REVIEW

THE ROLE OF AUTOMATION FOR EFFICIENCY IN PANNED CHOCOLATE PRODUCTION

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ABSTRACT – *With an ever-increasing demand for high-quality chocolate products, the integration of advanced technologies has become imperative for enhancing efficiency, quality, and sustainability in the production process. The application of precision machinery, smart sensors, and automated systems are employed in various stages of chocolate processing, especially in refining, conching, and molding processes. The optimization of the production line becomes more efficient and streamlined when precise and programmable equipments are utilized. By optimizing temperature control, mixing ratios, and particle size distribution, the process workflow can be fully automated and scalable, thereby increasing production efficiency. Chocolate liquid was pumped through pipes from the melting tank. Chocolate pumps are designed to handle the unique properties of chocolate, including its viscosity and temperature requirements. To ensure the quality of the chocolate, the temperature must be maintained at the right level (50°C). Temperature control mechanisms, such as heat exchangers or circulation loops, may be included in the piping system to ensure the chocolate stays at the desired temperature. Depending on the manufacturing process, liquid chocolate is piped to panned processing stations. Automated dosing will precisely measure and dispense the chocolate into the products for even coating. This type of dosing will enhance product consistency and reduce waste. Chocolate formulations and manufacturing processes can be customized to meet specific piping requirements. Automation systems can be programmed for different recipes and coating variations. This flexibility allows manufacturers to easily switch between product types without significant downtime, adapting to market demands. Chocolate types may have varying viscosities, so the piping system must accommodate these variations. By investing in automated technologies, chocolate producers could enhance their competitiveness, meet regulatory requirements, and deliver high-quality products to consumers.*

Keywords: Chocolate manufacturing, automation technology, panned chocolate production

INTRODUCTION

A recent survey of chocolate manufacturers revealed that the majority of them are using outdated machinery that lacks the capability to effectively remove impurities and reduce microbial contamination (Aebi 2009). This investigation aims to find a solution to the challenges faced by chocolate confection companies by building upon an existing model of chocolate production. The study will utilize a logical theory of technological processes and equipment, and will seek to make advancements based on current knowledge in the field of technology. The industry is increasingly turning to automation strategies to cut labour costs and improve production efficiency.

Automation is an emerging technology that has been used to carry out different tasks in industries without the necessity of human labour. The demand for chocolate in the world market makes the process of its production an important one. The difficulty in the production of chocolate using mechanical methods results in the need for innovations that will brighten the area. With automation, various challenges encountered during production will be mitigated (Anon 2023; Beckett 2009; Geschwindner & Drouven 2009). This review surveys at the way automation have been used in chocolate production and the various equipment used. Furthermore, it also looks at the cost implication of automation in chocolate production.

The integration of automation in chocolate production has significantly transformed the industry by enhancing efficiency, consistency, and scalability (Judal & Bhadania 2015). This review explores the role of automation in panned chocolate production, focusing on its impact on various stages of manufacturing and its broader implications for the industry.

Overview of Panned Chocolate Production

Panned chocolate, characterized by its smooth coating and glossy finish, requires precise and consistent production processes. Traditional methods, which rely heavily on manual labour, pose challenges in maintaining efficiency and quality (Iqbal *et al.,* 2017). Panned chocolate production involves coating chocolate-covered nuts, fruits, or other ingredients in a layer of sugar to create a visually appealing and delicious treat.

The primary objective of the base coating phase is to establish a sturdy coating layer that covers natural irregularities like the edges and tips of almonds. The optimal chocolate temperature for this process ranges between 31–35°C (88–95°F) for manual pans and 35–40°C (95–104°F) for automated pans equipped with spray systems. Compound coatings require temperatures 3–6°C (5–10°F) higher than chocolate (Iqbal *et al.,* 2017).

The process commences with loading a predetermined quantity of pre-treated centers into the pan, ensuring they are free from dust and debris. Variable speed drives, if available, are adjusted to lower settings to minimize flaking of the pre-coating from the centers. Once the pan starts, chocolate application begins immediately, followed by immediate cooling once centers are evenly coated to prevent excessive heat retention. After the first coating layer, this process is repeated three to five times, with support mechanisms in place to facilitate mixing and tumbling actions. Rapid engrossing, a critical phase, involves applying most of the coating weight, often necessitating increased pan speeds for faster product flow.

The introduction of chocolate into manual pans follows the 2/3–2/3 rule, considering product speed at its peak position. As the application proceeds, air cooling accompanies rapid chocolate application to counterbalance temperature increases in the product bed. Intermittent cooling cycles aid in maintaining optimal conditions, while the smoothing process commences after about 80 % of the total chocolate is applied. Subsequently, polishing and sealing steps are executed to enhance product appearance and integrity.

Polishing involves applying a sub-coat, typically consisting of colloids in sugar syrup, to achieve a glossy surface. The product undergoes drying and tumbling until a high gloss is achieved, after which sealing with shellac or confectionery glaze occurs. Shellac application is followed by solvent evaporation and subsequent rotation to enhance glossiness. Finally, products are stored overnight for shellac curing before packaging. Proper packaging ensures product protection from moisture transfer, scratching, splitting, and light-induced rancidity, preserving texture, flavor, and appearance. Careful handling minimizes the risk of damage to the chocolate coat, maintaining product integrity and customer satisfaction.

Traditional Panning Process

The art of panning dates back to the early days of confectionery making, where the process was largely manual (Rajesh & Mastanaiah 2015). The origins of panned chocolate can be traced to techniques used in sugar confectionery, where nuts and fruits were coated with sugar syrup. Over time, these methods were adapted for chocolate, leading to the development of panned chocolate. Traditional panning involved manually tumbling centers, such as nuts, fruits, or chocolate pieces, in rotating pans while gradually adding liquid chocolate or sugar coatings. Skilled artisans controlled the process by adjusting pan rotation speed, temperature, and the amount of coating applied, relying on their experience and intuition to achieve the desired results. The first step in traditional panned chocolate production involves preparing the centres (e.g., nuts, dried fruits, or chocolate cores). These centres must be of uniform size and quality to ensure even coating during the panning process. The centres are placed in a large, rotating pan (often made of copper or stainless steel). The coating material, typically melted chocolate or sugar syrup, is added incrementally. The rotation of the pan ensures that the centres are evenly coated. The process requires constant attention and adjustments to ensure uniform coverage and prevent clumping. After coating, the panned chocolates are dried and polished. Drying can be done at room temperature or in controlled environments to ensure the coating sets properly. Polishing involves tumbling the chocolates with glazing agents to enhance their shine and prevent sticking.

Traditional panning is highly labour-intensive, requiring skilled artisans to monitor and adjust the process continuously. This makes scaling up production challenging and increases labor costs. Manual control of the panning process can lead to inconsistencies in product quality. Variations in coating thickness, texture, and appearance are common, resulting in lower yields and higher rates of defective products. The traditional panning process is time-consuming, with multiple steps requiring precise timing and handling. This limits production capacity and responsiveness to market demands.

Belt coater

Belt coaters are predominantly used for chocolate coating. Introduced in the late 1960s, they represent an advancement from traditional coating pans designed for chocolate dragees. Unlike conventional coating pans, belt coaters utilize an endless, revolving belt, which can be made from either a stainless-steel grid or synthetic material, driven by two disk wheels. This belt carries the products evenly across its width in a low-height panning cavity, allowing for continuous motion. The belt's speed is adjustable, providing flexibility. Key benefits of this system include a uniformly distributed product bed and the elimination of dead zones. Additionally, due to the larger specific surface area, the retention and drying times are reduced (Zeng 2021).

Chocolate spraying systems

The traditional method of applying chocolate involves manually using a ladle. This approach is not only labour-intensive but also prone to inconsistencies, such as excessive chocolate accumulating in one area, which can cause products to stick together, especially light and flat items like flakes or raisins, as well as small products. To address these issues, chocolate spraying systems can be integrated into classic coating pans and belt coaters. These systems automate the chocolate panning process, significantly reducing the need for manual labor. They also decrease panning time, which is particularly beneficial for sticky products like cornflakes or coffee beans. By expediting the chocolate application, processing time can be cut by up to 50%. The spraying technique involves dispersing chocolate through a nozzle with compressed air, creating a fine spray that evenly covers a large surface area (Zeng 2021).

Impact of Automation on Production Efficiency

Quality Control

Automation significantly enhances the consistency and quality of panned chocolates by minimizing human error and ensuring precise control over every aspect of the production process. Automated systems use sensors and feedback loops to continuously monitor and adjust variables such as temperature, humidity, coating thickness, and rotation speed in real-time. This level of control ensures that each batch of chocolates meets stringent quality standards, resulting in uniform appearance, texture, and taste. Automated coating pans, for example, can be programmed to maintain exact temperature and rotation settings, which prevents issues like uneven coating or chocolate bloom. Additionally, automated ingredient mixing systems ensure that the proportions of ingredients are precise, eliminating the variability that can occur with manual mixing. These systems also allow for the precise application of coatings, ensuring that each piece is uniformly coated without excess or deficiency.

Speed and Throughput

Automated production lines drastically increase speed and throughput. Continuous operation of machinery and optimized process control allow for higher production volumes without compromising quality, meeting growing market demands efficiently. By automating repetitive and time-consuming tasks, manufacturers can significantly reduce cycle times and increase output. For instance, automated systems can handle multiple batches simultaneously, minimizing downtime between production runs without the need for breaks, leading to a significant increase in output. For instance, automated coating pans can coat hundreds of kilograms of chocolate per hour, compared to much lower quantities achieved manually.

Cost Reduction

The initial investment in automation technology for panned chocolate production can be substantial, covering the cost of advanced machinery, control systems, and integration. However, these costs are often offset by long-term savings and increased efficiency. Automated systems reduce the need for a large manual workforce, leading to significant savings in labor costs. Moreover, automation minimizes material wastage through precise dosing and control, further reducing operational costs. Maintenance costs, although present, are often lower over time due to the predictive maintenance capabilities of advanced systems, which prevent costly breakdowns and downtime.

Automation significantly impacts labor costs by reducing the number of employees needed for production. This does not necessarily mean job losses, as workers can be reallocated to more strategic roles, such as overseeing automated systems, quality control, and maintenance. Moreover, automated systems optimize the use of raw materials, ensuring that each batch uses the exact amount needed without excess. This precision reduces wastage and leads to more sustainable production practices.

Challenges and Limitations of Automation

Integration with Existing Systems

Implementing automated systems in panned chocolate production often involves integrating new technologies with existing infrastructure. This process can be complex due to compatibility issues between old and new equipment. For instance, legacy systems may not support modern control interfaces or communication protocols, necessitating extensive modifications or even complete overhauls of the existing setup. The integration process can lead to significant downtime and production halts, impacting overall productivity. The new automated equipment needed to be integrated with the facility’s existing production management software, which did not support the communication protocols used by the new machines. This required custom software development and significant modifications to the existing system.

Interoperability
Ensuring that various automated components and systems can work seamlessly together is another critical challenge. Different manufacturers often use proprietary technologies, which may not be easily compatible with each other. Achieving interoperability requires careful planning, selection of compatible components, and sometimes the development of custom interfaces or middleware. This adds layers of complexity to the implementation process and can increase the risk of operational issues if not managed correctly. For example, the robotic arms and coating pans were sourced from different manufacturers, leading to initial incompatibility in their communication protocols. To resolve this, a middleware solution was implemented to enable seamless communication between the two systems.

Software Updates and Cybersecurity Risks
Automated systems rely heavily on software for their operation and control. Regular software updates are necessary to enhance functionality, fix bugs, and improve security. However, managing these updates can be challenging, especially in a production environment where downtime must be minimized. Unplanned updates or updates that cause compatibility issues can disrupt production.

Cybersecurity is a significant concern for automated systems, particularly those connected to the Internet or internal networks. These systems can be vulnerable to cyber-attacks, which could lead to data breaches, operational disruptions, or even physical damage to equipment. Implementing robust cybersecurity measures, such as firewalls, intrusion detection systems, and regular security audits, is essential but requires continuous effort and expertise. Manufacturers had to invest in cybersecurity infrastructure, including firewalls and monitoring systems, and conduct extensive staff training on cybersecurity best practices.

Troubleshooting and Maintenance
The complexity of automated systems can make troubleshooting and maintenance challenging. Identifying the root cause of a malfunction in a system with numerous interconnected components requires specialized diagnostic tools and expertise. Additionally, maintenance of automated systems often involves more than just mechanical repairs; it requires software diagnostics and updates, calibration of sensors and actuators, and sometimes reprogramming of control logic.

This complexity means that regular maintenance and emergency repairs must be handled by skilled technicians with specialized knowledge of the automated systems in use. Training staff to this level of expertise can be time-consuming and costly, and there may be a need for ongoing education to keep up with technological advancements.

Economic and Workforce Impact
The high initial cost of automation technology can be a barrier for smaller producers. Additionally, automation may lead to workforce displacement, necessitating retraining and potential job losses. While automation can improve overall efficiency and reduce labor costs, it also requires a significant upfront investment in equipment and technology. Smaller producers may struggle to afford these costs, limiting their ability to compete with larger, more automated competitors. Moreover, the shift towards automation can have a significant impact on the workforce, with potential job losses and the need for retraining and reskilling of workers.

Adaptability and Flexibility
Automated systems may lack the flexibility to adapt to new product variations or custom orders, which can be a concern for producers aiming to offer a diverse product range. Customization of automated processes to meet specific product requirements can also pose challenges. While automation can improve efficiency and consistency, it may also limit the ability of manufacturers to quickly respond to changing market demands or produce small batches of specialized products. This can be particularly challenging for producers who rely on product differentiation and customization to attract and retain customers.

Future Trends and Innovations

Advancements in Technology
Emerging technologies, such as advanced robotics, Artificial intelligence (AI), and machine learning, promise further enhancements in efficiency and precision. Innovations in sensor technology and data analytics are expected to drive continued improvements in panned chocolate production processes. For example, AI and machine learning algorithms can analyze production data to identify patterns and optimize processes, while advanced sensors can provide real-time feedback on critical parameters such as temperature, humidity, and coating thickness.

Sustainability and Automation
Automation plays a crucial role in promoting sustainability by optimizing resource use, reducing energy consumption, and minimizing waste. Sustainable automation practices are becoming increasingly important in response to environmental concerns and consumer demand for eco-friendly products. By reducing waste and energy consumption, automation can help manufacturers reduce their environmental impact and meet sustainability goals. Additionally, automation can

improve traceability and transparency in the supply chain, enabling manufacturers to track and report on their environmental performance.

Market Trends and Consumer Preferences

The ability to produce high-quality panned chocolate at scale while maintaining flexibility for customization is a key competitive advantage. As consumer preferences continue to evolve, manufacturers must be able to adapt quickly to new trends and demands. Automation can help achieve this by improving efficiency and enabling faster product development and production.

Process Automation

Process automation in panned chocolate production refers to the use of technology to automate various production steps, such as ingredient mixing, coating, and drying, with minimal human intervention. Key examples include automated coating pans, which rotate to coat centers like nuts or fruits with precise control over temperature, rotation speed, and coating material flow; ingredient mixing and dosing systems that ensure accurate mixing and dosing; and drying systems that maintain consistent temperatures and humidity levels for proper coating setting. The benefits of process automation include increased efficiency by reducing production time, enhanced consistency and quality through uniform coating, cost savings from reduced labor costs and material wastage, and scalability to meet increased demand. However, challenges include the high initial investment for setup, the need for specialized technical expertise to operate and maintain systems, and the requirement for regular maintenance, which can cause production downtime.

Robotics and Machinery

In panned chocolate production, robots and specialized machinery are essential for automating tasks that require precision, speed, and consistency, such as coating, enrobing, and packaging. Modern coating pans are equipped with temperature control, automated spray nozzles for even coating distribution, and variable speed settings to accommodate different coating materials. Enrobers coat products by passing them through a curtain of liquid chocolate, ensuring an even and thorough coating. Automated conveyors transport products through various production stages, facilitating smooth transitions and reducing manual handling. Additionally, robotic arms perform tasks such as sorting, packaging, and palletizing finished products, enhancing speed and accuracy while minimizing human error.

Control Systems and Software

Advanced control systems and software are essential for real-time monitoring and optimization in modern panned chocolate production. These systems utilize sensors and feedback loops to automatically adjust critical parameters such as temperature, humidity, and coating thickness, ensuring consistent product quality and efficiency. SCADA (Supervisory Control and Data Acquisition) systems offer comprehensive control and monitoring capabilities, overseeing the entire production process from ingredient input to final packaging. PLCs (Programmable Logic Controllers) are deployed to automate specific processes within the production line, ensuring precise control, coordination, and seamless operation of various production stages. Together, these advanced systems enhance the accuracy, reliability, and efficiency of panned chocolate production.

Integration of Internet of Things (IoT) and AI in Production Systems

The integration of IoT and Artificial intelligence (AI) technologies has significantly enhanced the capabilities of automated systems in panned chocolate production. IoT (Internet of Things) devices, such as sensors and smart machines, collect data throughout the production process, facilitating real-time monitoring and predictive maintenance that reduce downtime and improve efficiency. AI (Artificial Intelligence) algorithms analyse this data to identify patterns, predict equipment failures, optimize resource usage, and adjust production parameters to improve quality and reduce waste. The benefits of integrating IoT and AI include predictive maintenance, where AI schedules maintenance proactively to avoid unexpected downtime; enhanced quality control through continuous monitoring by IoT sensors; improved operational efficiency with AI-driven real-time adjustments; and data-driven decision-making supported by insights from IoT-collected data. However, the integration of these technologies also presents challenges such as the complexity and technical expertise required for implementation, ensuring data security to prevent unauthorized access and cyber threats, and the high initial investment costs, which are often justified by long-term gains in efficiency and productivity.

Technological Evolution in Panned Chocolate Manufacturing

The technology behind panned chocolate production has undergone significant evolution over the decades, resulting in enhanced efficiency, consistency, and product quality. The first significant advancements in panned chocolate manufacturing involved the introduction of mechanized equipment to assist with the panning process. Early innovations included motorized pans and automated heating systems, which reduced the need for manual labor and improved control over the process. These machines allowed for more uniform coating of chocolate on nuts, fruits, and other centers, reducing labor intensity and increasing production capacity. Next evolution of technology saw the development of continuous coating pans, which could operate non-stop, unlike the batch processes of earlier machines. This innovation was driven by the demand for higher output and better control over the coating process. Continuous coating pans improved the efficiency of the panning process, significantly increasing the throughput and consistency of the coated products. Introduction of precision dosing systems enables exact measurement and control of the coating materials applied which integrated into panning machines (Löser 2009; Rajesh & Mastanaiah 2015). This development was crucial in achieving consistent product quality as precision dosing minimized waste and ensured uniform coating thickness, enhancing both the appearance and taste of the final products. Modern automated coating pans are equipped with sophisticated control systems that regulate temperature, humidity, and rotation speed, ensuring consistent coating application and minimizing the need for manual adjustments (Sandey *et al.,* 2017). Temperature control systems ensured that the coating materials remained at the ideal viscosity, preventing issues such as melting or hardening too quickly. This development improved the overall quality and shelf life of panned chocolates. The advent of computerized control systems marked a major milestone in automation. These systems allowed for precise control over all aspects of the panning process, including rotation speed, temperature, humidity, and coating material flow. Computerized control systems integrated with sensors enabled real-time monitoring and adjustments, leading to highly consistent and reproducible results. This automation reduced the need for skilled labor and minimized human error. The integration of Internet of Things (IoT) and smart technologies brought about a new era of connectivity and data-driven production. IoT-enabled machines could communicate with each other and with central control systems to optimize the panning process. IoT and smart technologies facilitated predictive maintenance, reduced downtime, and optimized resource usage. This level of automation enhanced overall efficiency and allowed manufacturers to quickly adapt to changes in production demands.

CONCLUSIONS

Automation has fundamentally transformed panned chocolate production, offering significant benefits in terms of efficiency, quality control, and cost reduction. While challenges remain, particularly regarding technical complexities and workforce impacts, the continued advancement of automation technologies holds great promise for the industry's future. By embracing automation, chocolate manufacturers can enhance their production capabilities, meet growing demand, and maintain high standards of quality and sustainability.

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