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ASSESSING THE CLEANABILITY OF STAINLESS STEEL SURFACES – EFFECT OF SURFACE ROUGHNESS AND VARIOUS PARAMETERS ON CLEANING OF PROTEIN BASED SOILS

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Abstract

This study demonstrates the use of a previously developed testing method by the authors for assessing the cleanability of stainless steel surfaces.

The effect of surface roughness and various parameters on cleaning of protein based soils was investigated, namely soaking time, temperature, and the use of an alkaline detergent. For this reason, stainless steel surfaces of various alloys and different degree of surface roughness were soiled under defined conditions, fixed to a test stand and sprayed with a water jet from a low-pressure nozzle for up to 20 minutes. The progress of cleaning was determined at set times by removing the plates and taking photographic pictures under UV light illumination. With the image processing program ImageJ, the area of the cleaned surface was identified and quantified.

Our findings indicate that there is an optimum soaking time of 15 minutes compared to a shorter or longer soaking time (5 or 30 min., resp.). As could be expected, the use of an alkaline detergent for soaking and a slightly elevated temperature (30 ^{0}C vs. room temperature) for rinsing improve cleaning significantly. However, neither the alloy (AISI 316L vs. Duplex steel) nor the degree of surface roughness (electropolished vs. mechanically polished) have a significant effect on cleanability.

Key words: *Cleaning, Low-pressure water jet, Stainless steel, Protein based soils, Roughness.*

1. Introduction

Cleaning of surfaces is a necessary step in food processing. Soil that adheres to the surface of machinery and equipment needs to be removed, in order to establish hygienic conditions for production. Protein based soils are highly critical, as they are not easily soluble. Protein films may adhere strongly to the surface of equipment, thus being a cause of product contamination, if not removed properly [1]. As cleaning is a time consuming and cost effective step in food production, efficient cleaning is necessary to improve overall efficiency of equipment [2].

Various parameters are known to have an effect on cleaning efficiency. An elevated temperature, a higher mechanical impact, and use of chemicals may shorten cleaning time, thus improving cleaning efficiency [3]. However, the hygienic design of the equipment, the properties of the surfaces, and the composition and preconditions of the soil need also to be taken into account. Namely the thickness of soil films, the temperature and relative humidity of the atmosphere while drying and the drying time itself will influence cleaning [4].

In a previous paper, a method was proposed by the authors to assess the cleanability of stainless steel surfaces. It was shown, that the cleaned area of a soiled surface using a water jet from a low-pressure nozzle could be quantified over time by taking photographic pictures and using image analysis [5].

This paper focuses on the effect of various parameters while measuring the cleanability of stainless steel surfaces: different soaking time before cleaning, use of a common detergent vs. pure water, and an elevated temperature of water. Stainless steel plates of various degree of surface roughness were fixed to a test stand and sprayed with a water jet from a low-pressure nozzle for a period of several minutes. The plates were previously soiled with a protein film of pre-defined layer thickness and dried for 4 hours at defined conditions of temperature and relative humidity. The progress of cleaning was determined at set times by removing the plates and taking photographic pictures under UV-illumination. With the image processing program ImageJ, the area of the cleaned surface could be identified and quantified.

2. Materials and Methods

A special test stand (HPM Technologie GmbH, 72525 Muensingen, Germany) was used as described previously [5]. It consists of a 10 L pressurized container MDJ and three universal spray heads PTR. Partially demineralized water (8 ^{0}dH) at tap temperature (21 ^{0}C) was used for all cleaning experiments except one. In this case hot water (85 ^{0}C) was filled in the pressurized container, resulting in an elevated spray temperature of 30 ^{0}C. Three stainless steel plates were fixed to a rack each time. The spray head nozzles were positioned right above the plates at a distance of 220 mm. Plates were tilted slightly by 20 degrees to allow drainage of cleaning fluid. The angle between the surface and the spray jet was 90 degrees. In each nozzle pressurized fluid (1 bar) and process air (1.5 bars) were mixed, resulting in a jet of fine droplets. Before each experiment the flow was set to 90 mL/min.

Stainless steel plates (size 200 x 100 mm) were provided by Henkel Lohnpoliertechnik GmbH (19306 Neustadt-Glewe, Germany). They were made of different alloys (AISI 316 L, Material No. 1.4404; Duplex steel, Material No. 1.4462), which are frequently used for machinery and equipment in food and pharmaceutical industry. The surface of each plate was either mechanically polished or electropolished. Roughness was measured according to DIN EN ISO 4288. Ra values of mechanically polished plates were 0.8 µm, while Ra values of electropolished surfaces were below 0.2 µm (0.14 - 0.16 µm).

Each set of experiments consisted of the following steps: pre-cleaning of plates, application of the test soil, drying, soaking and cleaning under defined conditions, and, finally, evaluation of the cleaning experiment. For pre-cleaning plates were soaked in alkaline cleaning solution (Grasset by J. Kiehl KG, 85233 Odelzhausen, Germany, dilution 1 : 100) at 70 ^{0}C for 10 min., cooled down in partially demineralized water (8 ^{0}dH), gently wiped with a cleaning rug and flushed thoroughly with demineralized water. They were dried for 45 min. at 60 ^{0}C to remove all water.

Protein-based soil was prepared by mixing 20 g of milk protein powder (Protein-Concentrate 85, Tartex & Dr. Ritter, 79108 Freiburg, Germany) with 80 g of water (8 ^{0}dH). This mixture was kept at room temperature for 24 h prior to use in order to allow for complete solution of protein particles. Test soil was applied evenly by use of an 8-fold applicator frame (BYK-Gardner GmbH, 82538 Geretsried, Germany) using gap No. 8 (nominal height 203.2 µm). Protein solution was filled in the applicator frame, which was moved slowly over the stainless steel plate. Protein films were dried for 4 h prior to the experiments at 40 ^{0}C and 50% relative humidity in a climate chamber.

For the cleaning experiment, soiled plates were fixed in the test stand, sprayed with partially demineralized water from the spray jet for 1 minute and soaked for a given time (5 to 30 minutes) without further spraying. If detergent (Grasset, see above, dilution 1 : 40) was used, it was sprayed onto the surface for 3 seconds from a pressurized flask, after the first minute of spraying. Soaking time was same as with pure water (5 to 30 minutes). All plates were spray-washed by the water jet from the low-pressure nozzle and removed after a given time (5 to 20 minutes). After the experiment the plates were gently dried by pressurized air.

Evaluation of the experiment was done by taking a photographic picture with a digital camera (Canon, PowerShot G11). Pictures of protein films were taken in a specially designed box (Figure 1) under UV-light illumination (wavelength 312 nm).

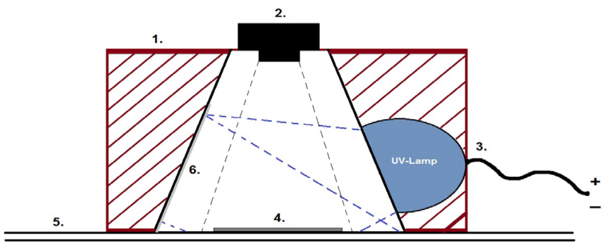

Figure 1. Mobile box for UV-illumination: 1. Box; 2. Digital camera; 3. UV-light; 4. Soiled plate; 5. Dark cardboard; 6. Mirror foil

A mirror on the opposite side was reflecting the light, thus minimizing uneven illumination. As proteins naturally show fluorescence, no staining was necessary. Figure 2 shows the original protein film on a stainless steel surface, when illuminated by UV-light. Dark areas show the clean regions of the plate, whereas a lighter color indicates the soil film.

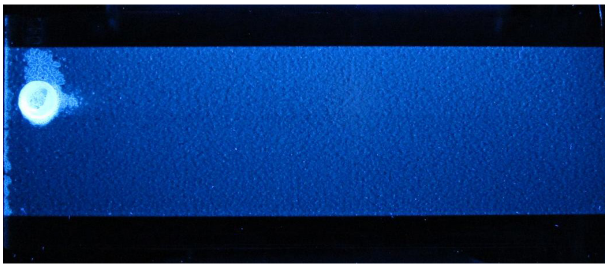

Figure 2. Original protein film on stainless steel surface. UV-illumination (wavelength 312 nm). Dark areas: clean areas; lighter color: soiled areas.

All photographic pictures were evaluated using the image processing program ImageJ (source: http:/rsbweb.nih.gov/ij/plugins/mbf-collection.html) as described previously [5]. RGB picture was first transformed into grey scale. In a second step the total area of the cleaned surface was detected by the image processing software ImageJ. A threshold level of 20 (of 255) proved best for all experiments with protein films.

The area of the clean surface was quantified by the software ImageJ and expressed as fraction of the area cleaned (AC) using formula 1:

$$AC = (TAC / RA) \cdot 100\% \quad (1)$$

TAC: Total area cleaned (mm^2) as detected by ImageJ
RA: Rectangular area between set bars (mm^2).

The position of the bars was set in the same way for all experiments.

3. Results and Discussion

The effect of soaking time was tested in a first set of test runs. Soaking time was varied from 5 to 30 minutes prior to cleaning. Pure water or detergent was used for 20 minutes cleaning time. Typical results of cleaning experiments with protein based soils are shown in Figure 3.

Data is presented as mean values ± standard deviation. The number of replica is noted in brackets. As can be seen from data with detergent the fraction of the area cleaned (AC) increases with an increase in soaking time from 5 to 15 minutes: 5 minutes, 38.1 ± 4.2% (n = 6); 15 minutes, 54.7 ± 12.2% (n = 9). When soaking time was further increased to 30 minutes, AC dropped to 36.8 ± 3.3 (n = 6).

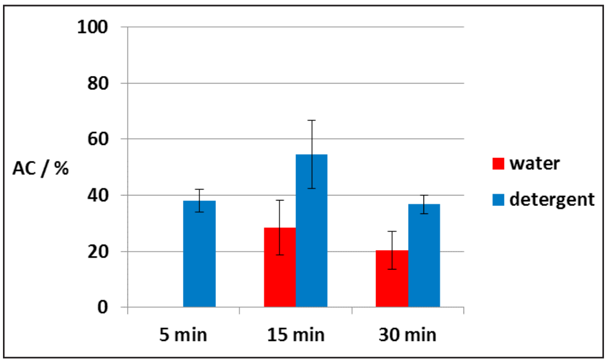

Figure 3. Area cleaned (AC) of protein films for various soaking times. AISI 316 L (Mat. No. 1.4404), mechanically polished, Ra = 0.8 µm. Cleaning time 20 minutes

A similar decrease of AC can be detected, when pure water was used for soaking: 15 minutes, 28.4 ± 9.8%; 30 minutes, 20.4 ± 6.7% (n = 9). A soaking time of 5 minutes was not tested for water. Similar data was obtained for a cleaning time of 10 minutes (not shown).

Obviously, a short soaking time (5 minutes) is not sufficient for the detergent to penetrate into the dry protein film and loosen the soil structure. When soaking time was extended to 30 minutes, the surface starts to dry again under given atmospheric conditions in the lab (22-28 °C, 43-58% RH) and the soil structure hardens. Thus a soaking time of 15 minutes was used for all further experiments.

The effect of various parameters on cleaning was investigated in a further set of experiments. Results of a comparison of water vs. detergent and water at elevated temperature can be seen in Figure 4.

It is obvious that the area cleaned (AC) increases with an increase in cleaning time from 10 to 20 minutes in all cases (water: 10 minutes, 22.7 ± 9.1%; 20 minutes, 28.4 ± 9.8%; n = 9). As could be expected, the use of an alkaline detergent prior to cleaning has a positive effect on cleaning (detergent: 10 minutes, 31.9 ± 4.4%; 20 minutes, 54.7 ± 12.2%; n = 9). It is known, that protein based soils are more susceptible to a rinsing fluid, if they are treated with an alkaline solution [6]. Interestingly, the effect of a slightly elevated temperature (30 °C) vs. room temperature (22 °C) was largest, even though pure water only was used (water at 30 °C: 10 minutes, 49.0 ± 7.6%; 20 minutes, 75.0 ± 6.4%; n = 9). An elevated temperature increases the diffusion mobility of the solvent, thus loosening the soil structure. Thus the cleaning effect of the spray jet is increased compared to a lower temperature. Similar results were obtained when electropolished surfaces were investigated (not shown).

The effect of different steel alloys (AISI 316L vs. Duplex steel) is shown in Figure 5 for pure water (AISI 316L: 10 minutes, 22.7 ± 9.1%; 20 minutes, 28.4 ± 9.8%; Duplex steel: 10 minutes, 20.6 ± 2.5%; 20 minutes, 32.9 ± 5.6%; n = 9).

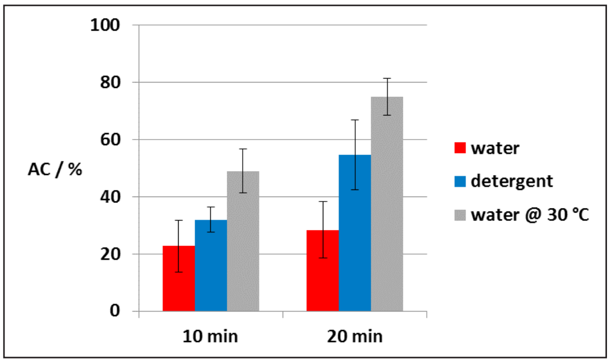

Figure 4. Area cleaned (AC) of protein films for various cleaning times. AISI 316 L (Mat. No. 1.4404), mechanically polished, Ra = 0.8 µm. Soaking time 15 minutes

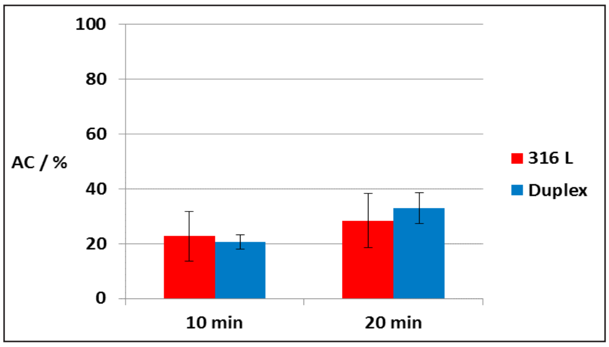

Figure 5. Area cleaned (AC) of protein films for different cleaning times with pure water and various alloys of stainless steel. AISI 316 L (Mat. No. 1.4404) vs. Duplex steel (Mat. No. 1.4462), mechanically polished, Ra = 0.8 µm

Even though there are slight variations of mean values, no significant difference could be detected for either alloy by Student's t-test. Experiments with detergent showed similar results (Figure 6), at a higher level of area cleaned (AISI 316L: 10 minutes, 31.9 ± 4.4%; 20 minutes, 54.7 ± 12.2%; Duplex steel: 10 minutes, 28.8 ± 4.7%; 20 minutes, 52.2 ± 19.3%; n = 9).

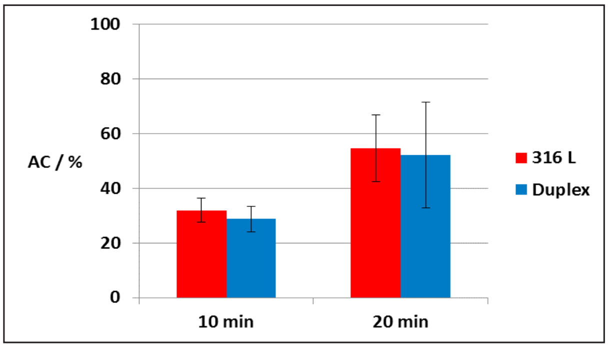

Figure 6. Area cleaned (AC) of protein films for different cleaning times with detergent and various alloys of stainless steel. AISI 316 L (Mat. No. 1.4404) vs. Duplex steel (Mat. No. 1.4462), mechanically polished, Ra = 0.8 µm

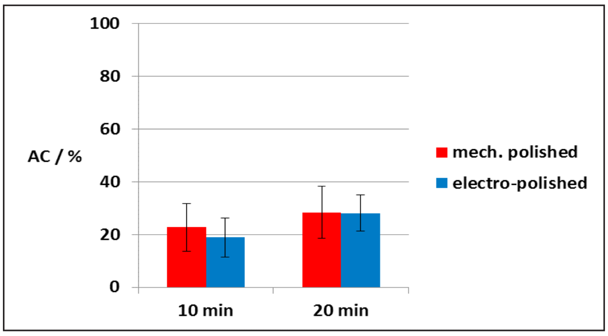

Figure 7. Area cleaned (AC) of protein films for different cleaning times with pure water and various degree of surface roughness. AISI 316 L (Mat. No. 1.4404), mechanically polished (Ra = 0.8 µm) vs. electro-polished (Ra ≤ 0.2 µm)

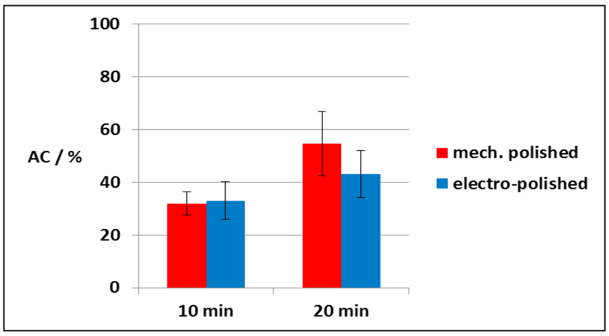

Figure 8. Area cleaned (AC) of protein films for different cleaning times with detergent and various degree of surface roughness. AISI 316 L (Mat. No. 1.4404), mechanically polished (Ra = 0.8 µm) vs. electro-polished (Ra ≤ 0.2 µm)

Finally, the effect of different surface roughness on cleanability was investigated. It can clearly be seen from Figure 7, that there is no improvement in cleaning when electropolished surfaces were cleaned with pure water (Mechanically polished: 10 minutes, 22.7 ± 9.1%; 20 minutes, 28.4 ± 9.8%; electro-polished: 10 minutes, 18.8 ± 7.4%; 20 minutes, 28.1 ± 6.9%; n = 9).

While the same holds true for the use of detergent at short times (10 min.), a surprising finding was made for extended cleaning times (20 minutes) using detergent (Figure 8).

In this case, a significantly better cleaning result was obtained on the mechanically polished surface (Student's t-test, $p < 0.05$, n = 9) as compared to the electropolished surface (Mechanically polished: 10 minutes, 31.9 ± 4.4%; 20 minutes, 54.7 ± 12.2%; electro-polished: 10 minutes, 33.1 ± 7.2%; 20 minutes, 43.1 ± 8.9%).

As cleaning of protein films is mainly determined by adhesion forces between soil and surface, this may indicate that adhesion forces are higher for electropolished surfaces. Bobe *et al*. calculated adhesion forces between particles of different shapes and surfaces of various degrees of roughness [6]. They concluded that adhesion forces may vary by several orders of magnitude depending on the surface structure. Their calculations show that adhesive forces for spherical particles may be minimal for a certain degree of surface roughness depending on the particle diameter. If these calculations hold true for protein films is not known.

From our findings, however, it seems likely that a protein film clings more strongly to a very smooth surface. In contrast, a more rugged surface, as in the case of a mechanically polished surface with a Ra value of 0.8 µm, may have less adhesion forces and may enable some rinsing fluid to bypass the surface from underneath. Thus the film structure is washed off by draining water from above and partly from beneath. It needs to be investigated, if this effect, which can be seen clearly for our cleaning experiments with low mechanical impact, holds true to more rapid cleaning with a high mechanical impact.

4. Conclusions

- The purpose of the current study was to implement a testing method, which was previously developed, for assessing the cleanability of stainless steel surfaces used in food industry. The method uses photographic pictures and the image processing program ImageJ to identify and quantify the area of the cleaned surface in experiments under standardized conditions.

- This study has shown that it is possible to quantify the effect of surface roughness and various parameters on cleaning of protein films on stainless steel surfaces.

- Parameters investigated were soaking time before cleaning, use of an alkaline detergent before and of an elevated temperature while rinsing. There is an optimum soaking time before the cleaning experiment (in our case 15 minutes), while the use of a detergent before rinsing and an elevated rinsing temperature improved cleaning significantly. Similar to previous experiments, no effect could be seen for different alloys (AISI 316L vs. Duplex steel).

- Also, little if any effect was due to a different surface roughness (electro-polished vs. mechanically polished). These findings improve our understanding of cleanability by helping to focus on the main effects on cleaning with low mechanical impact: soaking conditions and rinsing temperature.

Acknowledgement

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5. References

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