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SCIENTIFIC AND TECHNOLOGICAL FOUNDATIONS OF A LOW-WASTE TECHNOLOGY FOR TREATING INDUSTRIAL WASTEWATER WITH COMPOSITE REAGENTS

Razzaqov Hasan Qalandarovich
Professor, Candidate of Technical Sciences,
Professor of the Department of Chemistry and Oil and Gas Technology,
Bukhara State University, Uzbekistan, Bukhara

Amonov Mukhtor Rakhmatovich
Doctor of Technical Sciences, Professor,
Professor of the Department of Chemistry and Oil and Gas Technology,
Bukhara State University, Uzbekistan, Bukhara

Abstract

This thesis develops the scientific and technological foundations of a low-waste technology for treating industrial wastewater with composite reagents. The technology combines the bentonite–sapropel composite coagulant (60:40), potassium–aluminium sulfate and iron (III) chloride, and a polymer flocculant system (sodium polyacrylate, PAC, KMS, PAA). The low-waste character rests on three factors: local and partly reusable reagents, a dense and rapidly dewatering sludge, and valorisation of the sludge into useful products (ceramic and sorbent materials). Compared with the conventional aluminium/iron process, the sludge volume was reduced by 46 %, reagent consumption by 29 %, COD removal reached 94 % and water recovery 96 %. The developed technological scheme and mass balance substantiate the sustainability and environmental soundness of the process.

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Keywords: low-waste technology, composite reagent, coagulation–flocculation, sludge valorisation, reagent regeneration, water recovery, mass balance, industrial wastewater, sustainable technology.

1. Introduction

Conventional coagulation of industrial wastewater is effective but generates large volumes of wet, metal-laden sludge and consumes reagents that are neither locally produced nor recoverable [1, 2]. As environmental standards tighten, the goal shifts from treatment alone to a low-waste technology in which reagent consumption, sludge production and secondary pollution are minimised while treated-water quality and recovery are maximised [6, 7]. Achieving this requires an integrated design rather than the optimisation of a single stage [3, 5].

This work establishes the scientific and technological foundations of such a low-waste process built around composite reagents: the bentonite–sapropel composite coagulant, potassium–aluminium sulfate and iron(III) chloride as auxiliary coagulants, and the polymer flocculant system (sodium polyacrylate, PAC, KMS, PAA). The process is defined by its flow scheme, its mass balance and its waste-minimisation loops [3, 8].

2. Process concept and methods

The technology comprises rapid mixing with the composite coagulant, flocculation with the polymer system, lamellar settling and a polishing filtration stage (Fig. 1). Two internal loops confer the low-waste character: a sludge-handling line that dewaters and valorises the settled solids, and a partial reagent-recovery/reuse line that returns conditioned mineral solids to the coagulation stage. Performance and waste indices were quantified on the model effluent

(COD 480 mg L^{-1}) and benchmarked against a conventional aluminium/iron process.

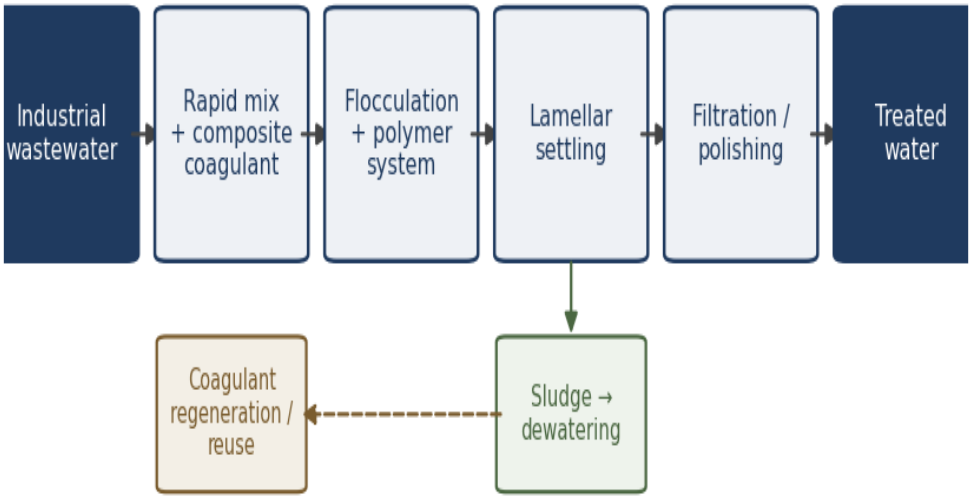

Fig. 1. Technological flow scheme of the low-waste process, showing the sludge-valorisation and reagent-reuse loops.

3. Results and discussion

The composite coagulant is central to the waste reduction. Because its mineral fraction acts as a ballast, it produces a denser sludge that dewaters more readily, lowering the settled-sludge volume and its residual moisture. The organo-mineral nature of the solids also makes them suitable feedstock for ceramic and sorbent materials, converting a disposal liability into a by-product. Relative to the conventional process, sludge volume fell by 46 % and reagent consumption by 29 %, while COD removal rose to 94 % (Fig. 2).

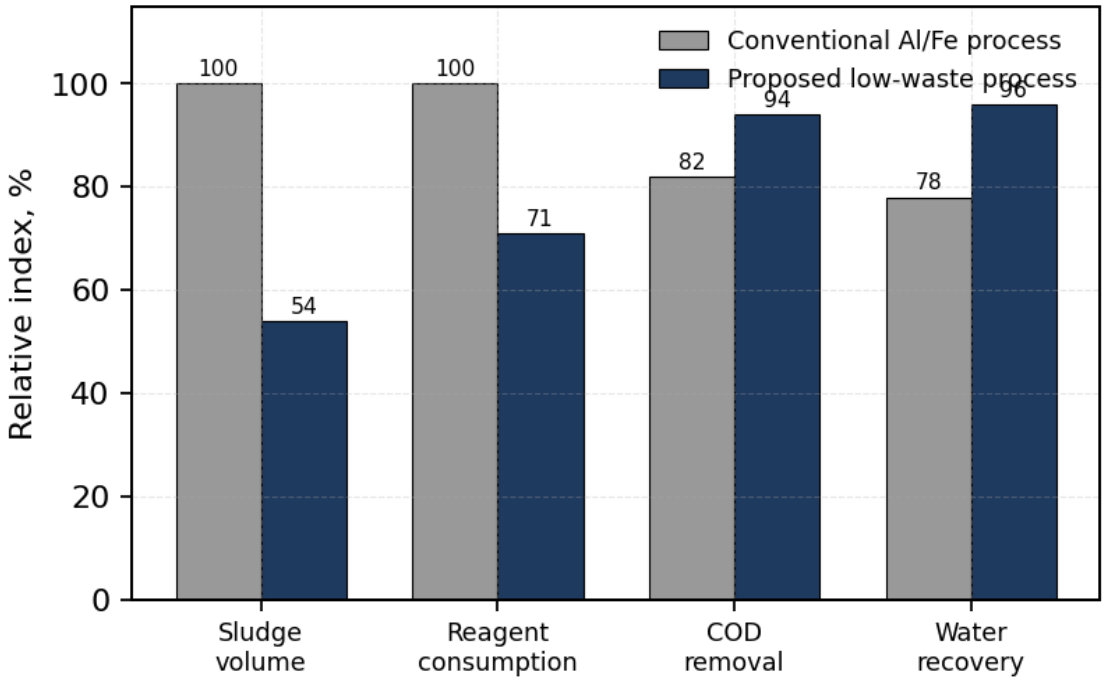

Fig. 2. Relative comparison of the conventional and the proposed low-waste process across key indices.

Table 1 presents the consolidated technological and environmental indicators together with a simplified mass balance. The proposed process simultaneously improves treatment quality and recovery (water recovery 96 %) and reduces waste generation, demonstrating that the two objectives are compatible when composite, locally sourced reagents replace single-function salts.

Table 1. Technological and environmental indicators of the conventional and proposed low-waste processes.

Indicator	Conventional Al/Fe	Proposed low-waste
Turbidity removal, %	93.0	98.4
COD removal, %	82.0	94.0
Specific reagent consumption, g m^{-3}	155	110
Sludge volume, L m^{-3} (relative)	100	54
Sludge moisture after dewatering, %	82	68
Water recovery, %	78	96
Sludge valorisation	none	ceramic / sorbent

The scientific basis of the technology can be summarised as a hierarchy of coupled effects: composite reagents raise coagulation–flocculation efficiency and densify the sludge; the denser sludge lowers dewatering cost and enables valorisation; and the reuse loops cut fresh-reagent demand. Together these convert a linear treat-and-dispose scheme into a nearly closed material cycle.

4. Conclusions

A low-waste technology for industrial wastewater treatment was founded on composite reagents — the bentonite–sapropel coagulant, auxiliary aluminium and iron salts, and the polymer flocculant system — integrated with sludge-valorisation and reagent-reuse loops. The process reduced sludge volume by 46 % and reagent consumption by 29 % while achieving 94 % COD removal and 96 % water recovery, establishing that high treatment quality and minimal waste generation can be attained simultaneously through an integrated, composite-reagent design.

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