

Wastewater Oil Separation with Automatic pH Balancing System: A Review

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DOI: <https://doi.org/10.51244/IJRSI.2026.1306000032>

Received: 22 May 2026; Accepted: 28 May 2026; Published: 18 June 2026

ABSTRACT

Industrial wastewater generated from petroleum industries, automobile workshops, food processing plants, textile industries, and chemical manufacturing units contains large quantities of oil contaminants, grease particles, suspended solids, and acidic or alkaline substances. Improper discharge of untreated wastewater causes severe environmental pollution, affects aquatic ecosystems, contaminates groundwater resources, and creates major public health concerns. Conventional wastewater treatment systems often suffer from limitations such as low oil separation efficiency, inaccurate pH control, high manual intervention, and increased operational cost. Therefore, the development of automated wastewater treatment systems integrating efficient oil separation and automatic pH balancing mechanisms has become an important research area in environmental engineering.

This review paper presents a comprehensive study on wastewater oil separation technologies integrated with automatic pH balancing systems. Various oil-water separation methods such as gravity separation, dissolved air flotation, electrocoagulation, membrane filtration, and electromagnetic separation are critically reviewed. The paper also discusses the role of ultrasonic level sensors, pH sensors, solenoid valves, and intelligent control systems in achieving automated wastewater treatment. The proposed system continuously monitors wastewater level and pH conditions while automatically controlling oil separation and chemical dosing processes. Automated pH balancing ensures that treated wastewater remains within the acceptable environmental discharge range.

The review highlights the advantages of automation including improved treatment efficiency, reduced human intervention, accurate monitoring, reduced chemical wastage, enhanced environmental safety, and operational reliability. Challenges such as high installation cost, maintenance requirements, sensor calibration, and energy consumption are also discussed. Furthermore, future developments involving Artificial Intelligence (AI), Internet of Things (IoT), smart monitoring systems, and energy-efficient technologies are analyzed for sustainable wastewater management. The study concludes that integrated oil separation and automatic pH balancing systems provide an efficient, economical, and environmentally sustainable solution for industrial wastewater treatment applications.

Keywords: Wastewater treatment, Oil-water separation, Automatic pH balancing, Industrial wastewater, Electromagnetic separator, Ultrasonic sensor, Solenoid valve, Environmental pollution control, Smart wastewater management, IoT-based monitoring, Industrial automation, Water purification.

INTRODUCTION

Water is one of the most essential natural resources for human survival, industrial development, agricultural activities, and ecological balance. Rapid industrialization and urbanization across the world have significantly

increased the generation of industrial wastewater containing harmful contaminants such as oil, grease, suspended solids, toxic chemicals, heavy metals, and acidic or alkaline compounds. Industries including petroleum refineries, automobile manufacturing units, food processing plants, textile industries, metal machining industries, chemical processing plants, marine industries, and power generation sectors produce large quantities of oily wastewater during various manufacturing and cleaning operations. The improper disposal of untreated wastewater into rivers, lakes, groundwater systems, and oceans causes severe environmental pollution and creates major public health concerns. Oil contamination in wastewater has become one of the major environmental challenges faced by modern industries. Oil and grease present in wastewater form a thin layer on the water surface, reducing oxygen transfer between air and water. This affects aquatic organisms, disturbs photosynthesis, and damages the natural ecosystem. In addition, oily wastewater may contain hazardous hydrocarbons, toxic organic compounds, and chemical pollutants that can accumulate in living organisms and enter the food chain. Long-term exposure to contaminated water may lead to severe environmental degradation and health-related problems. Apart from oil contamination, industrial wastewater also contains acidic and alkaline substances that alter the pH value of water. The pH level is an important parameter in wastewater treatment because it determines the chemical nature of water and directly affects biological and chemical processes. Extremely acidic or alkaline wastewater can corrode pipelines, damage treatment equipment, reduce microbial activity, and negatively affect aquatic life when discharged into natural water bodies. Environmental protection agencies and pollution control boards have established strict wastewater discharge standards requiring industries to maintain pH within an acceptable range, generally between 6.5 and 7.5, before releasing treated water into the environment. In conventional wastewater treatment plants, oil separation and pH balancing are often performed manually. Traditional methods involve periodic monitoring, manual sampling, and manual addition of neutralizing chemicals such as acids or alkalis. However, manual systems suffer from several limitations including inaccurate measurements, delayed response time, increased labor cost, inconsistent treatment quality, and higher chances of human error. Moreover, conventional oil separation methods such as gravity separation are often ineffective for removing fine or emulsified oil particles from wastewater. To overcome these challenges, automated wastewater treatment technologies have gained significant attention in recent years. Modern industrial wastewater management systems integrate advanced sensors, automatic control mechanisms, intelligent monitoring systems, and efficient oil separation techniques to improve treatment performance and operational reliability. Automation not only reduces human intervention but also enhances treatment efficiency, ensures continuous monitoring, minimizes chemical wastage, and improves environmental safety. The proposed “Wastewater Oil Separation with Automatic pH Balancing System” is an advanced wastewater treatment approach designed to automatically remove oil contaminants and maintain proper pH balance before water discharge. The system integrates multiple components such as ultrasonic level sensors, electromagnetic oil separators, pH sensors, solenoid valves, chemical dosing units, and automated controllers to achieve efficient wastewater treatment. The process begins with the collection of industrial wastewater in a storage or base tank. An ultrasonic sensor continuously monitors the liquid level and activates the treatment process when the wastewater reaches a predefined limit. After level detection, the wastewater passes through an electromagnetic oil separation unit where oil particles are separated from water using electromagnetic or electrocoagulation principles. The separated oil is then transferred to a dedicated storage tank for recycling or disposal. The filtered water subsequently enters a pH balancing chamber where a pH sensor continuously measures the acidity or alkalinity of the water. Depending on the measured pH value, the control system automatically opens solenoid valves to add acidic or alkaline solutions for neutralization. Once the pH reaches the permissible neutral range, the treated water is safely discharged or reused for industrial applications. The increasing demand for sustainable industrial practices and stricter environmental regulations has accelerated research in automated wastewater treatment technologies. Researchers worldwide are exploring advanced oil-water separation techniques such as membrane filtration, dissolved air flotation, electrocoagulation, magnetic separation, adsorption methods, and nanotechnology-based filtration systems. Similarly, smart pH balancing systems integrated with Programmable Logic Controllers (PLC), Internet of Things (IoT), Artificial Intelligence (AI), and real-time monitoring technologies are becoming increasingly popular for industrial wastewater management. One of the significant advantages of automated wastewater oil separation systems is the reduction in operational cost and environmental impact. Automated systems optimize chemical usage, reduce energy consumption, improve separation efficiency, and enhance water recycling opportunities. Industries can reuse treated water for cooling systems, cleaning operations, and manufacturing processes, thereby conserving freshwater resources and

supporting sustainable development goals. Furthermore, the integration of smart sensors and automation technologies allows continuous monitoring of critical treatment parameters such as oil concentration, water level, flow rate, turbidity, and pH value. Real-time monitoring improves system reliability and enables immediate corrective action whenever abnormal conditions are detected. The use of intelligent control systems also minimizes maintenance requirements and improves overall plant productivity. Despite numerous advantages, automated wastewater treatment systems also face certain challenges. High installation costs, sensor calibration issues, maintenance complexity, power consumption, and handling of highly contaminated wastewater remain major concerns in industrial applications. In addition, effective treatment of stable oil emulsions and fluctuating wastewater characteristics requires further technological advancements and optimization techniques. In recent years, environmental sustainability and water conservation have become critical priorities for industries and governments worldwide. The development of intelligent wastewater treatment systems capable of efficient oil separation and automatic pH balancing plays a vital role in reducing industrial pollution and protecting natural water resources. Therefore, continuous research and innovation in this field are essential for achieving safe, economical, and environmentally friendly wastewater management solutions. This review paper focuses on the analysis of various wastewater oil separation techniques and automatic pH balancing technologies used in industrial wastewater treatment systems. The paper also discusses the working principles, advantages, limitations, applications, and future scope of automated wastewater treatment systems. The integration of oil separation mechanisms with intelligent pH control systems represents an important step toward smart environmental engineering and sustainable industrial development.

LITERATURE REVIEW

Industrial wastewater treatment involving oil-water separation and automatic pH balancing has attracted significant research attention over the past few decades due to increasing environmental concerns and strict pollution control regulations. Researchers have explored various physical, chemical, electrochemical, and automated control methods to improve wastewater treatment efficiency. Several studies have focused on oil separation technologies, while others have emphasized intelligent pH control systems and industrial automation techniques. The following literature review discusses important contributions made by researchers in the field of wastewater oil separation and automatic pH balancing systems.

Metcalf and Eddy (2014) presented one of the most comprehensive studies on wastewater engineering and industrial treatment technologies. Their research explained the importance of primary, secondary, and tertiary treatment processes for industrial wastewater management. The authors highlighted that oil and grease contamination in industrial wastewater creates operational problems in treatment plants and severely affects aquatic ecosystems. They discussed traditional oil separation methods such as gravity separators, skimmers, and dissolved air flotation systems. The study also emphasized the importance of pH control in maintaining biological treatment efficiency and preventing corrosion in pipelines and treatment equipment. Their work became a fundamental reference for modern wastewater treatment system design.

Tchobanoglous, Burton, and Stensel (2013) investigated advanced wastewater treatment technologies used in industrial applications. Their research focused on wastewater characteristics, environmental discharge standards, and modern treatment methodologies. The authors explained that maintaining wastewater pH within the acceptable discharge range is essential for environmental safety and efficient treatment operations. They analyzed different neutralization techniques involving acidic and alkaline dosing systems. The study also highlighted the advantages of automation in wastewater treatment plants, including reduced human error, improved treatment accuracy, and continuous monitoring capability.

Chen (2004) conducted detailed research on electrochemical technologies in wastewater treatment systems. The study mainly focused on electrocoagulation and electrochemical oil separation processes for oily industrial wastewater. Chen explained that electrochemical treatment methods are highly effective in removing emulsified oil particles, suspended solids, and toxic contaminants from wastewater. The research demonstrated that electrocoagulation technology can significantly improve oil-water separation efficiency compared to conventional gravity separation techniques. The author concluded that electrochemical methods reduce chemical consumption and provide faster wastewater treatment, although higher energy consumption and electrode maintenance remain important limitations.

Ahmad, Sumathi, and Hameed (2006) studied coagulation techniques for removing oil and suspended solids from industrial wastewater generated in palm oil processing industries. The researchers used chitosan as a natural coagulant for wastewater treatment and evaluated its effectiveness in reducing oil concentration and turbidity. Their results showed significant improvement in oil removal efficiency and water clarity. The study highlighted that proper pH adjustment plays a major role in improving coagulation performance. The researchers concluded that coagulation combined with pH balancing can provide an economical and environmentally friendly solution for oily wastewater treatment.

Ibrahim (2011) investigated various oil-water separation techniques used in industrial wastewater treatment plants. The author reviewed physical, chemical, and membrane-based separation technologies and compared their performance characteristics. The study explained that traditional gravity separation systems are effective only for free-floating oil particles and cannot efficiently remove stable emulsified oil. Ibrahim emphasized that advanced separation methods such as electrocoagulation, membrane filtration, and dissolved air flotation provide better treatment efficiency. The author also stressed the importance of automation and real-time monitoring in improving wastewater treatment reliability.

Zhao, Liu, and Wang (2014) researched the application of membrane technology for oily wastewater treatment. Their study focused on ultrafiltration and nanofiltration membranes capable of removing microscopic oil droplets and dissolved contaminants. The researchers found that membrane filtration systems offer high purification efficiency and excellent water quality. However, membrane fouling and high operational costs were identified as major challenges affecting long-term performance. The study suggested integrating automatic cleaning systems and pH monitoring units to improve membrane life and treatment stability.

Singh (2016) analyzed dissolved air flotation (DAF) technology for industrial wastewater treatment. The research explained that DAF systems inject fine air bubbles into wastewater, allowing oil particles and suspended contaminants to float to the surface for removal. Singh reported that DAF systems achieve high oil removal efficiency and are widely used in petroleum, food processing, and chemical industries. The study also highlighted the importance of maintaining proper pH conditions during flotation processes to achieve maximum separation efficiency.

Kumar and Verma (2020) developed an automatic pH monitoring and control system for industrial wastewater treatment plants. Their research focused on the integration of pH sensors, microcontrollers, and solenoid valves for automatic neutralization processes. The system continuously monitored wastewater pH and automatically controlled chemical dosing based on sensor readings. Experimental results demonstrated improved pH stabilization accuracy, reduced chemical wastage, and faster treatment response time compared to manual control systems. The researchers concluded that automated pH balancing systems significantly improve industrial wastewater treatment performance.

Patel and Shah (2021) proposed a smart wastewater management system using Internet of Things (IoT) technology and automation. Their research integrated pH sensors, turbidity sensors, ultrasonic level sensors, and wireless communication systems for real-time wastewater monitoring. The developed system allowed remote supervision and automatic control of wastewater treatment operations through cloud-based platforms. The authors emphasized that IoT-enabled systems reduce operational costs, improve monitoring efficiency, and support predictive maintenance in industrial wastewater treatment plants.

Li and Zhang (2022) investigated advanced oil-water separation technologies for industrial wastewater treatment applications. Their study reviewed modern separation techniques including magnetic separation, nanomaterial-based filtration, electrochemical treatment, and smart automated systems. The researchers concluded that intelligent wastewater treatment systems integrating oil separation and automatic pH balancing provide better environmental protection and higher operational efficiency. The study also highlighted the future importance of Artificial Intelligence (AI) and machine learning algorithms in optimizing wastewater treatment processes.

Rana and Gupta (2019) examined the role of sensor-based automation in wastewater treatment systems. Their research focused on real-time monitoring of wastewater parameters such as pH, turbidity, temperature, and oil

concentration. The authors developed an automated control framework capable of reducing manual intervention and improving treatment consistency. Their findings showed that automated wastewater treatment systems provide better process control, faster response time, and improved environmental compliance.

Sharma and Kulkarni (2018) studied electrocoagulation technology for oily wastewater treatment generated from automobile industries. The researchers analyzed the effects of current density, electrode material, and pH conditions on oil removal efficiency. Experimental results showed that electrocoagulation effectively removes oil and suspended solids while reducing chemical oxygen demand (COD) in wastewater. The study concluded that integrating automatic pH balancing systems with electrocoagulation units enhances overall treatment performance.

Verma and Singh (2020) researched PLC-based industrial wastewater treatment automation systems. Their study involved automatic control of pumps, valves, sensors, and chemical dosing units using programmable logic controllers. The developed system achieved stable wastewater treatment performance with minimal operator involvement. The researchers highlighted that PLC-based automation improves reliability, reduces operational errors, and enables continuous industrial wastewater treatment.

Karthikeyan et al. (2021) explored smart environmental monitoring systems for industrial wastewater treatment applications. Their research integrated wireless sensor networks with automated wastewater treatment units for real-time monitoring and control. The study demonstrated that smart monitoring systems improve treatment efficiency and reduce maintenance requirements. The authors suggested that future wastewater treatment systems should incorporate AI-based predictive analysis for improved operational decision-making.

Overall, the reviewed literature indicates that wastewater oil separation and automatic pH balancing systems are essential for modern industrial wastewater treatment applications. Researchers have demonstrated the effectiveness of advanced oil separation methods such as electrocoagulation, membrane filtration, dissolved air flotation, and electromagnetic separation. Similarly, automated pH balancing systems using sensors, microcontrollers, PLCs, and IoT technologies have shown significant improvement in treatment efficiency and environmental protection. However, challenges related to energy consumption, maintenance cost, sensor calibration, and treatment of highly contaminated wastewater still require further research and technological development.

Summary of Literature Review

The literature review indicates that industrial wastewater treatment has become an important research area due to rapid industrialization and increasing environmental pollution. Various researchers have studied different techniques for oil-water separation and automatic pH balancing in order to improve wastewater treatment efficiency and environmental safety. Traditional wastewater treatment methods such as gravity separation and manual chemical dosing were found to be simple and economical; however, these methods suffer from limitations including low separation efficiency, slow processing speed, and high dependence on manual monitoring. Researchers such as Metcalf and Eddy (2014) and Tchobanoglous et al. (2013) emphasized the importance of maintaining wastewater quality and controlling pH before environmental discharge.

Several advanced oil separation technologies including electrocoagulation, dissolved air flotation, membrane filtration, and electromagnetic separation have been investigated by different researchers. Chen (2004) and Sharma and Kulkarni (2018) reported that electrochemical and electrocoagulation methods significantly improve oil removal efficiency, especially for emulsified oil particles. Similarly, Zhao et al. (2014) demonstrated that membrane filtration systems provide excellent purification performance, although membrane fouling and high maintenance costs remain major challenges. Singh (2016) explained that dissolved air flotation systems are highly effective for removing suspended oil contaminants from industrial wastewater.

The literature also shows significant progress in automation and intelligent monitoring technologies for wastewater treatment systems. Researchers such as Kumar and Verma (2020), Patel and Shah (2021), and Verma and Singh (2020) developed automated pH balancing and wastewater monitoring systems using sensors, microcontrollers, PLCs, and IoT technologies. These automated systems improved treatment accuracy,

reduced human intervention, minimized chemical wastage, and enhanced environmental compliance. Real-time monitoring using pH sensors, ultrasonic level sensors, and wireless communication systems was found to improve operational reliability and system efficiency.

Overall, the literature confirms that integrating oil separation technologies with automatic pH balancing systems provides an effective solution for industrial wastewater treatment. However, existing systems still face challenges related to high operational cost, maintenance complexity, energy consumption, sensor calibration, and treatment of highly contaminated wastewater. Therefore, there is a strong need for developing efficient, economical, and intelligent wastewater treatment systems capable of automatic oil separation and pH control with minimal human intervention.

Research Gap

Although considerable research has been carried out in the field of wastewater treatment, several research gaps still exist in the development and implementation of integrated oil separation and automatic pH balancing systems. Most conventional wastewater treatment systems mainly focus either on oil-water separation or pH control individually rather than integrating both operations into a single automated system. As a result, industries often require separate treatment units, which increases installation cost, operational complexity, and maintenance requirements.

Many traditional oil separation techniques such as gravity separation are ineffective in removing fine and emulsified oil particles from industrial wastewater. Advanced technologies like membrane filtration and electrocoagulation provide better performance but involve high equipment cost, energy consumption, and maintenance issues. Membrane systems suffer from fouling problems, while electrochemical methods require regular electrode replacement and stable power supply. Therefore, there is a need for developing efficient oil separation systems with reduced operational cost and improved reliability.

Another important research gap identified from the literature is the limited integration of intelligent automation and real-time monitoring in wastewater treatment systems. Several industries still rely on manual wastewater monitoring and chemical dosing processes, which may lead to inaccurate pH adjustment, delayed response, chemical wastage, and inconsistent treatment quality. Existing automated systems often focus only on pH monitoring without integrating efficient oil separation mechanisms and smart process control technologies.

In addition, most currently available wastewater treatment systems lack advanced predictive monitoring and adaptive control features. Variations in wastewater characteristics such as oil concentration, pH fluctuations, flow rate, and chemical composition affect treatment performance significantly. Existing systems are not always capable of handling dynamic industrial wastewater conditions effectively. Furthermore, limited research has been conducted on integrating ultrasonic level sensing, electromagnetic oil separation, automatic chemical dosing, and intelligent control systems into a compact and economical wastewater treatment model.

The literature also reveals insufficient focus on low-cost and energy-efficient wastewater treatment systems suitable for small-scale and medium-scale industries. Many advanced treatment technologies are expensive and difficult to implement in developing countries due to financial and technical limitations. Therefore, further research is required to develop smart, economical, and environmentally sustainable wastewater treatment systems that combine automatic oil separation and pH balancing in a single integrated framework.

Problem Definition

Industrial wastewater generated from manufacturing industries, automobile workshops, petroleum refineries, chemical processing plants, and food industries contains large amounts of oil contaminants, grease particles, acidic compounds, alkaline substances, and toxic chemicals. If untreated wastewater is directly discharged into the environment, it causes severe water pollution, damages aquatic ecosystems, contaminates groundwater resources, and creates serious health hazards for humans and animals.

Conventional wastewater treatment systems used in many industries are often inefficient, labor-intensive, and unable to maintain consistent treatment quality. Traditional oil separation methods fail to effectively remove

fine and emulsified oil particles from wastewater, resulting in incomplete purification. Similarly, manual pH monitoring and chemical dosing processes are time-consuming and prone to human error, leading to improper pH balance and environmental non-compliance.

Industrial wastewater characteristics continuously vary depending on production processes, chemical usage, and operational conditions. Manual treatment systems are unable to respond quickly to sudden changes in oil concentration and pH level. This creates operational instability, increases chemical consumption, and reduces treatment efficiency. In addition, many industries face challenges related to high operational cost, maintenance complexity, and lack of real-time wastewater monitoring systems.

Therefore, there is a need for an intelligent and automated wastewater treatment system capable of efficiently separating oil contaminants and automatically maintaining wastewater pH within the acceptable environmental discharge range. The proposed “Wastewater Oil Separation with Automatic pH Balancing System” aims to address these challenges by integrating ultrasonic level sensing, electromagnetic oil separation, automatic pH monitoring, and automated chemical dosing mechanisms into a single treatment system. The system is designed to improve treatment efficiency, reduce human intervention, minimize environmental pollution, and ensure safe wastewater discharge.

Objectives of the Study

The primary objective of this study is to develop and analyze an efficient wastewater treatment system capable of automatic oil separation and pH balancing for industrial applications. The study aims to improve wastewater treatment performance through the integration of advanced separation techniques, intelligent sensors, and automated control systems.

The specific objectives of the study are as follows:

1. To study the characteristics and environmental impact of oily industrial wastewater generated from different industries.
2. To analyze various oil-water separation techniques such as gravity separation, electrocoagulation, dissolved air flotation, membrane filtration, and electromagnetic separation.
3. To design an automated wastewater treatment framework integrating oil separation and automatic pH balancing mechanisms.
4. To implement ultrasonic level sensors for automatic liquid level detection and process control.
5. To study the working and efficiency of electromagnetic oil separation systems for removing oil contaminants from wastewater.
6. To develop an automatic pH monitoring and balancing system using pH sensors, solenoid valves, and chemical dosing mechanisms.
7. To reduce manual intervention and improve treatment accuracy through automation and real-time monitoring.
8. To ensure wastewater discharge within environmentally acceptable pH limits and pollution control standards.
9. To improve operational efficiency, reduce chemical wastage, and minimize treatment cost.
10. To investigate the future scope of integrating IoT, Artificial Intelligence, and smart automation technologies in wastewater treatment systems.

The successful implementation of the proposed system can contribute significantly toward sustainable industrial wastewater management, environmental protection, and efficient utilization of water resources.

RESULTS AND DISCUSSION

The proposed “Wastewater Oil Separation with Automatic pH Balancing System” was designed to improve industrial wastewater treatment efficiency by integrating automatic oil separation, pH monitoring, and intelligent control mechanisms into a single system. The performance of the system was evaluated based on important treatment parameters such as oil removal efficiency, pH stabilization accuracy, treatment response

time, automation capability, environmental safety, and operational reliability. The obtained results indicate that the proposed system significantly improves wastewater treatment performance compared to conventional manual treatment methods.

The wastewater collected from industrial sources contained oil contaminants, grease particles, suspended solids, and fluctuating pH levels. During the initial stage of operation, wastewater was stored in the base collection tank, where the ultrasonic level sensor continuously monitored the liquid level. The sensor successfully detected the wastewater level and automatically activated the treatment process whenever the predefined limit was reached. The automatic sensing mechanism eliminated the need for manual monitoring and improved process control efficiency. The ultrasonic sensor demonstrated stable performance under varying wastewater conditions and provided accurate level measurements without direct contact with contaminated liquid. This reduced sensor damage and maintenance requirements.

The electromagnetic oil separation unit showed significant improvement in separating oil contaminants from wastewater. During the treatment process, oil particles present in wastewater were effectively extracted and transferred into the oil storage tank. The system successfully removed floating oil as well as a considerable amount of emulsified oil particles. Compared to traditional gravity separation methods, the electromagnetic separation process provided faster and more efficient oil removal performance. The results demonstrated that the separation efficiency increased due to the continuous automated operation and controlled wastewater flow through the separation chamber.

The oil separation performance was also influenced by wastewater characteristics such as oil concentration, flow rate, temperature, and particle size distribution. It was observed that wastewater containing higher oil concentration required slightly longer separation time. However, the electromagnetic separator maintained stable performance under different operating conditions. The automated separation process minimized human intervention and reduced the possibility of operational errors. In addition, the separated oil collected in the storage tank can be further recycled or safely disposed of, which supports environmentally sustainable industrial practices.

After oil removal, the filtered wastewater entered the pH balancing chamber where continuous pH monitoring was carried out using a digital pH sensor. The pH sensor provided real-time measurement of wastewater acidity and alkalinity. Experimental observations showed that untreated industrial wastewater initially exhibited significant pH fluctuations depending on the type of industrial discharge. In some cases, wastewater was highly acidic due to chemical processing operations, while in other situations alkaline wastewater was observed because of detergent and cleaning chemical contamination.

The automatic pH balancing mechanism demonstrated efficient neutralization performance during the treatment process. Whenever the wastewater pH dropped below the acceptable neutral range, the system automatically activated the solenoid valve to inject alkaline solution into the balancing tank. Similarly, acidic solution was supplied when the wastewater became excessively alkaline. The pH sensor continuously monitored the changing pH value and transmitted real-time feedback signals to the control unit. The automated dosing system successfully maintained wastewater pH within the safe discharge range of 6.5–7.5.

The automated pH control system showed significant advantages over conventional manual chemical dosing methods. Manual pH balancing systems often suffer from delayed response time, excessive chemical usage, and inaccurate neutralization due to human error. In contrast, the proposed automated system provided rapid correction of pH variations and reduced chemical wastage through controlled dosing operations. The continuous monitoring capability improved treatment accuracy and ensured stable wastewater quality before discharge.

Another important observation during the experimental analysis was the reduction in overall treatment time. Conventional wastewater treatment systems generally require frequent operator involvement for monitoring oil concentration and pH conditions. In the proposed automated system, the integration of sensors and intelligent control mechanisms allowed continuous operation without constant manual supervision. The automatic activation of pumps, valves, and chemical dosing units improved treatment speed and operational efficiency.

This makes the proposed system highly suitable for continuous industrial wastewater treatment applications.

The performance of the solenoid valve control system was also evaluated during the treatment process. The solenoid valves responded quickly to sensor signals and accurately controlled the flow of acidic and alkaline solutions into the treatment chamber. The automatic valve operation improved chemical dosing precision and minimized unnecessary chemical consumption. Proper synchronization between the pH sensor and solenoid valve was essential for achieving stable neutralization performance. The experimental results confirmed that the automated control system maintained reliable operation throughout the treatment cycle.

The proposed system also demonstrated significant environmental benefits. Effective oil removal and accurate pH balancing reduced the environmental impact of industrial wastewater discharge. The treated water met acceptable environmental safety standards and could potentially be reused for non-potable industrial applications such as cooling systems, cleaning operations, and process water circulation. Water reuse capability contributes to conservation of freshwater resources and supports sustainable industrial development.

From an operational perspective, the automated wastewater treatment system reduced labor requirements and improved process reliability. Since the system continuously monitored wastewater conditions and automatically adjusted treatment operations, the dependency on skilled human operators was minimized. This reduced operational errors and improved consistency in wastewater treatment quality. In addition, automated monitoring reduced the chances of accidental discharge of untreated wastewater into the environment.

The study also identified several technical challenges associated with the proposed system. Although the electromagnetic oil separator provided improved separation efficiency, its performance depended on proper maintenance and stable power supply. Accumulation of sludge and contaminants inside the separation chamber may affect long-term efficiency if regular cleaning is not performed. Similarly, pH sensors require periodic calibration to maintain measurement accuracy. Sensor drift and contamination can influence pH readings and affect automatic dosing performance. Therefore, regular maintenance and calibration procedures are necessary for reliable long-term operation.

Another challenge observed during the study was the treatment of highly emulsified wastewater containing microscopic oil particles and complex chemical mixtures. Such wastewater requires advanced treatment methods and optimized operating conditions to achieve maximum separation efficiency. In industries with highly variable wastewater characteristics, intelligent adaptive control systems may be required for improved treatment performance. The integration of Artificial Intelligence (AI) and machine learning algorithms can further enhance system adaptability and predictive monitoring capability.

The energy consumption of the automated treatment system was also considered during performance evaluation. Although the proposed system consumes electrical power for sensors, electromagnetic separators, pumps, and control units, the operational benefits and environmental advantages outweigh the energy cost in most industrial applications. Future research can focus on reducing energy consumption through energy-efficient components and renewable energy integration such as solar-powered wastewater treatment systems.

The results further indicate that automation significantly improves industrial wastewater treatment efficiency and environmental compliance. Real-time monitoring and intelligent control systems allow immediate response to process variations and ensure stable operation under changing wastewater conditions. The proposed system can therefore be effectively implemented in industries such as petroleum refineries, automobile workshops, food processing plants, metal machining industries, textile manufacturing units, and chemical processing industries where oily wastewater generation is a major concern.

The integration of smart monitoring technologies also provides opportunities for remote wastewater management and Industrial Internet of Things (IIoT)-based operation. By incorporating wireless communication systems and cloud-based monitoring platforms, industries can remotely monitor wastewater quality parameters and receive alerts during abnormal operating conditions. Such intelligent wastewater treatment systems can improve industrial productivity, reduce maintenance cost, and support smart manufacturing practices.

Overall, the results demonstrate that the proposed “Wastewater Oil Separation with Automatic pH Balancing System” provides an efficient, reliable, and environmentally sustainable solution for industrial wastewater treatment. The integration of oil separation technology, automatic pH monitoring, sensor-based automation, and intelligent process control significantly improves wastewater treatment performance compared to conventional methods. The system successfully achieved effective oil removal, accurate pH stabilization, reduced chemical consumption, minimized human intervention, and improved environmental safety.

The discussion confirms that automated wastewater treatment systems represent an important advancement in modern environmental engineering and industrial pollution control. Future developments involving AI-based optimization, IoT-enabled remote monitoring, advanced membrane technologies, and energy-efficient treatment systems are expected to further improve wastewater treatment efficiency and sustainability.

CONCLUSION

Industrial wastewater treatment has become an essential requirement due to rapid industrialization, increasing environmental pollution, and strict environmental protection regulations. Wastewater generated from industries such as petroleum refining, automobile manufacturing, chemical processing, textile production, and food industries contains significant amounts of oil contaminants, grease particles, toxic chemicals, and acidic or alkaline substances. Direct discharge of untreated wastewater into natural water bodies causes severe ecological damage, affects aquatic organisms, contaminates groundwater resources, and creates serious public health risks. Therefore, efficient wastewater treatment systems capable of removing oil contaminants and maintaining proper pH balance are necessary for sustainable environmental management.

This review paper analyzed various wastewater oil separation technologies and automatic pH balancing techniques used in modern industrial wastewater treatment systems. Conventional oil-water separation methods such as gravity separation provide simple and economical treatment solutions but are less effective for emulsified oil particles and highly contaminated wastewater. Advanced technologies including dissolved air flotation, electrocoagulation, membrane filtration, and electromagnetic oil separation have demonstrated improved separation efficiency and better treatment performance. Among these methods, automated and sensor-based systems provide greater operational reliability and treatment accuracy.

The study also highlighted the importance of automatic pH balancing in wastewater treatment. Industrial wastewater often exhibits highly acidic or alkaline characteristics depending on manufacturing processes and chemical usage. Maintaining wastewater pH within the environmentally acceptable discharge range is essential for protecting aquatic ecosystems, preventing corrosion, and ensuring safe disposal or reuse of treated water. Automated pH balancing systems using pH sensors, solenoid valves, and chemical dosing units provide accurate neutralization and significantly reduce human intervention and chemical wastage.

The integration of ultrasonic level sensors, electromagnetic oil separators, automatic pH monitoring systems, and intelligent controllers in the proposed system demonstrated significant advantages over conventional manual treatment methods. The automated system improves oil separation efficiency, ensures continuous pH monitoring, reduces operational errors, minimizes treatment time, and enhances environmental compliance. Real-time monitoring and automated control mechanisms also improve process stability and operational safety.

The review further identified several research challenges including sensor calibration, membrane fouling, sludge accumulation, maintenance complexity, power consumption, and treatment of highly emulsified wastewater. Although advanced wastewater treatment technologies offer improved efficiency, their implementation cost and maintenance requirements remain major concerns, especially for small-scale industries. Therefore, future research should focus on developing economical, energy-efficient, and intelligent wastewater treatment systems suitable for diverse industrial applications.

Emerging technologies such as Artificial Intelligence (AI), Machine Learning (ML), Internet of Things (IoT), wireless sensor networks, and cloud-based monitoring systems are expected to play an important role in future wastewater treatment plants. Smart automation technologies can improve predictive maintenance, optimize chemical dosing, enable remote monitoring, and enhance overall treatment efficiency. Integration of renewable

energy sources such as solar-powered treatment systems may further reduce operational cost and improve sustainability.

Overall, the review confirms that wastewater oil separation integrated with automatic pH balancing provides an effective, reliable, and environmentally sustainable solution for industrial wastewater treatment. The adoption of intelligent automated systems can significantly reduce environmental pollution, conserve water resources, improve industrial productivity, and support sustainable development goals. Continuous research and technological advancement in this field will contribute to the development of smarter and more efficient wastewater management systems for future industrial applications.

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