EFFICIENT INDUSTRIAL WASTEWATER RECYCLING WITH IOT

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ABSTRACT: Water treatment is essential for preventing water crises and ensuring water quality for different purposes. Parameters like pH, TDS, and turbidity are used to measure water quality, which varies based on the source of wastewater. Industrial wastewater is typically highly polluted. This paper proposes a smart water quality management system using IoT sensors to monitor parameters in a treatment plant. It focuses on treating detergent production line wastewater, adhering to environmental standards. The system's outputs have applications in water reuse, firefighting, and ornamental plant agriculture. The system is programmed using Arduino coding software, displaying sensor data on a computer with Realterm software. Overall, this study presents an integrated approach to efficient water treatment and quality management.

1. INTRODUCTION

Freshwater scarcity is a pressing global challenge. To meet the increasing demand driven by population growth, it is crucial to implement water treatment methods, particularly for treating diverse wastewater streams from domestic, industrial, and municipal sources.

To minimize the environmental and health risks associated with pollutants in wastewater, monitoring and regulating the quality of treated water is crucial. Industrial effluents, including those from detergent production, can contribute to contaminated wastewater. Monitoring parameters like pH, TDS, and turbidity is essential for tracking treated wastewater quality.

Integrating the Quality 4.0 concept, which utilizes Industry 4.0 technologies, offers a promising approach to managing wastewater quality. The aim of the study is to enable the use of treated industrial wastewater in agriculture as a means to decrease the demand for freshwater in irrigation.

2. LITRETURE REVIEW

Industry 4.0, introduced in 2011, focuses on automation, digitization, data analytics, and smart production systems. [1]–[6]

Quality 4.0 integrates Industry 4.0 technologies with traditional quality methods to improve process performance, reduce errors, and enhance output quality through digitalization, management system, analytics, data, app development, connectivity, scalability, collaboration, competency, leadership, culture, and compliance. [3], [6]–[13]

Internet of Things (IoT) refers to connected electrical gadgets, coined in 1999 by Kevin Ashton. Data transmission between linked devices is the main emphasis of IoT. [14] The Internet of Things (IoT) technology has various advantages for water management, including energy management, cost reduction, and system efficiency. [15]–[17]

An automated water treatment system that incorporates Industry 4.0 technologies including the Internet of Things (IoT), big data, machine learning, and artificial intelligence is referred to as a smart water treatment system. [18], [19]

Industrial wastewater treatment involves pre-treatment (screening and grit removal), primary treatment (gravity sedimentation and chemically enhanced sedimentation), biological treatment, filtering, and tertiary treatment (disinfection chlorination). [20], [21]

Detergent manufacturing involves combining solid components (soda ash, sodium tripolyphosphate, sodium perborate, CMC) with liquid ingredients (oils, water, sulfonic acid, oxygenated water, fragrances). They are mixed, dehydrated, and filtered to produce powdered detergent. [22], [23]

Wastewater from detergent manufacturing contains contaminants like solids and dissolved substances. Treatment methods, including sedimentation, filtration, pH adjustment, and disinfection, are used to manage and address these pollutants. [24], [25]

3. EXPERIMENTAL

3.1 Traditional Water Treatment System

3.1.1 Traditional Water Treatment System Definition

The traditional wastewater treatment system typically relies on manual or semi-automated processes for treating wastewater, often involving physical, chemical, and biological treatment methods. These systems may have limited real-time monitoring and control capabilities, and the decision-making process is often reliant on human intervention based on periodic sampling and analysis.

Traditional wastewater treatment methods use various techniques to eliminate pollutants and meet regulatory requirements while minimizing environmental harm. These systems offer flexibility for handling wastewater discharge, ultimately preserving water quality and protecting public health. On the other hand, traditional wastewater treatment methods are expensive and energy-intensive, involving chemicals and high labor costs. The development of new technologies is crucial for meeting water quality standards and improving the sustainability of treatment approaches.

3.1.2 Traditional Wastewater Treatment Process Overview

The industrial wastewater from a detergent production line is discharged into an industrial wastewater collection tank to initiate the traditional industrial wastewater treatment process, as shown in Figure 1. Wastewater is then pumped to a coagulation tank, where it is mixed with lime injected as a coagulant. The wastewater is subsequently sent to a lime sedimentation tank, where excess lime and coagulated particles settle at the bottom.

The effluent flows from the lime sedimentation tank to the flocculation tank, where alum is added as a flocculant and mixed with an acid or base (as detected by a pH sensor) for pH adjustment. Following this, the wastewater is directed to an alum sedimentation tank, where any extra alum and the floculated particles "flocs" settle to the bottom.

The wastewater is pumped from the alum sedimentation tank to a sand filter for filtering before being chlorinated to remove organic materials for disinfection. Regular sampling is conducted every three hours for laboratory examination to manually check the quality of treated wastewater. Analyzing pH, TDS, and turbidity characteristics is a common way to assess the quality of treated wastewater. Release of the wastewater into the Nobaria Canal occurs if the parameters satisfy the necessary requirements. The wastewater is directed to the industrial wastewater collecting tank via a manual bypass opening for retreatment, error correction, and system problem-solving if the parameters are not within allowable bounds, at which point the treatment process is turned off.

The valves located at the bottom of the alum and lime sedimentation tanks are used to draw out sediments and water, aiding in the removal of sediment buildup at the tank bottoms. The water in the bottom sludge tanks is released when $FeCl_3$ flocculant is injected into the water-sedimented particles, allowing the sediment particles to "form cake." Afterward, the sediments are gathered by the government and disposed of at designated land burial locations.

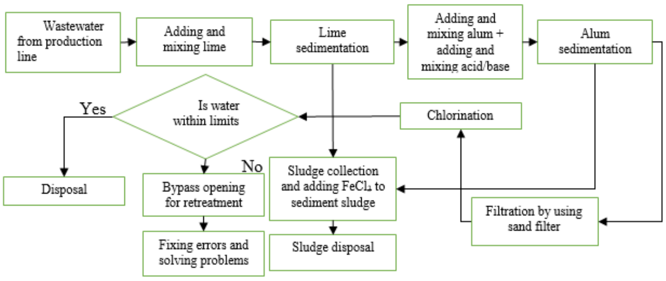


Figure 1: Traditional Wastewater Treatment

3.2 Proposed System (Pilot Model Flow chart)

3.2.1 Smart Wastewater Treatment System Definition

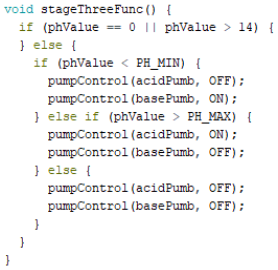
A smart wastewater treatment system incorporates smart technology, including sensors, automation, and data analysis, to optimize the treatment process. It employs real-time monitoring and control techniques to enhance efficiency, reduce resource consumption, and promote environmental sustainability by monitoring factors such as pH, turbidity, and chemical levels for proactive management of treatment processes. The system features remote monitoring capabilities, allowing operators to access and manage it from any location with internet connectivity.

Smart wastewater treatment systems offer notable benefits, including improved treatment efficiency and regulatory compliance through real-time monitoring and control. By optimizing resource usage and automating processes, these systems lower operational costs and energy consumption. Predictive maintenance capabilities minimize downtime and extend equipment lifespan, contributing to more sustainable wastewater management practices.

The smart wastewater treatment systems also present challenges. Initial implementation costs can be high, and specialized technical expertise may be necessary for installation, operation, and maintenance. There is a risk of system failures or malfunctions, which could disrupt wastewater treatment operations. Data security and privacy concerns may arise, and the rapid pace of technological advancements may lead to component obsolescence, necessitating frequent upgrades.

3.2.2 Smart Wastewater Treatment System (Pilot Model) Overview

Figure 2 shows the Arduino code script utilized for pH regulation within the system, which guarantees accurate pH adjustment within predetermined boundaries, thereby enhancing system performance and ensuring adherence to regulatory standards.



```
void stageThreeFunc() {
  if (phValue == 0 || phValue > 14) {
  } else {
    if (phValue < PH_MIN) {
      pumpControl(acidPumb, OFF);
      pumpControl(basePumb, ON);
    } else if (phValue > PH_MAX) {
      pumpControl(acidPumb, ON);
      pumpControl(basePumb, OFF);
    } else {
      pumpControl(acidPumb, OFF);
      pumpControl(basePumb, OFF);
    }
  }
}
```

Figure 2: Arduino Code Script

3.2.3 Proposed System Implementation

The pilot implementation of the smart wastewater system at Abo El Hol Company, depicted in Figure 3, involves collecting industrial wastewater in Tank 0 from the detergent production line. From Tank 0, the wastewater is transferred to Tank 1 for coagulation with lime, then naturally flows to Tank 2 for lime sedimentation, settling excess lime and coagulated particles.

Wastewater flows as a result of gravity from Tank 2 to Tank 3, where alum is added as a flocculant and mixed with wastewater to encourage flocculation. After that, the wastewater flows naturally from Tank 3 to Tank 4 via gravity. The wastewater flows via a pipeline to Tank 4 for alum sedimentation when it reaches a certain level in Tank 3. Extra alum and flocs in Tank 4 settle at the bottom of the tank. A pH sensor in Tank 4 is used for pH adjustment, injecting either base or acid if the pH drops below the permitted range of 6 to 9.

Afterward, before being pumped to Tank 5, the wastewater is pumped from Tank 4 to the filter membrane for filtering. After the wastewater passes through the filter membrane in Tank 5, TDS and turbidity are measured using TDS and turbidity sensors. There should be no more than 1500 mg/l of TDS. A feedback pump pumps the wastewater to Tank 0 for retreatment if its TDS exceeds the specified limit. Similar to the turbidity measurement, it shouldn't be more than 50 NTU. If it is, a feedback pump and line are used to pump the water to Tank 0 for retreatment. The treated wastewater is sent to Tank 6 if the TDS and turbidity levels are within the acceptable limits. The wastewater is then directed to Tank 8 for chlorination to disinfect it. Following chlorination, the effluent is either released into the Nobaria Canal or recycled for various industrial applications, including agriculture.

Using bottom tanks, the sludge "settled water and sediments" in the bottom of Tanks 2 and 4 get discharged into Tank 7. The water is drained from Tank 7, leaving the sediment particles behind "to form cake" after adding $FeCl_3$ flocculant to the water-sedimented particles. The sediments are gathered by government specialists and disposed of in approved landfills.

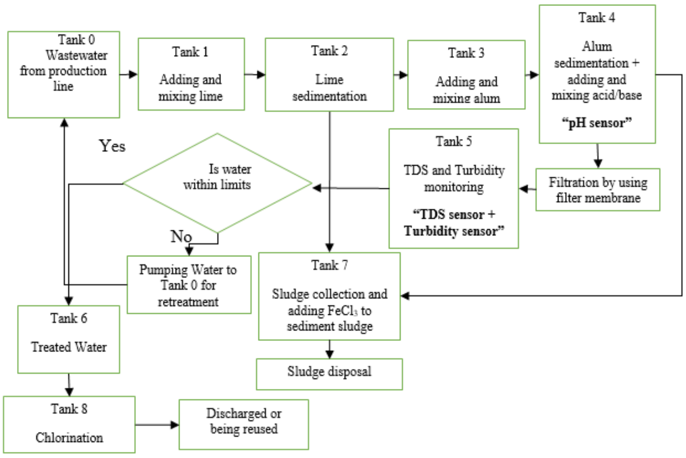
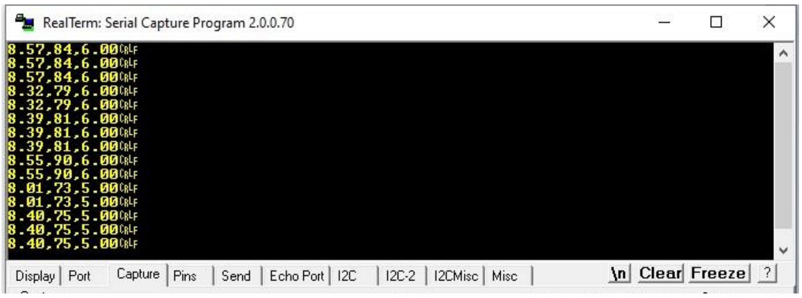


Figure 3: Smart Wastewater Treatment System

The proposed system enables convenient monitoring of collected data through a user interface on the computer. Figure 4 illustrates the real-time data obtained from pH, TDS, and turbidity sensors in tanks 4 and 5 for monitoring treated industrial wastewater parameters.



```
8.57,84,6.00CRLF
8.57,84,6.00CRLF
8.57,84,6.00CRLF
8.32,79,6.00CRLF
8.32,79,6.00CRLF
8.39,81,6.00CRLF
8.39,81,6.00CRLF
8.39,81,6.00CRLF
8.55,90,6.00CRLF
8.55,90,6.00CRLF
8.01,73,5.00CRLF
8.01,73,5.00CRLF
8.40,75,5.00CRLF
8.40,75,5.00CRLF
8.40,75,5.00CRLF
```

Figure 4: RealTerm User Interface

4. RESULTS AND DISCUSSION

The smart wastewater treatment system project is assessed by gathering data from pH, TDS, and turbidity sensors over a 15-hour timeframe. The data is obtained from both the industrial wastewater in Tank 0 and the treated wastewater in Tank 6. The alkaline components utilized in the detergent production process cause the pH levels of industrial wastewater discharged from the detergent production line to surpass the upper control limit (USL), as seen in Figure 5. A smart pH sensor in Tank 4 allows for real-time pH level control and monitoring. If the pH parameter is out of the control limits, pH adjustment is performed, such as injecting HCl if the pH exceeds the Upper Specific Limit (USL) of 9 or injecting NaOH if pH falls below the Lower Specific Limit (LSL) of 6. Additionally, readings of the treated wastewater, specifically the "pH After Treatment," are collected to ensure compliance with the specified pH limits.

Wastewater parameters before and after treatment demonstrate an average pH improvement of 22.02%, TDS improvement of 49.61%, and turbidity improvement of 65.17%. These findings highlight the effectiveness of the treatment process in enhancing water quality parameters, indicating its potential for environmental remediation efforts.

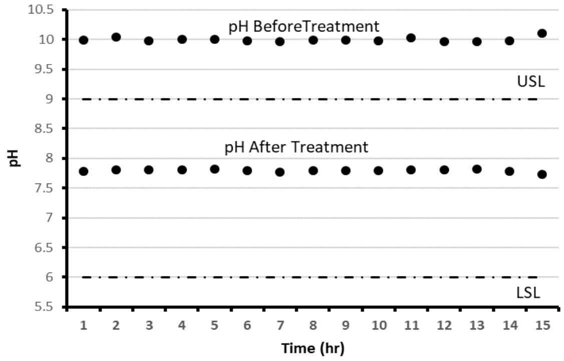


Figure 5: The industrial wastewater pH readings before and after treatment

Figures 6 and 7 illustrate the TDS and turbidity of industrial wastewater that is discharged from the detergent production line before treatment. These readings, at 1500 mg/l and 50 NTU, are higher than the upper specification limit (USL), indicating that components used in the detergent production line have polluted the industrial wastewater. This contamination is evident in the changes in the TDS and turbidity parameter readings that are outside of the USL. Filtration and chemical-enhanced sedimentation, such as lime coagulation and alum flocculation, are the methods used to control TDS and turbidity parameters. Tank 5 utilizes TDS and turbidity sensors for monitoring and control. Improved data within control limits indicate successful treatment. If parameters exceed limits, a feedback pump redirects wastewater for retreatment. Treated wastewater is reused if within acceptable bounds or discharged into the Nobaria Canal.

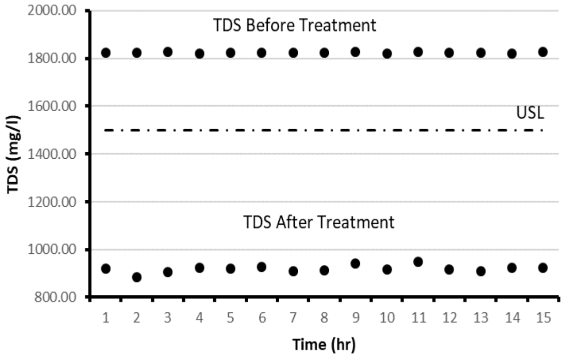


Figure 6: The industrial wastewater TDS readings before and after treatment

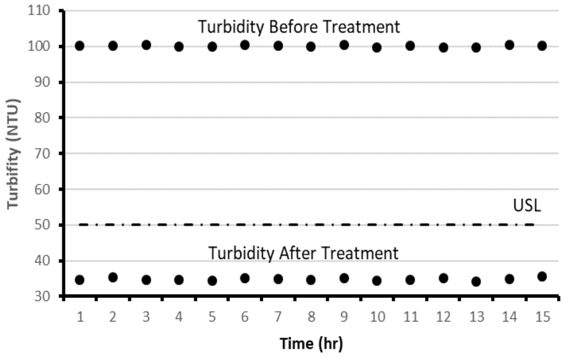


Figure 7: The industrial wastewater turbidity readings before and after treatment

The smart wastewater treatment system reduces labor and chemical costs through the use of smart sensors and actuators, resulting in an 83.33% reduction in labor needs and a 55.84% decrease in monthly chemical expenses compared to traditional systems.

5. CONCLUSIONS AND FUTURE WORK

Implementing a smart wastewater treatment system in detergent production improves process quality, reduces costs, increases efficiency through real-time data monitoring, and enhances treated wastewater quality for agricultural use. The system integrates Quality 4.0 principles and utilizes smart sensors for data collection, efficient storage, compliance analysis, and seamless connectivity to conserve 960 m^3 of freshwater and mitigate pollution risks.

Scaling up the proposed system to an industrial capacity of 960 m^3 requires meticulous planning for sensor placement and algorithm scalability, integrating machine learning for predictive modeling and optimizing resource allocation in practical industrial settings.

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