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Monitoring the Different Stages of Industrial Cleaning using Ultrasonic Sensors†

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Abstract: Clean-in-Place (CIP) technologies use a combination of time, temperature, chemicals and mechanical force (caused by flowing water) to clean processing equipment in the food and drink, pharmaceutical and fast moving consumer goods sectors. One of the major challenges facing CIP processes is that they often over clean affecting a factory's productivity and environmental impact. This paper presents an ultrasonic sensor method which can be used to monitor and therefor optimize the cleaning of pipe work. In this work we monitor the cleaning of different industrially relevant fouling materials in a flat pipe section. As each fouling material has different cleaning stages we propose the use of machine learning techniques to identify these stages of cleaning and determine when the pipe is clean.

Keywords: Ultrasonic Sensors, Process Analytical Technologies, Clean-in-Place

1. Introduction

The cleaning of processing equipment is important for manufacturing sectors such as food and drink, pharmaceutical and fast moving consumer goods. Cleaning ensures the equipment remains hygienic and reduces the possibilities of cross contamination of materials. Cleaning of this equipment is often performed automatically using Clean-in-Place (CIP) systems which do not require human intervention or dismantling of equipment. CIP technologies remove surface fouling from the processing equipment by a combination of time, temperature, chemicals and the mechanical force of the flowing fluids. Although essential, for most process manufacturing operations cleaning has negative effects on a manufacturer's productivity and efficiency, as any time spent cleaning equipment cannot be used to manufacture revenue generating products. This issue has been exacerbated in recent years as consumer trends have led to manufacturers producing a larger variety of products with their equipment increasing the frequency of cleaning. Cleaning also has negative effects on the environment due to the vast amounts of water, energy and chemicals used.

CIP processes are generally inefficient as they are designed to clean materials which cause the most equipment fouling, resulting in over-cleaning in the majority of operations. Research performed to optimize CIP processes has generally focused on understanding the effects of different cleaning parameters (e.g. water flow rate)[1] or measuring the properties of the water used to cleaning the equipment [2] [3]. One proposed method to optimize CIP processes is to monitor the internal surface fouling of the equipment and research has been performed using different sensor techniques [4], [5] [6].

In this work an ultrasonic sensor is developed to monitor the fouling removal during the cleaning of food materials. We will present how features extracted from the received ultrasonic signals vary during cleaning and propose the use of machine learning techniques to determine the different stages of cleaning.

2. Methodology

The experiments were performed on a rectangular Perspex test section with a flat stainless steel bottom. Water was used as the cleaning fluid and is fed into the test section through a hose fitting on one side and exited through an similar fitting in the opposite side. The ultrasonic measurement system featured a 2 MHz ultrasonic transducer, a Lecoeur US box and a laptop. Temperature was also recorded using a PT100 probe and a data logger. Bespoke MATLAB software was used to control the ultrasonic system and record the received signal. The ultrasonic transducer was located on the outside of the stainless steel plate and operated in reflection mode. During the cleaning experiments, the waveforms reflected from the interface between the stainless steel and the fouling material were recorded. Experiments were performed using tomato paste and gravy as the fouling material. Each experiment began by placing a known volume of material on the internal surface of the stainless steel plate in the region where the ultrasonic transducer was located. The cleaning experiments were performed for approximately 15 minutes for the tomato paste and 30 minutes for the gravy. The reflected ultrasonic signals were recorded every second and windowing was used to isolate the reflection from the stainless steel/fouling layer interface. These reflected signals were first analyzed in terms of their maximum amplitude and secondly compared to a reflected signal from the interface with no fouling present using a root mean square error method. Several repetitions were made for each fouling material and a webcam was used to image the fouling removal and aid analysis of the ultrasonic results.

3. Results and Conclusion

3.1. Tomato paste

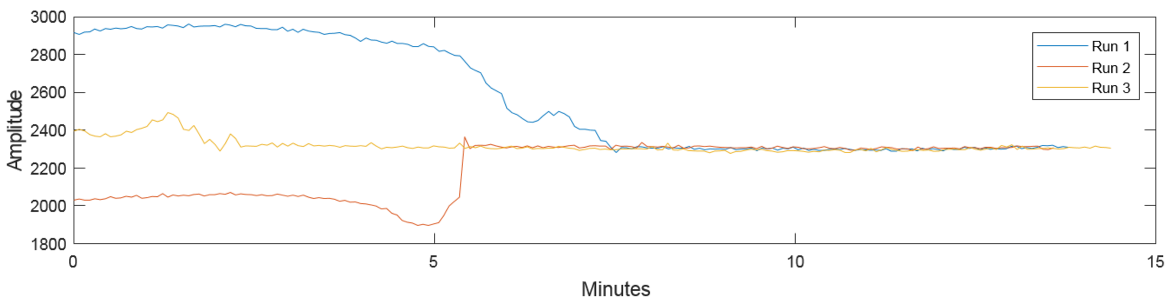

Figure 1. Reflected ultrasonic signal maximum amplitude during the cleaning of tomato paste

Figure 1 displays the maximum amplitude of the reflected ultrasonic signal during the cleaning of tomato paste. For the three experiments presented, the amplitude reaches the same value once the test section is clean. This was confirmed with images from the webcam. It is interesting to note that 1) the initial amplitude of the signal was not the same before cleaning, 2) The change in signal amplitude was different during cleaning and 3) the time taken to clean the surface ranged between 2-8 minutes. It is believed that these differences are a result of how the tomato paste sample was placed on the plate and how it was cleaned. Although care was taken to place the same volume of tomato paste for each experiment it was difficult to form a layer of uniform and repeatable thickness and surface adherence. Images from the webcam also confirmed that the removal of this surface fouling was different for each experiment. In some it would be removed slowly, dissolving into the water, as it had good adherence to the surface. In others it would be removed quickly in large lumps transitioning from fully fouled to clean in a small number of seconds.

3.2. Gravy

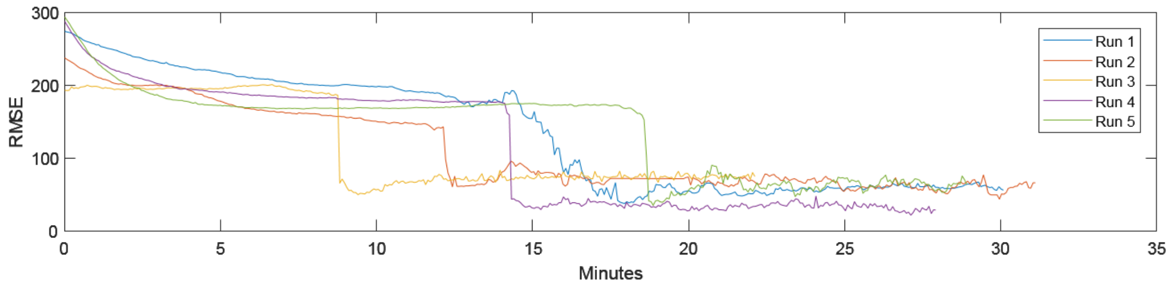

Figure 2. Root mean square error between reflected ultrasonic signals recorded during cleaning and a reflected ultrasonic signal from a known clean pipe. The results are for 5 experiments using gravy as the fouling material.

Figure 2 shows the root mean square error of a reflected ultrasonic signal during cleaning and a reflected signal from a known clean pipe. The reflected signal from a known clean pipe was taken from Run 4. The cleaning of gravy took significantly longer than the cleaning of tomato paste and the cleaning process was different. Whereas the tomato paste would either dissolve slowly or quickly be removed as a lump the gravy would be cleaned much slower (~9-20 minutes). After the majority of the gravy had been removed a thin layer always remained on the surface. Air bubbles would form on this layer and cause temporal variation in the reflected ultrasonic signals as observed between 15 and 30 minutes in Figure 2. The results also show almost identical trends for the RMSE which is a reduction from approximately 200-300 to 50 once the surface was clean. This reduction happens relatively quickly for all experiments expect Run 1. The results indicate that the RMSE method may be a more suitable data processing technique for monitoring CIP using ultrasonic sensors. The results presented in this work show that ultrasonic sensors can be used to monitor the cleaning on surface fouling for different food materials. Follow on work will focus on 1) different types of fouling material 2) measurement in cylindrical pipe sections, more representative of processing equipment and 3) developing classification machine learning techniques to identify the different stages of cleaning for different fouling materials.

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