Prosimy cytować jako: Inż. Ap. Chem. 2010, 49, 1, 111-112



**Radek ŠULC, Ondřej SVAČINA**

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

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

# Effect of flocculant dosage onto flock size at flocculation in agitated vessel

## Introduction

Flocculation is one of the most important operations in solid-liquid separation processes in water supply and wastewater treatment. Flock properties such as size, density and porosity affect the separation process and its efficiency. Thus the knowledge of flock properties in dependence onto operational conditions has been important for the proper design of separation process.

The aim is to propose the simple semiempirical generalized correlation quantifying effect of flocculant dosage onto flock size, to verify experimentally the model proposed and to assess flock shape by fractal dimension.

## Generalized correlation quantifying effect of flocculant dosage

Based on our previous work [1–3] we assume that the dependence of flock size on the flocculant dosage can be given by a simple formula:

$$(1/d_f) = A_f \log^2(D_F/c_{K0}) + B_f \log(D_f/c_{K0}) + C_f, \qquad (1)$$

where $(1/d_f)$ is reciprocal flock size, $D_F/c_{K0}$ is a dimensionless flocculant dosage, $A_f$, $B_f$, $C_f$ are the model parameters, $D_F$ is flocculant dosage (flocculant dosage per tank volume; mg/l), $c_{K0}$ is a initial kaolin concentration (g/l). Then the generalized correlation quantifying effect of flocculant dosage onto flock size can be derived as follows:

$$\Delta(1/d_f)^* = A_f^* \left([D_F/c_{K0}]^*_{\log}\right)^2 \qquad (2)$$

rewritten

$$\frac{d_{f\max}}{d_f} = 1 + A_f^* \left([D_F/c_{K0}]^*_{\log}\right)^2, \qquad (3)$$

where:

$$\Delta(1/d_f)^* = \frac{1/d_f - 1/d_{f\max}}{1/d_{f\max}}, \qquad (4)$$

$$\Delta[D_F/c_{K0}]^*_{\log} = \frac{\log(D_F/c_{K0}) - \log((D_F/c_{K0})_{\max})}{\log((D_F/c_{K0})_{\max})}, \qquad (5)$$

$$A_f^* = \frac{B_f^2}{4A_f C_f - B_f^2}, \qquad (6)$$

where $d_{f\max}$ is a maximal flock size reached at flocculant dosage $[D_F/c_{K0}]_{\max}$, $[D_F/c_{K0}]_{\max}$ is a dimensionless flocculant dosage in that $d_{f\max}$ can be reached, $A_f$ is a flock size shift coefficient and $A_f$, $B_f$, $C_f$ are parameters of Eq. (1). The generalized correlation parameters $d_{f\max}$, $[D_F/c_{K0}]_{\max}$ and $A_f^*$ depend generally on the flocculation process conditions such as mixing intensity, flocculation time, etc.).

## 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 – kaolin slurry (tap water + kaolin particles). Solid fraction of kaolin was 440 mg/l. 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 flock size was determined based on an analysis of images obtained by digital camera in a plane illuminated by a laser light ([3] in detail). The scheme of experimental apparatus for image analysis is shown in Fig. 1. Technical parameters are presented in Tab. 1.

For the camera resolution 800×800 pixels used the scale 1 pixel ∝ 45 μm was found for our images. It corresponds to scanned area 35×35 mm (approx. 6% of tank cross-section area). The model wastewater was flocculated by the organic polymer flocculant *Sokoflok 56A* (medium anionity, 0.1% wt. aqueous solution; flocculant weight per flocculant solution volume $m_F/V_F = 1$ mg/ml; *Sokoflok Ltd*., Czech Republic). Experimental conditions are specified in Tab. 2. During sedimentation the images of flocks passing through the plane illuminated and having 10-bit depth were captured with frame rate 10 $s^{-1}$, exposure = 5 ms, and gain 35 dB. The image capturing starts 20 s after impeller

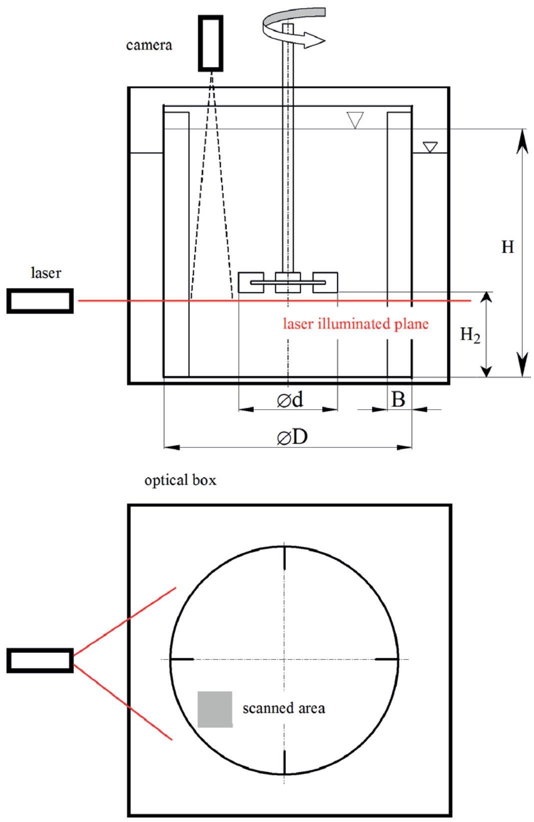


Fig. 1. Schema of experimental apparatus for image analysis

Tab. 1. Technical parameters

| Item | Specification |
|---|---|
| Laser diode | NT 57113, 30 mW, wave length 635 nm (red light), *Edmund Optics*, Germany |
| Diode optics | optical projection head NT54-186, Projection Head Line, *Edmund Optics*, Germany |
| Camera | color CMOS camera *SILICON VIDEO®SI-SV9T001C*, EPIX Inc., USA |
| Camera optics | objective 12VM1040ASIR 10-40 mm, *TAMRON Inc*., Japan |
| Image processing card | PIXCI SI PCI Image Capture Board, *EPIX Inc*., USA |
| Camera control software | *XCAP®*, *EPIX Inc*., USA |
| Operation software | *Linux CentOS version 5.2, Linux kernel 2.6* |
| Software for image analysis | *SigmaScan Pro 5.0* |

Prosimy cytować jako: Inż. Ap. Chem. 2010, 49, 1, 111-112



Tab. 2. Experimental conditions

| Parameter | Kaolin concentration $c_{K0} = 0.44$ g/l |
|---|---|
| $\varepsilon_V$ [W/m$^3$] | 40 |
| $n$ [rev/min] | 180 |
| $t_F$ [min] | 6.66 |
| $nt_F$ [–] | 1200 |
| $D_F$ [ml/l] | 0.4, 1.2, 2, 2.4, 3.2 4.4, 5.6, 6.8, 8 |
| $D_F$ [mg/l] | 0.4, 1.2, 2, 2.4, 3.2 4.4, 5.6, 6.8, 8 |
| $D_F/c_{K0}$ [mg$_F$/g$_K$] | 0.909, 2.727, 4.545, 5.455, 7.273, 10, 12.727, 15.455, 18.182 |
| No. of date | 9 |

shutdown and takes 120 s. Finally 1200 images were obtained for given flocculation experiment and ones were stored into a hard disk as 24-bit jpg format. The images captured were analyzed using *SigmaScan* software and its pre-defined filters ([4] in detail).

## Experimental data evaluation

From images captured the largest flock was identified and its projected area was determined for given flocculant dosage. The dependence of equivalent diameter $d_{feq}$ calculated according to flock area onto flocculation time was fitted according to the generalized correlation (2). The generalized correlation parameters are presented in the Tab. 3. The comparison of experimental data and generalized correlation is depicted in Fig. 2.

For flock shape characterization the fractal dimension of 2$^{nd}$ order $D_{f2}$ was used. The relation among projected area A, characteristic length scale $L_{char}$ and fractal dimension $D_{f2}$ is given by:

$$A = CL_{char}^{D_{f2}} \tag{7}$$

The largest flocks determined in obtained images were used for fractal dimension estimation. The maximum flock size was used as a characteristic length scale. The fractal dimension $D_{f2}$ was determined for each flocculant dosage. For illustration the dependence of projected area on maximum flock size is shown in Fig. 3 for flocculant dosage $D_F = 2$ ml/l (i.e. dimensionless flocculant dosage $(D_F/c_{K0}) = 4.545$ mg$_F$/g$_K$). The fractal dimension $D_{f2}$ plotted in dependence on dimensionless flocculant dosage for given flocculation time and mixing intensity is shown in Fig. 4.

Tab. 3. Generalized correlation $\Delta(1/d_{feq})^* = f(\Delta[D_F/c_{K0}]^*_{\log})$: parameters fitted

| $\varepsilon_V$ [W/m$^3$] | $n$ [rev/min] | $[D_F/c_{K0}]_{max}$ [mg$_F$/g$_K$] | $D_{Fmax}$ [ml/l] | $d_{feq\ max}$ [mm] | $A_f^*$ [–] | $I_{yx}$ *1 [–] | $\delta_{r\ ave}/\delta_{r\ max}$ *2 [%] |
|---|---|---|---|---|---|---|---|
| 40 | 180 | 4.693 | 2.07 | 1.3101 | 0.8215 | 0.9691 | 5/12.8 |

*1 correlation index
*2 relative error of equivalent flock size $d_{feq}$: average/maximum absolute value

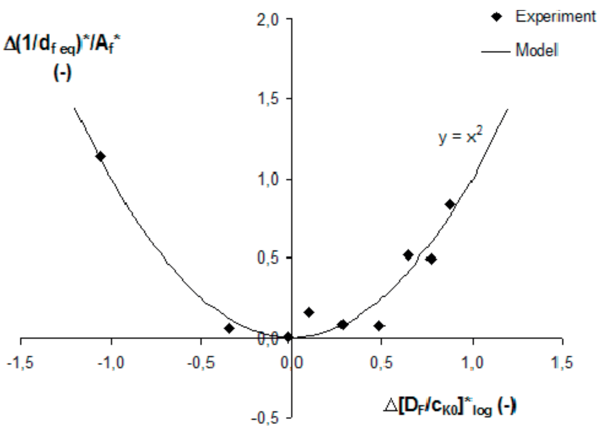


Fig. 2. Generalized correlation $\Delta(1/d_{feq})^* = f(\Delta[D_F/c_{K0}]_{\log}^*)$

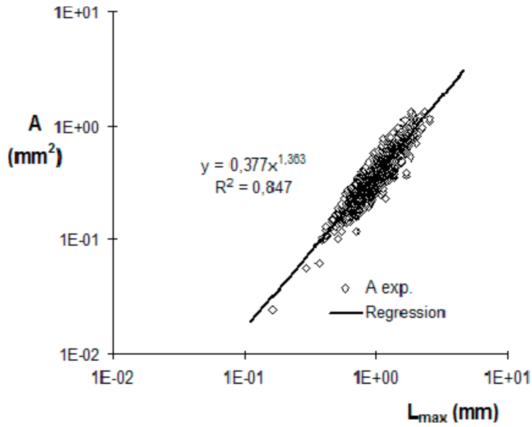


Fig. 3. Fractal dimension determination – example for $D_F = 2$ ml/l

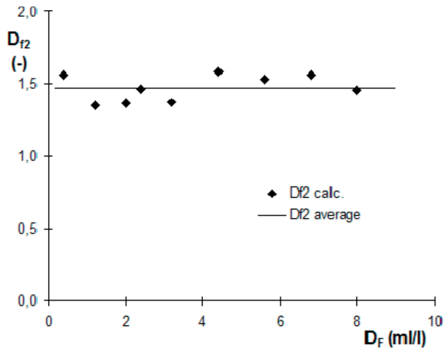


Fig. 4. Fractal dimension vs. dimensionless flocculant dosage – $D_{f2} = f(D_F/c_{K0})$

The effect of flocculant dosage onto fractal dimension $D_{f2}$ was tested by hypothesis testing. The hypothesis test result and the parameter β evaluated from data is presented in the Tab. 4. The fractal dimension was found independent of flocculant dosage and the value $D_{f2} = 1.469 \pm 0.086$ was determined as average value.

Tab. 4. Fractal dimension – hypothesis testing

| $\varepsilon_V$ [W/m$^3$] | m [–] | t-distribution $t_{(m-2),\ \alpha = 0.05}$ | Relation $D_{f2} = B.(D_F/c_{K0})^{\beta}$ $\beta_{calc}$ | t-characteristics \|t\| Hypothesis $D_{f2} = B.(D_F/c_{K0})^0$ $\beta_{pred} = 0$ |
|---|---|---|---|---|
| 40 | 9 | 2.3646 | 0.011 | 0.4 (Yes) |

## Conclusions

The simple semiempirical generalized correlation describing effect of flocculant dosage onto flock size was proposed and used for data treatment. The flock shape was characterized by fractal dimension $D_{f2}$. Using the statistical hypothesis test the fractal dimension was found independent of flocculant dosage and the value $D_{f2} = 1.469 \pm 0.086$ was determined as average value 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).
[3] *R. Šulc, O. Svačina*: submitted in Acta Polytechnica.
[4] *O. Svačina*: Application of image analysis for flocculation process monitoring. Diploma work. Czech Technical University, Faculty of Mechanical Engineering 2009 (in Czech).

***This Research has been subsidized by the Research Project of MSMT of Czech Republic MSM:6840770035.***