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Research Article

Implementing Total Dissolved Solids Automation in the 1st Leaching Station for Rubber Glove Manufacturing

Nattapong Chotipan and Ratta Chotipan *

Department of Industrial Enginerring, Faculty Engineering, Princess of Naradhiwas University, Mueang, Narathiwat 96000, Thailand.

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ABSTRACT

This research implemented a Total Dissolved Solids (TDS) automation control system to regulate TDS levels and water flow rates in the first leaching tank. The integration of TDS sensors enables real-time monitoring of dissolved solids in the water an essential component of automation that can be incorporated into a Supervisory Control and Data Acquisition (SCADA) system.The implementation of this system has improved glove quality while optimizing water usage in the production process. Prior to its deployment, the company experienced unplanned downtime due to ineffective TDS control, leading to defects such as sludge accumulation (SD), dirt contamination (D), and discoloration (DC) in the gloves. High concentrations of dissolved solids, including minerals, salts, and heavy metals, were identified as key contributors to these defects.The objectives of this study were to install a TDS automation system, regulate water flow rates, and record TDS and flow rate data through SCADA integration. This approach aimed to minimize non-value-added processes, reduce water consumption, and prevent unplanned downtime caused by TDS-related glove defects. The findings demonstrate that the system effectively reduces water consumption by approximately 5 liters per minute (a 25% reduction) and eliminates unplanned downtime associated with water quality issues at the leaching tank by improving TDS automation control by nearly 100%. The implementation of this system has led to significant cost savings, including reductions in non-value-added costs, water expenses, and unplanned downtime, totaling approximately 308,457.78 baht per month. The return on investment (ROI) was achieved within 0.33 months, highlighting the system's effectiveness in enhancing operational efficiency and reducing production costs.

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1. Introduction

Allergies resulting from residual rubber chemicals in compounding ingredients are classified as Type IV allergies or chemical sensitivities, which affect the skin (Knudsen, *et al.*, 2000; Nettis *et al*., 2002; Chen *et al.*, 2004). One of the most practical and cost-effective ways to minimize allergenic proteins and skin-sensitive chemicals in rubber gloves is by implementing an appropriate washing process during manufacturing (Figure 1). This process, known as leaching, involves washing the gel formed on the glove former with flowing water at an elevated temperature to remove most chemicals before drying. The dried film then undergoes

*** Corresponding author.**

E-mail address: *ratta.c@pnu.ac.th*

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a similar washing process while still on the manufacturing line to remove any leachable proteins from the latex film surface before being dried again and stripped from the former (Aksoy *et al.*, 2023; Yatim, 2002). Leaching is a process in which rubber gloves are cleaned in hot water (55-65°C). Water direction and the fresh water ratio controlled by water overflow, using a manual flow rate meter to maintain the water level. Water is regulated for a few minutes to remove chemical, biological, and dissolved solids residues (Abdullah and Yatim, 2014). TDS is typically measured in milligrams per litre (mg/L) or parts per million (ppm). TDS is defined as the amount of minerals, salts, metals, organic compounds, and other substances that can be dissolved in water. The effects of leaching are observed in the glove's appearance and properties, including improved film clarity, reduced discoloration, significantly lower protein content, and enhanced physical properties (Abdullah and Yatim, 2014).

Effective leaching protocols are critical in glove manufacturing. Typically, there are two types of leaching processes: wet gel leaching at station number 6 (Figure 1) and dry film leaching at station number 10 (Figure 1). Wet gel leaching involves washing deposits while the gel is still wet before curing. During this process, water is absorbed into the rubber through capillary action, dissolving soluble materials and carrying them out of the wet films under continuous water flow. This stage benefits from the osmotic effect, which enhances the extraction of soluble materials (Abdullah and Yatim, 2014; Lovato *et al.*, 2023). This indicates a greater extraction of soluble materials in water compared to the dry gel leaching method, resulting in an increased production of total dissolved solids in water. This research exclusively examines and initially implements wet gel leaching.

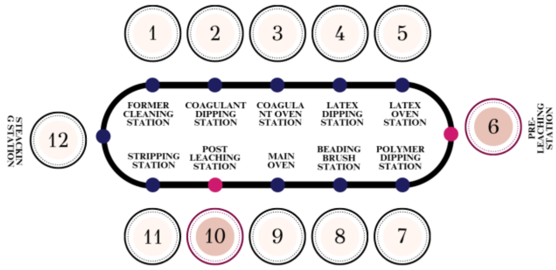

Figure 1 Typical manufacturing process in a glove production line.

1. Measurement of Total Dissolved Solids (TDS)

The quantification of Total Dissolved Solids (TDS) is essential for assessing water quality in environmental science and engineering disciplines. Conventional methods, such as gravimetric analysis and electrical conductivity correlation, have been widely utilized; however, they exhibit notable limitations, including time consumption, sample dependency, and detection constraints. This study introduces a novel approach to TDS measurement using charged aerosol detection without the need for chromatographic separation. The proposed method offers several advantages, including rapid analysis, minimal sample volume requirements, and enhanced sensitivity, achieving a detection limit as low as 0.054 mg/L (Gilmore *et al.*, 2016). This technique represents a significant advancement in water quality analysis, providing a more efficient and precise alternative to traditional methodologies.

2. Optimization of Leaching Tank Water Quality Control in Industrial Processing

The first leaching tank was designed using stainless steel and featured an I-shaped configuration, diverging from conventional fixed fresh water flow rate systems. Instead of a continuous 20 LPM fresh water top-up with an overflow mechanism, the system required manual intervention for water quality control. The tank's water wtemperature was maintained within a standardized range of 55 to 70°C through a heat ex-changer utilizing hot oil as the primary heat source. Quality assurance personnel conducted daily manual sampling to assess TDS levels in the leaching tank. If the measured TDS met or exceeded the predefined standard limit or control specification, the quality

Figure 2 Original sampling point procedure at the leaching tank.

assurance team immediately alerted production personnel, who manually adjusted the fresh water inflow to restore TDS parameters within acceptable limits. The original sampling point procedure for the leaching tank is illustrated in Figure 2. This method underscores the necessity of continuous monitoring and manual regulation to ensure process stability and product quality.

3. Challenges in Manual TDS Monitoring and Control

Historically, production experienced high unplanned downtime due to TDS levels exceeding the specification limit, occurring more than six times per month. Process analysis revealed that quality control inspectors measured TDS once daily, leading to delayed issue resolution. When TDS levels exceeded the control specification limit (2300 ppm), approximately 203 minutes of unplanned downtime was required to address sludge-related defects. Alternatively, restoring TDS levels to the standard control specification through manual adjustment of the flow rate valve could take up to eight hours. This manual approach increased the likelihood of human error and compromised process control efficiency.

4. Implementation of Automated TDS Monitoring and Control

To enhance the leaching process, this study proposes the integration of a Total Dissolved Solids (TDS) sensor into the first leaching tank of the rubber gloves production line (Bhardwaj and Gurpreet, 2022; Biswa *et al*., 2022; Senthil and Pemmasani, 2022). The TDS sensor provides continuous measurement of TDS concentrations, ensuring that operations remain within specifications and maintain high-quality rubber gloves (Adjovu *et al*., 2013; Meena, 2024). This automated approach improves upon the existing method, which relies on manually adjusting the flow rate to dilute solids.

Under the manual system, TDS levels were monitored by quality assurance inspectors only once daily. If TDS exceeded the specified limit ($\geq$2500 ppm), restoring it to control specifications could take up to eight hours, increasing non-value-added activities and operational costs (Pasika and Gandla, 2020). The implementation of continuous TDS measurement mitigates these inefficiencies, enhances product quality, and reduces costs by providing real-time data and automated adjustments (Akram *et al*., 2022).

5. System Integration with SCADA for Optimal Process Control

The proposed system ensures that the correct amount of water is consistently added to the leaching tank. Water flow rates are automatically adjusted in response to TDS fluctuations: the flow rate increases when TDS levels exceed a predefined threshold and decreases when levels fall below the set point. This system is integrated with a Supervisory Control and Data Acquisition (SCADA) system to facilitate real-time monitoring and control of the rubber glove manufacturing process (Alihussein and Abedalati, 2003; Saravanan *et al*., 2018; Moleda *et al*., 2020). The implementation of automated TDS regulation minimizes human intervention, enhances process efficiency, and ensures compliance with quality standards.

2. Materials and Methods

The design of the TDS sensor control system is illustrated in Figure 2. The working principle of the system begins with writing the control program on the computer with the program under the desired This program is then sent to the PLC set for use in controlling the operation of the TDS Sensor and transmit TDS value data via the Internet. The system also enables monitoring and control through monitoring equipment, which manages the TDS automation system via the crystal brand are changed to “server. This setup allows for system monitoring, control, and alert notifications.

To improve the leaching process, a TDS sensor will be installed in the first leaching tank of the rubber glove production line to measure the concentration of the dipping tank solution. Additionally, an automated valve for fresh water topping-up will be installed, and a Programmable Logic Controller (PLC) will be designed to control the TDS parameter and integrate it with the SCADA system.

The approach of the automated TDS control system is illustrated in the flowchart (Figure 4). Based on our evaluation, with a leaching tank capacity of 2,400 liters, the automated valve will open to increase the flow rate to 30 liters per minute (LPM) if the TDS concentration surpasses the standard control specification (≥2,300 ppm), as shown in the TDS control diagram in Figure 2. Conversely, the automated valve will reduce the flow rate to 15 LPM if the TDS concentration drops below the threshold (≤1,500 ppm). (Figure 4)

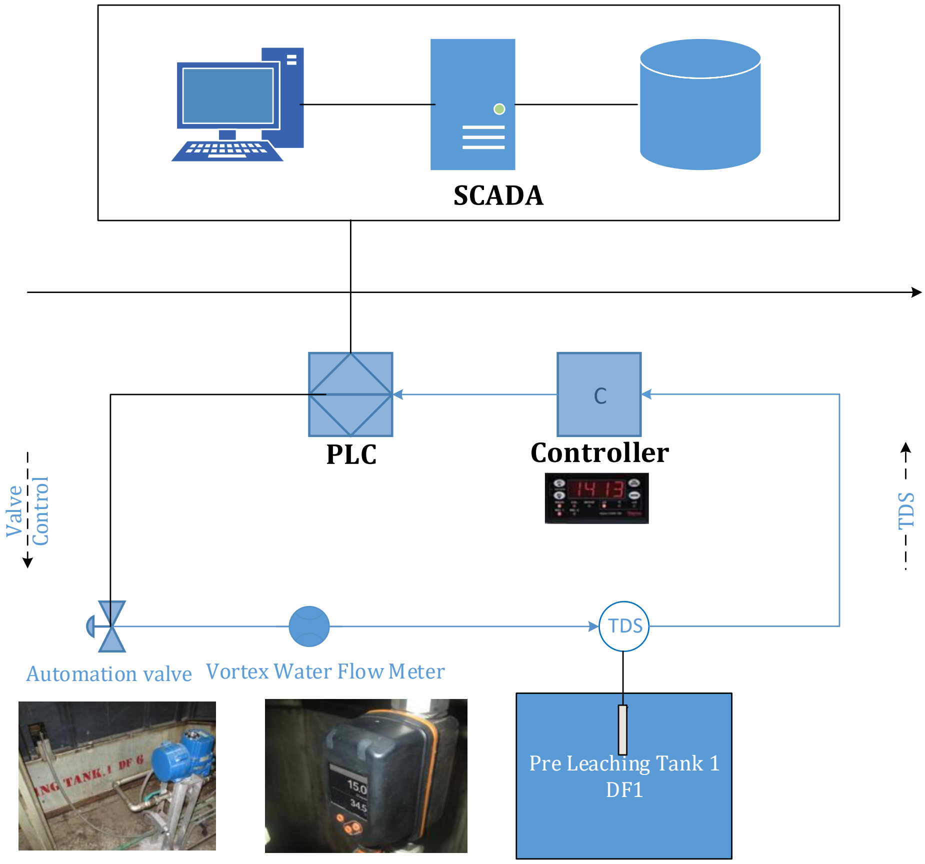

Figure 3 The SCADA Synchronize system.

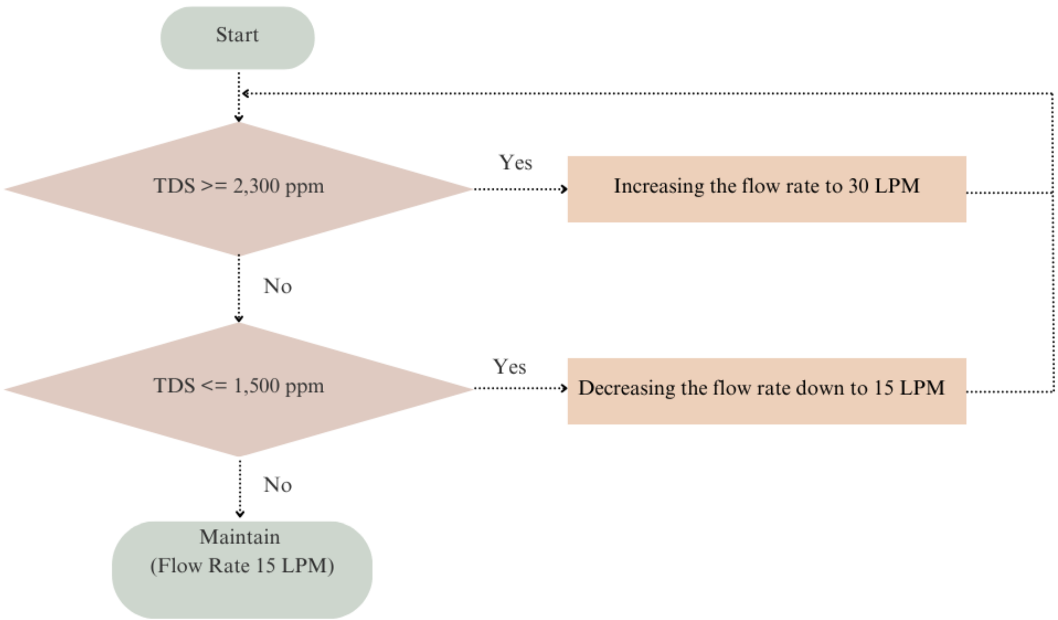

Figure 4 TDS control Diagram.

Table 1 Equipment List.

No	Description
1	TDS controller Model:ALOHA TDS 190 with sensor
2	Electric wire model: JZ-500 SQMM "PRYSMIAN
3	Control Cabinet model:CB-03 "TAMCO"
4	Fan Model: PMV 12.00 size 50 cm."Omron"
5	ANALOG I/O UNIT MODEL : CJ1W-DA041 “OMRON”
6	BALL VALVE with motorized actuator

The leaching process needs to be improved by installing a TDS sensor in the first leaching tank of the rubber glove production line to measure the concentration of the dipping bath solution, installing an automated valve (Alihussein and Abedalati, 2003), and designing a PLC to control the TDS parameter and link it to SCADA (Dobriceanu *et al*., 2008; Singh and Walingo, 2024).

Real-time TDS monitoring and automatic adaptive flow rate control will be implemented and integrated into the SCADA system.

3. Results and Discussion

The results include two components: the adoption of the TDS system and cost savings, both referenced in relation to Return on Invested Capital (ROIC).

3.1 The TDS system implementation

As previously mentioned regarding the use of a SCADA screen within this chapter, the user interface and all of the details can be observed (Zainurin et al., 2022), as shown in Figure 5. This application will be continuously updated, and readings can be checked at any time using the storage system. If the TDS level in the leaching tank station suddenly raise above the threshold value, an automated warning message will be sent to the concerned authorities’ SCADA screen at the front of the production line as shown in Figure 5.

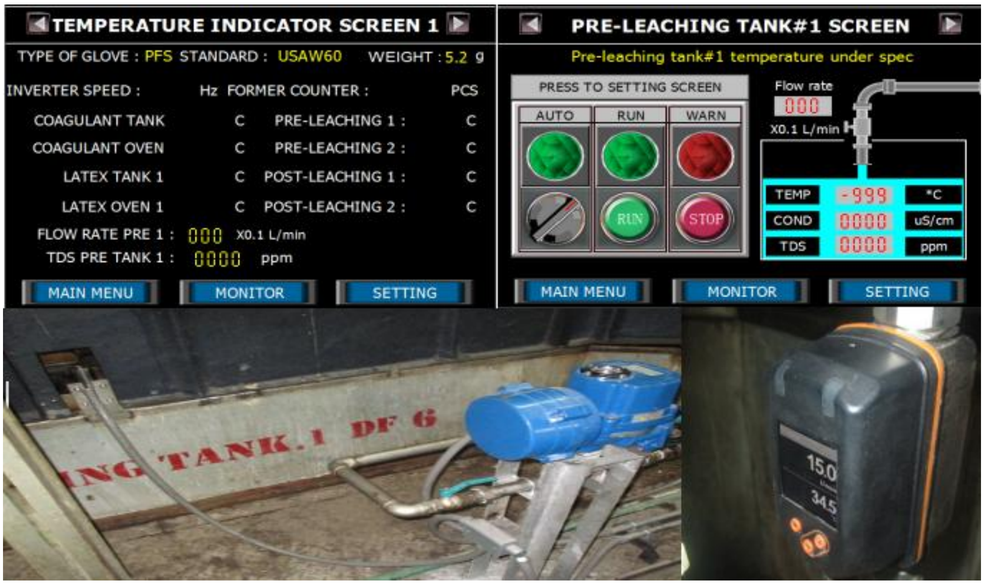

Figure 5 TDS and water flow rate which synchronized to SCADA

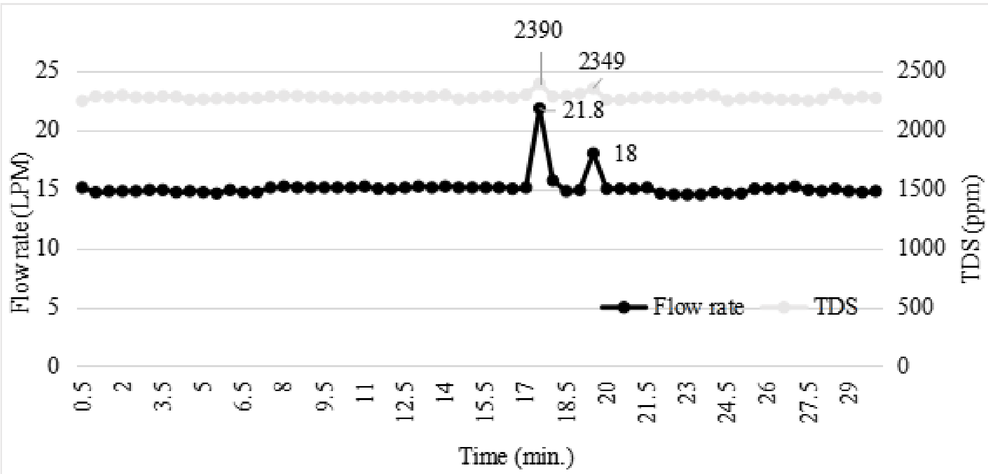

Figure 6 The consistent trend of TDS and water flow rate in real time.

The chart referenced in Figure 4 shows the TDS and water flow rate, which are linked to SCADA, the automated valve, and the TDS sensor, respectively. These figures illustrate the component installation.

The TDS system was observed, and the automated system adjusted the flow rate, successfully restoring TDS levels within the desired range. The effectiveness of the proposed TDS system is evaluated in terms of TDS, and flow rate levels. Sensor readings are used for this evaluation. These graphs are automatically generated to provide users with a clear understanding of all stored data. They are continuously updated as new data is sent to the storage system.

The results for this model are shown in the various figures available in this section. Figures 6-8 display the graphs obtained from measurements recorded at 30-second intervals under controlled conditions, ensuring that TDS levels remained at or below 2300 ppm while maintaining a consistent flow rate of 15 LPM.

Figure 6 displays the TDS data obtained from the sensors incorporated into the proposed model. Flow rate data is shown on the primary axis, and TDS data is shown on the secondary axis, and time is represented on the X-axis. The values are presented in the graph based on time.

Figure 6 presents real-time data collected at 30-second intervals, illustrating the relationship between Total Dissolved Solids (TDS) and water flow rate under controlled conditions. Initially, TDS levels were maintained at or below 2,200 ppm, with a constant flow rate of 15 liters per minute (LPM). At approximately 17.5 seconds, a significant deviation occurred: TDS levels rapidly escalated to 2,390 ppm. In response, the system promptly increased the flow rate to 21.8 LPM, effectively reducing the TDS back to standard levels within 2 seconds.

Measurements were taken at hourly intervals under controlled settings, ensuring that TDS levels did not exceed 2300 ppm while maintaining a constant flow rate of 15 LPM.

Figure 7 displays the TDS data obtained from the sensors incorporated in the proposed model. Flow rate data is shown on the primary axis, TDS data on the secondary axis, and time on the X-axis. The values in the graph are presented based on the date. It illustrates that the system can automatically adjust according to the design specifications. The chart shows that the water flow rate increases automatically when the TDS of the leaching tank exceeds the set point, and decreases once the TDS falls back within the set point.

Measurements were taken at 40-minute intervals under controlled settings, ensuring the TDS system's automatic adjustment capabilities according to control specifications

Figure 8 displays the TDS data obtained from the sensors incorporated in the proposed model. Flow rate data is shown on the primary axis, TDS data on the secondary axis, and time on the X-axis. The values in the graph are presented based on time. Figure 8 illustrates the deviation that occurred: at the beginning of the graph, TDS levels escalated to 2,395 ppm. In response, the system promptly increased the flow rate to 28.4 LPM, and after around 40 minutes, the TDS levels reduced to 2,053 ppm.

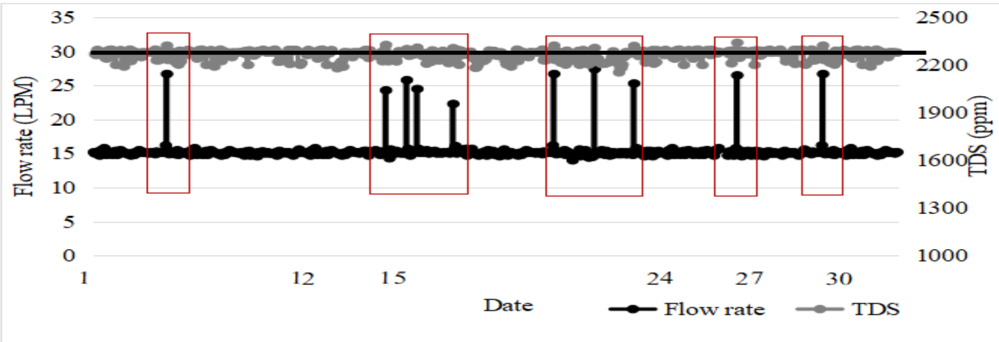

Figure 7 The system can be adjudicated automatically according to the design.

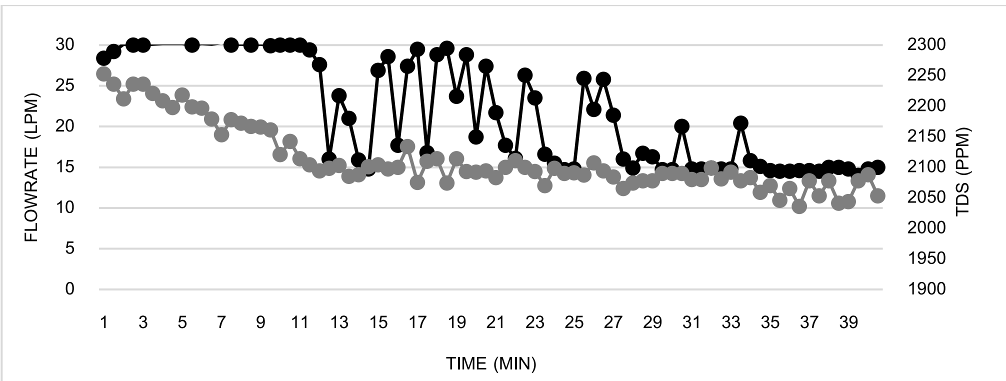

Figure 8 The system can be adjudicated automatically according to the design within 40 minutes.

It illustrates that the system can autonomously adjust in accordance with the design within 40 minutes. Following the implementation of the TDS control automation system, production is no longer dependent on manual adjustments. The TDS automation system efficiently regulates TDS to meet control standards in about 40 minutes for each case, resulting in a time reduction of around 7 hours and 20 minutes compared to 8 hours required with the old technique, while also realizing cost savings on water.

3.2 Economic Benefits and Return on Investment

This study illustrates that the operational expenses associated with rubber glove manufacturing can be markedly reduced through a cost-consequences analysis of unanticipated downtime resulting from TDS parameters exceeding control specification limits (Sobotka and Sagan, 2016; Guzman, 2025). A successful outreach facilitation was conducted, considering the projected cost savings from the implementation of the TDS system, which included reductions in non-value-added activities costs, water expenses, and unplanned downtime as following:

3.3 Time spent on non-value-added activities.

As previously indicated, the TDS parameter exceeded the specification limit, resulting in substantial unplanned downtime for production, which occurred on average more than six times each month. After examining the procedure, we concluded that TDS is measured by process quality control inspectors once daily. Since it was too late to address the issue at that point, the production team immediately added personnel to tighten monitoring and sampling eight times daily while awaiting the installation of the new TDS automation system. The cost of these non-value-added activities, based on the time spent, is shown in Table 2, and the cost of non-value-added activities is detailed in Table 3.

Table 3 show the production department can reduce the cost for non-value-added activities, with a value of 307.98 THB/month.

Table 2 Time spent on non-value-added activities.

Item	Description	Time	Unit	Remark
1	Time to stay alerted TDS by worker.	10	Min/Time	
Total time spent on non-value-added activities		**10**	Min/Time	

Table 3 The cost for non-value-added activities.

Item	Description	Price	Unit	Remark
Cost for non-value-added activities				
1	1 person x 10 minutes per time x 8 times x (38.5 THB / 60 minutes)	51.33	THB/Cases	
2	Average 6 cases per month x 51.33 THB/cause	307.98	THB/Month	
The cost for non-value-added activities		**307.98**	THB/Month	

Table 4 Number of Water saving.

Item	Description	QTY	Unit	Remark
1	Water saving	5	Liter Per Minute	
	Water saving 5 LPM x 60 minutes	300	Liter Per Hour	
Total number of water savings for 8 hours		**2,400**	Liter Per 8 Hours	

Table 5 Water saving cost.

Item	Description	Price	Unit	Remark
Water saving: 2,400 liters per 8 hours.				
1	2,400 L x 0.2904 THB Per Liter	696.96	THB/Cause	
2	Average 6 Causes per month x 696.96 THB per cause	4,181.76	THB/Cause	
Total water saving cost		**4,181.76**	THB/Month	

Table 6 Duration time for the restoration process each unplanned downtime resulting from TDS-related glove defects.

Item	Description	Time	Unit	Remark
Duration time for the restoration process				
1	Stop production to clear the gloves.	30	Minute	
2	Drain contaminated water of 2,400 liters each tank.	18	Minute	
3	Clean tank.	20	Minute	
4	Add fresh water contaminated water of 2,400 liters.	90	Minute	
5	Heat temperature up to set point.	15	Minute	
6	Start running the production line until you get the first piece of glove.	30	Minute	
Total duration time for the restoration process.		**203**	Minute/Time	

3.4 Water expenses

As mentioned above, in order to keep the TDS parameter within specification at the leaching tank station, we use a set flow rate of 20 LPM to regulate the concentration of chemicals dissolved in water. Following the installation of the TDS automation system, we are able to sustain a flow rate of at least 15 LPM. Water expenses must be calculated based on the liters of water used each minute. Since the water savings amount to 5 liters per minute based on the previously practiced problem-solving that took around 8 hours, this is shown in Tables 4 and 5.

Table 5 shows the production department can reduce the cost of water savings, with a value of 4,181.76 THB per month.

3.5 Unplanned downtime cost.

Unplanned downtime in the production process necessitates halting the production line, draining contaminated water containing persistent microbes and chemical residues, cleaning the tank, replenishing it with fresh water, and reheating it to the required temperature. This restoration process takes approximately 203 minutes, during which production is suspended, resulting in an output loss of approximately 20 cartons per 60 minutes. Given a cost of 728.09 baht per carton, the financial impact of this downtime is substantial, as shown in Table 6 and 7.

On average, TDS-related glove defects lead to unplanned downtime occurring more than six times per month. The associated costs must be assessed based on the time required for rectification and the financial loss incurred due to reduced glove production.

Table 7 Unplanned downtime cost.

Item	Description	Price	Unit	Remark
Unplanned downtime cost				
1	Financial loss incurred due to output loss - Duration time for the restoration process: 203 minutes. (Production capacity is 20 cartons / 60 minutes) - Output loss of approximately 20 cartons per 60 minutes. $= \left(\frac{203\ x\ 20}{60}\right)$ = 67.66 cartons / 143 minutes - Glove cost of 728.09 baht per carton $= 67.66\ x\ 728.09$ $= 49{,}267.42$ THB / Downtime	49,267.42	THB/Downtime	
2	- Water usage lost cost - Drain contaminated water of 2,400 liters each tank - Water cost 0.2904 THB Per Liter $= 2{,}400\ x\ 0.2904$ = 696.96 THB	696.96	THB	
3	- Water usage lost cost - Fresh water water of 2,400 liters each tank - Water cost 0.2904 THB Per Liter $= 2{,}400\ x\ 0.2904$ = 696.96 THB	696.96	THB	
4	Total lost cost = Item 1 + Item 2 + Item 3 $= 49{,}267.42 + 696.96 + 696.96$ = 50,661.34 THB Per Causes	50,661.34	THB/Downtime	
2	Average unplanned downtime cost. (6 times / Month x 50,661.34 THB/Downtime)	**303,968.04**	THB/Month	
Total unplanned downtime cost		**303,968.04**	THB/Month	

Table 7 shows the production department can save on the cost of unplanned downtime, with a value of 303,968.04 THB per month.

Return of Investment Cost.

- The total cost for this project is around 100,837 Baht.
- Cost savings per month are around 308,457.78 Baht.

$$\mathrm{ROI} = \frac{100{,}837\ \mathrm{Baht}}{308{,}457.78\ \mathrm{Baht/Month}}$$

$$\mathrm{ROI} = 0.33\ \mathrm{Month}$$

3.6 Economic Benefits and Return on Investment

The implementation of the automated TDS control system has led to significant cost savings. Specifically, non-value-added activities have been reduced, resulting in monthly savings of 307.98 THB, while water costs have been reduced by 4,181.76 THB per month. Additionally, unplanned downtime expenses have been lowered by 303,968.04 THB per month. The total cost savings amount to approximately 308,457.78 THB per month, achieving a return on investment (ROI) within 0.33 months. These economic benefits underscore the financial viability and efficiency improvements associated with the automated TDS control system and SCADA integration.

4. Conclusion

The optimization of TDS measurement and leaching tank water quality control is critical for improving industrial processes, particularly in rubber glove manufacturing, as it is the most effective method to minimize undesirable materials in rubber gloves. The integration of automated TDS sensors and SCADA-based process control significantly reduces downtime expenses, minimizes non-value-added activities, resulting in monthly savings of 307.98 THB, and reduces water costs by 4,181.76 THB per month. The total cost savings amount to approximately 308,457.78 THB per month, achieving a return on investment (ROI) within 0.33 months. These economic benefits underscore the financial viability and efficiency improvements associated with automated TDS control and SCADA integration, while ensuring consistent product quality. Furthermore, this research highlights the role of TDS sensors in detecting microbial contaminants, chemical residues, and variations in dissolved solids, which have historically been overlooked as a critical control point (CCP) in the rubber glove industry.

For this research, only wet gel leaching has been studied and implemented. Further research will require a combination of leaching protocols, both wet gel and dry film leaching. Leaching also results in gloves possessing improved physical properties. By implementing a proactive, automated approach to TDS management, manufacturers can achieve substantial cost savings, enhance process efficiency, and ensure compliance with stringent quality standards. The integration of real-time monitoring systems and SCADA-based automation represents a significant advancement in industrial process optimization, contributing to more sustainable and reliable manufacturing operations.

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