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Inline fouling mitigation during food processing: a sustainable novel solution

Luanga Nchari*, Charles Edge, Mohammed Shafiq

Jacobs Douwe Egberts, R&D, Ruscote Avenue, Banbury, OX162QU, United Kingdom

Abstract

Fouling within the food industry has an impact on both capital and operation costs. There is a great demand for cost effective and sustainable antifouling solutions. An increase in internal fouling results in poor thermal efficiency during food processing. This is coupled with poor heat and mass transfer local to the metal surface of designed heat exchangers, pipes and other equipment. Internal fouling could also potentially increase unwanted fluid flow pressure due to restricted flow. [1, 2] It is demonstrated in this work, how fouling is mitigated with ultrasound non-invasively during pilot scale production. When using a plate heat exchanger set-point temperature of 140°C, 128°C and 138°C was achieved without and with an attached ultrasonic transducer respectively. The duration for complete fouling of a tubular heat exchanger increased from 10 to 25 hours with ultrasonic transducers. The presence of ultrasound reduces the carbon footprint owing to substantially reduced fouling.

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Keywords: Ultrasonic; Fouling; Non-invasive, Coffee, Heat exchangers, High pressure water, Sustainable

* Corresponding author. Tel.: +44-129-5223963.
E-mail address: luanga.nchari@jdecoffee.com

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1. Introduction

Traditional methods of cleaning in the food industry include high pressure water, rinsing with chemicals and mechanical scrubbing.[1, 2] The described novel method that uses ultrasonic transducers over traditional methods is non-invasive, cost effective, eco-friendly and thermally more efficient. In addition, this solution distinguishes itself by inhibiting fouling continuously during production and is not a post process treatment.

Ultrasonic technology in antifouling began with the US Navy in the 1950s. It was found that there was significantly less marine growth around sonar transducers compared to other sections of the hull. Antifouling ultrasonic transducers have been commercially available in the marine industry for over a decade. Conventional methods such as high pressure water washing also used in the food industry are older. [3]

2. Fundamentals

2.1. Fouling

Fouling is a five step process. In the first stage (initiation), nucleation of the fouling species occurs followed by the transportation of the fouling species to the surface. At the attachment stage the species deposit on the surface with possible removal of the attached species into the fluid stream. Finally, the fouling deposit may harden or weaken in the aging stage. The most common fouling model is linear where the fouling rate is steady. The fouling rate in this model compromises two rival terms including an anti-deposition or mitigation (Equation 1).

The fouling rate = (deposition term) – (anti-deposition term):

$$\frac{dR_f}{dt} = \alpha Re^{\beta}\, Pr^{\delta} exp\left[\frac{-E}{RT_{film}}\right] - \gamma \mathrm{T}_w \tag{1}$$

α, β, γ and δ are parameters, T_w is the wall shear stress and T_{film} is the fluid temperature. From the equation, it is obvious that there are threshold conditions of temperature and velocity with insignificant fouling rates in heat exchangers. Fouling resistance (*FR*) characterizes the thermal effect of fouling. It is related to the deposit thickness and thermal conductivity. *FR* is included in a basic heat transfer equation where U and U_0 are the overall heat coefficients with and without fouling respectively. [1, 4]

$$\frac{1}{U} = \frac{1}{U_0} + FR \tag{2}$$

With an increase in deposition, the fouling resistance increases also resulting in a change in deposit temperature in the liquid phase. A change in deposit temperature will affect the deposition rate. [5]

2.2. Ultrasonic transducers

The principle of how an ultrasonic transducer works is illustrated in Fig. 1. The transducer has a piezoelectric element that generates ultrasonic waves by repeated expansion and contraction. Ultrasonic waves are transmitted through the metal into the liquid. Vibrations in the metal/liquid interphase could potentially prevent foreign particle adhesion on the metal from the liquid. [6]