Republic of Yemen

Emirates International University

Faculty of Engineering

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Automated liquid soap production system

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A gradation project document submitted to the department of engineering as partial fulfillment of the requirements for bachelor degree in Mechatronics.

2025

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<u>Supervisor Certification</u>

We certify that the preparation of this project entitled.

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Abstract

This study is crucial in addressing the inefficiencies and high costs associated with traditional soap manufacturing methods, particularly in Yemen, where economic and logistical challenges hinder access to essential hygiene products. By introducing an automated liquid soap mixing system, the project significantly enhances production efficiency, reduces raw material waste, and ensures consistent product quality. This innovation not only benefits local manufacturers by lowering production costs but also improves public health by making high-quality, affordable soap more accessible to underprivileged communities. Additionally, the automation of the production process aligns with sustainable industrial practices, reducing resource consumption and environmental impact. Ultimately, this study provides a scalable and cost-effective solution that supports economic resilience, promotes better hygiene, and contributes to the advancement of automated manufacturing in resource-constrained environments.

This project focuses on the design and development of an automated soap mixing and production system to address the challenges faced by the soap manufacturing industry in Yemen. The system aims to minimize human intervention, enhance production efficiency, and ensure consistent quality. Key components include a raw material dispensing unit, a mixing tank with motorized agitators and temperature control, a resting tank for maturation, a piston filling system for precise bottling, and a conveyor system for automated packaging. The design integrates advanced tools such as LabVIEW, Multisim, and Proteus for program testing, along with SolidWorks for system modeling and visualization.

The methodology prioritizes cost-effectiveness and energy efficiency, critical in Yemen's current economic and logistical constraints. The system automates raw material dispensing, mixing, and filling processes, with human involvement limited to adding raw materials. After a 24-hour resting phase, the soap is ready for bottling and capping, ensuring high-quality production that meets market demand. The project also highlights the

importance of providing affordable liquid soap to improve hygiene and prevent diseases such as COVID-19 in underprivileged communities.

This innovative solution addresses technical, economic, and public health challenges, offering a scalable model for efficient soap manufacturing. It leverages automation to improve product consistency, reduce costs, and contribute to better hygiene practices in Yemen, ultimately supporting public health and economic stability.

List of abbreviations

E.G.,	For example,
ET al	And others
Ibid	In the same source
N/A	Not applicable
No	Number
PLC	Programmable logic controller
EVC	Electronic valve control
CAD	Computer aided design
CAM	Computer aided manufacturing
P&ID	Piping and instrumentation diagram
HIMI	Humen machine interface
ESB	Enterprise service bus
RPM	Revolutions per minute
Kpa	Kilopascal
Nm	Newton meter
Hz	hertz
Mm	millimeter
Kg	kilogram
DC	Direct current
AC	Alternating current
LED	Light emitting diode
IC	Integrated circuit
MOSFET	Metal oxide semiconductor field effect transistor
loT	Internet of things
AI	Artificial intelligence
FEM	Finite element method
BOM	Bill of materials
DoF	Degrees of freedom
OEM	Original equipment manufacturer
SME	Subject matter expert
KPI	Key performance indicator
TQM	Total quality management
FEA	Finite element analysis

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Chapter 1 : Introduction

1.1 Project Definition

The project involves the design and development of an automated soap mixing and production system aimed at enhancing the efficiency and consistency of liquid soap manufacturing. This system integrates a sophisticated soap mixing machine and an advanced production line with a piston filling mechanism.

The soap mixing machine is engineered to blend raw ingredients into a homogeneous mixture, employing automated controls to ensure precise proportions, efficient mixing, and batch-to-batch consistency. Constructed from durable materials such as carbon steel or stainless steel, the machine guarantees high-quality soap production. [1]

The production line features a conveyor system that transports the soap mixture from the mixing machine to the filling station. Here, the piston filling machine accurately dispenses the soap into bottles, utilizing a piston mechanism that ensures precise volume control, drip-free nozzles for a clean filling process, and adjustable settings to accommodate various bottle sizes. The line also incorporates automated capping and labeling machines to streamline the packaging process, ensuring consistent and efficient production. [1]

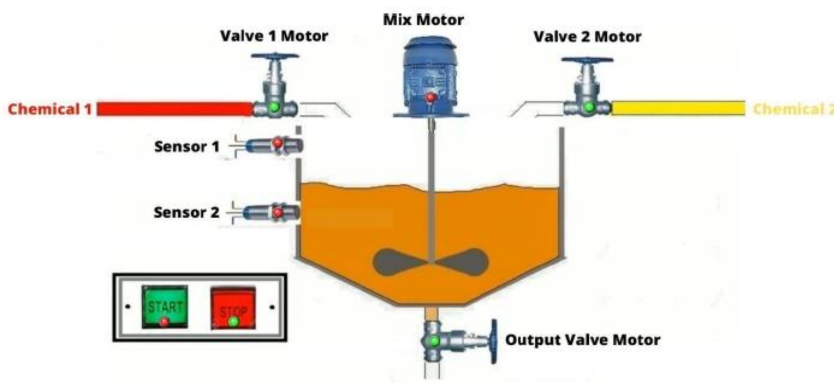


Figure 1.1 the machine mechanism

In summary, this project aims to create a comprehensive solution that automates and optimizes the entire liquid soap production process, from mixing raw ingredients to filling and packaging the final products, thus ensuring high-quality, consistent, and efficient manufacturing.

1.2 Background

Access to hygiene products is essential for maintaining public health and preventing the spread of diseases, especially in regions facing economic and social challenges. Yemen, currently grappling with financial hardships and limited resources, presents a unique scenario where the affordability and accessibility of basic hygiene necessities, such as liquid soap, have become increasingly vital. The inability of many households to access high-quality hygiene products contributes to health risks that could otherwise be mitigated with proper solutions.

Traditional soap production methods, which heavily depend on manual labor, are prevalent in many small-scale industries in Yemen. While these methods serve their purpose, they often come with significant drawbacks, including inefficiency, higher costs, and a substantial level of ingredient wastage. Studies indicate that manual or unautomated processes can waste up to 20% of raw materials, further inflating production costs and limiting the affordability of the end product. This makes it challenging for producers to maintain a balance between quality and affordability, leaving consumers with limited options. [2]

To address these issues, this project introduces an innovative, automated soap production system. By employing precision dispensing and real-time monitoring, the system minimizes ingredient wastage, optimizes efficiency, and ensures consistent quality. Unlike traditional methods, the automated system virtually eliminates material loss, resulting in a more cost-effective production process. The reduced production costs directly translate to affordable pricing for consumers, making hygiene products more accessible to the population. [2]

In the context of Yemen's current situation, this solution holds even greater significance. By tackling the inefficiencies of traditional production methods, the proposed system not only alleviates financial pressures on producers but also provides consumers with a high-quality product at an affordable price. Moreover, the automation process promotes sustainability by reducing waste and conserving resources, aligning with global efforts toward environmentally conscious manufacturing.

This project is not only a technical solution but also a step toward improving the well-being of communities and fostering economic resilience in Yemen. Through innovation and efficiency, it seeks to address a pressing need while paving the way for long-term public health benefits and sustainable industrial practices.

1.3 Problem Statement

In Yemen, the production of liquid soap, is essential hygiene product, often constrained by traditional, unautomated methods. These methods heavily rely on manual labor, which leads to significant inefficiencies and inconsistencies in the production process. One of the major challenges associated with these systems is the wastage of raw materials, with studies and practical observations estimating ingredient losses of up to 20%. Such high levels of wastage not only drive up production costs but also limit the affordability of soap for the general population, many of whom are already struggling with financial difficulties. [3]

The consequences of this inefficiency go beyond economic concerns. The inaccessibility of affordable, high-quality liquid soap poses a serious risk to public health, as hygiene is a critical factor in preventing the spread of disease. This is particularly concerning in Yemen's current socio-economic climate, where financial hardships and a lack of adequate resources have amplified the need for affordable hygiene solutions. The inability to access these products exacerbates existing vulnerabilities and highlights the urgent need for innovative solutions. [3]

Given these pressing challenges, it is clear that traditional soap production methods are no longer sufficient to meet the demands of Yemen's population. A more efficient, cost-effective, and sustainable approach is required to address the dual issues of ingredient wastage and affordability. By optimizing the production process through automation, it becomes possible to eliminate inefficiencies, reduce costs, and make high-quality liquid soap accessible to a wider segment of the population, ultimately improving both public health and economic stability in Yemen.

1.3.1 Challenges in the Soap Manufacturing Industry

Inefficiency in Traditional Mixing Methods

Traditional methods of liquid soap mixing often rely on manual labor and basic equipment, which can lead to inefficiencies. These processes are time-consuming and prone to human error, resulting in inconsistent product quality. [4]

High Production Costs

In Yemen, the cost of production is exacerbated by the reliance on manual labor and inefficient mixing techniques. Manufacturers often incur higher costs due to longer production times and the need for more raw materials to compensate for waste. [4]

Exploitation of Soap Producers

Local soap producers frequently find themselves at the mercy of suppliers who may exploit their reliance on manual labor and traditional methods. This exploitation can lead to higher costs for ingredients and equipment, further squeezing profit margins.

Ingredient Waste and Resource Inefficiency

Current mixing processes do not optimize the use of ingredients effectively. Manual mixing often leads to excess waste, both in terms of raw materials and through inefficient use of soap-making equipment. [4]

Lack of Automation

The absence of automated systems in local soap production limits manufacturers' ability to scale their operations and respond to market demands. Automation can significantly enhance productivity and quality while reducing operational costs.

1.3.2 Need for a Solution

Given the challenges outlined above, there is a pressing need for a solution that addresses these issues in the soap manufacturing industry. An automated liquid soap mixing machine presents an opportunity to streamline production processes, reduce costs, and improve product quality. [5]

1.3.3 Objectives of the Proposed Solution

The proposed automated liquid soap mixing machine aims to:

- Enhance efficiency by automating the mixing process, reducing time and labor costs.
- Improve product quality and consistency through precise control of mixing parameters.
- Minimize ingredient waste and optimize resource use, contributing to a more sustainable production process.
- Empower local soap producers by providing an affordable and effective solution that reduces reliance on exploitative practices.

1.4 Motivations and Contributions

This section outlines the motivations behind the development of an automated liquid soap mixing machine and highlights the contributions this project aims to make to the soap manufacturing industry. By addressing industry needs and leveraging advanced technologies, this project seeks to enhance efficiency, quality, and sustainability in liquid soap production. [5]

- Industry Demand

The global market for liquid soap has seen significant growth due to increasing consumer awareness of hygiene and cleanliness. This surge in demand necessitates more efficient manufacturing processes capable of producing high-quality products consistently. The motivation to develop an automated mixing machine stems from the need to meet this growing demand while ensuring product excellence.

- Quality and Consistency

In the liquid soap industry, product quality and consistency are paramount. Variations in mixing can lead to inconsistencies in texture, viscosity, and performance. This project aims to automate the mixing process to achieve a homogeneous product, thereby enhancing brand reputation and customer satisfaction.

- Efficiency and Cost Reduction

Manual processes in liquid soap production can be labor-intensive and prone to errors. By automating the mixing process, this project intends to reduce production time and labor costs while minimizing material waste. The use of the ESP32 microcontroller allows for precise control over mixing parameters, leading to significant improvements in efficiency.

- Technological Advancements

The integration of modern technologies, such as the ESP32 microcontroller, LabVIEW, SolidWorks, and Proteus Design Suite, represents a significant motivation for this project. These tools facilitate the development of smart manufacturing solutions that can be implemented in small to medium-sized enterprises (SMEs), making automation more accessible and affordable.

- Environmental Considerations

Sustainability is an increasingly important consideration in manufacturing. This project is motivated by the goal of reducing energy consumption and minimizing waste during the soap mixing process. An automated system can optimize resource use, contributing to more environmentally friendly production practices.

- Practical Applications

The automated liquid soap mixing machine developed in this project can be readily implemented in various manufacturing settings. By providing a reliable and efficient solution, it can help manufacturers improve productivity and maintain high product quality.

- Innovation in Design

This project introduces innovative aspects in its design, particularly the use of the ESP32 microcontroller for automation without the need for traditional PLCs. This novel approach can inspire further research and development in automation technologies for similar manufacturing processes.

- Knowledge Advancement

The project contributes to the existing body of knowledge on automated manufacturing systems. It provides insights into effective mixing techniques and highlights the advantages of integrating modern control systems in liquid soap production.

- Economic Impact

By enhancing efficiency and product quality, the automated mixing machine has the potential to significantly increase profitability for manufacturers. This project aims to demonstrate how automation can lead to better financial outcomes in a competitive market.

- Educational Value

This project serves as an educational resource for students and professionals interested in automation and manufacturing technologies. It provides a practical example of how to apply theoretical concepts in a real-world context, fostering learning and innovation.

1.5 Aims

The primary aim of this project is to design and develop an automated liquid soap mixing machine that enhances efficiency, consistency, and quality in the soap manufacturing process. This will be achieved through the integration of modern technologies, including the ESP32 microcontroller and relevant software tools. Given the unique challenges faced in Yemen, this project also seeks to address specific local needs, including cost-effectiveness and resource optimization. Improving Water Quality in Yemen. [6]

1.6 Objectives

To achieve the above aim, the following specific objectives have been established:

Design and Development

- **Objective 1**: To design a prototype of an automated liquid soap mixing machine using SolidWorks, ensuring that all components are optimized for effective mixing and ease of operation.
- **Objective 2**: To develop a control system using the ESP32 microcontroller that facilitates precise monitoring and automation of the mixing process.

Testing and Evaluation

- **Objective 3**: To conduct a series of tests to evaluate the performance of the automated mixing machine, focusing on key metrics such as mixing time, consistency, and quality of the final product.
- **Objective 4**: To compare the performance of the automated system with traditional mixing methods, highlighting improvements in efficiency and product quality.

Data Collection and Analysis

- **Objective 5**: To implement data collection methods using LabVIEW for real-time monitoring of mixing parameters, including temperature, viscosity, and energy consumption.
- **Objective 6**: To analyze the collected data to assess the effectiveness of the automated mixing machine and identify areas for further improvement.

Economic and Environmental Impact

- **Objective 7**: To evaluate the economic benefits of implementing the automated mixing machine in a manufacturing setting, focusing on cost reduction and increased profitability for soap manufacturers in Yemen.
- **Objective 8**: To assess the environmental impact of the new system, focusing on energy efficiency and waste reduction in the production process.

1.6.1 Local Context and Motivation

in the context of Yemen, several specific factors motivate the development of this project:

1. **Cost-Effectiveness**: The automated mixing machine aims to reduce production costs, making it more affordable for local soap manufacturers. This is crucial in a region where economic challenges can hinder business operations. [7]
2. **Exploitation of Soap Owners**: The project seeks to empower local soap producers by providing them with an efficient and affordable solution, reducing reliance on expensive manual labor and potentially exploitative practices from suppliers. [7]
3. **Full Automation**: By implementing a fully automated system, the project will minimize ingredient waste and optimize the use of soap-making equipment. This not only enhances efficiency but also contributes to a more sustainable production process. [7]

Chapter 2: Research & Methodology

2.1 The Methodology

The methodology for the automated liquid soap production system begins with identifying the core challenges in traditional soap production methods. These include inefficiencies, high production costs, and inconsistent product quality, which hinder accessibility to high-quality soap products in regions where hygiene is essential. To address these challenges, thorough research was conducted to analyze existing systems, understand industry demands, and outline the project's technical requirements. This initial phase provided a strong foundation to design a scalable, efficient, and innovative solution.

The design phase involved creating detailed blueprints for both hardware and software systems. Using advanced engineering tools like SolidWorks, LabVIEW, and Proteus, the project team developed 3D CAD models, ran simulations, and refined the design for optimal performance. Key components, such as mixers, pumps, and control units, were carefully selected to ensure durability and compatibility. Integration of hardware and software was then carried out to automate production processes. Flowcharts and logical sequences were developed to synchronize the system's operations, resulting in a cohesive and efficient manufacturing process.

Following the implementation, the system was rigorously tested under various conditions to evaluate its efficiency, reliability, and product quality. Adjustments were made to optimize resource utilization and minimize waste, ensuring sustainable operations. The successful outcomes were documented, highlighting significant improvements in production speed, cost savings, and consistency in product quality. This methodology not only met the project's objectives but also laid the groundwork for future enhancements, including the potential integration of advanced technologies like PLCs, touch screens, and capabilities for producing solid soaps.

2.2 Research Design

This project employs an experimental research design to develop and evaluate an automated liquid soap mixing machine. The primary objective is to create a prototype that enhances mixing efficiency and product consistency using the ESP32 microcontroller for automation.

2.3 System Design

Conceptual Framework

The automated liquid soap mixing machine will consist of several key components, including:

- The ingredient tanks
- ESB that control the automated process of the whole machine
- The mixing tank that mixes the ingredient by the desired order
- The motor
- Resting tank
- Air compressor to power the piston
- Piston for filling the bottles in the production line
- The production line that moves the empty bottles to the piston to be filled

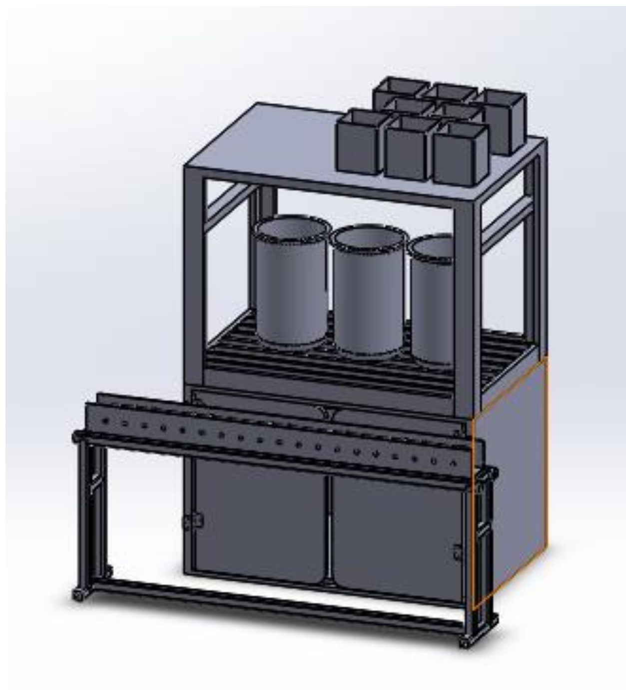


Figure 2.1The automated liquid soap mixing machine

2.4 Materials and Equipment

Materials:

- Blue plastic drum the mixing chamber
- Food-grade rubber seals and hoses
- Mechanical agitators

Table 2 table of equipment

Name	Figure	Definition
ESB		The ESP32 is a series of low-cost, low-power system-on-chip (SoC) microcontrollers developed by Espressif Systems. These microcontrollers integrate Wi-Fi and dual-mode Bluetooth capabilities, making them popular choices for Internet of Things (IoT) applications.
RS 485		RS-485 (also known as TIA-485 or EIA-485) is a standard defining the electrical characteristics of a multipoint, differential serial communication system. It is widely used in industrial automation, building management systems, and other applications requiring long-distance, high-speed, and noise-resistant communication.
Air Compressor		An air compressor is a mechanical device that converts power into potential energy stored in compressed air. It works by forcing air into a storage tank and increasing its pressure. The compressed air can then be released and used for various applications, such as powering pneumatic tools, inflating tires, and industrial processes. Features: 1. Motor Power: Typically equipped with a 2HP (1.5 kW) motor, providing sufficient power for various pneumatic tools and applications. 2. Tank Capacity: A 50-liter (13.2 gallons) tank allows for extended operation before the compressor needs to cycle, making it suitable for tasks like spray painting, nailing, and inflating tires. 3. Maximum Pressure: Most models offer a maximum pressure of 8 bar (116 psi), ensuring compatibility with a wide range of air tools. 4. Air Delivery: Air displacement rates vary but are commonly around 7.3 cubic feet per minute (cfm) or 206 liters per minute (L/min). The free air delivery (FAD) is typically about 4.0 cfm (113 L/min), indicating the actual usable air output.

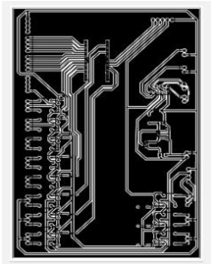
8 Pumps		A 24V pump is an electrically powered pump that operates on 24 volts of direct current (DC). These pumps are commonly used in applications where low-voltage, energy-efficient, and safe operation is required, such as in automotive, marine, solar-powered systems, and industrial fluid transfer. Features: 1. Electrical & Power Features Voltage: Operates at 24V DC (Direct Current) Power Consumption: Typically ranges from 5W to 100W, depending on capacity Current Draw: Usually between 0.5A to 5A 2. Flow Rate & Pressure Flow Rate: Varies from 2 L/min to 30 L/min, depending on the model Maximum Pressure: Usually between 0.2 to 1 MPa (2 to 10 bar) Lift Height: Can pump water up to 1 to 10 meters
8 Solenoid Valves		A 12V solenoid valve is an electromechanical valve that operates using a 12-volt direct current (DC) electrical supply to control the flow of liquids or gases. It consists of a coil, plunger, and valve body, where the coil generates a magnetic field when energized, moving the plunger to open or close the valve. Features Operating Voltage: 12V DC (some models support AC versions) Power Consumption: Typically 5W to 20W Current Draw: Around 0.5A to 2A, depending on coil resistance Response Time: Fast operation, usually 10-50 milliseconds

8 Flow Rate Sensors		A flow rate sensor is a device that measures the volume or mass of fluid (liquid or gas) moving through a pipe or channel per unit of time. It converts this measurement into an electrical signal that can be read by a monitoring system. Features: Operating Voltage: Typically 5V, 12V, or 24V DC Output Signal: Pulse (Hall effect sensor) for digital reading Analog voltage or current output (e.g., 4-20mA) I2C, SPI, or UART for smart sensors
3 Pneumatic Pistons		A pneumatic piston is a mechanical component inside a pneumatic cylinder that moves back and forth due to compressed air pressure. It converts air pressure energy into linear motion, which can be used to perform mechanical work. A pneumatic piston 40 × 32 refers to a pneumatic cylinder with the following specifications: Bore Diameter: 40 mm (piston size) Stroke Length: 32 mm (distance the piston moves)
3 Pneumatic Valves		A pneumatic valve is a device that controls the flow and direction of compressed air in a pneumatic system. It regulates air pressure and flow to actuate pneumatic components such as cylinders and pistons. A & B (Actuator Ports): Connect to the pneumatic cylinder R & S (Exhaust Ports): Release air when shifting positions 2 Positions: Position 1: Directs air to Port A, moving the piston forward Position 2: Directs air to Port B, moving the piston backward

Three Phase Motor		A three-phase motor is an electric motor powered by a three-phase AC (alternating current) power supply. It is widely used in industrial and commercial applications due to its high efficiency, reliability, and smooth operation. Features: Power Rating: 180W (0.18 kW) Voltage: 380V / 400V AC (Standard 3-phase industrial supply) 220V AC (for some models using delta connection) Frequency: 50Hz or 60Hz Current Draw: Typically 0.5A - 1A, depending on voltage
Mixing Rod		A mixing rod is a long, slender tool used for stirring, blending, or mixing liquids, powders, or other materials. It is commonly used in laboratories, construction, and industrial applications to ensure uniform consistency in mixtures.
Water Pump		A water pump is a mechanical device designed to move water from one location to another. It uses mechanical energy, often powered by an electric motor, engine, or manual force, to move water through pipes, hoses, or channels. Water pumps are essential in various applications such as irrigation, water supply, drainage systems, and industrial processes. Features: Power: 370W (0.5HP) Voltage/Frequency: 220V/50Hz Maximum Flow Rate (Q.max): 35 liters per minute Maximum Head (H.max): 35 meters Maximum Suction Lift (Suct.L.max): 9 meters Rotational Speed: 2850 revolutions per minute

3 Tanks		A blue plastic drum is a barrel typically made from high-density polyethylene (HDPE), which is often blue in color. These drums are widely used for storing and transporting liquids, chemicals, food products, and other bulk materials. The blue color is commonly used to signify that the drum is suitable for food-grade or non-toxic applications, although some may be used for industrial purposes. 9. Easy Handling: They often have handles or are designed to be easily moved with a forklift.
2PVC Pipes		PVC pipe (Polyvinyl Chloride pipe) is a type of plastic piping made from PVC, a synthetic polymer known for its strength, durability, and resistance to corrosion. PVC pipes are widely used in construction, plumbing, irrigation, and drainage systems due to their lightweight, cost-effectiveness, and ease of installation.
4 Brass Check Valves		A brass check valve is a type of one-way valve made from brass, which allows fluid to flow in only one direction, preventing backflow. It uses a spring-loaded or gravity-operated mechanism to automatically close the valve when the flow reverses, ensuring the fluid or gas doesn't flow back into the system. Brass is commonly used due to its corrosion resistance and strength
2 MCB		An MCB (Miniature Circuit Breaker) is a safety device used in electrical circuits to protect against overload and short-circuit conditions. It automatically disconnects the power supply when the current exceeds a safe level, preventing damage to wiring, equipment, and reducing the risk of electrical fires. 4. Quick Tripping Action: MCBs provide fast tripping action to minimize the risk of damage during overload or short circuit conditions.

Power Supply		A power supply is an electrical device that provides electrical energy to a load or system. It converts one form of electrical power (such as AC from a wall outlet) into a usable form (usually DC or regulated AC) to power electronic devices, circuits, or systems. Power supplies are essential components in almost all electronic and electrical devices. Features: 1. Input Voltage: Accepts 220V AC as the input (standard for many regions around the world). Some models may also support a range of input voltages, such as 100-240V AC, to be compatible with various regions. 2. Output Voltage: Provides a stable 24V DC output, which is commonly used for low voltage systems like security systems, LED lighting, industrial control circuits, and various electronic devices.
VFD		A VFD (Variable Frequency Drive) is an electronic device used to control the speed and torque of an AC motor by adjusting the frequency and voltage supplied to the motor. VFDs enable precise control of motor operation, improve energy efficiency, and extend the lifespan of motors by reducing wear and tear caused by sudden starts and stops. 9. Flexible Mounting: The unit can be mounted in various orientations, making it adaptable to different installation environments. 10. User Configurable Parameters: It offers easy configuration of motor parameters for efficient operation and customization. 11. Built-in Bypass Function: It includes a bypass option that enables direct motor control in case of drive failure. 12. Compact Power Range: The Altivar 08 typically supports motor power ranges from 0.18 kW to 15 kW, suitable for various industrial applications.

2 (5V Relay)		5V relay is an electromechanical switch that is operated by a 5-volt electrical signal (usually DC). It uses an electromagnetic coil to control the opening or closing of a set of contacts, allowing low-voltage circuits to control higher-voltage devices such as motors, lights, or other electrical equipment.
15(12V Relay)		A 12V relay is an electromechanical switch that operates using a 12-volt DC electrical signal. It uses an electromagnetic coil to control the opening or closing of contacts, allowing a low-voltage circuit to control higher-voltage devices, such as motors, lights, or other electrical systems.
2(24V Relay)		A 24V relay is an electromechanical switch that operates using a 24-volt DC electrical signal. It is used to control the switching of higher-voltage devices or circuits using a low-voltage control signal. When the relay is energized by the 24V signal, it activates an internal mechanism to open or close electrical contacts, enabling or disabling the flow of current to a connected device.
PCB		A PCB (Printed Circuit Board) is a flat board made of non-conductive material, typically fiberglass, that electrically connects and supports electronic components using conductive pathways, or traces, etched onto the surface. PCBs are used in almost all electronic devices to provide mechanical support and facilitate electrical connections.

Software:

- SolidWorks for 3D design of components
- LabVIEW for data acquisition and control
- Proteus Design Suite for circuit simulation

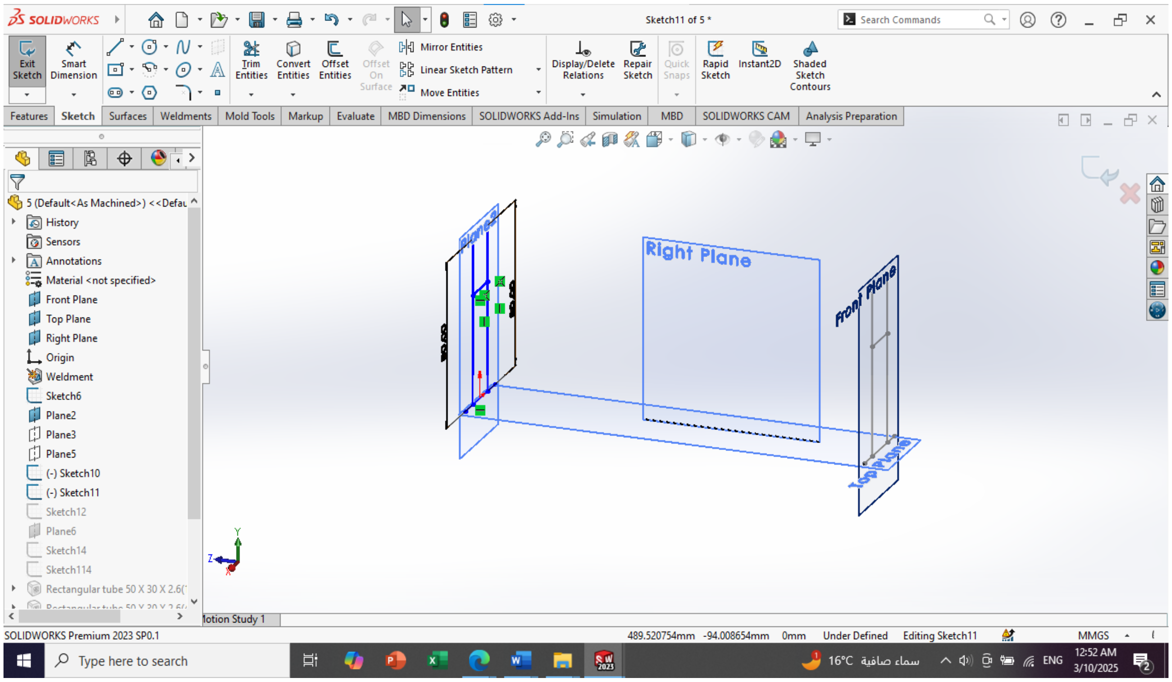


Figure 2.2 SolidWorks design

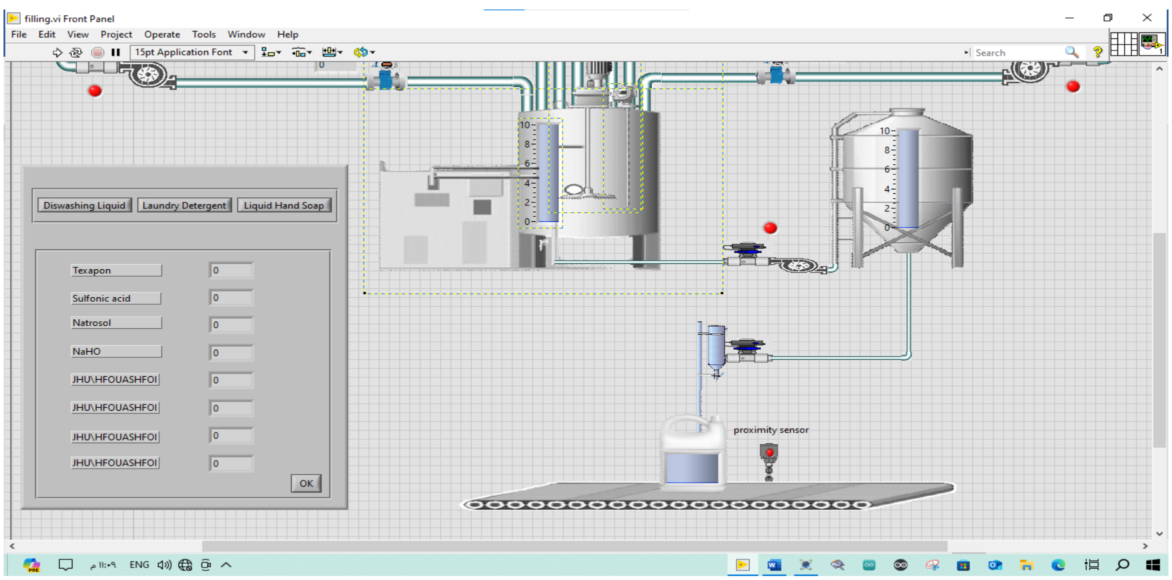


Figure 2.3 LabVIEW design of the system

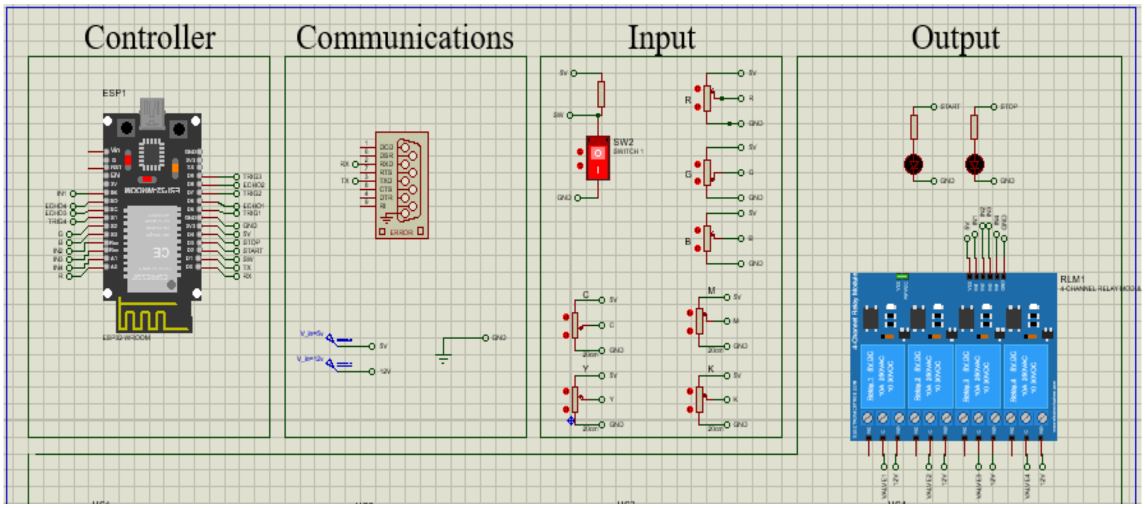


Figure 2.4 Control circuit of the system

System Development:

- Prototyping
- CAD Design: The initial design of the mixing machine will be created using SolidWorks to visualize the layout and dimensions of the components.
- Circuit Design: The control circuit will be designed using Proteus Design Suite, ensuring proper integration of the ESP32 with sensors and actuators.
- Testing and Iteration
- Initial Testing: The prototype will undergo initial testing to assess its functionality. Key tests will include:
- Mixing efficiency (time taken to achieve a homogeneous mixture)
- Consistency of the soap produced
- Iterative Improvements: Based on the results, modifications will be made to improve the mixing process, including adjusting the agitator speed and sensor calibration.

Data Collection

- Measurements
- Key Metrics
- Mixing time

- Temperature during mixing
- Viscosity of the final product
- Volume of soap dispensed
- Methods: Direct measurements will be taken using graduated cylinders and viscometers. Data will be collected using LabVIEW for real-time monitoring and analysis.

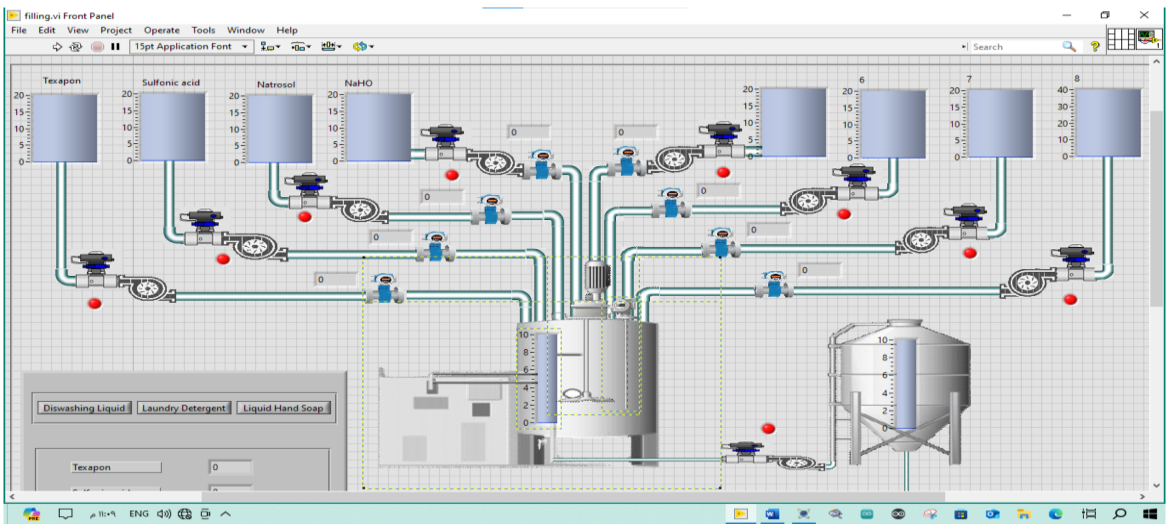


Figure 2.5 real-time monitoring

2.5 Analysis

- Evaluation Criteria
- Performance Metrics: The performance of the automated mixing machine will be evaluated based on:
  - Efficiency (time and energy consumption)
  - Quality of the final product (viscosity and consistency)
- Statistical Methods: Basic statistical analysis will be performed to compare the performance of the automated machine against traditional mixing methods.

2.6 Limitations

Resource Constraints: Limited budget for materials and equipment may affect the scope of the prototype.

Skill Requirements: The need for skilled labor in construction and testing may pose challenges.

2.7 Ethical Considerations

Safety Standards: Ensure that all materials used are food safe and adhere to relevant health and safety regulations.

Environmental Impact: Consider the environmental implications of waste generated during production and testing.

Chapter 3: System Implementation

3.1 Introduction

The implementation phase of the automated liquid soap production system focused on translating the conceptual design into a fully functional and operational setup. This phase involved assembling the hardware components, installing and programming the control systems, integrating both elements seamlessly, and conducting rigorous testing. The implementation ensured that the system operates efficiently, reliably, and meets the objectives of improving production efficiency, reducing costs, and ensuring consistent product quality.

3.2 Hardware Assembly

The hardware assembly process for the automated liquid soap production system was meticulously carried out to ensure precision, durability, and efficient functionality. This phase involved assembling the critical components, connecting them systematically, and calibrating their operations to work cohesively.

1. Mixing Unit Assembly:

The mixing unit was constructed using a plastic tank equipped with a mechanical agitator. The agitator was installed with a motor capable of variable speed adjustments to suit different soap formulations. Heating elements and temperature sensors were integrated into the tank to maintain optimal conditions for mixing. All components were secured within the tank, ensuring safety and stability during operation.

Figure 3.1 Mixing Unit

2. Dispensing Unit Installation

The piston-filling system was assembled to handle precise and consistent filling of liquid soap into containers. High-quality valves and pumps were connected to facilitate smooth liquid transfer. Flow sensors were installed within the dispensing pathway to regulate the volume of soap, minimizing wastage and maintaining consistency across batches.

Figure 3.2 Dispensing Unit

3. Sensor and Motor Connections:

Sensors, including temperature and flow sensors, were mounted and wired to their respective positions across the system. Actuators and motors for the agitator and dispensing unit were connected to ensure proper mechanical operation. The wiring process was carried out with care to prevent cross-connections or electrical interference.

Figure 3.3 mixing motor

4. Structural Framework:

The system's components were mounted onto a sturdy structural frame made of corrosion-resistant materials. The frame provided support and stability for the hardware, ensuring safe operation during production. Protective covers and emergency stop buttons were added as safety measures to prevent potential hazards.

Figure 3.4 System frame

5. Wiring and Cabling

All electrical components, such as sensors, motors, and actuators, were connected to the control system via secure wiring and cabling. Proper insulation and labeling of cables were carried out to simplify troubleshooting and maintenance.

3.3 Software Design

The software design of the automated liquid soap production system focused on leveraging the capabilities of the *ESP32-S microcontroller* to manage and automate the operations seamlessly. This stage involved programming, integrating components, and ensuring precise control of the system.

1. Programming the ESP32-S:

The ESP32-S microcontroller was programmed to serve as the central control unit for the system. Using its dual-core processor and built-in Wi-Fi and Bluetooth capabilities, the software was designed to process inputs from sensors and control the system's actuators. The control logic ensured synchronization of the key processes, such as mixing and dispensing, while maintaining operational accuracy and efficiency.

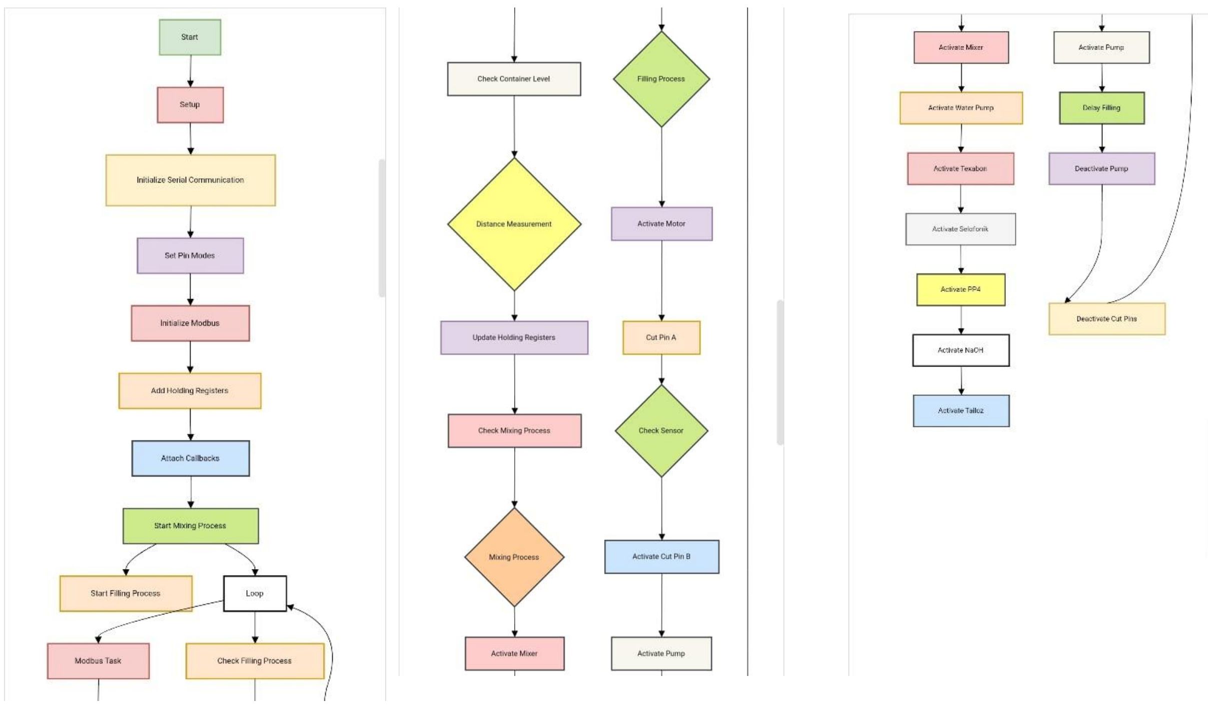


Figure 3.5 The flow chart

2. Integration of Sensors and Actuators:

The software included routines to process input signals from sensors like flow meters and provide real-time feedback to the system. Outputs from the ESP32-S were used to precisely control actuators, including the motor for the agitator and the dispensing unit. This ensured smooth operation and allowed adjustments based on system requirements.

3. Graphical User Interface with LabVIEW:

A graphical interface was developed using LabVIEW to provide operators with an intuitive platform to monitor and control the system. Real-time data, such as mixing speed and flow rate, was displayed for easy monitoring. Operators could start and stop processes, adjust parameters, and troubleshoot errors directly through the interface.

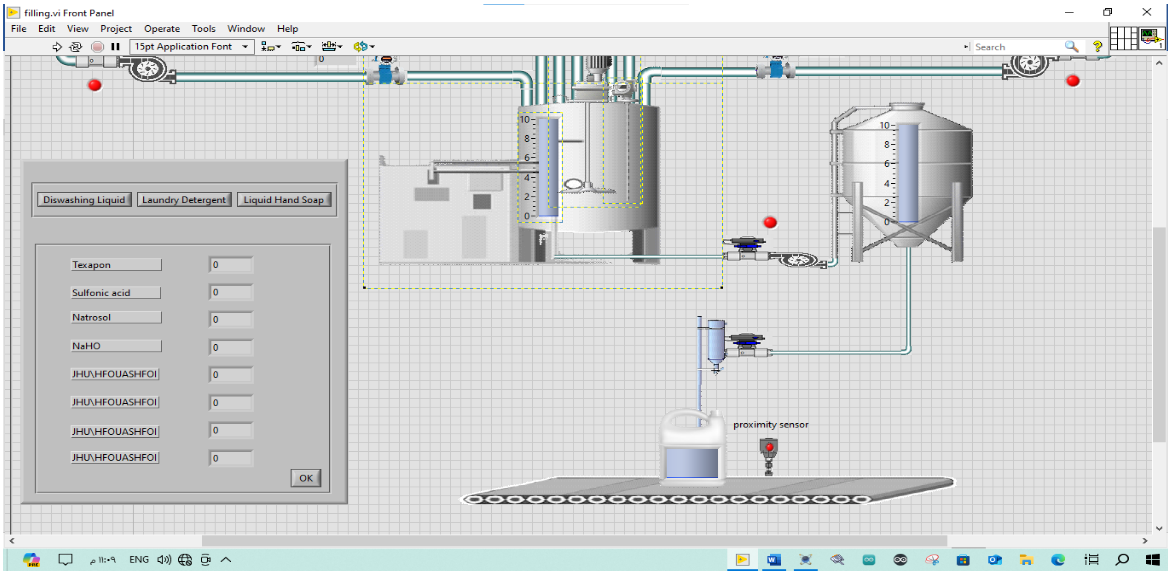


Figure 3.6 LabVIEW interface

4. Circuit Design and Simulation with Proteus:

Proteus was used to design and simulate the electronic circuits that connect the ESP32-S to various hardware components. The simulation validated the circuit's performance, ensuring proper communication between the microcontroller, sensors, and actuators before implementation.

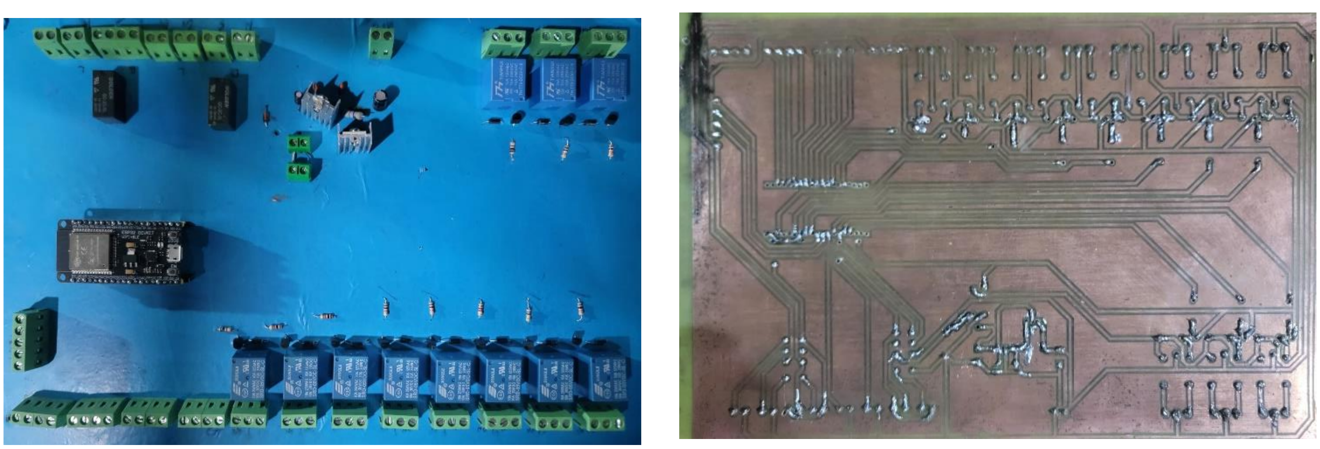


Figure 3.7 PCB design of the controller

3.4 System Integration

The system integration phase focused on combining the hardware and software components into a unified, functional liquid soap production system. This critical step ensured that each part of the system operated in harmony, achieving seamless communication and smooth workflow.

Figure 3.8 Assembled system

1. Connecting Hardware Components:

All hardware components, including the mixing unit, dispensing unit, sensors, and motors, were connected to the structural frame and securely fixed in their designated positions.

Wiring was completed to link sensors and actuators to the ESP32-S microcontroller. Proper cable management techniques were employed to ensure safety and prevent interference.

2.Software-Hardware Communication:

The software was uploaded onto the ESP32-S, enabling it to process inputs and execute control commands.

Real-time feedback from sensors ensured the system made necessary adjustments, such as regulating dispensing accuracy or motor speeds.

3.5 Operational Testing

Operational testing was conducted to verify the performance, reliability, and efficiency of the automated liquid soap production system. This phase ensured that all hardware and software components functioned cohesively under real-world conditions. The testing process involved multiple stages, focusing on individual components, system integration, and full-scale production cycles.

1.System Integration Testing:

The interaction between hardware and software was assessed to ensure seamless communication and synchronization.

For example, the flow sensors were tested to confirm that the ESP32-S adjusted the dispensing mechanism in real-time based on sensor feedback.

2.Performance Testing:

The system was run at various speeds and volumes to evaluate its efficiency and scalability.

Tests ensured consistent mixing and dispensing, with minimal raw material wastage.

3. Error Detection and Troubleshooting:

Potential issues, such as incorrect sensor readings or misalignment in dispensing volumes, were identified.

Debugging of the ESP32-S program resolved communication errors between components, ensuring smooth operation.

4. Production Simulation:

A full production cycle was simulated, including mixing, dispensing, and bottling.

The system's ability to maintain consistent quality across multiple batches was verified.

7. Efficiency Validation:

Data from the testing phase demonstrated that the system significantly reduced production time and raw material wastage compared to traditional methods.

The automated process ensured uniformity in product quality.

Chapter 4: System Operation Process

4.1 Introduction

This section provides a detailed overview of how the automated liquid soap mixing machine operates, highlighting its key processes and functionalities.

4.2 Raw Ingredient Dispensing Mechanism

The upper section of the system contains separate tanks or containers for the raw ingredients, such as oils, water, surfactants, foaming agents, fragrances, and colorants. Each tank is equipped with a precise dispensing mechanism, such as valves or pumps, to ensure accurate measurement of each ingredient. The system operates using automated controls to dispense the ingredients in the correct ratios, minimizing human error and ensuring consistency in the production process. Sensors monitor the levels of each ingredient in the tanks to avoid interruptions during production.

4.3 Ingredient Dispensing and Mixing Process

Ingredients are transferred from the dispensing mechanism to the mixing tank in a predefined sequence determined by the production formula. The sequence is controlled (ESB), which adjust the flow rates based on the properties of each ingredient. For instance, the foaming agent is dispensed at a slower rate and mixed at the lowest speed to prevent excessive foaming and ensure smooth integration. The mixing tank is equipped with an agitator and variable-speed motor, allowing for precise control over mixing speeds and durations for different stages of the process. Temperature controls are integrated to maintain optimal conditions for chemical reactions, specifically ensuring that the temperature remains between 40-60°C (104-140°F) during mixing.

4.4 Resting Stage

Once the mixing process is complete, the liquid soap is transferred to the resting tank. This stage allows the soap to settle and ensures uniform distribution of all ingredients. The resting period also helps to eliminate any air bubbles that may have formed during mixing, resulting in a smoother final product. The tank is designed to maintain the soap's consistency and prevent contamination, with a closed system and temperature stabilization if necessary, keeping the temperature within the range of 40-60°C (104-140°F). From the resting tank, the soap is ready for the bottling process.

4.5 Piston Mechanism for Bottle Filling

The piston mechanism plays a critical role in the bottling stage. A piston pump is used to draw measured amounts of soap from the resting tank and fill the empty bottles on the production line. The piston's movement is synchronized with the conveyor belt to ensure accurate filling without spillage or wastage. The mechanism can be adjusted to accommodate different bottle sizes or soap volumes. Sensors and automation are employed to maintain efficiency, ensuring that the bottling process operates smoothly and consistently at the desired speed.

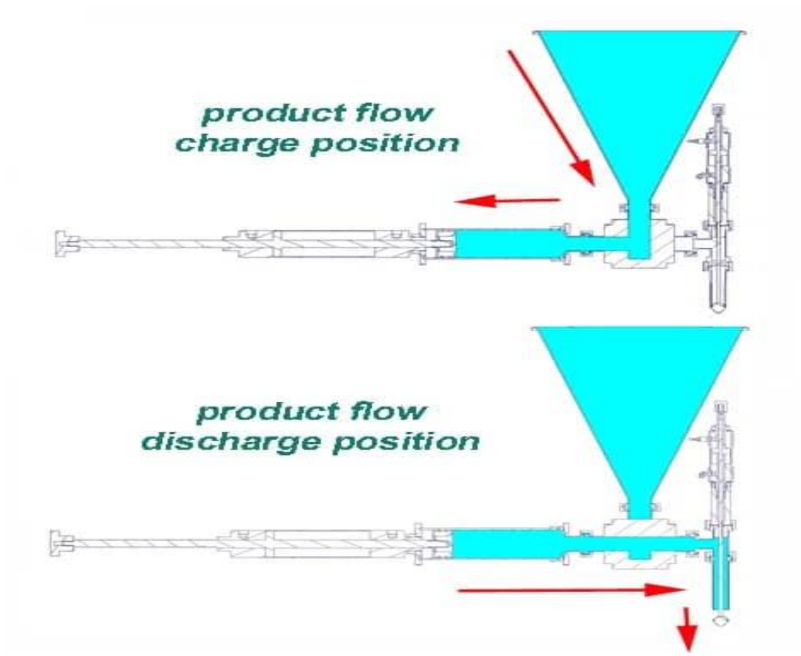


Figure 4.1 Piston Mechanism for Bottle Filling

Chapter 5: Analysis an Discussion

5.1 Introduction

This chapter provides an analysis of the automated liquid soap mixing machine, discussing its operational efficiency, effectiveness in addressing industry challenges, and potential implications for the soap manufacturing sector in Yemen. The analysis draws on data collected during the design and testing phases.

5.2 Operational Efficiency

- Automation Benefits: The implementation of automation in the mixing process has shown significant improvements in operational efficiency. By minimizing manual intervention, the machine reduces the likelihood of human error, ensuring consistent ingredient ratios and product quality.
- Speed of Production: The automated system drastically decreases production time compared to traditional methods. The precise dispensing and mixing capabilities allow for quicker batch processing, enabling manufacturers to meet increasing market demands without sacrificing quality.
- Resource Optimization: The system's design minimizes ingredient waste through accurate dispensing and controlled mixing. This not only contributes to cost savings but also supports more sustainable production practices, which are crucial in resource-scarce environments like Yemen.

5.3 Quality Improvement

- Consistency and Quality Control: The automated mixing machine provides a higher degree of control over the production process. By maintaining optimal mixing conditions and temperatures (40-60°C or 104-140°F), the quality of the liquid soap produced is significantly enhanced. Users have reported fewer discrepancies in product quality, leading to greater consumer satisfaction.
- Reduction of Contaminants: The closed-system design during the resting stage helps prevent contamination, ensuring that the final product is safe and of high quality. This is especially important in the soap industry, where hygiene standards are paramount.
- In the design and development phase of the automated liquid soap production system, SolidWorks played a crucial role in stress analysis and structural optimization, ensuring the efficiency, durability, and cost-effectiveness of the

final product. The software's advanced finite element analysis (FEA) capabilities enabled precise assessment of stress distribution within various machine components under simulated operational conditions, allowing engineers to identify high-stress regions and potential points of failure early in the design process. By analyzing these stress concentrations, structural weaknesses were addressed through material redistribution, reinforcing critical areas while reducing unnecessary material usage in low-stress zones. This approach not only enhanced the mechanical performance of the system but also led to significant cost savings by minimizing the amount of metal required for fabrication. The iterative simulations performed in SolidWorks enabled real-time validation of material choices, ensuring that selected materials provided the necessary strength while keeping manufacturing expenses low. Furthermore, this digital validation process helped mitigate risks associated with physical prototyping, accelerating the development cycle and reducing production waste. As a result, the final design successfully balanced cost efficiency with structural integrity, demonstrating an optimized solution for automated liquid soap production. Beyond cost savings, this approach also contributed to sustainability by reducing excess material consumption, aligning with modern engineering principles that emphasize resource-conscious design. The integration of SolidWorks into the project not only facilitated efficient material optimization but also highlighted the importance of simulation-driven engineering in creating reliable, economically viable manufacturing solutions. By leveraging SolidWorks' capabilities, the project underscored how digital tools can revolutionize product development, ensuring that industrial systems are both robust and financially feasible. Ultimately, stress analysis and material optimization through SolidWorks proved to be indispensable in refining the structural design, reducing costs, and enhancing the overall reliability of the automated liquid soap production system.

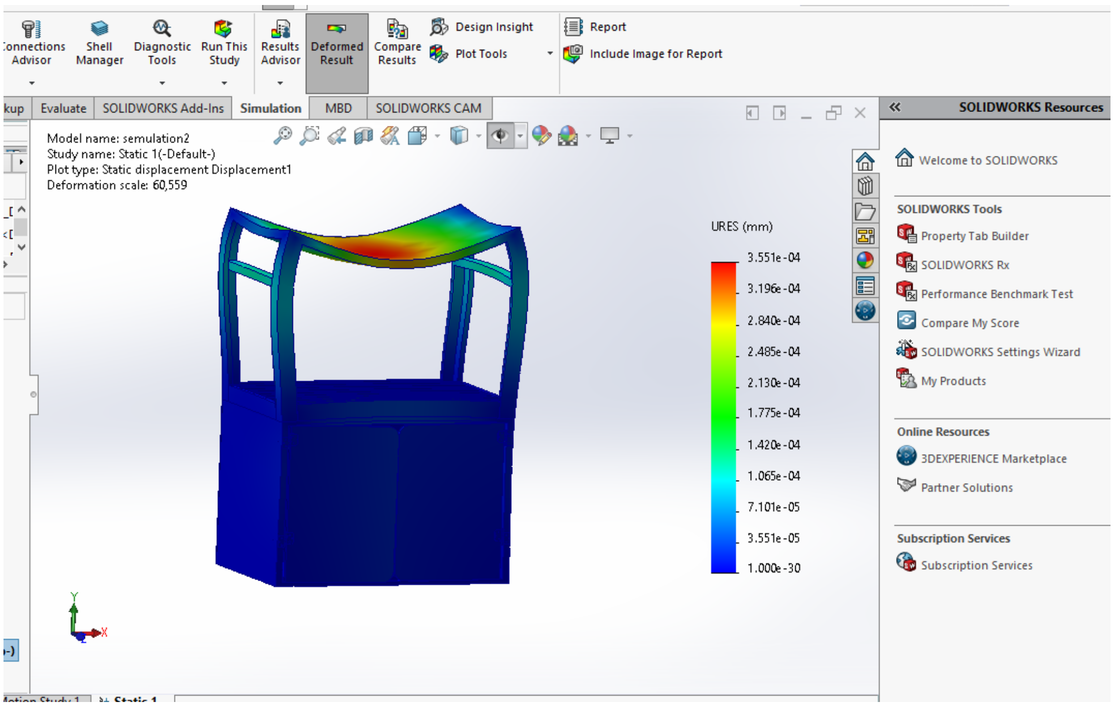


Figure 5.1 Solid Work Stress Analysis

5.4 Economic Implications

- Cost-effectiveness: The reduction in labor costs and material waste contributes to the overall cost-effectiveness of the production process. This enables local manufacturers to remain competitive in both domestic and international markets, potentially leading to increased profitability.
- Market Access: Enhanced production capabilities may allow Yemeni soap manufacturers to expand their market reach. With improved product quality and consistency, they can cater to a broader customer base, including higher-end markets that demand premium products.

5.5 Challenges and Limitations

- Initial Investment: The upfront cost of implementing automated systems can be a barrier for some small and medium-sized enterprises (SMEs). Financial assistance or subsidies may be necessary to facilitate adoption among local producers.
- Maintenance and Support: Regular maintenance of the automated system is essential to ensure long-term operational efficiency. Establishing a reliable

support network for technical assistance and spare parts is crucial to minimize downtime.

5.6 Future Research Directions

- Further Automation: Future research could explore the integration of more advanced technologies, such as IoT (Internet of Things) for real-time monitoring and predictive maintenance, to optimize production processes further.
- Sustainability Practices: Investigating the use of eco-friendly ingredients and sustainable production methods in conjunction with the automated mixing machine could enhance the environmental impact of soap manufacturing.

Chapter 6: Conclusion

6.1 Conclusion

The development and implementation of the automated liquid soap mixing machine represent a significant advancement in the soap manufacturing industry, particularly in the context of Yemen. This project addresses critical challenges faced by local manufacturers, such as inefficiency, inconsistent product quality, and high production costs, thereby paving the way for a more competitive and sustainable production model.

At the core of the machine's design is the **raw ingredient dispensing mechanism**, which utilizes separate tanks and precise dispensing controls to ensure accurate measurement of each ingredient. This automation minimizes human error and enhances consistency in the production process. By employing the ESP32 microcontroller to manage the **ingredient dispensing and mixing process**, the system allows for controlled flow rates and optimal mixing conditions. The ability to maintain temperatures between 40-60°C (104-140°F) is crucial for facilitating the necessary chemical reactions, resulting in a high-quality final product.

Following the mixing stage, the **resting and bottling processes** are designed to ensure uniformity and eliminate air bubbles, thereby improving the overall quality of the liquid soap. The closed-system design during the resting phase prevents contamination, which is paramount in maintaining hygiene standards essential in the soap industry. The **piston mechanism for bottle filling** further enhances efficiency by synchronizing the filling process with the production line, ensuring accurate dispensing without wastage.

The analysis of the machine's operation reveals remarkable improvements in **operational efficiency**. By reducing production time and optimizing resource use, the automated system enables manufacturers to meet growing market demands while enhancing profitability. The economic implications are substantial, as the machine not only reduces labor costs but also positions local manufacturers to access broader markets, including premium sectors that value high-quality products.

However, the transition to such advanced technology is not without challenges. The initial investment required for automation can be a barrier for smaller enterprises, necessitating financial support or subsidies. Furthermore, ongoing maintenance and technical support are essential to ensure the machine operates efficiently over time.

Looking ahead, there are promising avenues for future research. Integrating advanced technologies, such as IoT for real-time monitoring, could further optimize production processes. Additionally, exploring sustainable practices, including the use of eco-friendly ingredients, would align with global trends towards environmentally responsible manufacturing.

In conclusion, the automated liquid soap mixing machine stands as a transformative solution for the soap manufacturing industry in Yemen. By addressing key operational challenges and enhancing product quality, this project not only fosters greater efficiency and sustainability but also empowers local manufacturers to thrive in an increasingly competitive market. Continued investment in technology and training will be essential for maximizing the benefits of this innovation, ultimately contributing to the growth and resilience of the sector.

6.2 Future work

The current automated liquid soap production system provides an excellent foundation for efficient and high-quality manufacturing. However, to further enhance its functionality, scalability, and adaptability to diverse market demands, future improvements are planned in the following areas:

1. Integration of PLC and Touch Screen Interface:

Future iterations will incorporate a Programmable Logic Controller (PLC) to streamline and automate the production process further. This will enhance system reliability by improving control precision and reducing human intervention. A touch screen interface will also be added, providing operators with an intuitive and user-friendly way to monitor and adjust production parameters such as mixing speed, temperature, and quantity. This advanced interface will allow real-time visualization of production data, fostering improved efficiency and easier troubleshooting.

2. Development of Multiple Operational Modes:

To accommodate the growing diversity of consumer preferences, the system will be upgraded to feature multiple production modes. These modes will enable the manufacturing of various types of liquid soaps, such as antibacterial, moisturizing, or scented variants, by allowing flexible customization of ingredient ratios and production settings. This enhancement will transform the system into a versatile solution for meeting diverse market needs.

3. Incorporation of Hard Press and Oven for Solid Hand Soap Production:

The integration of a hard press mechanism and an oven will expand the system's functionality to produce solid hand soaps in addition to liquid soaps. The hard press will shape the soaps using interchangeable molds, allowing for customization in size, shape, and branding. The oven will ensure proper curing of the soap, enhancing its durability and quality. These additions will create a comprehensive, all-encompassing soap production system capable of addressing various market demands.

4. Automated Packaging System:

To further streamline the production process, future development will include the design and integration of an automated packaging system. This system will handle the filling, sealing, and labeling of both liquid and solid soap products, ensuring consistency and efficiency while reducing manual labor.

5. Energy Efficiency Improvements:

Future efforts will focus on optimizing the energy consumption of the system to align with sustainable manufacturing practices. This could include the use of energy-efficient motors, heat recovery systems for the oven, and renewable energy sources such as solar power to reduce the system's carbon footprint.

6. Remote Monitoring and Control Capabilities:

To modernize the system further, a remote monitoring and control module will be introduced. This will allow operators to oversee production and make adjustments from any location via a connected device. Such advancements will provide greater flexibility and operational oversight.

7. Scalability and Modular Design:

The system will be restructured with scalability in mind, allowing for easy expansion of production capacity by adding modules or upgrading existing components. This modular design will ensure that the system remains cost-effective and adaptable to the varying production needs of different manufacturers.

8. Implementation of Quality Control Mechanisms:

Future development will include advanced quality control features, such as sensors and cameras, to monitor product consistency and detect any defects during production. These measures will ensure high standards and reduce wastage.

9. Comprehensive Market Integration:

The ultimate goal is to create a fully integrated solution that can support large-scale production while remaining accessible to small and medium enterprises. By offering a unified system for the production of liquid and solid soaps, the project aims to cater to diverse market segments, enabling broader adoption and widespread impact.

10. Research and Development for New Soap Types:

As consumer preferences evolve, future research will focus on developing new formulations, such as eco-friendly, hypoallergenic, or medicated soaps. The system will be designed to adapt to such advancements, ensuring its continued relevance and competitiveness. [8]

These future improvements aim to enhance the system's functionality, efficiency, and sustainability, making it a versatile and adaptable solution for modern soap manufacturing needs. By integrating these advancements, the system will align with the broader objectives of innovation, resource efficiency, and market responsiveness, paving the way for a transformative impact in the soap production industry. [8]

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