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TREATMENT AND MANAGEMENT OF BIOHAZARDOUS LIQUID WASTE IN CLINICAL LABORATORIES IN SUDAN – KHARTOUM STATE

Issam Osman Elhassan Elkhalifa
PhD Student
Alsalama College of science & technology,
Khartoum-Sudan

M.I.Shukri
Professor
Alsalama College of science & technology,
Khartoum-Sudan

Abstract: **This study emphasizes the importance of effective biohazardous liquid waste management in clinical laboratories to protect public health and the environment, particularly in low-income settings like Sudan. Improper disposal practices in Sudan lead to significant risks, including groundwater contamination and disease outbreaks. The research explores the potential of Programmable Logic Controllers (PLC) and Supervisory Control and Data Acquisition (SCADA) systems to automate waste treatment processes, enhancing precision and minimizing human exposure to hazardous materials.**

Biohazardous liquid waste originates from healthcare facilities, research labs, pharmaceutical production, and veterinary clinics, including substances like blood, bodily fluids, cytotoxic drugs, and chemicals. Inadequate management contributes to the spread of infectious diseases, antibiotic resistance, and environmental pollution. While global guidelines from organizations such as WHO and IAEA provide recommendations for segregation, containment, and safe disposal, implementation in low-income regions is insufficient. Sudan's Health Care Waste Regulation of 2005 offers a framework but lacks enforcement. The study concludes by highlighting the urgent need for automated and efficient waste management systems to bridge these gaps, ensuring compliance with global standards and safeguarding both community health and ecosystems.

Keywords: **Biohazardous liquid waste, Programmable Logic Controllers (PLC), Supervisory Control and Data Acquisition (SCADA), cytotoxic waste, healthcare waste regulation, WHO guidelines, IAEA standards**

I. INTRODUCTION

1.1. General Area of research:

The general area of this research is biomedical engineering with a focus on healthcare waste management. Biomedical engineering involves the application of engineering principles to the fields of biology and healthcare. Waste management in healthcare is critical due to the potential hazards posed by bio-hazardous waste, which includes biological materials, chemical reagents, and other hazardous substances generated in clinical settings.

Clinical laboratories generate significant amounts of liquid waste containing hazardous materials, including chemical reagents, biological fluids, and disinfectants. Improper disposal of such waste poses risks to public health and the environment. Automated systems like PLC and SCADA offer precise control, monitoring, and optimization of waste treatment processes, ensuring efficient and safe disposal.

1.2. Specific Topic:

The specific topic of this research is the treatment and management of biohazard liquid waste in clinical laboratories using Programmable Logic Controllers (PLC) and Supervisory Control and Data Acquisition (SCADA) systems. This topic addresses the need for advanced, automated systems to handle hazardous waste efficiently and safely, minimizing human intervention and reducing the risk of contamination and exposure.

1.3. Challenges in Sudan and Third-World Countries:

The focus of this research is on the treatment and management of liquid waste using new and automated methods, especially in the healthcare sector and facilities, so that management and treatment are carried out before disposal. Sudan has a large number of hospitals, laboratories, and many primary healthcare units that dispose of liquid waste into sewers and natural drainage systems. This poses a real danger to humans, especially sewage workers, as it can leak into groundwater, causing the mixing of contaminated waste water with drinking water. This contributes to the spread of chronic diseases, epidemics, and cancers, representing a real threat to the community.

The attention in healthcare facilities is mainly focused on disposing of solid waste. Thus, there are many technologies for managing and disposing of solid waste, and it is well-defined, but there is little attention given to liquid waste, especially in Sudan and third world countries in general.

1.4. Definition of Biohazard Liquid Waste:

Biohazard liquid waste is any waste that contains biological materials, pathogens, or chemicals that can cause harm to human health or the environment. The term "biohazard" refers to substances that are hazardous due to their potential to transmit infectious diseases or have toxic properties. Liquid waste of this type may include a variety of substances such as blood, urine, bodily fluids, pharmaceuticals, and chemicals used in treatments, all of which can be hazardous and require careful management [1].

Biohazard liquid waste is often categorized as hazardous waste due to the risk of contamination with dangerous microorganisms or toxic chemicals. It is different from other types of liquid waste (such as industrial waste or household waste) due to its potential infectious nature and its ability to harm living organisms, especially through improper disposal [2].

1.5. Sources of Biohazard Liquid Waste:

Biohazard liquid waste originates from a variety of sources, most notably healthcare settings, research laboratories, pharmaceutical manufacturing, and biotechnology companies. Key sources of biohazard liquid waste include:

1.5.1 Healthcare Facilities: In hospitals and clinics, a significant amount of biohazardous liquid waste is generated daily. This waste includes blood, urine, bodily fluids, and waste from clinical procedures[3].

1.5.2. Chemotherapy and Oncology Centers: Facilities administering chemotherapy produce liquid waste that includes cytotoxic drugs, chemicals, and solvents. These substances are highly toxic to both human cells and the environment[3].

1.5.3. Research Laboratories: Laboratories involved in scientific research with biological materials, infectious agents, or genetically modified organisms often produce biohazard liquid waste[4].

1.5.4.Pharmaceutical Manufacturing: Manufacturing processes for drugs, particularly those in the pharmaceutical industry, generate hazardous waste, including liquids containing unreacted chemicals, solvents, or residues from the production of active pharmaceutical ingredients[5].

1.5.5. Veterinary Clinics and Animal Research: Animal research facilities and veterinary clinics also generate biohazard liquid waste, especially when dealing with animals infected with diseases or when performing diagnostic tests[6].

1.6. Importance of Treatment and Management:

1.6.1. Public Health and Environmental Implications:

Biohazard liquid waste poses significant risks to public health and the environment. Healthcare waste management, including the handling and disposal of biohazard liquid waste, is a crucial part of ensuring that the spread of infectious diseases is prevented. The risks associated with improper management of biohazard waste are multifaceted:

a. **Infectious Disease Control**: Pathogens present in healthcare waste, such as bloodborne viruses (e.g., Hepatitis B, C, HIV), can be transmitted if waste is not disposed of properly[3].
b. **Antibiotic Resistance**: Antibiotic resistance is an increasing concern globally, and improper disposal of pharmaceutical waste is one of the contributing factors. The release of antibiotics into the environment through improper disposal can promote the development of antibiotic-resistant bacteria[3].
c. **Chemical and Radioactive Hazard Control**: Many biohazardous materials, such as cytotoxic drugs and radioactive waste, can cause long-term environmental damage. Cytotoxic drugs, when not disposed of correctly, can leach into water systems and poison aquatic life[7].

1.7. Global Guidelines and Local Policies

The World Health Organization (WHO) and International Atomic Energy Agency (IAEA) have established guidelines for managing liquid medical waste. These guidelines include protocols for segregation, containment, treatment, and safe disposal. However, the implementation of these protocols in low- and middle-income countries remains insufficient. In Sudan, the Health Care Waste Regulation of 2005 provides a legal framework for waste management. Despite this, enforcement is limited, and specific provisions for liquid waste management are underdeveloped.

1.8. Federal Ministry of Health Rules

The Federal Ministry of Health (FMoH) in Sudan has established regulations for healthcare waste disposal, including liquid waste, to safeguard public health and the environment. These regulations are outlined in the Health Care Waste Regulation of 2005.

1.9. Role of the World Health Organization (WHO)

The WHO plays a critical role in the management and treatment of healthcare liquid waste in third-world countries, including Sudan. While the WHO does not directly manage waste disposal systems, its influence is substantial in raising awareness, providing guidelines, offering technical support, and advocating for policies that address healthcare waste challenges. Key aspects of the WHO's involvement include:

a. Raising awareness about the risks associated with healthcare waste.
b. Providing technical guidelines for safe waste management.
c. Supporting policy development to improve waste treatment and disposal systems.
d. Advocating for enhanced global and local efforts to address healthcare waste management challenges effectively.

1.10. Classification of Waste:

Waste arises in many different forms and its characterization can be expressed in several forms. Some common characteristics used in the classification of waste includes the physical states, physical properties, reusable potentials, biodegradable potentials, source of production and the degree of environmental impact [8].

Stated that waste can be classified broadly into three main types according to their physical states; these are liquid, solid and gaseous waste. Although it is clear that several classifications exist in different countries. The most commonly used classifications are illustrated below [9].

a. Physical state: Solid waste, Liquid waste and Gaseous waste.
b. Source: Household/Domestic waste, Industrial waste, Agricultural waste, Commercial waste, Demolition and construction waste.
c. Environmental impact: Hazardous waste and Non-hazardous waste

1.11. Type of biomedical waste:

1. Solid Biomedical Waste.
2. Liquid Biomedical Waste.

1.12. Liquid Biomedical Waste:

Amongst all the category of biomedical waste (BMW), liquid wastes pose a serious threat to human health and the environment because of their ability to enter watersheds, pollute ground water, and drinking water when improperly handled and disposed. At the same time, illegal and unethical reuse of this untreated waste, can be extremely dangerous and even fatal in causing diseases like cholera, plague, tuberculosis, hepatitis B, diphtheria etc., in either epidemic or even in endemic form, which can pose grave public health risks and consequences and thus is a major problem for healthcare facilities, their employees, and the community at a large [10].

Wastewater is not similar to sewage, for the former is any water that has been adversely affected in quality by anthropogenic influence and comprises liquid waste either discharged from health care facilities (HCF) or from domestic residences, commercial properties, industry, and or agriculture and encompasses a wide range of potential contaminants and microbial concentrations whereas sewage is a subset of wastewater that is contaminated with feces or urine [10].

1.13. Types of Liquid Waste:

The liquid waste generated from a HCF is usually of the following types [10]:

a. Infectious waste:
  i. Blood and body fluids
  ii. Laboratory wastes (cultures of infectious agents, cultures from laboratories, biological, discarded vaccines, culture dishes and devices)

b. Chemically hazardous:
  i. Formaldehyde (obtained from pathology labs, autopsy, dialysis, embalming)
  ii. Mercury (broken thermometers, sphygmomanometer, dental amalgams)
  iii. Solvents (pathology and embalming)
  iv. Radioactive isotopes

c. pharmaceutical liquid waste (discarded/unused/expiry date medicines)

d. Photographic chemicals (fixer and developer)

Due to the limited scope of the research study, solid waste which can be disposed. Only liquid wastes will be discussed in detail, which require tighter environmental controls because of their potential to cause environmental harm, of via sewer networks or lost to ground waters.

1.14. Current and Emerging Waste Treatment Methods:

Several treatment methods are used to address the unique characteristics of biohazard liquid waste. These include [3]:

a. **Chemical Neutralization**: This method involves adding specific chemicals to biohazard liquid waste to neutralize harmful pathogens and chemicals. Chemical disinfectants, such as chlorine bleach, are commonly used to kill microorganisms. However, this method can be hazardous if not properly managed and can contribute to chemical pollution if excess chemicals are used [3].
  i. **Autoclaving**: Autoclaving, or steam sterilization, is a widely used method for treating medical waste. It uses high-pressure steam to kill pathogens, rendering the waste safe for disposal[3].
  ii. **Incineration**: Incineration involves burning hazardous waste at high temperatures, which effectively destroys pathogens and toxic chemicals. It is an effective method for treating biohazard waste, particularly for liquid waste with high chemical or pharmaceutical contamination[3].

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iii. **Membrane Filtration**: Membrane filtration uses semi-permeable membranes to remove pathogens, chemicals, and other contaminants from biohazard liquid waste[3].

iv. **Bioremediation**: Bioremediation utilizes microorganisms, such as bacteria or fungi, to degrade organic contaminants in the waste. This method is environmentally friendly and can be used in some cases to treat liquid waste [3].

1.15. The management of Bio-hazard1 liquid waste:

The management of Bio-hazard liquid waste in clinical laboratories represents a critical intersection of public health, environmental sustainability, and biomedical engineering. Hazardous liquid waste from healthcare facilities contains a mixture of chemical and biological contaminants that pose significant risks to human health and the environment if improperly managed. Traditional methods of waste treatment, often manual and labor-intensive, face challenges such as inefficiency, lack of real-time monitoring, and inadequate compliance with evolving safety and environmental standards [5].

1.16. Types of Clinical Laboratory Liquid Waste:

a. Biological Waste: Includes blood, body fluids, and liquid cultures from microbiology labs, may contain infectious pathogens [6].

b. Chemical Waste: Includes reagents, solvents, acids, and bases used in testing and research, examples: Formalin, xylene, ethanol, and other laboratory reagents [6].

c. Radioactive Waste: Liquid waste from labs using radioactive isotopes, examples: Scintillation fluids, radioactive tracers [6].

d. Mixed Waste: A combination of biological, chemical, or radioactive waste.

1.17. What is Programmable Logic Controller (PLC)?

A PLC (Programmable Logic Controller) is an industrial computer used for automation of electromechanical processes, such as control of machinery on factory assembly lines, amusement rides, or light fixtures. PLCs are expected to work flawlessly for years in industrial environments that are hazardous to the very microelectronic components that give modern PLCs their excellent flexibility and precision. Prior to PLCs, many of these control tasks were solved with contactor or relay controls. This is often referred to as hardwired control. Circuit diagrams had to be designed, electrical components specified and installed, and wiring lists created. Electricians would then wire the components necessary to perform a specific task. If an error was made the wires had to be reconnected correctly. A change in function or system expansion required extensive component changes and rewiring[11] Figure 1.

Figure 1. Programmable Logic Controller (PLC)

1.18. Programmable Logic Controllers (PLC):

A PLCs are often defined as miniature industrial computers that contain hardware and software used to perform control functions. More specifically, a PLC would be used for the automation of industrial electromechanical processes, such as control of machinery on factory assembly lines, amusement rides, or food processing. They are designed for multiple arrangements of digital and analog inputs and outputs with extended temperature ranges, immunity to electrical noise, and resistance to vibration and impact. A PLC will consist of two basic sections: the central processing unit (CPU) and the Input/Output (I/O) interface system [11].

1.19. Block Diagram of PLC System

Figure3. shows, in block form, the four major units of a PLC system and their interconnections, which are briefly described here [12]Figure 2:

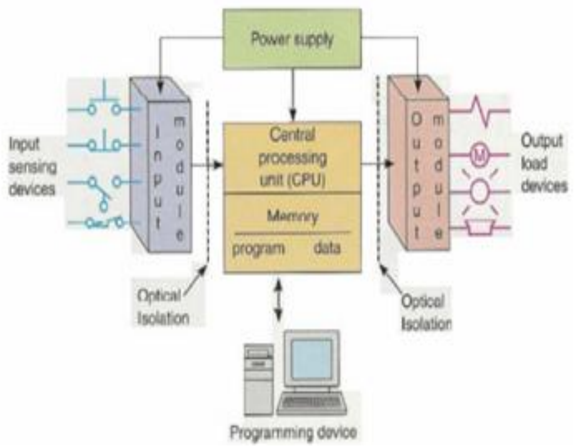

Figure 2. Block Diagram of PLC System

a. Central Processing Unit (CPU):

i. **Microprocessor Unit**:Carries out the mathematical and logical operations of the system.

ii. **Memory Unit**: Stores the system software and the user program data and information.

iii. **Power Supply**: Converts the AC line voltage to various DC operational values. The power supply is filtered and regulated to ensure proper operation of the PLC system.

b. PLC Programmer/Monitor:

i. A programming device used to communicate with the circuits of the PLC. This may be a hand-held terminal, industrial terminal, or a personal computer.

c. Input/Output Modules:

i. **Input Module (I)**: Has terminals into which outside process electrical signals, generated by sensors or transducers, are entered. These sensors or transducers can be thousands of meters away from the CPU.
ii. **Output Module (O)**: Has terminals into which output signals are sent to activate relays, solenoids, various solid-state switching devices, motors, and displays. This output signaling elements may also be thousands of meters away from the CPU.
iii. An electronic system for connecting I/O modules to remote locations can be added as necessary.

d. Racks and Chassis

i. There is a rack on which the PLC parts are mounted and the enclosures on which the CPU, the PM, and the I/O modules are mounted.

e. Optional Devices

i. **Printer**: A device using which the program in the CPU may be printed. In addition, operating information may be printed upon command.
ii. **Program Recorder/Player**: PLCs use fluffy disks, with hard disks for secondary storage. This recorder provides the backup and a way to download the program written-off from the PLC process system.
iii. **Master Computers**: Often used to coordinate many individuals, interconnected PLCs. These interconnected electrical buses are sometimes referred to as "Data Highways" [12].

1.20. Primary PLC Programming Languages:

1.20.1. Function Block Diagram (FBD):

Function Block Diagram is a fundamental and graphical programming language for PLCs. It allows technicians to create programs by connecting functions written in lines of code into boxes (blocks) and linking these blocks together [13].

1.20.2. Ladder Diagram (LD):

Also known **as** Ladder Logic**,** Ladder Diagram is a visual PLC programming language similar to electric relay circuits. It is standardized by PLC Open and organized into rungs that resemble a ladder when combined example of ladder diagram [13].

1.21. Introduction to SCADA System:

A SCADA stands for Supervisory Control and Data Acquisition. It is a real-time industrial process control system used to monitor and control remote or local industrial equipment like motors, valves, pumps, relays, sensors, etc. A SCADA combines telemetry and data acquisition. Previously, industrial processes were controlled by PLC, CNC, PID, and microcontrollers programmed in certain languages or codes without visual animation. A SCADA software introduced animation for easier process understanding [13].

ASCADA is a system comprising hardware, software, and protocols, used in controlling processes in chemical plants, oil and gas pipelines, electrical generation and transmission, manufacturing, and water purification. In a SCADA system and PLCs can control processes and supervisors can set parameters via host control functions. A SCADA systems implement distributed databases called tag databases, containing data elements known as tags or points. Points can be "hard" (actual input/output) or "soft" (results of logic/math operations) [13].

1.22. Automated Control Systems, PLC and SCADA Integration:

Automation technologies, particularly Programmable Logic Controllers (PLC) and Supervisory Control and Data Acquisition (SCADA) systems, have emerged as transformative tools in industrial process management. While these technologies have seen extensive applications in manufacturing and utilities, their adoption in the healthcare sector for waste treatment remains underexplored. Current literature highlights the potential of PLC and SCADA to enhance the precision, efficiency, and reliability of waste management systems. However, research addressing their specific implementation for Bio-hazard liquid waste treatment in clinical and chemotherapy settings is sparse, leaving critical gaps in design optimization, operational scalability, and integration with safety protocols [14].

This study aims to address these gaps by developing and modeling an automated system for the treatment and management of Bio-hazard liquid waste using PLC and SCADA technologies. By focusing on clinical laboratories, the research targets environments where liquid waste management is particularly challenging due to high toxicity levels and stringent regulatory requirements [14].

The rationale for this research lies in its potential to advance sustainable healthcare practices by reducing environmental contamination, ensuring compliance with international waste management standards, and safeguarding public health. Furthermore, it seeks to bridge the technological gap in healthcare waste treatment by introducing robust automation frameworks that are adaptable and scalable [14].

Automated control systems often involve the integration of Programmable Logic Controllers (PLCs) and Supervisory Control and Data Acquisition (SCADA) systems to monitor, control, and optimize industrial processes [14] figure 3.

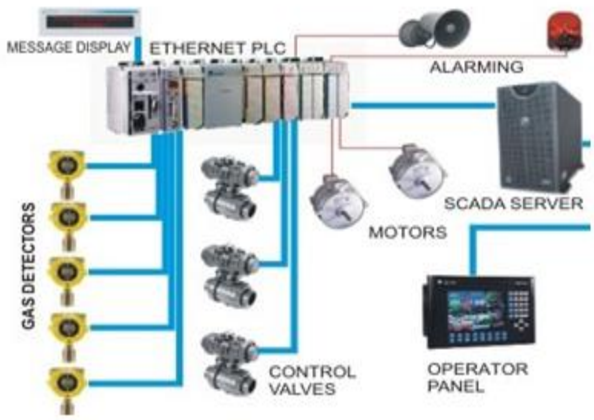

Figure 3. Integration of (PLCs) and (SCADA) systems

1.23. How PLC and SCADA Work Together [14]:

a. Data Acquisition:

i. Sensors connected to the PLC capture process data (e.g., temperature, pressure).
ii. The PLC processes this data and sends it to the SCADA system.

b. Real-Time Control:

i. The PLC executes control logic based on sensor inputs (e.g., turning a motor on/off).
ii. SCADA monitors the PLC's actions and provides feedback to operators.

c. Visualization and Monitoring:

i. SCADA visualizes the process data collected by PLCs through graphical interfaces.
ii. Operators can view system performance, trends, and alarms.

d. Remote Control:

i. SCADA allows operators to send commands to PLCs (e.g., start/stop processes) from a centralized or remote location.

1.24. Sensors and Actuators

The waste treatment process leverages **sensors** to measure critical parameters and **actuators** to implement adjustments based on sensor feedback, all controlled by the PLC for optimal system performance.

1.24.1. Flow Rates:

Flow rate sensors ensure consistent waste flow. The PLC adjusts pump speeds and valve positions to maintain optimal flow rates Figure 4.

Figure 4. Flow meter measuring

1.24.2. PH Control:

PH sensors monitor waste acidity/alkalinity. The PLC regulates chemical dosing systems to keep pH within acceptable levels for effective treatment Figure 5.

Figure 5. Ph meter value and total dissolved solids

1.24.3. Temperature:

Temperature sensors monitor system heat. The PLC adjusts heating/cooling to maintain optimal temperature, ensuring efficient physical and chemical processes Figure 6.

Figure 6. temperature meter measuring

1.24.4. Timer Measurement:

The programmable timer relay can be used in any combination of multi-channels without synchronization error caused by multiple single-channel timer relays. Loops can be nested arbitrarily Figure 7.

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Figure 7.Programmable Timer Relay

1.24.5. Chemical Concentration:
Sensors track real-time chemical levels. The PLC controls dosing to ensure effective treatment, minimizing waste and cost.

1.25. Design of a Program Using Ladder Language in PLC:
The design of a waste treatment program using Ladder Logic in Programmable Logic Controllers (PLCs) is crucial for automating and optimizing the process of handling biohazardous and cytotoxic liquid waste. This approach ensures precision, reliability, and compliance with environmental and safety standards. Ladder Logic, being a visual programming language, provides an intuitive framework for controlling industrial processes, making it an ideal choice for managing the complex stages of liquid waste treatment. This language is written in a program (ISP soft). ISP soft is a software development tool for Delta's new generation programmable logic controllers. IEC 61131-3. In addition to basic programming functions, ISP Soft also contains many auxiliary tools. The multilingual environment and the friendly user interface provide users with a convenient and efficient development environment This document outlines the methodology and key considerations in developing a Ladder Logic program for waste treatment systems Figure 15.

1.26. Key Components of the PLC-Based Waste Treatment System:
1.26.1. Waste Collection and Initial Screening:
a. Automation Process:
i. Sensors detect the presence of waste in containers.
ii. PLC controls the opening and closing of valves to transfer liquid waste to the initial screening unit.
iii. A screening mechanism, managed by the PLC, removes large solids and debris.

b. Logic Design:
i. Input: Waste level sensors and manual start signals.
ii. Output: Actuators for valve and conveyor control.
iii. Ladder Logic: Uses conditional branches to activate valves based on sensor readings.

1.26.2. Pre-Treatment Stage:
a. Chemical Dosing:
The PLC regulates the dosing of neutralizing agents using real-time data from chemical concentration sensors.
b. pH and Temperature Control:
i. Sensors provide continuous feedback on pH levels and temperature.
ii. The PLC adjusts chemical dosing and activates heating or cooling systems as needed.

c. Logic Design:
i. Input: Sensor data for pH, temperature, and chemical levels.
ii. Output: Pump speed and dosing valve control.
iii. Ladder Logic: Implements proportional control loops for maintaining optimal conditions.

1.26.3. Primary Treatment:
a. Automated Waste Transfer:
i. PLC controls pump to move waste to holding tanks.
ii. Tank levels are monitored, and flow rates are adjusted dynamically.

b. Logic Design:
i. Input: Tank level sensors.
ii. Output: Pump control signals.
iii. Ladder Logic: Ensures smooth transitions by prioritizing tanks based on fill levels.

1.26.4. Disinfection Stage:
a. Chemical Disinfection:
i. The PLC controls the mixing of disinfectants and monitors chemical concentration in real time.
ii. Feedback loops ensure effective pathogen elimination while preventing overdosing.

b. Mixing and Monitoring:
i. Agitators are activated by the PLC to ensure uniform mixing.
ii. Continuous monitoring of pH and temperature ensures optimal reaction conditions.

c. Logic Design:
i. Input: Sensor data for chemical concentration, pH, and temperature.
ii. Output: Mixer and dosing valve control.
iii. Ladder Logic: Includes interlocks to prevent unsafe chemical reactions.
1.26.5. Advanced Treatment and Filtration:
a. Filtration and Fermentation:
i. The PLC manages advanced filtration units to remove residual particles.

ii. Optional fermentation processes are controlled to enhance biodegradation.

b. Logic Design:

i. Input: Flow and pressure sensors.
ii. Output: Filtration unit control and fermenter activation.
iii. Ladder Logic: Uses timers and counters for cycle management.

1.26.6. Final Disposal:

a. Disposal Control:

i. Treated waste is directed to siphon tanks or sewer systems under PLC supervision.
ii. Final inspections are automated to ensure compliance with discharge standards.

b. Reactivation of Decomposing Bacteria:

The PLC regulates the addition of nutrients to enhance bacterial growth in sewer systems.

c. Logic Design:

i. Input: Waste quality sensors.
ii. Output: Discharge valve control and nutrient dosing.
iii. Ladder Logic: Verifies compliance before initiating disposal Figure 8.

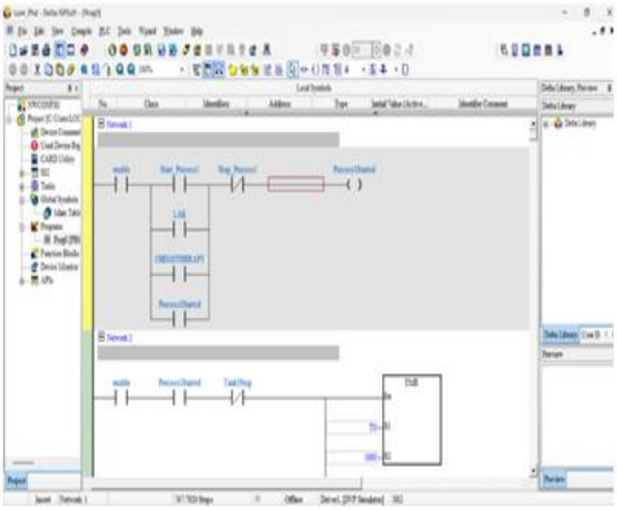

Figure 8. Design Program for Waste Treatment Using Ladder Language

1.27. PLC and SCADA Integration:

The integration of Delta PLC with the SCADA system provides a robust solution for monitoring and controlling the biohazard liquid waste treatment process. Both systems work together to provide Commgr real-time data, automate processes, and allow operators to make informed decisions quickly. The integration process involves both hardware and software components, each playing a critical role in the system's operation.

1.28. Communication Between PLC and SCADA:

Delta PLC supports various communication protocols such as Commgr, Modbus, TCP/IP, and Ethernet. These protocols enable seamless communication between the PLC and SCADA system, ensuring that real-time data is transmitted efficiently and securely. The SCADA system receives data from the PLC, including sensor readings such as pH, temperature, flow rate, amount of radiation, and chemical concentrations. This data is visualized in a user-friendly interface, allowing operators to monitor the status of the treatment process Figure 16.To accomplish this, used the program (Gommgr 1.14 – delta) to interface the system togetherthis is a program for Communication management software between Programmable Logic Controllers (PLCs)and Human Machine Interfaces (SCADA) Figure 9.

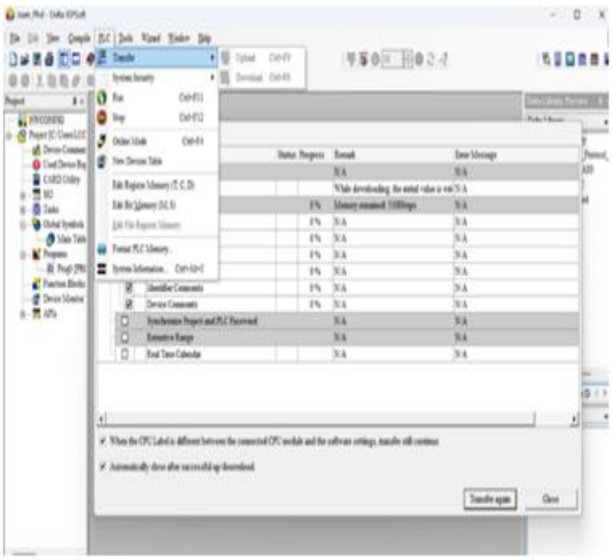

Figure 9. Gommgr 1.14 – delta) Communication management software

Therefore, the ladder language program design that was installed on the PLC must be output to the SCADA screen. To do this, the program Dop soft -DELAT must be used, which gives a real-time view of the system operation. All operations generated by the PLC can be monitored moment by moment, errors can be processed, and data can be recorded and saved to avoid these errors.

1.29. A Human Machine Interface (HMI):

A Human Machine Interface (HMI) is a digital product that facilitates communication between operators and automated equipment. The HMI provides a variety of communication ports for seamless interaction with various devices. The

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touch panel allows intuitive parameter configuration, while the LCD screen displays monitoring data related to the machine equipment. Additionally, flexible editing software enables designers to create customized interface screens tailored to the specific needs of different applications.
To create the Human Machine Interface (HMI), used the program (Dop soft -DELAT version: 4.00.16 build) whose outputs are displayed on the SCAD screen to monitor the execution of the PLC outputs during the process, which provides greater safety for the operator from the risks resulting from waste treatment and from the equipment, and managing the waste treatment system meets all required environmental, health and safety Figure 10.

Figure 10. communication (PLC and SCADA system) with Commgr

1.30. Real-Time Monitoring:
The SCADA system continuously displays real-time data from the PLC. Operators can see the status of key parameters, including pH levels, temperature, flow rate, amount of radiation, and the operating status of various equipment. If any parameter exceeds predefined thresholds, the SCADA system generates an alarm to notify operators of potential issues. This real-time monitoring allows for immediate intervention if necessary, ensuring that the treatment process remains safe and efficient.

1.31. Data Logging and Reporting:
The SCADA system logs all data from the PLC for historical analysis. This data can be used to generate detailed reports on system performance, chemical usage, treatment efficiency, and any incidents or anomalies. Regular reporting is essential for regulatory compliance, ensuring that the waste treatment facility meets all required environmental and health standards.

1.32. Control and Adjustment:
Operators can use the SCADA system to adjust treatment parameters remotely. For example, they can change chemical dosing levels, adjust pump speeds,increase time, or control other system settings based on the data provided by the sensors. These adjustments are communicated to the Delta PLC, which sends control signals to the appropriate actuators.

1.33. Alarm and Fault Management:
In the event of a fault or abnormal condition, such as a malfunction in the filtration system or excessive chemical concentration, the PLC sends an alarm to the SCADA system. The alarm triggers a notification to the operator, allowing them to take corrective action. Additionally, the SCADA system logs these events for future analysis and troubleshooting.

1.34. Design Parameters:
The design of the biohazard liquid waste treatment system requires careful consideration of various parameters that influence the treatment process. These parameters are monitored and regulated by the Delta PLC to ensure that the system operates efficiently and effectively.

1.35. Safety and Compliance:
Ensuring safety and regulatory compliance is a fundamental aspect of the biohazard liquid waste treatment system. The system must be designed to meet environmental regulations, protect operators from exposure to hazardous materials, and ensure that the treated waste is safe for disposal.

1.36. Hazardous Material Detection:
The system includes sensors that detect the presence of hazardous materials, such as cytotoxic drugs or chemical agents. If these materials are detected, the system automatically adjusts the treatment process or triggers an emergency shutdown to prevent further contamination.
1.37. Emergency Shutdown:
In the event of an emergency, such as a system malfunction or hazardous material leak, the PLC will initiate an emergency shutdown sequence. This will stop all ongoing processes and prevent the spread of contamination. The SCADA system will notify operators of the shutdown and the cause of the incident.

1.38. Regulatory Compliance:
The system is designed to meet international standards for waste treatment and disposal, including the Basel Convention on hazardous waste management, EPA regulations, and OSHA safety standards. The system will undergo regular inspections and audits to ensure ongoing compliance with these regulations.

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1.39. Operator Training:
Operators will receive thorough training on how to operate the SCADA system, monitor treatment processes, and respond to alarms and emergencies. Proper training ensures that the system is operated safely and efficiently, reducing the risk of human error and system failure.

1.40. Process Flowchart of clinical laboratories:
Proper management and treatment of laboratory waste are vital to maintaining safety, ensuring environmental compliance, and minimizing the impact of biohazard materials. This document outlines the systematic flow of processes involved in handling, treating, and disposing of clinical laboratory waste, emphasizing automation and control for efficiency and safety Figure 11.

1.40.1. Waste Collection and Initial Screening:
The waste is collected from clinical laboratories, chemotherapy units, or healthcare facilities into specially designed containers that prevent contamination. At this stage, large solids, debris, and non-hazardous materials are screened out. This initial step ensures that only the biohazard liquid waste enters the treatment process.

Figure 11. Process Flowchart of clinical laboratories

1.40.2. Pre-Treatment Stage:

a. Chemical Dosing: In the pre-treatment stage, harmful chemicals present in the waste are neutralized using chemical agents. The Delta PLC controls the chemical dosing system, ensuring the correct amount of neutralizer is injected based on real-time data from the sensors.

b. pH Control: pH levels are critical to the effectiveness of the chemical dosing and the overall treatment process. If the pH level is outside the acceptable range, the PLC adjusts the chemical dosing system to bring the pH to (7.45).

c. Temperature Control: Waste streams with extreme temperatures can cause system malfunctions. Temperature sensors continuously monitor the waste, and the PLC adjusts cooling or heating systems as needed to ensure that the waste remains within an optimal temperature range for treatment between (30℃ - 40℃).

d. Natural yeasts: Natural yeasts refer to microorganisms, primarily strains of fungi from the Saccharomyces genus, that occur naturally in the environment. These yeasts are commonly used in biological processes such as fermentation and biodegradation.

In the context of waste treatment, natural yeasts play a crucial role in:

i. **Biodegradation:** They help break down organic matter in liquid waste by consuming organic compounds and converting them into simpler, less harmful substances. Their metabolic activity supports the decomposition of organic pollutants, reducing the environmental impact of discharged waste.

ii. **Bioremediation:** Natural yeasts contribute to the degradation of contaminants by promoting the growth of beneficial bacteria that further break down waste components. They help balance the microbial ecosystem in wastewater treatment processes.

iii. **Odor Control:** Yeasts can help in neutralizing foul odors by breaking down sulfur-containing compounds and other volatile organic compounds (VOCs).

1.40.3. Primary Treatment:
During the primary treatment stage, the first stage is to collect all laboratory waste in a tank with a known capacity according to the size of the laboratory and the waste produced during work. The capacity is determined by the number of patients the laboratory receives, in addition to the number of solutions used in the examination and the number of workers in the laboratory, and the PLC adjusts the speed pumps and locks the valves to ensure the flow of waste to the next tank.

1.40.4. Disinfection Stage:
Disinfection is a crucial stage in the treatment process, as it eliminates pathogenic microorganisms present in the waste. This is typically achieved through:

a. Chemical Disinfection:
Disinfectant chemicals, such as (Sodium Hypochlorite, Bleach), are added to the waste stream. The PLC monitors

the chemical concentration in the waste and adjusts dosing based on real-time feedback from sensors.

Will use (Sodium Hypochlorite, Bleach) effective against bacteria, viruses, fungi, and some spores, used with Concentration (0.1%) for general disinfection (e.g., disinfecting surfaces) or (0.5%) for high-risk contamination (e.g., biohazards) which makes the medium acidic in pH (<6), the medium Acidic environments enhance the heat's ability to denature proteins in bacteria and viruses and for 10 minutes in temperature 37℃ is more enough to sterilize and treatment medical waste and water treatment.

i. The pH and temperature are calculated by measuring them with a pH meter and a temperature sensor so that the reaction is good and to prevent the rise of gases.
ii. After pouring the disinfectant with the liquid waste, the mixer is turned on to ensure that all liquids are mixed with the disinfectant or sterilizing chemical to ensure that viruses, bacteria and fungi are killed from the liquid.

1.40.5. Final disposal:

The final stage of the process is the disposal of the treated waste, after the purification process a special treatment is carried out which may include advanced filtration or fermentation (Naturalyeast) to reactivate the decomposing bacteria in the waste, so it can be disposed of by PLC control in the siphon tank or general sewer so that the chemicals in the fourth stage that kill harmful bacteria and fungi are much less or non-existent in the fifth and final stage because they can also kill the natural decomposing bacteria present in the siphon tank or public sewer, unless help the decomposing bacteria multiply again to improve the sewer. The PLC monitors the final characteristics of the waste, ensuring that it meets all environmental and safety standards before it is discharged or disposed.

1.41. Simulation Process and treatment clinical waste of laboratories:

A quantity of 1000 m^3 of liquid waste was introduced to the laboratory, which contains residues from the remaining samples that were tested on, such as urine, blood, and some of laboratory reagents (most of the tests contain a large number of bacteria, fungi, and viruses). It is emptied into a special basin that contains a path for the treatment system, which consists of several tanks designated for treatment and controlled by the PLC and in controlling the treatment area and SCADA to clarify the process path and control it by the technician specialized in operation and monitoring (process management). The results were as shown on the following screen Figure 12.:

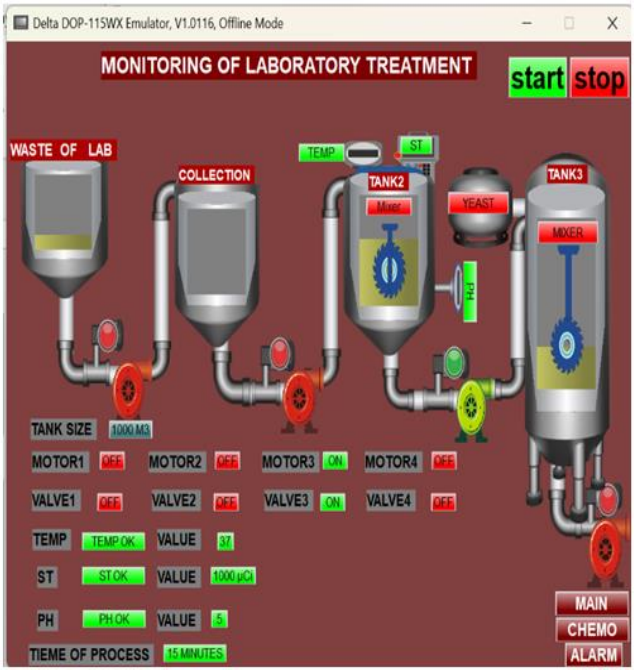

Figure 12. Results of Process and treatment clinical waste of laboratories

1.41. MATLAB Simulation:

To simulate the system for treating and managing 1000 m³ of biohazard liquid waste from clinical laboratories using MATLAB, you can create a model that incorporates the following steps:

a.Define the System Parameters: This includes flow rates, treatment efficiency, and other relevant variables.
b. Model the Treatment Process: Simulate the PLC (Programmable Logic Controller) and SCADA (Supervisory Control and Data Acquisition) system logic.
c. Simulate Waste Treatment: Use differential equations or iterative calculations to represent the treatment process over time.
d. Visualize Results: The results output in digital display to show how the waste is treated over time.
Below is the MATLAB code to simulate the treatment of 1000 m³ of biohazard liquid waste.

1.41.1. Explanation of the Code:

a. System Parameters:

i. total_waste_volume: The total volume of biohazard liquid waste to be treated (1000 m³).
ii. inflow_rate: The rate at which waste enters the treatment system (5 m³/hour).
iii. treatment_efficiency: The percentage of waste treated effectively (95%).

b. Simulation Loop:

i. The loop iterates over time steps, calculating the inflow of waste, the amount treated, and the remaining untreated waste.

ii. The main function ensures that the inflow does not exceed the remaining waste.

c. Outputs: The results output in digital display to show how the waste is treated over time.

This code provides a basic framework for simulating the treatment of biohazard liquid waste.

1.43. PLC and SCADA System Implementation for Simulation:

Each tank's operation should be modeled with the following control logic:

1.43.1. Liquid Laboratory Waste Tanks:

a. Tank 1 (Collection after sorting):

i. Level sensors to detect waste levels.
ii. Automatic transfer to Tank 2 when full.

b. Tank 2 (Buffer storage):

i. Volume measurement for dosage calculation = 1000 m3.
ii. Control logic to start Tank 3 processing when full.

c. Tank 3 (Treatment with Sodium Hypochlorite Concentration5%):

i. Injection Sodium Hypochlorite (100 litter).
ii. pH sensors (maintain acidic medium) ≤ 6.
iii. Temperature control system ≤ 37℃.
iv. Timer of sterilization ≥ 15-minute.
v. Mixer operation logic (running at variable speeds).

d. Tank 4 (Final treatment with natural yeast):

i. Dosing control for yeast injection (Natural yeasts refer to microorganisms, primarily strains of fungi).
ii. Flow control to drainage system.

1.43.2. Result in monitor:

iii. pH meter ≤ 6, Temperature ≤ 37℃ and Timer ≥ 15-minute.

1.44. Sterilization and treatment clinical waste of laboratories:

There are two methods for sterilizing and disposing of liquid waste in laboratories approved by the World Health Organization(WHO), which are:

a. Autoclaving:

Autoclaving is the most common type of steam treatment and utilizes saturated steam under pressure to decontaminate waste Potential infected air evacuated from the autoclave is filtered effectively (HEPA filter) Autoclaves operate at temperatures of (12 – 134)°C Autoclaves which do not have an integrated shredder should ensure that the air is removed from the autoclave chamber before the waste is decontaminated (by a vacuum pump), as air remaining in the waste can inhibit the decontamination efficiency of the autoclaving process.

i. Autoclave Treatment:

- Collect the waste in a container that is autoclave-compatible (polypropylene or glass)
- Tightly close the container for transport to prevent spilling. Transport the container to the autoclave using a secondary container or autoclave tray on a hand cart.
- Autoclave using the appropriate liquid cycle121:℃, ≥ 15 psi, 30-60 min
- Once cycle is complete and the liquid has cooled, dispose down the drain.

ii. Facts: the size of autoclave between (18 - 150) litter, power of heating between (3 -30) Kw, all process handling manually.

b. chemical treatment:

chemical treatment methods mostly use disinfectants These are problematic as they produce toxic effluents and increase the risk of exposure of such toxins to health-care waste workers Two exceptions are ozone treatment and alkaline hydrolysis Ozone is a strong gaseous disinfectant and can be generated on site, avoiding the need to transport and store it Alkaline hydrolysis uses sodium or alkaline hydroxide at high temperature and pressure to destroy tissues and formaldehyde It is also proven to destroy prion waste Alkaline hydrolysis is also capable of destroying chemicals such as pharmaceuticals.

1.45. Comparison Between PLC and SCADA System and Sterilization Methods for Liquid Waste Treatment:

1.45.1. PLC and SCADA System Implementation for Simulation:

a. Advantages:

i. Full automation reduces human error.
ii. Continuous monitoring and data logging.
iii. Precise control over treatment parameters.
iv. Scalable for large waste volumes (>1000 m3).
v. Integration with other systems for efficient management.

b. Disadvantages:

i. High initial cost.
ii. Requires skilled personnel for operation and maintenance.

1.45.2. Autoclaving:

a. Advantages:

i. Effective pathogen destruction.
ii. Environmentally friendly (no toxic emissions).
iii. WHO-approved and widely used.

b. Disadvantages:

i. Limited capacity (18-150) liters per cycle.
ii. High energy consumption.
iii. Manual operation increases risk of human error.

1.45.3. Chemical Treatment:

a. Advantages:

i. Effective for tissue and chemical waste.
ii. On-site generation reduces transport risks.

b. Disadvantages:

i. Potentially toxic effluents.
ii. High exposure risk to healthcare workers.
iii. More research required for pharmaceutical waste disposal.

1.46. Comparison Methods:

Criteria	PLC and SCADA System	Autoclaving	Chemical Treatment
Automation	Fully automated	Manual	Partially automated
Capacity	>1000 m^3	18-150 liters	Varies
Energy Efficiency	Optimized control	High consumption	Moderate
Pathogen Control	Effective with monitoring	Effective	Effective but risky
Environmental Impact	Low (controlled discharge)	Low (if properly managed)	High (toxic effluents)
Cost	High initial, low operating	Moderate	High (chemicals cost)

Table 1. show Comparison Between PLC and SCADA System and Sterilization Methods

1.47. Conclusion:

The simulation results of the PLC and SCADA system for treating clinical and chemotherapy liquid waste demonstrate the effectiveness and efficiency of automated control in managing hazardous waste.

The system successfully processed a total capacity of 1000 m^3, achieving the desired treatment parameters such as pH, temperature, and sterilization time. The PLC and SCADA system provided real-time monitoring and control, ensuring compliance with safety and environmental standards.

For clinical waste, the automated system effectively managed bacteria, fungi, and viral contamination through a well-structured treatment process, including sodium hypochlorite sterilization and yeast-based final treatment. Similarly, the chemotherapy waste treatment process efficiently controlled radiation levels and ensured compliance with IAEA guidelines for safe disposal.

A comparative analysis between different treatment methods highlighted the strengths of the PLC and SCADA system in terms of automation, scalability, and efficiency. While autoclaving and chemical treatments provide effective pathogen control, they have limitations in terms of capacity, energy consumption, and environmental impact.

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