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Inferring Elemental Composition of Dairy Heat Exchanger Fouling from Electrical Resistance

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ABSTRACT

Fouling in dairy heat exchangers progressively reduces thermal efficiency, elevates energy consumption, challenges product quality and food safety, and increases downtime because of frequent cleaning. Although cleaning-in-place (CIP) is extensively employed in the industry, cleaning schedules are often determined by elapsed time or empirical heuristics rather than direct, real-time data on fouling growth and characteristics. Industrial monitoring signals, such as pressure drop and temperature gradient, provide indirect indications of fouling and typically respond only after substantial deposition. Consequently, CIP is often initiated prematurely, wasting water, chemicals, and energy. These limitations underscore the necessity for online monitoring methods capable of tracking internal fouling progression and, ideally, providing insight into deposit composition in addition to overall severity.

This study investigates the technical feasibility of inferring the elemental composition of dairy fouling from online electrical resistance measurements. The hypothesis of this work was that dairy deposits evolve in composition and structure as fouling progresses, and that these changes alter the electrical pathways across the fouling layer. Therefore, electrical resistance signals may contain "fingerprints" that reflect not only the extent of fouling but also its compositional state, which could be a potential factor in determining the chemical concentrations used in CIP.

In laboratory experiments, dairy fouling was deposited on a heated stainless-steel (SS304) box pipe surface (15 mm × 142 mm), maintained at 70 °C to simulate a heat exchanger wall, by continuously circulating reconstituted skim milk under controlled conditions. Discrete trials were conducted for 1, 2, 3, 4, 6, 9, and 12 hours. Several repeat trials were conducted for 6 hours to establish experimental variation. Electrical resistance was measured online throughout deposition to capture time-resolved electrical responses during fouling development. At each endpoint, deposits underwent ex situ compositional analysis by energy-dispersive X-ray spectroscopy, enabling determination of elemental fractions, mainly C, O, N, and Ca, and their evolution with fouling progression. The electrical resistance end values were then correlated with the corresponding compositions to construct an inference model.

By explicitly targeting a relationship between fouling composition and its electrical resistance, rather than relying solely on deposit mass or run time, this approach aims to bridge laboratory compositional diagnostics and real-time sensing. The outcomes support the development of practical, data-driven monitoring tools that can inform condition-based adaptive cleaning

strategies, optimize CIP cycles, and advance dairy heat exchanger operation towards closed-loop, evidence-driven fouling management.

KEY WORDS

Dairy heat exchanger fouling, electrical resistance monitoring, inferring online elemental composition

BIOGRAPHY

Mihiraj Karunanayake is a doctoral candidate in Chemical and Materials Engineering at the University of Auckland, New Zealand, researching dairy fouling using computer-aided tomography (CAT) and online sensing. He is a Chartered Electrical Engineer with more than eight years of industrial experience, and his experience includes research and development focused on practical engineering applications. His research interests include dairy heat exchanger fouling, embedded systems, IoT, wireless sensor networks, energy management, deep learning, and artificial cognitive systems, with additional experience in marine control systems. He holds a BSc (Hons) in Electrical and Electronic Engineering and an MSc in Artificial Intelligence.

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