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Radek ŠULC, Pavel DITL

e-mail: radek.sulc@fs.cvut.cz

Department of Process Engineering, Faculty of Mechanical Engineering, Czech Technical University, Prague, Czech Republic

Effect of flocculent dosage onto flocculation kinetics of clay slurry in agitated vessel at mixing intensity 168 W/m³ and clay concentration 0.78 g/l

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 kaolinite clay slurry in baffled tank agitated by a *Rushton* turbine at given mixing intensity 168 W/m^3 and clay concentration 0.78 g/l.

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:

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

where Z_e^* is turbidity removal degree, Z_r^* is a residual turbidity degree, Z_0 is a turbidity of suspension before flocculation starting, Z_e is a eliminated turbidity due to flocculation, Z_r is a residual turbidity of clarified water after flock separation, t_F is the flocculation time.

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

$$\Delta Z_r^* = A_{Zr^*}^* \left(\Delta [Nt_F]_{\log}^*\right)^2 \qquad (2)$$

$$\Delta Z_r^* = \frac{Z_r^* - Z_{r_{\min}}^*}{Z_{r_{\min}}^*} \qquad (3)$$

$$\Delta [Nt_F]_{\log}^* = \frac{\log [Nt_F] - \log([Nt_F]_{\min})}{\log([Nt_F]_{\min})} \qquad (4)$$

where $Z^*_{r\ min}$ is a minimal residual turbidity degree reached at time $[Nt_F]_{min}$, $[Nt_F]_{min}$ is dimensionless flocculation time in that $Z^*_{r\ min}$ can be reached, A^*_{Zr*} is a residual turbidity shift coefficient, t_F is a flocculation time, N is impeller rotational speed.

Šulc, Ditl [2] proposed generalized correlation for flocculation kinetics in an agitated tank that takes into account flock breaking as follows:

$$\Delta Z_r^* = A_{21}^*\left(\Delta [Nt_F]_{\log}^*\right)^2 + A_{22}^*\left(\Delta\left[\frac{D_F}{c_{C0}}\right]_{\log}^*\right) + B_{11}^*\left(\Delta [Nt_F]_{\log}^*\right)\left(\Delta\left[\frac{D_F}{c_{C0}}\right]_{\log}^*\right) \qquad (5)$$

$$\Delta Z_r^* = \frac{Z_r^* - Z_{r_{\min}}^*}{Z_{r_{\min}}^*} \qquad (6)$$

$$\Delta\left[\frac{D_F}{c_{C0}}\right]_{\log}^* = \frac{\log\left(\frac{D_F}{c_{C0}}\right) - \log\left(\left[\frac{D_F}{c_{C0}}\right]_{\min}\right)}{\log\left(\left[\frac{D_F}{c_{C0}}\right]_{\min}\right)} \qquad (7)$$

where Z^*_r is a residual turbidity degree reached at time t_F and flocculent dosage D_F at given mixing intensity, $Z^*_{r\ min(t,D)}$ is a minimal residual turbidity degree that can be reached at time $[Nt_F]_{min}$ and flocculent dosage $[D_F/c_{C0}]_{min}$ at given mixing intensity, $[Nt_F]_{min}$ is a dimensionless flocculation time in that $Z^*_{r\ min(t,D)}$ can be reached, $[D_F/c_{C0}]_{min}$ is a dimensionless flocculent dosage in that $Z^*_{r\ min(t,D)}$ can be reached, A_{12}^*, A_{22}^* are residual turbidity shift coefficients owing to flocculation time and flocculent dosage respectively, B_{11}^* is a miscellaneous turbidity shift coefficient owing to miscellaneous effect of flocculation time and flocculent dosage, D_F is flocculent dosage (flocculent dosage per tank volume; mg/l), c_{C0} is a clay concentration (g/l). The models parameters $[Nt_F]_{min}$ and $[D_F/c_{C0}]_{min}$ represent optimal conditions at which the minimum residual turbidity $Z^*_{r\ min(t,D)}$ 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, etc.). The model proposed allows to calculate the dependence of flocculent dosage on flocculation time for required turbidity removal degree.

Experimental

The flocculation experiments were conducted in a fully baffled cylindrical vessel of diameter D = 150 mm, filled in height $H = D$ by a model wastewater – clay slurry (tap water + kaolinite clay particles). Solid fraction of kaolin was 780 mg/l corresponding turbidity 351 FAU approx. The vessel was agitated by *Rushton* turbine of diameter d = 60 mm that was placed at an off-bottom clearance of H_2/d = 0.85. The baffle width B/D was 0.1. 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). Turbidity is indicated in FAU unit.

Experimental data evaluation

The turbidity removal degree plotted in dependence on flocculation time for constant flocculent dosage is shown in fig. 1.

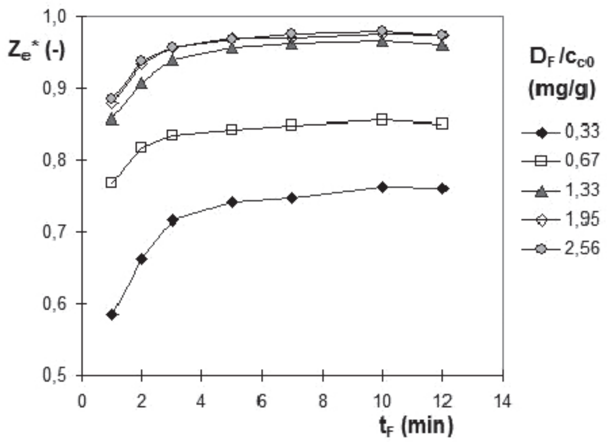

Fig. 1. Experimental data

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 very slightly decreases due to flock breaking. The maximum turbidity removal 98% was observed at flocculation time 10 min and flocculent dosage 2 ml/l. The measured data were fitted according to this generalized correlation (2). The generalized correlation parameters are presented in the tab. 1. The comparison of experimental data and generalized correlation (2) is depicted in fig. 2.

The effect of flocculent dosage onto generalized correlation parameters can be confirmed or disproved by a hypothesis testing. The hypothesis test result and the parameter β evaluated from data is presented in the tab. 2. The independency of all correlation parameters on flocculent dosage was not confirmed.

Tab. 1. Generalized correlation $\Delta Z_r^* = f(\Delta[Nt_F]^*_{log})$: parameters fitted

D_F [ml/l]	$A^*_{Zr^*}$ [-]	$[N.t_F]_{min}$ [-]	$Z^*_{r\ min}$ [-]	t_{Fmin} [min]	$Z^*_{e\ max}$ [mm]	I_{yx}^{*1} [-]	$\delta_{r\ ave}/\delta_{r\ max}^{*2}$ [%]
0.26	8.1254	3418	0.2389	11.8	0.7611	0.996	0.6/1.3
0.52	7.1282	2668	0.1473	9.2	0.8527	0.994	0.33/0.5
1.04	38.991	2587	0.0356	8.9	0.9644	0.998	0.21/0.6
1.52	56.081	2357	0.0234	8.2	0.9766	0.998	0.2/0.5
2	54.419	2492	0.0221	8.6	0.9779	0.998	0.2/0.4

Notice: *1 correlation index.
Notice: *2 Relative error of degree Z_e^*: maximum/average absolute value.

Tab. 2. Correlation parameters – hypothesis testing

Parameter [–]	m [-]	t-distribution $t_{(m-2),\ \alpha = 0.05}$	Relation parameter = $B(D_F/c_{C0})^{\beta}$ β_{calc}	t-characteristics $\lvert t \rvert$ Hypothesis parameter = $B(D_F/c_{C0})^0$ $\beta_{pred} = 0$
$A^*_{Zr^*}$	5	3.1825	1.151	4.2 (No)
$[Nt_F]_{min}$	5	3.1825	– 0.156	3.6 (No)
$Z^*_{r\ min}$	5	3.1825	– 1.301	8.4 (No)
$Z^*_{e\ max}$	5	3.1825	0.13	6.9 (No)

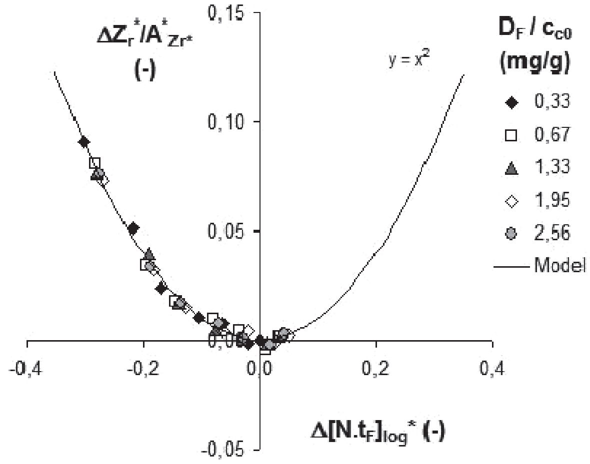

Fig. 2. Generalized correlation: $\Delta Z_r^* = f(\Delta[Nt_F]^*_{log})$ for D_F/c_{c0} = const.

The generalized correlation parameters (5) fitted for measured data are presented in the Table 3. The comparison of experimental data and generalized correlation (5) is depicted in fig. 3. The optimal flocculation process parameters calculated are presented in tab. 4.

Tab. 3. Generalized correlation $\Delta Z_r^* = f(\Delta[Nt_F]^*_{log}, \Delta[D_F/c_{C0}]^*_{log})$: parameters fitted

Model	A_{21}^* [-]	A_{22}^* [-]	B_{11}^* [-]	$[Nt_F]_{min}$ [-]	$[D_F/c_{C0}]_{min}$ [mg_F/g_C]	$Z^*_{r\ min}$ [-]	I_{yx}^{*1} [-]	$\delta_{r\ ave}/\delta_{r\ max}^{*2}$ [%]
(5)	66.493	2.902	5.649	2025	2.790	0.0192	0.996	0.6/1.3

Notice: *1 correlation index.
Notice: *2 Relative error of degree Z_e^*: maximum/average absolute value.

Tab. 4. Generalized correlation $\Delta Z_r^* = f(\Delta[Nt_F]^*_{log}, \Delta[D_F/c_{C0}]^*_{log})$: optimal flocculation process parameters calculation

Model	N [rev/min]	$[Nt_F]_{min}$ [-]	$[D_F/c_{C0}]_{min}$ [mg_F/g_C]	$Z^*_{r\ min}$ [-]	$t_{F\ min}$ [min]	$D_{F\ min}$ [ml/l]	$Z^*_{e\ max}$ [-]
(5)	290	2025	2.790	0.0192	7	2.18	0.9808

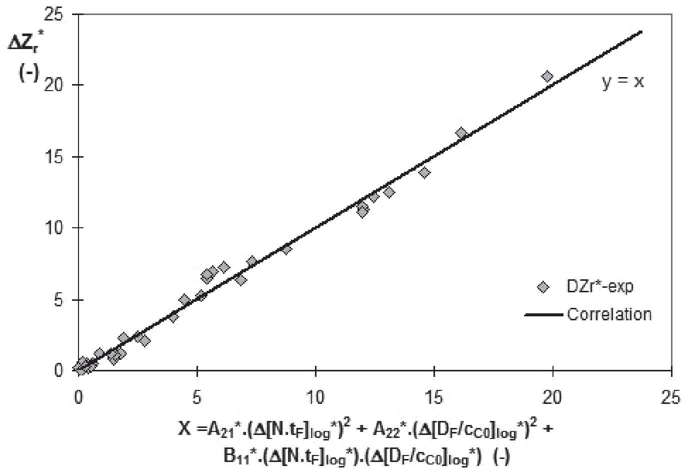

Fig. 3. Generalized correlation (5): $\Delta Z_r^* = f(\Delta[Nt_F]^*_{log}, \Delta[D_F/c_{C0}]^*_{log})$

Conclusions

The effect of flocculent dosage onto flocculation kinetics of clay slurry was investigated in baffled tank agitated by a *Rushton* turbine at given mixing intensity 168 W/m^3 and kaolinite clay concentration 0.78 g/l. Created flocks were separated by sedimentation. The maximum turbidity removal degree 98% was observed experimentally at flocculation time 10 min and dosage 2 ml/l. The experimental data obtained were treated by semi empirical flocculation models proposed by [1] and [2]. The correlation (5) allows to determine optimal flocculation process conditions at which the minimum residual turbidity can be reached and to calculate the dependence of flocculent dosage on flocculation time for required turbidity removal degree. The model predicts maximum turbidity removal degree 98.3% for flocculation time 7 min and dosage 2.176 ml/l for given conditions.

LITERATURE

[1] *R. Šulc*: Flocculation in a turbulent stirred vessel. PhD thesis. Czech Technical University, Faculty of Mechanical Engineering 2003 (in Czech).
[2] *R. Šulc, P. Ditl*: Czasopismo Techniczne – Seria: MECHANIKA. **105**, nr 2, 341 (2008).

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