Enhancement of the cleanability of milk fouling on highly finished inner surface of stainless steel tubing

Ikko Ihara[1*], Tomomi Kaneko[1], Yushi Sakamoto[1], Eric McLamore[2], John K. Schueller[2,3], Kiyohiko Toyoda[1], Kazutaka Umetsu[4], and Hitomi Yamaguchi[3]

[1] Dept. Agricultural Eng., Kobe University, 1-1 Rokkodai-cho, Nada, Kobe, 657-8501 Japan
[2] Dept. of Agricultural and Biological Eng.,University of Florida, Gainesville FL, USA
[3] Dept. of Mechanical and Aerospace Eng.,University of Florida, Gainesville FL, USA
[4] Dept. of Animal Hygiene, Obihiro University of Agricultural and Veterinary Medicine, Inada, Obihiro, 050-8555 Japan

*Corresponding author. e-mail: ihara@port.kobe-u.ac.jp

KOBE UNIVERSITY

UF UNIVERSITY of FLORIDA
The Foundation for The Gator Nation

国立大学法人 帯広畜産大学
Obihiro University of Agriculture and Veterinary Medicine

Abstract

Milk fouling is both a technical and economical problem in the dairy industry. Proteins and minerals in milk form deposits on the surface of stainless steel equipment. The objective of this work was to evaluate the cleanability of milk fouling deposits on highly finished inner surfaces of stainless steel tubes prepared by Magnetic Field Assisted Finishing (MAF) process. Fouling and cleaning tests were carried out using an experimental loop including steel tubes which had different surface roughness profiles. The relationship between the internal surface roughness profiles of stainless steel tubes and milk residues was investigated.

Photo 1 Milking system

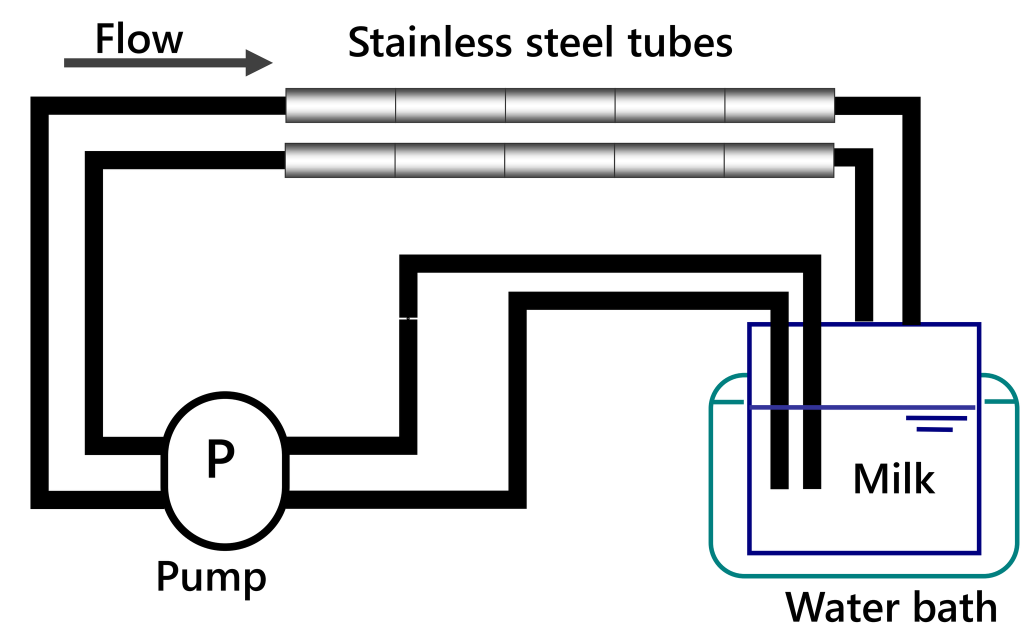

Fig. 2 Schematic experimental loops

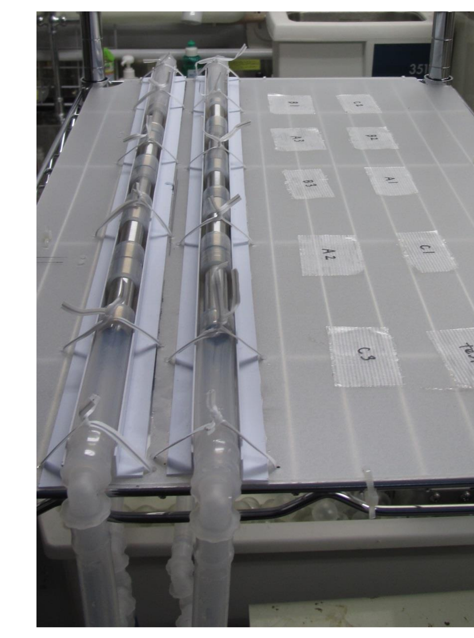

Photo 4 Experimental setup

Preparation of stainless steel tubing

Different stainless steel tubes (SUS304, Ø12.7 mm outside diameter × Ø10.7 mm inside diameter, approx 65 mm length) with three levels of internal surface roughness were prepared for this work.

To prepare steel tubes with a smoother internal surface, we used a special equipment developed for MAF[1] with a workpiece rotation system (Fig. 1). Nd-Fe-B permanent magnets generate the magnetic field needed for attracting the magnetic abrasive to the finishing area. The surface profiles for average roughness (*Ra*) and peak-to-valley height (*Rz*) are shown in Table 1.

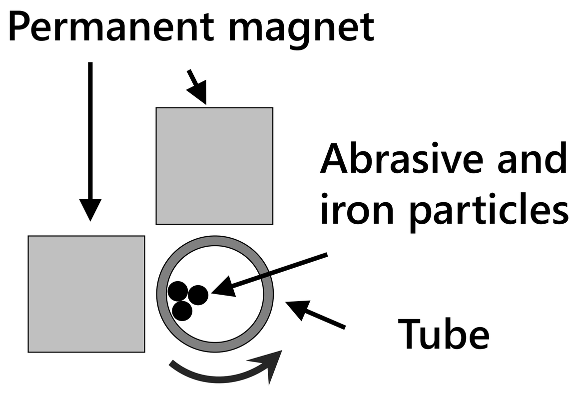

Fig. 1 Schematic of MAF

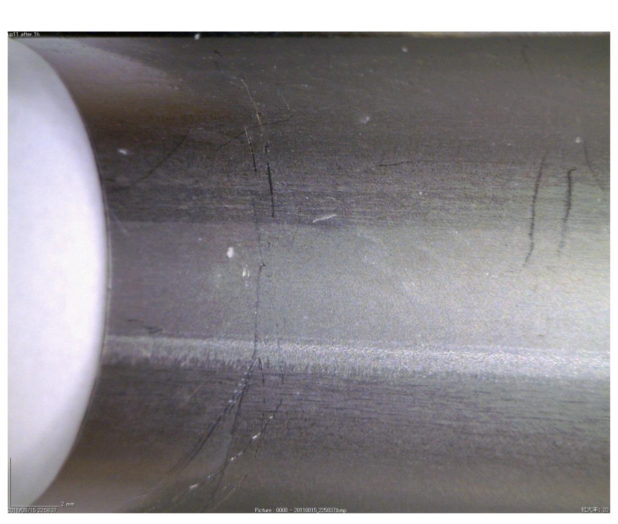

Photo 2 Unpolished workpiece (B)

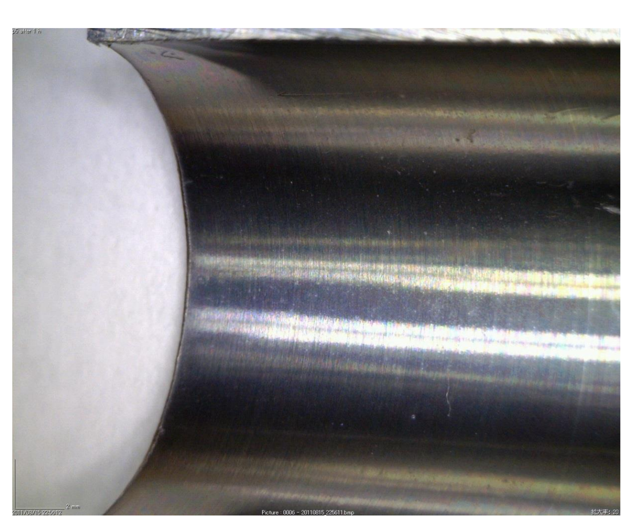

Photo 3 Polished workpiece (A)

Table 1 Surface roughness of tested workpieces

Workpiece	A (polished)	B (unpolished)	C (unpolished)
R_z (μm)	0.10	2.4 ± 0.4	23.8 ± 2.0
R_a (μm)	0.01 ± 0.001	0.37 ± 0.07	3.7 ± 0.4

Fouling and cleaning test

Fouling experiments with whole milk were carried out in two experimental loops consisting of 10 tubes under test (Fig. 2). The experiments were carried out with whole milk at 40°C and run for 8 hr with a 7 min-on / 3 min-off cycle, at a flow rate of 0.4 L/min, which corresponds to the flow rate in a typical dairy piping system between a milking robot and a bulk cooler. Cleaning experiments with deionized water at 20°C were carried out in the experimental equipment loops immediately after the fouling experiments. Deionized water was flushed for 5 min at a mean flow rate of 0.4 or 0.8 L/min without circulation. After the cleaning test, the test pipes were dismantled from the experimental loops and dried in air for 24 hr in a incubator at 23°C. All the stainless steel tubes were washed with 13 mL of deionized water using an ultrasonic cleaner for 20 min. The light absorbance at 660 nm of the washing solution was measured using a spectrophotometer (Hitachi, U-5100) to determine residues which are removed by the ultrasonic cleaner. Residual proteins in washed solution was analyzed by the Bradford method.

Results and discussion

Raw data indicated that milk fouling levels in each experiment were not consistent due to the non-constant milk components including protein, mineral, sugar and fat. The data are normalized with respect to workpiece C (3.7 μm *Ra*). Figures 3 and 4 show the relationship between milk or protein concentration in washing solutions and surface roughness under different flow rates of cleaning solution. At a low flow rate of 0.8 mL/min, the smoother the tube surface, the lower the relative milk concentration in the washing solution. The effect of surface roughness *Ra* on the cleanability was analyzed using Tukey's multiple comparison test. A difference in protein cleanability was significant between workpieces A (0.01 μm *Ra*) and C (3.7 μm *Ra*).

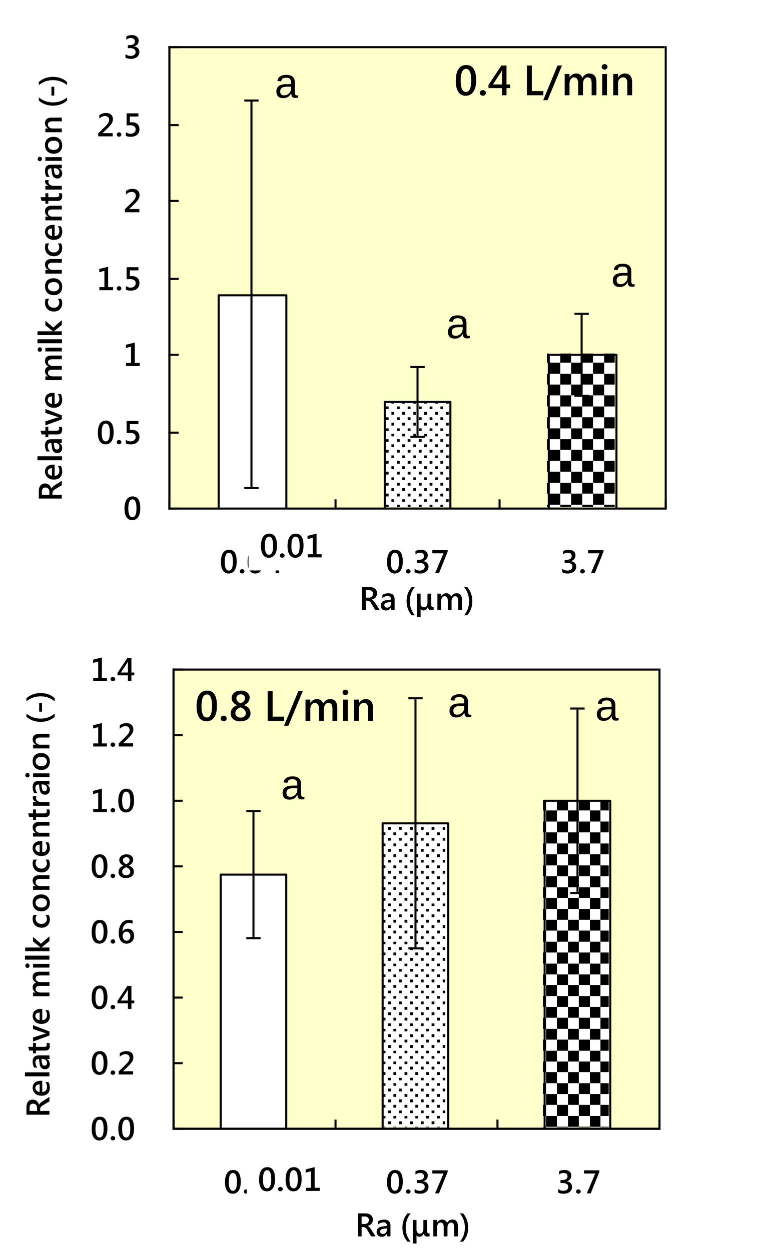

Fig. 3 Influence of surface roughness (*Ra*) on cleanability of milk fouling under different flow rates of cleaning solution. Error bars show standard deviation (n=12).

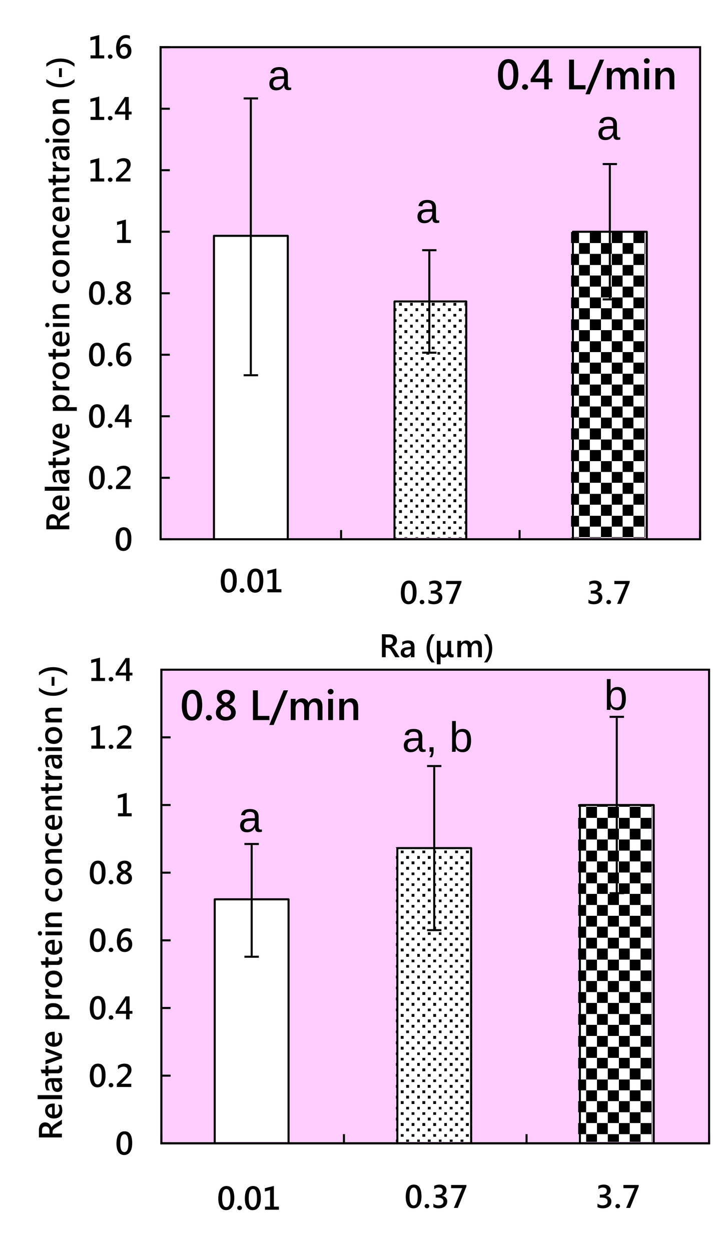

Fig. 4 Influence of surface roughness (*Ra*) on cleanability of protein fouling under different flow rates of cleaning solution. (n=12). Letters shows significant differences ($p<0.05$).

Conclusion

This research investigates the relationship between internal surface roughness of stainless steel tubing and the cleanability of milk fouling. Stainless steel tubes with an internal surface roughness of 0.01 μm Ra were prepared by a MAF process. The experiments demonstrated that the tube surface roughness affected the cleanability of protein components of milk. As a result, smoothing the tube surface enhanced the cleanability of the milk protein foulings from the tube surface.

Acknowledgement

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[1] Yamaguchi, H., Shinmura, T., Kobayashi, A., (2001): JSME International Journal Series C, 44(1), 275–281.