Detection of biofilms, cracks, and pores in stainless steel tanks in the food industry

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Creation of biofilms

Stainless steel, predominantly austenitic steel, is widely used in the food and beverage industry in equipment used for processing, storage, and transportation of products, because it is easy to clean and has a high corrosion resistance. However, in case of insufficient cleaning caused by too low cleaning temperature, cleaning flow, cleaning time or concentration of detergents layer of sediments will develop on the inside surface of the equipment. Moreover, if corrosion or cracking have caused damage of the stainless steel surface, such areas will gather sediments that is almost impossible or at least very difficult to remove in a normal Cleaning in Place (CIP) process.

Layers of sediments, so-called biofilms, are a common hygienic problem in the food industry. It usually consists of protein, fat, carbohydrates, and minerals such as phosphates and carbonates in which bacteria, primarily thermoduric, psychrotrophic, and spore forming species, can attach, survive, and reproduce. The content of such bacteria in biofilms can be very high, and will gradually be released and cause contamination of food products during processing.

Creation of cracks, and pores

Stainless steel is generally very resistant to corrosion due to an ultra-thin layer of chromium oxide that is only a few nanometres thick. This layer prevents surface corrosion by blocking oxygen diffusion to the steel surface. However, corrosion may occur due to complicated reactions resulting in a gradual degradation of the metal (Jessen, 2011). General corrosion often initiated at very low or very high pH values is highly dependent on temperature. It will usually attack large parts of the interior surface of, for example, a storage tank.

Another type of corrosion known as pitting corrosion, which is wellknown in the food industry, occurs if chemical or mechanical damage of the layer of oxides has taking place. This results in fast galvanic corrosion, which accelerates especially if the surface is exposed to chloride ions in the cleaning water (Parrott & Pitts, 2011). Although the maximum acceptable level of chloride in drinking water is low, in Denmark e.g. 250 mg per litre, disinfection of the equipment with hot water can lead to local evaporation and a substantial increase in the concentration of chloride ions, perhaps even formation of a chloride-rich solid film. Heat-affected zones of the steel, such as weldings are often sensitive to this type of corrosion, especially if they have a rough surface finish. Pitting corrosion is usually restricted to a single point or a small area while the majority of the steel surface in the tank is unaffected (Figure 1).

Fig. 1. Small hole or pore in stainless steel caused by pitting corrosion.

Pitting corrosion creates small pinholes or pores on the surface of the metal, which can lead into larger holes, or pits of different shapes deeper in the metal where deposits forming biofilms can gather (Figure 2).

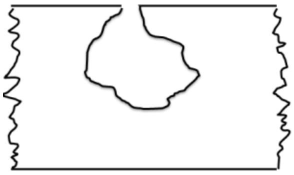

Fig. 2. An example of pitting corrosion.

Cracks in the metal surface will also collect deposits and biofilms. Cracks will often emerge from active sites of pitting corrosion, and in addition, so-called chloride stress corrosion is a common cause of cracking, because it has the potential to release stored energy in the steel (Parrott & Pitts, 2011). This can be tensile stress caused by small variations in the thickness of stainless steel plates and residual tensile stress caused by welding, grinding, and bending deformation of the steel plates during fabrication. Temperature variations during cleaning will often promote release of such stress forces and lead to cracking (Figure 3).

Fig. 3. Cracking in stainless steel.

Critical positions in tanks

The normal procedure for cleaning tanks in a CIP process is to spray the cleaning liquids over the internal surface with a turbine or disperser and let the liquid flow down the wall. However, insufficient cleaning is the result, if partially clogging of the sprayer occurs. This will rapidly lead to formation of biofilms, which may also happen, if the design of the tank makes it difficult to obtain an effective spraying of the cleaning solutions, for example, around manholes and pipe connections, and on agitators (Figure 4).

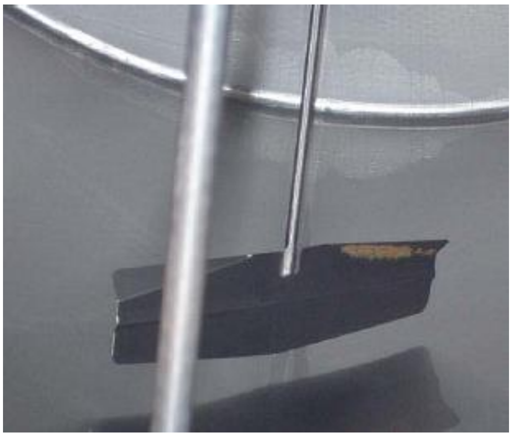

Fig. 4. Visible biofilm on the agitator in a milk tank.

Such blind spots in tanks, where the cleaning will be insufficient, can be detected by a so-called spray coverage test in which an easily water-miscible fluorescent substance, e.g., riboflavin manually is sprayed onto the inside of the tank followed by a sequence of the CIP process, typically a pre-rinsing step which completely removes the fluorescent tracer, if the surface is satisfactory covered by the washing jets. Finally, the surface is inspected with UV-light that reveals areas not properly covered by the washing operation. This test clearly identifies the so-called spray shadows that are difficult-to-clean locations. Two examples are shown in figure 5.

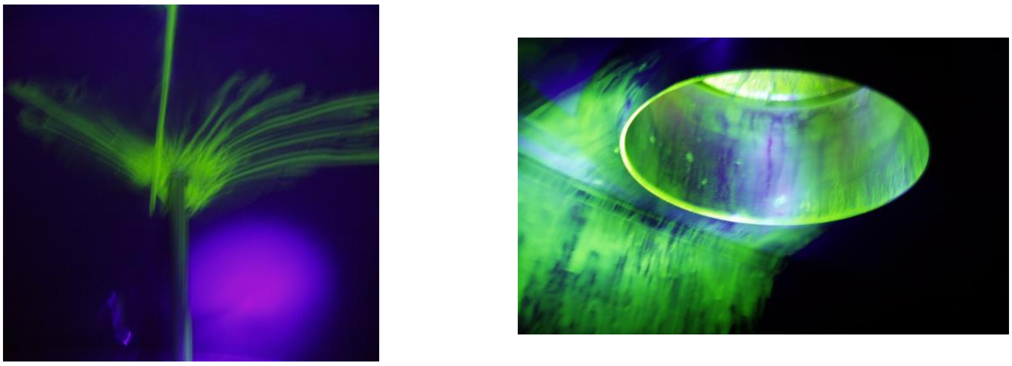

Fig. 5. Spray shadows showing locations where CIP will be inefficient.

Over the years, a multitude of tanks for different applications and of different design have been tested using a procedure named Bactoforce TankSafe (Bactoforce, 2013), which includes penetrant testing and manual inspection. The results have revealed that cracks and pores can occur at all positions in a tank. Figure 6 shows the outcome of such an examination of a milk storage tank.

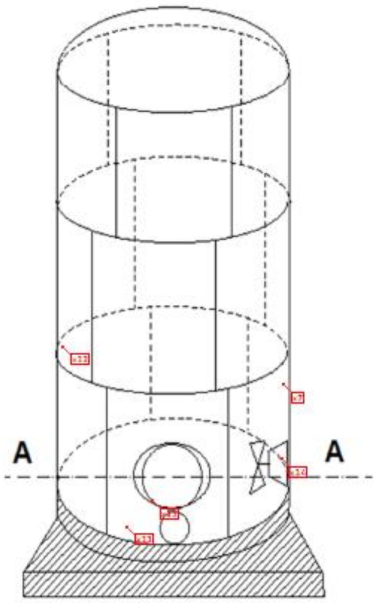

Fig. 6. Cracks and pores found in a tank by penetrant testing and manual inspection.

Detection of biofilms

There are several different methods available for detection of biofilms on surfaces in the food industry for example ATP bioluminescence, UV light detection, and total organic carbon (TOC) measurement in rinse water.

ATP (adenosine triphosphate) is the principal energy carrier of all living organisms and ATP bioluminescence is a commonly used method for monitoring surface cleanliness. After swabbing a surface and measuring of the probe, the result provides an estimate of the cleanliness including bacteria cells and organic sediments. The method requires only simple equipment but the cost per analysis is relatively high. The method is especially useful in the presence of microorganisms rather than organic sediments alone (Whitehead *et al*., 2008). In addition, the ATP-method is not particularly useful if large areas need inspection.

Organic sediments appear as whitish or yellow coatings on the surface of the equipment. However, it is not necessarily visible to the naked eye, but clearly visible under UV-light (Figure 7), because the molecular configuration of organic material causes sediments to fluoresce when illuminated by UV light of a wavelength of approximately 350 nm.

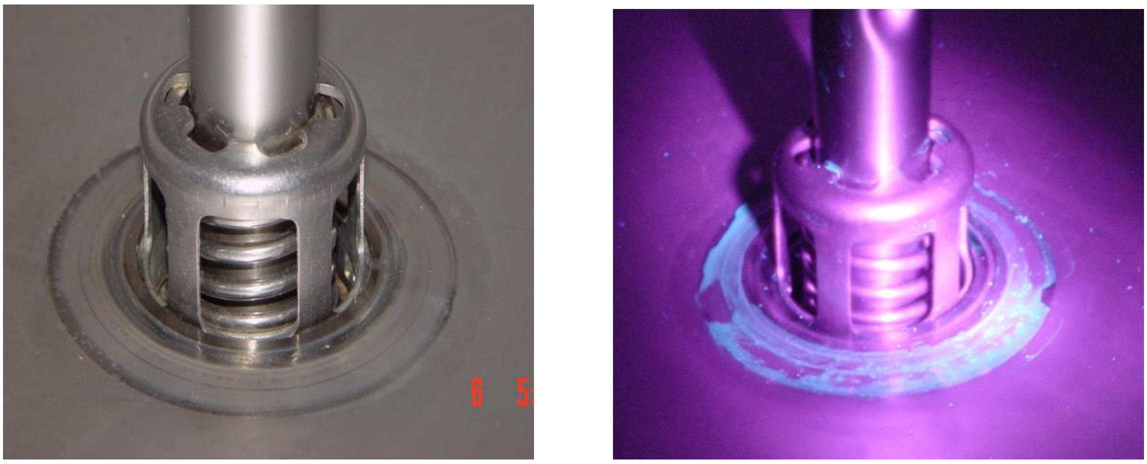

Fig. 7. Inspection in visible and ultraviolet light, respectively.

It is therefore evident that highlighted areas that fluoresce need more intensive cleaning. The method is advantageous because it does not require direct contact with the surface and large areas are quickly examined.

Validation of cleaning efficiency by measuring total organic carbon (TOC) in rinse water after cleaning is wellknown (Jenkins *et al*., 1996). TOC is the amount of carbon in organic material such as product residues or biofilms. Since the early 1970s, public authorities has recognized TOC as an analytic technique for measuring water quality and it is furthermore applied for controlling levels of endotoxins, microbes, and biofilms in the pharmaceutical industry. Measuring TOC has also obvious potential for use in the food industry for validation of CIP processes. Various international standards and guidelines such as ISO Standard 8245:1999 issued by International Organization of Standardization (1999) describe the main principle of TOC analysis. The method involves oxidation of a sample of rinse water after CIP. This converts organic compounds to carbon dioxide that eventually passes a sensor, which may be based on, for example, Non-dispersive infrared technique. The repeatability and reproducibility of the method is good.

Detection of cracks and pores

A number of methods are available for monitoring corrosion and crack formation in tanks for example penetrant testing and testing based on Eddy Current, Magnetic Flux Leakage, and Ultrasonic.

The simplest and most effective non-destructive method for detecting cracks and pores in tanks is the penetrant method, which is a low-cost inspection technique often used in the food industry. The main steps of the procedure involve pre-cleaning of the test surface, spraying the surface with a food-grade penetrant that bind to damaged areas and penetrate into cracks and pores, inspection with ultraviolet light (Figure 8), registration of defects, and finally cleaning of the tested surface.

Fig. 8. Inspection with UV-light for cracks and pores in a storage tank.

Several organizations describe the method e.g. the International Organization for Standardization (2013). The main advantage of the penetrant testing method is that inspection of large areas is rapid, it is a low cost method with high sensitivity, and the result that is seen directly on the tested material provides a visual presentation of the defect. Classification of the identified defects is subjective and depends on the inspector, but it is possible to supplement the classification with an objective measurement of the depth of the damage by a hand-held electronic devise based on, for example, Alternating Current Potential Drop (Sposito, 2009).

Measurements based on Eddy Current and Ultrasonic principles are more complicated and need sophisticated and expensive measuring equipment. None of these methods is especially suitable for inspection of large surfaces and the interpretation of the results is not obvious and requires substantial training and experience. Parrott & Pitts (2011) found that Eddy Current testing, using standard or even purpose-designed probes has limited penetration of a stainless steel wall and it is also very sensitive to surface imperfections that are very difficult to distinguish from cracks. They found ultrasonic testing more promising but the procedure requires several complimentary scans with different probes so it is a time consuming method. In a study carried out for the Health and Safety Executive, which is a crown non-departmental public body in the United Kingdom, Parrott & Pitts (2011) stated that penetrant testing is the most effective method for non-destruction testing for cracks in reactors in the chemical processing and petrochemical industries, without doubt, this statement is valid also for the food industry.

Testing experience and documentation

Bactoforce has tested tanks, spray-drying towers and other vessels throughout Europa for more than 20 years using the penetrant method and our experience is that this test method works very well and gives reliable results. The results of more than 5,000 inspections per year show that defects may occur already in the construction phase and throughout the whole lifetime of a tank. In average one third of all inspections reveals defects in tanks, showing that such inspections are a sound investment as part of a quality control programme and a maintenance scheme because it prevents microbiological hazards. Documentation of all data from an inspection takes place in a Web-based reporting system called R-Force (Bactoforce, 2013), where clients have access to their own results that include the status of all inspections on-site, and new inspections planned. This system keeps the clients updated about the hygiene condition of their process installations so the result can be used in the local quality control.

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