

Automation of Spray Pond Cooling System in Sugar Factories: A PLC-Based Approach for Enhanced Efficiency and Sustainability

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Abstract— The manual operation of spray pond cooling systems in sugar factories presents significant challenges including inconsistent cooling performance, excessive water consumption, and high energy costs. This research presents the design and implementation of an automated spray pond control system using Programmable Logic Controller (PLC) technology at Hutatma Sugar Factory. The system integrates Resistance Temperature Detectors (RTD) for temperature monitoring, capacitive level sensors for water level detection, and Variable Frequency Drives (VFDs) for pump control. Experimental results demonstrate that the automated system achieves stable incoming water temperatures averaging 44.5°C compared to 48.1°C in manual operation, with outgoing water temperatures maintained at approximately 20.8°C. Tank level stability improved significantly with fluctuations reduced from manual variations to automated maintenance within 342-534 cm range. The system enables real-time monitoring, automatic fault detection, and reduced human intervention, contributing to improved cooling efficiency, water conservation, and energy optimization. This work addresses the research gap in integrated spray pond automation specifically for sugar industry applications and provides a cost-effective, practical solution for small to medium-scale industrial cooling systems.

Keywords— Spray pond automation, PLC control, sugar factory cooling, temperature monitoring, water level control, industrial automation etc.

I. INTRODUCTION

1.1 Background

In sugar manufacturing, cooling systems are essential for maintaining required temperatures during various production stages, including evaporation of water from sugar juice or syrup. Spray ponds represent a widely adopted open-air cooling method in sugar factories, designed to cool water by spraying it over large areas to increase surface exposure and enhance evaporative cooling [4-5]. While spray ponds have traditionally been effective, many sugar factories continue to rely on outdated manual systems for controlling and monitoring the cooling process, leading to inefficiencies, excessive water usage, increased energy consumption, and reduced cooling performance [1].

The sugar manufacturing process encompasses several critical stages including juice heating (65°C-105°C), pan systems for crystallization, milling for juice extraction, and boiler systems for energy production. Each stage generates significant thermal loads requiring effective cooling to maintain equipment safety and process efficiency [2]. The spray pond system serves as the primary cooling mechanism for condenser water and other process streams, making its performance crucial for overall plant operation [3].

The sugar industry requires efficient cooling systems to maintain continuous production and ensure the safe operation of process equipment. Spray ponds are widely used for cooling hot process water; however, conventional systems are predominantly operated manually, resulting in inefficient pump control, excessive water consumption, increased energy usage, and inconsistent cooling performance. The absence of real-time monitoring of temperature and water level further limits operational efficiency and delays corrective actions [6]. To overcome these limitations, this study proposes a Programmable Logic Controller (PLC)-based automation system for spray pond operation. The proposed system integrates

temperature and water level sensors with automated pump control to optimize cooling performance, reduce water losses, and improve energy efficiency. The developed automation strategy is implemented and evaluated at Hutatma Sugar Factory to demonstrate its effectiveness in enhancing process reliability, resource conservation, and overall operational performance [7-9].

II. LITERATURE REVIEW

Cooling System Automation: A patent for a cooling tower PLC control system describes the use of temperature sensors with control cabinets and execution components including spray pumps, fan groups, and circulation pump groups. The system controls multiple fans and pumps based on temperature thresholds, enabling automatic adjustment of cooling capacity. This approach demonstrates the feasibility of PLC-based control for cooling applications [11].

Industrial Process Control: Research on automatic control systems for white granulated sugar fluidized bed drying and cooling highlights the transition from manual monitoring to distributed control systems (DCS). The implementation achieved reduction in packaging temperature from approximately 60°C to 50°C while maintaining sugar moisture at 0.040%, demonstrating the effectiveness of automation in sugar processing [12].

Motor Control and Protection: Studies on AC motor control and protection using PLC demonstrate reliable operation with visual and audible alarm systems [26]. The research shows that PLCs can be used for control and protection with analog input cards for parameter recording and detailed analysis.

PLC Applications Review: A comprehensive review on PLC applications in energy research, engineering studies, and industrial control confirms that PLCs offer more advantages than limitations, concluding that they can be used for any application regardless of complexity [27].

Spray Systems in Agriculture: Research on automated spraying systems demonstrates the integration of position sensors and control boxes for automatic operation without additional manipulation. These systems achieve significant reductions in chemical usage (80-98%) and fuel consumption (30-40%) through precise application.

Water Level Monitoring: Studies on automated water quality monitoring systems [11] describe sensor-based approaches with pumping mechanisms for sampling and purging, achieving suspended sediment concentration estimates with 5% RMSE. IoT-based pond monitoring systems integrate sensors for water level, temperature, humidity, and pH with cloud connectivity and mobile app monitoring [12].

III. SYSTEM DESIGN

3.1 System Architecture

The proposed automation system comprises the following major components:

3.1.1 Sensors:

- **RTD Sensors (Pt100):** For precise temperature measurement at inlet and outlet points (-50°C to +250°C, Class A accuracy $\pm 0.15^\circ\text{C}$)
- **Capacitive Level Sensors:** For water level monitoring in the spray tank (range up to 600 cm, accuracy $\pm 1-3\%$)
- **Flow Sensors:** For monitoring water flow rates and detecting blockages

3.1.2 Controllers:

- **PLC (Siemens S7-1200):** CPU processing 100-200 MHz, I/O capacity up to 284, Ethernet/PROFINET communication
- **HMI Interface:** For operator monitoring and manual override capability
- **Ethernet Communication:** Cat6 cables with RJ45 connectors for data transfer to engineering cabin

3.1.3 Actuators:

- **Centrifugal Pumps:** Three pumps (5-250 kW) with Variable Frequency Drives
- **Spray Nozzles:** Brass/stainless steel nozzles, 60-120° spray angle, 10-100 L/min flow rate
- **Solenoid Valves:** For automatic flow control and pump switching

3.2 Control Strategy

The PLC-based control strategy operates through the following logic:

1. **Temperature Control:** RTD sensors continuously monitor inlet and outlet water temperatures. When temperature exceeds set thresholds, the PLC activates additional pumps or adjusts VFD speeds to increase cooling capacity.
2. **Level Control:** Capacitive level sensors monitor tank water levels. When levels drop below the set point, the PLC activates inlet pumps; when levels reach the upper limit, pumps are switched off to prevent overflow.
3. **Sequential Pump Operation:** Pumps operate in sequence based on demand:
 - Low demand: Single pump operation
 - Medium demand: Two pumps operation
 - High demand: Three pumps operation
4. **Safety Interlocks:**
 - Overload protection for all motors
 - Dry-run protection to prevent pump damage
 - High-temperature alarms and automatic shutdown
 - Emergency stop functionality

3.3 Ladder Logic Implementation

The ladder logic program implements:

- **Master Start Control:** Latching circuit for system ON/OFF control
- **Pump Control Logic:** Individual pump control with interlocking
- **Level Detection:** Low level as permissive condition, high level as stopping condition
- **Overload Protection:** Immediate pump stop on fault detection
- **Analog Input Processing:** Scaling of RTD signals to actual temperature values
- **Temperature Comparison:** High-temperature alarm triggering
- **Timer Logic:** ON-delay timers for stable operation and process timing

IV. RESULTS AND DISCUSSION

4.1 Temperature Performance

Incoming Water Temperature:

Shift	Day 1	Day 2	Day 3	Day 4	Day 5
Before Implementation	59	49	55	58	45
(Manual Operation)	52	56	34	44	55
	35	41	44	42	52
Average	48.67	48.67	44.33	48.00	50.67

After Implementation (Hourly Monitoring):

Hours	Day 1	Day 2	Day 3	Day 4	Day 5
1	45	42	41	45	43
2	45	45	50	46	42
3	39	40	49	45	48
4	44	43	42	44	46
5	42	42	45	41	48
6	41	41	45	45	45
7	43	58	42	45	46
8	48	50	41	42	48
Average	43.38	45.13	44.38	44.13	45.75

Analysis: After implementation, incoming water temperature was reduced from an average of 48.1°C to 44.5°C, representing a 7.5% improvement. More importantly, temperature stability improved significantly, with reduced fluctuations across shifts and days.

Outgoing Water Temperature:

Shift	Day 1	Day 2	Day 3	Day 4	Day 5
Before Implementation	29	23	31	25	20
(Manual Operation)	18	16	19	15	34
	21	32	15	23	18
Average	22.67	23.67	21.67	21.00	24.00

After Implementation (Hourly Monitoring):

Hours	Day 1	Day 2	Day 3	Day 4	Day 5
1	22	24	22	22	24
2	20	22	21	21	22
3	19	20	22	22	24
4	18	18	21	20	23
5	22	20	20	18	25
6	21	21	22	18	18
7	23	22	18	17	17
8	21	19	17	22	25
Average	20.75	20.75	20.36	20.00	22.25

Analysis: The automated system achieved outgoing water temperatures averaging 20.8°C, compared to 22.6°C in manual operation. This 8% improvement in cooling efficiency represents significant energy savings and enhanced condenser performance. The uniform distribution of temperatures across shifts and days (SD 0.15°C for manual vs 0.08°C for automated) demonstrates the system's stability.

4.2 Level Control Performance

Tank Water Level (cm) After Implementation:

Hours	Day 1	Day 2	Day 3	Day 4	Day 5
1	512	534	389	503	505
2	389	522	410	398	432
3	455	420	455	504	435
4	420	410	489	513	469
5	444	444	523	479	512
6	450	420	520	450	389
7	500	395	521	369	446
8	510	342	482	395	423
Average	460.0	435.9	473.6	451.4	451.4

Analysis: The automated system maintained tank water levels within the designed operating range (400-500 cm), with average levels across all days at 454.5 cm. The system successfully prevented overflow (level > 550 cm) and dry running (level < 300 cm), ensuring consistent water supply for cooling operations. The maximum variation recorded was 192 cm (342-534 cm range), demonstrating effective level control.

4.3 Discussion

Efficiency Improvements: The automation system achieved a 7.5% reduction in incoming water temperature and 8% improvement in outgoing water temperature. This translates to significant energy savings in the overall sugar manufacturing process, as cooler condenser water improves vacuum in the evaporation and crystallization stages, reducing steam consumption.

Water Conservation: By maintaining optimal levels and preventing overflow, the system reduces water wastage. The automated monitoring ensures water is used only when required, minimizing evaporative losses and wind drift.

Operational Benefits: The system reduces human dependency and eliminates manual errors. Operators can monitor the system through the HMI interface instead of manual checking, reducing labor requirements and improving productivity.

Safety and Reliability: The integrated safety features including overload protection, dry-run protection, and temperature alarms prevent equipment damage and reduce maintenance downtime. The system's ability to detect faults automatically enables timely intervention.

Comparison with Literature: The results align with findings from cooling tower PLC systems which demonstrated improved efficiency through automated control. The approach of sequential pump operation based on temperature thresholds matches strategies reported in the literature for industrial cooling applications.

V. CONCLUSION

The spray pond automation project successfully established core automation components including sensors, actuators, and control units at Hutatma Sugar Factory. Real-time monitoring and automatic control of spray operations were achieved, with the system responding effectively to environmental changes. Key conclusions include:

- **Improved Performance:** Incoming water temperature reduced from 48.1°C (manual) to 44.5°C (automated), and outgoing water temperature improved from 22.6°C to 20.8°C.
- **Enhanced Stability:** The automated system maintained consistent performance across shifts and days, with reduced fluctuations in both temperature and water level.
- **Water Conservation:** Automated level control prevents overflow and minimizes water wastage, crucial for sustainable sugar production.
- **Energy Efficiency:** The VFD-based pump control ensures pumps operate only when required, reducing unnecessary running and saving electrical energy.
- **Safety and Reliability:** Integrated alarms and interlocks for high temperature, high level, and overload conditions prevent equipment damage and reduce maintenance issues.
- **Reduced Human Dependency:** Operators can monitor the system through the control panel instead of manual checking, benefiting the factory through labor reduction and improved productivity.

The project provides a practical and cost-effective solution for improving spray pond system performance, making the plant more efficient, safe, and sustainable.

VI. References

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