Symposium on Natural and Applied Sciences
Hosted Online from London, United Kingdom
Date: 5th June, 2026
Website: https://econferencia.com

AGGREGATE-FORMATION MECHANISM OF NATURAL AND SYNTHETIC POLYMER FLOCCULANTS AND A COMPARATIVE ANALYSIS OF THEIR EFFICIENCY IN INDUSTRIAL WASTEWATER TREATMENT

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Abstract

This thesis compares the aggregate-formation mechanisms of natural and synthetic polymer flocculants and their efficiency in industrial wastewater treatment. Synthetic polyacrylamide (PAA) and sodium polyacrylate, together with modified natural-based polyacetylcellulose (PAC) and KMS, were studied. High-molecular-mass PAA formed large, strong flocs mainly by a bridging mechanism, whereas anionic sodium polyacrylate exhibited a charge-patch mechanism. Natural flocculants are environmentally safe but produce smaller and looser flocs. Owing to synergism, the composite system (PAA + sodium polyacrylate + PAC + KMS) provided the largest floc size ($d_{50} \approx 820$ μm) and 98.6 % turbidity removal. In settling velocity and residual turbidity the composite system surpassed all individual reagents.

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Keywords: flocculant, polyacrylamide, sodium polyacrylate, polyacetylcellulose, bridging mechanism, charge patch, floc, settling velocity, synergism, wastewater.

1. Introduction

Coagulation destabilises colloids, but the growth of destabilised particles into rapidly settling aggregates is governed by flocculation, in which macromolecular polymers link primary particles into flocs [1, 2]. The nature of the polymer — its molecular mass, charge density and conformation — determines whether aggregation proceeds by interparticle bridging, by charge neutralisation, or by charge-patch attraction [1, 4]. Understanding these mechanisms is essential for selecting a flocculant that yields large, dense and mechanically strong flocs [2, 3].

This study compares synthetic flocculants — polyacrylamide (PAA) and sodium polyacrylate — with modified natural-based flocculants, polyacetylcellulose (PAC) and KMS, and evaluates a composite system that combines all four [4, 5]. The objective is to relate the aggregate-formation mechanism of each polymer class to measurable treatment performance in industrial wastewater [7, 8].

2. Materials and methods

The flocculants studied were high-molecular-mass polyacrylamide (PAA), anionic sodium polyacrylate, polyacetylcellulose (PAC) and KMS. They were applied after primary coagulation of the model effluent (initial turbidity 320 NTU, COD 480 mg L^{-1}). Jar tests used rapid mixing at 200 min^{-1} for 60 s, flocculant addition during slow mixing at 40 min^{-1} for 15 min, and settling for 30 min.

Mean floc size (d_{50}) was determined by image analysis of the settling suspension; residual turbidity was followed nephelometrically during quiescent settling; and

floc strength was characterised by the recovery of size after a controlled high-shear pulse. The composite system was dosed as a pre-blended sequence: PAA and sodium polyacrylate for bridging, PAC and KMS for surface conditioning and floc densification.

3. Results and discussion

Floc size increased with flocculant dose up to an optimum and then declined as excess polymer re-stabilised the particles (Fig. 1). The high-molecular-mass PAA produced the largest single-polymer flocs ($d_{50} \approx 760$ µm) through long-range bridging, whereas the natural-based PAC and KMS gave smaller, more compact aggregates governed by adsorption and local charge patching. Sodium polyacrylate occupied an intermediate position, combining moderate bridging with charge neutralisation.

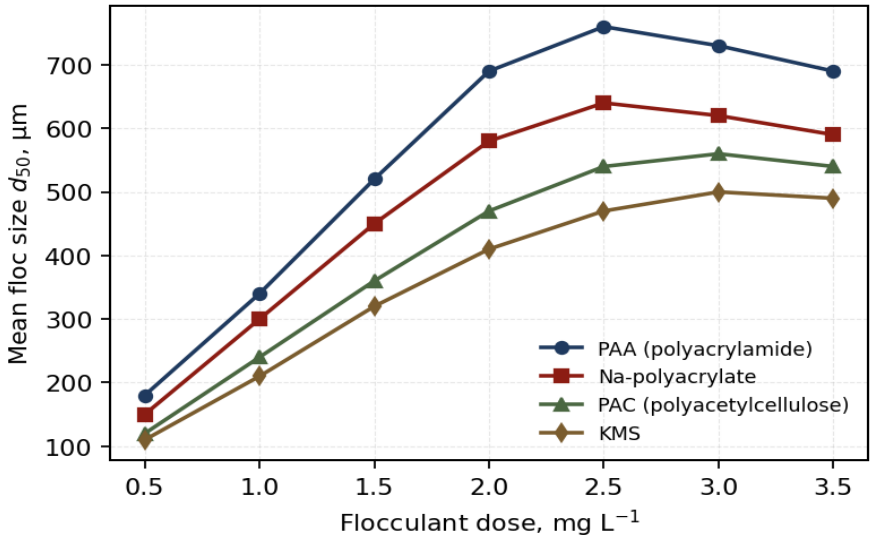

Fig. 1. Mean floc size (d_{50}) as a function of dose for the individual flocculants.

The settling curves (Fig. 2) translate these structural differences into treatment kinetics. Synthetic flocculants cleared the supernatant faster than natural ones, but the composite system reduced residual turbidity below 2 % within 20 min — a performance that neither the synthetic nor the natural class achieved alone. The synergy arises because the bridging polymers build a large open skeleton while PAC and KMS densify and reinforce it, yielding aggregates that are simultaneously large and shear-resistant.

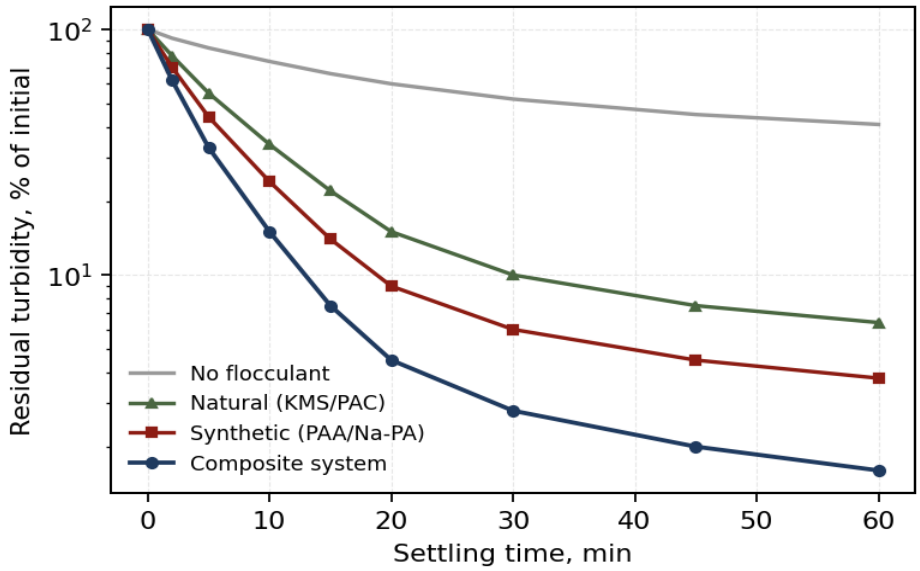

Fig. 2. Residual turbidity versus settling time for the flocculant classes and the composite system.

Table 1 consolidates the comparison. The composite system attained the highest floc size (820 µm), the strongest floc structure and the greatest turbidity removal (98.6 %) at the lowest total polymer dose, confirming that a rational combination of mechanisms outperforms any single flocculant.

Table 1. Aggregate characteristics and treatment efficiency of individual flocculants and the composite system.

Flocculant	Nature / charge	Dose, mg L^{-1}	d_{50}, µm	Removal, %
PAA (polyacrylamide)	Synthetic, high-MW	2.5	760	97.8
Sodium polyacrylate	Synthetic, anionic	2.5	640	96.2
PAC (polyacetylcellulose)	Modified natural	3.0	560	93.5
KMS	Natural-derived	3.0	500	91.8
Composite (all four)	Hybrid system	2.0	820	98.6

Mechanistically, the results confirm two coexisting pathways: long-chain bridging (PAA) that maximises floc size, and adsorption/charge-patch stabilisation (natural polymers) that increases floc density and strength. Their combination reconciles the classic trade-off between floc size and floc robustness.

4. Conclusions

Synthetic and natural polymer flocculants form aggregates by distinct mechanisms — bridging versus charge-patch adsorption — which impose a trade-off between floc size and floc strength. A composite system combining PAA, sodium polyacrylate, PAC and KMS resolved this trade-off, delivering the largest and strongest flocs and 98.6 % turbidity removal at the lowest total dose, thereby demonstrating a clear synergistic advantage for industrial wastewater treatment.

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