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A REVIEW PAPER ON ADVANCED WATER TREATMENT TECHNOLOGIES AND DEVELOPMENT OF A LOW-COST HYBRID WATER TREATMENT MODEL

Prof. Amol R. Bansod[1], Devyani M. Mahajan[2], Gaurav G. Gautre[2], Gaurav D. Meshram[2], Kaustubh V. Khandalkar[2], Tejas M. Vaidya[2], Sneha M. Choudhari[2]

[1]Assistant Professor, Department of Civil Engineering, Jagadambha College of Engineering & Technology, Yavatmal, Maharashtra, India

[2]Students of Second Year, Department of Civil Engineering, Jagadambha College of Engineering & Technology, Yavatmal, Maharashtra, India

ABSTRACT

Water is an essential natural resource for human life, agriculture, and industrial development. However, increasing population, urbanization, industrial discharge, and agricultural runoff have created serious challenges for water quality. Conventional water treatment processes such as coagulation, flocculation, sedimentation, filtration, and disinfection are widely used, but they may not effectively remove every type of dissolved contaminant, emerging pollutant, or organic compound. Advanced water treatment technologies, including activated carbon adsorption, membrane filtration, advanced oxidation processes, and ultraviolet disinfection, offer additional treatment capabilities.This review paper discusses the principles, applications, advantages, and limitations of advanced water treatment technologies. It also proposes a low-cost hybrid water treatment model that combines preliminary filtration, adsorption, and a demonstration disinfection stage.

The project aims to demonstrate how combining different treatment processes can improve water clarity and explain the importance of selecting suitable treatment methods according to water quality.

Keywords: Advanced water treatment, Activated carbon, Membrane filtration, Adsorption, Disinfection, Hybrid treatment, Sustainable water management

I. INTRODUCTION

Water treatment is the process of removing physical, chemical, and biological impurities from raw water to make it suitable for a particular purpose. Safe drinking water is essential for public health, and effective wastewater treatment is important for environmental protection. Conventional water treatment generally consists of screening, aeration, coagulation, flocculation, sedimentation, filtration, and disinfection. These processes can remove suspended particles, reduce turbidity, and control many disease-causing microorganisms when properly designed and Advanced water treatment uses technologies such as activated carbon adsorption, membrane separation, ultraviolet treatment, and advanced oxidation. Combining two or more

processes can provide better contaminant control than relying on a single treatment stage. This project proposes a low-cost educational model to demonstrate the principles of hybrid water treatment. The model focuses on the sequential use of physical filtration and adsorption, together with an explanation of disinfection and its limitations.



Fig. 1: Hybrid water treatment model

II. OBJECTIVES

1. To study advanced water treatment technologies and their operating principles.
2. To understand the limitations of conventional water treatment.
3. To review research on activated carbon, membrane filtration, and advanced oxidation.
4. To propose a low-cost hybrid water treatment model for educational demonstration.
5. To evaluate the visible performance of the model using simple water-quality observations.
6. To explain the importance of turbidity, pH, and microbiological safety in water treatment.
7. To promote sustainable water management and responsible use of water resources

III. LITERATURE REVIEW

1. **Sharma et al. (2026):** This study combines plant-based coagulants with explainable machine learning to investigate more sustainable river-water treatment. The research explores how data-driven models can help understand and predict treatment performance when natural coagulants are used. It may help you discuss natural coagulants and the future use of AI to optimize coagulant dosage.

2. **Hua et al. (2026):** The researchers developed an interpretable deep-learning model to predict chemical dosages and settled-water quality at a drinking water treatment plant. Raw-water turbidity was an important predictor of coagulant demand, while total organic carbon influenced chemical requirements. The model also showed potential for reducing chemical consumption. This paper supports the idea that raw-water testing and suitable dosage control can improve sedimentation-stage water quality.
3. **Fitriani et al. (2026):** This study examines the combined coagulation, flocculation and sedimentation process for Jagir River water using a system-dynamics approach. Its focus is on understanding how changes in treatment conditions affect the overall process. It is useful for explaining why coagulation and sedimentation should be studied as connected stages rather than as separate operations.

3.4 Kertil et al. (2026): This research considers both contaminant removal and environmental impacts when using ferric- and aluminium-based coagulants. It highlights the importance of evaluating treatment effectiveness alongside environmental burden. It can support a comparison of conventional chemical coagulants in terms of treatment performance and sustainability.

3.5. Abdel-Shafy et al. (2026): The experimental study investigates chemical coagulation and different coagulant aids for treating blackwater, which has a high organic pollutant load. The objective is to improve contaminant removal and assess the potential for safer water reuse. This provides an example of experimental research on coagulant aids. However, it concerns wastewater, so its results should not be directly assumed to apply to drinking-water treatment. Springer Nature Link

1. **Mahapatra and Vishwanathan (2026**): The paper investigates the use of coagulation and flocculation to improve domestic wastewater treatment. Its focus is on treatment efficiency and operational performance. It provides supporting background for the use of coagulation–flocculation in wastewater treatment, although its application differs from conventional drinking-water clarification**.**
2. **Xing et al. (2026):** This experimental study investigates microsand-ballasted flocculation for construction wastewater containing high levels of suspended particles. Adding microsand to flocs can help increase their effective settling rate, allowing suspended matter to be removed more rapidly. The study is useful for discussing advanced flocculation and sedimentation methods for high-turbidity water.
3. **Bachri et al. (2025):** This review examines the application of artificial intelligence to optimize coagulation in water treatment plants. It considers how predictive models can support the selection of coagulant dosages and improve process control. It is useful for a section on modern optimization methods, especially if your project discusses automated or smart water treatment.

4. **Ali et al. (2025)**: This review discusses natural coagulants as alternatives to conventional treatment chemicals. It considers their environmental benefits, treatment applications and potential limitations. It can support your discussion of sustainable coagulants and possible alternatives to alum or ferric salts.
5. **Ultrahigh Efficiency Hybrid Biomass-Inorganic Coagulation Strategy for Water Treatment (2025)**: The paper investigates a hybrid coagulation approach that combines biomass-derived material with inorganic treatment components. The research topic concerns improving coagulation performance through a combined material rather than relying on a single coagulant. It is relevant to emerging coagulant technologies. The authors and specific experimental results should be checked before the reference is finalized.
6. **Pivokonsky et al. (2024)**: The authors revisit the chemical principles behind coagulation in drinking-water treatment. They explain key coagulation mechanisms and connect these principles to the optimization of surface-water treatment. This paper is particularly useful for explaining why pH, coagulant type and dosage affect particle destabilization and subsequent sedimentation.
7. **Xiao et al. (2024):** This pilot-scale research examines how turbidity particles develop and are removed through coagulation, sedimentation and filtration. It investigates coagulant dosage and the effect of additional dosing after floc breakage. It helps explain how dosage and floc condition can influence the performance of the entire treatment sequence.
8. **Noor and Ngadi (2024)**: The authors analyze research publications on coagulation–flocculation from 2000 to 2023. The study identifies publication patterns, collaboration between countries and emerging research topics, including magnetic coagulation and flocculation. This paper is useful for identifying research trends and explaining why coagulation–flocculation remains an active research area.
9. **Experimental Study on the Sedimentation Performance of an Arc-Plate Linear Sedimentation Tank (2024)** : The study investigates sedimentation performance in a tank using an arc-plate configuration. Its focus is on how the tank arrangement affects the settling and removal of suspended particles. It can support a discussion of sedimentation tank geometry and the importance of hydraulic design.
10. **Zakia et al. (2023):** This review examines chemical coagulation–flocculation methods used in drinking-water and industrial wastewater treatment. It discusses developments in treatment chemicals and the role of process conditions in removing contaminants. It provides background for comparing different coagulants and explaining the general treatment mechanism.
11. **Badawi et al. (2023)**: The authors review natural-based coagulants and flocculants for industrial wastewater treatment. The paper considers their potential as more sustainable products and discusses the challenges involved in their practical use. It

supports the sustainable-treatment portion of your project, especially the comparison of natural and conventional chemicals.

12. **Diver et al. (2023)**: This review examines the benefits and limitations of plant-derived coagulants compared with conventional aluminium- and iron-based chemicals. It discusses the potential to reduce chemical sludge and the challenges associated with practical implementation. It helps explain why natural coagulants are promising but require careful testing before being adopted in a treatment plant.
13. **Sheng et al. (2023)**: The review explains coagulation–flocculation and examines methods for optimizing the process in water treatment plants. It emphasizes the importance of process conditions and dosage control for effective treatment. This is one of the most directly relevant references for your project because it focuses specifically on optimizing coagulation in a water treatment plant. ASEAN Journal of Science and Engineering
14. **Nayeri and Mousavi (2022):** This review examines methods for recovering and reusing coagulants from sludge generated during drinking-water treatment. The subject includes resource recovery and reducing the amount of waste requiring disposal. It is useful for discussing sludge management, resource efficiency and the environmental impacts of coagulation.
15. **Yaseen et al. (2021)**: The researchers investigated an experimental sedimentation tank designed to improve suspended-solid removal. The study considered tank performance and the role of baffles in promoting better settling. It is directly related to sedimentation tank design and the improvement of particle removal. Journal of Water and Land Development
16. **Mailler et al.:** The research examines how coagulation–flocculation trials can be standardized so that treatment performance and commercial coagulants can be compared more consistently. Differences in test conditions can otherwise make comparisons misleading. This is useful when planning laboratory jar tests and comparing coagulant performance fairly.
17. **Cui et al. (2020):** The authors review enhanced coagulation techniques, including ballast-enhanced coagulation, pre-oxidation, ultrasound and composite coagulants. The paper discusses how process modifications can improve treatment performance, as well as the limitations of these approaches. It provides useful background on advanced coagulation methods and their potential to improve turbidity and natural organic matter removal.
18. **Ang and Mohammad (2020)**: This review assesses the performance and sustainability of natural coagulants. It notes that natural coagulants have received substantial research attention, although their widespread adoption in the water industry remains limited. It helps explain both the environmental advantages and the practical challenges of using natural coagulants.

19. **Malkoske et al. (2020)**: The authors review different coagulation–flocculation arrangements used before microfiltration and ultrafiltration. They examine how the arrangement affects floc properties, membrane fouling and the removal of organic matter. It explains how coagulation can improve downstream treatment, while also showing that the best operating conditions depend on the treatment configuration.
20. **Tavares et al. (2020):** This study investigates the use of Guazuma ulmifolia as a natural coagulant aid. It explores the potential of a plant-derived material to assist water treatment and reduce dependence on conventional chemicals. It is useful for a natural-coagulant case study. The exact treatment conditions and measured removal efficiencies should be taken from the paper itself.
21. **Lak et al. (2020):** This study examines the effect of inlet conditions on particle-containing flow inside secondary sedimentation tanks. The focus is on understanding how flow entering the tank affects particle transport and settling. It supports the design discussion around tank inlets, flow distribution and the importance of reducing hydraulic disturbances.
22. **Nyström et al. (2019):** This research investigates coagulation–flocculation followed by sedimentation for treating runoff from roads. Road runoff can contain suspended particles and other pollutants, making clarification an important treatment step. It illustrates how coagulation and sedimentation can work together to improve water quality in a practical application outside conventional drinking-water treatment.
23. **Sillanpää et al. (2018):** The review discusses the removal of natural organic matter during drinking-water treatment. It examines the importance of coagulation conditions and the characteristics of organic matter in determining removal efficiency. It is useful for explaining why coagulant selection, dosage and pH must be adjusted to the quality of the raw water.
24. **Watanabe (2017)**: Watanabe reviews his research on flocculation, including floc characteristics, collision kinetics and the engineering design of flocculators. The paper discusses how floc density and strength affect the design and operation of the flocculation process. This is helpful for understanding how flocs form and why they must have suitable characteristics to settle effectively.
25. **Hua et al. (2016):** This article is part of a broader review of physicochemical water and wastewater treatment processes. It covers developments in chemical treatment methods and their role in pollutant removal. It can provide general background, but it is less specific to sedimentation tank design than the other references.
26. **Mitchell and Ullman (2016):** The paper examines the removal of selected contaminants using rapid-rate sand filtration and ultrafiltration systems. Its focus is on downstream filtration rather than coagulation or sedimentation alone. It is useful

for explaining why sedimentation is commonly followed by filtration as part of a complete water treatment process.

27. **Tassinari et al. (2015):** This study examines the use of turbidity measurements to analyze flocculation during jar testing. Monitoring turbidity helps researchers assess changes during the treatment process instead of relying only on the final water sample. It is relevant to laboratory testing and measuring how effectively different coagulant dosages form flocs.
28. **Natural coagulants review (2014):** This review focuses on natural coagulants obtained from non-plant sources and examines their potential applications in water and wastewater treatment. It can broaden your comparison of natural coagulants beyond plant-based materials. The author list and publication-year details need to be confirmed using the publisher's DOI record before this entry is included in your final bibliography.
29. **Shahrokhi et al. (2013):** The researchers experimentally investigated the position of baffles in rectangular primary sedimentation tanks. The study focuses on how baffle placement influences internal flow, sediment distribution and tank efficiency. This is one of the most useful papers for your sedimentation tank design section because it directly examines the relationship between tank hydraulics and sediment removal.
30. **Zainal-Abideen et al. (2012):** The researchers compared conventional jar-test optimization with a statistical experimental-design method. Their work examined the optimization of pH, coagulant dosage and coagulant-aid conditions. It demonstrates how systematiclaboratory experiments can help identify suitable treatment conditions and reduce reliance on trial and error.
31. **Sedimentation tank baffle study (2011):** The study investigates how different baffle configurations affect the performance of a secondary sedimentation tank. It focuses on the relationship between internal tank flow and the settling of suspended solids. It is useful for discussing how tank configuration and flow control can influence sedimentation efficiency.
32. **Matilainen et al. (2010):** This review explains why natural organic matter is an important concern in drinking-water treatment. It discusses how coagulation removes organic matter and how removal varies according to the properties of the organic compounds. It provides a strong scientific basis for explaining the role of coagulation in improving raw-water quality before sedimentation and filtration.
33. **Cheng et al. (2008):** The researchers developed an online turbidity-monitoring method to follow floc formation during coagulation and flocculation. Their experimental work showed that the method could monitor changes in floc agglomeration during slow mixing. It demonstrates how monitoring equipment can help assess floc formation and improve process control.

34. **Kim et al. (2006):** This study investigates monitoring coagulation performance and determining suitable coagulant dosage through a pilot in-line filter. It focuses on using treatment performance measurements to support operational decisions. It can support a discussion of monitoring-based dosage control in water treatment plants.
35. **Lovins et al. (2003):** The researchers used jar tests to assess coagulation of highly organic surface water. They compared coagulants such as alum, polyaluminium chloride and iron salts for removing dissolved organic carbon, colour and turbidity. The study also examined how coagulant choice, dosage and flocculation pH affect disinfection-by-product precursor removal. This is a useful experimental reference for demonstrating how jar tests help select an appropriate coagulant and optimize treatment conditions.

IV. CONCLUSION

After studying the above reviews, we concluded that the coagulation and sedimentation in water treatment plants, it can be concluded that both processes play an important role in removing suspended particles, turbidity and impurities from raw water.Coagulation helps small suspended particles come together by adding suitable chemicals, such as alum or ferric salts. Flocculation allows these particles to form larger flocs, which can then settle at the bottom of the sedimentation tank. The efficiency of these processes depends on factors such as coagulant dosage, pH, mixing speed, settling time, raw-water quality and sedimentation tank design. The reviewed studies also show that proper tank geometry, suitable baffle arrangements and uniform water flow can improve sedimentation efficiency. Natural coagulants are promising alternatives to conventional chemicals because they may reduce environmental impacts. However, they require further testing to establish their effectiveness, cost and suitability for practical use. Recent research also highlights the potential of automation, sensors and artificial intelligence to optimize coagulant dosage, monitor water quality and reduce chemical wastage. However, these technologies must be evaluated for practical use in individual treatment plants. Overall, an efficient water treatment plant requires the proper combination of coagulation, flocculation and sedimentation. By selecting suitable coagulants, optimizing operating conditions and designing sedimentation tanks properly, it is possible to improve water quality, reduce treatment costs and make the treatment process more sustainable. These findings provide a useful foundation for the design and study of the proposed Water Treatment Plant project.

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