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Eco-intelligent monitoring for fouling detection in clean-in-place

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Abstract

Clean-in-place (CIP) is a widely used technique applied to clean industrial equipment without disassembly. Cleaning protocols are currently defined arbitrarily from offline measurements. This can lead to excessive resource (water and chemicals) consumption and downtime, further increasing environmental impacts. An optical monitoring system has been developed to assist eco-intelligent CIP process control and improve resource efficiency. The system includes a UV optical fouling monitor designed for real-time image acquisition and processing. The output of the monitoring is such that it can support further intelligent decision support tools for automatic cleaning assessment during CIP phases. This system reduces energy and water consumption, whilst minimising non-productive time: the largest economic cost for CIP.

Keywords: Sustainability; Monitoring; Image processing

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1. Introduction

Food and drink production is the largest manufacturing sector within the UK and uses approximately 430 mega litres of water per day (1) equating to about 10% of all industrial water consumption. Additionally the industry is also the fourth highest industrial energy user in the UK, consuming 37 TWh with an associated 11 MT of CO_2 produced in 2010 (2).

Furthermore it is estimated that between 9 and 30% of the site energy used by a food processing plant is for cleaning (3,4), as reported in Fig. 1, whilst between 7 and 33% of a production site’s water is utilised by the cleaning process (5,6). The usual procedure for cleaning equipment in the food industry is the Clean-in-Place (CIP) system that avoids the need for equipment disassembly.

CIP is a complex operation which typically involves a warm water rinse, washing with alkaline and/or acidic solution, and a clear rinse with warm water to flush out residual cleaning agents (7).

CIP is an important component in guaranteeing food safety in food processing plants. Successful cleaning between production runs avoids potential contamination and products that fail to meet quality standards. Carrying out CIP correctly – from design to validation – ensures secure barriers between food flows and cleaning chemical flows (8).

The current standard for CIP is not to utilise real time monitoring but to establish, during system commissioning, the worst case scenario for material fouling (e.g. material type, condition) and to determine, by invasive techniques, the appropriate time required to clean the system.

This procedure is then routinely used for all CIP cycles,

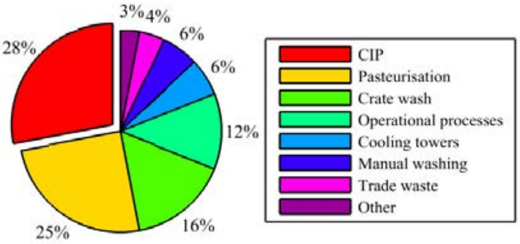

Fig. 1.Water use of a milk processor (4)

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regardless of actual fouling level. This precautionary approach results in systematic over-cleaning, which has considerable economic and environmental impact from excess water, cleaning chemicals and energy consumption during the cleaning process (9).

The purpose of this research is to establish the feasibility of an optical system for real-time surface fouling detection within openable components (i.e. tanks and vessels).

This paper undertakes a review of the state of the art on modern fouling detection methods.

The experimental setup of the optical system and the procedures for novel real-time CIP monitoring systems are described, along with the validation of the results in laboratory environment.

The paper concludes with a summary of discussions and implications for future of CIP.

2. Modern CIP

Cleaning food deposits, which contain both proteins and minerals, is a complex process that involves interactions between surface, deposits and detergent. It requires a multistage process, having many steps that may be controlled by shear stress, mass transfer, and chemical reaction (10). These cleaning stages can be described as follows:

- Diffusion of the cleaning solution from the bulk into deposit;
- Chemical reactions start and the deposited materials are broken;
- Dispersion of the deposit material into the cleaning solution by the shear action.

The most common CIP treatment is a two-stage process: a first stage using alkali (commonly NaOH) and second stage using acid base (nitric or phosphoric), usually separated by a water rinse step. The alkaline is used first to remove the protein and fat deposits and expose the thin minerals layer which is then dissolved by the acid step (11).

Since any cleaning time is downtime (i.e. non-productive time) it is also important that CIP is carried out effectively and efficiently, contributing to an overall low total cost of ownership.

Applying real time monitoring technologies represent some benefits such as reducing the amount of water which saves money in water supply charges of industry. In most cases, it will also have the effect of reducing the volume of wastewater discharge effluent, which will also reduce trade effluent charges. Savings in water are not the only benefit: for example the Carbon Trust reports that the UK brewing sector could save 4,600 tCO_2 (or 1% of total brewery sector carbon) by implementing real time cleaning verification systems (12,13). Such a monitoring technology would lead to an eco-efficiency improvement in industrial processes, reducing the consumption of resources, reducing the impacts on the natural environment, and increasing the product or service value (14).

Rapid *in situ* industrial methods for determining fouling levels in process equipment include Adenosine Triphosphate (ATP) swabs, which cause photoluminescence of protein and microbes, to determine cleanliness of tank/pipework inner surfaces.

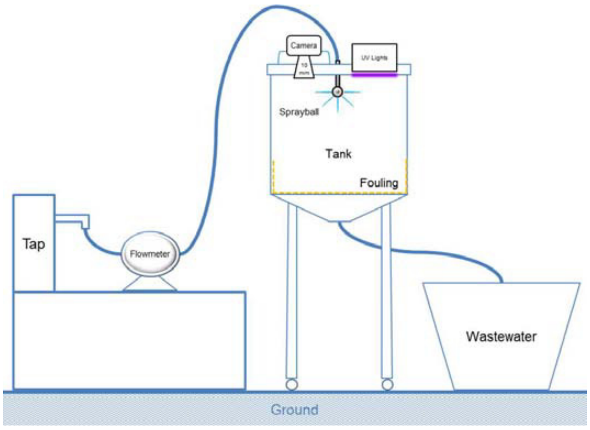

Fig.2. Experimental setup general scheme

Fig. 3. Methodology flow chart

This technique requires the system to be opened in several places where a swab is physically wiped over the inner surface which is time consuming, opens up the opportunity for contamination, introduces the risk of damage to the equipment, and requires a clean, before and after the procedure.

Alternatively, UV light detection methods, are particularly used for the detection of residual cells and soiling on industrial surfaces (15).

Microscopy *in vitro* methods include Scanning Electron Microscopy (SEM) (16), and Epifluorescent microscopy (17).

Optical methods have been used for the detection of food fouling: UV illumination is a widely recognised method for detecting food soil, with little change in findings when microorganisms are included. Performance can be improved in certain circumstances by altering the wavelength (15).UV light (353 nm) can also be used for the detection of residual cells and soiling on industrial surfaces (18). The molecular configuration of organic material allows some organic residues to fluoresce when illuminated by UV light (19). Thus, UV light may be used to detect residual soil when work surfaces are illuminated by an appropriate wavelength; highlighting areas in an industrial plant that need be cleaned more intensively. Unlike ATP bioluminescence, UV light detection methods do not require direct contact with the surface.

3. Experimental setup

In this work, an image based methodology for optical fouling detection has been developed. The methodology consists of 5 main steps as illustrated in Fig. 3.

Each step of this procedure is described in detail in this section, along with the description of the equipment utilised for the experimental campaign.