Prosimy cytować jako: Inż. Ap. Chem. 2009, 48, 4, 126-127

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Effect of mixing intensity onto flock size at flocculation in agitated vessel

Theoretical background

The equilibrium flock size distribution has been usually characterized by the maximum flock size. The effect of mixing intensity onto this steady-state maximum flock size has been often described for given flocculation system by the following equation:

$$d = C / \varepsilon_{ave}^{m} \tag{1}$$

where C is a coefficient related to the strength of the flocks, m is a coefficient related to the breakup mode and the fractal dimension, ε_{ave} is an average turbulent dissipation rate per unit mass (specific power input). In the literature focusing on a water treatment an average velocity gradient (so called G-value) has been used for mixing intensity characteristics instead of ε_{ave} in eq. (1). Usually three flock breakup mechanisms have been suggested: a) surface erosion [1], b) flock splitting (disruption) due to hydrodynamic stress [9], filament fracture due to tensile failure [5]. The relationship (1) would predict constant flock size for ε_{ave} = const. regardless of tank size. According to *Ducoste* et al. [4] the inability of eq. (1) to properly predict the flocculation performance consists of oversimplification of description of the three-dimensional nature of the turbulence with ε_{ave}.

The eq. (1) assumes steady state. However usually the steady state has not been defined and its achievement has not been proved. It is known the flock breakup occurs mainly in an impeller region. Following it the number of passage through the impeller region should be crucial which was confirmed by *Šulc, Ditl* [7]. Unlike this in the literature the flocculation performances occurring at various process conditions (mixing intensity, tank size) have been compared in the same flocculation time and different contact time with an impeller has not been considered. For flocculation occurred in an agitated vessel *Šulc, Ditl* [7] recommend a dimensionless flocculation time t^*_F defined as the product nt_F (where t_F is a flocculation time, n is an impeller rotational speed) as a scale of flocculation time. The dimensionless time nt_F is proportional to a number of passages of liquid through an impeller. Further the steady-state maximum flock size has been defined as the result of a balance of flock growth and breakup. As the effect of mixing intensity onto flock size could be described unless flock breakup occurs (i.e. flocculation performance decrease is not observed in the course of time). Lastly the agglomeration can occur by various mechanisms (salt-induced flocculation, bridging flocculation, diffusion-limited cluster-cluster aggregation, reaction-limited cluster-cluster aggregation). The relationship between agglomeration, breakup and fluid motion is more complex and this complexity must be respected.

Assuming that mixing intensity can be characterized by turbulent energy dissipation rate and number of passage through impeller region by nt_F then:

$$d = \mathrm{f}\,(\text{flocculation system, physicochemical conditions, flocculator geometry, agglomeration/breakup, agglomeration/breakup mode, aggregate strength, } nt_F, \varepsilon). \tag{2}$$

Assuming the same flocculation system, physicochemical conditions, flocculator geometry, flock breakup by flock splitting due to hydrodynamic stress, *Bouyer* approach [3] and fixed aggregate strength for given physicochemical conditions and constant dimensionless time nt_F then the flock size should show the following trend:

$$d = d(\varepsilon^{-1/4}) \tag{3}$$

Experimental data analysis

Šulc, Ditl [7] investigated the effect of mixing intensity onto flocculation kinetics in baffled tank stirred by *Rushton* turbine. The model wastewater (aqueous suspension of amorphous SiO_2) was flocculated by organic flocculent. Flocks were separated by a sedimentation in the tank. The dependences of residual turbidity on a flocculation time were measured at various mixing intensities (Fig. 1). The flocculation efficiency has been defined as the rate of turbidity removal:

$$Z_e^*(t_F) = \frac{Z_e(t_F)}{Z_0} = \frac{Z_0 - Z_r(t_F)}{Z_0} = 1 - Z_r^*(t_F) \tag{4}$$

where Z_0 is a turbidity before flocculation, Z_r is a residual turbidity after flocculation, Z_e^* is a turbidity removal degree and Z_r^* is residual turbidity degree.

Šulc, Ditl [8] proposed following generalized correlation for flocculation kinetics in an agitated tank that takes into account flock breaking:

$$\Delta Z_r^* = A^*(\Delta[nt_F]^*_{\log})^2 \tag{5}$$

$$\Delta Z_r^* = \frac{Z_r^* - Z_{r_{\min}}}{Z_{r}} \tag{6}$$

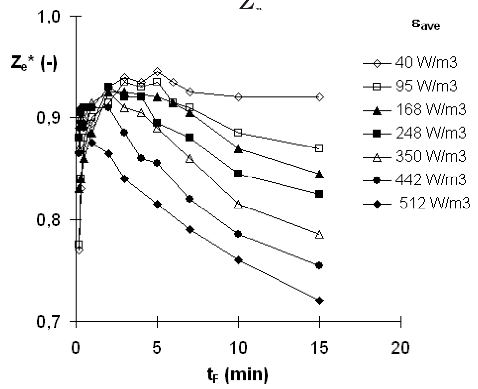

Fig. 1. Turbidity removal degree Z_e^* vs. flocculation time t_F [7]

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Table 1

$1/Z_r^*$ for nt_F = const.

ε_{ave}	e_{imp}	n	$[nt_F]_{min}$	$1/Z_r^*$ [–] for nt_F = const.				
				nt_F [–]				
[W/m^3]	[m^2/s^3]	[RPM]	[–]	1500	2000	2500	3000	4000
40	0.121	180	798	0.0693	0.0759	0.0826	n/a *1	n/a *1
95	0.249	240	641	0.0855	0.0969	0.1080	0.1185	0.1378
168	0.400	290	770	0.0861	0.0985	0.1111	0.1234	0.1464
248	0.553	330	493	0.0971	0.1116	0.1252	0.1378	0.1605
350	0.735	370	534	0.1021	0.1202	0.1372	0.1531	0.1818
442	0.894	400	433	0.1282	0.1469	0.1641	0.1799	0.2079
512	1.010	420	194	0.1671	0.1846	0.1998	0.2133	0.2364
m_{calc}: ε_{imp} ∈⟨0.121÷0.735⟩ m^2/s^3				– 0.206	– 0.242	– 0.266	– 0.237	– 0.25
m_{calc}: ε_{imp} ∈⟨0.894÷1.010⟩ m^2/s^3				– 2.172	– 1.874	– 1.616	– 1.397	– 1.052
m_{calc}: ε_{ave} ∈⟨0.040÷0.351⟩ m^2/s^3				– 0.17	– 0.201	– 0.22	– 0.197	– 0.208

*1 out of measured range

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

where $Z^*_{r\ min}$ is a minimal residual turbidity degree reached at $[nt_F]_{\min}$, $[nt_F]_{\min}$ is a dimensionless flocculation time in that $Z^*_{r\ min}$ can be reached, A^* is a residual turbidity shift coefficient. 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, etc.).

According to *Lambert* law the turbidity Z depends on cross-sectional area of flock σ and flock concentration N_p as follows:

$$Z \propto N_p \sigma \tag{8}$$

Assuming that flock structure is compact and cross-sectional area of flock σ is proportional to flock size d_f

$$\sigma \propto d_f^2 \tag{9}$$

and the particle/flock mass conservation must be fulfilled thus the flock concentration N_p can be expressed as follows:

$$N_p d_j^3 \propto const. \tag{10}$$

then:

$$Z(t_F) \propto 1/d_f(t_F) \tag{11}$$

and for same turbidity before flocculation (i.e. for same initial particle concentration)

$$Z_r^* \propto 1/d_f \tag{12}$$

Using the generalized correlation (5) and the data [7] the residual turbidity degree Z_r^* at given constant dimensionless flocculation time nt_F for various mixing intensities was calculated. Based on *Ducoste* et al. [4] and *Šulc, Ditl* [6] the local turbulent energy dissipation rates per unit mass in an impeller region ε_{imp} were estimated for various mixing intensities. The data are presented in Table 1. The plot of log $(1/Z_r^*)$ vs. log ε_{imp} is depicted in Fig. 2.

Using a local turbulent energy dissipation rate in impeller region ε_{imp} as a mixing intensity parameter the exponent m was found 0.2488 on average in the range ε_{imp} ∈⟨0.121÷0.735⟩ m^2/s^3 for $nt \geq 2000$ which is close to expected value 0.25. For dimensionless flocculation time close to $[nt_F]_{\min}$ the lower value of the exponent m was found ($m = 0.2$ for $nt = 1500$). For ε_{imp} ∈⟨0.894÷1.010⟩ m^2/s^3 the exponent m was found much higher then 0.25 probably due to flock restructuring or intermittency of turbulence [2]. *Argaman, Kaufman* [1] also observed the exponent jump but they did not take it into account. Using an average turbulent energy dissipation rate ε_{ave} as a mixing inmeter the exponent m was found 0.2065 on average in the range ε_{imp} ∈ ⟨0.121÷0.735⟩ m^2/s^3 for $nt \geq 2000$. Comparing to the value of exponent m obtained using ε_{imp} the values of the exponent m calculated using ε_{ave} are regularly shifted approximately by 0.042. This shift reflects the mutual relation between ε_{imp} and ε_{ave}.

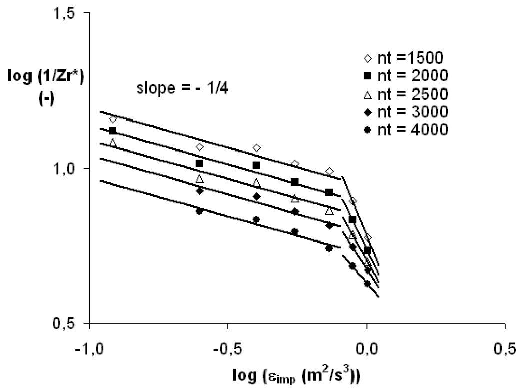

Fig. 2. log $(1/Z_r^*)$ vs. log ε_{imp} for nt_F = const.

R E F E R E N C E S

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