tag{8}$$

Parameter $Z_r{}^*{}_{min(t,D)}$ and corresponding parameters $[nt_F]_{min}$ and $[D_F/c_{C0}]_{min}$ represent optimal conditions at which the minimum residual turbidity can be reached. The coefficients $A_{12}{}^*$, $A_{22}{}^*$, $B_{11}{}^*$ determine the ratio of residual turbidity change due to flocculation time and flocculent dosage and miscellaneous effect of both variables respectively.

The generalized correlation parameters depend generally on the flocculation process conditions such as mixing intensity, flocculent type, pollution type, temperature, acidity…). The model proposed can be simplified neglecting the miscellaneous term (i.e. assuming that $B_{11}{}^* = 0$).

3. Experimental

3.1. Experimental apparatus

The flocculation experiments were conducted in a fully baffled cylindrical vessel with flat bottom (4 baffles per 90°tank, baffle width $B/D = 0,1$) of diameter $D = 150$ mm, filled in height $H = D$ by a model wastewater – kaolin slurry (tap water + kaolin particles). The vessel was agitated by Rushton turbine of diameter $d = 60$ mm that was placed at an off-bottom clearance of $H_2 = 0,85 \cdot d$. The impeller motor and speed control unit Cole Parmer Servodyne model 50000-25 was used in our experiments. The impeller speed was set up and the value of impeller power input was calculated using impeller power characteristics.

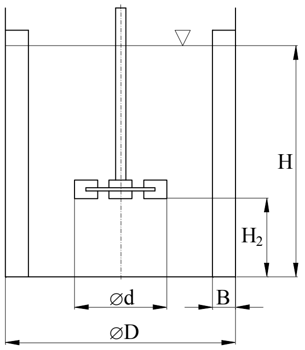

Fig. 1. Experimental apparatus

Rys. 1. Aparatura badawcza

3.2. Experimental procedure

The dependences of residual turbidity on a flocculation time were measured at given mixing intensity ε = 168 W/m^3 for different flocculent dosage. The experimental conditions are summarized in Table 1. Kaolin slurry (suspension of water and kaolin particle) was used as a model system. Solid fraction of kaolin was 580 mg/l, corresponding turbidity 290 FAU approx. The model wastewater was flocculated by the organic polymer flocculent Sokoflok 16A (0,1 % wt. aqueous solution; flocculent weight per flocculent solution volume m_F/V_F = 1 mg/ml). The generated flocks were separated by sedimentation. After sedimentation is finished the clarified water sample was withdrawn. The sampling point was located in the level of upper impeller edge. The sedimentation time was 5 minute. The turbidity of clarified water sample was measured using MultiLab5 (WTW, Germany). The built-in photometer measured turbidity using reference ray method. Turbidity is indicated in FAU unit (Formazine-Attenuation Units).

Table 1

Experimental conditions

		Kaolin concentration
Parameter		c_{C0} = 0,58 [g/l]
ε_V	[W/m^3]	168
n	[rev/min]	290
t_F	[min]	1; 2; 3; 5; 7; 10; 12
D_F	[ml/l]	0,26; 0,52; 1,04; 1,52; 2
Number of date		35

3.3. Experimental data

The turbidity removal degree plotted in dependence on flocculation time for constant flocculent dosage is shown in Fig. 2.

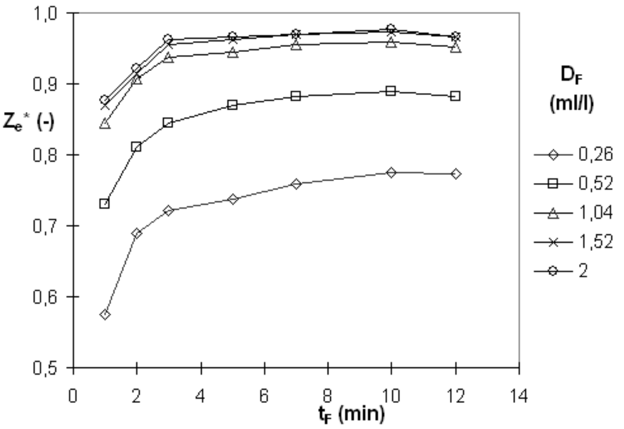

Fig. 2. Experimental data – turbidity removal degree vs. flocculation time for D_F = const

Rys. 2. Wyniki badań – stopień obniżenia zmętnienia w funkcji czasu flokulacji dla D_F = const

Increasing flocculation time the turbidity removal degree increases at given flocculent dosage for all applied flocculent dosages for $t_F \leq 10$ min. For $t_F > 10$ min the turbidity removal degree slightly decreases due to flock breaking. The maximum turbidity removal 97,6% was observed at flocculation time 10 min and flocculent dosage 2 ml/l.

4. Experimental data evaluation

4.1. Generalized correlation $\Delta Z_r^* = f(\Delta[nt_F]^*_{log})$

The measured data were fitted according to this generalized correlation (2). The generalized correlation parameters are presented in the Table 2. The comparison of experimental data and generalized correlation is depicted in Fig. 3.

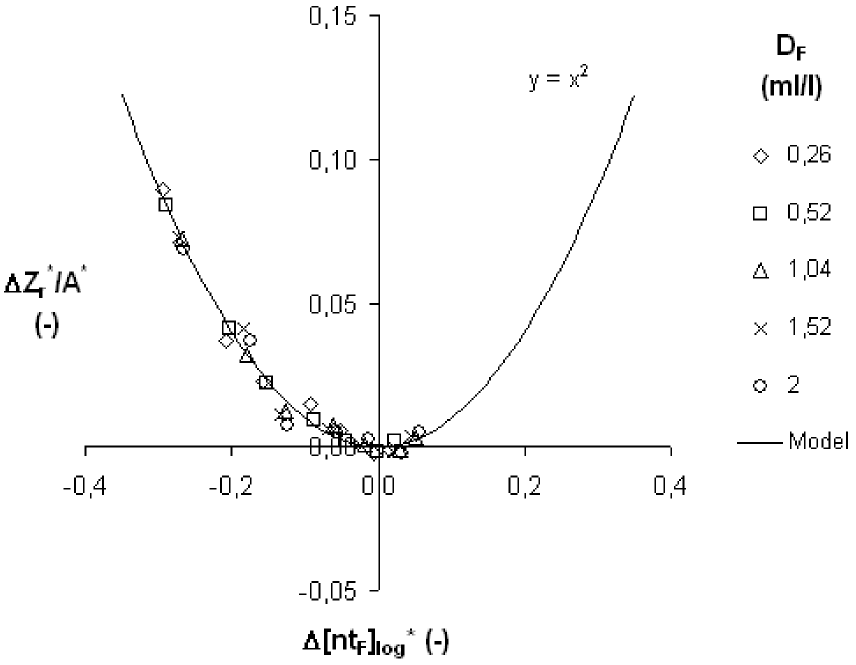

Fig. 3. Generalized correlation $\Delta Z_r^* = f(\Delta[nt_F]^*_{log})$

Rys. 3. Uogólniona korelacja $\Delta Z_r^* = f(\Delta[nt_F]^*_{log})$

The effect of flocculent dosage onto generalized correlation parameters can be confirmed or disproved by a hypothesis testing. The independency of all correlation parameters on flocculent dosage was not confirmed due to hypothesis testing.

Table 2

Generalized correlation $\Delta Z_r^* = f(\Delta[nt_F]^*_{log})$

D_F	A^*	$[nt_F]_{min}$	$t_{F\,min}$	$Z_{r\,min}^*$	$Z_{e\,max}^*$	I_{yx}	$\lvert\delta_r\rvert_{ave/max}^{*1}$
[ml/l]	[-]	[-]	[min]	[-]	[-]	[-]	[%]
0,26	9,4878	3072	10,6	0,2296	0,7704	0,9917	1,03/2
0,52	16,246	2916	10,1	0,1139	0,8861	0,9993	0,2/0,4
1,04	35,622	2316	8	0,0433	0,9567	0,9957	0,3/0,7
1,52	46,824	2453	8,5	0,0293	0,9707	0,9891	0,43/1
2	51,084	2239	7,7	0,0272	0,9728	0,9848	0,51/1,1

Notice: *1 Relative error of turbidity removal degree Z_e^*: average/maximum absolute value.

4.2. Generalized correlation $\Delta Z_r^* = f(\Delta[nt_F]^*_{log}, \Delta[D_F/c_{C0}]^*_{log})$

4.2.1. Model with miscellaneous term (MwMT)

The generalized correlation parameters fitted for measured data are presented in the Table 3. The comparison of experimental data and generalized correlation (5) for $B_{11}^* \neq 0$ is depicted in Fig. 4. The optimal flocculation process parameters calculated are presented in Table 4.

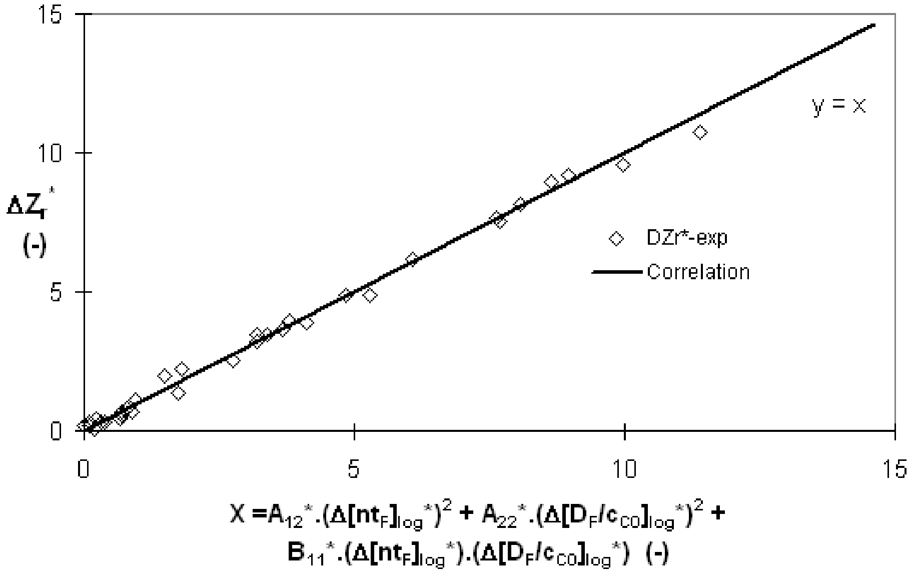

Fig. 4. Generalized correlation (5) – $\Delta Z_r^* = f(\Delta[nt_F]^*_{log}, \Delta[D_F/c_{C0}]_{log}^*) – B_{11}^* \neq 0$

Rys. 4. Uogólniona korelacja (5) – $\Delta Z_r^* = f(\Delta[nt_F]^*_{log}, \Delta[D_F/c_{C0}]_{log}^*) – B_{11}^* \neq 0$

Table 3

Generalized correlation $\Delta Z_r^* = f\,(\Delta[nt_F]^*_{log}\,,\,\Delta[D_F/c_{C0}]^*_{log})$: parameters fitted

Model	A_{12}^*	A_{22}^*	B_{11}^*	$[nt_F]_{min}$	$[D_F/c_{C0}]_{min}$	$Z_{r\ min}^*$	I_{yx}	$\lvert\delta_r\rvert^{*1}$ *ave/max*
	[-]	[-]	[-]	[-]	[mg/g]	[-]	[-]	[%]
MwMT	58,7283	2,84611	6,4539	1976	3,216	0,0264	0,997	0,7/2,5
MwoMT	80,4794	4,89251	0	2910	3,716	0,0176	0,993	¼,1

Notice: *1 Relative error of turbidity removal degree Z_e^*: average/maximum absolute value.

Table 4

Generalized correlation $\Delta Z_r^* = f\,(\Delta[nt_F]^*_{log}\,,\,\Delta[D_F/c_{C0}]^*_{log})$: optimal flocculation process parameters calc

Model	n	$[nt_F]_{min}$	$[D_F/c_{C0}]_{min}$	$Z_{r\ min}^*$	$t_{F\ min}$	$D_{F\ min}$	$Z_{e\ max}^*$
	[rev/min]	[-]	[mg/g]	[-]	[min]	[ml/l]	[-]
MwMT	290	1976	3,216	0,0264	6,8	1,87	0,9736
MwoMT	290	2910	3,716	0,0176	10	2,16	0,9824

Notice: *1 Relative error of turbidity removal degree Z_e^*: average/maximum absolute value.

4.2.2. Model without miscellaneous term (MwoMT)

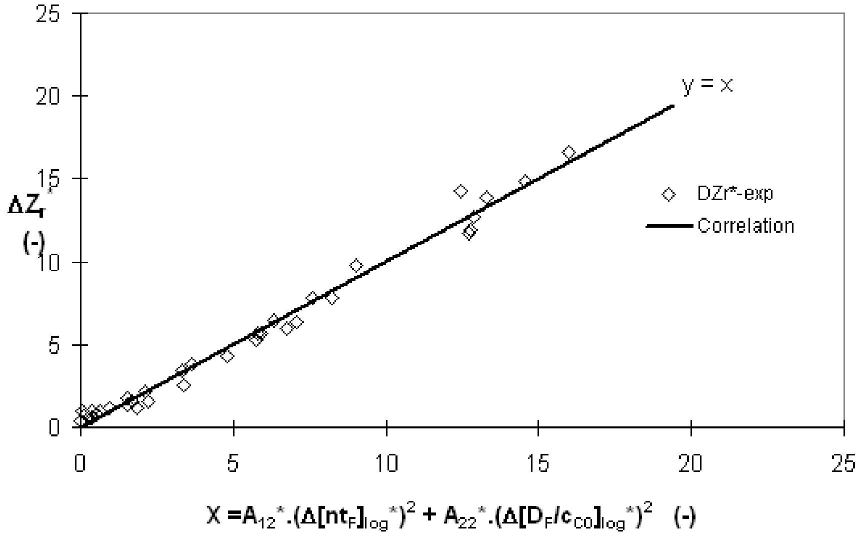

Fig. 5. Generalized correlation (5) – $\Delta Z_r^* = f\,(\Delta[nt_F]^*_{log}\,,\,\Delta[D_F/c_{C0}]_{log}^*) - B_{11}^* = 0$

Rys. 5. Uogólniona korelacja (5) – $\Delta Z_r^* = f\,(\Delta[nt_F]^*_{log}\,,\,\Delta[D_F/c_{C0}]_{log}^*) - B_{11}^* = 0$

The generalized correlation parameters fitted for measured data are presented in the Table 3. The comparison of experimental data and generalized correlation (5) for $B_{11}^* = 0$ is depicted in Fig. 5. The optimal flocculation process parameters calculated are presented in Table 4.

5. Conclusions

The following results have been gained:

The effect of flocculent dosage onto flocculation kinetics of kaolin slurry was investigated in baffled tank agitated by a Rushton turbine at given mixing intensity 168 W/m^3 and kaolin concentration 0,58 g/l. Created flocks were separated by sedimentation.

Kaolin slurry (water + kaolin particles) was used as a model wastewater.

Tests were carried out at a constant particle concentration 580 mg/l. The model wastewater was flocculated by organic flocculent Sokoflok 16A (solution 0,1%wt.).

The dependences of residual turbidity on a flocculation time were measured at given mixing intensity for different flocculent dosage. The turbidity removal degree plotted in dependence on flocculation time for constant flocculent dosage is shown in Fig. 2.

Increasing flocculation time the turbidity removal degree increases at given flocculent dosage for all applied flocculent dosages for $t_F \leq 10$ min. For $t_F > 10$ min the turbidity removal degree slightly decreases due to flock breaking. The maximum turbidity removal 97,6 % was observed at flocculation time 10 min and flocculent dosage 2 ml/l.

Simple semiempirical flocculation kinetics model proposed by [1] was used for data treatment. The generalized correlation parameters are presented in the Table 4. The comparison of experimental data and generalized correlation is depicted in Fig. 3. The effect of flocculent dosage onto generalized correlation parameters was investigated by hypothesis testing. The independency of all correlation parameters on flocculent dosage was not confirmed.

Simple semiempirical generalized correlation quantifying the effect of flocculation time and flocculent dosage onto flocculation proposed by [2] was used for data treatment. The generalized correlation parameters are presented in the Table 3. The comparison of experimental data and generalized correlation is depicted in Fig. 4 and in Fig. 5 respectively. Optimal flocculation process parameters calculated are presented in the Table 4.

Symbols

A^* – residual turbidity shift coefficient; model parameter (2)
A_{12}^* – generalized correlation parameter; model parameter (5)
A_{22}^* – generalized correlation parameter; model parameter (5)
B_{11}^* – generalized correlation parameter; model parameter (5)
D – tank diameter [m]
D_F – flocculent dosage [ml/l]
$[D_F/c_{C0}]_{min}$ – generalized correlation parameter; model parameter (5) [mg/g]
I_{yx} – correlation index

n – impeller rotational speed [rpm]
$[nt_F]_{min}$ – model parameter (2), (5)
t – hypothesis test characteristics
t_F – flocculation time [minute]
$t_{(m-2),\alpha}$ – critical value of t – distribution for (m-2) degrees of freedom and significance level α
t_{sed} – sedimentation time [minute]
Z_0 – turbidity before flocculation [FAU]
Z_r – residual turbidity after flocculation [FAU]
Z_e^* – turbidity removal degree
Z_r^* – residual turbidity degree
$Z_r^*{}_{min}$ – model parameter (2), (5)
α – parameter, significance level
β – parameter
δ_r – relative error [%]
$\Delta[D_F/c_{C0}]^*_{log}$ – variable
$\Delta[nt_F]^*_{log}$ – variable
ΔZ_r^* – variable
ε – specific impeller power input (per volume unit) [W/m^3]

Indexes

* – dimensionless
$*^x$ – link
ave – average
max – maximum
min – minimum

Literature

[1] Šulc R.: *Flocculation in a turbulent stirred vessel (PhD thesis)*, Czech Technical University, Faculty of Mechanical Engineering, Prague 2003 (in Czech).

[2] Šulc R., Ditl P.: *Flocculation of clay slurry in a vessel agitated by Rushton turbine: effect of clay concentration at mixing intensity 40 W/m^3*, in Proceedings of 34th International Conference of Slovak Society of Chemical Engineering SSCHI 2007, Tatranské Matliare, Slovak Republic, 2007.

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