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ASSESSMENT OF THE INFLUENCE OF HYDRODYNAMIC MIXING REGIMES ON FLOC FORMATION AND TREATMENT EFFICIENCY IN THE COAGULATION–FLOCCULATION PROCESS

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Abstract

This thesis assesses the influence of hydrodynamic mixing regimes on floc formation and treatment efficiency in the coagulation–flocculation process. Experiments were carried out with the bentonite–sapropel composite coagulant and a polymer flocculant system, varying the rapid-mix velocity gradient G, the slow-mix gradient and the Camp number (Gt). The optimal rapid-mix gradient was $G \approx 350–500\ s^{-1}$, ensuring rapid reagent distribution and completion of charge neutralisation; an excessive gradient broke the flocs and lowered efficiency. In slow mixing, an optimum of $G \approx 20–40\ s^{-1}$ and $Gt \approx (3–4)\cdot 10^4$ produced the largest ($d_{50} \approx 700\ \mu m$) and strongest flocs. Under the optimal regime turbidity removal reached 96.3 %. The results show that management of mixing energy is a key factor governing floc structure and treatment efficiency.

Keywords: hydrodynamic mixing, velocity gradient, Camp number, floc formation, floc strength, fractal dimension, coagulation, flocculation, treatment efficiency.

1. Introduction

The chemistry of coagulation defines whether particles can aggregate, but hydrodynamics determines whether they actually do. Mixing controls the transport of reagent to colloids, the frequency of particle collisions and the shear that both builds and breaks flocs [2, 3]. The mean shear is quantified by the velocity gradient $G = (P/\mu V)^{1/2}$, and the cumulative shear exposure by the Camp number Gt [1]. An adequate description of the process therefore requires the joint optimisation of the rapid-mix and slow-mix regimes [4].

This work evaluates how rapid-mix and slow-mix hydrodynamics influence floc size, floc strength and treatment efficiency when the bentonite–sapropel composite coagulant is combined with the polymer flocculant system. The aim is to identify the mixing conditions that maximise removal without producing fragile, over-sheared flocs [5, 7].

2. Materials and methods

Model industrial wastewater (turbidity 320 NTU, COD 480 mg L^{-1}) was treated with the composite coagulant (100 mg L^{-1}) followed by the polymer flocculant system. In a programmable jar-test unit the rapid-mix velocity gradient was varied from 100 to 1100 s^{-1} (60 s) and the slow-mix gradient from 15 to 90 s^{-1} (2–30 min), giving Camp numbers Gt between $1.3 \cdot 10^4$ and $8.1 \cdot 10^4$.

Floc size (d_{50}) was measured by image analysis, floc strength as the ratio of re-grown to initial size after a shear pulse, and floc compactness through the fractal dimension D_f derived from size–settling data. Residual turbidity after 30 min of settling defined the treatment efficiency.

3. Results and discussion

Rapid mixing exhibited a pronounced optimum (Fig. 1). Both turbidity removal and floc size rose with G up to about 400 s^{-1} and then fell: insufficient mixing left the coagulant unevenly distributed, whereas excessive shear neutralised this gain by fragmenting nascent aggregates. The maximum removal of 96.3 % coincided with the largest flocs (≈ 700 µm), locating the optimal rapid-mix window at G ≈ 350–500 s^{-1}.

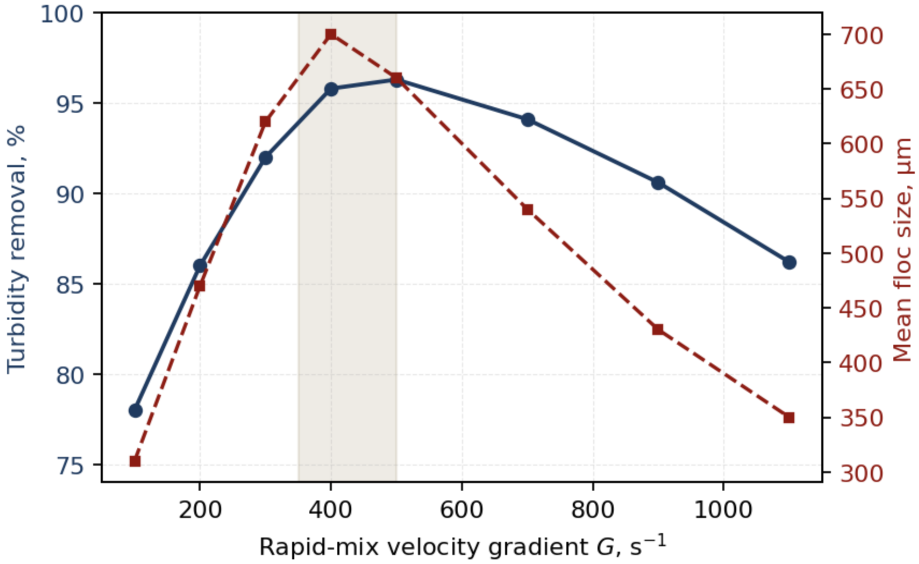

Fig. 1. Turbidity removal and mean floc size as functions of the rapid-mix velocity gradient G.

Slow mixing showed a two-fold dependence on gradient and time (Fig. 2). At a low gradient (G ≈ 20 s^{-1}) flocs grew steadily and plateaued near 700 µm; at higher gradients they grew faster but then eroded, so the size passed through a maximum and declined. The optimum corresponded to G ≈ 20–40 s^{-1} and a Camp number of $(3–4)\cdot10^4$ — enough collisions to build large aggregates yet below the threshold of shear-induced breakage.

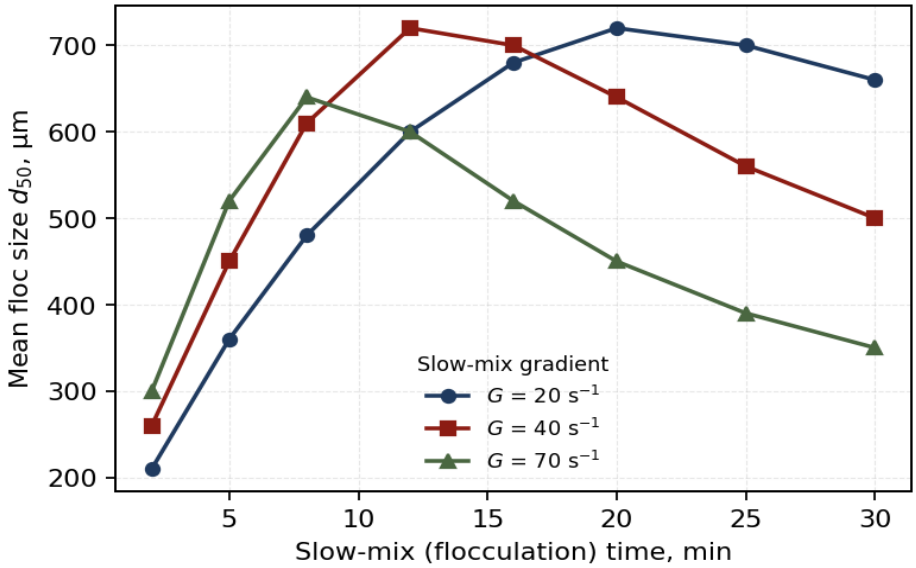

Fig. 2. Evolution of floc size with slow-mix time at different slow-mix velocity gradients.

Table 1 summarises three characteristic regimes. The optimal regime produced the largest flocs with a lower fractal dimension — an open, porous structure that captures more particles — while the under-mixed and over-mixed regimes yielded smaller, more compact flocs and lower removal. This confirms that floc morphology, and hence efficiency, is a direct consequence of the imposed hydrodynamics.

Table 1. Effect of hydrodynamic regime on Camp number, floc fractal dimension D_f and treatment efficiency.

Regime	Rapid-mix G, s^{-1}	Slow-mix G, s^{-1}	Gt, $\times 10^3$	D_f	Removal, %
Insufficient mixing	150	15	13.5	2.55	84.1
Optimal mixing	400	40	36.0	2.10	96.3
Excessive mixing	900	90	81.0	2.62	88.6

The results integrate into a single principle: efficiency is maximised when the rapid mix is intense enough to disperse the coagulant instantly but not so intense as to shear the incipient flocs, and when the slow mix supplies sufficient collisions (Gt) to grow large flocs while remaining below their breakage limit.

4. Conclusions

Hydrodynamic mixing is a decisive control on floc formation and treatment efficiency. A rapid-mix gradient of $G \approx 350$–$500\ s^{-1}$ and a slow-mix regime of $G \approx 20$–$40\ s^{-1}$ with a Camp number of $(3–4)\cdot 10^4$ produced the largest, most porous flocs and the highest turbidity removal (96.3 %). Deviations towards under- or over-mixing reduced both floc size and efficiency, demonstrating that mixing-energy management is an essential design variable of the coagulation–flocculation process.

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