Available online at www.sciencedirect.com

ScienceDirect

Procedia CIRP 55 (2016) 134 – 139

www.elsevier.com/locate/procedia

5th CIRP Global Web Conference Research and Innovation for Future Production

A multi-sensor approach for fouling level assessment in clean-in-place processes

Alessandro Simeone[1], Nicholas Watson[2], Ian Sterritt[3], Elliot Woolley[1]*

[1]*Centre for Sustainable Manufacturing and Recycling Technologies (SMART), Loughborough University Leicestershire, LE11 3TU, UK*
[2]*Faculty of Engineering, Nottingham University, UK*
[3]*Martec of Whitwell Ltd, Chesterfield, UK*

* Corresponding author. Tel.: 4401509225410;.*E-mail address:* E.B.Woolley@lboro.ac.uk

---

Abstract

Clean-in-place systems are largely used in food industry for cleaning interior surfaces of equipment without disassembly. These processes currently utilise an excessive amount of resources and time, as they are based on an open loop (no feedback) control philosophy with process control dependent on conservative over estimation assumptions. This paper proposes a multi-sensor approach including a vision and acoustic system for clean-in-place monitoring, endowed with ultraviolet optical fluorescence imaging and ultrasonic acoustic sensors aimed at assessing fouling thickness within inner surfaces of vessels and pipeworks. An experimental campaign of Clean-in-place tests was carried out at laboratory scale using chocolate spread as fouling agent. During the tests digital images and ultrasonic signal specimens were acquired and processed extracting relevant features from both sensing units. These features are then inputted to an intelligent decision making support tool for the real-time assessment of fouling thickness within the clean-in-place system.

Peer-review under responsibility of the scientific committee of the 5th CIRP Global Web Conference Research and Innovation for Future Production

Keywords: Monitoring; resource efficient manufacturing; image processing; ultrasonic; intelligent

---

1. Introduction

In modern food manufacturing contexts, the standard procedure for cleaning equipment is the Clean-in-place (CIP) system, which uses a mix of chemicals, heat and water applied over a set period of time without the requirement of dismantling.

CIP is a multi-stage process, typically starting with a pre-rinse, followed by caustic solution wash, an intermediate rinse, and terminates with a sanitation phase made of an acid solution wash and a final rinse [1].

Existing CIP processes are time intensive and waste large amounts of energy, water, and chemicals [1,2] . Furthermore, it is estimated that on average, a food and beverage plant will spend 20% of each day on cleaning equipment, which represents significant downtime for a plant [2]. Monitoring of fouling can provide useful information on cleaning status and ensure efficient, effective operation of the equipment.

Ultraviolet (UV) light detection methods, are particularly used for the detection of residual cells and soiling on industrial surfaces [3,4]. State of the art on thickness assessment techniques includes transient thermal probe developed by [5] to estimate the fouling thickness of heat exchangers.

Pneumatic gauges for non-contact thickness measurement based on pressure profiles were developed and implemented by [6–8] presenting however distortions in measurement of soft deposit due to either the impinging jets or the suction streams [9].

An application of Heat flux sensor can be found in [10] aimed at monitoring local fouling of non-heated surfaces in commercial plants.

Peer-review under responsibility of the scientific committee of the 5th CIRP Global Web Conference Research and Innovation for Future Production
doi:10.1016/j.procir.2016.07.023

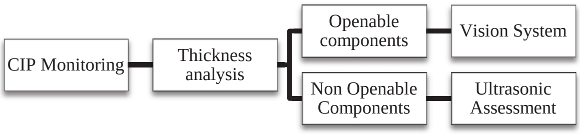

Fig. 1. Framework for thickness assessment

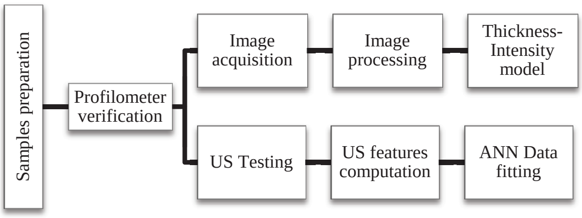

Fig. 2. Thickness assessment procedures

Ultrasonic (US) measurement techniques transmits low power (< 100 mW cm^{-2}) high frequency (> 20 KHz) mechanical waves through physical systems and are most commonly used is medical imaging and non-destructive testing. The techniques can be used to obtain information about the physical chemical structure of liquid materials and can identify any inhomogeneities within fluid systems by how they scatter or reflect the waves.

Ultrasound techniques have previously been used to detect fouling in heat exchangers [11–13] and pipe work [14,15]. Neural network (NN) classification can be found in [16] for determining the presence of fouling in heat exchangers.

This paper proposes a methodology for a multi-sensor monitoring system able to assess the fouling thickness within openable and non openable components of CIP equipment, utilising a vision and ultrasonic sensing units respectively for tanks and pipeworks, as outlined in Fig. 1. The output of these sensors will ultimately need to be correlated with the threshold of cleanliness to industrial standards.

2. Materials and experimental procedures

In this section, a description of the experimental setup utilised for both the vision system and ultrasonic tests is reported, with the procedure adopted for this research illustrated in Fig. 2.

2.1. Samples preparation

For the experimental campaign of thickness assessment tests, chocolate spread was used as fouling material, with the following characteristics (for 100 g of product): density=1.26 g/ml, protein = 5.4 g, water = 0 g, fat = 30 g, viscosity = 28.1 Pa·s (10 s^{-1}, 25°C).

In order to produce repeatable samples, a series of eight RK Printcoat Instruments close-wound stainless steel hand-coaters were used to apply a known-thicknesses layer of chocolate spread on two different substrate materials: stainless steel for the vision system tests and transparent polymer for ultrasonic tests.

Table 1. Nominal and measured thickness values

Test #	Nominal wet film deposit thickness (µm)	Measured average thickness (µm)
1	6	5.96
2	12	12.43
3	24	24.45
4	40	40.25
5	50	50.14
6	60	60.36
7	80	80.04
8	100	99.69

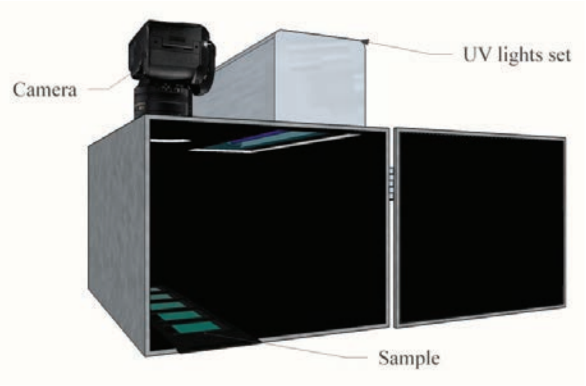

Fig. 3. Darkroom box design for image acquisition tests

The consistency between the sample thickness and the nominal value was verified using a Taylor Hobson CLI 2000 3D profilometer. Each sample was subject to a number of non-contact measurements, utilising the substrate as baseline and acquiring the average thickness. The nominal and measured thickness values are reported in Table 1.

2.2. Vision System setup

A darkroom box (Fig. 3) was designed and realised in order to allow a comprehensive and consistent experimental campaign of digital image acquisition of chocolate spread samples.

The darkroom box is insulated from external light sources and endowed with a set of two 18 W 370 nm fluorescent UV lights to allow the fluorescence of the chocolate layer [3].

The image acquisition was carried out using a Nikon D3300 DSLR Camera and a 10-20 mm wide angle Sigma zoom.

Nine different photographic configurations were used by varying the following parameters:

- ISO sensitivity = [1600, 3200, 6400]
- Shutter speed (s) = [1/10, 1/25, 1/50]

Other photographic parameters were kept constant:

- Focal length = 10 mm
- F-Stop = F/5
- WB = auto

By combining the ISO sensitivity and the shutter speed values a number of 9 digital images was acquired for each test, for a total number of 72 image instances.