Development and validation of a test rig for evaluation of more sustainable Cleaning-in-Place (CIP) strategies for the cheese industry

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INTRODUCTION

- Fouling in dairy is defined as the collection of thermally insulating materials or deposits formed on heat transfer surfaces.
- Currently, the most used and effective industrial sanitation system is cleaning-in-place (CIP) (Fig. 1).
- Caustic and acid-based chemicals typically applied during CIP are relatively cheap, but considering the CIP process as a whole, from procurement to use, and disposal costs and high energy and water usage requirements, questions arise as to their levels of sustainability.
- Use of enzymes as effective agents for CIP and as a more sustainable alternative to chemicals treatments is gaining interest as enzymes work operate at lower temperatures (50°C) resulting in energy savings.
- Additionally, they are typically derived from natural sources, are easy to neutralize, and do not produce hazardous waste products.
- However, there is a need for the development of comprehensive knowledge and understanding of their effectiveness, safety, and impact on the quality of ripened cheeses.

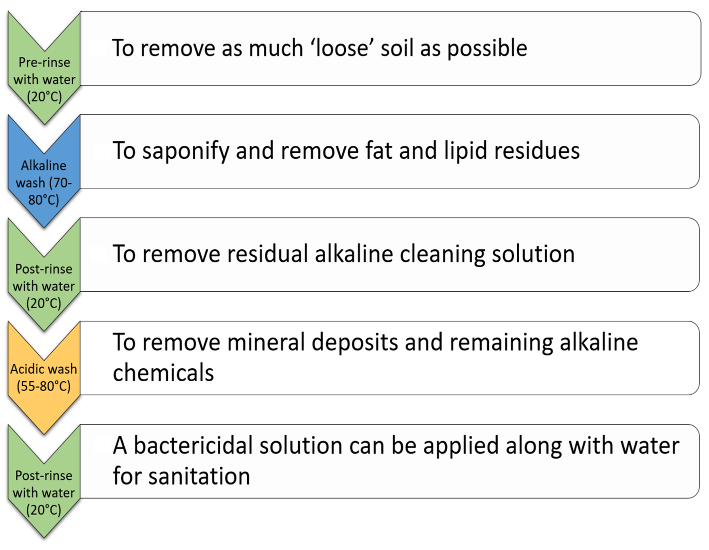

Fig. 1. Flowchart of a typical five-step cleaning-in-place (CIP) process employed in dairy. Adapted from (Pant et al., 2023).

OBJECTIVE

This study focuses on development and validation of a CIP rig, emulating industrial cleaning conditions, in conjunction with an artificial fouling model to explore the impact of diverse factors including fouling development times, varying Protein: Fat ratio of milk, and the efficacy of new enzyme-based sanitising agents on fouling removal.

MATERIALS AND METHODS

Materials: Milk was obtained from a dairy farm (Teagasc, Moorepark, Fermoy, County Cork, Ireland); Caustic detergent was obtained from Biocel Ltd.; Stainless steel (SS) 304 coupons (2 cm x 6.5 cm x 0.9 cm) (Fig. 2) and lab-scale CIP cleaning rig (Fig. 3) fabricated through both a local equipment manufacturer and Moorepark Technology Ltd (MTL); Enzymes Protease (Memzyme) and Lipase (Memlip) were obtained from Waters Technologies Ireland Ltd.

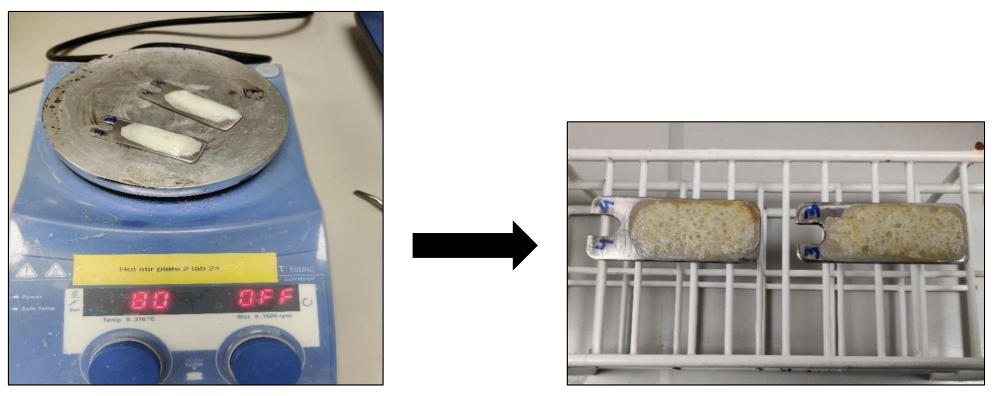

Fig. 2. Artificial fouling of stainless steel (SS) coupons on hot plate

Methodology:

- An artificial method of fouling stainless steel (SS) coupons was developed using hot plate to emulate plate heat exchanger (Fig. 2)
- 3 different fouling development times assessed with 3 levels of Protein:Fat ratio in milk (0.91, 0.83, 0.72)
- Cleaning protocols similar to those used in the cheese industry were used in the rig (Fig. 3)
- Residual fouling was determined in terms of in terms of Dry weight and protein, fat and mineral content

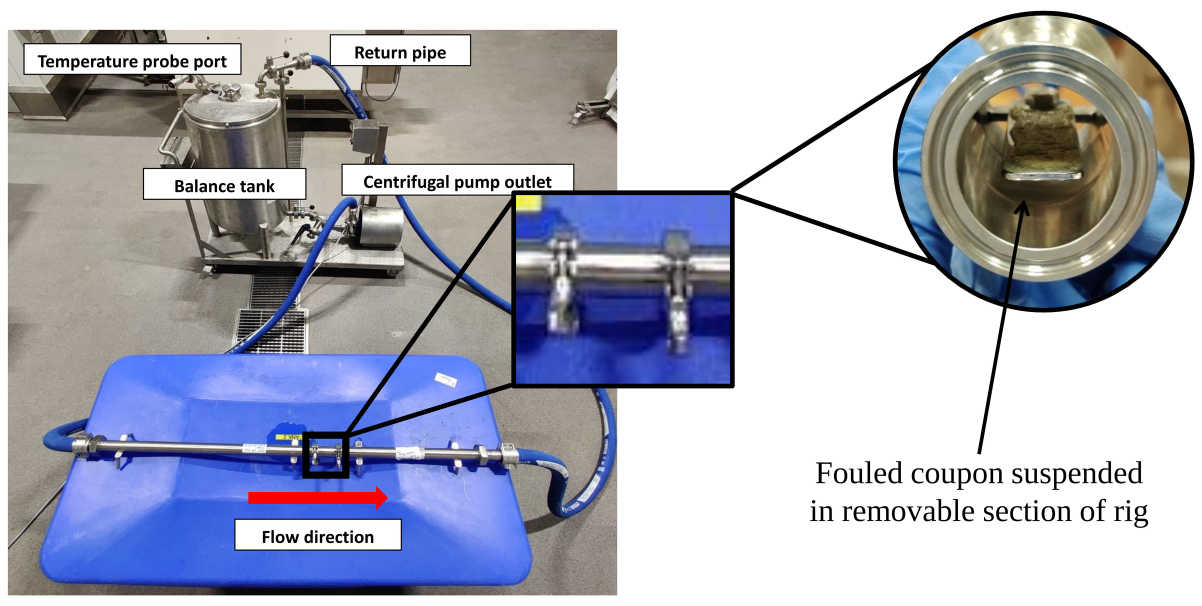

Fig. 3. CIP test rig comprising a tank for cleaning liquids, a pump, and a removable test section

RESULTS

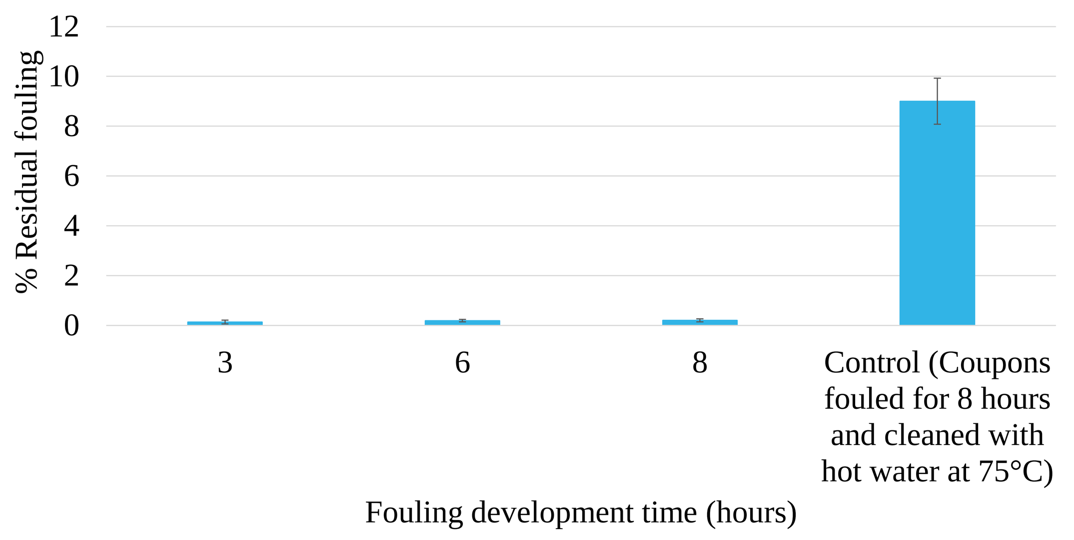

Fig. 4. % Residual fouling remaining after CIP with 1 % NaOH and hot water (75°C x 30 min) or hot water only

- To validate the cleaning efficacy of the rig system, a cleaning study was conducted using an artificial fouling model and a 1% commercial caustic detergent as the cleaning agent.
- Apart from the coupon cleaned without NaOH, no visible residual fouling was observed on the coupons post-cleaning.
- An analysis of the fouling dry weight indicated a significant fouling removal rate of over 99%.

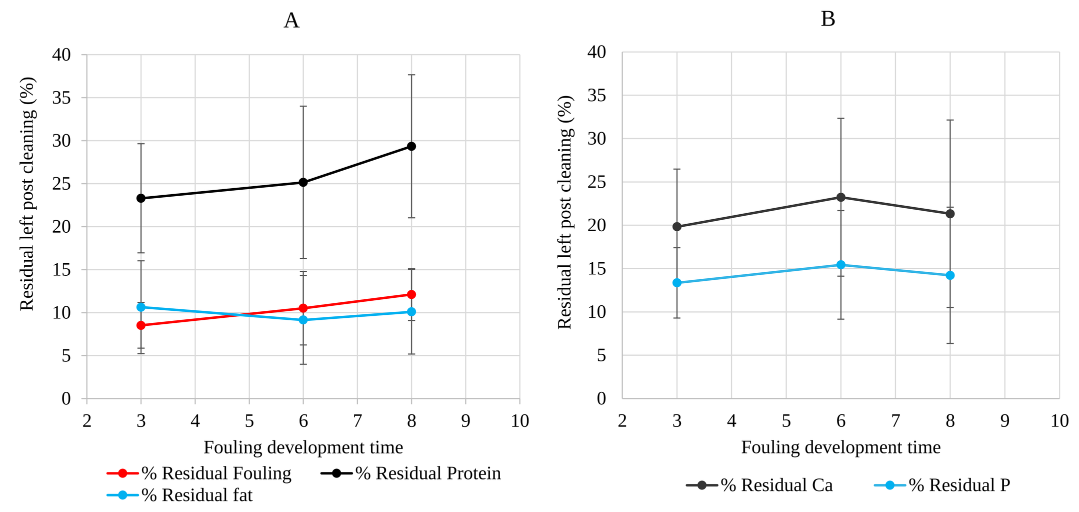

Fig. 6. Effect of fouling development time on (A) milk components; (B) minerals in residual fouling after cleaning with hot water (75°C x 30 min)

- Extending fouling development time yielded a minor increase in residual fouling. Nevertheless, when considered independently, it did not significantly impact residual fouling or the retention of protein and fat post-cleaning.
- The interaction between fouling development time and the Protein: Fat ratio exhibited a significant influence on residual fouling and the retention of protein after the cleaning process but had no significant effect on retention of fat.
- Fouling development time showed no significant effect on the retention of essential minerals, such as Calcium (Ca) and Phosphate (P), after the cleaning process.

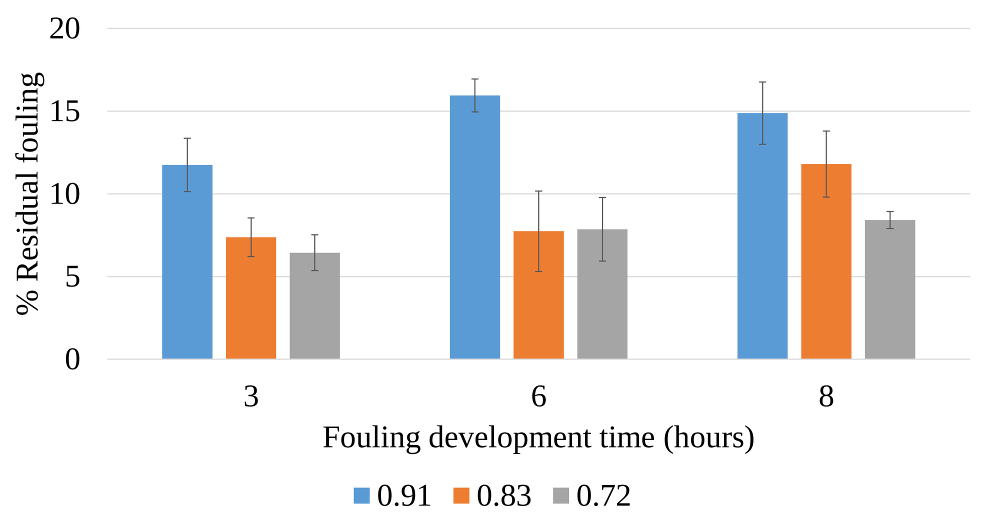

Fig. 5. % Residual fouling remaining after CIP with hot water (75°C x 30 min). Each colour represents a different Protien:Fat ratio

- Cleaning with hot water only (excluding NaOH) shows that the role of NaOH in removal of persistent fouling (that cannot be removed with just hot water only) as the maximum amount of fouling remaining across all the cleaning cycles was 7.38 % to 15.95 %.
- Thus, characterisation of the residual fouling would provide insights into the development of more sustainable replacements for caustic cleaners.

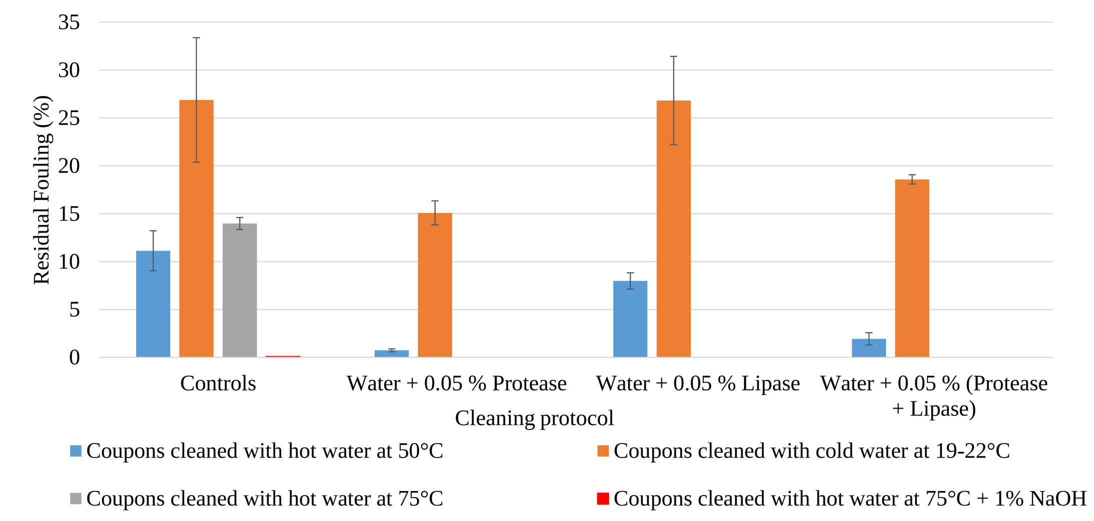

Fig. 7. Effect of cleaning for 30 minutes with different enzymes and temperatures (19-22°C, 50 °C, 75 °C) on residual fouling

- Cleaning with hot water at 75°C (individually) and with 1 % NaOH yielded results similar to those obtained previously.
- Protease at 50°C individually had the highest fouling removal which is in agreement from the previous results as protein was the major component in fouling persistence.
- While lipase individually showed the least ability to completely remove fouling, a combination of protease and lipase was less efficient than protease.

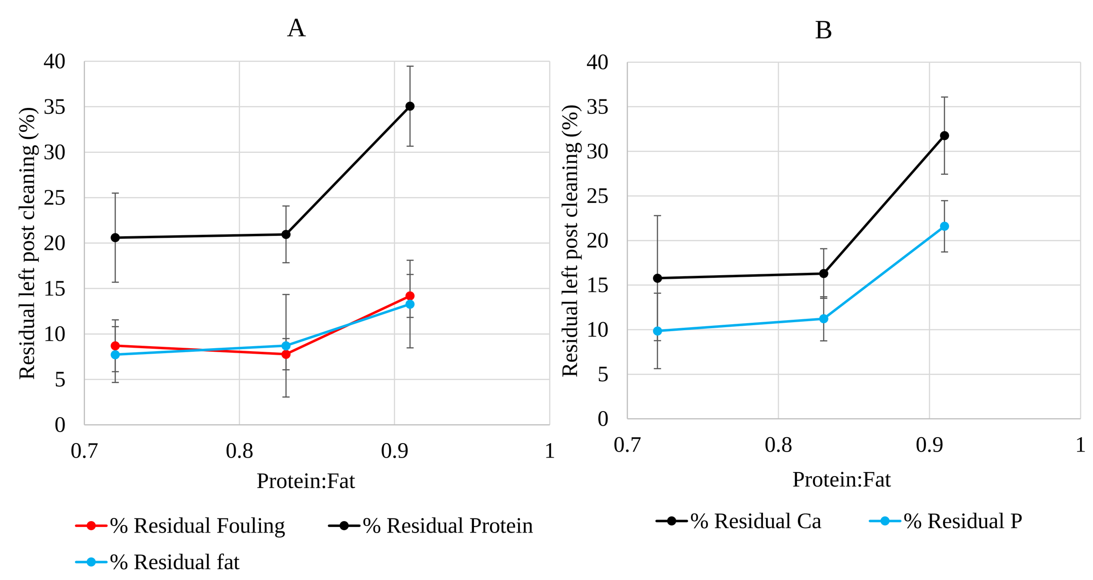

Fig. 6. Effect of Protein:Fat ratio of milk on (A) milk components; (B) minerals in residual fouling after cleaning with hot water (75°C x 30 min)

- Elevating the Protein: Fat ratio led to increased residual fouling, with a significant effect on total residual fouling, as well as protein and fat retention after cleaning.
- This suggests a central role for proteins in the persistence of fouling after cleaning.
- Increased Protein: Fat ratio demonstrated a direct correlation with the increased retention of essential minerals, such as Calcium (Ca) and Phosphate (P), following the cleaning process

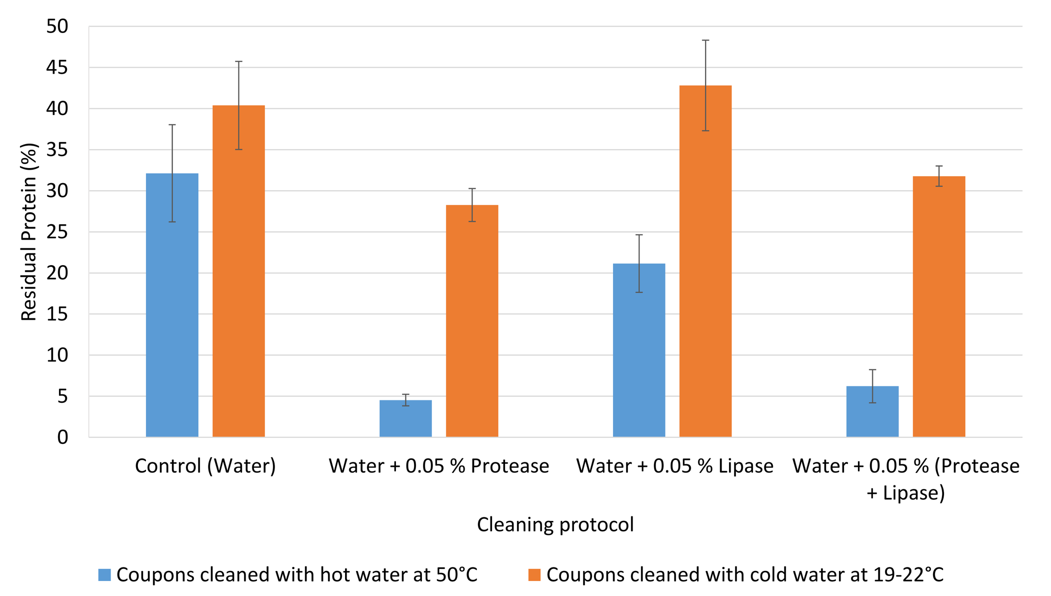

Fig. 8. Effect of cleaning for 30 minutes with different enzymes and temperatures (19-22°C and 50 °C) on retention of protein in residual fouling

- Protease at 50°C individually showed the highest protein removal which was expected as protease breakdowns proteins and enhances their removal.
- A combination of protease and lipase was more efficient in protein removal than lipase alone but less efficient than protease.

CONCLUSIONS

- Protein:Fat ratio in milk determines the amount of protein and fat present in residual fouling after cleaning and higher protein content results in significantly increased persistent level of fouling with high levels of Ca and P minerals in the residual fouling.
- A commercial protease can efficiently clean fouling (0.74 % residual fouling) at lower temperatures (50°C) and show a comparable efficacy to a cleaning agent like NaOH at 75°C (0.10 - 0.20 % residual fouling).
- The rig can be used to study different model systems for fouling and cleaning and create tailored cleaning procedures for practical use.
- Further research on enzymatic cleaning should focus on investigation of cleaning protocols involving various enzymes individually and in combination with other mild cleaning agents to completely remove fouling.
- The potential for removal of fouling by cheese curd, whey or in combination by enzymes should be appraised.
- Any potential effects of residual enzyme carry over and activity in dairy products should be quantified and eliminated.

REFERENCES

- Pant, K. J., Cotter, P. D., Wilkinson, M. G., & Sheehan, J. J. (2023). Towards sustainable cleaning-in-Place (CIP) in Dairy Processing: Exploring enzyme-based approaches to cleaning in the cheese industry. *Comprehensive Reviews in Food Science and Food Safety*, *22*(5), 3602–3619. https://doi.org/10.1111/1541-4337.13206
- Guerrero-Navarro, A. E., Ríos-Castillo, A. G., Avila, C. R., Hascoët, A. S., Felipe, X., & Rodriguez Jerez, J. J. (2019). Development of a dairy fouling model to assess the efficacy of cleaning procedures using alkaline and enzymatic products. LWT, 106, 44–49. https://doi.org/10.1016/j.lwt.2019.02.057
- Jimenez, M., Delaplace, G., Nuns, N., Bellayer, S., Deresmes, D., Ronse, G., Alogaili, G., Collinet-Fressancourt, M., & Traisnel, M. (2013). Toward the understanding of the interfacial dairy fouling deposition and growth mechanisms at a stainless steel surface: A multiscale approach. *Journal of Colloid and Interface Science*, *404*, 192–200. https://doi.org/10.1016/j.jcis.2013.04.021

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