Project Report

Automation of Decarbonization and Cleaning Process of Steel Trays in Baking Industry

Submitted by: Group 4 Team Engelberger

Lily Orkeh	9015959
Aishwariya Parmar	9022666
Nashiru Sulemana	9019765
Acharya Bijay	8986273
Abdul Subhan Danish	9007352

Guided by: Dr. Manoj Kumar Sharma

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Abstract

The baking industry relies heavily on the consistent performance and cleanliness of steel trays used throughout the production cycle, particularly in processes such as Danish Pastry manufacturing where hygiene and operational efficiency are critical. Traditionally, the decarbonization and cleaning of these trays has been carried out manually, a method that is highly time-consuming, labour-intensive, and prone to quality inconsistencies. The existing procedure requires approximately one hour to complete a single cycle of only twenty trays, limiting throughput and exposing workers to risks such as burns, fatigue, and repetitive strain. Additionally, manual handling contributes to higher operational costs, increased downtime, and unpredictable cleaning quality due to variations in human effort and technique.

This project proposes a fully automated decarbonizing, rinsing, and drying line designed to eliminate the inefficiencies of the manual cleaning workflow. The system uses an overhead motorized hoist to transport racks of trays through three major stages: decarbonization, rinsing, and air-drying. The trays are immersed in the decarbonizing tank for a precisely controlled 20-minute cycle, followed by a 3-minute rinsing phase, and finally a 3-minute hot-air drying process. Including transport time, the total automated cycle is completed in approximately 30 minutes, cutting the original cleaning duration in half and doubling the daily throughput from 160 to 320 trays within an 8-hour workday. This improvement is achieved through programmable logic control (PLC) automation, integrated temperature and proximity sensors, precision pumps, and a guided hoist assembly that ensures repeatable, reliable operation with minimal human intervention.

The automated process not only enhances productivity but also significantly improves cleaning consistency. Unlike manual rinsing, which varies from operator to operator, the automated rinsing unit applies uniform pressure at close range, ensuring each tray is cleaned thoroughly and identically. Precise control of heating time in the decarbonizing tank prevents tray deformation caused by prolonged exposure to high temperatures, a common issue in the manual method. The upgraded system further reduces downtime by replacing aging PID controllers with modern, stable PLC-based control, improving the reliability of the heating, pumping, and hoist mechanisms. Safety is also greatly enhanced: automation minimizes human contact with hot surfaces and chemicals, reducing the risk of burns and other injuries.

From a financial perspective, the proposed system demonstrates strong feasibility and rapid return on investment. The total capital cost of the automated setup is approximately CAD 29,728. Despite slightly higher daily energy consumption, the dramatic reduction in labour, from two full-time operators to a single monitoring role, results in substantial annual savings. Operating costs drop from CAD 120,670 to CAD 64,518 per year, generating annual savings of over CAD 56,000. This translates to a payback period of approximately 6 to 7 months and an impressive first-year return on investment (ROI) of 88%, with ROI increasing further in subsequent years as maintenance and labour savings accumulate.

Overall, the automation of the tray decarbonizing and cleaning process delivers comprehensive benefits across operational efficiency, product quality, worker safety, and financial performance. By transforming a slow and inconsistent manual procedure into a fast, standardized, and intelligent system, this project provides a scalable solution that aligns with modern industrial automation standards in the baking sector. The proposed upgrade is strongly recommended as a practical, cost-effective step toward improving productivity and ensuring long-term sustainability in high-volume pastry production facilities.

Acknowledgement

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1.0 Team Engelberger

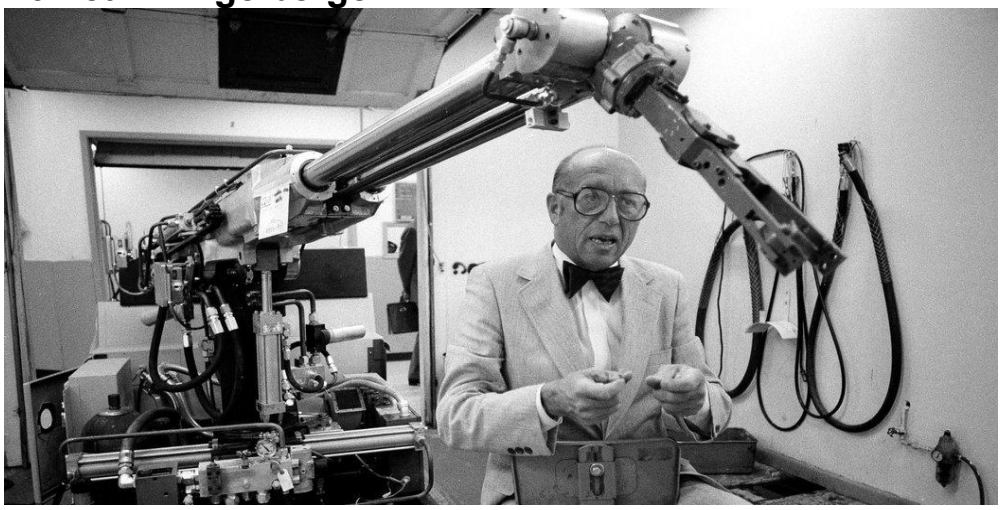


Fig 1. Portrait of Joseph Frederick Engelberger

Joseph Frederick **Engelberger**

Title / Identity

- Known as the **"Father of Automation and Robotics."**

Birth and Death

- Born: July 26, 1925 – Brooklyn, New York, USA
- Died: December 1, 2015 – Newtown, Connecticut, USA (age 90)

Education

- B.S. in Physics (1946) – Columbia University
- M.S. in Electrical Engineering (1949) – Columbia University

Career

- **Unimation, Inc.** (Co-founder, 1957): World's first robotics company.
- Worked with General Motors to deploy the **first industrial robot (Unimate).**
- Later founded Transitions Research Corporation (1984): developed hospital service robots like **HelpMate.**

Contributions and Accomplishments

- Introduced **Unimate (1961)** – first industrial robot in a GM plant.
- Expanded robotics into **healthcare, homes, and space exploration.**
- Advocated robots for dull, dirty, and dangerous tasks.
- Authored **Robotics in Practice** (1980) and **Robotics in Service** (1989).
- Won major honours: **Japan Prize (1997), IEEE Robotics and Automation Award (2004).**

2.0 Introduction to Decarbonization and Cleaning Process

The baking industry in Ontario has seen consistent growth, forming a significant segment of the province's food sector. By May 2025, there were 4,901 bakeries in Ontario, reflecting a 2.47% increase since 2023. Of these, 2,266 (46.24%) are independently owned, while 2,635 (53.76%) are part of multi-location chains. Toronto hosts the largest number of bakeries at 939, followed by Ottawa with 383 and Mississauga with 354. On average, bakeries in the province have been operational for nearly seven years, indicating both a relatively young industry and steady market renewal (IBISWorld, 2025).

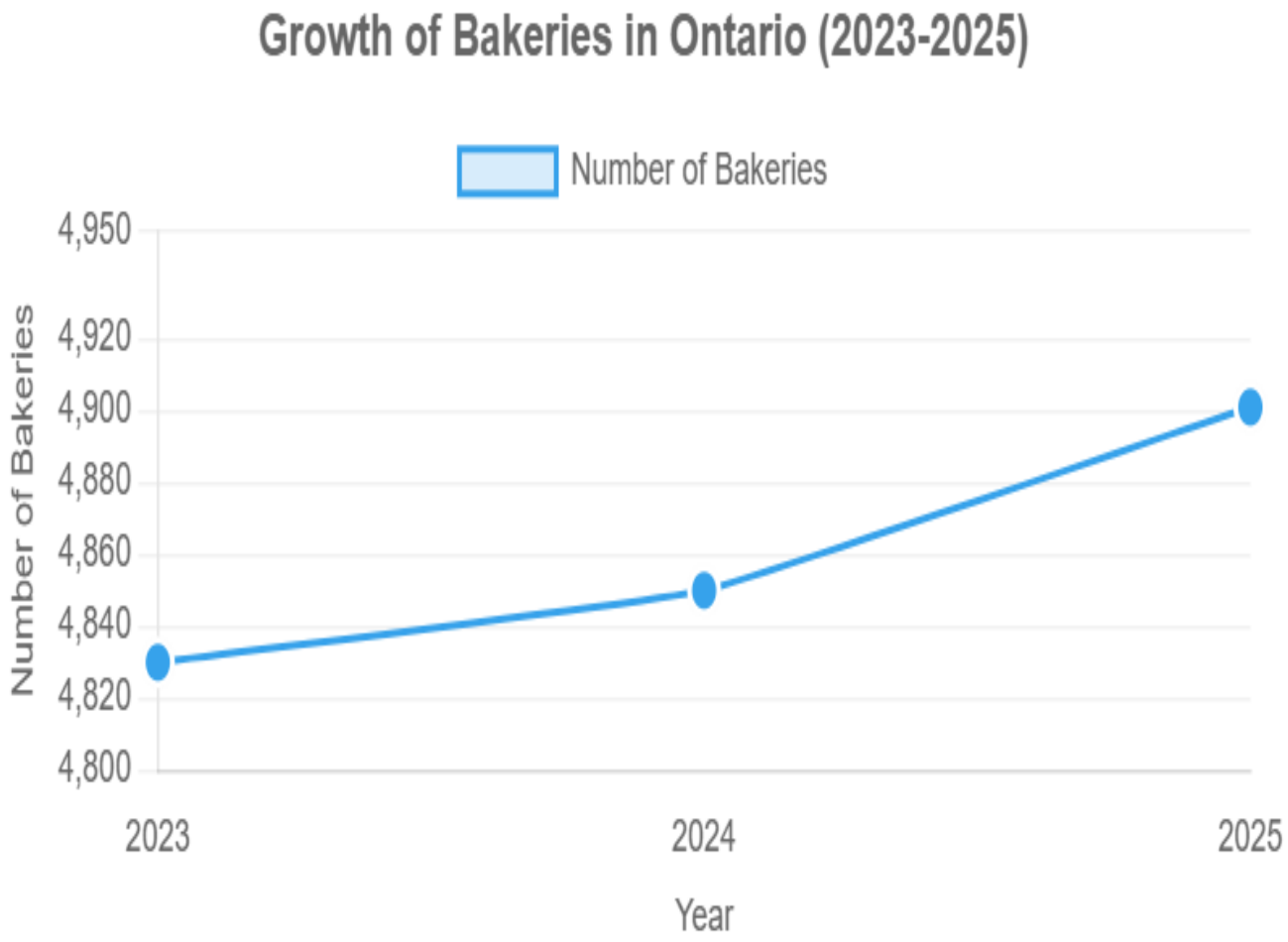


Fig 2: Growth of Bakeries in Ontario (2023–2025). The chart illustrates the steady increase in the number of bakeries in Ontario, showing a 2.47% growth from 2023 to 2025. Note. Data from IBISWorld (2025). Graph created by the author.

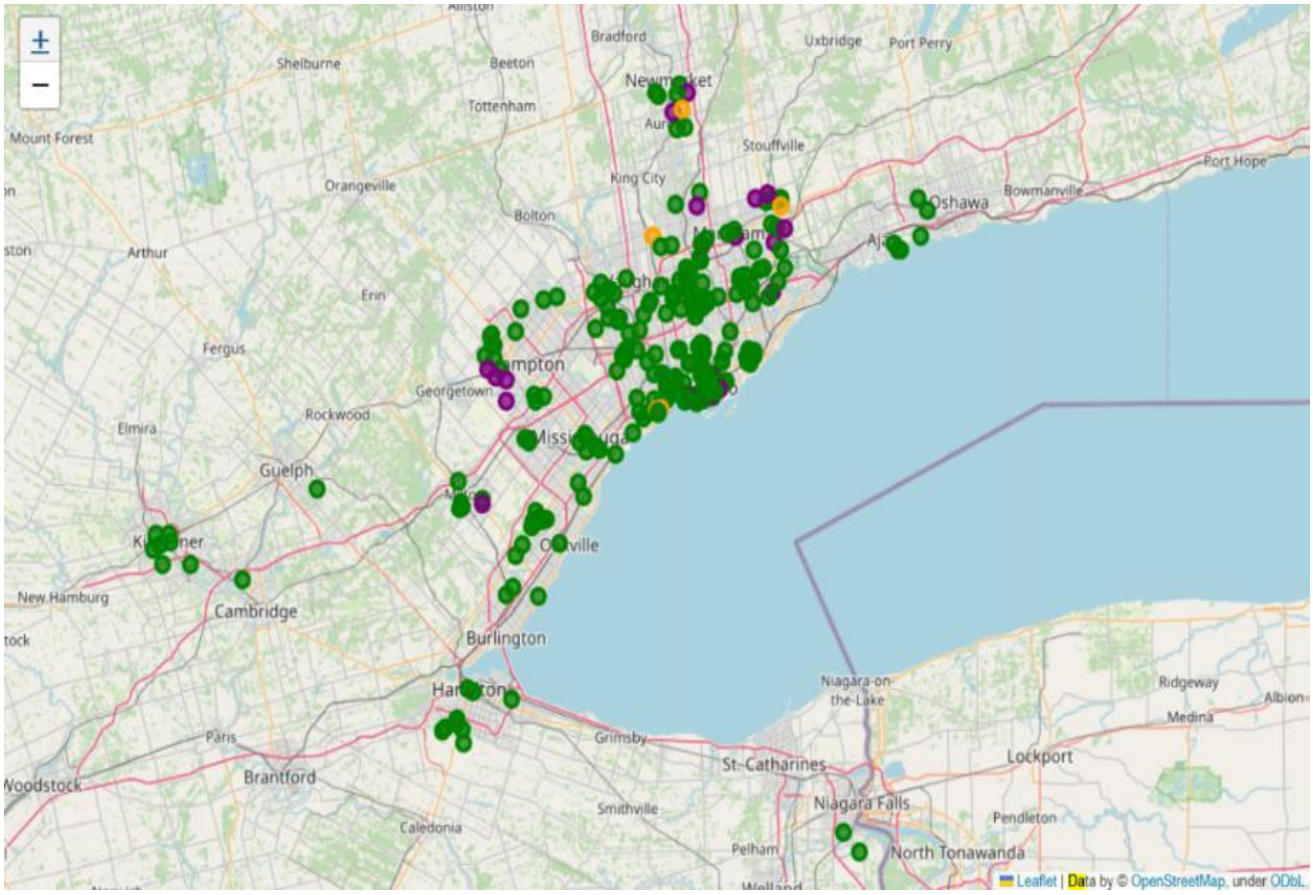


Fig 3. *Bakery distribution in Ontario*

Ontario's bakery sector growth reflects broader trends observed nationally and internationally. For instance, the province's bakery and tortilla manufacturing sector reported 1,248 businesses in 2020, marking a 5.3% increase over five years and generating $7.7 billion in manufactured goods revenue (Ontario Ministry of Agriculture, Food and Rural Affairs [OMAFRA], 2021). Across Canada, the bakery products market was valued at USD 10.7 million in 2024 and is projected to reach USD 15.1 million by 2033, fuelled by rising consumer demand and expanding export opportunities (IMARC Group, 2024).

Bakeries continue to rely extensively on steel trays for production, and keeping them clean is critical for food safety, process efficiency, and product consistency. Steel trays are commonly used because they are durable, withstand high temperatures, and distribute heat evenly, which contributes to uniform baking results. Despite their importance, the decarbonization of trays in many facilities is still performed manually. Workers must lift trays onto hoists, submerge them in chemical baths (decarbonization tanks), rinse, and allow them to air-dry. This method is labour-intensive, time-consuming, and produces inconsistent results while exposing staff to repetitive strain and chemical hazards (Calleri, Logroño, and Logroño, 2024).

Fig 4: Stainless steel baking tray used in bakery operations

Research on automation in food production indicates that digital solutions can enhance operational efficiency and improve environmental outcomes over the product life cycle (Rahimi Fard et al., 2022). Additionally, mechanized tray cleaning systems can improve hygiene consistency, reduce labour costs, and increase workplace safety (Kyaw et al., 2022). Given the scale of Ontario's bakery industry, nearly 5,000 businesses, even the smallest efficiency improvements can have significant impact.

To address these challenges, this project proposes a fully automated tray cleaning and decarbonization system. The system would eliminate manual hoist handling, automate chemical management, and integrate mechanical tray transfer with rinsing and drying. The aim is to provide a scalable, cost-effective solution that aligns with the operational demands of Ontario's growing bakery sector.

3.0 Review of Literature

Cleaning and decarbonizing industrial trays have undergone significant transformation over the years. Historically, manual methods such as scrubbing and soaking trays in caustic or alkaline solutions were the most common practices. Although these approaches were widely adopted, they were labour-intensive, exposed employees to harmful chemicals, and frequently delivered inconsistent results. Research by Kathare et al. (2022) reported an average of 11 occupational disease cases per million workers annually linked to cleaning and disinfection agents, underscoring the health risks posed by manual cleaning practices.

Fig 5: Manual scrubbing

With industrial modernization, semi-automated hoist systems emerged to ease the physical workload. However, these systems still demanded considerable manual involvement for loading, operating, and transferring trays between cleaning tanks, leaving many of the efficiency and safety issues unresolved (JEROS, n.d.). For instance, a mid-sized bakery in Ontario, such as Knot Bakery, handles more than 1,200 trays daily, all of which require cleaning before reuse (Knot Bakery, 2023). This volume highlights the significant labour commitment and suggests how automation could substantially improve efficiency in tray cleaning operations.

Fig 6: Automatic tray cleaning system requiring manual intervention

Chemical innovations, including the development of solutions such as Carbsolve, enhanced the removal of carbon deposits and shortened soaking times. Nonetheless, these products still required careful handling, appropriate disposal, and consistent manual oversight (JEROS, n.d.). Modern industrial tray cleaning equipment, such as that produced by JEROS, can now manage between 2,000 and 10,000 trays per day in larger bakeries, and some facilities even report processing up to 40,000 trays daily when operating at high capacity (JEROS, n.d.).

Fig 7: Carbosol

Recent advancements have also applied automation to related cleaning processes. For example, automated dishwashers and conveyorized degreasing systems demonstrate the potential benefits of continuous flow operations and reduced labour demands. However, these technologies have not been fully adapted to the specialized challenges of heavy-duty steel tray decarbonization. Their limitations often include high installation costs, complex maintenance, and limited adaptability to different tray sizes or severe carbon buildup (Adapt Laser, 2020; cleanLASER, n.d.; Cryonomic, n.d.). Meanwhile, the global tray sealing machines sector was valued at USD 1.29 billion in 2024 and is expected to expand to USD 1.64 billion by 2030, growing at a compound annual growth rate (CAGR) of 4.2%. This trend demonstrates the industry's increasing movement toward automated solutions (Grand View Research, 2024).

Fig 8: Automated cleaning system

Despite these technological advances, there remains no widely implemented, fully automated solution designed specifically for industrial tray decarbonization. Addressing this gap requires developing a system that is cost-efficient, safe, and low maintenance, while integrating automation, chemical management, and process control into a single streamlined workflow.

4.0 Shortcomings in Existing Systems in the Bakery Industry

i) High dependence on manual labour

Existing tray decarbonization processes rely extensively on human operators to lift, position, and retrieve trays from hoists and tanks. This manual approach is physically demanding, time-consuming, and increases labour costs, especially in facilities with high production volumes.

ii) Variable Cleaning Effectiveness

The quality of cleaning often varies because it depends on human factors such as tray handling, soaking duration, and attention to detail. As a result, carbon deposits may not be consistently removed, potentially affecting hygiene and product quality.

iii) Worker Safety Concerns

Operators are exposed to hazards including hot surfaces, chemical solutions, and moving hoists. These conditions elevate the risk of accidents and occupational injuries.

iv) Inefficient Time and Resource Utilization

The workflow includes waiting periods during soaking or drying, and manual hoist operation introduces additional delays. This leads to lower throughput and suboptimal use of chemicals, water, and energy.

v) Challenges in Scaling Operations

Since the process depends on human labour, expanding production capacity requires more personnel, raising costs and complicating scheduling. High-volume operations are therefore difficult to scale efficiently.

vi) Absence of Real-Time Monitoring

Current systems lack sensors or automated feedback to monitor tray cleanliness or process parameters. Without real-time data, it is difficult to optimize the process or identify inefficiencies promptly.

5.0 Statement of Problem

In industrial and commercial environments, keeping steel trays clean is essential for operational efficiency, hygiene, and product quality. Currently, the process of decarbonizing and cleaning these trays is performed manually. Operators must lift each tray, place it onto a hoist, move it into a decarbonization tank for about 20 minutes, transfer it to a rinsing tank, and finally leave it to air-dry. Both tray handling and hoist operation require continuous human intervention, making the process labour-intensive and time-consuming.

This manual approach also introduces variability in cleaning results, as effectiveness depends on human handling, soaking duration, and attention to detail. Additionally, workers face potential hazards from hot surfaces, chemical solutions, and moving equipment. The heavy reliance on labour limits scalability, making it difficult to meet high production demands efficiently.

There is therefore a clear need to automate the decarbonization and cleaning process. Automation can improve efficiency, ensure consistent cleaning, enhance safety, and reduce labour costs, providing a scalable solution suitable for industrial environments.

6.0 Objectives of the Project

- To analyse the requirements and suggest the project plan.
- Research, identify and give clarity to the project.
- To design and implement an automated system for decarbonizing and cleaning steel trays.
- To create and build an electromechanical system for lifting, moving, and placing trays.
- To design and develop using the simulation software.
- Implementation and testing of software solution.
- To conduct testing and perform a detailed analysis of the results.
- To conduct cost-benefit analysis to confirm economic viability.

6.0.1 Key Constraints and Specifications:

- The system must accommodate standard tray dimensions used in the facility.
- Cleaning time per tray should not exceed the current manual process significantly.
- Chemical use should be optimized to minimize cost and environmental impact.
- The automated system must be reliable, maintainable, and scalable to meet future production needs.
- The project must be completed within the semester timeline and meet academic reporting standards, including a detailed technical report and final presentation.

7.0 Existing and Proposed Idea for Automated the System

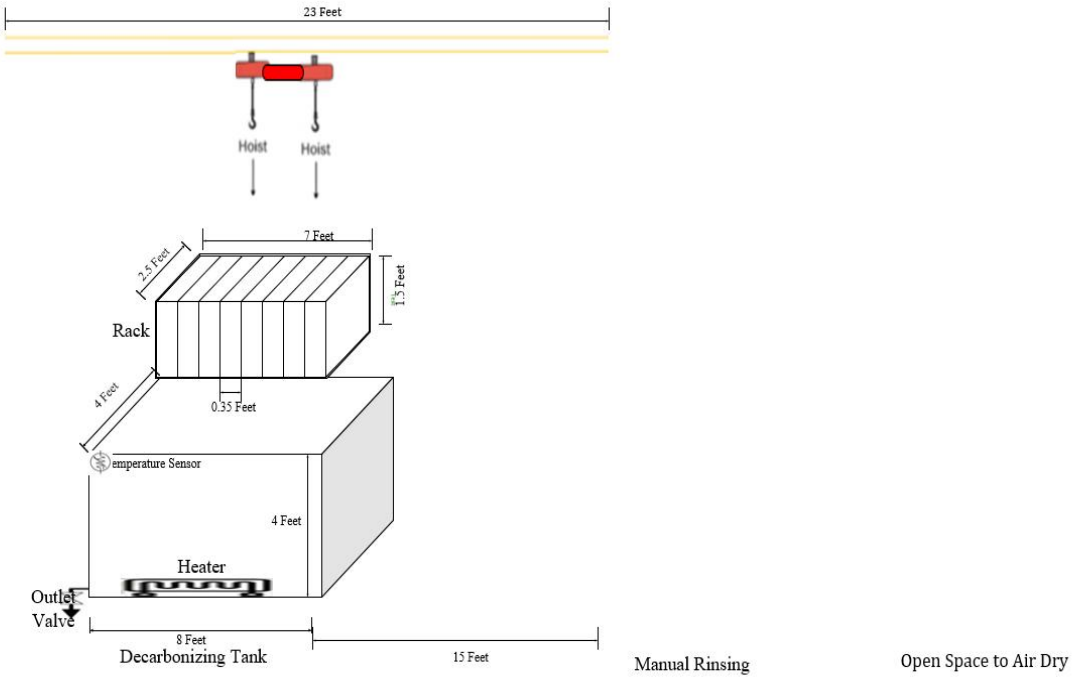


Fig 9: Existing bakery tray decarbonization and cleaning process. Created by author.

EXISTING MANUAL SYSTEM

Loading & Positioning

Two operators place the dirty trays onto a Rack. The loaded rack is then moved manually to the first station. The operators then attach the rack to a hoist, using visual guides or physical stops to position the rack correctly over the Decarbonizing Tank.

Decarbonizing Tank: Deep Chemical Cleaning

The operator uses the Hoist to lower the rack into the Decarbonizing Tank. The Heater maintains the chemical bath at the correct temperature to dissolve carbon, grease, and residue. The operator manually monitors the temperature and soaks the parts for a prescribed time.

Manual Rinsing: Clean Water Wash

After soaking, the operator lifts the rack from the decarbonizing tank and moves it to the Manual Rinsing station. Instead of an automated jet wash, the operator uses a hose with a spray nozzle to thoroughly rinse off all leftover chemicals and debris from the parts. The wastewater drains away through an Outlet Valve at the bottom of the rinsing station.

Open Space to Air Dry

The cleaned rack is moved to the Open Space to Air Dry. Here, parts dry naturally at ambient temperature rather than an enclosed, high-pressure air dryer. Once completely dry, the operator moves the rack to the final offloading area where the clean parts are removed.

The empty rack is then manually cycled back to the loading area to begin the process again with a new batch of dirty parts.

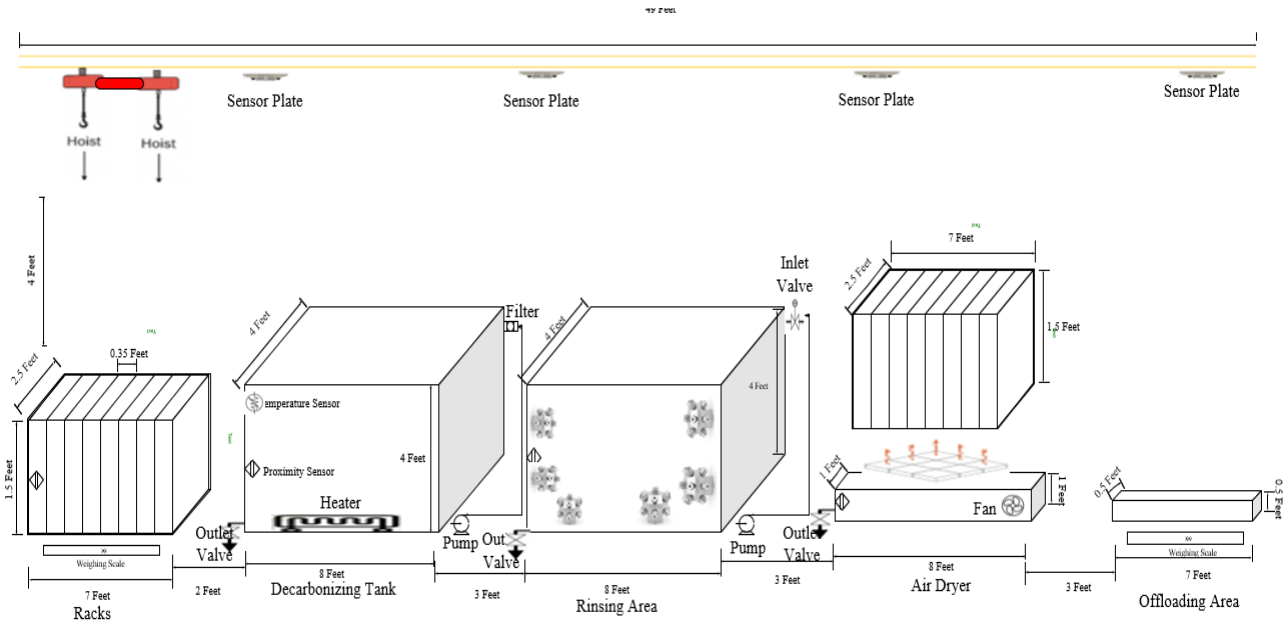


Fig 10: Automated bakery tray decarbonization and cleaning process. Created by author.

PROPOSED SYSTEM STRUCTURE

Fully Automated 4-Stage Cleaning

Line parts move through four stations: Decarbonizing Tank → Rinsing Tank → Air Dryer → Offloading Area, using hoists guided by top-mounted sensor plates that control stopping, lifting, and dropping.

Loading & Positioning Control

Dirty trays or metal parts are placed on racks, weighed for safety, and picked up by a hoist that uses sensor signals to locate each station accurately.

Decarbonizing Tank: Deep Chemical Cleaning

The hoist lowers racks into a heated chemical bath that dissolves carbon, grease, and burnt residue. Temperature and proximity sensors ensure safe operation, while a pump + filtration loop keeps the solution clean.

Rinsing Tank: Clean Water Jet Wash

After decarbonizing, racks enter a clean-water tank where multiple spray nozzles and a pump remove any leftover chemicals or debris, followed by draining through an outlet valve.

Air Drying & Final Offloading

Warm, high-pressure air from an industrial blower dries the parts completely. The hoist then moves the cleaned rack to the offloading area for final weighing and safe removal, while the empty rack cycles back for reloading.

7.0.1 Step-by-Step Process Description:

Production Floor (Placing dirty trays on racks):

Trays come from the production floor after being used (e.g., in ovens). They are dirty and require cleaning before reuse. They are placed on the racks.

Rack Loading:

When the rack is full of multiple trays, the hoist picks it up and places into the cleaning system. This takes about 1 minute.

Decarbonizing Tank:

The rack with trays is submerged into the decarbonizing tank to remove carbon build-up, grease, and burnt food residues. This stage requires about 20 minutes.

Spraying Tank (Washing Stage):

After decarbonizing, the rack moves to the spraying tank. Here, pressurized water or cleaning solution is used to wash off loosened dirt. This process takes about 3 minutes.

Drying Stage:

The trays are transferred to the drying section equipped with fans/blowers to ensure they are completely dry. This process takes about 2 minutes.

Return Stage:

Rack with clean trays is returned to loading bay for reuse or storage. This takes about 2 minutes.

7.0.2 Distance and Layout:

The equipment layout covers the following approximate distances:

49 feet total length.

This represents the footprint of the line from production floor to drying stage.

7.0.3 Summary of Cycle Times:

- Loading rack: 1 minutes
- Decarbonizing soak: 20 minutes
- Spraying wash: 3 minutes
- Drying: 3 minutes
- Offloading: 1 minutes

Total cycle time (one rack): ~30 minutes (including wait time)

8.0 Project Description

This project focuses on the automation of steel tray decarbonization, a process that is still carried out manually in many facilities. At present, operators are responsible for lifting trays and placing them onto a hoist, which lowers them into the decarbonization tank. After approximately twenty minutes, the trays are removed and moved to a rinsing tank, before being left in open space to dry. While effective, this method is repetitive, physically demanding, and exposes workers to potentially harmful chemicals. Moreover, the manual approach limits efficiency, consistency, and overall productivity.

To address these shortcomings, the project proposes the design and simulation of an automated handling system. Instead of requiring manual intervention at each stage, trays will be moved seamlessly through the decarbonization, rinsing, and drying phases by a fully automated setup. The system will also include an automatic chemical filtering mechanism, ensuring that the cleaning solution remains effective over time while reducing waste and operational costs.

The outcomes of the project will include a comprehensive simulation model of the automated process, complete with tray movement, treatment cycles, rinsing, and drying. In addition, system diagrams and process flowcharts will be developed to illustrate how automation can be applied in practice. The project will also generate performance data, such as cycle times and throughput rates, which will be compared against the current manual system to highlight improvements in efficiency, safety, and consistency.

By the end of the study, the project will deliver a detailed report and analysis, summarizing the system design, simulation results, and recommendations for industrial application. Although no physical prototype will be constructed, the simulation outcomes will provide valuable insights into how such automation can be scaled up and implemented in real-world operations.

Through this work, the project demonstrates how the adoption of automation can enhance operational performance, reduce labour dependency, improve workplace safety, and support more sustainable industrial practices.

8.0.1 Major Deliverables:

i) Simulation Model:

A comprehensive simulation of the automated tray handling, decarbonization, and rinsing workflow. Representation of tray movement, dwell times in tanks, automated chemical filtering, and process sequencing.

ii) Design Documentation:

Detailed block diagrams and flowcharts illustrating system architecture, control logic, and integration of mechanical and chemical operations. Documentation of assumptions, parameters, and constraints used in the simulation.

iii) Automation and Control Logic:

Development of control algorithms to manage tray movement, timing, and chemical filtering intervals. Simulation of process coordination, safety interlocks, and efficiency optimization.

iv) Performance Analysis Report:

Analysis of throughput, cycle times, resource use (chemical and energy), and system efficiency. Comparison of simulated automated process performance against the current manual workflow.

By delivering these outputs, the project will provide a fully modelled, functional representation of the automated cleaning system, allowing insights into potential operational improvements, labour reduction, and process optimization, while minimizing cost and risk.

9.0 Methodology of Execution

This project focuses on simulating the automation of the decarbonization and cleaning process for steel trays, emphasizing tray movement, chemical management, and overall process coordination. The simulation approach allows us to analyse system performance and optimize design parameters without constructing a physical prototype.

9.0.1 Software Tools:

Automation Studio/Factory Talk: Used to model the workflow, including tray handling, dwell times in the decarbonization tank, automatic chemical filtering, and rinsing.

Control Logic Simulation: PLC style logic is implemented within the software to manage sequencing, timing, and interlocks between stages.

Data Analysis Tools: Excel is used to evaluate throughput, cycle times, and chemical usage to measure system efficiency.

9.0.2 Hardware Components (Modelled in Simulation):

Hoist or Conveyor System: Simulated to transport trays between stages, with adjustable speed, load capacity, and travel distance.

Decarbonization Tank: Modelled as a timed processing stage, representing chemical action on carbon deposits.

Chemical Filtering System: Includes pumps, filters, and valves in the model to simulate automatic filtering and solution refresh at set intervals.

Rinsing Tank: Modelled to remove residual chemicals, with dwell time configurable in the simulation.

Drying/Tray Unloading Station: Represents the final stage for trays to dry or be collected for reuse.

Sensors (Modelled Logically):

Limit switches or position sensors to detect tray arrival at each stage. Interlocks to prevent trays from advancing before the previous step is complete.

Actuators (Modelled as Software Components):

Motors for the hoist/conveyor. Valves for chemical solution flow and filtering.

10.0 Work Done

10.0.1 Design/Mechanism with real time dimensions

De-carbonizing Tank

The **decarbonizing tank** is a **rectangular steel vessel** designed to accommodate an **internal loading platform** capable of supporting the weight of a **full loading rack**; the platform is **perforated** to permit **unobstructed circulation** of **process water** and to facilitate efficient **contact** between the **liquid** and the **parts being treated.**

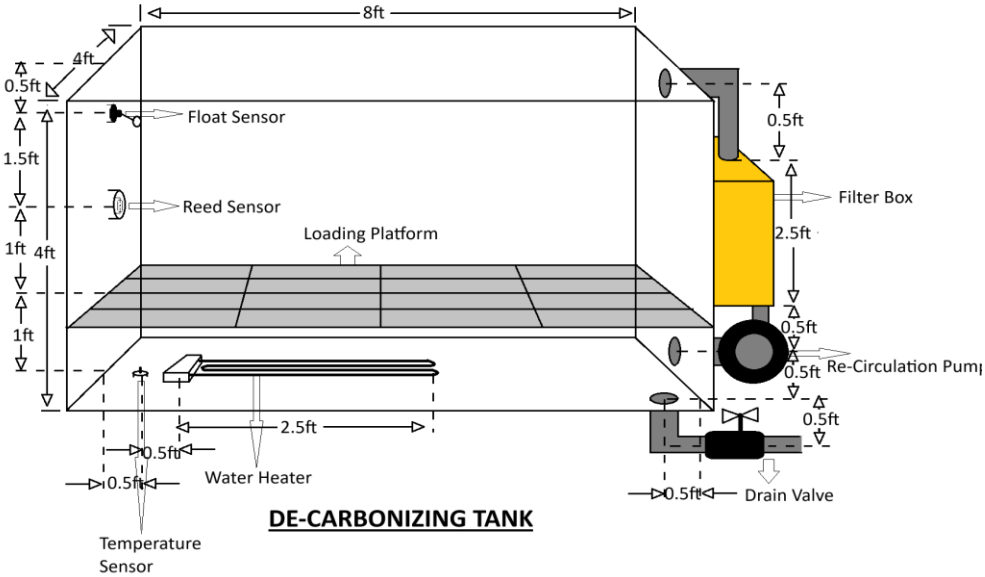


Fig 11: The Decarbonizing Tank (by the author)

The tank is instrumented with three sensors—a temperature (heat) sensor to monitor and control process temperature, a float sensor to detect liquid level, and a reed sensor for position and presence of loading rack—each integrated into the control scheme to ensure safe, repeatable operation.

A dedicated filtration system is connected to the tank to remove suspended solids and protect downstream components, while an immersion-type water heater mounted at the base provides the required thermal input for decarbonizing reactions or cleaning cycles.

For maintenance and process control, a drain valve is installed at the lowest point of the vessel to allow complete and rapid evacuation of the tank contents, enabling safe servicing and efficient changeover between batches.

The overall design emphasizes structural robustness, operational reliability, and maintainability, with sensor placement and auxiliary systems arranged to support automated control, minimize downtime, and ensure consistent process performance.

Working Mechanism:

When the operator loads trays onto the loading rack and initiates the cycle by pressing the start button, the programmable logic controller (PLC) executes a predefined sequence of interlocked checks and actions to ensure safe and effective decarbonizing.

The PLC first verifies the presence of process liquid in the decarbonizing tank via the float sensor; if the float indicates sufficient liquid level, the controller then reads the temperature probe to determine whether the bath has reached the required setpoint. If the measured temperature is below the setpoint, the PLC energizes the immersion heater and monitors the temperature until the target is achieved, at which point it de-energizes the heater and records the status.

With liquid level and temperature confirmed, the PLC commands the hoist to lower the loaded rack into the tank; a reed sensor mounted in the tank confirms correct rack position and provides a presence interlock to the controller.

Once the reed sensor signal is received, the PLC starts the recirculation pump, establishing continuous flow through the filtration system and nozzle system to generate controlled agitation and maintain uniform chemical contact across all tray surfaces. The pump circulation both sustains the required process turbulence for effective decarbonizing and protects the heater and pump through ongoing monitoring of pressure and temperature interlocks.

The PLC times the cycle according to the selected program, and upon completion it stops the pump, signals the hoist to remove the rack, and logs cycle data for process control and traceability, thereby ensuring a repeatable, safe, and efficient decarbonizing operation.

Filtration System of Decarbonizing Tank

The filtration system integrated with the decarbonizing tank consists of a recirculating pump, a dedicated filter housing, and a fine mesh filter element engineered to capture loose carbon particles generated during the process.

During normal operation, the pump draws liquid from the lowest region of the tank, beneath the loading platform, and delivers it under pressure to the filter housing. As

the fluid passes through the fine mesh element, suspended carbon particulates are retained within the filter cavity, while clarified liquid exits the housing and is returned to the tank via an inlet located near the top. This arrangement establishes a continuous recirculation loop that operates throughout the duration of the rack immersion.

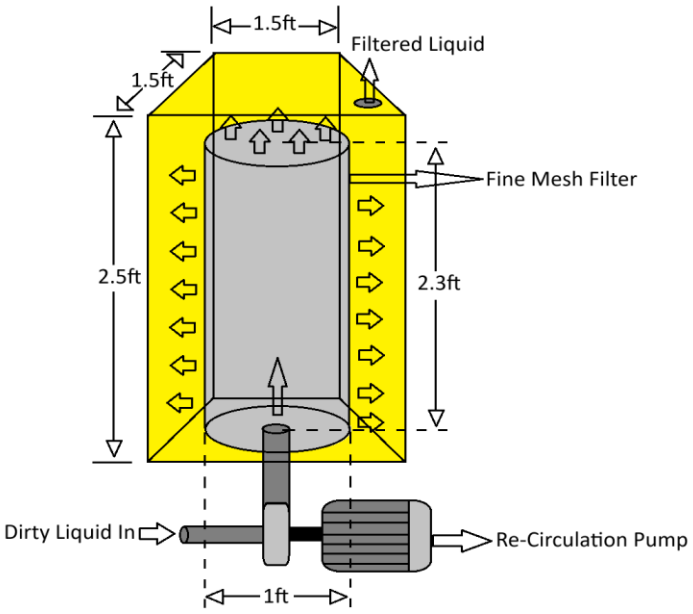


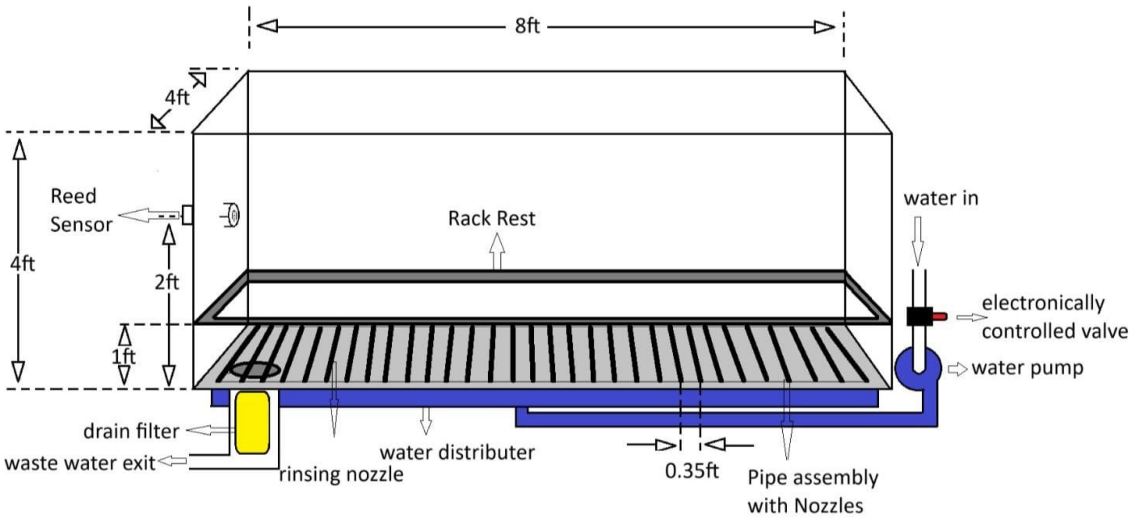
Fig 12: The Filtration System for De-Carbonizing Tank (by the author)

The system is designed to provide sufficient flow rate and differential pressure to ensure effective particle capture without disturbing the loaded parts. The filter housing is configured for easy access, allowing the mesh element to be inspected, cleaned, or replaced with minimal downtime.

Additional features include valving and bypass provisions to permit isolation of the filter for maintenance or backflushing. Instrumentation such as a pressure differential gauge or sensor may also be installed to indicate when servicing is required.

Overall, the filtration system is intended to protect downstream components, preserve process liquid quality, and support consistent decarbonizing performance through reliable, low-maintenance operation.

Rinisng Tank:



RINSING TANK

Fig 13: The Rinsing Tank (by the author)

The rinsing tank is a purpose-built vessel incorporating a rack rest positioned one foot above the tank floor to suspend the loading rack during the rinsing cycle, ensuring complete exposure of parts to the spray pattern. A reed sensor is installed within the tank to detect the presence and correct position of the rack, interlocking the rinsing sequence with the control system to prevent pump operation or valve actuation unless the rack is properly seated.

At the base of the tank, twenty-one rinsing nozzle pipes are manifolded to a central water distributor pipe, which delivers pressurized water to each nozzle. This distributor is powered by a dedicated pressurizing pump sized to provide the required flow rate and spray pressure for effective cleaning. The incoming water supply is regulated by an electronically actuated inlet valve that remains closed when the system is idle, conserving water and preventing unwanted flow. Integrated with the control logic, the valve opens only during an active rinse cycle.

Wastewater is discharged through a drain system located at the lowest point of the tank, allowing complete evacuation of liquid for maintenance or batch changeover while minimizing carryover between cycles. The piping and nozzle arrangement are engineered for uniform coverage and ease of access, and the system incorporates isolation valves and service ports to facilitate routine inspection, filter maintenance, and safe servicing of the pump and nozzles.

Overall, the rinsing tank configuration emphasizes reliable detection and control, efficient water distribution, and straightforward maintenance, ensuring consistent and repeatable process performance.

Working Mechanism

The rinsing sequence begins when the hoist lowers the loaded rack from the decarbonizing tank into the rinsing tank, where a reed sensor confirms correct rack position and transmits a presence signal to the programmable logic controller (PLC). Upon receiving this confirmation, the PLC initiates the pre-programmed rinse cycle by energizing the electronically actuated inlet valve and starting the pressurizing pump, thereby establishing a controlled flow of water through the distribution manifold to the array of nozzles. These nozzles are oriented at a 54° angle to the tray surfaces, ensuring spray impingement into all recesses and crevices and producing a uniform spray pattern that effectively dislodges and removes residues.

The PLC times the operation according to the selected cycle parameters, maintaining pump pressure and valve position for the prescribed duration to achieve complete rinsing. Throughout the cycle, the controller monitors interlocks to inhibit pump or valve operation if the rack is not detected or if a fault occurs. At the end of the cycle, the PLC closes the inlet valve and stops the pump, allowing wastewater to drain from the tank. This automated sequence ensures repeatable, safe, and efficient rinsing, while minimizing operator intervention and water wastage.

The Rinsing Drain Filter:

The rinsing drain filter is a simple yet effective mechanism designed to separate solid carbon particles from wastewater during the rinsing cycle. The system employs a mesh separator through which the wastewater is directed; as the liquid passes through, the carbon particles are trapped and collected in a dedicated carbon collector bin. The clarified water then exits the filter and flows into the drainage system, ensuring that only clean effluent is discharged.

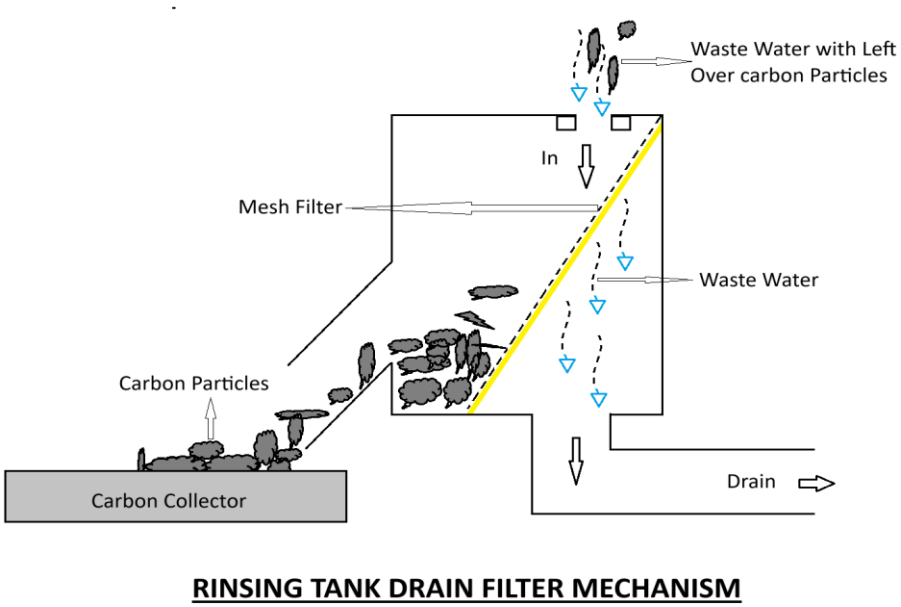


Fig 14: The Drain Filter for Rinisng Tank (by the author)

This arrangement provides reliable particle capture, protects downstream piping, and supports consistent rinsing performance while maintaining straightforward operation and low maintenance requirements.

The Nozzle Assembly:

The nozzle assembly consists of 21 pipes; each fitted with four flat-blade spray nozzles—two positioned on either side of the pipe. The nozzles are installed at an inclination angle of 54°, ensuring precise targeting of the tray bottom for effective rinsing. Each nozzle delivers a pressurized flat-blade spray pattern engineered to maximize coverage efficiency.

With this arrangement, every nozzle covers approximately 50% of the tray area; specifically, two nozzles are oriented to clean the front section of the tray, while the remaining two provide complete coverage of the rear section.

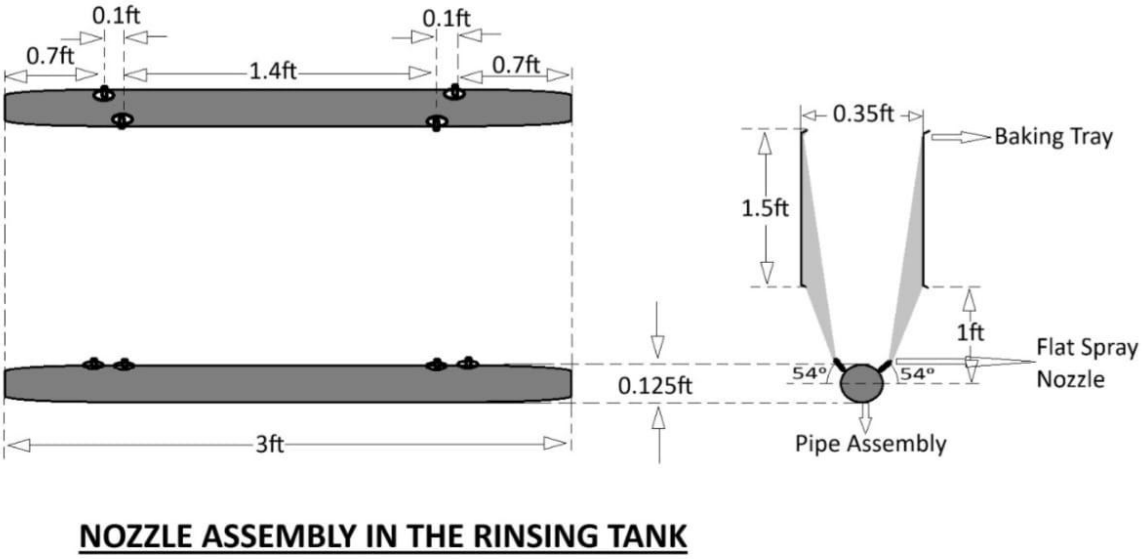


Fig 15: The Spray Nozzle Assembly in Rinisng Tank (by the author)

This configuration achieves uniform water distribution across the tray surface, thereby enhancing cleaning effectiveness and ensuring operational reliability throughout the rinsing cycle.

Drying Station:

The drying station is engineered to deliver high-efficiency air drying using a configuration similar to a large-scale hair dryer, adapted for industrial applications. The system is composed of three primary components: a high-capacity blower, a duct heater, and a platform integrated with multiple air nozzles. The blower generates a continuous stream of air, which is subsequently heated as it passes through the duct heater.

This heated air is directed through the nozzles mounted on the platform, ensuring uniform distribution across the target surface.

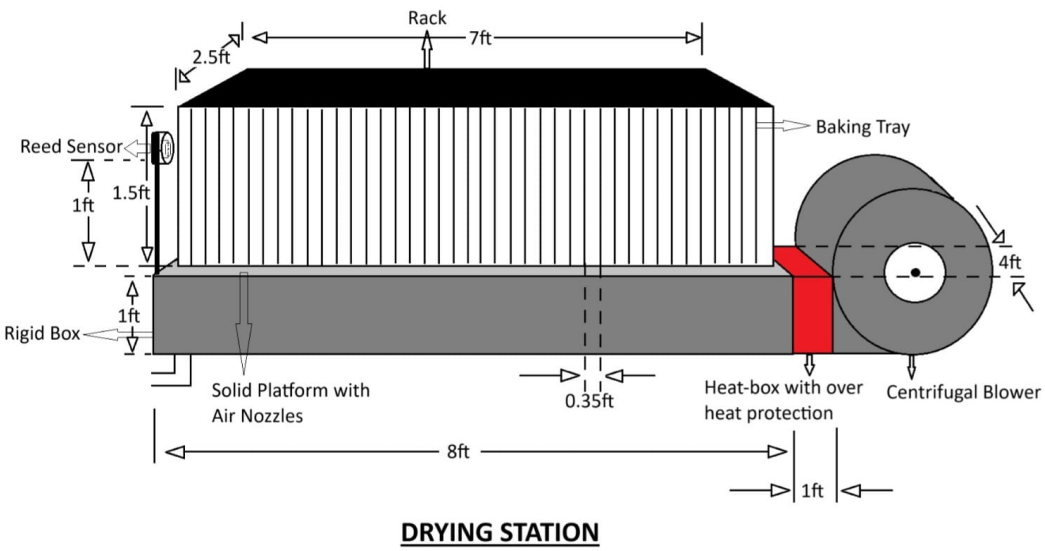


Fig 16: The Drying Station (by the author)

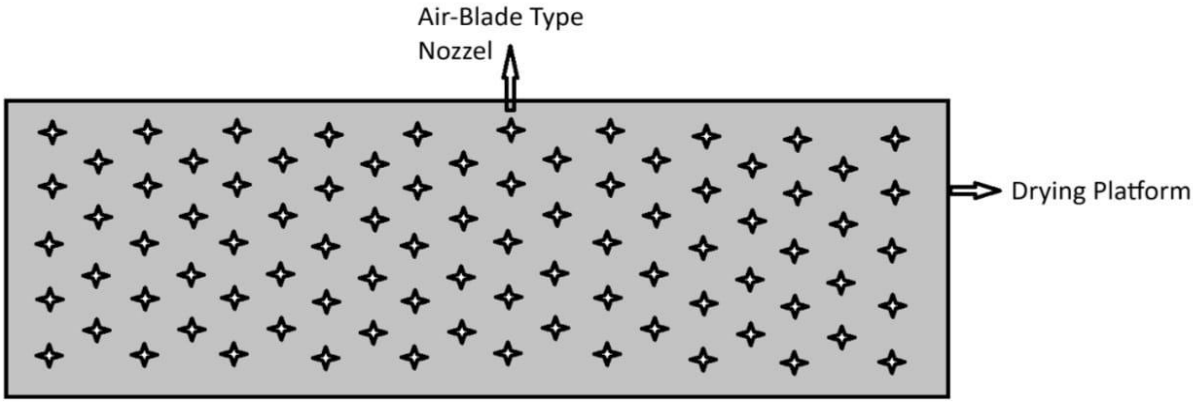
The nozzle arrangement and airflow design are optimized to achieve rapid and consistent drying performance, making the station particularly suitable for high-throughput operations where efficiency and reliability are critical.

After completion of the rinsing process in the rinsing tank, the hoist lifts the loading rack and transfers it to the drying station. Once the rack is lowered into position, a reed sensor detects its presence and communicates the signal to the programmable logic controller (PLC). The PLC then initiates the operation of the centrifugal blower and heater box, which deliver a controlled stream of hot air through the air plates for several minutes to achieve thorough drying. This automated sequence ensures that the baking trays are dried efficiently and consistently, completing the decarbonizing process with high reliability and minimal operator intervention.

Loading Platform:

The loading platform is constructed as a solid and rigid structure engineered to support the full weight of the loading rack during operation. Integrated within the platform are multiple air nozzles designed to regulate both the flow and pressure of air with high precision. These nozzles are strategically positioned to direct airflow through the baking trays, beginning at the bottom of the rack and progressing upward.

Working Mechanism



AIR SPRAY JET SYSTEM

Fig 17: The Drying Platform (by the author)

This arrangement ensures that hot air is distributed uniformly across all levels of the rack, resulting in effective and consistent drying of the trays The robust design and optimized airflow configuration contribute to reliable process performance, supporting high-efficiency drying in demanding industrial applications.

10.0.2 Components details and specifications

Immersion-type water heater:

The water heater installed at the base of the decarbonizing tank is an immersion-type element designed in the form of a twisted coil rather than a continuous helix. This geometry is specifically chosen to enhance surface contact and promote rapid, uniform heat transfer to the process liquid.

Fig 18: water_heater

Located at the lowest point of the vessel, the twisted-coil element delivers thermal energy directly into the fluid, thereby reducing warm-up time and minimizing thermal stratification by encouraging localized circulation around the coil turns. The twisted configuration also increases turbulence in the immediate vicinity of the element, improving mixing and temperature homogeneity without requiring additional mechanical agitation.

The heater is fully integrated with the tank's temperature sensor and control system, enabling precise maintenance of process setpoints and preventing overheating through automatic cut-out and interlock functions. Mechanically, the element is mounted and protected to resist damage from racks or parts, while remaining accessible via a service port for inspection and replacement to minimize downtime during maintenance.

Electrical and safety provisions—including proper grounding, over-temperature protection, and adequate clearances from combustible materials—are incorporated to ensure safe and reliable operation throughout decarbonizing cycles. Overall, the twisted-coil immersion heater provides an efficient, controllable, and maintainable heat source tailored to the operational requirements of the decarbonizing tank.

Reed Sensor:

A reed sensor is a simple, magnetically actuated switch that detects the presence or position of a magnetic field; it is compact, reliable in harsh environments, and widely used for proximity and position sensing in industrial and consumer applications.

Fig 19: reed_sensor

A reed sensor, also known as a reed switch, is a magnetically operated electrical switch designed for reliable proximity and position detection. It consists of two thin ferromagnetic blades enclosed within a small hermetically sealed glass envelope. When exposed to a magnetic field, the blades magnetize and attract each other, thereby closing the electrical contact; once the magnet is removed, the blades separate and the circuit opens. The glass sealing provides effective protection against corrosion and contamination, ensuring long service life and dependable switching performance even in dirty or moist environments. This simple yet robust construction makes reed sensors highly suitable for industrial automation, consumer electronics, and other applications requiring compact, durable, and low-maintenance sensing solutions.

How It Works and Key Characteristics

The reed sensor operates on the principle of contact closure by magnetic actuation, in which a permanent magnet or an electromagnet generates the magnetic field that pulls the reeds together to close the circuit. When the magnetic field is removed, the reeds separate, reopening the circuit.

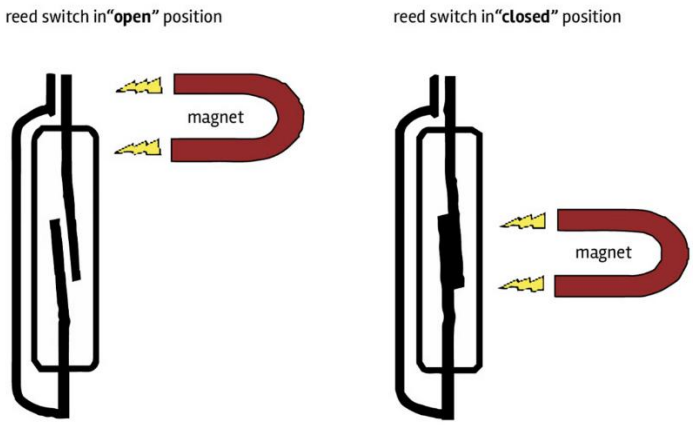


Fig 20: reed_sensor_mechanism

Reed sensors are available in multiple configurations, including normally open (NO), normally closed (NC), and changeover types, and can be specified in through-glass, shielded, or surface-mounted variants to suit different application requirements.

Key performance parameters include operate/release sensitivity (measured in ampere turns, AT), switching voltage/current ratings, contact material, and environmental ratings. Typical industrial reed sensors are capable of operating across wide temperature ranges and handling modest currents and voltages, depending on their construction. These characteristics make reed sensors a reliable and versatile choice for industrial automation, safety interlocks, and position detection systems.

Float Sensor:

A float sensor, also known as a float switch, is a mechanical liquid level sensor that operates using a buoyant float to open or close an electrical circuit. Its design is inherently simple yet highly reliable, making it suitable for use in harsh environments and across a wide range of applications. Float sensors are widely employed to control pumps, trigger alarms, and operate valves in tanks and reservoirs, ensuring accurate monitoring and regulation of liquid levels. Their straightforward construction, durability, and low maintenance requirements make them a dependable choice for industrial automation, water treatment systems, and process control operations.

FLOAT TYPE WATER LEVEL SENSOR

Fig 21: float_sensor

A float sensor operates by converting the vertical movement of a buoyant element into an electrical contact action. As the liquid level rises or falls, the float moves accordingly, and an internal magnet or mechanical linkage actuates a sealed switch to produce an on/off signal. This simple yet effective mechanism makes float switches both cost-effective and flexible, particularly for point level detection where a single threshold—or multiple thresholds in multi-point designs—is sufficient.

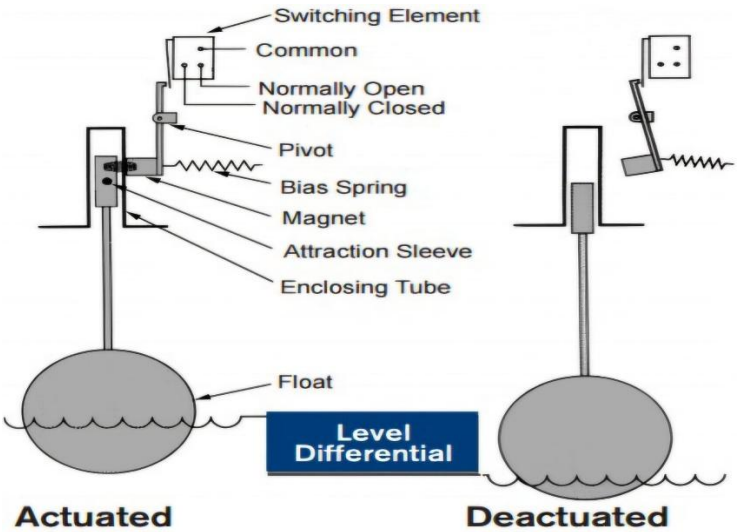


Fig 22: float_sensor_mechanism

Float sensors are widely applied to start or stop pumps, trigger alarms, and interlock valves in both industrial and domestic systems, providing reliable and low-maintenance control of liquid levels across a variety of applications.

Temperature sensor:

The temperature sensing element used in the system is a stainless-steel K-type thermocouple probe specifically designed for compatibility with two-wire temperature controllers. Rated for an operating range of 0–600 °C, the probe provides accurate and reliable measurement across typical industrial process conditions. Electrical termination is achieved through insulated fork leads, with red designated as positive and blue as negative, ensuring straightforward connection and polarity identification. For mechanical installation, the probe is offered with NPT threaded fittings and standard probe diameters, enabling secure mounting in a variety of industrial applications. Constructed with a 304 stainless steel sheath, the thermocouple is intended for immersion or insertion into process vessels and pipework, delivering robust performance, corrosion resistance, and long service life under demanding operating environments.

TEMPERATURE SENSOR PROBE TWO WIRE TEMPERATURE CONTROLLER (0~600°C)

Fig 23: temperature_sensor

Typical commercial thermocouple probe assemblies are rated for measurement ranges of 0–600 °C when supplied with two-wire controller terminations. Standard mechanical options include a 6 mm probe diameter with lengths commonly offered in

the 50–100 mm range, along with NPT 1/4" threaded fittings to ensure secure and reliable mounting in industrial applications. For electrical connection, the probes are typically shipped with two insulated fork terminals, accompanied by manufacturer wiring guidance specifying that the red fork connects to the positive (+) terminal and the blue fork to the negative (−) terminal. This arrangement provides straightforward installation, clear polarity identification, and dependable integration into process control systems.

Flat Blade Spray Nozzle

Fig 24: flat_fan_nozzle

A flat blade spray nozzle, also referred to as a flat fan nozzle, is engineered to produce a fan-shaped spray pattern that distributes liquid evenly across a surface area. The nozzle functions by directing fluid through a narrow rectangular orifice, which generates a thin sheet of spray at a defined angle, ensuring precise and consistent coverage.

This type of nozzle is widely applied in industrial processes such as cleaning, cooling, coating, and dust suppression, where both uniform coverage and strong impact are essential. Its simple design contributes to high reliability, versatility, and effectiveness, making it particularly suitable for operations that demand consistent liquid distribution with minimal maintenance requirements.

Fig 25: flat_spray

Water discharged from a flat blade spray nozzle forms a fan-shaped spray pattern that spreads liquid evenly across the target surface. As the fluid is forced through the nozzle's narrow rectangular orifice, it emerges as a thin sheet that quickly breaks into fine droplets, producing both uniform coverage and strong impact. The defined spray angle ensures precise targeting, while the distribution pattern maximizes cleaning or wetting efficiency. This flow characteristic makes flat blade nozzles highly effective in applications such as industrial rinsing, cooling, coating, and dust suppression, where consistent liquid delivery and reliable performance are essential.

Pressure Pump:

A water pressurising pump, commonly referred to as a booster pump, is an essential component used to maintain adequate water pressure in systems where the natural supply is insufficient. It operates by drawing water from the source line and forcing it through an impeller, thereby increasing both pressure and flow before distribution to the required outlets.

Fig 26: pressure_pump

These pumps are widely applied in residential, commercial, and industrial settings to ensure consistent water delivery for processes such as cleaning, cooling, irrigation, and equipment operation. By integrating pressure sensors or switches, the pump can automatically adjust to demand, providing reliable performance and uniform water supply across the system.

Electronically Controlled Water Valve:

Fig 27: water_valve

An electronically controlled water valve is a precision device designed to regulate water flow through electrical signals, enabling both automated and remote operation in fluid systems. The valve assembly typically consists of a valve body integrated with

an electric actuator—such as a solenoid or motor—that responds to input from sensors, timers, or control systems.

These valves are widely applied in residential, commercial, and industrial environments, supporting functions such as irrigation, leak prevention, process automation, and smart plumbing systems. By enabling real-time control and seamless integration with digital platforms, electronically controlled valves enhance system efficiency, safety, and responsiveness, making them essential components in modern water management solutions.

The Duct Heater:

The duct heater is a critical component of the drying station, engineered to elevate the temperature of the air stream as it passes through the duct system.

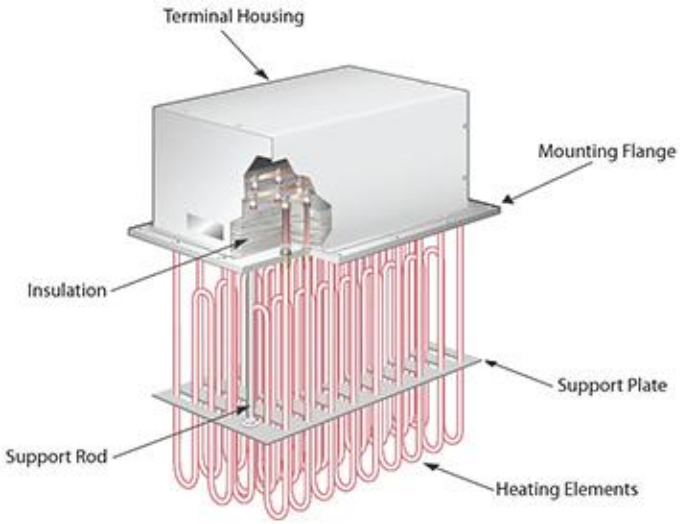


Fig 28: duct_heater

It incorporates durable heating elements, typically tubular or finned, housed within a stainless-steel frame designed to withstand high operating temperatures and continuous airflow. As the blower directs air through the duct, the heater raises its temperature to the required level, ensuring efficient drying of the baking trays. Integrated with the programmable logic controller (PLC), the duct heater delivers precise thermal control, uniform heat distribution, and reliable performance, making it an essential element for completing the decarbonizing process effectively and consistently.

Centrifugal Blower:

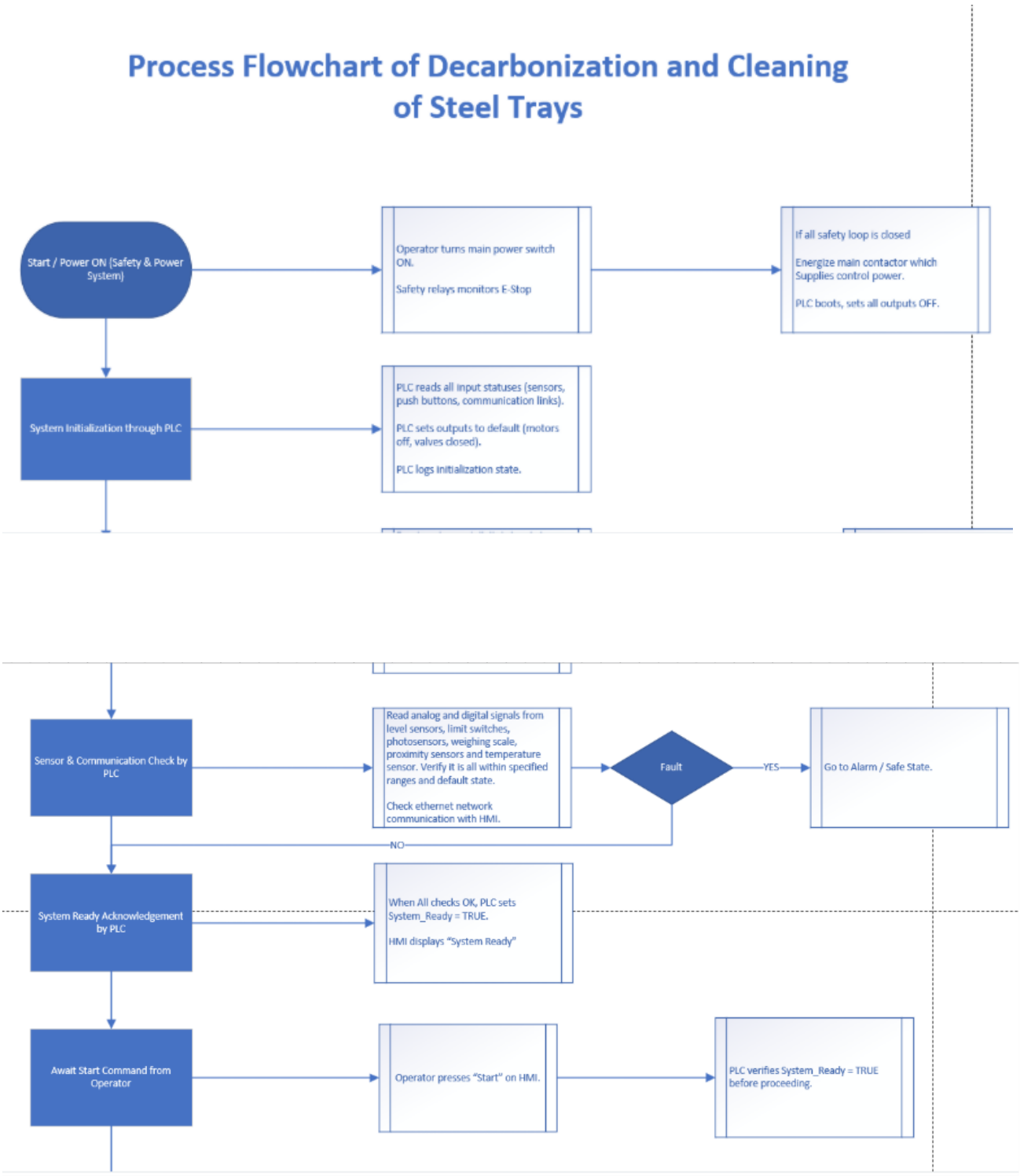
The centrifugal dryer, also referred to as a spin dryer or dewatering machine, is widely employed in industrial applications to remove surface water, oil, or solvents from components following washing or finishing processes. The system operates by placing

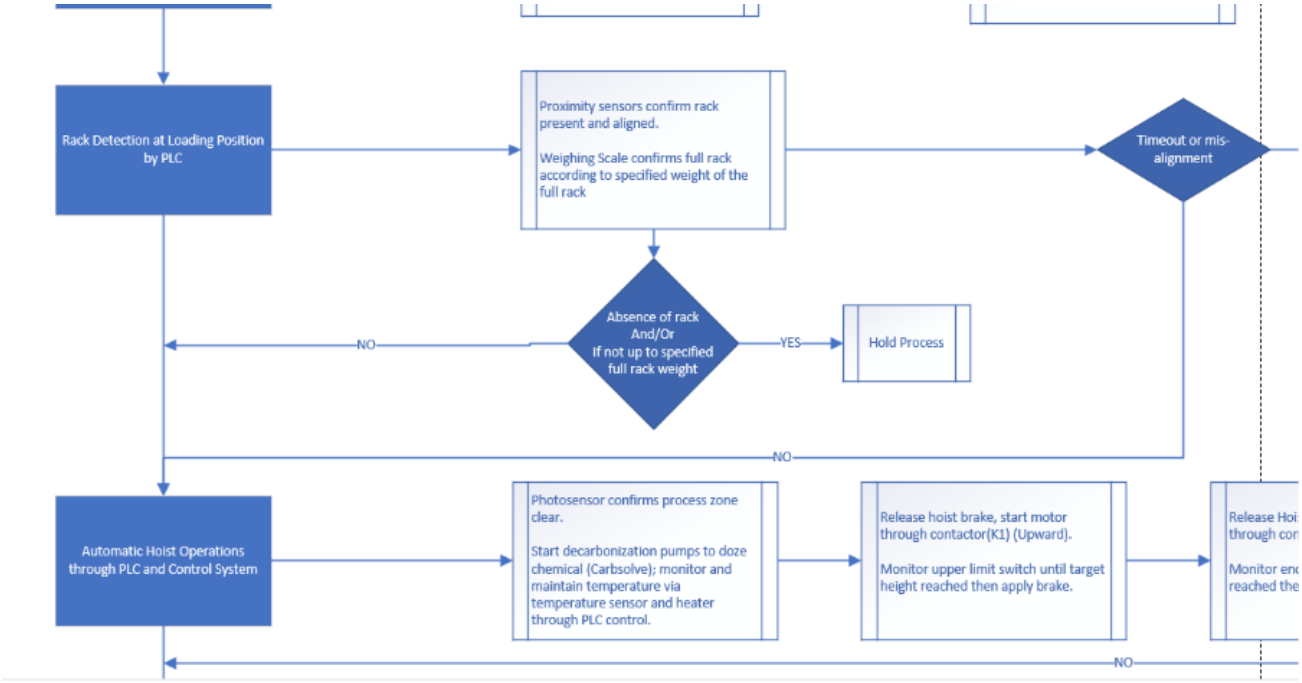
wet materials—such as plastic flakes, pellets, or metal parts—into a perforated rotating drum. As the drum spins at high speeds, centrifugal force drives the liquid outward through the perforations, leaving the materials clean and dry.

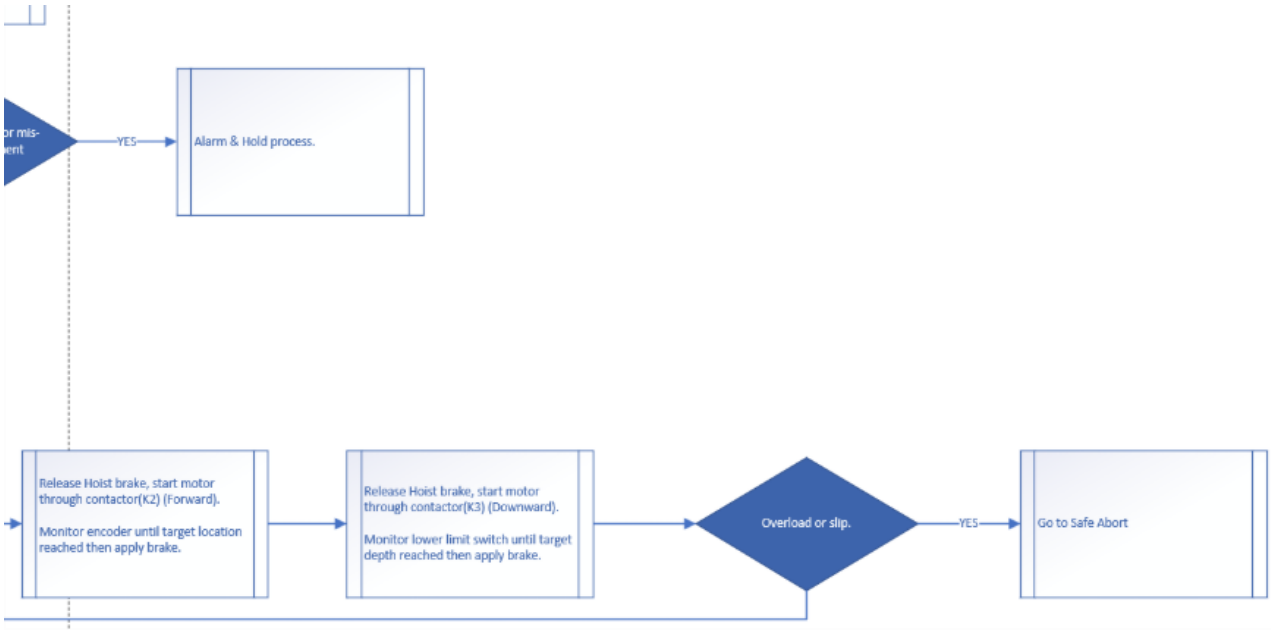
Fig 29: centrifugal_blower

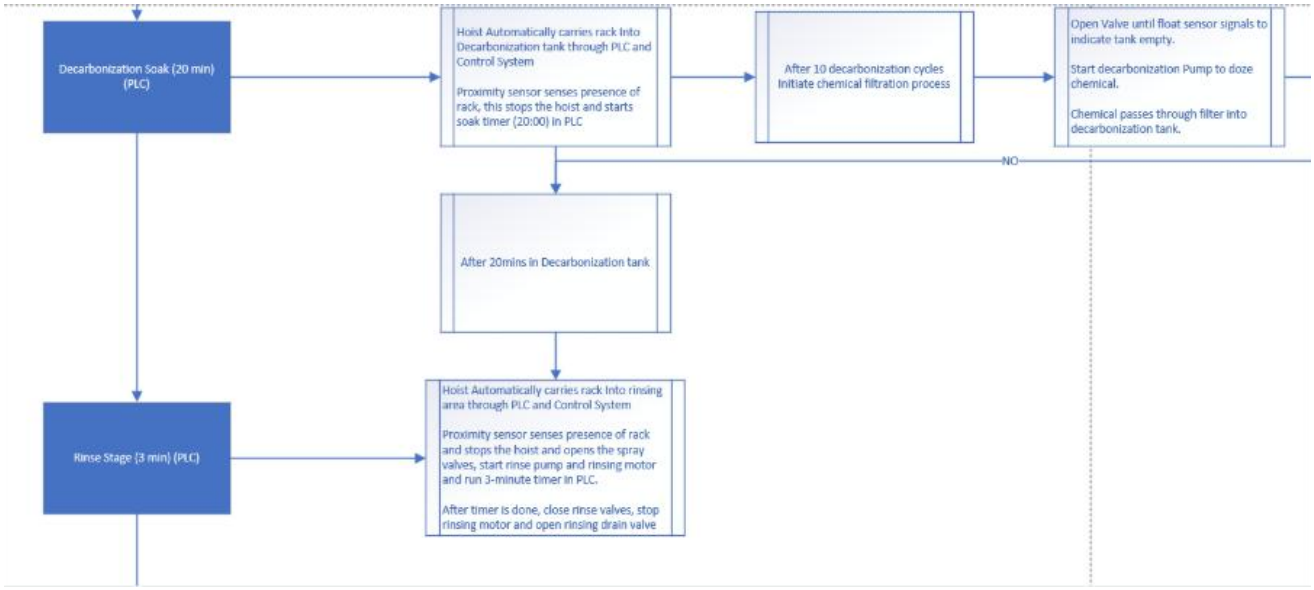
Certain models incorporate heating elements or hot air circulation to accelerate drying and enhance results. Centrifugal dryers are valued for their energy efficiency, rapid operation, and ability to reduce moisture content to very low levels, making them indispensable in recycling lines, electroplating workshops, and mass finishing operations. Their design ensures uniform drying without damaging delicate parts, while integrated safety features such as lid interlocks and timers provide reliable and secure operation. Overall, the centrifugal dryer is a critical piece of equipment for achieving consistent quality and high productivity in modern manufacturing and recycling systems.

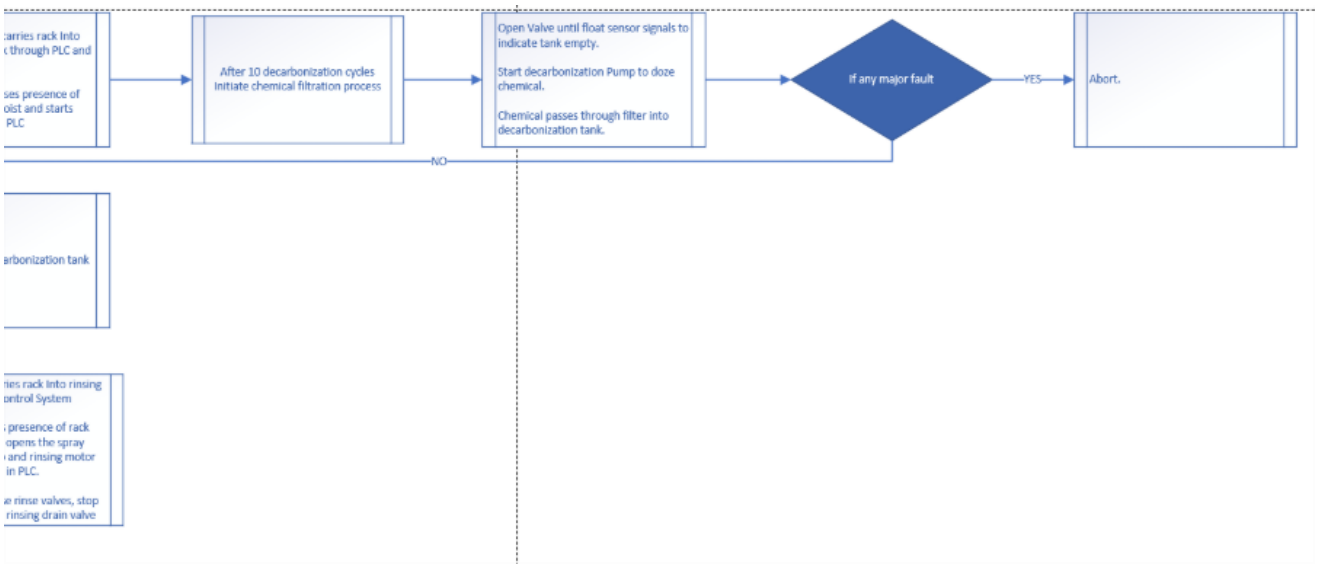
10.0.3 Flowchart

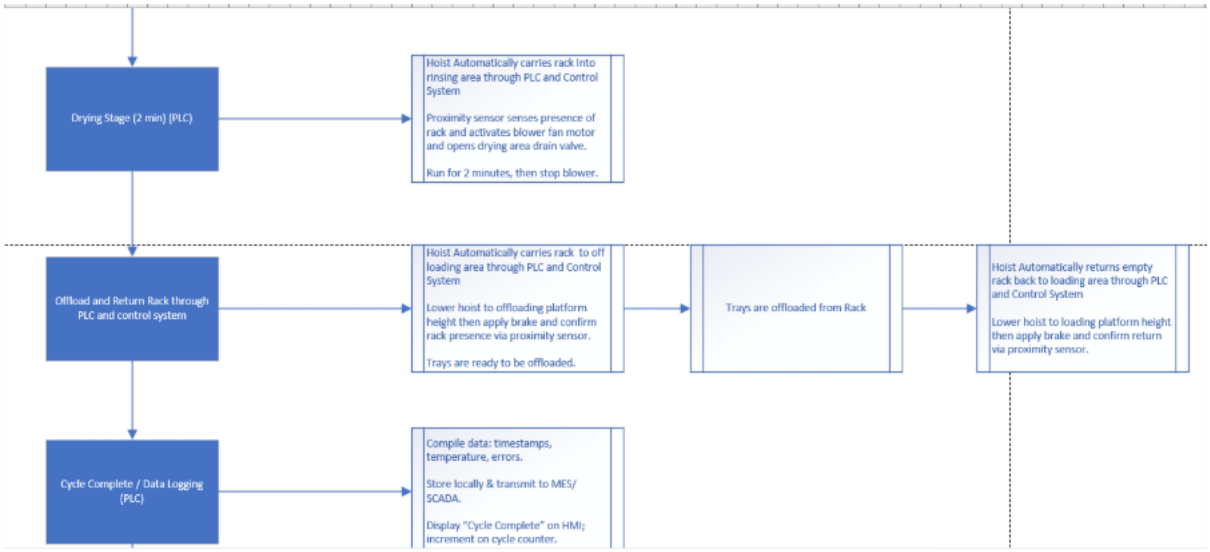


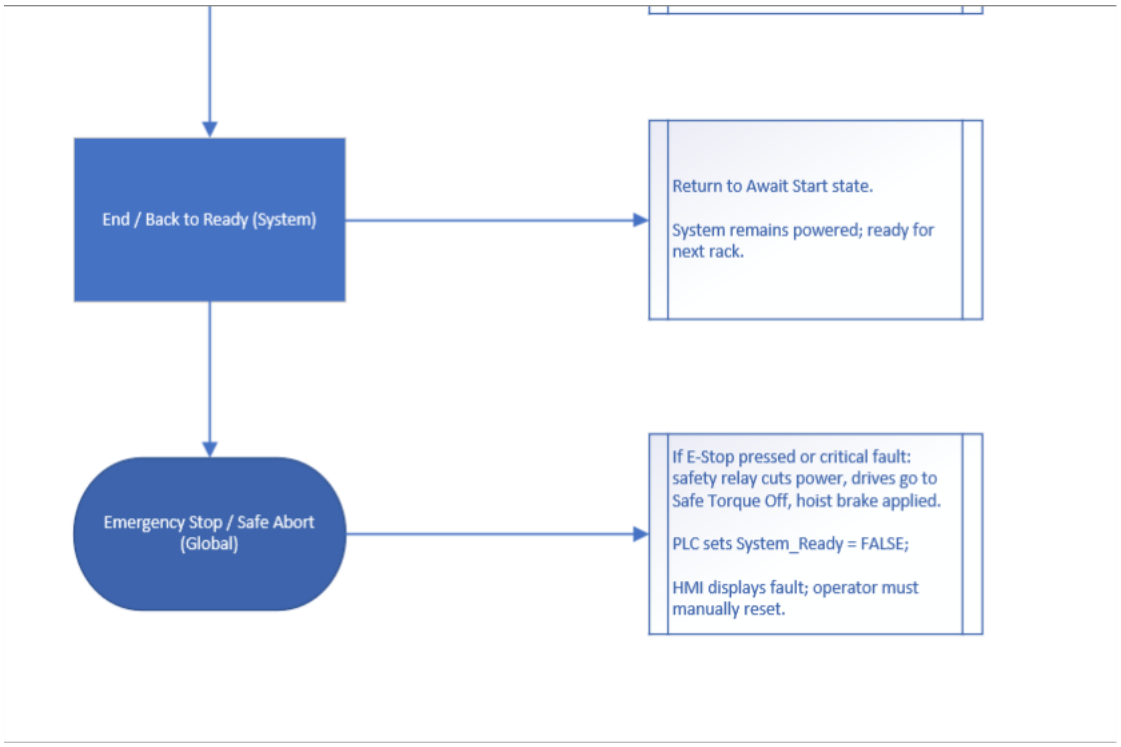

Rack Detection at Loading Position by PLC
Proximity sensors confirm rack present and aligned.
Weighing Scale confirms full rack according to specified weight of the full rack
Timeout or mis-alignment
Absence of rack And/Or If not up to specified full rack weight
NO
YES
Hold Process
NO
Automatic Hoist Operations through PLC and Control System
Photosensor confirms process zone clear.
Start decarbonization pumps to doze chemical (Carbsolve); monitor and maintain temperature via temperature sensor and heater through PLC control.
Release hoist brake, start motor through contactor(K1) (Upward).
Monitor upper limit switch until target height reached then apply brake.
NO


YES
Alarm & Hold process.
Release Hoist brake, start motor through contactor(K2) (Forward).
Monitor encoder until target location reached then apply brake.
Release Hoist brake, start motor through contactor(K3) (Downward).
Monitor lower limit switch until target depth reached then apply brake.
Overload or slip.
YES
Go to Safe Abort


Decarbonization Soak (20 min) (PLC)
Hoist Automatically carries rack Into Decarbonization tank through PLC and Control System
Proximity sensor senses presence of rack, this stops the hoist and starts soak timer (20:00) in PLC
After 10 decarbonization cycles Initiate chemical filtration process
Open Valve until float sensor signals to indicate tank empty.
Start decarbonization Pump to doze chemical.
Chemical passes through filter into decarbonization tank.
NO
After 20mins in Decarbonization tank
Rinse Stage (3 min) (PLC)
Hoist Automatically carries rack Into rinsing area through PLC and Control System
Proximity sensor senses presence of rack and stops the hoist and opens the spray valves, start rinse pump and rinsing motor and run 3-minute timer in PLC.
After timer is done, close rinse valves, stop rinsing motor and open rinsing drain valve


After 10 decarbonization cycles Initiate chemical filtration process
Open Valve until float sensor signals to indicate tank empty.
Start decarbonization Pump to doze chemical.
Chemical passes through filter into decarbonization tank.
If any major fault
YES
Abort.
NO


Drying Stage (2 min) (PLC)
Hoist Automatically carries rack into rinsing area through PLC and Control System
Proximity sensor senses presence of rack and activates blower fan motor and opens drying area drain valve.
Run for 2 minutes, then stop blower.
Offload and Return Rack through PLC and control system
Hoist Automatically carries rack to off loading area through PLC and Control System
Lower hoist to offloading platform height then apply brake and confirm rack presence via proximity sensor.
Trays are ready to be offloaded.
Trays are offloaded from Rack
Hoist Automatically returns empty rack back to loading area through PLC and Control System
Lower hoist to loading platform height then apply brake and confirm return via proximity sensor.
Cycle Complete / Data Logging (PLC)
Compile data: timestamps, temperature, errors.
Store locally & transmit to MES/ SCADA.
Display "Cycle Complete" on HMI; increment on cycle counter.


End / Back to Ready (System)
Return to Await Start state.
System remains powered; ready for next rack.
Emergency Stop / Safe Abort (Global)
If E-Stop pressed or critical fault: safety relay cuts power, drives go to Safe Torque Off, hoist brake applied.
PLC sets System_Ready = FALSE;
HMI displays fault; operator must manually reset.

10.0.4 Wiring diagram

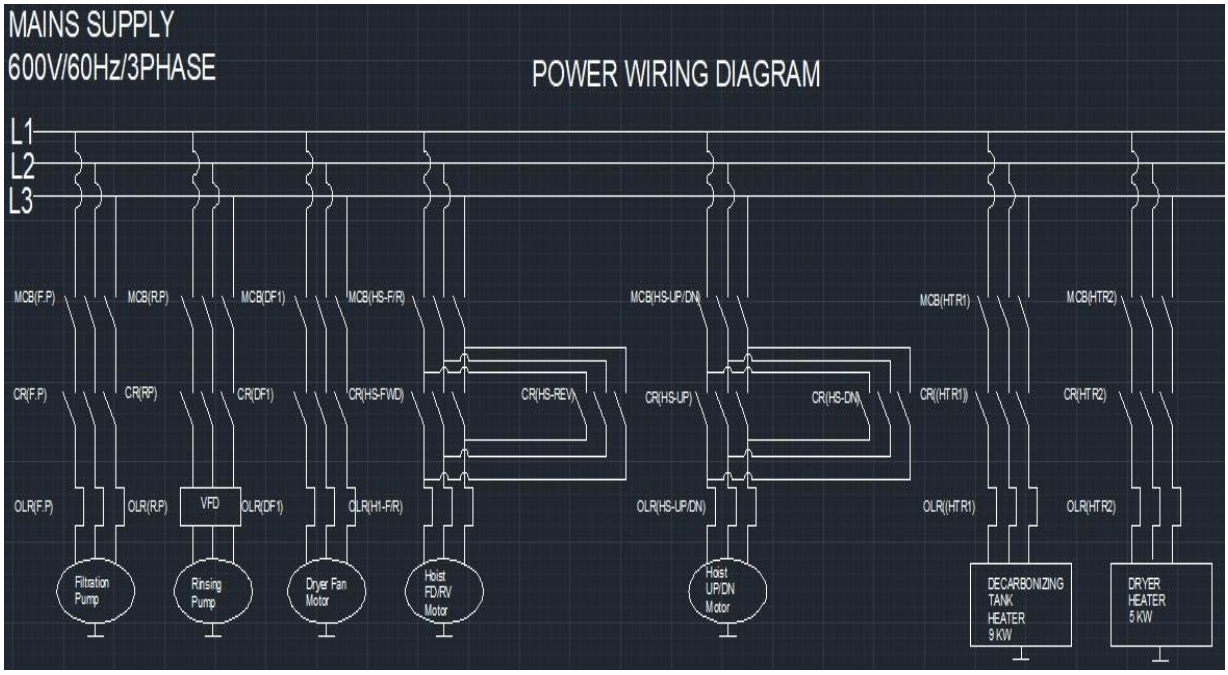


Fig. Power wiring diagram

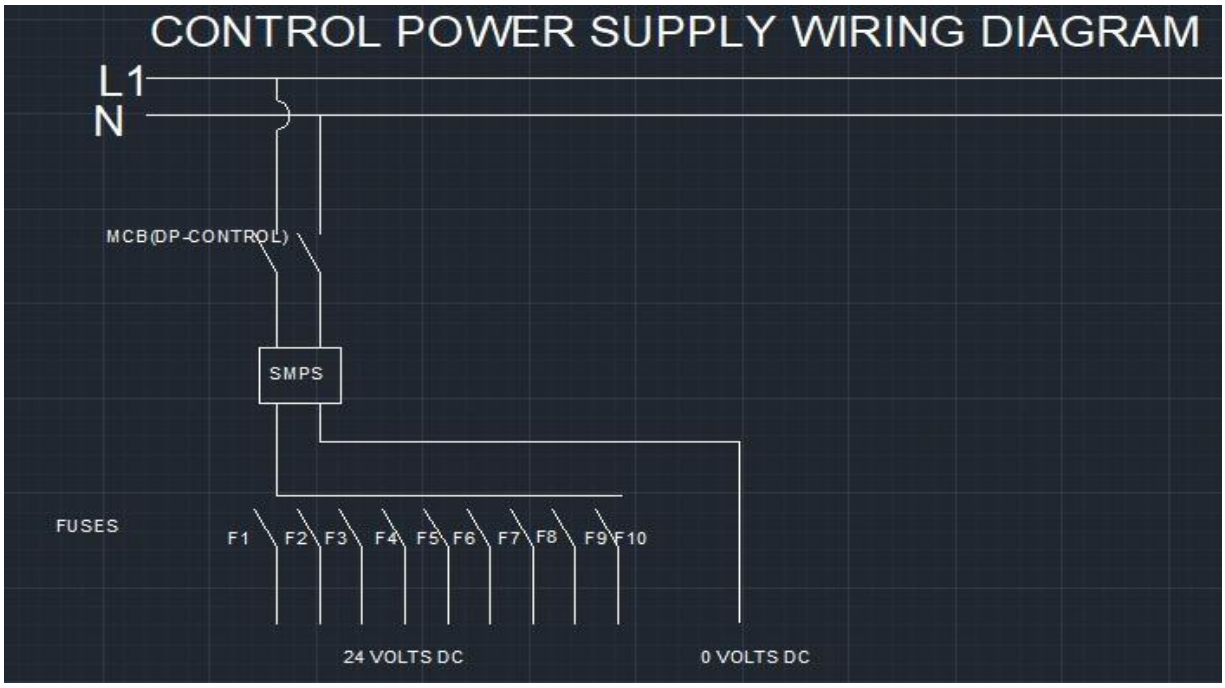


Fig. Control power supply wiring diagram

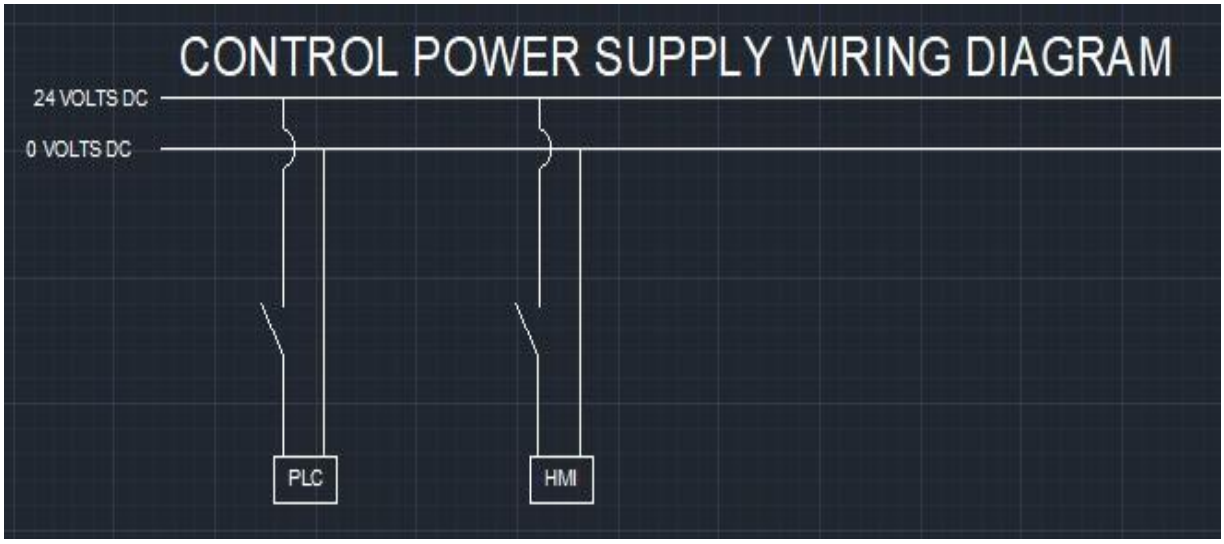


Fig. Control power supply wiring diagram

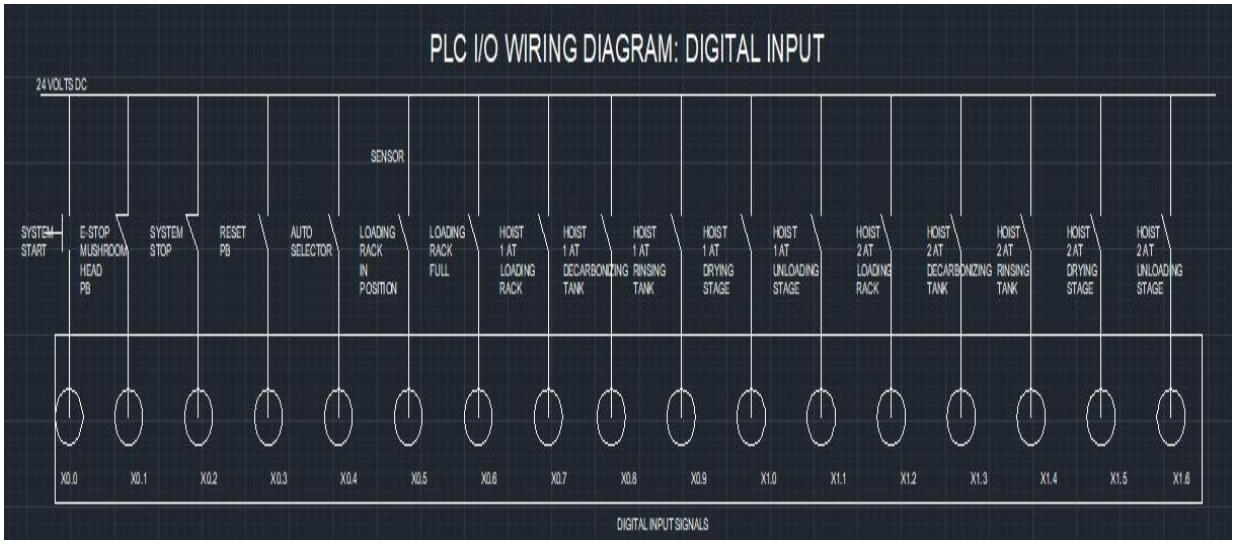


Fig. Plc I/O wiring diagram, digital input

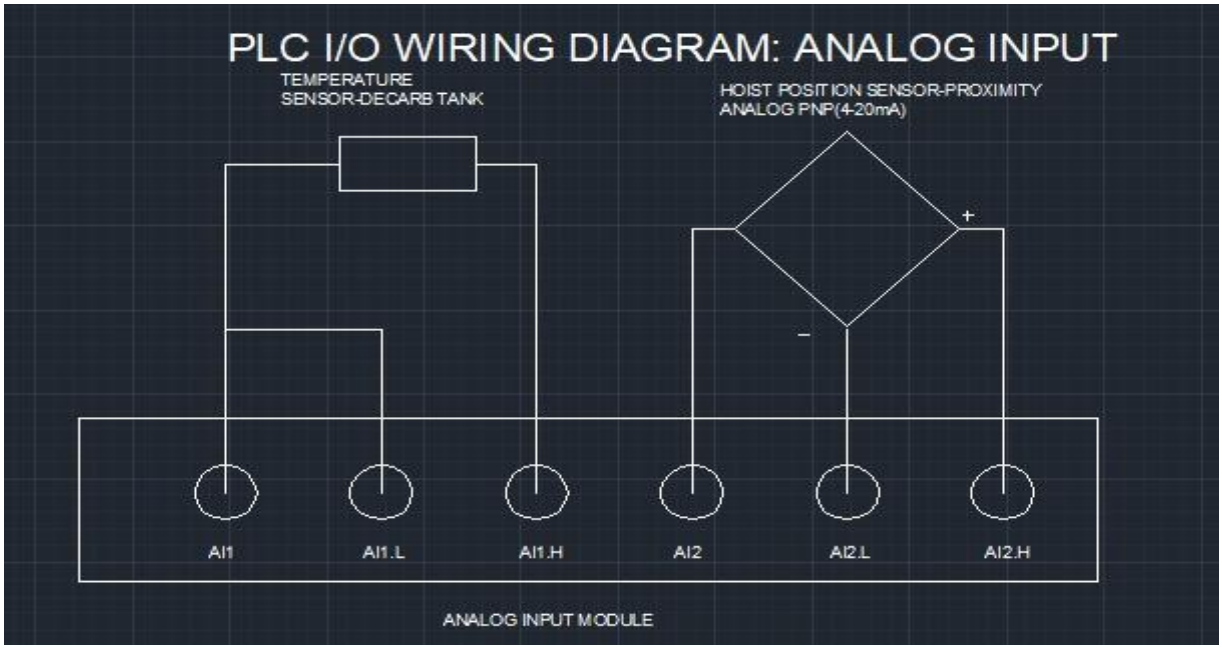


Fig. Plc I/O wiring diagram, analog input

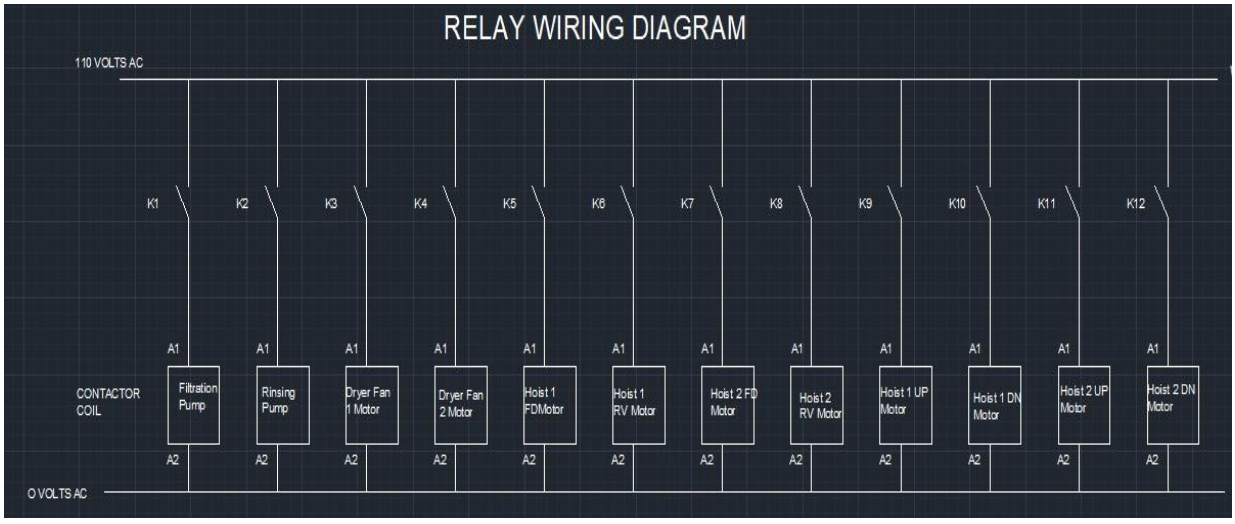


Fig. Relay wiring diagram

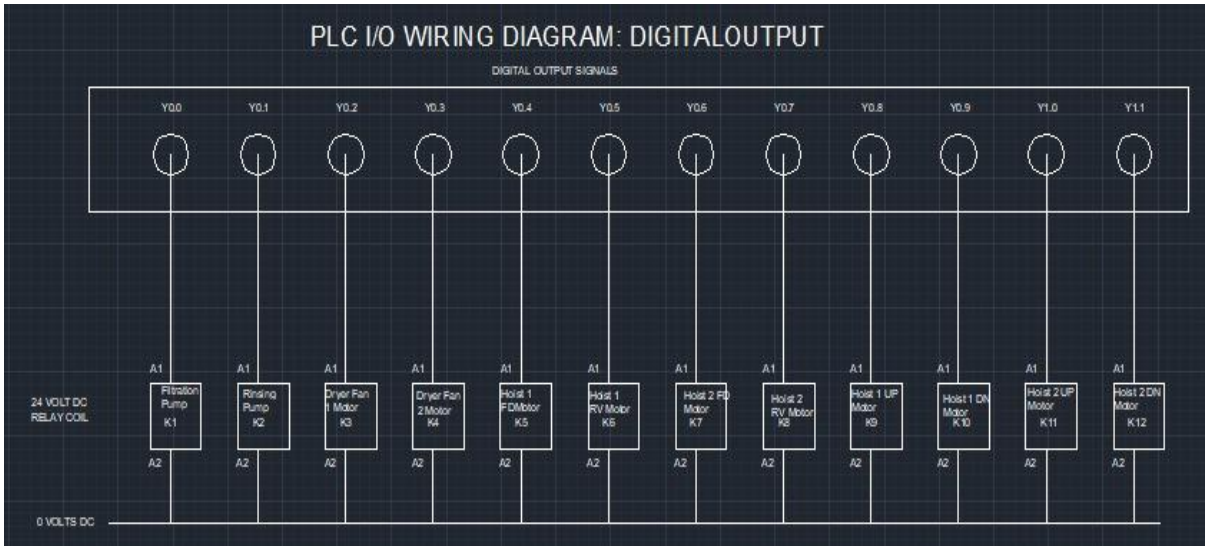
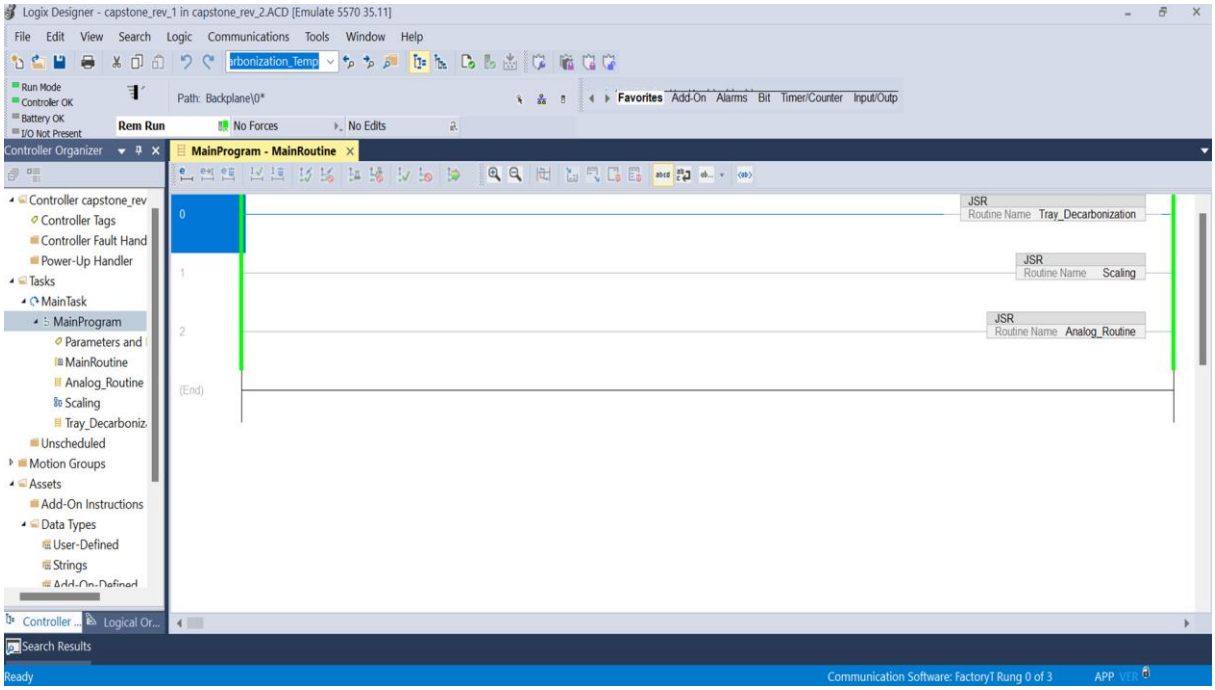
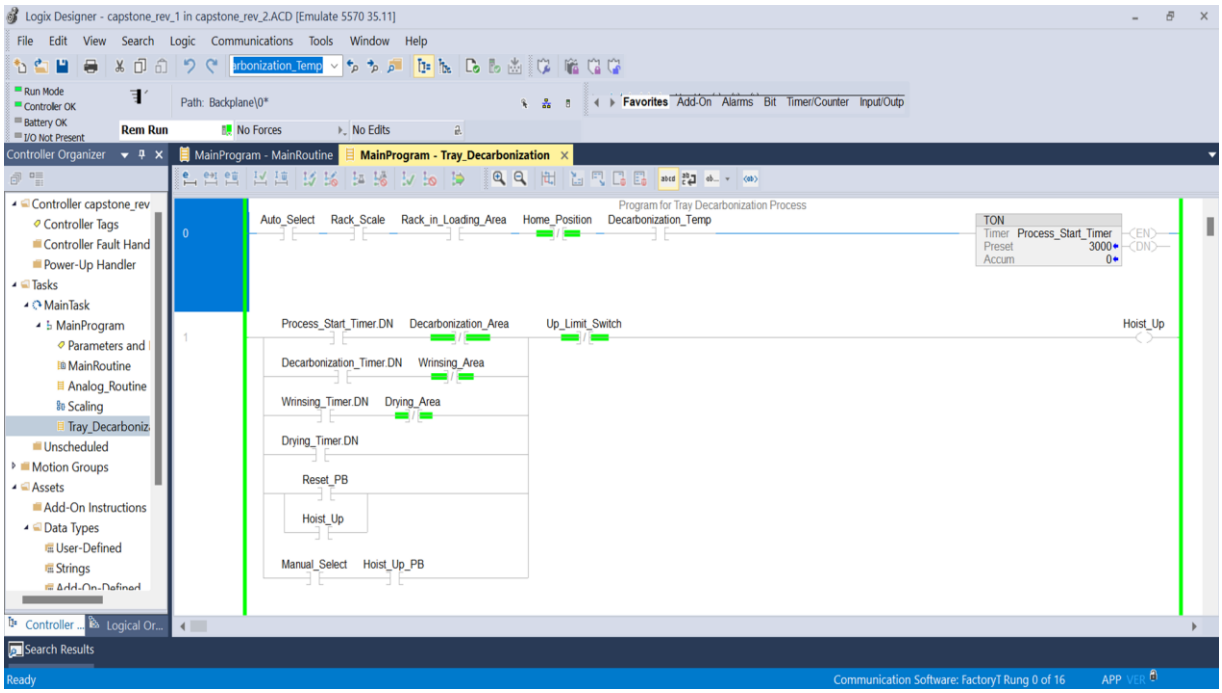
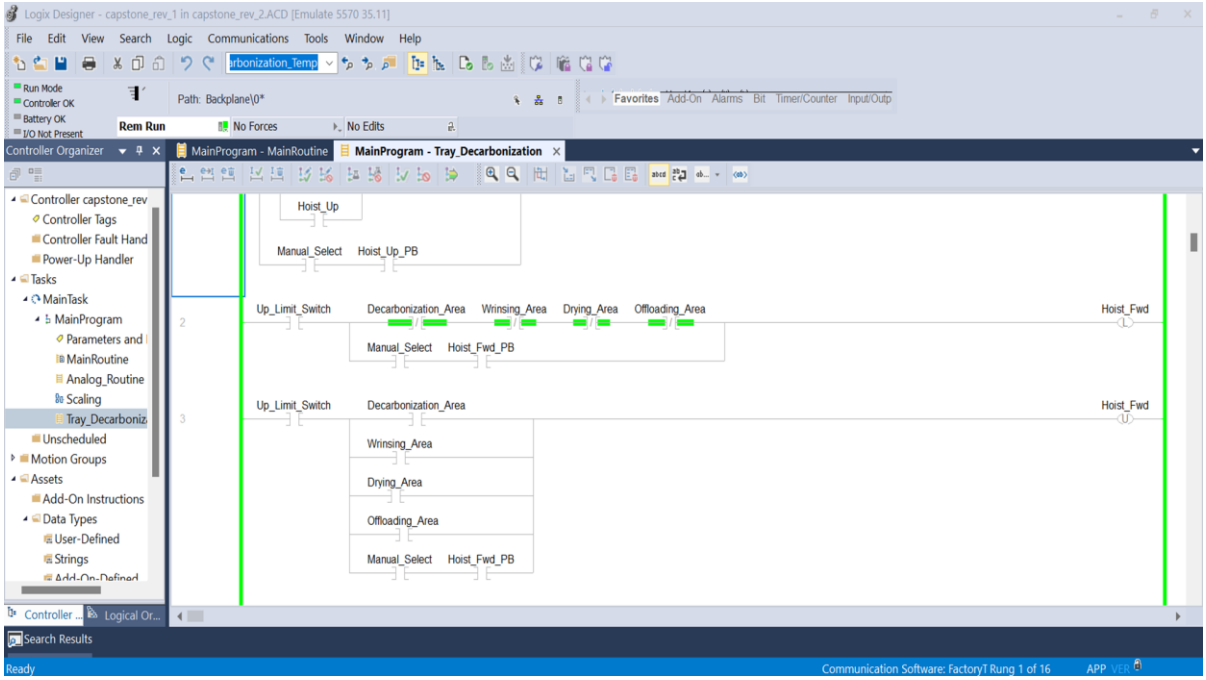


Fig. Plc I/O wiring diagram, digital output

10.0.5 Plc program implementation - Ladder Logic Diagram






Logix Designer - capstone_rev_1 in capstone_rev_2.ACD [Emulate 5570 35.11]
File Edit View Search Logic Communications Tools Window Help
Run Mode
Controler OK
Battery OK
I/O Not Present
Path: Backplane\0*
Rem Run
No Forces
No Edits
Favorites Add-On Alarms Bit Timer/Counter Input/Outp
Controller Organizer
MainProgram - MainRoutine
MainProgram - Tray_Decarbonization
Controller capstone_rev
Controller Tags
Controller Fault Hand
Power-Up Handler
Tasks
MainTask
MainProgram
Parameters and
MainRoutine
Analog_Routine
Scaling
Tray_Decarboniz
Unscheduled
Motion Groups
Assets
Add-On Instructions
Data Types
User-Defined
Strings
Hoist_Up
Manual_Select Hoist_Up_PB
Up_Limit_Switch Decarbonization_Area Wrinsing_Area Drying_Area Offloading_Area Hoist_Fwd
Manual_Select Hoist_Fwd_PB
Up_Limit_Switch Decarbonization_Area Hoist_Fwd
Wrinsing_Area
Drying_Area
Offloading_Area
Manual_Select Hoist_Fwd_PB
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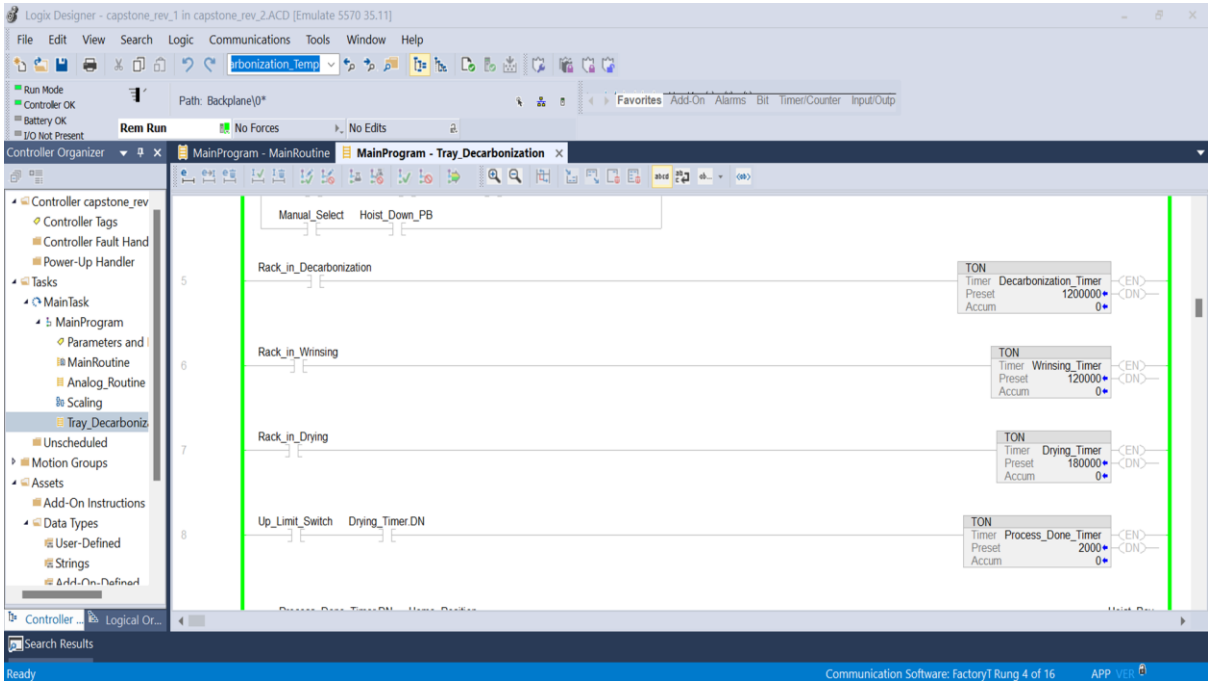
Ready
Communication Software: FactoryT Rung 1 of 16
APP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Rem Run
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No Edits
Favorites Add-On Alarms Bit Timer/Counter Input/Outp
Controller Organizer
MainProgram - MainRoutine
MainProgram - Tray_Decarbonization
Controller capstone_rev
Controller Tags
Controller Fault Hand
Power-Up Handler
Tasks
MainTask
MainProgram
Parameters and
MainRoutine
Analog_Routine
Scaling
Tray_Decarboniz
Unscheduled
Motion Groups
Assets
Add-On Instructions
Data Types
User-Defined
Strings
Manual_Select Hoist_Down_PB
Rack_in_Decarbonization
TON
Timer Decarbonization_Timer
Preset 1200000
Accum 0
Rack_in_Wrinsing
TON
Timer Wrinsing_Timer
Preset 120000
Accum 0
Rack_in_Drying
TON
Timer Drying_Timer
Preset 180000
Accum 0
Up_Limit_Switch Drying_Timer.DN
TON
Timer Process_Done_Timer
Preset 2000
Accum 0
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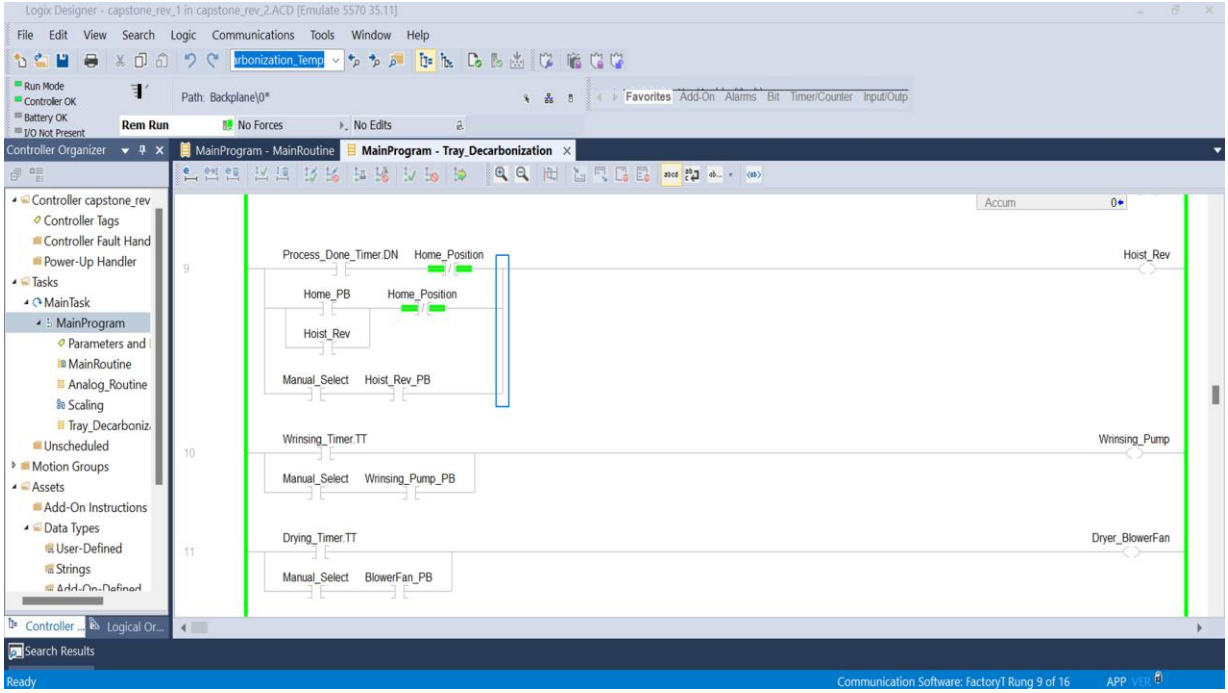
Communication Software: FactoryT Rung 4 of 16
APP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Rem Run
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No Edits
Controller Organizer
MainProgram - MainRoutine
MainProgram - Tray_Decarbonization
Controller capstone_rev
Controller Tags
Controller Fault Hand
Power-Up Handler
Tasks
MainTask
MainProgram
Parameters and
MainRoutine
Analog_Routine
Scaling
Tray_Decarboniz
Unscheduled
Motion Groups
Assets
Add-On Instructions
Data Types
User-Defined
Strings
Accum 0
Process_Done_Timer.DN
Home_Position
Hoist_Rev
Home_PB
Manual_Select
Hoist_Rev_PB
Wrinsing_Timer.TT
Wrinsing_Pump
Wrinsing_Pump_PB
Drying_Timer.TT
Dryer_BlowerFan
BlowerFan_PB
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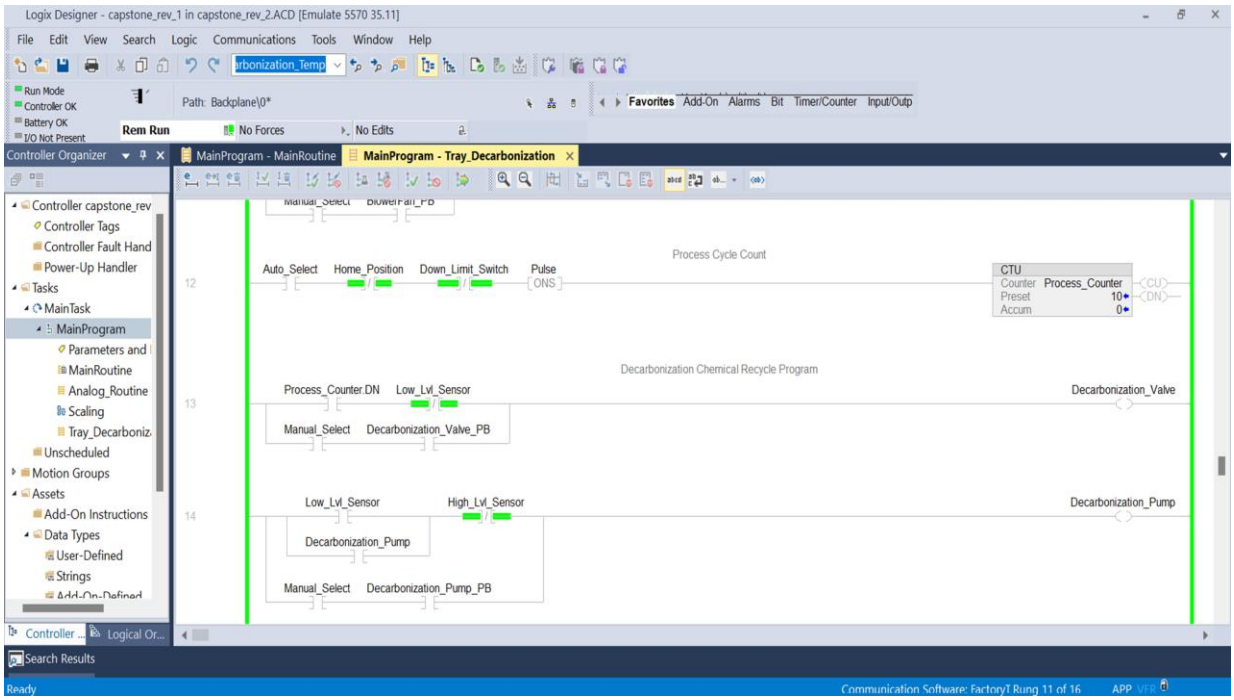
Communication Software: FactoryT Rung 9 of 16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Path: Backplane\0*
Rem Run
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Controller Organizer
MainProgram - MainRoutine
MainProgram - Tray_Decarbonization
Controller capstone_rev
Controller Tags
Controller Fault Hand
Power-Up Handler
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MainTask
MainProgram
Parameters and
MainRoutine
Analog_Routine
Scaling
Tray_Decarboniz
Unscheduled
Motion Groups
Assets
Add-On Instructions
Data Types
User-Defined
Strings
Process Cycle Count
Auto_Select
Home_Position
Down_Limit_Switch
Pulse
ONS
CTU
Counter Process_Counter
Preset 10
Accum 0
Decarbonization Chemical Recycle Program
Process_Counter.DN
Low_Lvl_Sensor
Decarbonization_Valve
Manual_Select
Decarbonization_Valve_PB
High_Lvl_Sensor
Decarbonization_Pump
Decarbonization_Pump_PB
Search Results
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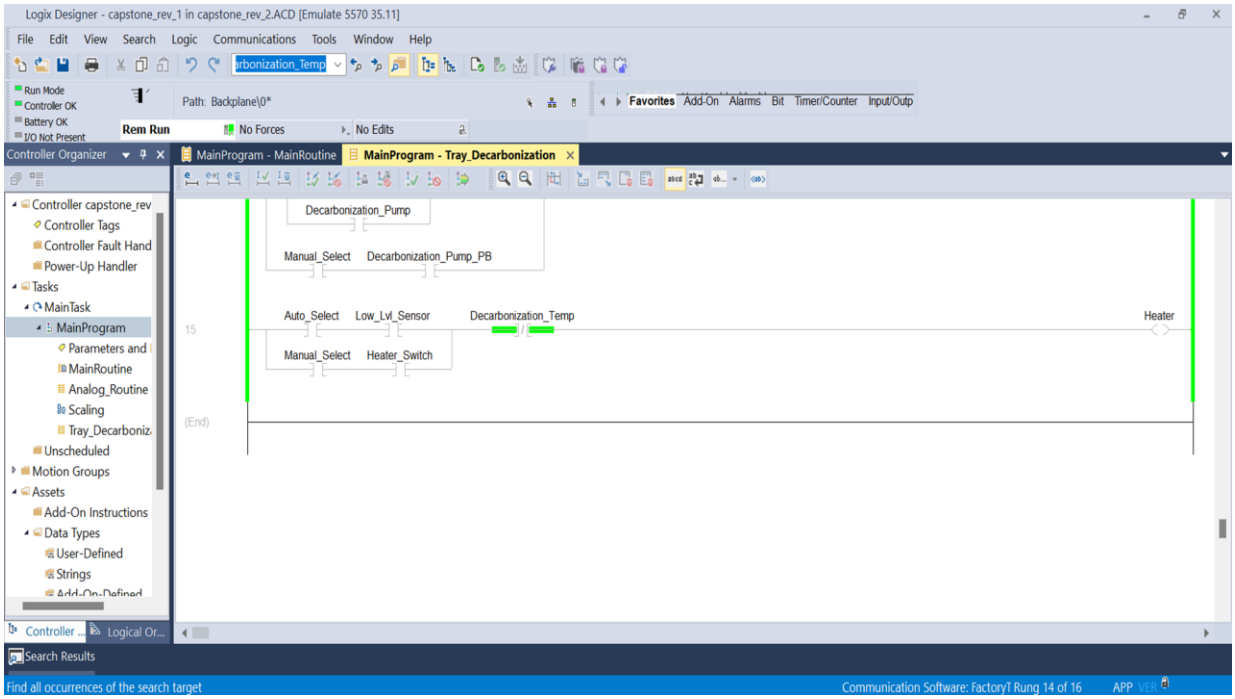
Communication Software: FactoryT Rung 11 of 16


Logix Designer - capstone_rev_1 in capstone_rev_2.ACD [Emulate 5570 35.11]
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Run Mode
Controller OK
Battery OK
I/O Not Present
Rem Run
Path: Backplane\0*
No Forces
No Edits
Favorites Add-On Alarms Bit Timer/Counter Input/Outp
Controller Organizer
MainProgram - MainRoutine
MainProgram - Tray_Decarbonization
Controller capstone_rev
Controller Tags
Controller Fault Hand
Power-Up Handler
Tasks
MainTask
MainProgram
Parameters and
MainRoutine
Analog_Routine
Scaling
Tray_Decarboniz
Unscheduled
Motion Groups
Assets
Add-On Instructions
Data Types
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Decarbonization_Pump_PB
Auto_Select
Low_Lvl_Sensor
Decarbonization_Temp
Heater
Manual_Select
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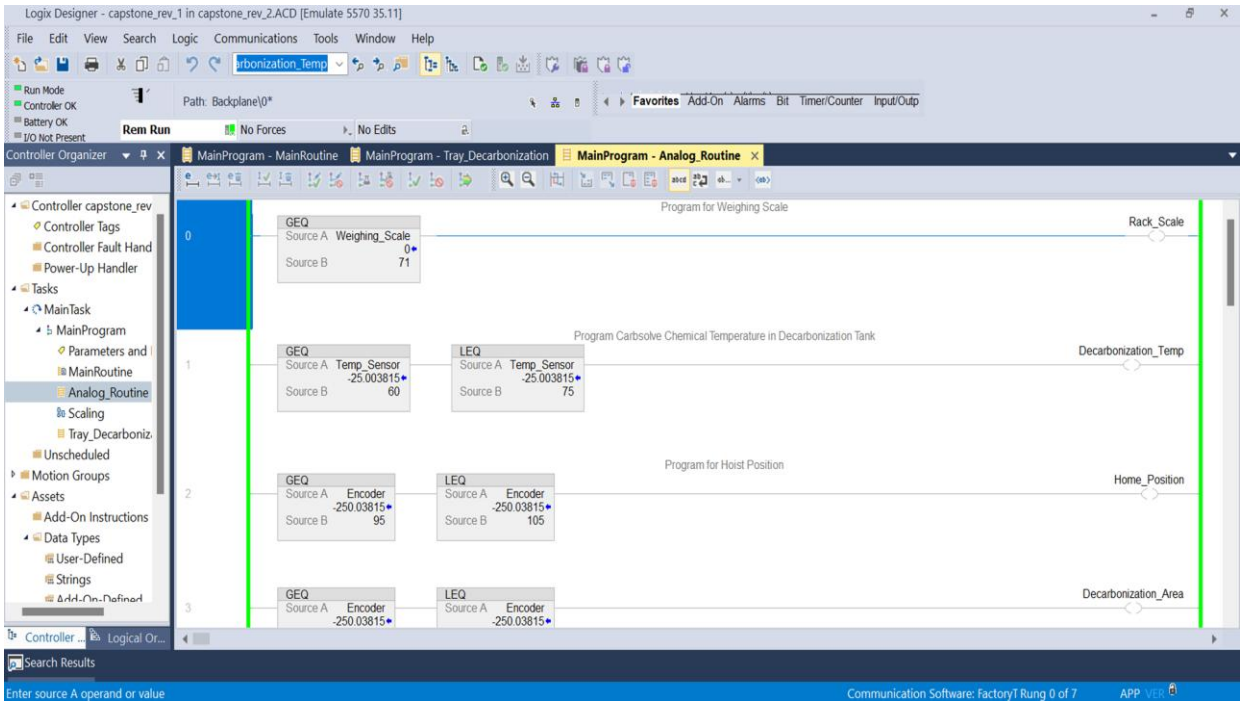
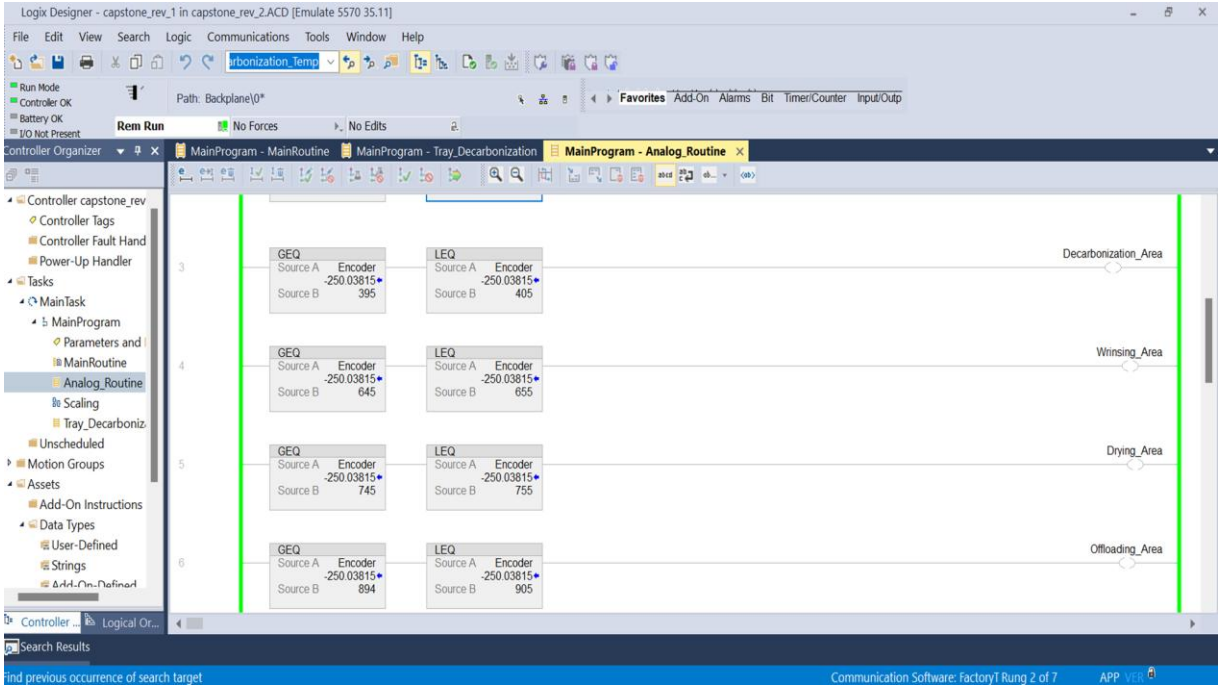
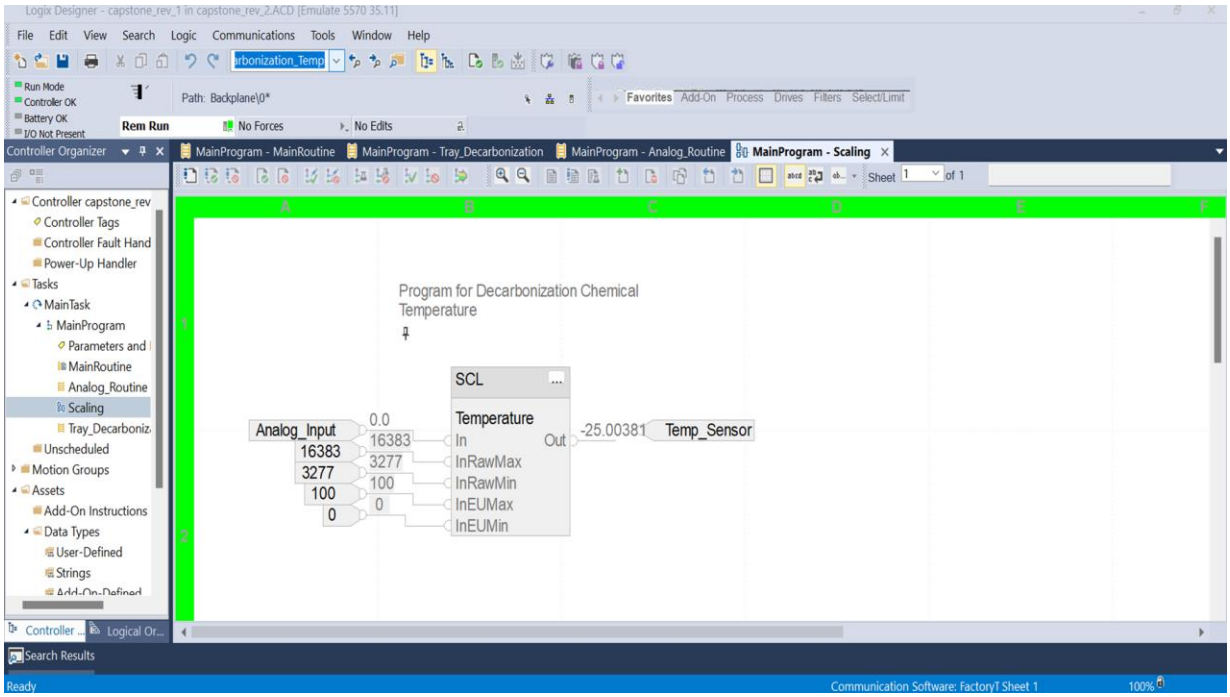
Communication Software: FactoryT Rung 14 of 16


Logix Designer - capstone_rev_1 in capstone_rev_2.ACD [Emulate 5570 35.11]
File Edit View Search Logic Communications Tools Window Help
Run Mode
Controller OK
Battery OK
I/O Not Present
Rem Run
Path: Backplane\0*
No Forces
No Edits
Favorites Add-On Alarms Bit Timer/Counter Input/Outp
Controller Organizer
MainProgram - MainRoutine
MainProgram - Tray_Decarbonization
MainProgram - Analog_Routine
Controller capstone_rev
Controller Tags
Controller Fault Hand
Power-Up Handler
Tasks
MainTask
MainProgram
Parameters and
MainRoutine
Analog_Routine
Scaling
Tray_Decarboniz
Unscheduled
Motion Groups
Assets
Add-On Instructions
Data Types
User-Defined
Strings
Program for Weighing Scale
GEQ
Source A Weighing_Scale
0
Source B 71
Rack_Scale
Program Carbsolve Chemical Temperature in Decarbonization Tank
GEQ
Source A Temp_Sensor
-25.003815
Source B 60
LEQ
Source A Temp_Sensor
-25.003815
Source B 75
Decarbonization_Temp
Program for Hoist Position
GEQ
Source A Encoder
-250.03815
Source B 95
LEQ
Source A Encoder
-250.03815
Source B 105
Home_Position
GEQ
Source A Encoder
-250.03815
LEQ
Source A Encoder
-250.03815
Decarbonization_Area
Search Results
Enter source A operand or value
Communication Software: FactoryT Rung 0 of 7


Logix Designer - capstone_rev_1 in capstone_rev_2.ACD [Emulate 5570 35.11]
MainProgram - MainRoutine
MainProgram - Tray_Decarbonization
MainProgram - Analog_Routine
GEQ Source A Encoder -250.03815 Source B 395
LEQ Source A Encoder -250.03815 Source B 405
Decarbonization_Area
GEQ Source A Encoder -250.03815 Source B 645
LEQ Source A Encoder -250.03815 Source B 655
Wrinsing_Area
GEQ Source A Encoder -250.03815 Source B 745
LEQ Source A Encoder -250.03815 Source B 755
Drying_Area
GEQ Source A Encoder -250.03815 Source B 894
LEQ Source A Encoder -250.03815 Source B 905
Offloading_Area


MainProgram - Scaling
Program for Decarbonization Chemical Temperature
SCL
Analog_Input
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3277
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0
0.0
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Temperature
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InRawMax
InRawMin
InEUMax
InEUMin
Out
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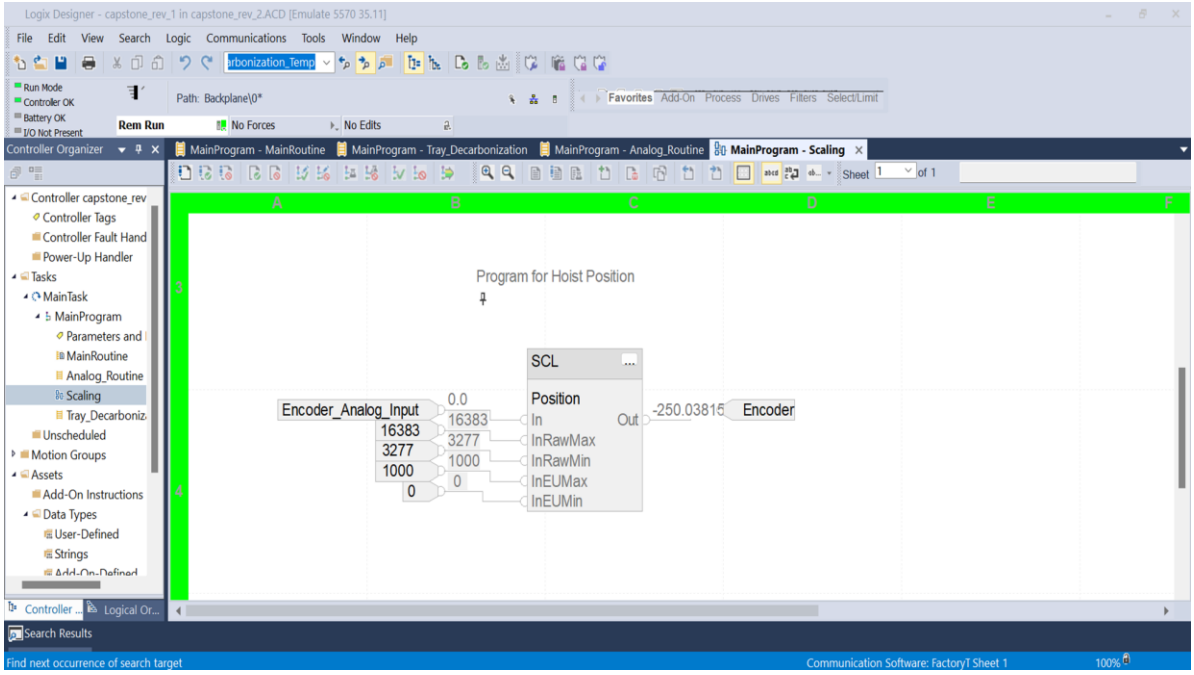
Temp_Sensor



Why use a PLC at all? And why use Ladder Logic?

i) What is a PLC (Programmable Logic Controller), and Why Use it?

Flexibility and Simple Modifications: The circuit of this motor controller would be constructed in the pre-PLC days using physical relays, timers, and hard-wired connections. A modification of the logic (e.g., there should be a 10-second delay before starting) would demand rewiring. All you do with a PLC is change the program in your computer and download it.

Reliability and Diagnostics: PLCs have adverse industrial characteristics (vibration, temperature, electrical noise). They are fitted with in-built diagnostics, which enable troubleshooting to be very simple compared to tracking thousands of wires.

A single PLC is Cost-Effective. When dealing with complicated control systems, a single PLC is much less expensive and occupies less space than all the relays, timers, and counters in a cabinet.

Integration and Communication: It is an easy way to communicate Modern PLCs with other industrial network devices, such as Human-Machine interfaces (HMIs), other PLCs, robots, and supervisory systems, which give rise to a single control system.

Centralized Control: A single machine or process may be controlled by a single PLC, and therefore, the system can be less complicated to manage and monitor.

ii) Why Use Ladder Logic?

Intuitive to Electricians: Ladder Logic was developed to mimic the ladder diagrams used to control electrical relay panels. Those diagrams could be read by already trained electricians and technicians, and therefore, they could easily troubleshoot PLC programs without needing the detailed knowledge of the software.

Visual Programming: It is a graphical programming language. With the help of the power flow between the left rail and the right rail, through the different logic conditions, you may see how the power is turned on as the output. This renders the flow of logic very clear.

Commonplace Standard: Ladder Logic (also referred to as LAD) belongs to the list of standard languages in IEC 61131-3, and is commonly provided by nearly all manufacturers of PLCs all over the world. Knowing that it provides you with a skill that can be used on various platforms.

10.0.6 Visualization tool - Factory Talk

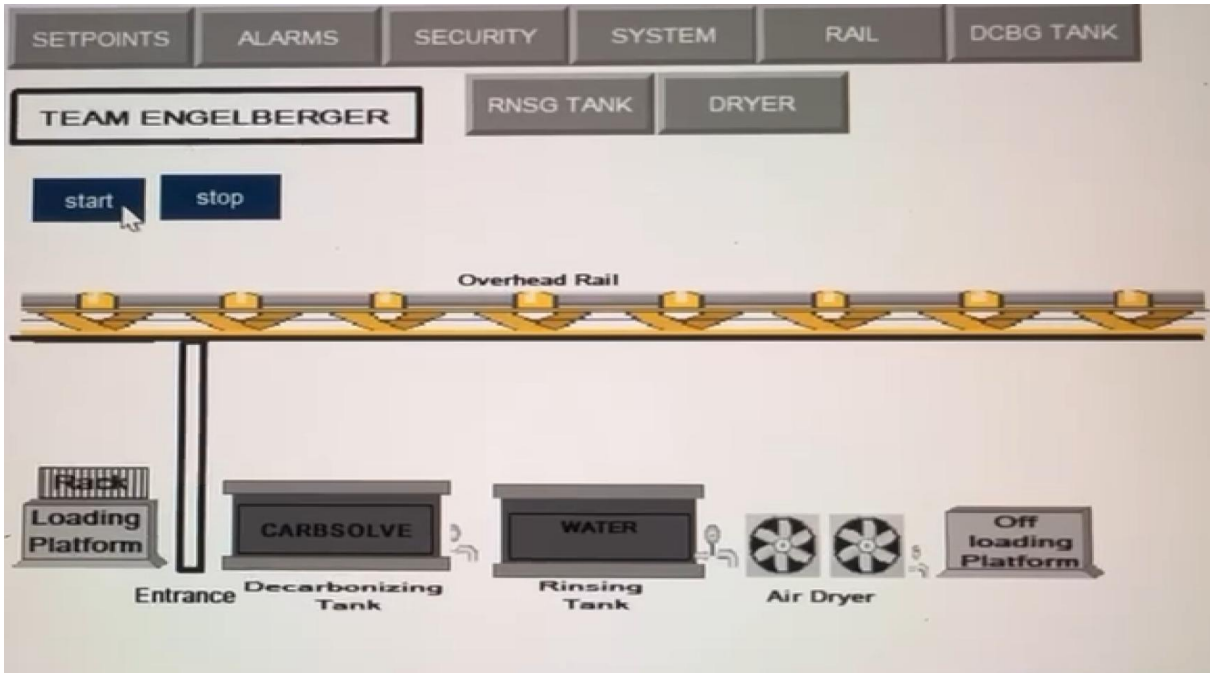


Fig. System Off, Rack at home position (Loading Platform)

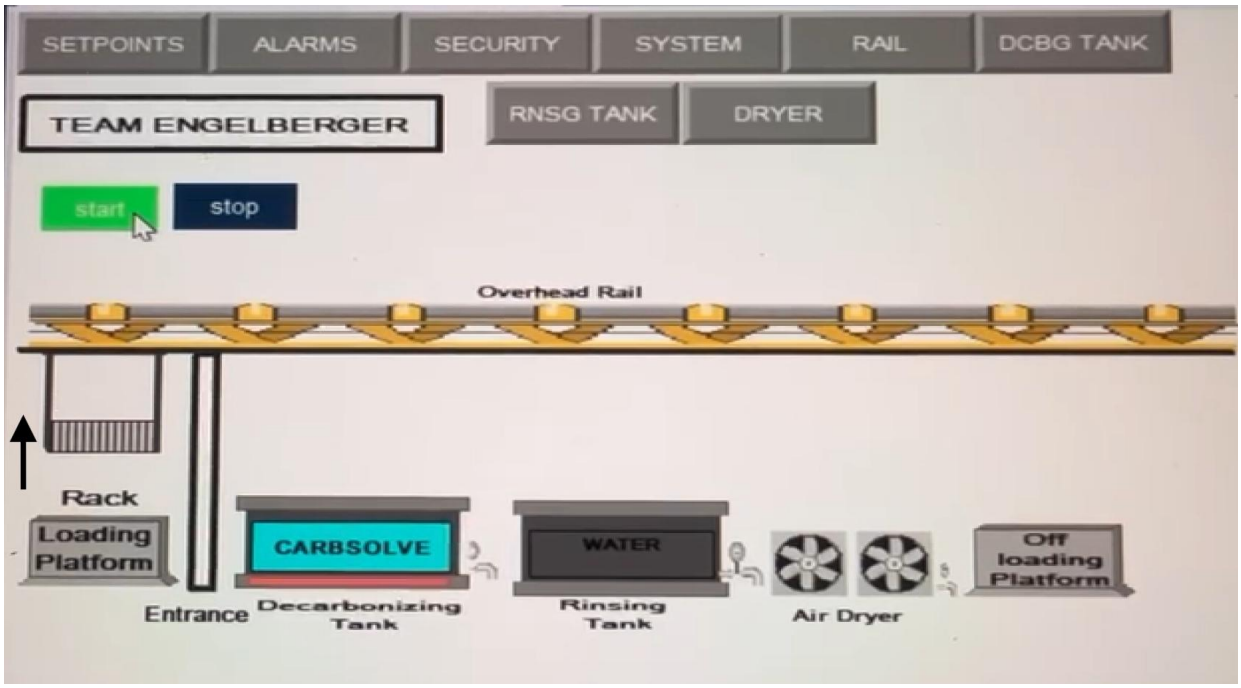


Fig. System Started, Hoist takes full rack with trays up

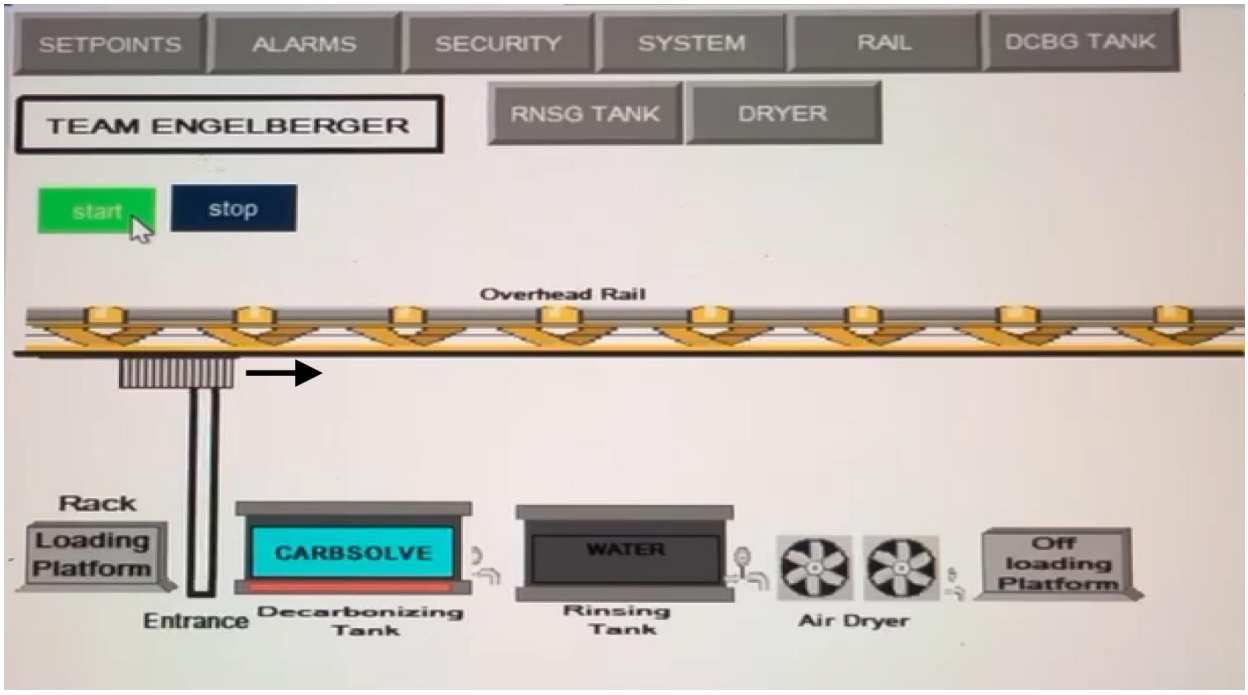


Fig. Hoist takes full rack with trays towards the decarbonization tank area

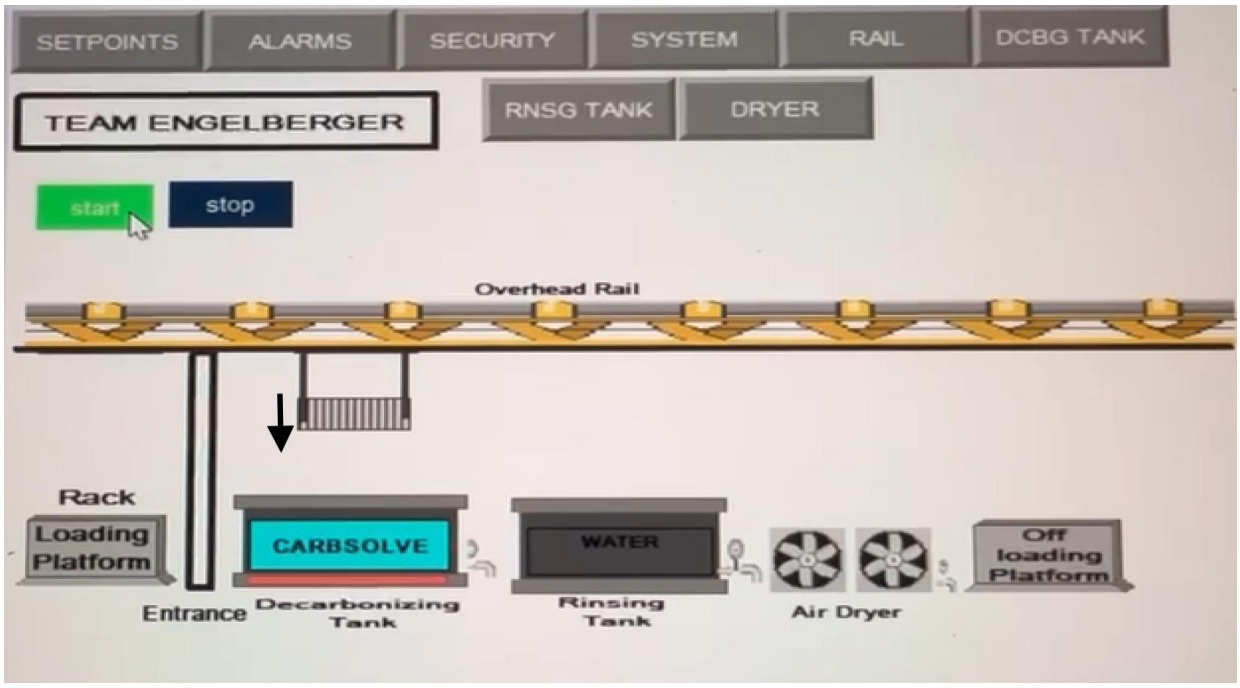


Fig. Hoist moves full rack with trays into the decarbonization tank

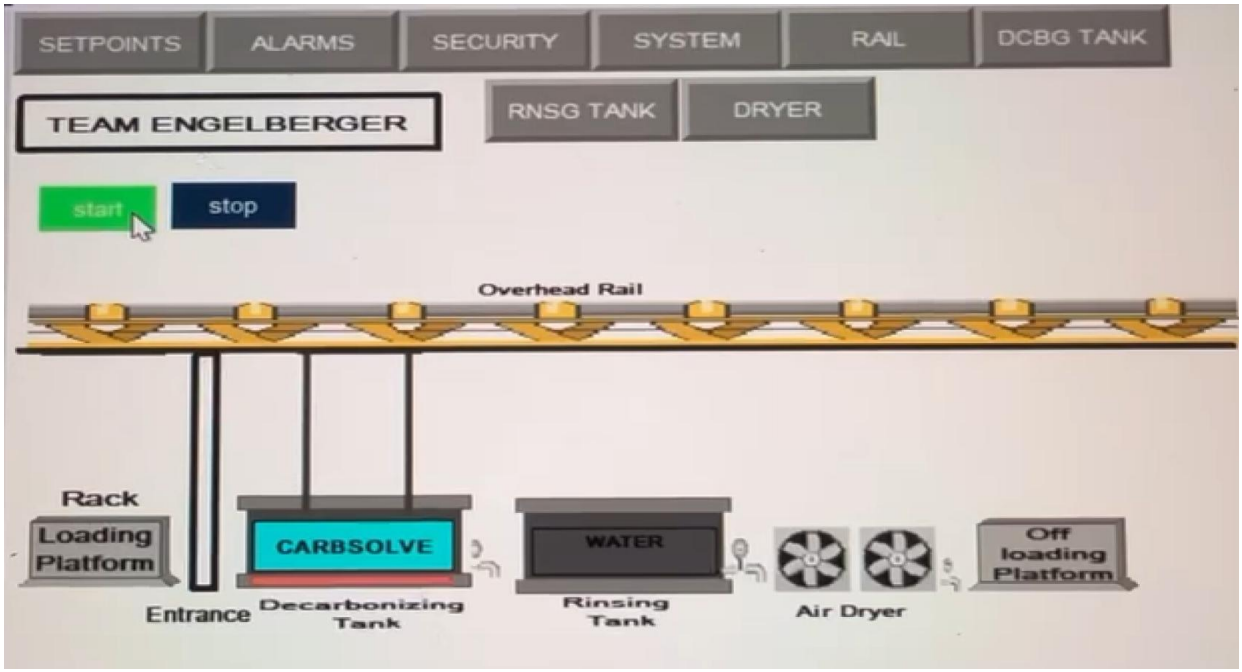


Fig. Trays soak in the decarbonization tank

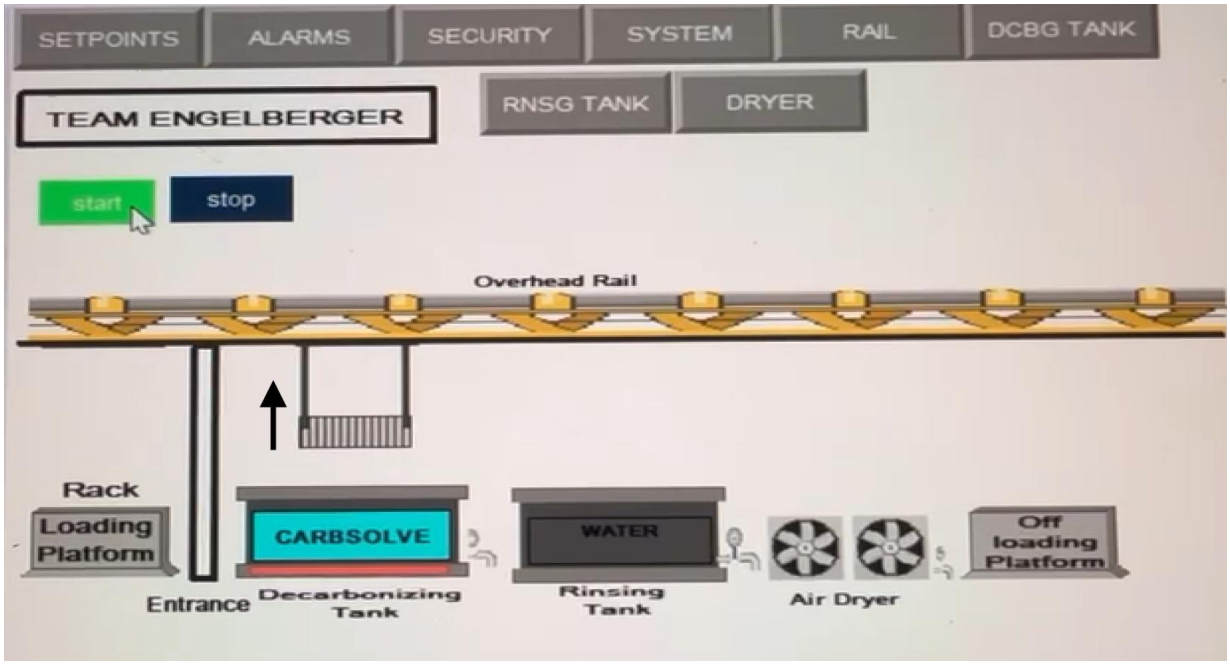


Fig. After decarbonization, hoist takes full rack with trays out of the decarbonization tank

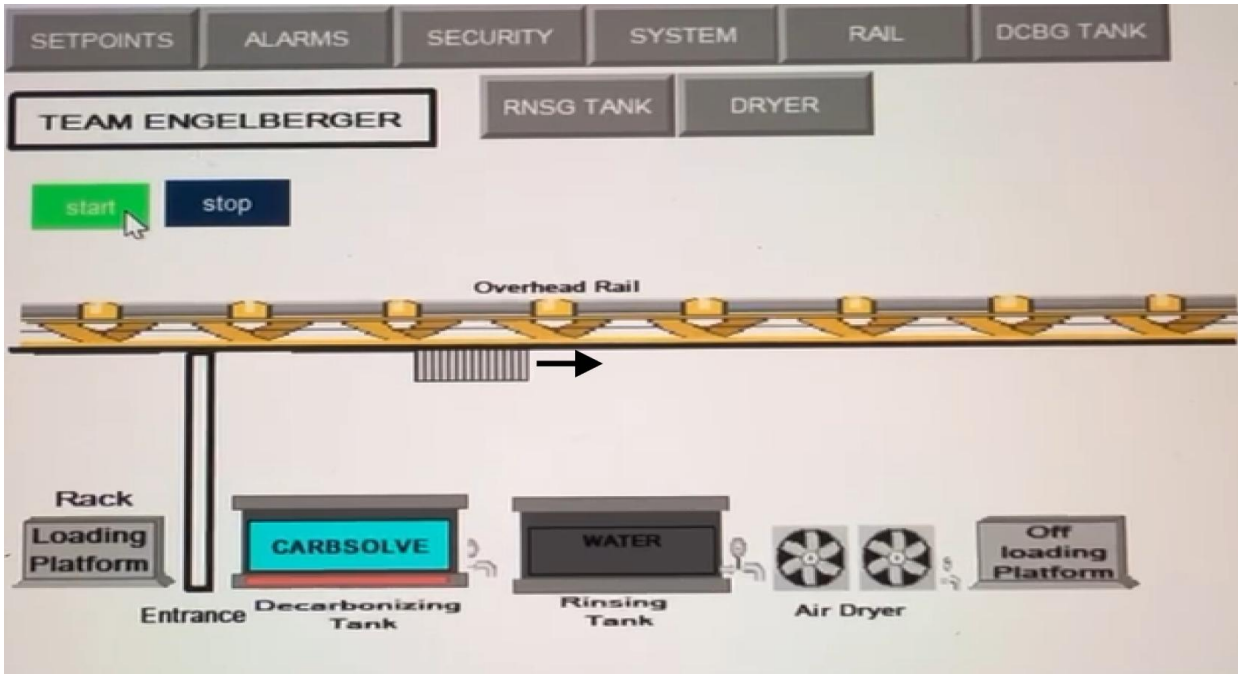


Fig. Hoist takes full rack with trays towards the rinsing area

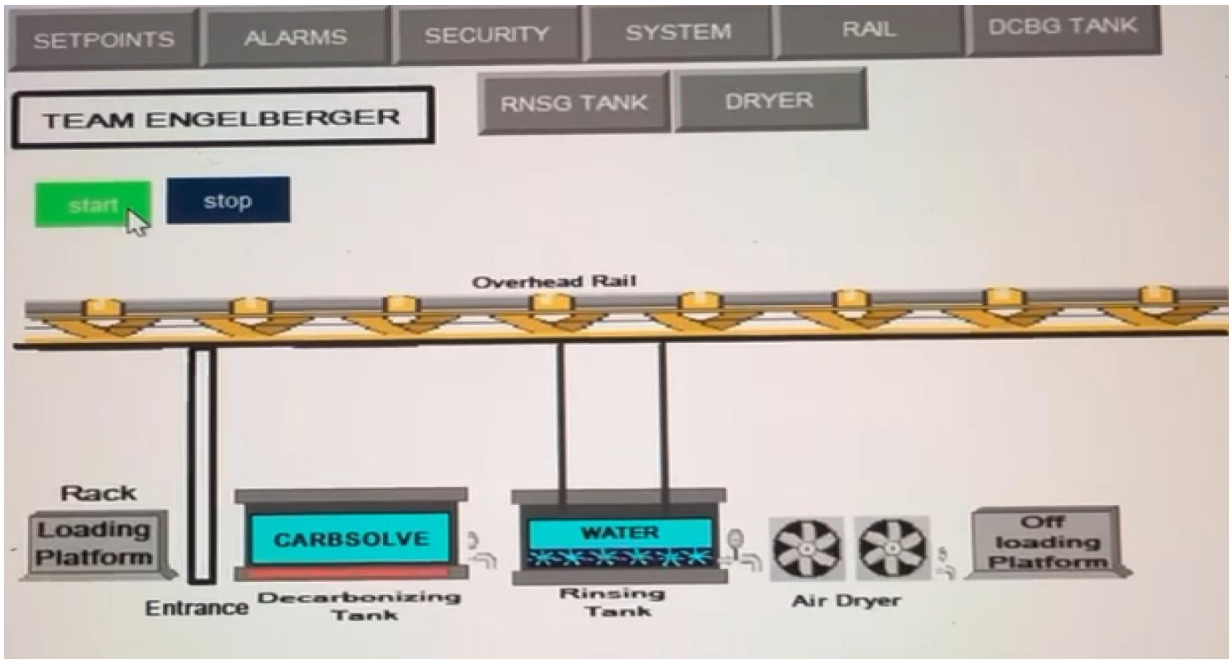


Fig. Hoist takes full rack with trays into the rinsing tank

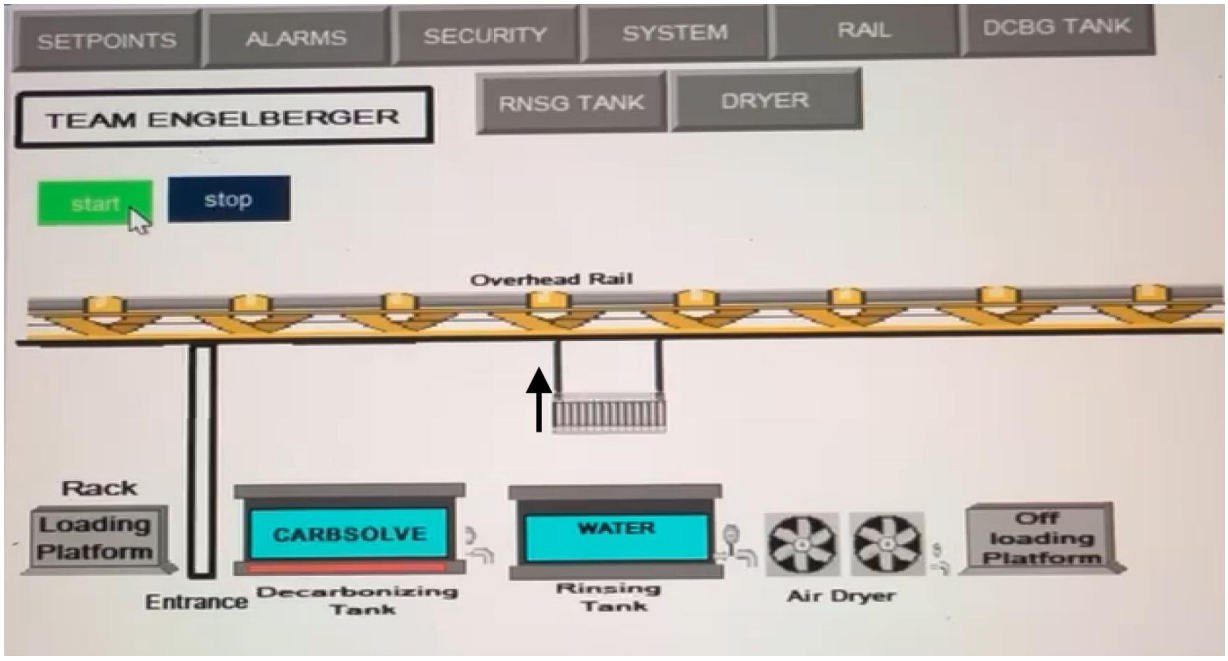


Fig. After rinsing, hoist takes full rack with trays out of the rinsing tank

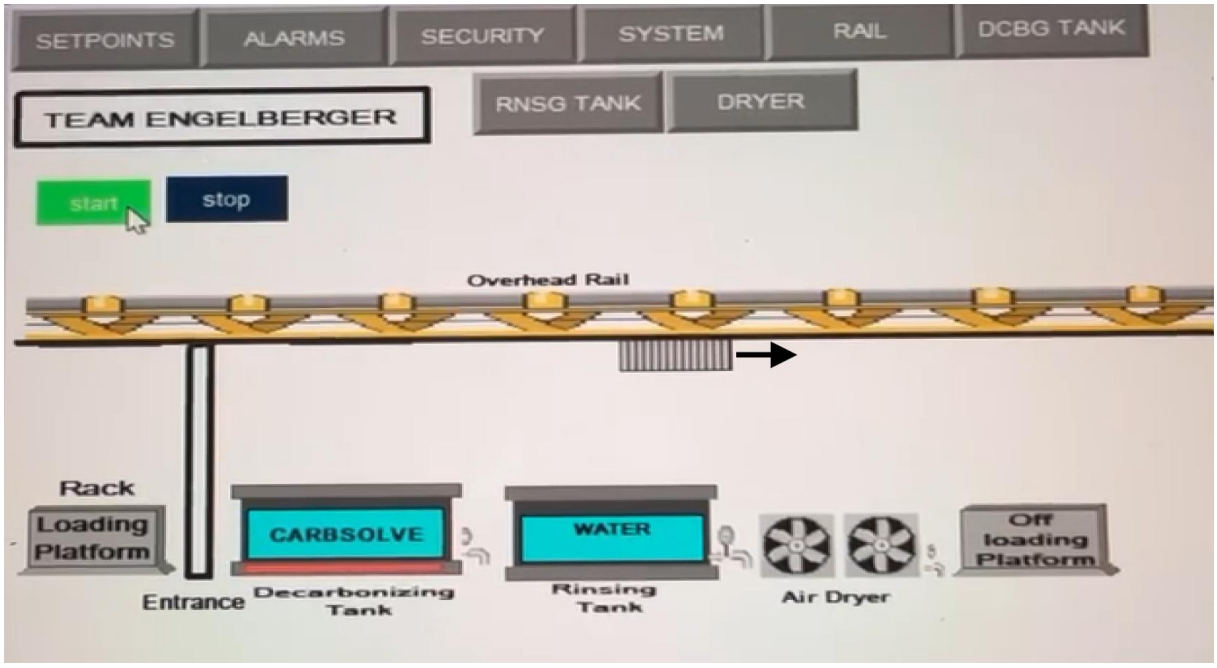


Fig. Hoist takes full rack with trays towards the drying area

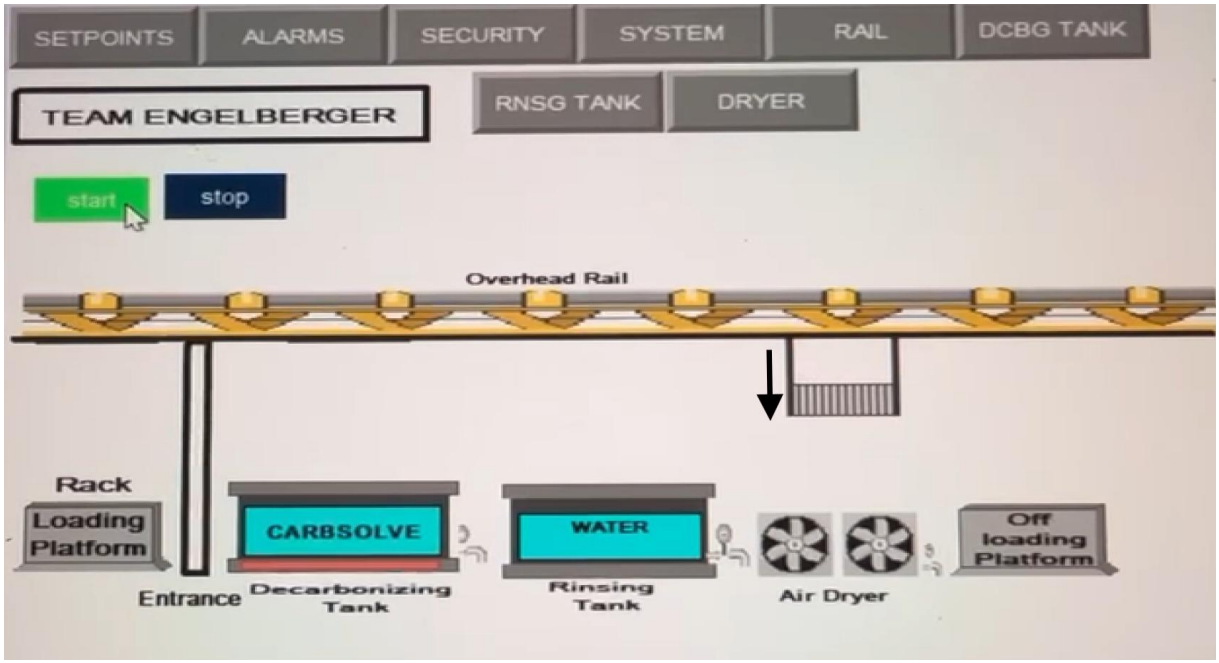


Fig. Hoist takes full rack with trays downwards onto the air dryer

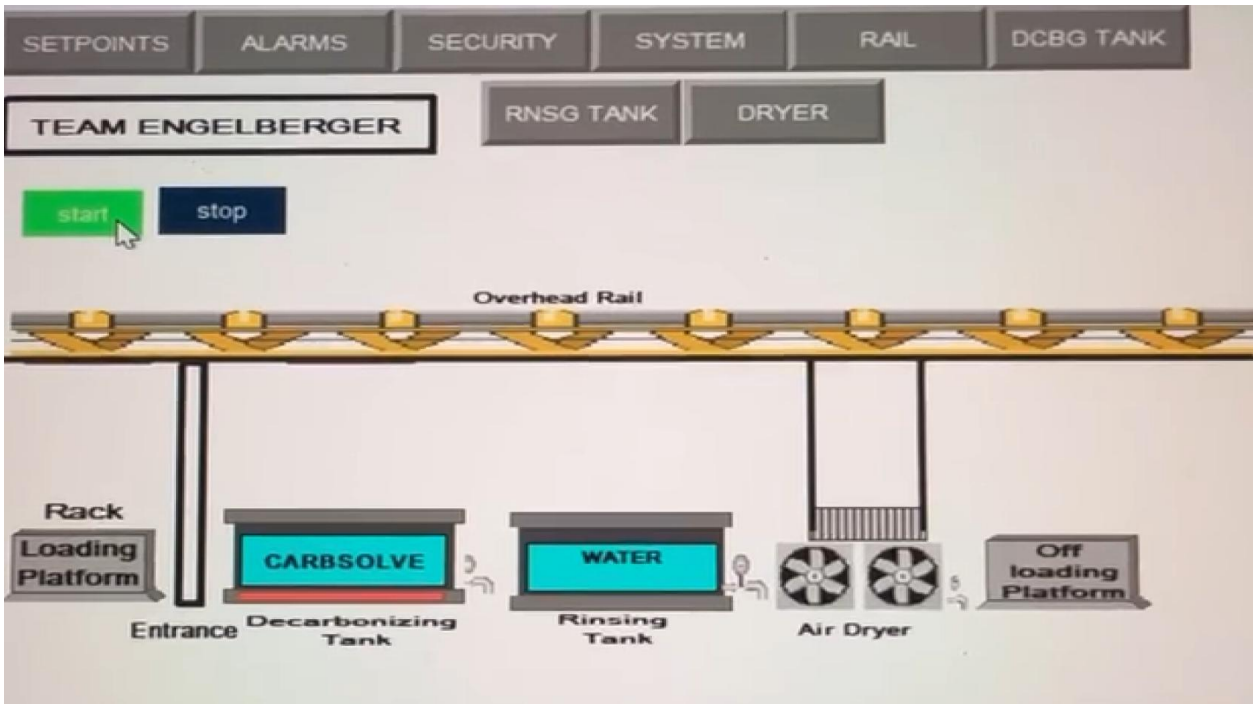


Fig. Dryer dries trays

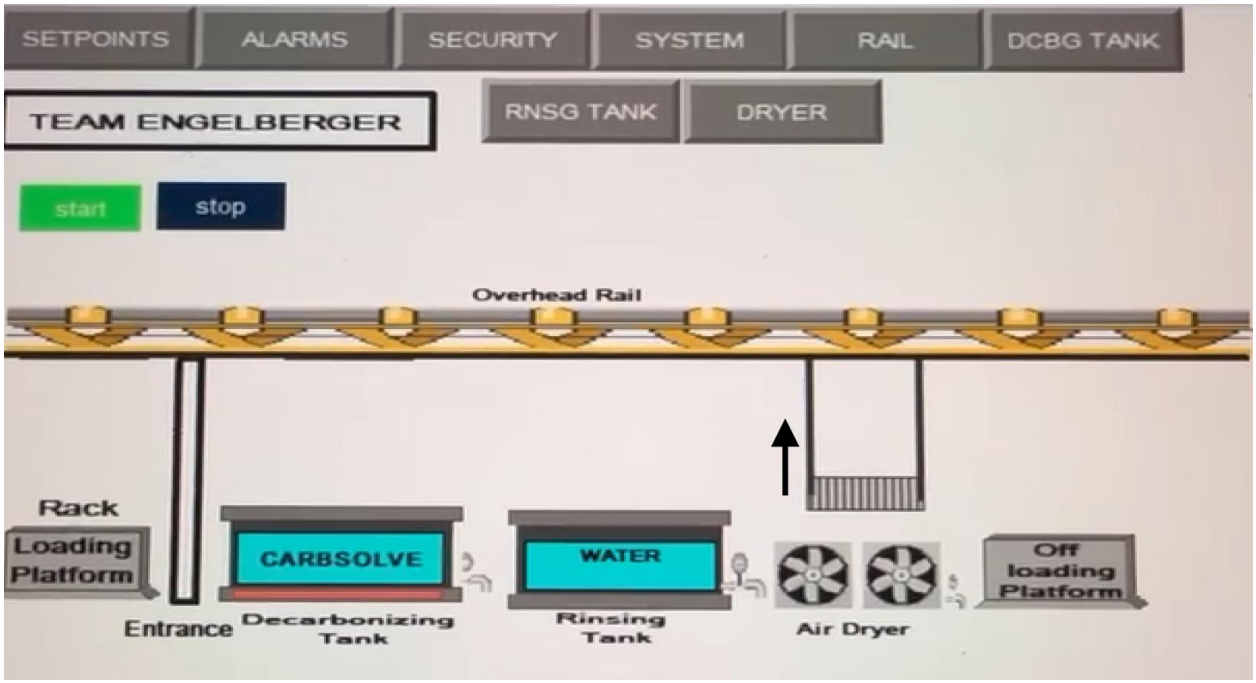


Fig. Hoist takes full rack with dry trays away from the dryer

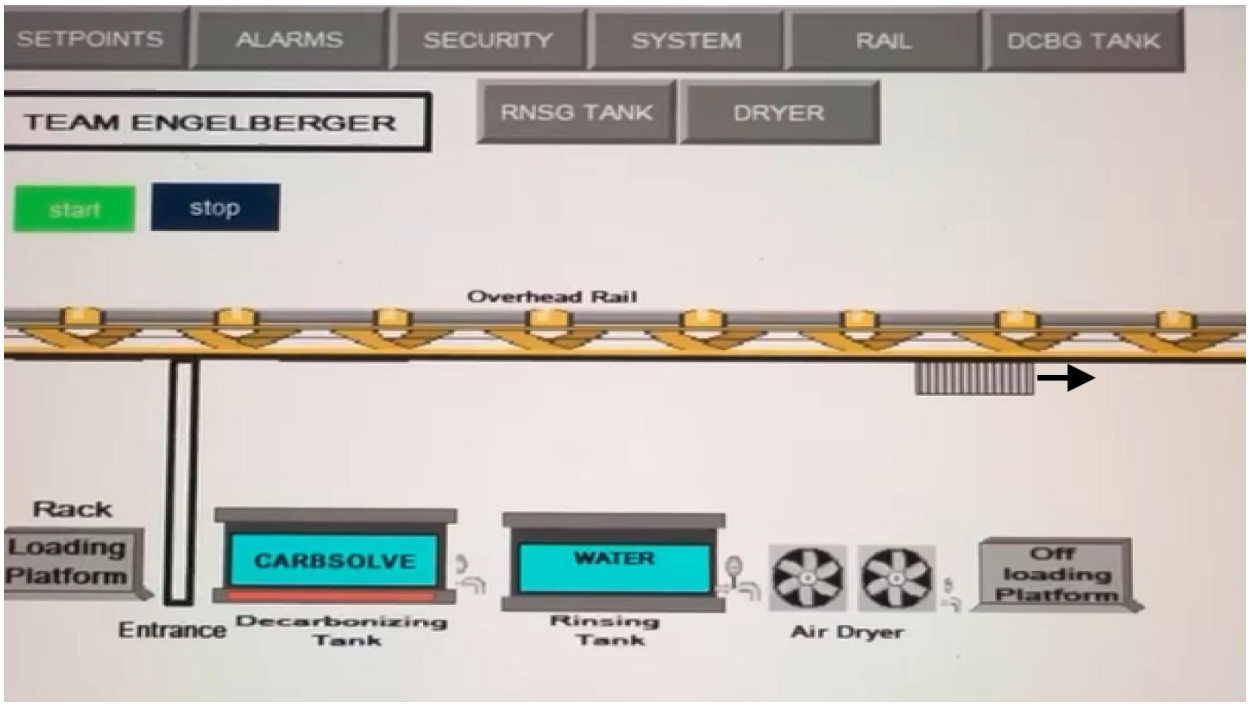


Fig. Hoist takes full rack with dry trays towards the offloading area

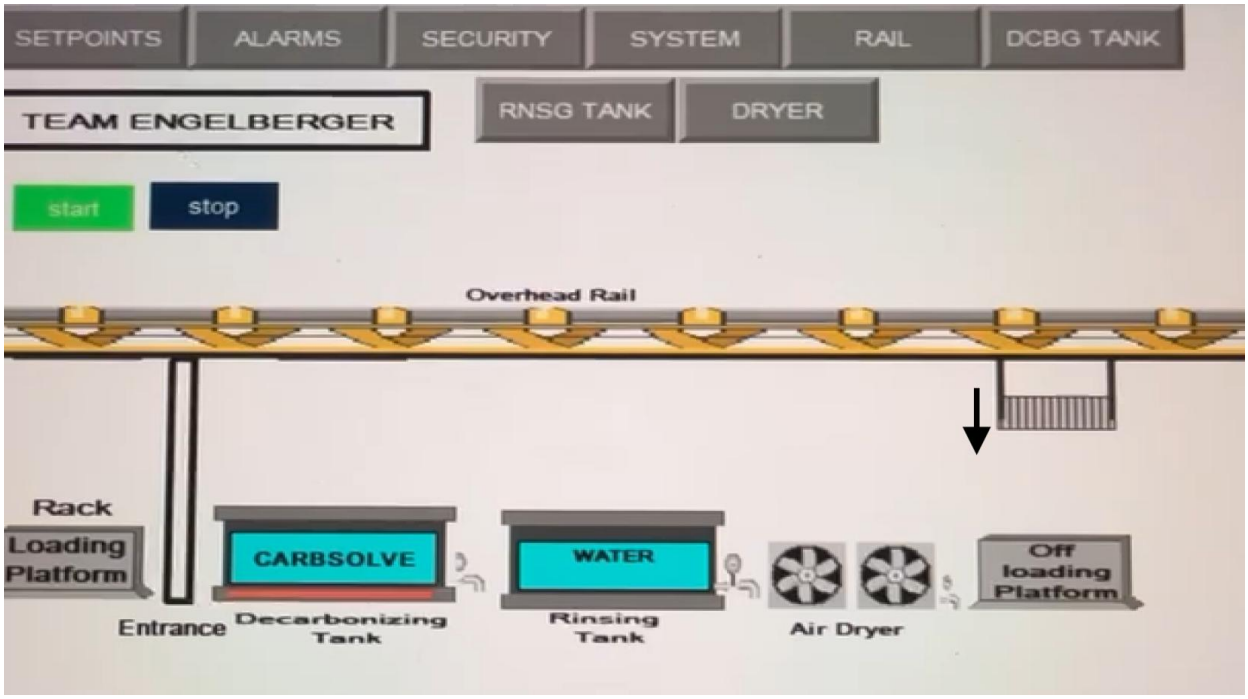


Fig. Hoist places full rack with dry trays on the offloading platform

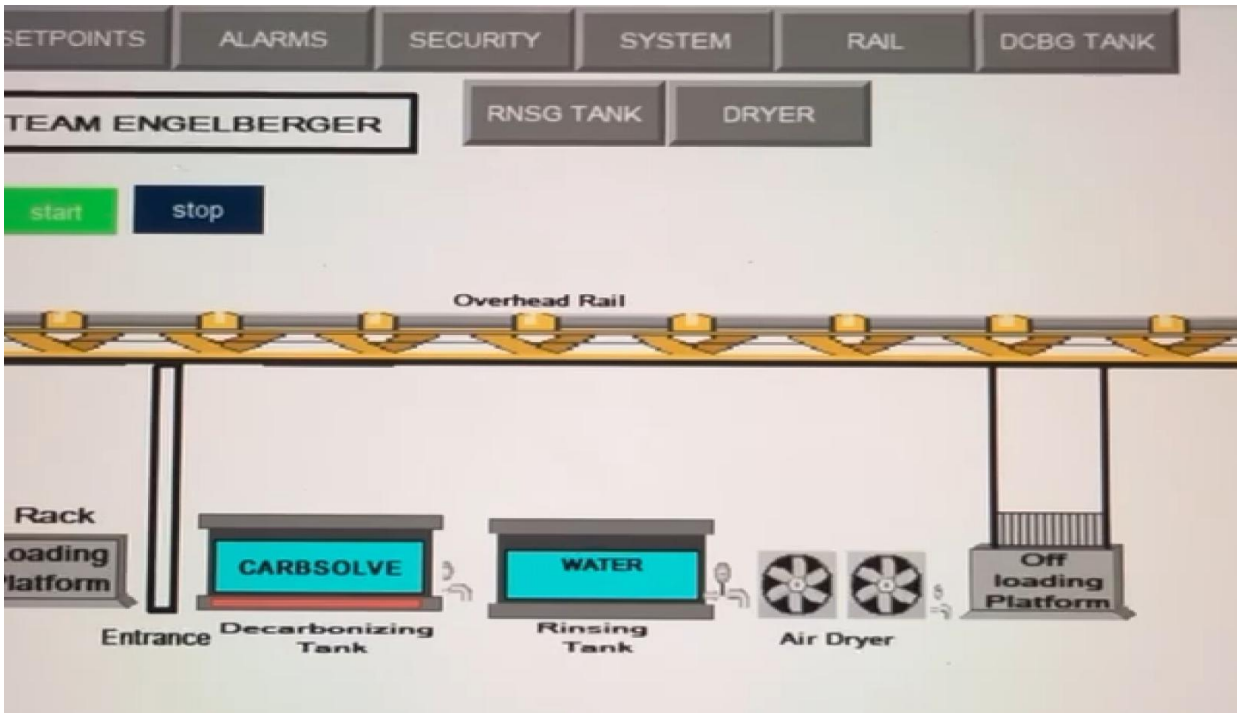


Fig. Full rack with dry trays on the offloading platform to be offloaded

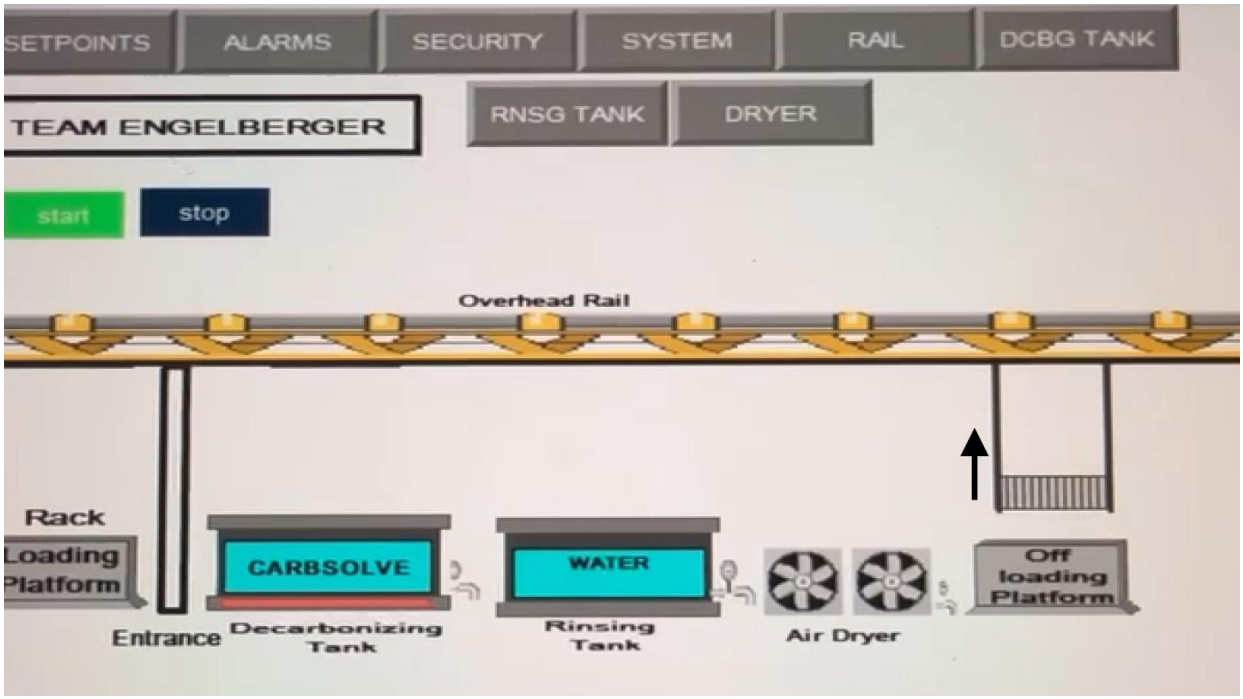


Fig. After offloading, hoist takes empty rack away from the offloading platform

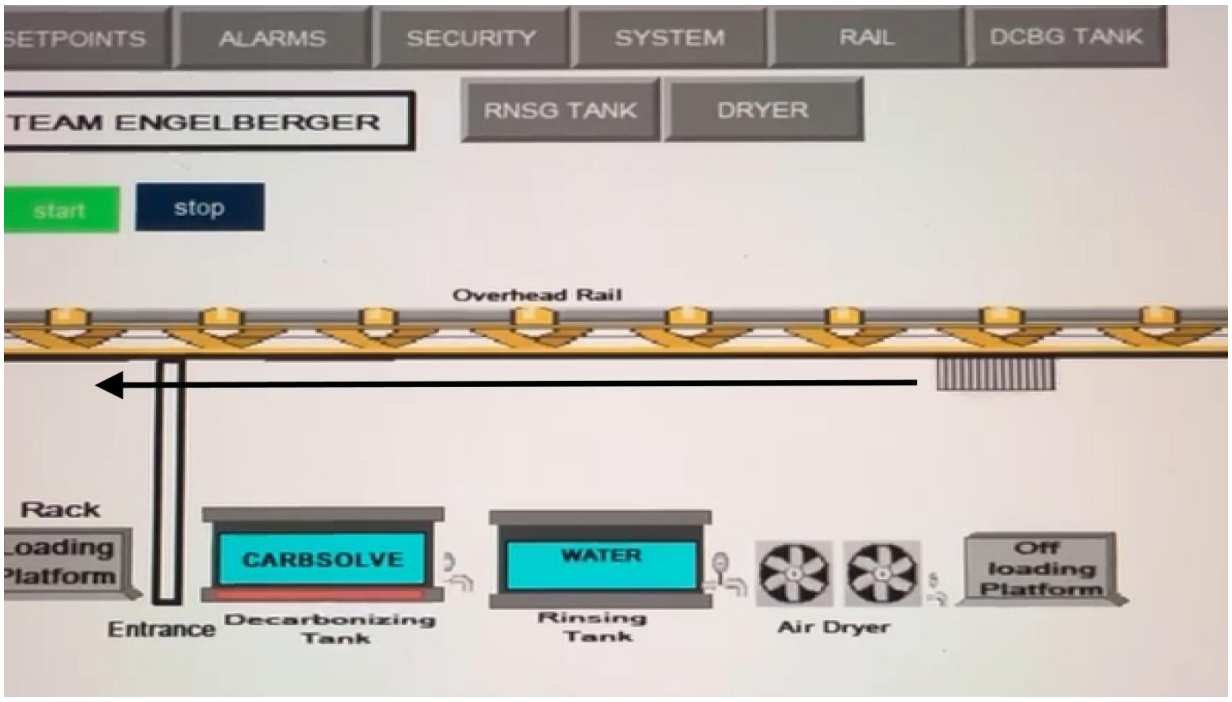


Fig. Hoist takes empty rack back to the loading area

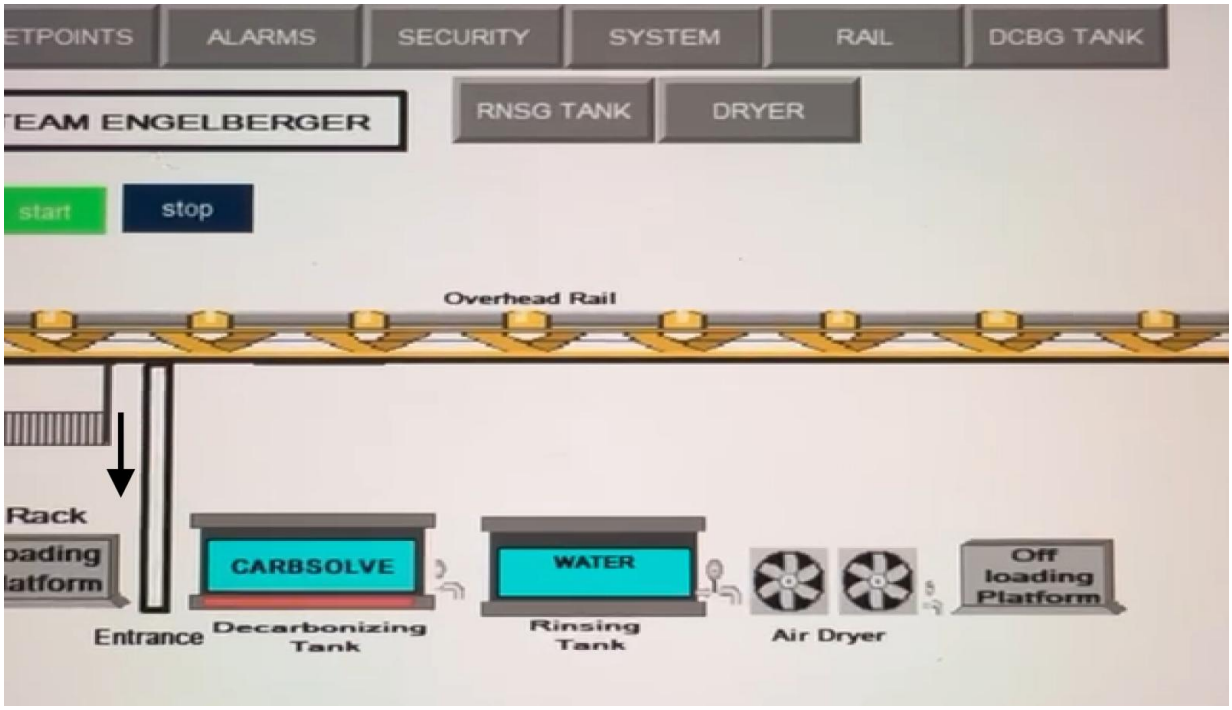


Fig. Hoist places empty rack on the loading platform to be filled with dirty trays again to restart the cycle.

The name of the brand is Rockwell Automation.

One of their main software suites used in integrating and controlling industrial automation is FactoryTalk and is one of their software suites.

What is FactoryTalk View?

FactoryTalk View is a Human-Machine Interface (HMI) software and Supervisory Control and Data Acquisition (SCADA) software. Simply put, it is the computer package that is employed to develop the graphical displays that enable the operator to monitor and control the industrial equipment via a computer.

Imagine it is the mission control centre of a factory or plant. These screens are used by the operators to monitor the status of a running pump, a full tank, a stopped conveyor, and the operator can give a command to start or to stop a process.

ii)What Is the Reason for Using FactoryTalk View?

The reason why companies implement FactoryTalk View is that it is a fundamental component in the Rockwell Automation ecosystem, a contender in the industrial control domain. The following are the reasons in particular:

The seamless integration with Allen-Bradley PLCs:

This is the biggest reason. Rockwell Automation is the manufacturer of the software (FactoryTalk) as well as the most widespread hardware controllers (Allen-Bradley PLCs such as ControlLogix and CompactLogix). They are also configured to interact with each other by default, and this saves time on setup, configuration nightmares, and possible communication failures tremendously.

An Integrated Development Environment:

The FactoryTalk Suite encourages a shared tag database. This implies that you can define a process variable (e.g., "Tank 101 Level") one time, and it can be recognised and used by other Rockwell software (such as the PLC programming software, Logix Designer). This automatically removes the time-intensive and error-prone state of re-creating the tags manually in other programs.

Scalability to various Needs:

There are versions of FactoryTalk View to suit several applications:

FactoryTalk Edition (SE): A complete, distributed SCADA system. It is used in large and complex plants that have more than one server, clients, and systems that are in a high availability state.

FactoryTalk View Machine Edition (ME): A small HMI runtime that can be used on one machine or smaller processes. It operates normally on Panel View Plus terminals. It is cheaper where standalone equipment is required.

Potent Visualization and Data Management:

It enables the development of an elaborate dynamic graphics of the factory floor.
It has strong capabilities of data logging (data about processes to files and databases) and alarming (indicating the operator about faults or abnormal conditions), which is essential in ensuring quality and in troubleshooting problems.

Strong Security Features:

It ensures that only operators can see specific screens or are allowed to make important commands that make the process secure against inappropriate access.

10.0.7 Bill of Materials

Table 1. Bill of Mechanical Components

Item Description	Specification / Details	Qty	UOM	Estimated Unit Cost (CAD)	Total Cost (CAD)	Picture	Item Link
Rinsing Tank	8 ft x 4 ft x 4 ft, SS304, Open Tank	1	Piece	6,999	6,999		Calculated fabricated rate
Float Valve for Decarbonizing Tank	WATER ANGLE VALVE BODY, FLOAT VALVE BODY, HORIZONTAL PIPING, BRASS, MNPT1/4"	1	Piece	59.30	59		BOB FLOAT VALVE, FOR WATER ANGLE VALVE BODY, FLOAT VALVE BODY, HORIZONTAL PIPING, BRASS, MNPT - 4926 - WWG48RJ91 | R400-3/4 - Grainger, Canada
Hoist and Crane Set	Horizontal 48 feet span , 8 feet lifting height, 1 ton Hoist with monorail drive system	1	Set	8,999	8,999		Monorails | Versatile & High-Capacity Material Handling | Gorbel
Drain Valve	1/2"	3	Piece	37	112		https://a.co/d/7Yj4jlU
Chemical Filtration Unit	filters and accessories	1		58	58		https://a.co/d/drnJi7e
S.S Pipe nipple	1/2"*4"	22	Piece	6	124		https://a.co/d/1RoCpFL
S.S Pipe	1/4"*36"	84	Piece	6	475		https://a.co/d/7KOabAK
Rinsing Tank Nozzles	Flat Fan Spray Tip 5PCS 1/2 Inch Male Threaded 65 Degree PP Standard Veejet Yellow Nozzles	42	Piece	4	158		https://a.co/d/i4nEzB6
S.S Tee	1/4" NPT	84	Piece	9	756		https://a.co/d/hNvDWo4
S.S Pipe nipple Tee	1/4"	21	Piece	8	168		https://a.co/d/6m9QDod
Drain Filter for Rinsing Tank	Downspout Cleanout with Leaf Filter STANDARD 2 x 3 or 3 x 4 Gutters	1	Piece	49	49		Downspout Cleanout and Leaf Filter Gutter Leaf Guard
Dryer Duct Lint Trap,90-Degree Indoor Dryer Vent with 4inch 8FT Hose, 2 Clamps, 2 Stainless Steel Mesh,Secondary lint (Metal)	4inch 8FT	1	Piece	43.99	44		https://a.co/d/9pNI1hv
3-1/4x10x24 Duct		1	Piece	214.72	215		https://a.co/d/5xGpKle

Item Description	Specification / Details	Qty	UOM	Estimated Unit Cost (CAD)	Total Cost (CAD)	Picture	Item Link
3 1/4-Inch x 10-Inch to 4-Inch Diameter Galvanized Rectangular to Round Duct Transition Microwave Vent Kit Round Transition Vent Adapter for Connecting HVAC Range Hood Ducting Fittings	1/4-Inch x 10-Inch to 4-Inch Diameter	1	Piece	52.84	53		https://a.co/d/5aFWlZ0
VEVOR Inflatable Blower, 380W&450W, 0.5 & 0.6 HP Bounce House Blower, Pump Commercial Air Blower for Inflatables, Bouncy Castle Electric Air Blower Fan Perfect for Bounce House, Waterslides, Yellow	0.6 Hp, 208V	1	Piece	72.99	73		https://a.co/d/6lNTHzK
Mechanical Components Sum = 18341 CAD							

Table 2. Bill of Electrical Components

Item Description	Specification / Details	Qty	UOM	Estimated Unit Cost (CAD)	Total Cost (CAD)	Picture	Item Link
Speed control pump	Grundfos 3-Speed 115 V 1/25 HP IB Nonsubmersible Circulation Pump	1	Piece	216	216		Grundfos 3-Speed 115 V 1/25 HP IB Nonsubmersible Circulation Pump (Without Flange) 1490100 | RONA
Induction Motors	1 HP / 3 Phase	1	Piece	650	650		

Recirculation pump for filtration		1	Piece	47.28	47		VEVOR Hot Water Recirculating Pump, 10 GPM, Instant Circulation Circulator Pump System, 3-Speed Control, 0.13 HP, 110-120V, NPT 3/4 in to NPT 1/2 in Adapter, Cast Iron Head, for Water Heater System : Amazon.ca: Patio, Lawn & Garden
Electrical Box, IP67 Waterproof Hinged Cover Stainless Steel Latch Junction Box,	ABS Plastic Electrical Enclosure with Mounting Plate,Wall Brackets, Cable Glands,24.8"x20.8"x9.8",Grey	1	Piece	230	230		https://a.co/d/1ELVBRh
5069-L306ER 5380 Controller 5069L306ER PLC Unit	Allen-Bradley CompactLogix	1	Piece	2,200	2,200		https://a.co/d/2dJbUfV
5069-IB16, 5069-IB16K Input Channel	16 inputs, sink, 200 mA		Piece	281	0		https://a.co/d/cJr2KVK
5069-OB16 /B Logix 5000 Series Compact DC Output	16 outputs, sink, 200 mA		Piece	372	0		https://a.co/d/cJr2KVK
5069-IY4 and 5069-IY4K analog input modules	4 Analog inputs, 200 mA		Piece	1,057	0		https://a.co/d/d6jsMka
2711P-T12W21D8S-B PanelView Plus 7 Standard 12 W Terminal	7” Touchscreen	1	Piece	1,000	1,000		2711P-T12W21D8S-B | Allen-Bradley | US
VFD 220V 2.2KW 3hp Variable Frequency Drive CNC VFD Motor Drive Inverter Converter for Spindle Motor Speed Control	For motor speed control	2	Piece	214.56	429		VFD 220V 2.2KW 3hp Variable Frequency Drive CNC VFD Motor Drive Inverter Converter for Spindle Motor Speed Control HUANYANG HY-Series : Amazon.ca: Tools

HUANYANG HY-Series							& Home Improvement
Item Description	**Specification / Details**	**Qty**	**UOM**	**Estimated Unit Cost (CAD)**	**Total Cost (CAD)**	Picture	Item Link
MEAN WELL EDR-120-24 Single Output DIN Rail Power Supply 24V 5 Amp 120W		1	Piece	41.35	41		MEAN WELL EDR-120-24 Single Output DIN Rail Power Supply 24V 5 Amp 120W : Amazon.ca: Electronics
16 Channel Relay Module, DC 5/12/24V 5mA Interface Board High/Low Level Trigger Small-Sized Two-Way Isolated Optocoupler Built-in Finite Current Resistor (DC24V)		1	Set	15.53	16		16 Channel Relay Module, DC 5/12/24V 5mA Interface Board High/Low Level Trigger Small-Sized Two-Way Isolated Optocoupler Built-in Finite Current Resistor (DC24V) : Amazon.ca: Industrial & Scientific
RTD Temperature Sensor, RTD PT100 Temperature Sensor Probe 1/2" NPT Thread Thermocouple Terminal Head,Simple and Easy to Install(200mm/7.9in)	RTD PT100	1	Piece	22.72	23		RTD Temperature Sensor, RTD PT100 Temperature Sensor Probe 1/2" NPT Thread Thermocouple Terminal Head,Simple and Easy to Install(200mm/7.9in) : Amazon.ca: Industrial & Scientific
50W Reed Proximity Switch Sensor	Position & safety sensors	4	Piece	19.65	79		uxcell ME-8111 Plunger Momentary Limit Switch 1NC+1NO 2Pcs for CNC Mill 3D Printer Door Switch : Amazon.ca: Industrial & Scientific
LAY37-11ZS Elevator Emergency Stop Mushroom Head Button (Red)		2	Piece	8.995	18		https://a.co/d/fgQYkjp

50W Reed sensor, IP67 rating		5	Piece	9.99	50		https://a.co/d/2h2DUnw
Analog Output Inductive Proximity Sensor, Cylindrical, 0-10V/4-20mA	Cylindrical, 0-10V/4-20mA	1	Piece	173.97	174		Analog Output Inductive Proximity Sensor, Cylindrical, 0-10V/4-20mA | ATO.com
5 KW Heat Strip with breaker		1	Piece	172.34	172		https://a.co/d/3ru8eLp
Power supply Breaker MCCB	Miniature Circuit Breaker - S200 80-100A - 3P - 80 A - C - (AC) 6 kA	1	Piece	92.53	93		https://a.co/d/c4b6ugL
Control Wiring, Cables, Conduits	Power & signal wiring	1 lot		700	700		
Electrical Components Sum = 6115 CAD							

Table 3. Bill of Installation and Commissioning

Item Description	**Specification / Details**	**Qty**	**UOM**	**Estimated Unit Cost (CAD)**	**Total Cost (CAD)**	Item Link
Automation Studio License	Educational	1	set	0	0	
FactoryTalk License	Educational	1	set	0	0	
Fabrication & Installation	Mechanical assembly	80	hrs	40	3,200	Wages in Ontario - Job Bank
Electrical Installation	Wiring, panel setup	40	hrs	40	1,600	Wages in Ontario - Job Bank
Safety Equipment, Accessories	PPE and safety accessories	1	Set	1,200	1,200	
Software, Labor/Installation, Miscellaneous = 6000 CAD						

Table 4. Final Sum of Bills

Item	**Cost (CAD)**
Mechanical Components	18,341
Electrical Components	6,115
Installation and Commissioning	6,000
Total Cost	30,456

10.0.8 Codes and Standards used – reason, no., statement

Table 5. Occupational Health and Safety Legislation Regulations

Reason/Category	Standard/Regulation No.	Statement/Purpose
General Safety Compliance	Occupational Health and Safety Act (OHSA)	The general legislation is a law that outlines the regulations of health and safety in the workplace.
Industrial Equipment Hazard	Reg, 551 (Industrial Establishments)	OSHA has regulations that are used to explain safety needs in industrial environments, such as the facilities of your hotel. The major sections include lifting devices, machine guarding, lockout, as well as emergency stops.
Hazardous Atmospheres	Reg. 551, Sec. 75-79	Particularly regulates the issue of safety in confined spaces and areas that may contain hazardous atmospheres, like the plenoidal tank area.
Chemical Management	Designated Substances Regulation (O. Reg. 60000)	Governs the levels of control and exposure to various dangerous chemicals at the workplace.
Chemical Hazard Communication	WHMIS 2015 (Hazardous Products Act)	Requires labelling, Safety Data Sheets (SDS), and worker education of the hazardous products, including the one used in the chemical decarbonizing tank.

Table 6. Federal Occupational Safety Regulations

Reason/Category	Standard/Regulation No.	Statement/Purpose
Electricity Safety	Canada Occupational Health and Safety Regulations (COHSR), Part VIII	Federal regulations outline particular standards of electrical safety in the workplace.
Code Compliance	COHSR 8.701	The code requires that all electrical equipment be in conformance with the Canadian Electrical Code.
Qualified Personnel	COHSR 8.302	They have a requirement that electrical equipment should be installed and

		maintained by qualified persons.
Safe Work Procedures	COHSR 8.14, 8.17, 8.18	Gives specifications on lockout procedures, working around energized parts, and arc-flash protection.

Table 7. Technical and Consensus Standards

Reason/Category	Standard/Regulation No.	Statement/Purpose
Electrical Installation	CSA C22.1 (Canadian Electrical Code, Part I)	The basic technical standard in Canada that provides a basic level of safety in the installation and inspection of electrical equipment.
Hazardous Locations	CSA C22.1, Rule 18-000 Series	Gives special wiring and equipment provisions to locations where there can be hazardous chemicals or atmospheres.
Industrial Machinery	CSA C22.1, Rule 28-000 Series	Regulates the wiring systems and safety of industrial machinery and automation systems.
Workplace Electrical Safety	CSA Z462 (Workplace Electrical Safety)	The Canadian standard on worker safety in working with electrical equipment is aimed at the prevention of shock and arc flashes.
Safety Program and Risk Assessment	CSA Z462, Clause 4.1 & 4.3.5	Describes the procedure of setting up the Electrical Safety Program and arc-flush Risk Assessment.
Safe Work Conditions	CSA Z462, Clause 4.4	Determines the procedure of providing an electrically safe work condition (lockout/tagout).
Personal Protective Equipment (PPE)	CSA Z462, Clause 5	Describes the parameters of the choice, use, and maintenance of PPE during electrical work.

11.0 Testing and Evaluations

Testing Protocol and Strategy of Validation.

A multi-stage and multi-level testing strategy should be adopted to guarantee the automated system shuts down its conceptual design and turns into a reliable and market-ready product. This is meant to de-risk the investment by identifying and fixing any problems in a controlled set-up before the system is in place in a live bakery.

11.0.1 Phase 1: Component- Level Testing

All the small units of the system should be shown to be sound and correct before the system can become a functional unit. This stage is parallel to trying all the components of a cake and then baking it.

i) Sensor Suite Validation:

Float and Reed Sensors: These sensors play a significant part in eliminating disastrous failures. Testing would involve:

Accuracy of the calibration: The tanks would be filled to the exact level, and the sensor activation points would be checked. Does the lower reed sensor activate a lower-level alarm at the specific point desired so that the heater does not run out of water?

Fail-Safe Response: To make sure the Programmable Logic Controller (PLC) of the system properly interprets sensor data and initiates a safe shutdown sequence, we would provide a simulation of failure, either a stuck float or broken pump, to prompt the operator on the Human-Machine Interface (HMI) screen to take appropriate action.

Durability Testing: The sensors would also undergo thousands of on/off cycles in the chemical solution to test their corrosion and mechanical wear resistance.

Temperature Sensor: The effectiveness of the decarbonizing tank depends on the ability to maintain a good temperature.

Accuracy Benchmarking: A K-type thermocouple would be placed in a water bath with a high-precision calibrated reference thermometer. Measurements would be performed at the complete range of operation (e.g., 50 °C to 90 °C) to develop a calibration curve and make the temperature reading of the system reliable.

Response Time: We would check the response time of the sensor to determine whether it can provide real-time feedback to the heater control system.

Positioning Sensors: The most significant element is the functioning of the hoist.

Repeatability Test: The hoist was ordered to move to the location of the Decarbonizing Tank 100 times in a row. The physical stopping point would be checked each time to ensure that it is constant within a few millimetres. Any mistake would result in mal-positioning and unsuitable sliding of the tray racks.

ii) Mechanical Subsystem Testing:

Testing of the Subsystem will be done on the mechanical parts of the system, which will likely involve the following:

Pump and Nozzle Performance:

Flow rate and pressure: The pump on the rinsing tank and the recirculation pump would be tested to ensure that they provide the needed water flow (in gal/min) and the required pressure (in PSI). There will be bad pressure leading to bad cleaning.

Spray Pattern Analysis: A test rig would be set up, and the nozzles would be opened, and the spray pattern would be traced on a grid or plain water-sensitive paper. This is evidence that a gap between the nozzle (determined 0.7 ft to 0.1 ft to 1.4 ft, etc.) provides a hundred percent coverage and leaves no dry or poorly cleaned spots on the tray.

Clogging Resistance: The nozzles would be run with a little water that contains particles suspended in the water, and how much they are to clogging and the ease with which they can be cleaned, in case they need cleaning.

ii) Heater and Blower System:

Thermal Efficiency: The duct heater would be switched on, and time would be allowed to introduce ambient temperature air flow to the required drying temperature (e.g., 60-70 °C). This ramp-up and steady-state operation would be plotted in terms of power consumption.

Safety Interlock Testing: The safety interlock would be deliberately caused to cut off so that the coils of the heater would cut off before an unsafe temperature is reached. The thermal guard of the blower motor would also be inspected.

iii) Filtering system:

Particle Capture Efficiency: An amount and size distribution of test contaminant (e.g., fine carbon powder, simulated grease) would be added to the system. To be clearer, the sample of water from the output of the Field Liquid would be analysed to determine what percentage of the particles the filter could filter.

Throughput and Clogging Rate: The system would be used continuously to check on the time it would take before the filter mesh is full of debris, to cause the flow rate to reduce significantly, and hence decide on the maintenance period that must be taken.

11.0.2 Phase 2: System Integration Test.

The next one being checked is testing them once they are all checked as one integrated machine. This test attests to the PLC logic and mechanical compatibility of the stations.

Dry Run: The entire system is put on and run in the absence of water, tray, or heat. The engineers are monitoring the PLC program to the point where the order is flawless: Hoist picks up to Tank 1 to Tank 2 to Tank 1 to Tank 2 to Dryer to Tank 2 to Sprayer to Tank 2 to Dryer to Blower to Offload.

Wet Run: Wet run is run whereby water is added to the tanks, and the system is run using clean trays. These tests:

Physical: Are the trays stable on the rack when on the hoist? Are there splash-ups or any spills between stations?

Leaks in the system: All the pipes, joints, and seals of the tanks are checked to be sure that they do not leak under the pressure of working.

Cleaning Efficacy Testing: This is the performance test.

Standardized Soiling: To ensure that the tests are the same, dirty trays would be prepared in controlled circumstances. The new, same trays would be sprayed with a fake mixture of flour, oil, sugar, and water, and placed in an oven that created an even, reproducible layer of carbonized leftovers. The tray was going to be weighed before being soiled, after being soiled, and after being washed to determine the amount of residue left.

Cleaning Metrics: Cleaning depends upon:

Visual Inspection: No residual visible in the clean tray.

Water Break Test: Clean water is sprayed over the surface of the tray that is dry. The water is clean; in case it is in continuous and uninterrupted sheets. There are unseen hydrophobic residues left behind if it beads up (oils).

ATP Bioluminescence Testing: A swab test that identifies Adenosine Triphosphate, a molecule present in all organic cells. This will provide a numerical value of surface

purity, which will be an affirmation of the procedure of eliminating all the biological material.

11.0.3 Phase 3: Endurance and Stress Testing.

This step identifies the reliability and limits of the system under real-life conditions that are sustained.

Long Duration Run: The system would be running 24-48 hours in a loop, processing the trays. This is aimed at detecting any parts that overheated, aged too soon (such as bearings in the hoist motor), or experienced fatigue.

Throughput and capacity verification: The overall cycle time of single rack trays would be carefully timed in terms of load to offload. This time would be measured and estimated to the actual number of trays per hour and trays-per-day output, which would be compared with or above the promised output of 1200+ trays per day.

Failure Mode and Effect Analysis (FMEA): Deliberate errors are put into the system to test the robustness and safety measures of the system.

Situation: The tray becomes misloaded and gets stuck with the hoist. Does the sensor sense the excessive load and switch off the hoist motor?

Conditions: Water supply is discontinued. Do the level sensors alarm and stop the cycle before the pumps are spoiled?

Scenario: The PLC is reset during the mid-cycle. Does it restart in a safe condition, or does it attempt to restart some unsafe operation?

Detailed Evaluation of the Proposed System

In this section, a balanced evaluation has been made to consider the potential weaknesses and strengths of the system and the problems that must be addressed.

i) Strengths and Compelling Advantages.

Lessening of Labor Dependency and Cost: This is the most effective benefit. Lifting, soaking, rinsing, and drying are automated and therefore do not require manual work all the time. The financial analysis that forecasts labour savings of approximately 58,400 annually is an effective motivator. It also removes the burden of searching for employees to work in a hard and disagreeable job.

Cleaning Consistency and Quality Assurance never seen before: There will always be good and bad days on the part of the human worker; there are none with machines. The automated system will expose every tray to the same process, which

is, same chemical concentration, the same temperature, the same soak time, the same rinse pressure, and the same drying temperature. This avoids human error and variation and results in a better outcome of baking performance and production of a higher quality.

The system turns the workplace into a quantum leap in terms of safety:

Chemical Exposure: Workers are no longer hosing down trays with hard chemicals.

Ergonomic Injuries: The strenuous task of moving heavy and wet trays is done away with.

Thermal and Slip Hazards: There is minimal exposure to hot surfaces and wet floors.

Compliance: The design is in line with CSA, OHSA, and WHMIS standards, which give a clear guideline on how the design can be operated safely and legally.

Extraordinary and Verifiable Economic Payback: Financial analysis is very strong. A payback period of 6 to 7 months can be referred to as excellent in any industrial capital equipment scenario. ROI of 84% in the initial year will convert the project into a high-yield investment. This will be translated into the profit margin of the bakery since the savings are achieved every year.

High Operational Throughput and Scalability: The system eliminates a large production bottleneck by developing a continuous, automated flow. Bakeries will have an opportunity to produce more without having to consider the tray washing process. As noted in the prospects, the design is modular and therefore can be expanded with the business.

ii) Weaknesses, Risks, and Mitigation Strategies.

High Start-up Cost: The overall cost of the project of about 30,500 dollars, and a short payback period is a huge initial outlay, which can be prohibitive to very small artisanal bakeries with minimal access to capital.

Mitigation: The high ROI would enable it to raise finances. The manufacturer can consider the possibility of some leasing opportunities or a Tray Cleaning as a Service model to reduce the barrier to entry.

Heightened Technical Complexity and Maintenance Requirements: An Electromechanical system should be used to replace a simple manual process, which presents new points of failure (sensors, PLC, motors). Failure to function might stop the whole cleaning line.

Mitigation: Bakery maintenance personnel need to be thoroughly trained. The system is supposed to be set up with simple components and diagnostic codes that are well displayed on the HMI. It is strongly recommended that a partnership with the equipment provider on service support be entered.

Ongoing Reliance on Utilities and Consumables: The system is susceptible to power cuts and water wastage. It also demands constant provision of cleaning chemicals and replacement filters.

Mitigation: This risk cannot be avoided, but can be addressed by the standard operational measures, such as maintaining the backup chemical stock and plan of preventive maintenance, including changing the filters.

Chemical Handling and Environment: The system utilizes and consumes chemicals, though safer to the workers. The procedure of the safe addition of new chemicals and the safe disposal of spent solution is not described in the presentation.

Mitigation: The final design must comprise of closed and safe chemical dosing system and clear environmentally acceptable disposal of wastewater, which might involve neutralization.

12.0 Analysis

This part will be a synthesis of all the information, where it will present a conclusive, broad-based assessment of the viability and impact of the project.

Technical Feasibility Analysis: The system does not use speculative technology. It is an ingenious and strong combination of proven industrial parts: PLCs to control, feedback sensors to provide feedback, pumps to move fluids, and heaters to manage heat. Technical competence is also high, as it can be seen through the detailed engineering of the nozzle assembly, the filtration loop, and sensor-based automation logic. The engineering feasibility of the project is 100 percent.

Economic Viability and Potential of Disrupting the market: The economic argument cannot be refuted. The cost-benefit analysis, with its conservative and realistic assumptions on the labour rates and cost of energy, demonstrates that automation is not only a nice-to-have but a financially sound improvement. The system can turn into a standard item in the middle/large-sized bakeries and fundamentally transform the way one of the most vital, yet overlooked, aspects of the operation is handled.

Safety and Regulatory Compliance Alignment: The project team has been forward-looking in that the respective Canadian codes and standards (CSA C22.1, Z462, OHSA) have been identified proactively. It is much less expensive and more efficient to design compliance than to apply it to a completed machine. This is a proactive method that will de-risk the implementation process and accelerate time-to-market.

Strategic Positioning and Futureproofing: The Future Prospects section is what turns the project into a capstone assignment and transforms it into a product roadmap of the future. As the concepts of IIoT (predictive maintenance), water recycling (sustainability), and AI optimization (optimization of operations) demonstrate, this system is meant to be a platform where new ideas can constantly be implemented, which will keep it relevant even in the years to come.

12.0.1 Cost Benefit Analysis

This report presents a cost- benefit analysis for upgrading the existing decarbonizing of steel trays used in the Danish Pastry`s production facility. The current system has operational inefficiencies related to manual hard work, higher energy consumption, and inconsistent product quality.

The proposed upgrade introduces an automatic rinsing and drying system whereas there is all manual in the existing one. As well as this project reduces the number of labourer's needed to operate the machine and risk associated with the manual work.

Key assumptions

- Workday = 8 hours; year = 365 days (used for annual calculations)
- Electricity cost = CAD 0.141 / kWh
- Labor rate = CAD 20 / hour
- Maintenance = 5% of equipment investment per year
- Capital cost (investment) = CAD 29,728 (rounded from BOM totals)
- Energy use and labour inputs are as provided in the table

Current manual process leads to:

- Low throughput and variable cycle time
- High labour hours and labour risk (burns, fatigue)
- Inconsistent cleaning quality (rework / rejects)
- Frequent downtime (legacy PID controllers) and maintenance

  Objectives of the upgrade:
- Double throughput (from 160 → 320 units/day)
- Reduce labour from two operators to one (or less monitoring)
- Improve product quality consistency and safety
- Reduce downtime and maintenance

Comparison of Key performance Indicators

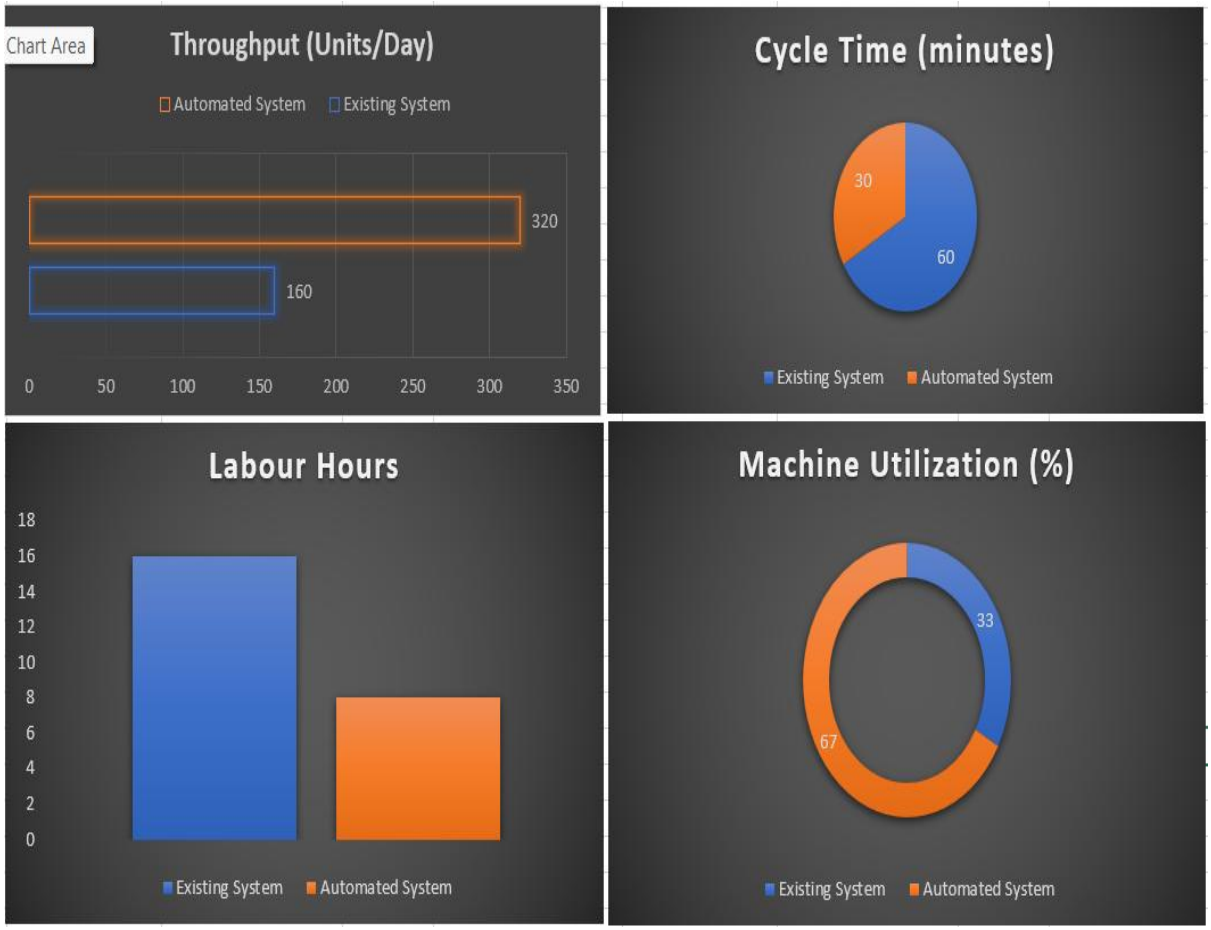


Fig. KPI Analysis

KPI	Data	Metrics	Remarks
Throughput	160	Units/Day	20 Pieces of trays per hour and equals 160 units per day/8 hours
Cycle Time	<60	Minutes	Cycle time depends on how the worker works and is usually more than 60 min
Labor Hours	16	Hours	Two workers working for 8 hours a day, weekly=16*7=112 hours
Machine Utilization	33.33%	%	Machine utilized for only 20 minutes every hour.

Table 8. KPI in Existing System

KPI	Data	Metrics	
Throughput	320	Units/Day	40 pieces of trays per hour and is equal to 320 units per day/8 hours.
Cycle Time	<30	Minutes	
Labor Hours	8	Hours/Day	
Machine Utilization	0.67%	%	

Table 9. KPI in Automated System

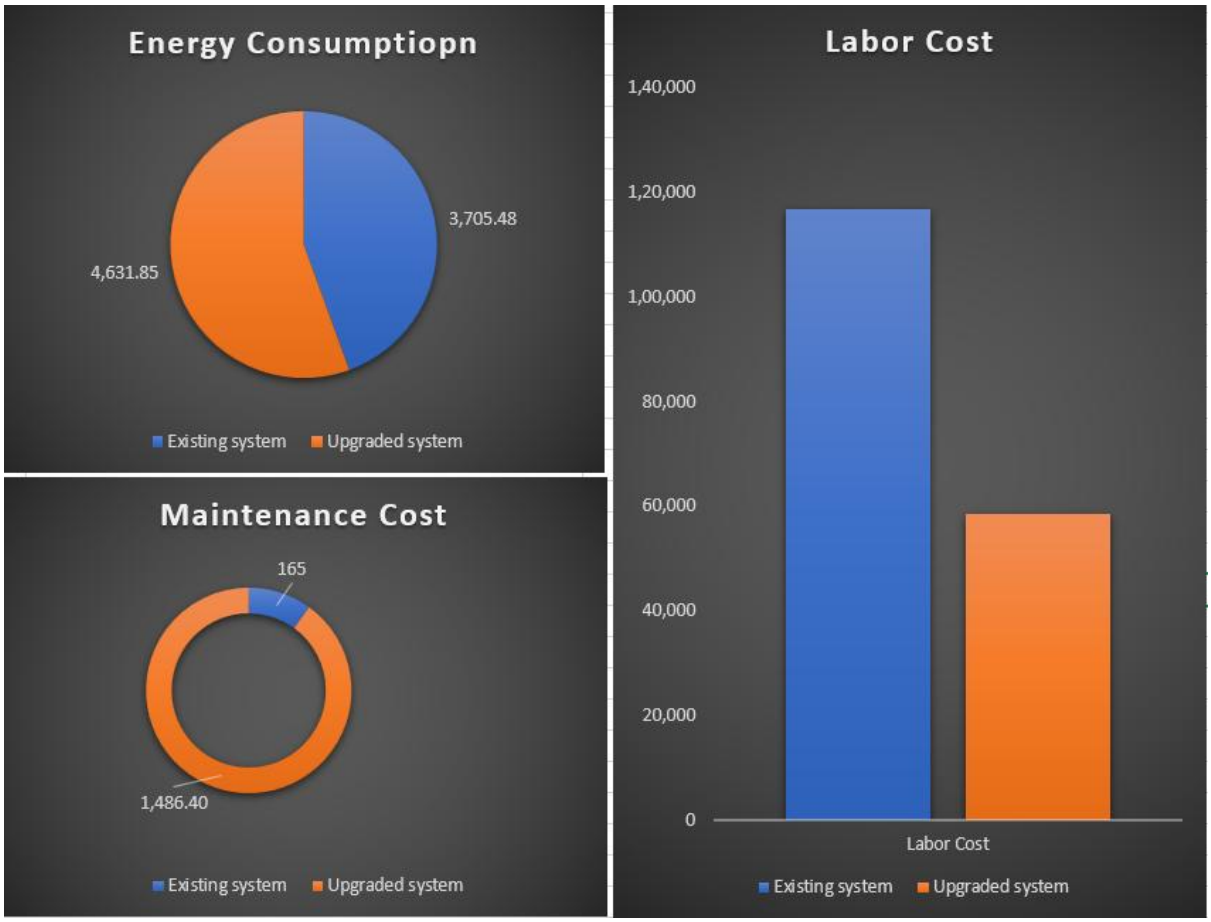


Fig. Cost Benefit Analysis

Item	Existing system	Cost of Existing System (CAD)	Upgraded system	Cost of Upgraded System (CAD)
Energy Consumption	(=9kw*8hr) =72 units/day, $ 0.141 per Kwh	3705.48	(=11.25 Kw*8hr) =90 units/day	4631.85
labor Cost	(=8hrs*20Phr*2W) =320 CAD/Day	116800	(=8hrs*20Phr*1W) =160 CAD/Day	58400
Maintenance Cost	5% of Investment Annually, Cost of Machine Calculated=3300	165	5% of Investment Annually, Investment 29728	1523.92
Total Operating Cost		120670.48		64555.8

Table 10. Cost Benefit Analysis

Annual Savings after upgrading

=Existing Operating cost- Operating Cost after Upgradation

=120670.48-64555.8

=**56114.7 CAD** (Canadian Dollar)

Benefits Analysis

i. Energy Efficiency

   a. Decarbonizing tank productivity will increase as it was operated manually and was depending on manpower. After automatic control and upgradation, productivity will be doubled from 20 to 40 minutes per hour. This also reduces the damage of S.S trays as they will be inside the tank at higher temperatures only for specified periods. Previously, trays were inside the decarbonizing tank for longer period, and it was causing bent on the trays.

ii. Reduced Labor Requirement

   a. Less manual monitoring due to automation. Just 5-10 minutes an hour is required in actual.
   b. Annual Savings=116800-58400=58400

iii. Improved Quality Consistency

a. As manual rinsing quality was differing from one cleaner to another cleaner and was not perfect always, the rinsing machine cleans each trays area from less than 2.5 feet in distance with 3 bar pressure.

iv. Reduced Downtime

a. As old type of PID controller fails frequently, using of latest PLC technology for monitoring of temperature and heater operation as well, there will be less downtime as compared to existing system.

v. Safety Improvement

a. Lower risk of burns and operator fatigue.

vi. Financial Analysis

Payback period= Capital (Investment) Costs/Annual Savings

=30478 /56152.23

=0.54 years

The payback period is 0.53 years and is equal to approximately 6 to 7 months.

Return on Investment (ROI)

= (56152.23-30478)/30478

=0.84

=84%

ROI increases in future years, as it is 84% in the year of investment.

The proposed automation of the decarbonizing, rinsing and drying line yields large operational and financial benefits. With a capital outlay of **CAD 30,478** and **projected annual savings of CAD 56,152**, the project pays back in **≈6–7 months** and produces an excellent ROI. Benefits include higher throughput, improved quality, safer working conditions and much lower labour exposure. Based on this analysis, the upgrade is strongly recommended.

13.0 Application Areas

Automation of steel tray decarbonizing, rinsing, and drying has broad applicability across the commercial baking and food processing industry, where metal trays, racks,

and moulds are used continuously and must be kept clean to meet strict hygiene and quality standards. Industrial bakeries producing pastries, breads, cookies, frozen doughs, and ready-to-eat baked goods rely on high-volume, high-temperature ovens that rapidly build carbon deposits on trays. Your automated system eliminates slow manual cleaning cycles, increases throughput, and provides consistent cleanliness—making it ideal for bakeries operating multiple shifts, central production facilities, and companies expanding to meet rising demand. The system also enhances safety by reducing worker exposure to hot tanks and harsh cleaning chemicals, making it suitable for facilities emphasizing modern food safety compliance such as HACCP, GMP, and FSMA standards.

Beyond baking, the technology can be applied to any food or industrial operation that uses steel trays or fixtures repeatedly at high temperatures. This includes confectionery plants, commercial kitchens, airline catering units, meat and poultry processors, and even non-food sectors like metal finishing, automotive component cleaning, and manufacturing environments where parts holders or moulds accumulate burnt residues. Any facility seeking to reduce labour, improve cleaning accuracy, or streamline repetitive washing and drying tasks can integrate this automated solution into their production line. The modular and scalable design makes it adaptable for both medium-sized plants and large-scale industrial operations.

Potential Companies / Market Targets

Below is a list of companies and sectors where your solution can be delivered. I've included both major global bakery manufacturers and regional operations that routinely use large quantities of steel trays.

Large Industrial Bakeries & Food Manufacturers

- Grupo Bimbo (world's largest baking company — operates across North America & Europe)
- Aryzta (specialty bakery products for retail & food service)
- Weston Foods / Weston Bakeries
- George Weston Limited
- Flowers Foods
- Hostess Brands

- McCain Foods (frozen goods, pastry lines)
- General Mills (Pillsbury operations)
- Kellogg's Bakery Division
- Campbell Company / Pepperidge Farm
- Rich Products Corporation

Global Pastry & Frozen Dough Producers

- Danish Crown production partners
- Lantmännen Unibake (huge pastry & bread manufacturer globally)
- Sara Lee Frozen Bakery
- La Brea Bakery
- Bridor (premium French pastry manufacturer)

Commercial & Centralized Bakery Chains

- Tim Hortons central baking facilities
- Starbucks bakery suppliers (e.g., Princi production sites)
- Panera Bread production facilities
- Cinnabon production centers
- Krispy Kreme production lines

Catering & Large-Scale Food Service

- Airline catering companies like Gate Gourmet, LSG Sky Chefs, Catering Point
- Sysco and Aramark production kitchens
- Compass Group central kitchens

14.0 Expected Outcomes

By the completion of this project, the following results are anticipated:

i) Simulated Automated System:

A comprehensive software model that represents tray movement, decarbonization, rinsing, chemical filtering, and unloading.

Control logic integrated to manage the timing, sequence, and automated chemical solution management.

ii) Optimized Tray Workflow:

Determination of appropriate dwell times in the decarbonization and rinsing tanks.

Optimized tray movement schedule to increase throughput and reduce potential delays or bottlenecks.

iii) Chemical Solution Management:

Simulation of automatic filtering cycles to maintain solution effectiveness.

Insights on reducing chemical usage and minimizing waste while sustaining cleaning performance.

iv) Quantitative Performance Metrics:

Data on cycle times per tray, overall throughput, and potential labour savings.

Comparison of the automated simulation with the current manual process to evaluate efficiency, safety, and resource usage improvements.

v) Feasibility and Industrial Insights:

Evaluation of how the simulated automated system could be applied in real-world industrial settings.

Identification of potential operational challenges, safety considerations, and areas for further optimization.

vi) Comprehensive Documentation:

Detailed block diagrams, flowcharts, and step-by-step explanation of the simulated process. A final report summarizing findings, analysis, and recommendations for potential implementation. These outcomes will provide a clear understanding of the benefits of automation for tray decarbonization, highlighting improvements in efficiency, consistency, safety, and cost-effectiveness, while also offering actionable insights for potential industrial application.

15.0 Conclusion

This project addresses the limitations of the current manual steel tray decarbonization process, including high labour requirements, inconsistent cleaning results, safety risks, and limited scalability. The objective is to simulate a fully automated system that integrates tray handling, decarbonization, rinsing, and chemical management with automated process control.

The project plan outlines a structured approach over 11 weeks, including simulation setup, modelling of mechanical and chemical processes, control logic implementation, testing, optimization, and performance analysis. By delivering a detailed simulation model, performance metrics, and documentation, the project will provide a comprehensive understanding of how automation can improve efficiency, safety, and reliability in industrial tray cleaning operations.

Ultimately, the expected outcomes will offer a clear roadmap for transitioning from a manual process to a scalable automated solution, while minimizing risks and resource use.

16.0 Future Scope and Advanced Enhancements

The developed automated cleaning system establishes a robust technological base that can evolve beyond simple automation and into a fully intelligent, energy-efficient, and scalable industrial solution. As the baking and food processing industries move toward digital transformation and Industry 4.0, several innovative upgrades can significantly enhance the system's performance, reliability, and commercial value.

i) IIoT Integration & Predictive Maintenance

Integrating Industrial Internet of Things (IIoT) sensors into the system opens the door to real-time monitoring and predictive analytics. Sensors can continuously measure chemical concentration, temperature uniformity, water quality, pump pressure, filter saturation, and motor vibration. This data is transmitted to a cloud or local monitoring dashboard, allowing operators to visualize equipment health at a glance. Predictive maintenance algorithms can then analyse trends to identify early signs of component degradation—such as clogging in the filtration unit, pump inefficiency, or overheating. Instead of waiting for failures or scheduling unnecessary routine maintenance, the system can prompt timely interventions, minimize downtime and extend machine life. This transforms the cleaning system into a smart, self-monitoring asset that supports uninterrupted bakery operations.

ii) Advanced Water & Energy Recycling

Water and energy consumption are major cost factors in industrial cleaning processes. By integrating water recycling loops—such as sediment separation, fine filtration, activated carbon treatment, or UV sterilization—the system can reuse rinsing water multiple times before disposal. This not only reduces operational cost but also aligns with sustainability goals. Similarly, waste heat from the decarbonizing tank or the drying chamber can be captured using heat exchangers and repurposed to preheat incoming water, lowering energy demand. The system can also incorporate solar thermal panels to support water heating, particularly in regions with high solar availability. Together, these enhancements drastically reduce the system's environmental footprint and long-term utility expenses.

iii) AI-Powered Cleaning Optimization

Artificial intelligence can elevate the cleaning process from fixed-cycle automation to adaptive decision-making. Using machine learning models trained on tray conditions—such as soil level, carbon thickness, or temperature distribution—the

system can automatically adjust chemical dosage, tank residence time, rinse pressure, and drying duration. Lightly soiled trays may require shorter cycles, reducing energy and chemical consumption, while heavily carbonized trays receive extended or intensified treatment. Over time, the AI model learns from operational data to fine-tune cleaning parameters for maximum efficiency and minimal waste. This not only ensures consistent cleaning performance but also reduces consumable usage and further shortens cycle times.

iv) Modular and Scalable System Design

As production capacities vary across bakeries—from small artisan units to massive industrial plants—scalability becomes a key advantage. Transforming the system into modular sections allows bakeries to configure the equipment based on their throughput requirements. For instance, multiple decarbonizing or rinsing modules can be added in parallel for high-volume facilities, while smaller bakeries can opt for a compact single-line configuration. Modular design also supports different tray dimensions, geometries, and even entirely different types of equipment, such as molds, racks, and pans used in other segments of food processing. This flexibility makes the system future-proof and easily adaptable across diverse environments.

v) Commercial Prototyping & Industry Partnerships

After developing and validating the prototype in a controlled environment, the next step is commercial implementation. Collaborating with established bakery equipment manufacturers allows the system to reach global markets faster. These partners can support large-scale fabrication, certification, distribution, and after-sales service, which are essential for wide industry adoption. Potential partners include manufacturers specializing in ovens, racks, conveyor systems, or industrial washing machinery. Joint development efforts can refine the product, integrate it with existing bakery production lines, and provide customers with a turnkey, high-performance cleaning solution.

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Close-up of a person holding a green scouring pad, commonly used for scrubbing surfaces during cleaning. Note. Reprinted from "Cleaning pads," by BlakeDavidTaylor, n.d., https://www.istockphoto.com/photo/cleaning-pads-gm840957220-137048071.

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