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Application of automation in wastewater treatment

AMCA5001

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3 Glossary of terms.

ICA-Instrumentation, Control, and Automation

AI-Artificial Intelligence

IoT-Internet of Things

PLC- Programmable logic Controllers

SCADA- Supervisory Control and Data Acquisition

PID- Proportional Integral Derivative

WWTP- Wastewater treatment plant

UV-Ultraviolet

DO Dissolved Oxygen

TIA- Totally Integrated Automation

ML-Machine Learning

4 Abstract

This report explores the role of Instrumentation, Control, and Automation (ICA) within wastewater treatment processes, emphasizing its importance in enhancing operational efficiency, environmental compliance, and overall plant performance. It begins by outlining the fundamentals of wastewater treatment and the integration of ICA technologies, including sensors, process controllers, and actuators. The report examines supervisory control systems and the significance of standards and regulations. Additionally, it discusses recent advancements, such as AI and IoT integration, and their transformative potential for predictive maintenance and process optimization. By analysing key components and innovations, this study highlights how ICA supports sustainable wastewater management and continuous improvement across treatment facilities.

5 Introduction

Wastewater treatment is essential for protecting public health and the environment by ensuring the safe handling and disposal of wastewater. As treatment processes become more complex due to the increasing demand and stricter regulations, Instrumentation, Control, and Automation (ICA) has become a key factor in improving efficiency, reliability, and compliance.

Historically, Wastewater treatment relied on manual monitoring and mechanical control, which were inefficient and prone to human error. Introducing sensors, programmable logic controllers (PLCs), and Supervisory Control and Data Acquisition (SCADA) systems has allowed real-time monitoring and automated process adjustments, significantly improving plant performance. More recently, advancements such as artificial intelligence (AI), the Internet of Things (IoT), and machine learning drive further automation, enabling predictive maintenance and optimised process control.

This report examines the application of ICA in wastewater treatment, focusing on key components such as sensors, controllers, and actuators. It also explores the role of supervisory control, regulatory requirements, and recent innovations shaping automation in this industry.

6 Historical Developments in Wastewater Treatment.

6.1 Early History of Wastewater Management.

Sanitation is a fundamental pillar for the successful, ongoing, and sustainable development of any community. Early traces of cesspits and Imhoff-type basins have been discovered in settlements from Mesopotamia, the Indus Valley, and Egypt, however, ancient Greeks can be seen as pioneers in the development of modern sanitation systems. Archaeological evidence from cities on Crete and other Aegean Islands demonstrates that sophisticated sewage systems existed as early as the Minoan civilization, recognized as Europe's first advanced society, which thrived from around 2700 to 1450 BC. Subsequent sewer systems have also been uncovered on Delos Island dating back to around 400 BC and in ancient Pella (approximately 300 BC) in Northern Greece, which served as the historical capital of the ancient Macedonian kingdom. Meanwhile, simpler open air wastewater and stormwater conveyance networks in various other Greek cities have been noted as contributing to the frequent outbreaks of waterborne illnesses such as cholera and the plague (Angelakis, et al., 2003)



(a)



(b)

Figure 1-(a) Theatre in Delos Island and (b) rainwater drainage and harvesting.

6.2 Industrial Revolution

During the eighteenth century, the rapid industrialization and urban growth led to an increased awareness of the necessity for proper waste and wastewater management. Britain was among the earliest nations to initiate organized efforts aimed at enhancing the environmental conditions in urban areas (Lofrano & Brown, 2010).

In the early 20th century, wastewater treatment facilities operated with manual sampling and mechanical flow regulation. Operators would gather water samples to monitor pH, turbidity, and dissolved oxygen levels. Flow control was managed through manually adjusted gates and valves, leading to inconsistent and a more reactive process. The introduction of basic pH and flow meters in the mid-1900s enabled continuous data gathering, enhancing monitoring and decision-making.

Manual monitoring would rely on operators or technicians to conduct chemical test to compare against specified control limits. This would need to be checked at regular intervals. The manual method can still be used today but only for non-critical water systems (Veolia, n.d.).

The initial applications of ICA in water treatment in the 1970s focused on activated sludge systems for eliminating organic matter. At that time, the primary effluent criteria revolved around suspended solids, with no emphasis placed on nitrogen or phosphorus removal. Over the years, stricter standards, including the need for nutrient removal, along with the demand for more efficient operations, have influenced the design of wastewater treatment processes (Olsson, et al., 2013).

Also in the 1970s, Supervisory Control and Data Acquisition (SCADA) systems were introduced, which brought a centralised oversight and real-time process modifications. Programmable Logic Controllers (PLCs) became widely used for automating pump operations, aeration, and chemical application. The incorporation of Proportional-Integral-Derivative (PID) controllers further boosted treatment.

In recent years there has been a greater focus on the development and use of ICA in water treatment to improve the ability to cope with the increased demands because of population growth (Yuan, et al., 2019).

(Olsson, 2006)The development of ICA has helped manage challenges that arise. There are various requirements, such as:

- Monitoring and managing changes in water quality within networks.
- Evaluating the condition of assets in relation to their serviceability.
- Implementing cost-effective no-dig technologies.
- Reducing leakages and unaccounted-for water.
- Recognizing interdependencies with other infrastructures.
- Conducting integrity checks on networks.
- Ensuring the security of systems.

7 Process of Wastewater Treatment Plant

There are several stages required in the wastewater treatment process. From the primary stages of removing larger contaminants to the disinfection process to remove harmful pathogens to end with water clean enough to re-enter the waterways.

7.1 Bar screens

Found at the beginning of the process in Wastewater treatment plant (WWTP). The bar screens are used to screen the larger contaminants found in sewage such as cans, paper or plastics. Part of the pretreatment process to make the sewage more homogenous. A safety sensor is employed to disconnect the power from the gearbox, while a level sensor is used to manage the system, activating it at a specific water height. The level sensor functions like a float, avoiding unnecessary system operations. The sensor set for the minimum water level remains active until the water level falls below the designated threshold. (Turgut, et al., 2023). The larger contaminants are removed and often taken to landfill.



Figure 2: Mechanical bar screen used in field.

7.2 Grit tank

The elimination of grit is a vital process in a municipal WWTP. Grit typically consists of inorganic fragments like sand, gravel, and cinders that contain minimal to no decomposable organic material. In standard municipal wastewater, grit can also manifest as non-decomposable organic substances such as eggshells, bone fragments, seeds, and coffee grounds. If grit is not eliminated, these particles

can accumulate in downstream pipes, channels, and processing tanks, leading to wear on mechanical equipment within the facility. Grit is usually extracted at the headworks of a municipal wastewater treatment plant, situated after the inlet screens and before the initial clarification stage. Various technologies are currently employed for grit removal, including vortex-type systems, hydro cyclones, detritus tanks, and velocity-controlled channels.

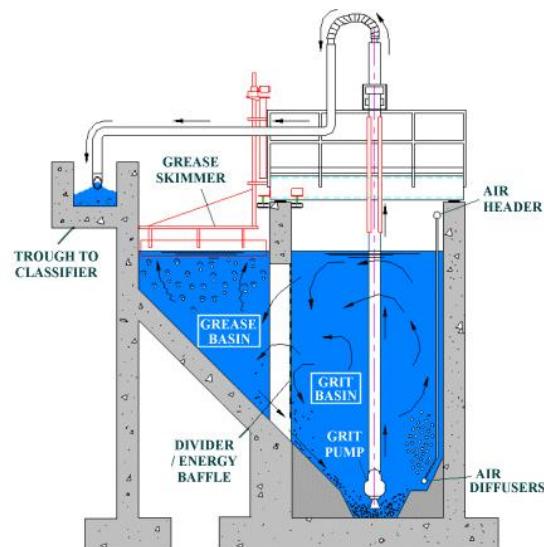


Figure 3: Schematic of grit tank

7.3 Settling tank

A settler is utilised early in the process to separate solids through sedimentation. The settlers function at a low flow rate, allowing settleable particles to descend to the bottom, referred to as sediment. Meanwhile, the lighter particles, which are less dense than water, rise to the top, known as scum. Sedimentation is employed to remove grit, for secondary clarification in activated sludge treatment, following chemical coagulation and precipitation, or for sludge thickening. Settlers can achieve a considerable initial reduction in suspended solids (50-70% removal) and organic material (20-40% BOD removal) and assist in preventing these elements from interfering with later treatment stages. (Tilley, et al., 2014)

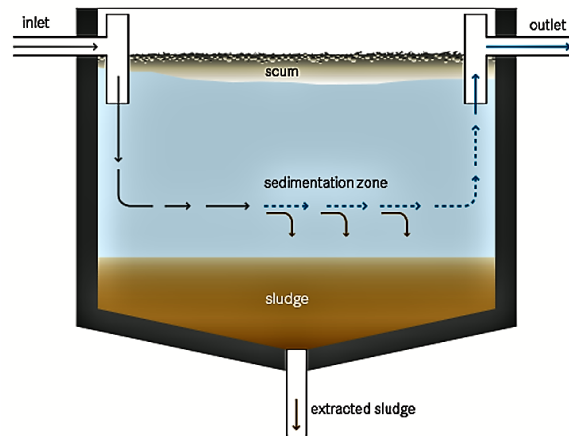


Figure 4: Settling tank schematic.

7.4 Aeration tank

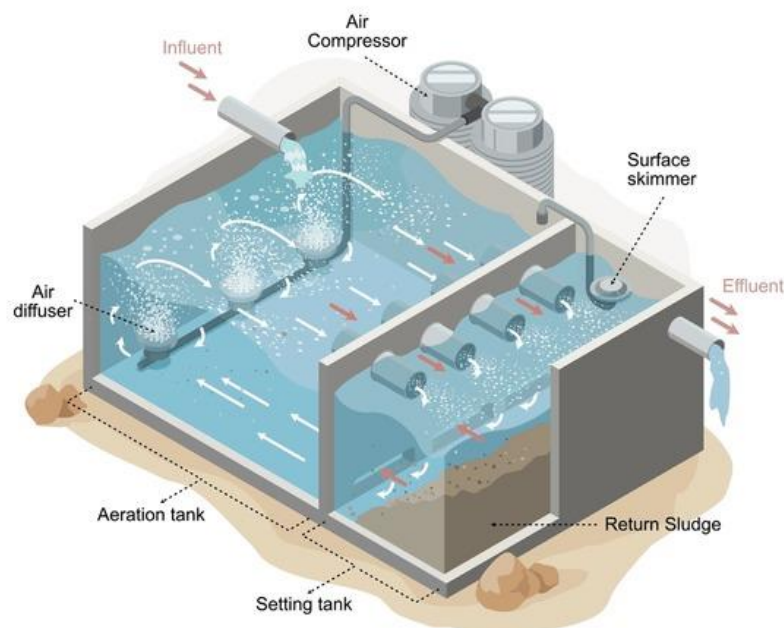


Figure 5: Aeration tank image.

Wastewater aeration involves adding air into wastewater to enable the aerobic breakdown of pollutants. This process is a key component of many biological wastewater treatment systems. Unlike in chemical treatment, which use chemicals to react with and stabilize contaminants in the wastewater, biological treatment relies on naturally occurring microorganisms in the wastewater to decompose these contaminants. (Jaehwan, et al., 2010)

7.5 Clarifier.

There many techniques used during the clarification stage. Listed below are different methods (Khan, et al., 2018):

1. Chemical methods

- Chlorination: Common and effective but may produce harmful by-products.
- Ozonation: Fast-acting but requires careful handling.
- Chloramine: Provides long-lasting disinfection.
- Hydrogen Peroxide & Peracetic Acid: Often used with other methods.

2. Physical Methods

- UV(Ultraviolet) Radiation: Disrupts microbial DNA without chemicals.
- Thermal Disinfection: Uses heat to kill pathogens.

3. Alternative and Emerging Methods

- Electrochemical Disinfection: Uses electric currents to generate disinfectants like chlorine.
- Ultrasonic Disinfection: Uses high-frequency sound waves to disrupt microorganisms.
- Photocatalysis: Involves the use of light-activated catalysts (e.g., titanium dioxide) to destroy pathogens.

7.6 Disinfectant

Disinfection plays a crucial role in wastewater treatment, helping to eliminate harmful microorganisms and prevent the spread of waterborne diseases. Common pathogens found in domestic wastewater include bacteria, viruses, and parasites like Giardia and Cryptosporidium. For disinfection to work effectively, the water must first be properly treated to remove suspended solids.

Different disinfection methods have their strengths and weaknesses—chlorination doesn't work well against certain parasites, while UV treatment struggles with helminth eggs. The level of disinfection also influences environmental regulations, such as how wastewater interacts with groundwater.

Unlike sterilization, which kills all microorganisms, disinfection simply reduces their numbers to lower the risk of disease. Many serious illnesses, like cholera, typhoid, and hepatitis, spread through contaminated water. To tackle this, wastewater treatment plants use various methods, including filtration, oxidation, and sedimentation, to ensure safer water for the environment and public health. (Gross & Farrell-Poe, 2004)



Figure 6:UV disinfection process.

8 Components of ICA in Wastewater Treatment.

ICA is widely applied in the wastewater treatment plant to continually monitor and control the many processes that the wastewater is passed through to ensure safe and effective treatment. A key factor in the development in ICA technology is to allow a more autonomous functionality. To be able to create automated processes. Several components are required such as process controllers, sensor, and actuators. The following are examples of what technology commonly used.

8.1 Sensors

8.1.1 pH sensor/monitor



Ph monitors are used to determine of the pH level. With pH measured on a scale of 1-14 with below 7 being the acidity and above 7 the alkalinity. The pH reading is important to determine how the water is treated. Slight changes in pH can have serious impact on the environment. Found throughout the process.

Figure 7: pH monitor

8.1.2 Dissolved oxygen (DO) sensors



Dissolved Oxygen (DO) refers to the quantity of oxygen present in each volume of water. Oxygen enters water through diffusion from the surrounding air, through aeration caused by turbulent movement, and as a byproduct of photosynthesis performed by plants. It is present in the aeration tank.

Figure 8:DO sensor

8.1.3 Flowmeter

The flow meter is non-contact measurement device measuring flow rate to track process efficiency and detect leaks.



Figure 9:Flowmeter

8.1.4 Level sensor

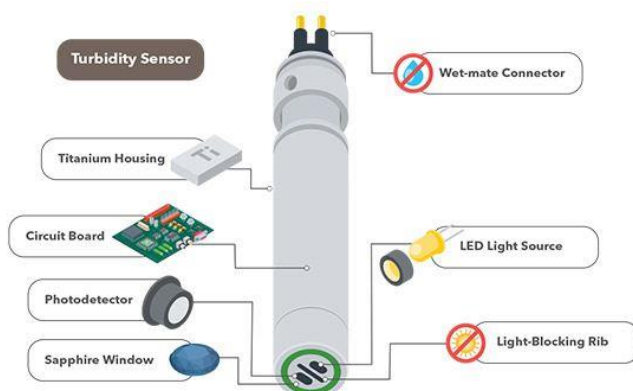
In wastewater treatment facilities, level sensors are frequently used to monitor the levels of liquids and solids in various tanks and containers. These sensors provide immediate data on the volume of wastewater, enabling operators to oversee the treatment process and adjust as needed to ensure optimal performance.



Figure 10:Level sensor

8.1.5 Turbidity sensor

Detects suspended particles, indicating water clarity.



8.2 Actuators

Actuators control mechanical components based on sensor feedback, automating treatment processes. Key types include:

8.2.1 Control valve



Regulate flow rates of water, chemicals, and air in treatment tanks and pipelines. Controlled with feedback from flow rate sensors.

Figure 11:Control valve

8.2.2 Pumps



Move water, sludge, and chemicals throughout the plant.

Figure 12:Wastewater pump

8.2.3 Aerators & Blowers



Provide oxygen for biological treatment, controlled based on DO sensor readings.

Figure 13:Surface aerator

8.2.4 UV Disinfection Systems



Activate UV lamps to kill pathogens based on sensor data.

Figure 14:UV Disinfection system

9 Supervisory Control and Data Acquisition (SCADA) Programmable Logic Controllers (PLCs).

A PLC is a computing device used in industrial environments to control specific processes, machinery, or sometimes an entire production line. This type of industrial computer operates without the need for a mouse, keyboard, or monitor. Because it functions as a computer in an industrial context, specialised logic software is created to manage the operations on the main computer. The corresponding program is then transferred to the PLC through wires. This program is saved in the PLC's memory. The logical programming is done using languages such as ladder logic, data list, or function block diagram, making it easily understandable for those with knowledge in electrical or technical fields. A PLC consists of various input and output points. It observes the status of switches and sensors through input terminals, and based on that information, it sends commands to output devices via output terminals. (Hassan Kaittan & Jasim Mohammed, 2024)

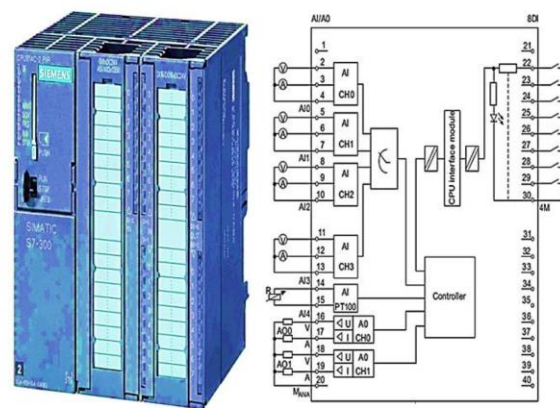


Figure 15:PLC and Example configuration layout.

SCADA systems usually comprise a network of sensors, controllers, and human-machine interfaces that work together to gather and analyse data regarding different elements of the water and wastewater treatment processes. These systems offer users immediate access to information and control over equipment, processes, and operational activities. This capability helps to ensure effective and efficient management of water and wastewater systems, minimize energy usage, enhance system reliability, and maintain compliance with environmental regulations. Besides monitoring and control, SCADA systems are also utilized for data analysis and reporting. They can gather data from various sensors and devices and save it in a database for analysis, reporting, and informed decision-making. This information can be utilized to recognize trends, detect issues, and enhance processes to boost efficiency and cut costs. SCADA solutions are developed with an emphasis on technology integration and operational functionality (Antriksh, 2024).

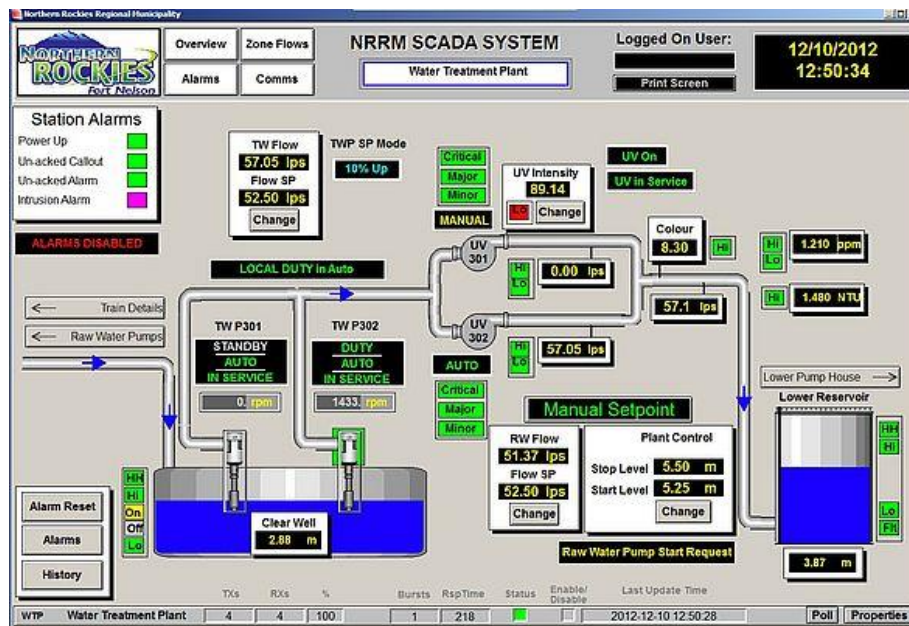


Figure 16: SCADA system in Wastewater plant.

Automating wastewater treatment requires smart control systems like PLCs to keep pumps, valves, and biochemical processes running smoothly. This allows ways to design and optimise ladder block algorithms using PLCs for data analysis, monitoring, and SCADA control. By connecting a PLC with SCADA, the system quickly detects issues, alerts personnel, and adjusts as needed to ensure efficient wastewater treatment. Built with TIA (Totally Integrated Automation) Portal, this setup improves reliability and makes managing treatment operations easier and more effective. Using PLCs with SCADA to automate wastewater treatment also offers major benefits over manual methods. It ensures more efficient and precise control of flow rates, chemical dosing, and treatment times, leading to better overall treatment. Figure 15 shows real-time sensor data allowing continuous monitoring, making it easier to adjust operations as needed and keep everything running smoothly. Plus, automation reduces the need for manual work, improving safety and reliability in the process. (Hassan Kaïttan & Jasim Mohammed, 2024).

10 The Fourth Industrial Revolution (Industry 4.0)

The Fourth Industrial Revolution (Industry 4.0) is bringing innovative technology to the water sector, making operations more efficient, secure, and dependable. Key technologies like IoT, Big Data, Cybersecurity, Cloud Computing, and AI/ML are leading the way in modernizing water and wastewater management. (Kuok, et al., 2024)

10.1.1 Internet of Things (IoT)

Enables real-time monitoring of water systems, helping detect leaks, track water quality, and manage assets remotely for a more reliable supply.

10.1.2 Big Data & Analytics

Processes substantial amounts of water-related data, improving decision-making and efficiency in operations like treatment and distribution.

10.1.3 Cybersecurity

As water systems become more connected, stronger security measures are essential to prevent cyber threats, data breaches, and system failures.

10.1.4 Cloud Computing

Provides easy access to critical data, reduces IT costs, enhances security, and improves smart metering and maintenance.

10.1.5 Artificial Intelligence & Machine Learning

Helps predict potential issues, optimize water treatment, and improve customer services by analysing real-time and historical data. (Autodesk, 2022) Mentions that implementing AI could lead to substantial operational savings of 20-30% in water and wastewater management. Additionally, it is noted that AI can predict emergencies by analysing data patterns and signalling that a breakdown might be about to occur, while continuously learning from these patterns to enhance accuracy over time.

By adopting these technologies, the water sector is moving toward smarter, more sustainable management, ensuring a safer and more efficient water supply for the future.

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