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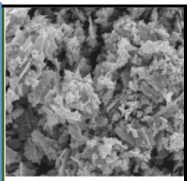

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Optimization of Cleaning-In-Place (CIP) Procedure of Milk Fouling Deposit Using Different Cleaning Parameters

Nur Aziemah Adilah Asming[1], Norashikin Ab Aziz[2], Nurfatimah Mohd Thani[3] and Nurul Izzah Khalid[1]*

[1]Department of Food Technology, Faculty of Food Science and Technology, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor Malaysia.
[2]Department of Process and Food Engineering, Faculty of Engineering, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia.
[3]Department of Food Science, Faculty of Science and Technology, Universiti Kebangsaan Malaysia, 43600 UKM Bangi, Selangor, Malaysia.

*Corresponding author:
Nurul Izzah Khalid
Department of Food Technology,
Faculty of Food Science and Technology,
Universiti Putra, Malaysia,
43400 UPM Serdang,
Selangor,
Malaysia.
Email: nurulizzah@upm.edu.my

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ABSTRACT

Cleaning-in-place (CIP) is a critical process across various industries, particularly in the food industry, where maintaining sanitation without equipment disassembly is imperative. However, challenges such as cross-contamination and escalating sanitation costs may arise when protocols are not diligently followed. This research focuses on optimizing the CIP techniques to mitigate milk fouling deposits in the dairy industry by strategically manipulating cleaning parameters. A physical model using raw milk to simulate industrial scenarios was prepared, followed by laboratory-scale sanitation experiments. Here, the Box–Behnken experimental design was employed to determine the optimal cleaning parameters for the detergent cycle step. The investigation evaluated the effects of temperatures (30°C, 50°C, 70°C), mixing ratio of cleaning solution (water: cleaning detergent) (0:50, 1:50, 1:100), and fluid velocities (0.5 m/s, 1.0 m/s, 1.5 m/s) on the removal of milk fouling deposits. The cleaning solution used in this work falls under the anionic chemical family and was used to clean equipment in the food industry. The cleaning time for the removal of milk fouling deposits was measured during the sanitation experiments. The optimal conditions were found at 60°C, detergent ratio 1:83, and fluid velocity 1.5 m/s, reducing cleaning time to 11.58 minutes for 100% removal from stainless-steel surfaces. These findings challenge the commonly practiced 30-minute detergent cycle step, highlighting potential time and cost savings. The study highlights temperature and fluid velocity's vital role in enhancing CIP efficiency, providing practical insights for dairy industry improvements.

INTRODUCTION

Cleaning-in-place (CIP) plays a crucial role in the food industry, where the presence of fouling deposits on equipment surfaces can significantly impact operational performance [1]. While existing literature, such as the work by Goode et al. [1], has shed light on the nature of fouling deposits and their effects on processing equipment, there remains a critical gap in understanding how to optimize CIP processes for specific contaminants like milk fouling deposits. Moreover, Guerrero-Navarro et al. [2] emphasized the challenges posed by deposit formation in dairy processing equipment, necessitating effective CIP procedures to maintain cleanliness and prevent contamination. The prevailing industry norm typically employs a 30-minute detergent cycle for CIP. However, recent evidence indicates that this method might not uniformly achieve optimal results across all types of fouling [3]. Thus, the conventional 30-minute detergent cycle may not consistently represent the most efficient approach, implying potential time and cost savings through alternative strategies.

The rationale for this study stems from the intricate factors influencing the efficiency of cleaning processes. Although the impacts of temperature, cleaning detergent concentration, and fluid velocity on cleaning effectiveness are widely recognized, the tenacity of fouling deposit such as milk fouling deposits, and the dimensions of equipment surfaces introduce distinctive

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challenges that demand customized cleaning methodologies [3]. It is crucial to acknowledge that the optimal cleaning parameters elucidated in this research may not be universally transferable to all systems owing to the variability in fouling characteristics and equipment dimensions [3].

Therefore, this research aims to address the specific challenges associated with optimizing CIP for milk fouling deposits by investigating the interplay of cleaning parameters such as temperature, fluid velocity, and detergent ratio during the detergent cycle step. By elucidating the relationships between these parameters and cleaning effectiveness, this study seeks to contribute valuable insights to the refinement of CIP techniques, particularly within the dairy industry. Ultimately, the goal is to enhance hygiene standards and operational efficiency by developing more tailored and effective cleaning protocols for challenging fouling scenarios.

METHODOLOGY

Sample preparation

The milk fouling deposit (MFD) were prepared by dropping and evenly spreading 2 ml of raw milk on a stainless-steel coupon measuring 4 cm x 4 cm x 0.9 cm. The coupon was baked in an oven for 2 hours at 90°C. Then, the coupon was inserted in a test section inside the laboratory-scale cleaning test rig.

Cleanability experiments

The laboratory-scale cleaning test rig (**Fig. 1**) used in this work was located at the Department of Process and Food Engineering, Faculty of Engineering, University of Putra Malaysia, Malaysia. The laboratory-scale cleaning test rig consists of a test section, a stainless-steel tank (55 L), thermolator, pipe fittings, a pump, and a control panel. Once the sample was ready, the coupon was attached in the test section. The cleaning detergent solution at different ratio (1:0, 1:100 and 1:50) was filled in holding tank of the thermolator. The cleaning solution (McQuin Industries, Malaysia) utilized in this study belongs to the anionic chemical family and was employed for cleaning equipment within the food industry. Following that, the thermolator was switched on to heat the solution at different temperature (30°C, 50°C and 70°C).

The fluid velocity was varied at different rates: 0.6 m/s (Re=29, 814), 0.9 m/s (Re=51, 111), and 1.5 (Re=75, 092). When the solution reached the specific temperature, the cleanability experiment was started. The valve connected to the holding tank was opened to allow the cleaning solution to be pumped into the conduit. It then passed through the test section, with the fluid circulating until the fouling deposit was removed. Each cleaning condition was performed in duplicate. In this study, the Box-Behnken experimental design (BBD), a form of response surface methodology (RSM), was utilized with the Design Expert software (Version 13, Stat-Ease Inc., Minneapolis, MN, USA). RSM was specifically applied to optimize cleaning parameters such as the ratio of cleaning detergent solution, temperature, and fluid velocity, aiming to improve cleaning efficiency and effectiveness. This optimization aims to minimize the cleaning time, targeting a range of 10 to 30 minutes. The prevalent industry standard utilizes a 30-minute detergent cycle for CIP, justifying its selection as a benchmark criterion.

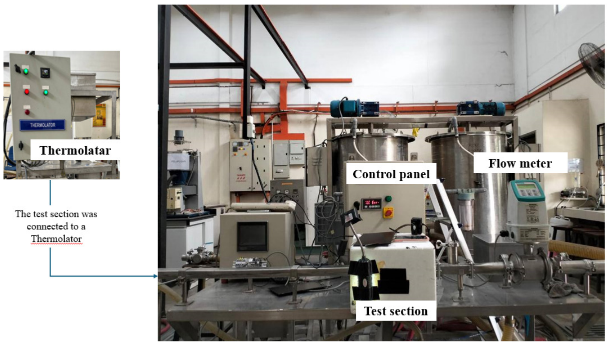

Fig. 1 The laboratory-scale cleaning test rig.

RESULT AND DISCUSSION

The study investigated the effect of cleaning parameters on the removal of milk fouling deposits. The results are shown in **Table 1** which indicates the cleaning time required to remove 100% of the milk fouling deposit. When the fouling deposit removal did not reach 100% after 30 minutes of cleaning time, the surface was considered unclean. Table 1 show Box-Behken response surface design arrangement where the shortest cleaning time to clean the MFD is 11 minutes at 70ºC, fluid velocity at 0.9 m/s, and cleaning detergent ratio of 1:50.

Table 1. Box-Behnken response surface design arrangement.

Run	Temperature (°C)	Fluid velocity (m/s)	Cleaning mixing ratio (Water: detergent)	solutio Cleanin	Cleaning time (min)
1	30	0.9	1:0		60.0 ± 0.00
2	70	0.9	1:0		22.5 ± 0.71
3	30	0.9	1:50		30.0 ± 2.83
4	70	0.9	1:50		11.0 ± 2.83
5	30	0.6	1:100		43.0 ± 5.66
6	70	0.6	1:100		12.5 ± 2.12
7	30	1.5	1:100		25.0 ± 0.00
8	70	1.5	1:100		13.0 ± 0.00
9	50	0.6	1:0		47.5 ± 17.68
10	50	0.6	1:100		18.0 ± 0.00
11	50	1.5	1:0		24.0 ±1.41
12	50	1.5	1:50		15.0 ± 0.00
13	50	0.9	1:100		24.5 ±2.12
14	50	0.9	1:100		23.5 ±0.71
15	50	0.9	1:100		26.5 ±3.54
16	50	0.9	1:100		26.5 ±2.12
17	50	0.9	1:100		28.0 ±2.83

Fig. 2 indicates that an increase in temperature and velocity can potentially reduce the cleaning time. The significance of temperature and fluid velocity is further evident in **Table 2**, where they exhibit a substantial effect (p<0.05) on the cleaning time required for milk fouling deposits. Thus, temperature and fluid velocity are crucial in the Cleaning-in-Place (CIP) procedure. According to Tamime [4], rising temperature reduces surface tension, facilitates easier fouling removal, and leads to accelerated cleaning and shorter cleaning times. Cleaning efficiency can be improved by combining temperature and fluid velocity.

An optimum fluid velocity to provide good cleaning is between 1.5 m/s and 2.1 m/s that is under a turbulent flow rate [4]. However, moderate flow velocities are sufficient for cleaning milk, beer, and fruit juice processing plants. In our project, as indicated in Table 1, cleanability experiments conducted at 0.9 m/s resulted in 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 the shear stress on the fouling layer, breaking bonds between the deposit and the surface. This facilitates the easy separation and removal of fouling deposits. Therefore, increased temperature and fluid velocity influence cleaning time.

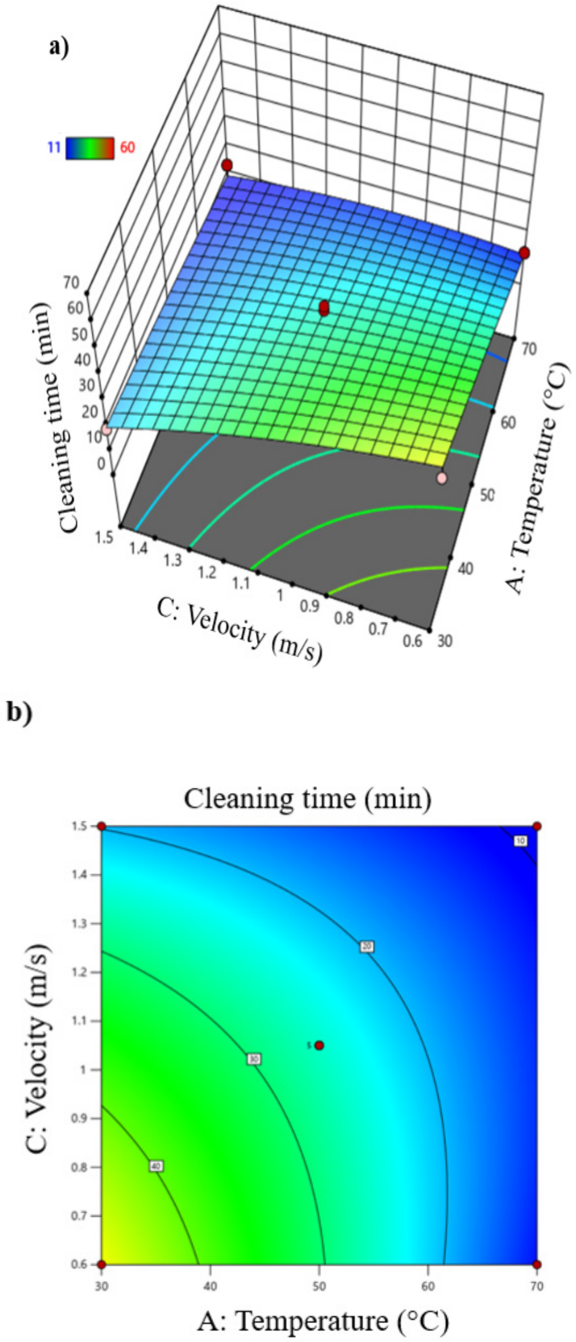

Fig. 2. Visualization of MFD Cleaning time across Velocity and Temperature: a) 3D Surface and b) Contour Plots.

Table 2. Analysis of variance for the developed response surface quadratic model for 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-Temperature	1081.13	1	1081.13	67.69	<0.0001
B-Concentration	593.13	1	595.13	37.26	0.0005
C-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			

Equation 1 presents a quadratic model developed to forecast the cleaning time during the removal of the detergent cycle step of Milk Fouling Deposit (MFD). The coefficients of determination (R^2) stand at 0.96, surpassing the 0.90 threshold, signifying that the model elucidates over 90% of the total data variance. Furthermore, the adjusted coefficient of determination (R^2adj) for the model exceeds 0.91, reinforcing the model's reliability in predicting experimental outcomes [5]. Consequently, the Response Surface Methodology (RSM) models effectively anticipate the cleaning time of MFD in the detergent cycle phase of the Clean-In-Place (CIP) process. Nevertheless, altering the cleaning detergent type may impact this quadratic model's accuracy.

Average Cleaning time = **(Equation 1)**

$$25.80 - 11.62A - 8.63B - 7.63C + 4.3AB + 6.13AC + 2.38BC - 0.9625A^2 + 6.04B^2 - 2.96C^2$$

Aiming for a cleaning time of less than 30 minutes, the optimal conditions for effectively removing the MFD were determined to be 60°C, 1:83 detergent ratio, and 1.5 m/s fluid velocity, resulting in a cleaning time of 11.58 minutes. To validate these findings, an experiment was conducted under the optimized conditions and repeated twice for confirmation. **Table 3** shows the experimental validation results of MFD, respectively. From the Table 3, the average errors for cleaning time are found to be well below the predicted values at only 4%, respectively for MFD. Thus, the developed response quadratic model can be used to predict the parameters for future experiments. The error might have occurred due to the limitation of thermolator in controlling the temperature. Thus, the cleaning time of MDF exceed the expected time.

Table 3. Experimental validation of milk fouling deposit for cleaning time.

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

CONCLUSION

In summary, this study successfully identified key parameters—temperature, fluid velocity, and cleaning detergent ratio—that significantly enhance the efficacy of the milk fouling deposit cleaning process during the detergent cycle step. Efficiency was assessed using cleaning time, with shorter durations indicating more effective cleaning. Optimal cleaning parameters were determined to be a temperature of 60°C, a cleaning detergent ratio of 1:83, and a velocity of 1.5 m/s, resulting in the shortest cleaning time required to achieve 100% removal of the milk fouling deposit.

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