Proceedings of International Conference on Heat Exchanger Fouling and Cleaning VIII - 2009 (Peer-reviewed)
June 14-19, 2009, Schladming, Austria
Editors: H. Müller-Steinhagen, M.R. Malayeri and A.P. Watkinson

Published online
www.heatexchanger-fouling.com

IMPROVING CLEANING OF INDUSTRIAL HEAT INDUCED FOOD AND BEVERAGES DEPOSITS: A SCIENTIFIC APPROACH TO PRACTICE.

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ABSTRACT

Heat induced fouling gives traditionally some of the hardest soils to be removed and cleaned. Especially in the food and beverages industry where safety is of primary importance, heating processes are necessary to destroy potential bacteria. During pasteurisation at temperatures between 60°C and 80°C proteins start to deposit and as cooking or further sterilisation takes place, calcium deposits occur and form more complex soils to clean. Performance drops, pressure drop increases and strong CIP (Cleaning In Place) solutions are used to bring the equipment to its initial stage.

This work presents experimental results on water rinsing, as the first step of CIP, on lab scale both on proteinaceous deposits of Sweet Condensed Milk (SCM) and brewery yeast. A lab scale rig shows how cleaning time of cooked soils drops with increasing temperature and flow rates. The results are aimed to be scaled up to a CIP pilot plant built at the University of Birmingham, where soiling and cleaning of stainless steel geometries take place. Conductivity and IR measurements determine the end point of each CIP step. Understanding of cleaning is obtained and improving suggestions are important outcomes of the work in order to minimise energy and water usage.

The results also exhibit the techniques developed to achieve consistent fouling and identify and understand the cleaning mechanisms involved in order to reduce effluents and prolong production times.

INTRODUCTION

Heating has a great effect on the food properties. Various processing operations are based on heating, such as canning, baking and pasteurising. The above might aim to preservation (e.g. killing of bacteria, inactivating enzymes), physical changes (i.e. taste, flavour), structural changes (baking) or drying and frying where mass transfer is also occurring due to evaporation of moisture (Bakalis et al., 2001).

The heat processes devised to give different degrees of shelf life to food products are usually classified either as pasteurisation or sterilisation. The former is a partial treatment that destroys only the more labile fraction of microbial population. The latter is a complete one, because the level of surviving organisms is lowered beyond any value detectable by usual analytical practices.

They are usually carried out in Heat Exchangers (HE). Fouling can be described as the unwanted build up of deposits on a surface. This is a major problem in the processing of personal products and foods. The build up of deposit increases pressure drop in flow, due to the increase in surface roughness and the decrease in cross-sectional area of the flow channels, and reduces heat transfer efficiency within process heat exchangers. Increased costs are therefore incurred to operate the plant. The interior surfaces of tanks and mixing vessels will also become coated with deposit. Fouling can also compromise product quality, either by cross contamination between different products run on the same process lines or as a result microbial growth within the deposit.

It is thus necessary to stop production to clean the process plant. The overall productivity of the process plant is therefore reduced, and failure to clean could compromise product quality or sterility.

In many cases the deposit has a very different chemical composition to the process fluid, due to the preferential deposition of some component of the material (for example whey proteins from milk). In other industries it is the deposition of the process material itself (e.g. toothpaste, shower gel etc.).

Fouling and the ways to minimise it have been investigated for many years (for detailed examples, see the series of conferences including Fryer et al, (1994), and Wilson et al (1998, 2002, 2006)). One of the key advances in fouling research was the realisation that fouling deposit can arise from a range of different mechanisms, and the classification of those mechanisms. The fouling process generally involves a number of steps (Epstein, 1983): initiation, transport, attachment, build up and ageing. The advantage of classification is that it allows results from different industries to be compared readily – this is not currently possible for cleaning, (Fryer and Asteriadou, 2009).

Fouling in food processing is common: for example, Bird (1992) reported papers on the cleaning of a number of foods, such as: chocolate desserts (Bird, 1991; Rene et al., 1988), coffee solutions, corn syrup, meat products, soya oil protein (Wilkinson, 1982) and tomato soft solids (Cheow and Jackson, 1982ab).

Cleaning is an absolute necessity in the food industry, since deposits are quite likely to form and adhere on the equipment surface. This can have various consequences to the process. First of all it can be the perfect environment for microbial growth; secondly the thickness of the deposited layer can hinder the heat transfer and drop the overall heat transfer coefficient. This would mean higher energy consumption in order to achieve the required temperature in the product.

There are four factors that affect the overall cleaning process. When designing cleaning procedures these factors need to be thoroughly considered (Jennings, 1957; Bishop, 1997).

Time: The longer a cleaning solution remains in contact with the equipment surface, the greater the amount of soil that is removed. Increasing time reduces the chemical concentration requirements.

Temperature: Soils are affected to varying degrees by temperature. In the presence of a cleaning solution most soils become more readily soluble as the temperature is increased.

Concentrations of chemicals: they vary depending on the chemical itself, type of food soil and the equipment to be cleaned. Concentration will normally be reduced as time and temperature are increased.

Mechanical Force: Mechanical force can be simple manual scrubbing with a brush or as complex as turbulent flow and pressure inside a pipeline. Mechanical force aids in soil removal and typically reduces time, temperature, and concentration requirements.

CIP programmes are usually single-stage or two-stage cleaning procedures. Two-stage cleaning employs both acid and alkali, whereas in single-stage cleaning only one cleaning agent is used. In no heated surfaces is usually applied a single-stage process (with formulated alkaline detergents). In heated surfaces, where fouling is generally more severe, are applied two-stage alkali-acid procedure (Kane and Middlemiss, 1985; Grasshoff, 1989; Karlsson, 1999). The work presented here is based on the CIP necessities and closed pieces of equipment are taken into account

Many people have worked on CIP improvement and monitoring. Grasshoff (1994) investigated the multi-stage CIP process thoroughly for a dairy plant heat exchanger. He used computer imaging. It is considered as a first attempt to quantify the removal of encrusted deposits from a solid surface.

Gillham et al (1999) ran experiments in order to see the mechanisms involved in the alkali-based cleaning of whey protein deposits on stainless steel surfaces. They used rate, deposit surface and heat transfer techniques. The results showed that reaction and diffusive transport processes occurring in the swollen deposit layer determine the cleaning rate under conditions of steady pipe flow.

Bird and Espig (1998) investigated the removal of crude oil films from stainless steel surfaces using non-ionic surfactants at different temperatures. Plain water rinsing was not effective and followed Arrhenius kinetics. Surfactant cleaning deviated strongly from Arrhenius kinetics. At high surfactant concentrations a smooth curve is produced which appears to be physically controlled at high temperatures and a combination of chemically and diffusion controlled at low temperatures. A four step cleaning mechanism is postulated where the surface modification of the oil surfactant adsorption is the rate-limiting step of the removal process. Also Bird and Bartlett (1995) elaborated on concentration and temperature optima during the removal of protein, starch and glucose for CIP processes.

Of course if fouling did not occur there would not be a need to clean, however, extensive research has not yet found a prevention method and so cleaning must still take place. However, cleaning is not optimized in the FMCG plants mainly due to lack of understanding of mechanisms and equipment interaction (Yang et al, 2008)

This work focuses on the preliminary water rinsing stage of cleaning cycles and its understanding from a process parameter point of view. Also appreciating the importance of how a deposit is removed is one of the key parameters here. The soils used are industrial ones and not ingredients of them.

MATERIALS & METHODS

The materials-soils used are Sweet Condensed Milk (SCM) and brewer's fermentation deposit. The first was supplied by Cadbury's and is a material with basic ingredients sugars and milk solids. The second was provided from fermenters from a Scottish & Newcastle brewery. It is from the last stages of beer processing where in the proteinaceous, sugar rich wort, yeast cells are added to produce beer with fermentation.

SCM is of interest since it undergoes heat treatment for pasteurization (in HE) and in pressure cookers. The brewer's deposit is at the last stages of beer production and is one of the major cleaning problems of fermentation vessels and surrounding pipe work with interesting biological composition. The fermentation vessel needs to be brought and maintained at low temperature while the process is taking place.

Fouling method of SCM

All samples were collected on stainless steel square coupons (0.029 m by 0.029 m). SCM coated coupons were heated for 240 min at 85-90^{o}C in a conventional oven before tested for cleaning. This represents the temperature conditions in a pasteuriser. SCM is the intermediate product towards chocolate crumb production. The various heating steps aim as well to dry the SCM. Thus, drying/baking in a conventional oven is not that far from the industrial process and is quite representative for experimental reasons.

Fermenter deposit acquisition

The above mentioned stainless steel test coupons were suspended in a fermentation vessel for 4 days using a bespoke rig (fig. 1). The rig and coupons were cleaned beforehand in the CIP fluid collection cart as part of the normal vessel CIP regime. Once clean, the rig was submerged in a sterilant soak bath until a vessel was available. Upon collection the coupons were placed in a clean, segregated storage container, which was refrigerated until experimentation. The coupons were not used if the storage time exceeded 2 days due to potential yeast degradation. The fouled coupons were weighed before cleaning experiments to determine the amount of deposit. A copy of the fermentation profile was collected to confirm normal fermentation progress.

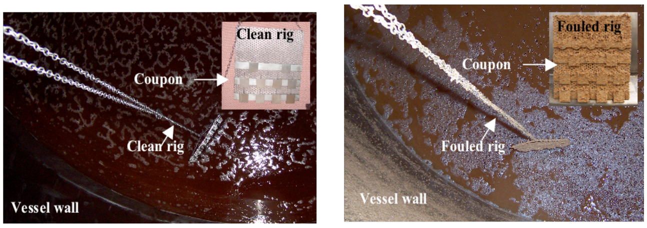

Fig. 1 Deposit collection. Prior to fermentation (left) and post fermentation (right)

Cleaning flow cell rig

The contribution of rinsing to surface cleanliness was investigated on a lab scale flow cell rig (fig. 2). The rig is comprised of a centrifugal pipe SolidC-1 (Alfa Laval), a flow transmitter PD 340 (Ecolab), a conductivity and temperature meter at the return (LMIT08) (Ecolab) and thermocouples. All these feed into Labview (NI 4.4.1) in a PC next to the rig. Most of the pipe work is hoses and an inverter is attached to the pump to regulate the flow rate. The fouled coupon is positioned in the centre of the test section (fig. 3). It is surrounded by a clear quartz type glass to allow observation of cleaning from top and front side mainly.

Cleaning progress is characterised by comparing the change in heat transfer coefficient (HTC) from that of a clean surface, and by monitoring fouled area reduction by image analysis using the software Image J. The camera that was used is a Cannon EOS 30D. The HTC is measured with the help of a heat flux sensor that is located underneath the fouled coupon and in direct contact with it (for detailed description of the principle of these sensors and how HTC is measured see Christian, 2004). The test coupons fit into the base of the test piece flush with the surface. The deposit protruded into the duct where the cleaning fluid is circulated at a set flow rate and temperature. The removal mechanism, percentage of deposit removed and cleaning time can be defined.

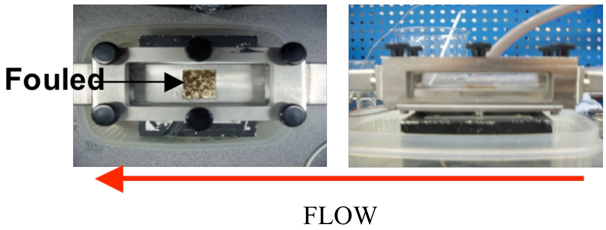

Fig. 3 flow cell with soiled coupon

RESULTS

Sweet Condensed Milk (SCM)

The SCM coupons, after getting soiled, were inserted in the cleaning rig. The experiments that took place with SCM in the cleaning rig are shown on table 1, where the flow rates and temperatures chosen are given together with the corresponding Reynolds numbers for water flows at the given conditions. They vary from transitional to turbulent. Reynolds number was calculated with eq. 1:

$$Re = \frac{d_h \cdot u \cdot \rho}{\mu} \qquad (1)$$

where
d_h is the hydraulic diameter [m]
u is the average velocity in the duct [m/sec]
ρ is water density at given conditions [kg/m^3]
μ is water viscosity at given conditions [kg/m/sec]

Table 1 Parameters variation for the rinsing experiments of the SCM soiled coupons.

Flow rate (l/min)	Re (Reynolds Numbers)			
	20°C	40°C	60°C	80°C
4	2543	3879	5374	6994
8	5085	7759	10748	13987
12	7628	11638	16122	20981
16	10170	15518	21496	27975

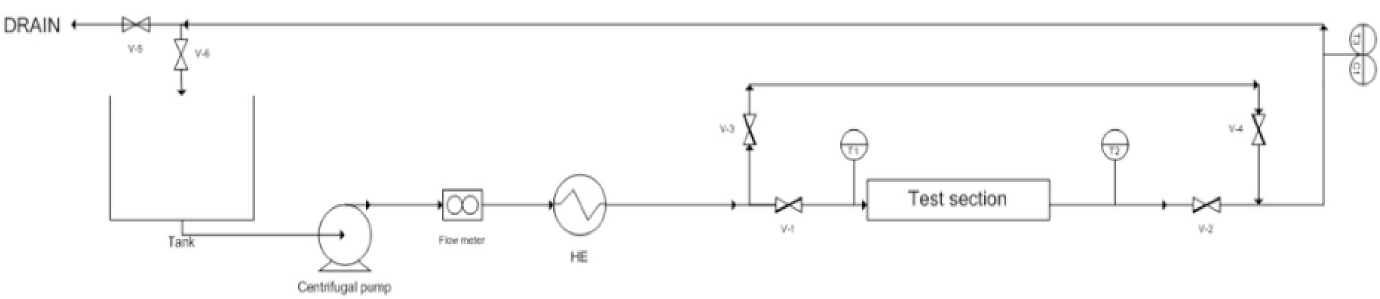

Fig. 2 Cleaning flow cell rig (where T is temperature, C is Conductivity)

The rinsing was with plain water in order to estimate the impact of parameters such as temperature and flow rate during rinsing as part of a CIP programme.

As already mentioned the heat transfer coefficient (HTC) was measured while the rinsing was taking place for all the above conditions (table 1). Also the camera was taking shots in order to measure the coupon surface-cleaning rate. As an example, fig. 4 shows the change of the HTC values and the soiled surface area [mm^2] while the rinsing is taking place at 4 l/min and 80°C. There it can be seen that the HTC starts from low values at the start of rinsing. There is a rapid increase until 50 sec probably due to diffusion and soil thinning. Then the increase is slower. The corresponding surface area starts to clear and that is shown with the drop of the amount of surface covered with SCM. After circa 230 sec the HTC has reached its highest value and the covered surfaced area has dropped to minimum value (followed by a very slow drop of negligible rate) indicating the end of the cleaning.

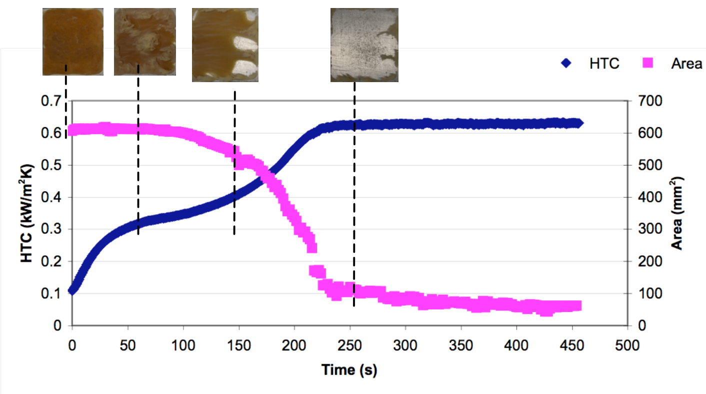

Fig. 4 Heat transfer coefficient and area being cleaned with time at 80°C and 4l/min

The response of the soil towards cleaning action can be presented as a deposit resistance, R_d profile. R_d will decrease when thickness of deposit layer decreases or when removal happens, the reverse of HTC curve. The R_d profile shows (fig. 5) the cleaning phases clearly as well. R_d [m^2K/kW] was calculated as:

$$R_d = \frac{1}{U_t} - \frac{1}{U_c} \qquad (2)$$

in which U_t is HTC [kW/m^2K] at time t. The heat transfer coefficient of the clean system, U_c was determined from the average value of the final 500 s of the collected data.

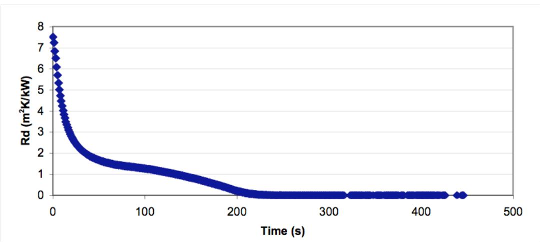

Fig. 5 Deposit resistance R_d during cleaning at 80°C and 4l/min

Similarly, all cleaning times are calculated for the different conditions. The results are summarized on fig. 6. There it is obvious that the higher the temperature the shorter the cleaning time for the same flow rate. Also the higher the flow rate the shorter the cleaning time for the same temperature. It can be observed that cleaning times at temperatures 20°C and 40°C vary significantly amongst each other. At higher temperatures (60°C and 80°C) the cleaning times drop a lot compared to the lower temperatures but do not differ as much amongst each other. As the flow rates increase the difference becomes smaller. At 16 l/min the cleaning times are almost identical.

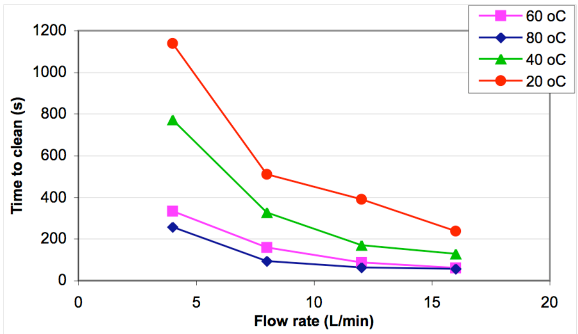

Fig. 6 Cleaning times variation with flow rates at different temperatures.

Plotting the same data against Re numbers (fig. 7) it is seen that at lower temperature values, the Re achieved is lower for the same flow rates compared to higher temperatures. Also the transient flow rate of circa 2500 Re gives significantly higher cleaning time compared to the values in the turbulent zone. All the rest are closer to each other with dropping variance as Re increases. Above 10000, cleaning times variations drop and above 20000 they are very close. Thus it can be seen that using Re values the cleaning times can be justified by clustering them into the transient and turbulent regimes.

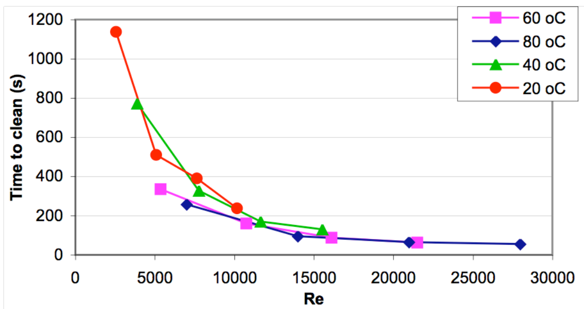

Fig. 7 Cleaning time variations with Re number at different temperatures.

Yeast

This paragraph describes some initial experiments on cleaning brewer's yeast deposits from the coupons using the technique that was described in the above sections.

The rig is used in a similar way as for the SCM.

On the flow cell the temperatures applied were: 20°C, 30°C, 50°C, 70°C and Re 10500. An increasing amount of deposit removal was seen by visual observation. It was revealed that rinsing at 70°C removed the most deposit in 10 minutes and that rinsing for longer than 10 minutes marginally improved deposit removal (figure 8). No water rinsing regime removed any substantial amount of deposit. In all flow cell-cleaning experiments a mechanism was preserved i.e. deposit islands of variable size were removed from variable positions on the coupon at variable times. However, with increasing temperature, island removal frequency did increase. Also, at the end of cleaning, the coupon was removed from the rig and it was clear that the remaining soil still had hard texture, which explained why further rinsing with water would not lead to removal.

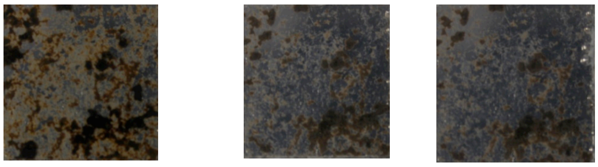

Fig. 8 Images taken at t_0, t_{10} and t_{30} for a 70°C experiment, and Re 10500.

On figure 9 is depicted the change of the HTC for an experiment run at 30°C and 12 l/min (Re circa 13000). It is shown that the HTC is increasing very slowly indicating the slow removal/detachment of material from the coupon. There is no cleaning observed after circa 1h of a pre-rinse flow at 30°C (as usually applied in a brewery). The step changes might correspond to chunks being removed. Further experimentation is needed to establish a good understanding of pre-rinse conditions and the necessity of the use of chemicals.

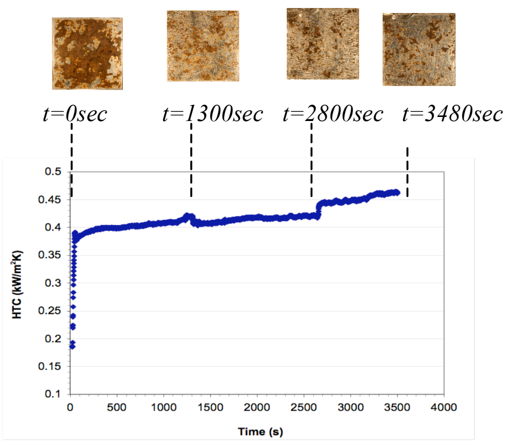

Fig 9 Change of HTC for an experiment of yeast removal at 30°C and 12l/min (Re circa 13000)

DISCUSSION

The results presented are the initial stages of a work that focuses on removing real industrial products from FMCG lines instead of their individual ingredients as many previous publications have suggested. The vast amount of data in the literature that focuses on the various components and their interaction help us understand that there is time to put this knowledge into application.

Here SCM and brewer's yeast were used as products whose production gives severe fouling implications on the process equipment surfaces. Thermally treated SCM soil was water rinsed. The results indicated that higher flow rates and temperatures lead to shorter cleaning times. However, there seems to be a set of conditions above which the drop in cleaning time is not much affected. This is probably a key observation together with the cleaning rates that will determine the stop of water rinsing and start of chemical wash. This will be better verified with scale up experiments that will take place in a CIP pilot plant already in use at the Chemical Engineering department of the University of Birmingham (fig. 10).

Similarly, for the results on yeast rinsing, it was observed that even at turbulent flow conditions and high temperatures (70°C) there was not complete cleaning observed. Rinsing at low temperatures, which is the case of CIP in breweries, there was a slow removal. That showed that during a CIP of a production line the water rinsing step might overrun. The right moment to swap to the chemical cleaning step might not be well identified so far. More experiments need to be carried out in order to understand better the impact of water rinsing on dried brewer's yeast removal. Also, experiments on the pilot plant will verify the above at a larger scale. In general it was observed that:

- No water flow regime gives a clean surface
- Cleanability beyond 10 min is negligible even at high temperatures
- 70 °C gave the best cleaning result at lab scale
- Removal mechanism is preserved
- the remaining soil maintained its hard texture showing that no significant diffusion of water took place.

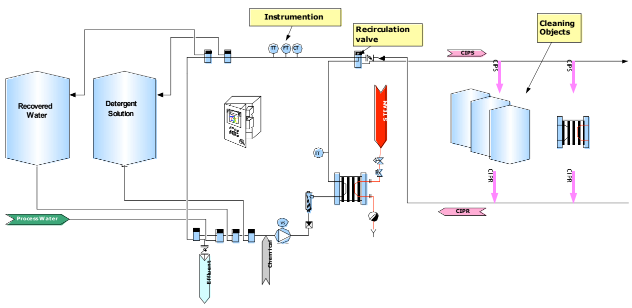

Fig 10 CIP pilot plant to be used for scale up experiments using industrial soils to be cleaned.

CONCLUSIONS

This paper describes experimental work on water rinsing of 30mm by 30mm stainless steel coupons in order to model the rinsing step in a CIP cycle. A lab scale cleaning rig was set up and used for that purpose. The monitoring of cleaning was done by:

- measuring the heat transfer coefficient (HTC)
- visual observation
- surface cleaning with software means

The soils in use are SCM (Sweet Condensed Milk) and brewer's yeast that are proteinaceous and sugary soils.

During the rinsing of SCM soil diffusion took place and soil thinning. The soil was gradually removed reaching a maximum HTC with minimum impact to surface complete cleaning. In many cases cooked SCM was not fully removed after HTC was stabilized. Chemicals are necessary at this stage to enhance cleaning and put in place more drastic removal mechanisms (e.g. swelling, reaction).

Brewer's yeast deposits were collected in-line from a fermentation vessel and were also characterized as far as it concerns removal with water rinsing representing the pre-rinse step in a CIP. There more experiments need to be done to cover all conditions. So far, high temperature (70^{o}C) and low (20^{o}C & 30^{o}C) have shown that no significant rinsing takes place, leaving the HTC unaffected or slightly increased. It was shown that 10min at the higher tested temperature gave no further cleaning. Chemicals usage is again a necessity.

Using a lab scale rig helps into understanding the cleaning mechanisms although processing conditions existing in a real plant cannot be achieved. This is going to be realized in a pilot plant that is designed to allow fouling and CIP runs to happen at high flow rates and temperatures with chemicals dosing. Further validation of the results will take place in processing plants.

In general, it is of key importance to use the pre-rinse lab scale and the future pilot plant experiments in order to improve CIP and minimize environmental burden. For this purposes work is going on in parallel that aims to measure effluent, water and energy costs and minimize them.

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Yang, A., Martin, E.B., Montague, G.A., and Fryer, P.J., 2008, Towards Improved Cleaning of FMCG Plants: a Model-based Approach, *18th European Symposium on Computer aided Process Engineering-ESCAPE 18* Bertrand Braunschweig and Xavier Joulia (Editors), 2008 Elsevier B.V./LTD. All rights reserved.