ADVANCES IN AGRICULTURAL AND FOOD RESEARCH JOURNAL

Original Research Article

Efficient Sanitation Strategies: Optimizing Cleaning in Place Parameters for Milk Fouling Deposit Mitigation

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Abstract: Cleaning-in-place (CIP) operations necessitate optimization to maximize the efficiency of cleaning detergents while minimizing cleaning time. Therefore, this research endeavours to enhance CIP methodologies for effectively addressing milk fouling deposits in dairy industry settings. Through strategic manipulation of cleaning parameters, including sanitation temperatures, detergent-to-water ratios, and fluid velocities, the study aims to optimize the removal of milk fouling deposits during the detergent cycle phase of the CIP process. To achieve this, a physical model mimicking milk fouling deposits was developed using raw milk to replicate real-world industrial conditions. Subsequent controlled laboratory experiments, guided by Response Surface Methodology (RSM), were conducted to evaluate the impact of varying sanitation temperatures (30°C, 50°C, or 70°C), cleaning detergent-to-water ratios (0:1, 1:100, or 1:50), and fluid velocities (0.6, 0.9, or 1.5 m/s) on the efficacy of milk fouling deposit removal. The results reveal that optimal conditions, characterized by a temperature of 60°C, a detergent ratio of 1:90, and a fluid velocity of 1.5 m/s, significantly reduce the detergent cycle time to 12 minutes, ensuring complete elimination of milk fouling deposits from stainless-steel surfaces. These findings suggest potential cost efficiencies and promise improved operational effectiveness in dairy industry sanitation practices. Moreover, the study underscores the critical role of temperature and fluid velocity in enhancing cleaning efficacy, offering valuable insights for enhancing CIP processes within dairy facilities.

Keywords: industrial hygiene; cleanliness; sanitation efficiency; cross-contamination prevention; stainless-steel surfaces.

Received: 9th June 2024

Accepted: 24th October 2024

Available Online: 16th January 2025

Published: 15th May 2025

Citation: Asming, N. A. A., Khalid, N. I., Ab Aziz, N., *et al.* Efficient sanitation strategies: Optimizing cleaning in place parameters for milk fouling deposit mitigation . *Adv Agri Food Res J* 2025; 6(1): a0000546. https://doi.org/10.36877/aafrj.a0000546.

1. Introduction

The exacting standards for sanitation and hygiene in food processing industries, notably in dairy processing plants, highlight the pivotal significance of efficient cleaning protocols. Implementing sanitation programs in the food industry is obligatory to uphold food safety standards throughout production processes, as mandated by Regulation 9: Food Safety Assurance Program, Food Hygiene Regulation 2009, enacted following Section 34 of the Food Act 1983, Malaysia. Sanitation is imperative within the food industry to uphold safe food production standards, as mandated by Regulation 15: Cleanliness of food premises, Food Hygiene Regulation 2009, enacted by Section 34 of the Food Act 1983, Malaysia. Maintaining pristine sanitation standards is imperative not only for regulatory compliance but also for safeguarding consumer health and ensuring the integrity of food products (Silva *et al*., 2023). In this context, the CIP process has emerged as an indispensable tool, offering a non-disruptive means of cleaning equipment while minimizing downtime and labour costs (Palabiyik *et al*., 2014). The standard CIP process widely employed in food industries typically consists of sequential steps: (1) pre-rinse, (2) alkaline treatment, (3) water rinse, (4) acid treatment (optional), and (5) final rinse (Khalid *et al*., 2016).

However, despite the widespread adoption of CIP methodologies, challenges persist in achieving optimal cleanliness, particularly concerning removing stubborn milk fouling deposits. These deposits, resulting from the complex composition of dairy products, pose significant hurdles to sanitation efforts due to their tenacious adhesion to surfaces and resistance to conventional cleaning (Zhang *et al*., 2024). Moreover, inadequate equipment cleaning can lead to microbial contamination, compromising product quality and safety (Khalid *et al*., 2024). Addressing the complexities associated with milk fouling deposit removal necessitates a nuanced understanding of the underlying mechanisms governing CIP processes. Numerous factors influence cleaning efficacy, including temperature, detergent concentrations, contact time, and fluid velocity (Tamime, 2008). However, the intricate interplay between these variables and their collective impact on cleaning outcomes remains poorly understood.

Researchers and stakeholders are intensifying efforts to optimize the CIP process for dairy processing equipment in response to sanitation challenges in the dairy industry. Laboratory-scale experimentation provides a controlled environment for systematically assessing the effectiveness of cleaning parameters and elucidating their interactions, leading to empirical insights crucial for process refinement (Fan *et al*., 2021). Optimized CIP processes offer benefits such as heightened sanitation practices, streamlined cleaning procedures, and enhanced operational efficiencies, thereby addressing financial burdens and ensuring product quality amidst stringent regulations (Dev *et al*., 2014).

Recent advancements in CIP processes have demonstrated significant improvements in cleaning efficiency, transitioning from laboratory-scale studies to industrial applications. For instance, Kim *et al*. (2023) explored the recovery of cleaning agents from CIP wastewater using nanofiltration (NF) and forward osmosis (FO) in dairy processing, effectively reducing environmental impact while maintaining high cleaning efficacy. In the petrochemical industry, Sharifi *et al*. (2024) examined the use of air micro-nano bubbles (AMNBs) to enhance CIP for reverse osmosis (RO) membranes, significantly improving cleaning efficiency and extending membrane lifespan. These studies highlight the potential for resource recovery and demonstrate innovative non-chemical methods to improve operational efficiency and sustainability across different industries.

This study aims to advance the understanding of CIP methodologies in dairy processing by constructing a physical model of milk fouling deposits and optimizing the impact of different cleaning parameters—such as temperature, fluid velocities, and cleaning detergent-to-water ratios—on the removal of milk fouling deposits within the CIP process.

2. Materials and Methods

2.1. Development of a Physical Model of Milk Fouling Deposit

Establishing a physical model for milk fouling deposits (MFD) holds significant importance in guaranteeing the reproducibility of such deposits in cleanability experiments (Fan *et al*., 2022). This physical model was used to develop raw milk sourced directly from Ladang 16 Universiti Putra Malaysia @ Farm Fresh Serdang, Selangor. The objective was to simulate real-world scenarios and replicate the formation of fouling deposits commonly encountered in milk processing equipment (Gottschalk *et al*., 2022). This methodology was modified from the work of Piepiórka Stepuk *et al*. (2016). MFD was created by applying and uniformly spreading 2 ml of raw milk onto stainless-steel coupons measuring 4 cm x 4 cm x 0.9 cm (Figure 1). The coupons were subsequently baked in a convection oven (Memmert Oven-Glass, West Germany) at varying temperatures (70°C, 80°C, or 90°C) for different durations (1 hour, 2 hours, 3 hours, or 4 hours). Applying heat during baking facilitated the development and adhesion of milk fouling deposits to the stainless-steel surface. The most suitable physical model for milk fouling deposits was selected for the cleanability experiments based on visual assessments of deposit formation. Optimal baking temperatures and durations were determined by ensuring no weight variations occurred after the baking process.

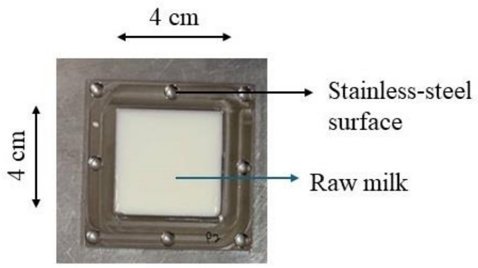

Figure 1. Images of samples before baking in the oven.

2.2. The Laboratory-Scale Cleaning Test Rig

In this study, the laboratory-scale cleaning test rig was utilized. Situated at the Department of Process and Food Engineering, Faculty of Engineering, University of Putra Malaysia, Malaysia, this cleaning test rig comprises crucial components. These include a transparent test section, enabling real-time visual monitoring, a 55 L stainless-steel tank fitted with a thermometer (heating elements), pipe fittings, a centrifugal pump, and a control panel for adjusting temperature and fluid velocity.

2.3. Cleanability Experiment Procedures

The preparation of Milk Fouling Deposit (MFD) was conducted according to the parameters determined in Section 2.1, encompassing specific baking temperatures and times. Subsequently, the prepared sample was affixed within the test section of the laboratory-scale cleaning test rig, as depicted in Figure 2, illustrating the process flow diagram (PFD) of the cleanability experiments. The test section, constructed from acrylic glass, facilitated convenient optical access, allowing the recording of the cleaning process from a top-view perspective. The cleanability experiments were recorded using a phone camera (Apple iPhone 11 equipped with a 12-megapixel wide-angle lens with an f/1.8 aperture) positioned to capture the top-view perspective of the test section. Subsequently, the recorded footage was converted into images to facilitate the precise determination of the cleaning time. Image analysis was conducted using ImageJ software, a Java-based public domain program developed by Wayne Rasband at the NIH (National Institutes of Health) in the USA. This software is known for its high user-friendliness and extensive customizability, featuring numerous plug-ins tailored to address various challenges in image processing and analysis (Khalid *et al*., 2015).

In this study, the detergent was the Kitchen Equipment Cleaner manufactured by McQuin Industries Sdn. Bhd is located in Sungai Buloh, Selangor, Malaysia. Classified under the anionic chemical family, the product's ingredients are anticipated to exhibit environmental safety at concentrations projected for both regular usage and in the event of accidental spills. Different cleaning detergent-to-water ratios (0:1, 1:100, or 1:50) were introduced into the holding tank of the thermometer, followed by activation of the thermometer to elevate the solution temperature to designated levels (30°C, 50°C, or 70°C). The ratio 0:1 represents the use of pure water without any detergent.

Additionally, fluid velocities were adjusted to predetermined values of 0.6 m/s (Reynolds number = 29,814), 0.9 m/s (Reynolds number = 51,111), and 1.5 m/s (Reynolds number = 75,092). These Reynolds numbers correspond to turbulent flow conditions, indicating the transition to turbulent behaviour in the fluid flow. Turbulent flow regimes are characterized by chaotic and irregular motion, leading to enhanced mixing and heat transfer properties within the system. Maintaining turbulent flow in cleaning processes is crucial to ensure effective cleaning. Before commencing the cleanability experiments, meticulous checks and tightening of all pipes, valves, and screws were performed to prevent any potential leakage. Upon reaching the desired temperature, the cleanability experiment commenced, with the cleaning solution pumped into the conduit, circulating through the test section until the fouling deposit was effectively removed. Each cleaning condition was repeated in duplicate.

2.4. Experimental Design and Optimization

Utilizing Box–Behnken Design (BBD) of response surface methodology (RSM), this research applied Design-Expert software (Stat-Ease Inc., Minneapolis, MN, USA) to conduct a total of 17 experiments within a three-factorial BBD framework. The factors investigated included temperatures (30°C, 50°C, or 70°C), fluid velocities of 0.6 m/s, 0.9 m/s, or 1.5 m/s, and cleaning detergent-to-water ratios (0:1, 1:100, or 1:50), as detailed in Table 1. Target cleaning times for the cleanability experiments were determined and presented in Table 2. This research aimed to minimize the cleaning time within 10 to 30 minutes to remove MFD efficiently. The prevailing industry norm typically employs a 30-minute detergent cycle for CIP. This criterion is justified based on its widespread adoption in industry practices and serves as a benchmark for evaluating the effectiveness of alternative cleaning strategies.

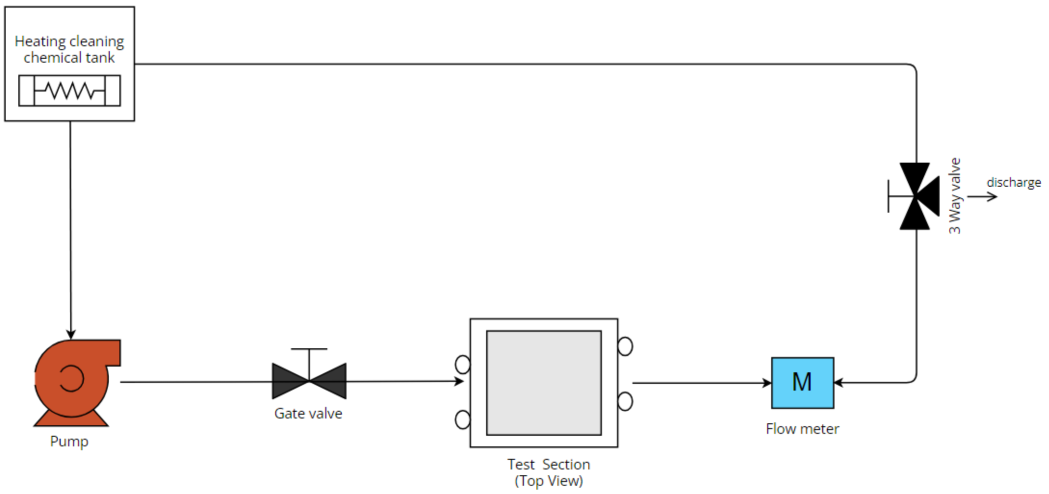

Figure 2. Process flow diagram of the cleanability experiments.

Table 1. BBD experimental variables and levels.

No.	**Variable**	**Level**		
		−1	**0**	**1**
A	Cleaning Temperature (˚C)	30	50	70
B	Cleaning detergent-to-water ratios (ratio)	1:0	1:100	1:50
C	Cleaning Fluid velocity (m/s)	0.6	0.9	1.5

Table 2. The desired target characteristics of the response.

Response	**Target Characteristics**	
Cleaning time	Minimum	10 to 30 minutes

2.5. Response Surface Model Validation Using Optimized Cleaning Parameters

The adequacy of the Response Surface (RS) model was assessed through cleaning validation. Two supplementary experiments were conducted utilizing the optimized cleaning parameters derived from the Design-Expert software (Stat-Ease Inc., Minneapolis, MN, USA). Equation 1 was employed to evaluate the validity of this work (Khalid *et al.*, 2020).

$$\text{Cleaning time model validation} = \frac{(\text{Experimental} - \text{Predicted})}{\text{Predicted}} \times 100\% \quad (1)$$

3. Results and Discussions

3.1. The Physical Model of MFD

Using a modification of the method described by Piepiórka Stepuk *et al*. (2016), MFD was dried and hardened on a stainless-steel sample holder during the heating process, forming a challenging-to-remove layer. Previous studies by Avila-Sierra *et al*. (2021) have reported fouling initiation at wall temperatures ranging from 60 to 65°C, with fouling severity increasing with higher wall temperatures. In this study, stainless-steel sample holders containing 2 ml of milk were heated at different temperatures (70°C, 80°C, or 90°C) for different baking times (1 hour, 2 hours, 3 hours, or 4 hours). The average weight of milk fouling deposits for each baking time is shown in Figure 3. After 2 hours of baking, each batch of samples consistently reached a plateau in weight, with no apparent changes observed upon extending the heating duration to 4 hours. Consequently, baking the samples for 2 hours at 90°C was deemed optimal for developing milk fouling deposits.

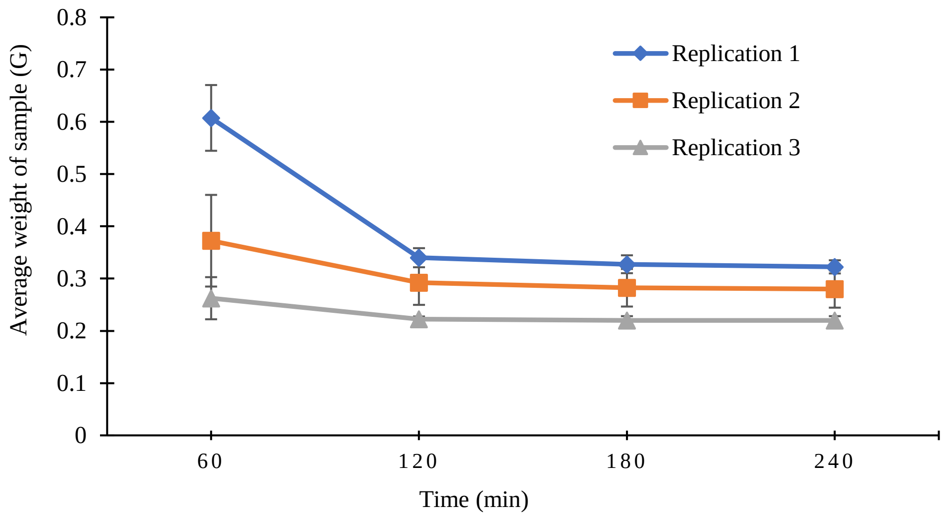

Figure 3. The average weight of the samples after baking at 90˚C.

3.2. Cleanability Experiments

Table 3 presents the cleaning time necessary to obliterate the milk fouling deposit. The surface was deemed inadequately cleaned if the fouling deposit was removed without 100% physical removal within a 30-minute cleaning interval. A standard practice in the food industry for the detergent cycle involves a 30-minute cleaning duration. Additionally, Table 3 shows the arrangement of the Box-Behnken design RSM. Table 3 shows that the shortest cleaning time to remove the MFD is 11 minutes, achieved at a temperature of 70°C, a fluid velocity of 0.9 m/s, and a cleaning detergent-to-water ratio of 1:50 (Run 4). The cleanability experiment conducted at 30°C without heat (Runs 1, 3, and 5) did not achieve 100% (complete) physical cleanliness within the allotted 30-minute duration. Conversely, cleaning at elevated temperatures of 70°C (Runs 2, 4, 6, and 8) resulted in the complete removal of

MFD within the same timeframe. Notably, the extended cleaning time of 48 minutes was observed during Run 9, conducted at a moderate temperature of 50°C, a low fluid velocity of 0.6 m/s, and in the absence of cleaning detergent. This underscores the significance of cleaning detergent presence in achieving effective cleaning.

Table 3. Box–Behnken response surface design arrangement and response (Cleaning time)

Run	Cleaning Temperature	Cleaning Fluid Velocity	Cleaning detergent-to-water ratios	Cleaning time C_t (min)		
				Replication		Average C_t
				1	2	
1	-1	0	-1	60	60	60
2	1	0	-1	22	23	23
3	-1	0	1	28	32	30
4	1	0	1	9	13	11
5	-1	-1	0	39	47	43
6	1	-1	0	11	14	13
7	-1	1	0	25	25	19
8	1	1	0	13	13	13
9	0	-1	-1	35	60	48
10	0	-1	1	18	18	29
11	0	1	-1	23	25	24
12	0	1	1	15	15	15
13	0	0	0	23	26	25
14	0	0	0	23	24	24
15	0	0	0	24	29	27
16	0	0	0	25	28	27
17	0	0	0	26	30	28

3.3. Influence of Cleaning Temperature and Fluid Velocity on Average Cleaning Time

The influence of cleaning temperature and fluid velocity on the average cleaning time is of paramount importance in the CIP process (Liu *et al*., 2006; Wang *et al*., 2016). Mechanical force is necessary for dislodging fouling deposits from the surface of process equipment. The shear stress induced by the flow effectively dislodges fouling deposits from the stainless-steel surface by surpassing the interfacial or adhesive forces between the deposit and the surface (Khalid *et al*., 2016). As shown in Figure 4, temperature and velocity elevations correspond to cleaning time reductions. The significance of temperature and fluid velocity is further underscored in Table 4, which shows a considerable impact ($p<0.05$) on the required cleaning time for milk fouling deposits. According to Tamime (2008), escalating temperature leads to diminished surface tension between the deposit and the surface, heightened detergent efficiency, reduced viscosity of the deposit, and diminished adsorption. Decreased surface tension facilitates easier fouling removal, resulting in accelerated cleaning processes and shortened cleaning durations.

The cleaning efficacy can be further enhanced by optimizing the temperature and fluid velocity combination. An optimal fluid velocity for effective cleaning falls within the range of 1.5 m/s to 2.1 m/s, corresponding to turbulent flow conditions (Tamime, 2008). The turbulence generated by flow conditions and surface geometry directly influences the performance of the CIP process (Fan *et al*., 2021). Nevertheless, moderate flow velocities suffice for cleaning milk, beer, and fruit juice processing plants. In this study, as indicated in Table 3, cleanability experiments conducted at 0.9 m/s yielded the removal of milk fouling deposits within 30 minutes, except at lower temperatures (30°C). Generally, higher fluid velocities contribute to decreased cleaning times by intensifying shear stress on the fouling layer, disrupting bonds between the deposit and the surface. This facilitates the separation and removal of fouling deposits. Thus, elevated temperature and fluid velocity exert a positive influence on reducing cleaning time during the detergent cycle phase of the CIP process.

In this study, the experiments were conducted under turbulent flow conditions. Turbulent flow promotes the hydraulic "scrubbing" of surfaces, thereby enhancing cleaning efficiency by facilitating the removal of contaminants. The flow's turbulent nature enables efficient mass and heat transport, which are essential for thorough cleaning and removing fouling deposits. Furthermore, turbulent flow conditions promote fluid exchange between bulk and near-wall regions, improving cleaning outcomes (Tamime, 2008).

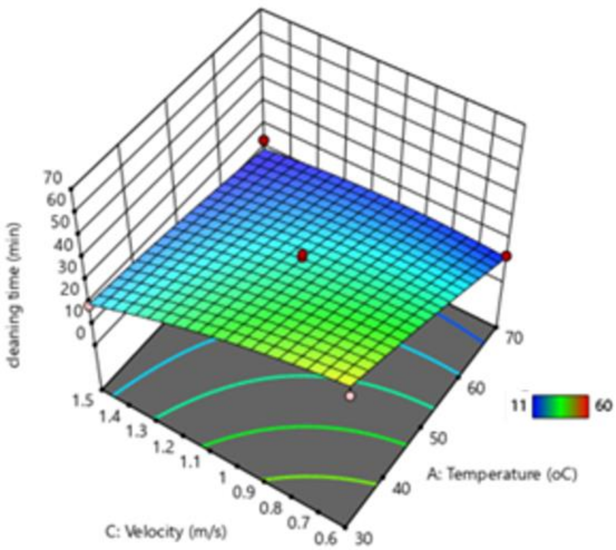

Figure 4. Response surface plot illustrating the cleaning time of milk fouling deposit influenced by the combined effects of fluid velocity and temperature.

Table 4. ANOVA for the formulated response surface quadratic model concerning the cleaning time of MFD.

Source	Sum of square	DOF	Mean square	*F*-value	*p*-value
Model	2585.23	9	287.25	17.99	0.0005
A-Cleaning Temperature	1081.13	1	1081.13	67.69	<0.0001
B- Cleaning detergent-to-water ratios	593.13	1	595.13	37.26	0.0005
C-Cleaning Fluid Velocity	465.13	1	465.13	29.13	0.0010
Residual	111.80	7	15.97		
Lack of Fit	99.00	3	33.00	10.31	0.0236
Pure Error	12.80	4	3.20		
Cor Total	2.697.03	16			

Note: DOF- Degree of freedom

3.4. Influence of Cleaning Detergent on Average Cleaning Time

Cleaning detergents are crucial in the food industry for eliminating protein-based residues, as Avila-Sierra et al. (2021) highlighted. Correspondingly, a commercial cleaning detergent was selected for this project to address the removal of milk fouling deposits. From the analysis of variance conducted for the developed response surface quadratic model (Table 4), it is evident that the effect of cleaning detergent-to-water ratios on cleaning time is statistically significant ($p<0.5$). This indicates that increased cleaning detergent concentration can reduce the time required to remove milk fouling deposits. Such efficacy is attributed to the cleaning solution's capacity to infiltrate the porous nature of the deposit layer, inducing cracks and facilitating deeper penetration until complete removal occurs, as observed by Khalid *et al*. (2016). Consistent with the findings of Liu *et al*. (2007), who reported on the adhesive strength reduction of egg albumin deposits with increasing concentrations of a commercial cleaning detergent containing sodium hydroxide (NaOH), ranging from 0% to 2%, the present study also aligns with these observations, demonstrating a decrease in cleaning time with higher detergent concentrations. While the chemical concentration utilized in this study is not explicitly measured, the results show that a detergent-to-water ratio of 1:100 can remove MFD within 19 minutes. For instance, as depicted in Table 4, milk fouling can be effectively cleaned in 19 minutes at a temperature of 30°C, a velocity of 1.5 m/s, and a concentration of 1:100 (half the chemical concentration recommended by the manufacturer). Consequently, adopting this approach may lead to reduced cleaning detergent expenses. Conversely, adhering to the manufacturer's recommended cleaning concentration could result in excessive usage, consequently escalating overall cleaning costs.

3.5. Cleaning Mechanism of MFD

The video of the removal of the Milk Fouling Deposit (MFD) could not be captured clearly due to the yellowish-white colour of the deposit (Figure 1). The cloudiness of the fluid during the cleaning process, resulting from the turbulent flow, prevented the capture of clear images showing the removal of the MFD. Therefore, despite the videos being recorded during the experiments, this work does not present image data.

3.6. Development of the RS Model for Prediction of Cleaning Time

Analysis of Variance (ANOVA) was employed to evaluate the established response surface (RS) quadratic model for removing MFD, as shown in Table 4. Fisher's F-value test and the lack of fit test were utilized to assess the significance and appropriateness of the RS models. The significance of these models was determined based on the F-value and the associated p-value (Haris *et al.*, 2019). A model is deemed significant when the F-value exceeds the p-value ($p<0.05$), as observed in this study, indicating substantial significance. However, the lack of fit for the RS models was significant ($p<0.5$), suggesting that the current model may not adequately represent the data. This result implies that further refinement of the model or the inclusion of additional variables may be necessary to improve the fit. The significance of the lack of fit could be attributed to unaccounted interactions or variability within the experimental data. Therefore, additional analysis is recommended to enhance the model's predictive capability.

The quadratic models, expressed by Equations 2 and 3, predict MFD's cleaning time. Equation 1, formulated in coded terms, assigns A, B, and C to temperature, cleaning detergent-to-water ratios, and fluid velocity, respectively. This coded equation enables the determination of the relative impact of each factor based on its corresponding coefficients. For instance, in the coded equation, the highest level is denoted as +1, while the lowest is represented as -1, depending on the factor type (as outlined in Table 1). For example, +1 and -1 for A (Temperature) represent 70°C and 30°C, respectively.

On the other hand, Equation 2 presents the actual quadratic models for predicting the cleaning time of milk fouling deposit, where response values are expressed in the original units for each factor. For instance, various temperatures, including the optimized temperature of 60°C, can be directly input into this equation to achieve the desired cleaning time. However, it is important to note that the actual equations (Equation 3) do not provide insights into the relative impact of each factor, which can only be inferred from the coded equation (Equation 2).

The high coefficients of determination (R^2) exceeding 0.90 demonstrate that the models developed through Response Surface Methodology (RSM) can account for over 90% of the total variation observed in the experimental data. This indicates an excellent fit between the predicted and observed values. Furthermore, the adjusted determination coefficients (R^2adj) also surpass 0.90, confirming the reliability of the models in accurately predicting the cleaning time of the MFD during the detergent cycle phase of the CIP process. The high R^2 and R^2adj values provide strong statistical evidence supporting the validity and predictive capability of the RSM-derived models (Equations 2 and 3). While the models are highly effective for the specific cleaning detergent used in this study, it is important to note that altering the type of cleaning detergent may impact the precision and accuracy of the model predictions. The cleaning performance and time requirements can vary depending on the chemical composition and properties of the detergent utilized. Therefore, further validation may be necessary if different detergent formulations are employed in the CIP process.

For removal of Milk fouling deposit (Coded Equation):

$$\textbf{\textit{Cleaning time}} = 25.80 - 11.62A - 8.63B - 7.63C + 4.3AB + 6.13AC + 2.38BC - 0.9625A^2 + 6.04B^2 - 2.96C^2 \tag{2}$$

For removal of Milk fouling deposit (Actual Equation):

$$\begin{aligned}\textbf{\textit{Cleaning time}} = {} & 118.00521 - 1.28646 * Temperature - 75.60833 * Concentration \\ & - 25.52778 * Velocity + 0.462500 * Temperature * Concentration \\ & + 0.680556 * Temperature * Velocity + 10.55556 * Concentration \\ & * Velocity - 0.002406 * Temperature^2 + 24.15000 * Concentration^2 \\ & - 14.62963 * Velocity^2\end{aligned} \tag{3}$$

3.7. RS Model Validation

Utilizing data obtained through numerical optimization, the optimal parameters for cleaning MFD during the detergent cycle phase were established as follows: 60°C cleaning temperature, a cleaning detergent-to-water ratio of 1:83 (approximately 1:90), and a fluid velocity of 1.5 m/s, resulting in a cleaning time of 11.58 minutes (approximately 12 minutes). Experiments were conducted under optimized conditions and replicated twice to validate these findings. The results of the experimental validation for MFD are presented in Table 5, indicating average errors in cleaning time well below the predicted values, at only 4%. Thus, the developed quadratic response model (Equations 1 and 2) exhibits promise for predicting cleaning parameters (temperature, cleaning detergent-to-water ratios, and fluid velocity) in future cleanability experiments. Noteworthy potential errors during these experiments include inaccurate temperature control, fluid velocity variations (attributed to the laboratory-scale cleaning test rig setup), improper detergent concentration (manual dosing), equipment malfunction, inadequate rinsing (from previous experiments), and contamination (from previous experiments). To mitigate such risks, meticulous equipment calibration, protocol adherence, regular maintenance, and implementation of quality control measures are imperative to ensure the reliability and reproducibility of cleanability experiments.

Table 5. Experimental validation of the cleaning time for MFD

	Cleaning time (minutes)	Percentage Error (%)
Predicted	11.58	4
Actual	12.00 ± 0.03	

4. Conclusions

This study demonstrated the successful replication of milk fouling deposits by heating raw milk on stainless steel surfaces at 90°C for 2 hours. In the CIP process, crucial parameters, including temperature, fluid velocity, and cleaning detergent concentration, significantly affect the efficiency of MFD removal, with the combined effect of temperature and fluid velocity proving particularly effective. Utilizing a commercial cleaning detergent from the anionic chemical family, optimal cleaning parameters were determined as a temperature of 60°C, a cleaning detergent ratio of 1:90, and a velocity of 1.5 m/s, resulting in the shortest cleaning time for complete removal of MFD. Future studies should consider increasing the number of repetitions for each cleanability experiment and exploring various types of commercial cleaning detergents used in the manufacturing process to enhance the accuracy and reliability of results. Furthermore, additional cycles, such as rinsing and disinfection in the CIP process, warrant further investigation. These recommendations aim to refine experimental procedures and improve precision in subsequent investigations.

Author Contributions: Nur Aziemah Adilah Asming: Conceptualization, Methodology, Data Curation, and Writing – Original Draft. Nurul Izzah Khalid: Conceptualization, Supervision, Project Administration, and Reviewing – Final Manuscript. Norashikin Ab Aziz: Supervision and Reviewing. Nurfatimah Mohd Thani: Reviewing. Bernard Maringgal: Reviewing.

Acknowledgements: The support from the Inisiatif Putra Muda Grant (GP-IPM) UPM.RMC.800-3/3/1/2023/GP-IPM/9747300, is acknowledged

Conflicts of Interest: The authors declare no conflict of interest.

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