An Effective CIP Procedure for Removing Dairy Protein Based Deposit – A Laboratory Investigation

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AN EFFECTIVE CIP PROCEDURE FOR REMOVING DAIRY PROTEIN BASED DEPOSIT – A LABORATORY INVESTIGATION

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ABSTRACT

In this paper, examples of using an in-situ electrochemical cleaning technique are illustrated. It can be shown that while using the standard chemical for cleaning in the dairy industry, the application of the in-situ electrochemical method is very effective in removing the dairy protein based fouling deposits. Both the gel protocol developed earlier and the real fouling procedure have been used to evaluate the effectiveness of the new method.

INTRODUCTION

Cleaning-in-Place (CIP) is employed in the food industry so that the processing equipments do not need to be dissembled when they are cleaned. A considerable amount of research has been conducted in recent years to seek ways of improving the procedure. Both the chemical reactions and fluid shear play roles in the removal of fouling deposit but the effect of chemical reaction is one that is of the key importance (Wilson, 2002). The dairy industry suffers from particular problems associated with cleaning production machinery including heat exchangers. To date, machinery involved in the handling of milk and other dairy products must be shut down entirely for an extended period of time during cleaning operations. The cleaning involves flushing high levels of caustic cleaning agents through the machines in order to remove residues build up and contamination. Once the cleaning is finished the machine must then be rinsed very thoroughly to remove all traces of these cleaning elements.

BASIC PRINCIPLES

The current research has taken a different approach to improve CIP (Chen, 2003). Electrolysis is well known for surface cleaning and polishing (Pieβlinger-Schweiger, 2001). The substances are ionized into electrically charged ions, and when an electric current is passed through them by means of conducting electrodes, the ions move (in the electrolyte solution) towards the oppositely charged electrodes thereby giving up their electric charges to become uncharged atoms or groups, and are either liberated or deposited at the electrode or react chemically therewith. Electrolysis has wide ranging industrial applications and is primarily used as a method of deposition at the cathode or sacrificial degradation at the anode. Electrolysis also finds application in cleaning and polishing techniques but, to date, has not been fully explored to its potential for in-situ actions. The method may include the step of applying said voltage to said component with the component acting as either anode or cathode. The voltage applied may be varied in a suitable manner so as to limit the current applied during electrolysis.

It provides an electrochemical apparatus comprising an electrolyte to be applied to in-situ metallic components of a machine requiring treatment according to any of the previously described methods and a voltage control means for applying a voltage to an electrolyte (i.e. the chemical cleaning solution) with the metallic components acting as either anode or cathode.

When an electric field is applied to a fouled metal surface, besides electropolishing, it can also remove the fouling. Gas bubbles are formed as a result of electrolysing of the solution on the surface of the electrodes.

$$2H_2O-4e \xrightarrow{\text{anode}} \uparrow O_2$$

$$2H_2O+4e \xrightarrow{\text{cathode}} \uparrow H_2$$
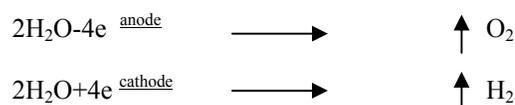
The electrochemical reactions also give the following results: the formation of protons (H^-) and the formation of hydroxyls (OH^-) depending on anode or cathode sides. This causes swelling of protein deposits making it easier to remove them. The gas bubbles formed provide an additional physical force to dislodge the attached foulant, whether mineral or protein. This last action might be the primary mover of the fouling deposit.

METHODS AND MATERIALS

(i) Preliminary tests

The preliminary experiments were conducted using a system shown in Figure 1. The first experiment was carried out using phosphoric acid used of 5% (w/w). The foulant was prepared by boiling milk. Stainless steel specimens (2.5 cm × 9 cm × 0.12 cm) were placed on a heated bottom of a beaker for at least two hours to allow the development of milk fouling formed by thermal denatured protein.

The fouled stainless steel specimen was mounted in the electrolytic cell of Figure 1 as one of the electrodes. The gap between anode and cathode was set at about 6 mm. The initial voltage applied was 5 V (DC) allowing an 8.3 V/cm electric-field strength and 0.2 A/cm^2 current density for electrolysing. Note that the current density used here is rather high.
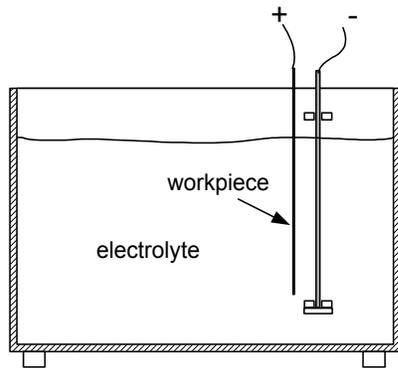

Figure 1. The electrochemical reaction cell used in the preliminary tests (when acid was used).

(ii) Cleaning of a tube fouled by either the protein gel or the real milk fouling

An established protocol has been followed to form uniform gel deposit and a detection method has been used to also measuring the deposit (removal) cleaning rate of a NaOH solution flowing through a metal tube (Xin et al, 2002a and b).

The cleaning system used to study the cleaning process is illustrated schematically in Figure 2. The apparatus consists of a stainless steel tube (ID = 16 mm and length = 150 mm), pre-coated with a WPC gel film using a rotation rig. This tube section is the test section. A NaOH solution reservoir containing heating coils and an agitator was used to prepare the cleaning solutions with a given concentration and temperature. The flow velocity of the cleaning solution is controlled by a valve and monitored by a float type flow meter. In the once-through cleaning system, the cleaning solution, containing the removed deposits was continuously transported to a UV spectrophotometer (HP 8312 model) by a sample pump. UV absorption at 248 and 256 nm was recorded at 10 s intervals to monitor the whole cleaning process.

The electrolysis was implemented into the test section (the tube section fouled with protein gel film) (see Figure 3).
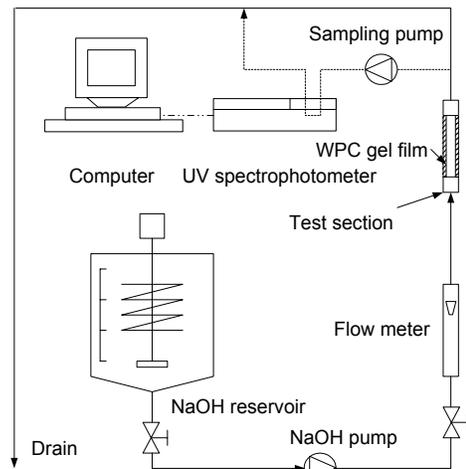

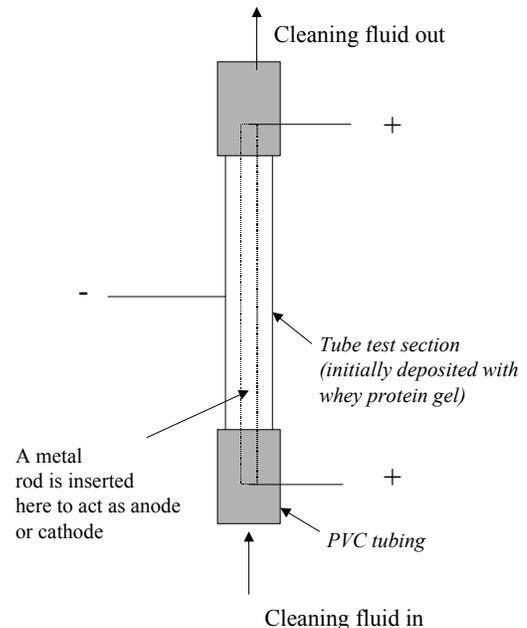Figure 2. The cleaning loop set up for cleaning a section of tube deposited with a gel film.

Figure 3. The test section.

A commercial WPC powder (80.4 wt.% protein, 7.4 wt.% carbohydrate, 5.6 wt.% fat, 3.8 wt.% moisture, 2.8 wt.% ash, pH 6.5) was purchased from a local dairy company. Aqueous dispersions of 25wt.% whey protein concentrate were prepared in a test beaker by agitating until a uniform suspension was obtained. The WPC solution was then accurately weighed and poured into a stainless steel test tube. Both sides of the tube were tightly sealed. The tube was placed on a rotating device and immersed into a water bath at a temperature of 79.5 ^{o}C. The tube was rotated horizontally for 30 minutes at a rotational speed of 60 rpm. The coated tube was then cooled from outside using running

tap water. The coated tube was inspected in order to ensure that it had a continuous uniform film before being put into the cleaning loop. The density of the gel was about 1.10±0.02 g.cm^{-3}, which is similar to that of skim milk deposits (1.1-1.2 g/cm^3).

The protein concentration measurement was conducted according to Xin et al (2002b). The most frequently employed spectral range for protein analysis is between 250 and 320 nm (the near ultraviolet region), UV absorbance measurements in this region provide the most accurate result for determining the protein concentration. In the study of the reactions between sodium hydroxide solutions and the protein deposits formed on the heat exchange surfaces. The sensitivity of this method is high enough to determine a very dilute protein solution (1mg/L) encountered in cleaning study. In this study it has been found that using 0.5 wt.% NaOH solutions instead of pH 13 buffer solutions did not affect the UV absorbance. A linear relationship between the UV absorbance difference at 248 and 256 nm and the WPC concentration in the cleaning solutions was established. Therefore, a continuous and non-invasive UV spectrophotometric method is developed and can be used to monitor the cleaning process on-line. The following expression is used for the estimation of protein concentration in the cleaning solutions in this paper:

WPC concentration (g/L)= 1.0368(A_{248}−A_{256})+0.0005

where A_{248} and A_{256} are the values of UV absorbance at the wavelengths of 248 and 256 nm, respectively.

RESULTS AND DISCUSSION

(i) Preliminary tests

When the electric field was applied, large amounts of gas bubbles were formed on the electrode surface, which provided a physical force to assist in dislodging the attached foulant (see Figure 4). As a comparison, one of the sample specimens was soaked in the same phosphoric acid solution for 24 hours. It was found that manual brushing had to be used to obtain the same cleaning result. Electrolysing is so effective in removing fouling that even some burnt-hardened crust on metal surfaces can be removed. The samples were prepared by heating the stainless steel specimens to about 300-350°C, then putting several drops of milk onto them, resulting in the milk deposit dry out and becoming burned eventually to form a hardened skin.

It has also been found that it was even more effective to remove milk fouling using a NaOH dilute solution (0.5wt %, which is the recommended optimal concentration for milk foulant removal) as an electrolyte, and electrolysing at a similar strength as above. In tests without electrolysis, the

foulant swelled after being in contact with the NaOH solution. Because of the lack of fluid shear, the deposit would stay swollen but would not come off the metal surface after more than half an hour. When the specimen was subjected to electrolysis after the similar foulant was put in contact with the solution, swelling of the foulant started almost immediately and some 10 to 15 min thereafter, the foulant was removed and a clean metal surface emerged.

It was evident that the gas production at the interface would have played a key role in removing the swollen deposit. The gas laterally separated the deposit from the metal surface. If the fluid shear were present in a significant way, the two would combine to make a greater impact.

(a) burnt-hardened milk fouling on the stainless steel coupon

(b)Placing coupon into electrolytic cell

(c) treated in phosphoric acid

(d) The foulant sheded off as a whole
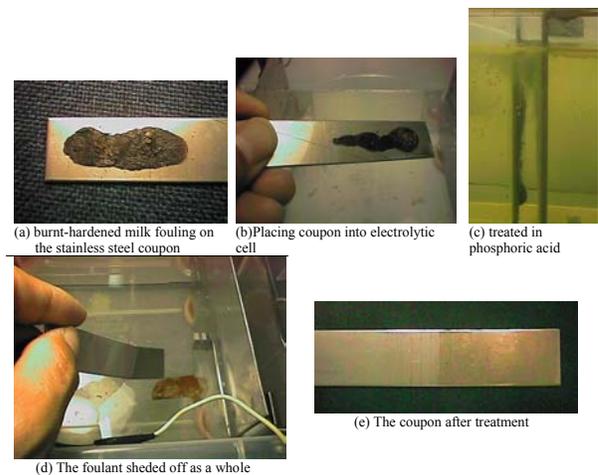
(e) The coupon after treatment

Figure 4. An illustration of the electrochemical removal of the 'burnt' milk deposit layer.

(ii) Cleaning of a tube fouled by either the protein gel or the real milk fouling

Figures 5-7 show the results of the cleaning with the technique benched marked against the conventional (or normal) cleaning without the applied electro-chemical influence. The Y-axis (absorption difference is the measure of the concentration of the removed materials in the exit-flow from the test section. Note here that lower current fluxes are used.

Cathodic cleaning

The area under each plot indicates the amount of dissolved proteins in solution exiting the test section. For the electrochemical cleaning approach, the peaks (see all the figures) have smaller areas than that of the normal cleaning regime. This indicates that the flow carried out lumps (those not dissolved) when electrochemical action took place.
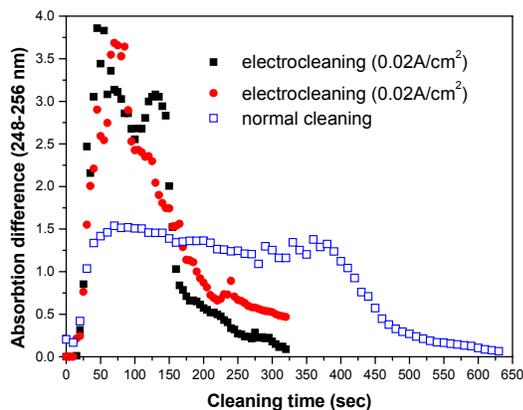
Figure 5. Cleaning profiles. Cleaning temperature 65°C, flow velocity about 0. 24 m/s, 0.5wt% NaOH solution,WPC gel film (0.6mm thick) (velocity = 0.24 m.s^{-1}) (Electro-chemical cleaning was at the cathode side - the tube wall).
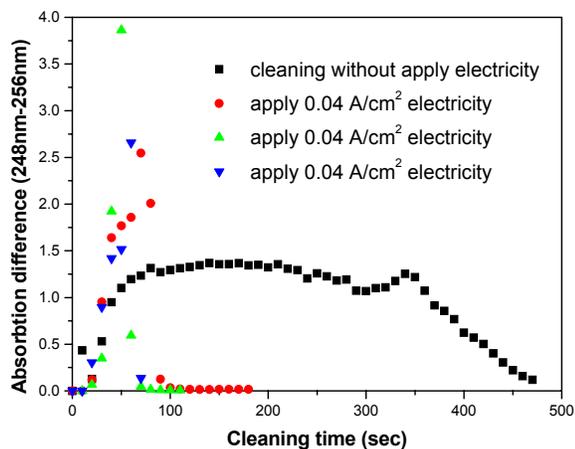

Figure 6. Cleaning profiles at a lower current flux. Cleaning temperature 65°C, flow velocity about 0. 24 m/s, 0.5wt% NaOH solution, WPC gel-film (0.6mm thick). (velocity = 0.18 m.s^{-1}) (Electro-chemical cleaning was at the cathode side - the tube wall).

Using the processing surface as the cathode, the process was very effective, however, the anode was affected adversely. It was then decided to use the periodic-reverse operation shown below and it was found that both surfaces were maintained clean and smooth. The low current density of 0.02 A/cm^2 was found to be effective as well.

(b) Periodic- reverse operation

Here, the anodic and cathodic modes are switched every 10 seconds with 3.0 voltage and current density of 0.02A/cm^2. The flow rate was about 0.3 m/s, temperature

65°C, 0.5wt% NaOH solution, WPC gel-film of 0.6mm thick. In both cases, the electro-chemical method gives superior results compared with the conventional method. One can see that the periodic-reverse operation, switching anode and cathode between two surface, works very well. This has shown the promise of such an approach to industrial situations to improve the existing CIP procedure for certain equipment, which would allow electrical insulation be set-up without too much complication.
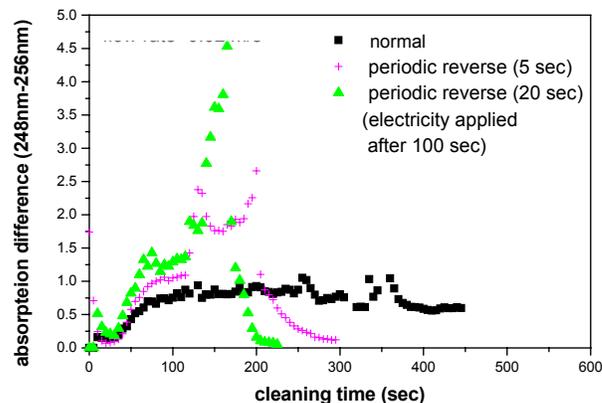

Figure 7. Cleaning profiles with periodic reversal operation at different periods. The other conditions are the same as that shown in Figure 6 (except velocity = 0.19 m.s^{-1}).

Subsequent experiments were carried out also on real milk fouling and the similar effect was observed (results not shown here). In order to see if the observation using the UV assay was quantitative, separate weight measurements of the deposit remained (after a certain cleaning time for both the normal cleaning and also the electrochemical cleaning) were conducted. The positive effect of the electrochemical action was evident. Further work is being conducted to see if a long-term treatment of such a CIP procedure would adversely affect the metal surface. It has been observed that the process can also remove and deactivate the bacteria that are deposited on the surface. However, more comprehensive research is required and indeed being conducted in our laboratory.

CONCLUSION

In this paper, we have shown several lab results of implementing the electrochemical cleaning principle *in-situ* of the process equipment. The results are highly encouraging and more work is going on to investigate the technique, which presents a possibility of removing protein deposits in a much reduced time period compared with the

conventional alkaline cleaning approach. There are still issues to be researched, e.g. what is the effect of the process on the surface and the effectiveness of the procedure on microbial deactivation. Field trials are also planned to see if the process can be scaled up properly.

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