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FRESH WATER GENERATOR SMART CHEMICAL DOSING SYSTEM

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ABSTRACT

Onboard merchant vessels, the efficient utilisation of waste energy is essential, particularly for the generation of freshwater. To achieve this, ships are typically equipped with freshwater generators (distilling plants) that operate using waste heat from engine operations. The main advantage of using onboard distillation systems is the significant reduction in operational costs by minimising dependency on shore-based freshwater supplies, while simultaneously maximising energy recovery from waste heat. This study focuses on the importance of chemical dosing in maintaining the performance and efficiency of the distilling plant. The findings of the research highlight three key factors affecting system efficiency which is reduction in freshwater production caused by improper dosing and system fouling, salt deposit formation (scaling) on the evaporator plates, which hinders heat transfer and reduces efficiency. To mitigate this, the plant must be operated within the optimal temperature range of 35°C to 45°C to minimise the risk of excessive evaporation and foam formation. Lastly, key factor affecting efficiency is lack of operator knowledge and training, which often results in poor maintenance practices and suboptimal chemical dosing, ultimately affecting the long-term performance of the system. The integration of automated chemical dosing systems is recommended to improve operational stability, reduce maintenance costs, and ensure reliable freshwater production onboard.

Keywords: Chemical, Dosing, Efficiency, Microcontroller, Wastewater.

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1.0 INTRODUCTION

In modern maritime operations, the utilisation of renewable energy and the recovery of waste energy have become increasingly common, particularly within the shipping industry. These practices aim to reduce pollution and operational costs, in accordance with the requirements of the International Convention for the Prevention of Marine Pollution (MARPOL) Annex VI, Regulation 22, which mandates that all merchant vessels comply with the Ship Energy Efficiency Management Plan (SEEMP) (International Maritime Organization [IMO], 2025). One widely adopted method involves the use of seawater and thermodynamic principles to generate distillate water for daily crew consumption and equipment use. This process is typically facilitated by a Fresh Water Generator (FWG), which harnesses waste heat from the ship's engine or steam system to evaporate and condense seawater into potable water (Faităr et al., 2021).

To ensure the FWG operates at an optimal level, continuous monitoring of production parameters and system efficiency is essential. Historically, chemical dosing was performed manually to prevent the formation of scale and to inhibit corrosion, both of which may result from the heating of seawater in the evaporator section of the plant (Wang and Zhao, 2022). Manual dosing, however, is subject to human error and often results in inconsistent chemical quantities that do not align with manufacturer

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specifications. (Insani Ilham et al., 2022). Over time, scaling on evaporator plates reduces heat transfer efficiency, resulting in a noticeable decline in plant performance (Ahmed and Mohamed, 2024). An automated chemical dosing system can significantly mitigate these inefficiencies while enhancing system reliability and safety. (Bello & Owoeye, 2022; Wang & Gu, 2022).

1.1 Dosing Chemical Operation

During plant operation, a vacuum is created in the evaporator chamber. A dedicated dosing tank, fitted with a flow control valve, automatically injects a precise quantity of chemical into the system via the seawater feed line (Cazarez-Candia and Ortega-Delgado, 2021). This controlled dosing ensures that the correct concentration of chemicals enters the shell side of the evaporator, thereby promoting consistent protection against scaling and corrosion (NSF International, 2024; Marine Chemicals Inc., 2024). Figure 1 illustrates the location of the dosing point within the FWG system.

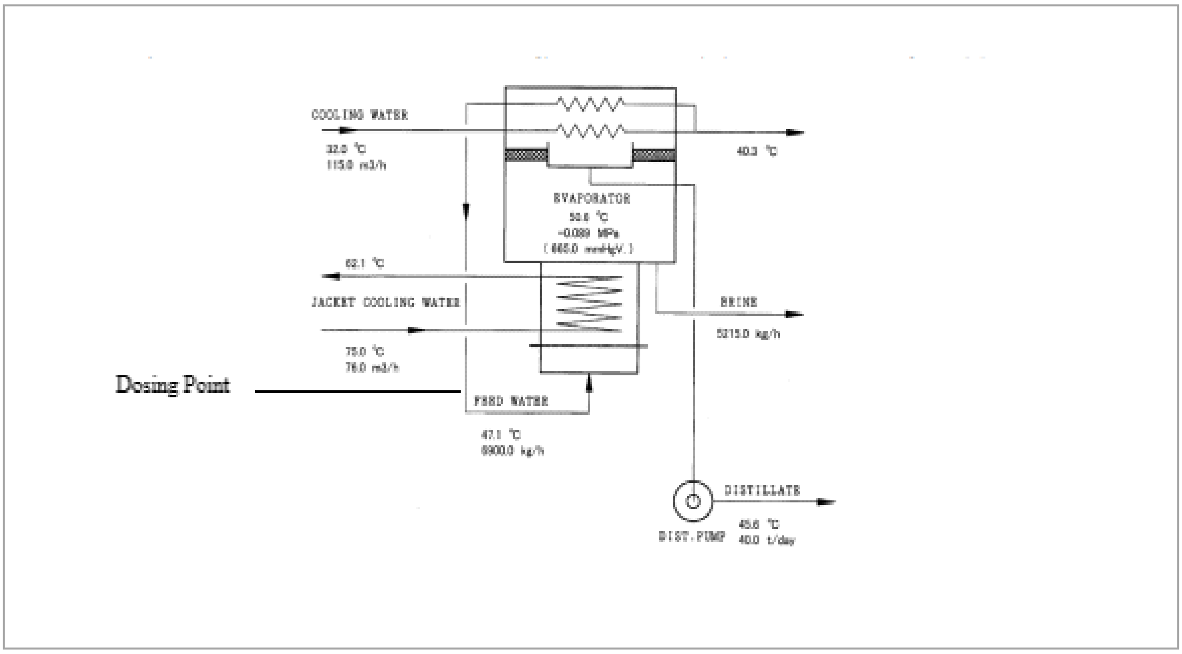

Fig 1 Chemical dosing point in Fresh Water Generator

1.2 Dosing Chemical Type

The chemicals used in the dosing process must possess specific properties, including:

- Antiscalant agents to prevent salt scaling on heat transfer surfaces (Ahmed & Mohamed, 2024).
- Corrosion inhibitors to protect metal components from chemical and electrochemical degradation (Wang & Zhao, 2022).
- Biocides to eliminate microbial growth and biofouling that could affect water quality and system cleanliness (Liu et al., 2024).

Appropriate chemical selection is essential for maintaining both equipment longevity and water purity, particularly in marine environments where operational reliability and regulatory compliance are critical. (NSF International, 2024; Vizag Chemical International, 2024).

2.0 LITERATURE REVIEW

Human factors play a vital role in ensuring the operational efficiency and safety of a Fresh Water Generator (FWG) system. In many marine and industrial settings, the FWG is responsible for converting seawater into potable water, which is subsequently used for both consumption and machinery operations

(Faităr et al., 2021). To achieve reliable and consistent water quality, precise chemical dosing is essential. Inaccuracies arising from manual handling can lead to several operational issues, including water contamination, equipment failure, and increased operational costs (Mohamed et al., 2023). To reduce dependence on manual intervention and minimise the risk of human error, the development of an automated dosing and filling control system is essential (Bello and Owoeye, 2022; Wang and Gu, 2022; Luo et al., 2022). The system implemented in this project addresses common errors through sensor-based automation and programmed logic (Cazarez-Candia and Ortega-Delgado, 2021). Key areas of concern include:

2.1 Overdosing of Chemicals

In the FWG system, overdosing of treatment chemicals, such as antiscalants or chlorination agents, may result in chemical contamination of the produced water. This not only renders the water unsafe for human consumption but may also cause damage to downstream equipment, particularly heat exchangers, pipelines, and boilers, where chemical buildup can lead to corrosion or thermal inefficiency (Ahmed & Mohamed, 2024; Wang & Zhao, 2022).

2.2 Underdosing of Chemicals

Insufficient chemical dosing results in scaling and corrosion within the FWG system. Without adequate chemical treatment, minerals and impurities present in seawater can deposit on heat transfer surfaces, reducing efficiency and increasing energy consumption (Mohamed et al., 2023; NSF International, 2024). Over time, this can result in equipment damage, performance degradation, and unplanned maintenance shutdowns (Faităr et al., 2021).

2.3 Resource Wastage

Manual errors, such as failing to stop the chemical dosing pump in a timely manner or overlooking tank levels, may result in overflow of the dosing tank, chemical wastage, or unnecessary system wear (Insani Ilham et al., 2022). These incidents not only waste resources but also increase the operational cost of running the FWG system and pose a risk of environmental non-compliance in maritime operations. (IMO, 2025.; Liu et al., 2024).

3.0 PROCEDURES

This research project integrates both practical experimentation and case study methodology to ensure that the designed automation system operates reliably and as intended. The core objective of the system is to automate the filling and chemical dosing processes in a Fresh Water Generator (FWG) dosing tank, using water level sensors, microcontroller logic, and simulated components.

Simulations were conducted using the Proteus Design Suite, while embedded control logic was programmed using the CCS C Compiler. Together, these tools validate the functionality of the water level sensors and the automatic operation of both the freshwater and chemical dosing pumps. The simulation replicates real-world behaviour by testing the system's response to varying water level conditions.

Auto Filling Process Flow

Figure 2 below shows complete flowchart of the automation process FWG dosing tank system. The system logic is based on three sensor points, each corresponding to specific tank levels and system actions:

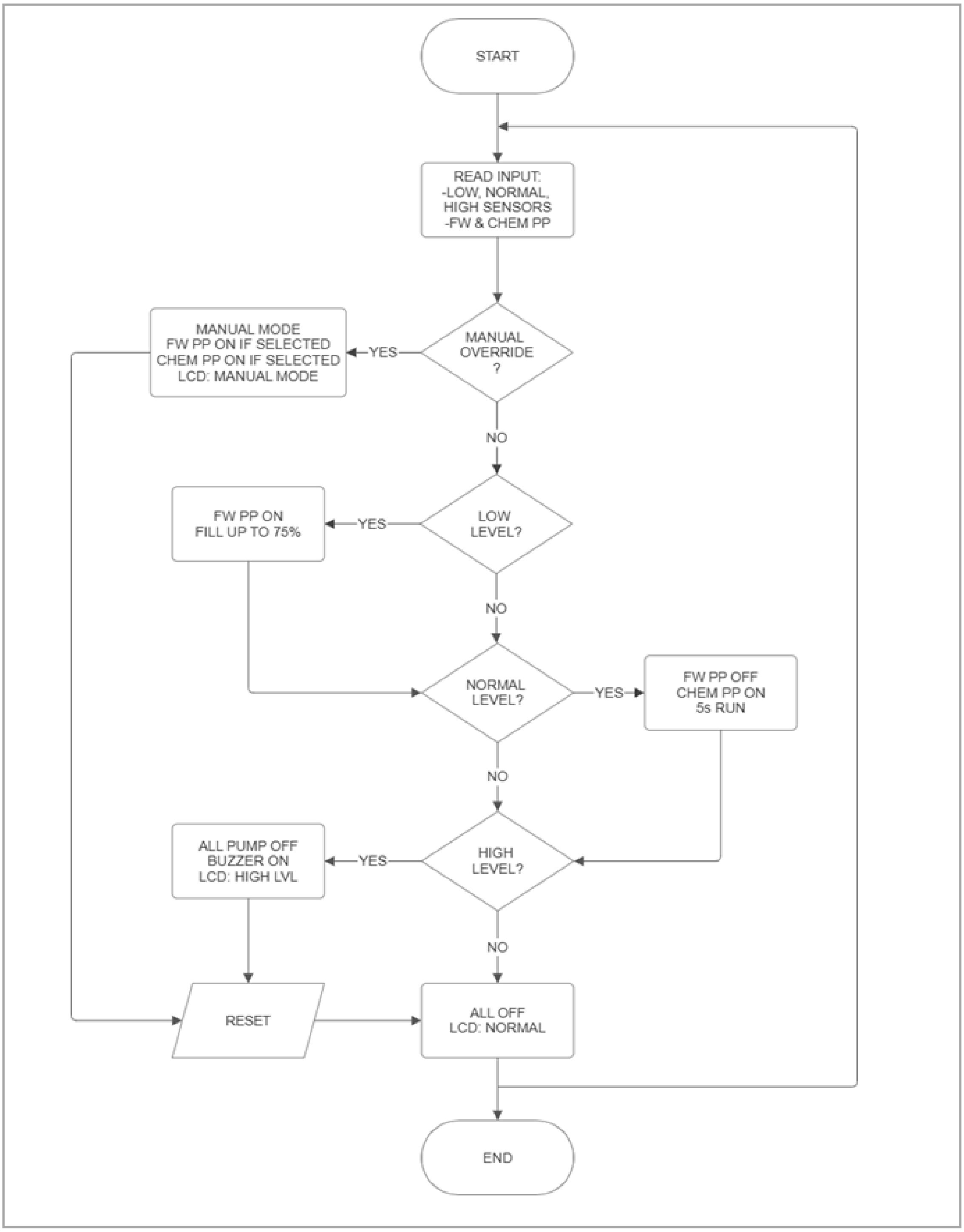

Fig. 2. Fresh Water Generator (FWG) Dosing Tank Auto Filling Process Diagram

Table 1. Truth table shows how sensor input values correspond to specific system responses.

Operation Mode	Low Level	Normal Level	High Level	Manual FW Pump	Manual Chemical Pump
FW pump running	1	0	0	1	0
Chemical pump running	0	1	0	0	1
Buzzer On	0	0	1	0	0

Table 1 shows the relationship between the sensor input levels and the system responses of the Fresh Water Generator (FWG) auto-filling system. At low level, the freshwater pump starts to fill the tank. When the normal level is reached, the chemical pump operates for dosing. At high level, both pumps stop and the buzzer activates to indicate a full tank. Manual override buttons allow independent pump control when required.

Figure 3 shows the simulation which accurately mimics real-world behaviour and validates the program logic. By observing how each sensor input affects the outputs (pumps and buzzer), the system's responsiveness and correctness can be evaluated.

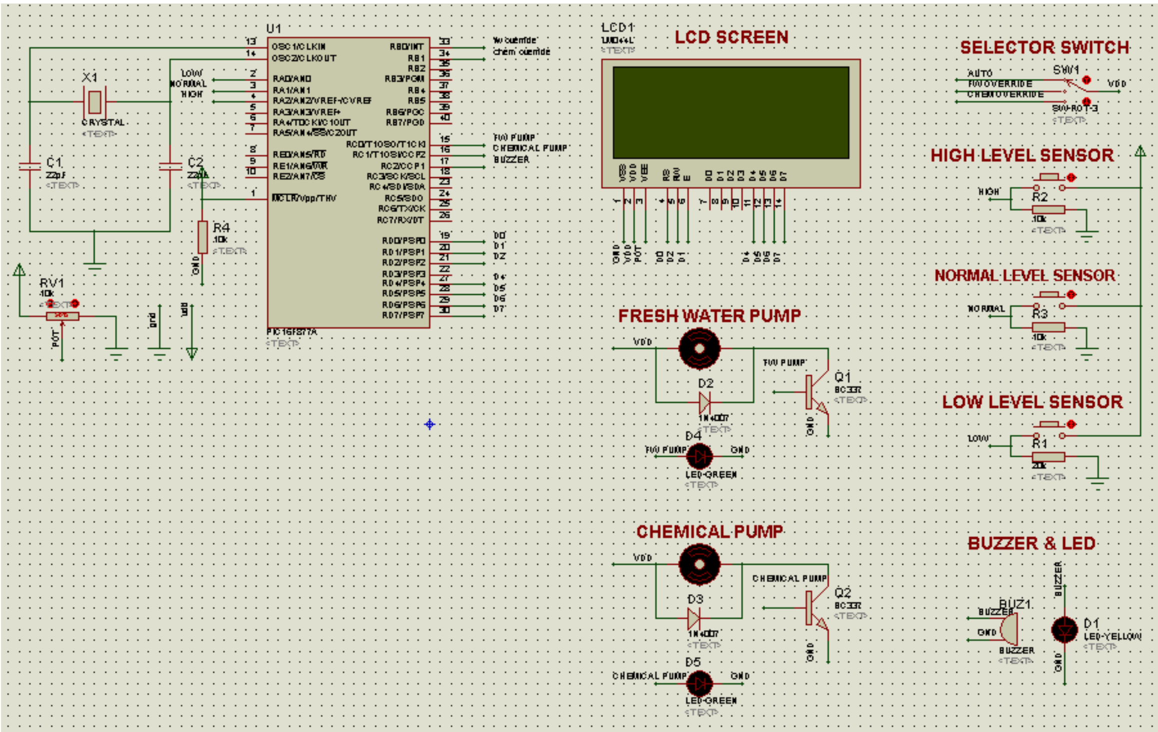

Fig. 3. Displays the Proteus environment used to simulate the system.

4.0 RESULTS

With the integration of a microcontroller and a well-structured control algorithm, the performance of the Fresh Water Generator (FWG) can be significantly enhanced. The automated system ensures accurate chemical dosing, thereby eliminating the risks of underdosing and overdosing, both of which may compromise water quality and system efficiency. By maintaining the correct chemical concentration, the plant is able to produce higher quality distilled water, suitable for both domestic and

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operational use onboard.

Furthermore, the implementation of an automated start-stop sequence improves the overall resource efficiency of the system. It optimises the use of water, chemicals, and manpower, reduces wastage, and enhances operational safety. This automation not only lowers the likelihood of human error but also contributes to reduced maintenance costs and improved reliability of the freshwater generation process.

- First Sensor (10% level - LOW):
  - When the water level drops to this point, the system automatically activates the freshwater pump to begin filling the tank.
  - A message is displayed on the LCD indicating the pump is running and the tank is being filled as shown in Figure 4.
  - This condition represents the "low-level trigger".

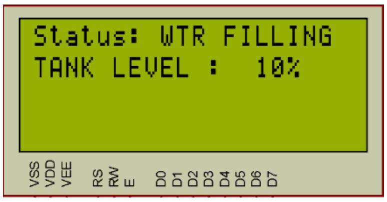

Fig. 4. LCD Display Output During Fresh Water Filling Up

- Second Sensor (75% level - NORMAL):
  - When the tank reaches this level, the system automatically stops the freshwater pump and initiates the chemical dosing pump.
  - The LCD updates the status to "Chemical Dosing in Progress" as shown in Figure 5.
  - The chemical dosing pump operates for a predefined time (e.g., 5 seconds) using a countdown display to simulate precise chemical injection.

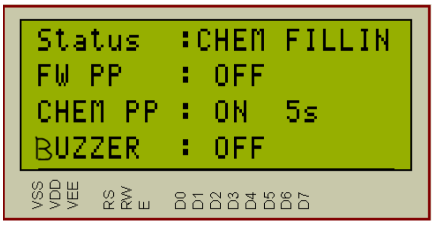

Fig. 5. LCD Display Output During Chemical Filling Up

- Third Sensor (100% level - HIGH):
  - This is the final sensor point located at the top of the dosing tank.
  - When triggered, the system automatically stops the chemical and freshwater pump if running and activates the buzzer, serving as an overfill protection and safety alert.
  - This state overrides all other inputs, ensuring that both pumps are turned off and the system enters a lock-safe mode. The LCD will display as shown in Figure 6.

ALAM Journal of Maritime Studies. Volume 6 Issue 1 Year 2025
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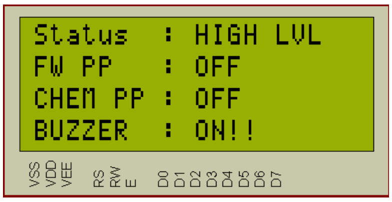

Fig. 6. LCD Display Output During High Level

Simulation Setup and Functionality

The system components were modelled as follows:

- Microcontroller: PIC16F877A simulates all logical operations and controls the peripherals.
- Toggle Switches: Used to manually represent the sensor states (LOW, NORMAL, HIGH), allowing users to simulate different tank levels.
- DC Motors / LEDs: Represent the Fresh Water Pump and Chemical Dosing Pump respectively. Their ON/OFF states show pump activity.
- Buzzer (Sounder): Indicates high-level alarm.
- LCD Display (LM044L): Provides real-time system status feedback, such as pump states, tank level percentage, and warning alerts.

Each simulated level condition (10%, 75%, 100%) is manually selected using toggle switches, enabling clear observation of how the system transitions through each mode – auto freshwater fill, chemical dosing, and alarm state.

Figure 7 shows the LCD screen display when FWG dosing system is on NORMAL condition. This is due to water level is at normal level without triggering any float switch.

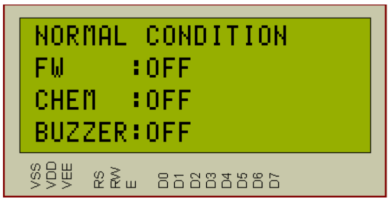

Fig. 7. LCD Display Output During Normal Condition

Figure 8 shows the LCD screen display when freshwater pump is selected to run in manual mode. This option will allow the user to manually fill the dosing tank with freshwater for other purpose such as rinsing the dosing tank with freshwater.

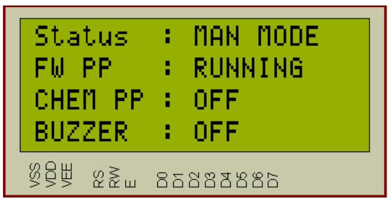

Fig. 8. LCD Display Output During FW pump manual mode

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Figure 9 shows the LCD screen display when chemical pump is selected to run in manual mode. This option will allow the user to manually top up the chemical due to minor adjustment of amount of chemical needed if required by the maker.

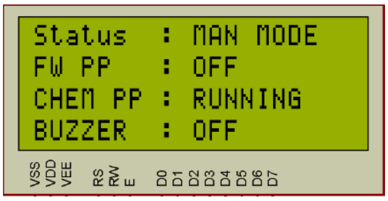

Fig. 9. LCD Display Output During Chemical pump manual mode

5.0 CONCLUSION

The presence of appropriate chemical dosing within the system plays a crucial role in enhancing the overall performance and reliability of the Fresh Water Generator (FWG) plant. Accurate dosing contributes to improved operational efficiency, optimised maintenance schedules, and extended equipment lifespan. In contrast, traditional manual dosing methods are often slow, inconsistent, and susceptible to human error, which may result in system inefficiencies and unplanned maintenance.

Modern automation technologies offer significant advantages through real-time control, precise dosing, and reliable feedback mechanisms. Advanced technologies, such as fibre-optic and microwave-based sensors, are being explored for integration into detection and control systems to further enhance accuracy and responsiveness. These innovations help reduce maintenance costs, prevent unexpected equipment failures, and optimise chemical usage.

The automated chemical dosing system implemented in this project represents a progressive step towards improving the production rate and performance of the FWG. Continued research and development in this area are essential to achieving greater robustness and efficiency across various industrial applications, particularly within the maritime sector.

In conclusion, this project underscores the potential of automation in addressing the limitations of traditional chemical dosing methods. The findings support the adoption of modern control systems to ensure sustainable, safe, and efficient operations. Future studies may focus on expanding system capabilities, refining sensor technologies, and integrating machine learning for predictive maintenance and adaptive control.

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