VISUALIZATION ON REMOVAL MECHANISMS OF FOOD DEPOSIT ON THE MODIFIED SURFACES

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ABSTRACT

Fouling impacts industrial production, in term of economics, product quality and plant efficiency. Fouling problem in the food industry is more severe than in other industries. Cleaning-in-place, the most popular technique used in food industry, is studied here. Cleaning processes involve three layers; the surface of the processing equipment, fouling deposit and the fluid process. The surface of the processing equipment is believed as one of the factors that generates fouling formation and recent years more research has used modified surface as an anti-fouling technique. This study observes removal from Ni-P and Ni-P-PTFE surfaces which have different surface free energies (20.11mN/m – 37.47mN/m). All surfaces were deposited with tomato fouling deposit and were cleaned with water alone at different flow rates and temperatures. A bench scale cleaning rig built in University of Birmingham enable heat transfer coefficient, fouling resistance, area value and sequence of deposit removal to be recorded, is used in this work. This rig represents a model of cleaning process in the industry. Results show that different surface energies can influence removal mechanisms of tomato deposit.

Keywords: *cleaning-in-place, Ni-P, Ni-PTFE, food fouling deposit.*

INTRODUCTION

Fouling is defined as an accumulation of unwanted deposit on the surface of processing equipment. Fouling has been recognized as a nearly worldwide problem in design and operation since it affects the operation of equipment. In food industry fouling formation is severe due to the heat sensitivity of food substance that promotes the formation of fouling on the heat surface. Furthermore the application of thermal processing is vitally important in maintaining the hygienic condition and reducing the concentration of harmful species (bacteria etc.) in processing area. Thus fouling formation is almost impossible to avoid in food industry. Accumulation of fouling can provide good nutrient for bacteria to growth. As a result daily cleaning is often needed in food plants for maintaining the quality of food production in term of being safe to eat, good nutrition and good looking [1].

Cleaning-in-place (CIP) is the most sensible technique to mitigate food-fouling problem. However regular CIP can be uneconomical in terms of downtime and materials [2]. Many works have been carried out to improve the CIP process, but it is not known in practice whether these are optimal.

Understanding of fouling and cleaning mechanisms to mitigate fouling problem is important. Epstein [3] illustrates that fouling process involves fluid-fluid, deposit-fluid, deposit-deposit and deposit-wall interaction. Deposit-wall interaction often concerns most researchers. For hygienic reason, in the food industry stainless steel is used to fabricate almost all the process equipment [4]. However, some work has found that stainless steel surface encourage more substances to attach on it [5, 6, 7]. Due to stainless steel surface is hydrophilic and has high free surface energy, γ. Thus more work recently is investigating the influence of low γ on fouling formation. Baier [8], McGuire & Swartzel [9], Britten et al. [6], Muller-Steinhagen et al., [10] and Zhao & Liu [11] found that the attachment of fouling deposit and the strength of adhesion are reduced when using surface with low γ. Study of the effect of γ on cleaning of fouled surface is less developed. Owing to the low γ can reduce the adhesion force, thus the result from it may provide the optimal CIP process.

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In this paper, the Ni-P and Ni-P-PTFE surfaces are employed to the CIP study. To investigate the effect of various γ (20.11mN/m-37.47mN/m) on removal mechanisms of tomato deposit. Tomato deposit is used because it can be cleaned by water alone, hence, excluding the chemical effect from the coated surfaces.

MATERIALS AND METHODS

All the coated surfaces are supplied by Department of Mechanical Engineering, University of Dundee, Nethergate. The surface energy of stainless steel disks (i.e. fouling disk) is modified by Ni-P-PTFE composite coatings. The composition and the plating conditions for the electroless Ni-P-PTFE solutions used are listed in Table 1 and details can obtain from Zhao et al. [12].

Table 1. The composition and plating conditions for the electroless Ni-P-PTFE solutions.

Composition	
$NiSO_4 \cdot 6H_2O$	25 g/l
$H_3C_6H_5O_7 \cdot 2H_2O$	18 g/l
$NaH_2PO_2 \cdot H_2O$	30 g/l
$NaCH_3COO$	18 g/l
$(NH_2)_2CS$	1 ppm
PTFE (60 wt%)	0-10 ml/l
$C_{20}H_{20}F_{23}N_2O_4I$ (FC-4)	0-1.0 g/l
pH	4.8-5.0
Temperature	88-93 °C

The commercial tomato puree contains (wt%): 4.5 protein, 12.9 carbohydrate, 12.6 sugar, 0.2 fat, 2.8 fibre and 67 water. 0.84 g mass of tomato puree was used for covering evenly on the whole top of fouling disk and for getting a model fouling of carbohydrate based fouling. In order to produce tomato deposit, tomato puree was simply baked in the oven at temperature 100˚C for one hour.

Cleaning is performed using the bench scale rig of Christian [13], which can record temperature, heat flux and image continuously. The rig consists of three main parts which are a heating tank, rectangular flow channel with test section and data logger system. The test section holds the fouled stainless steel disk and a copper disk (microfoil heat flux sensors (MHFS) and two disk thermocouples were permanently attached to it). Readings from thermocouples and MHFS are collected by a signal conditional unit (SC-2345) and information is recorded by Labview software on a standard P.C. Within the rig, fluid flows across a disk fouled with deposit: the surface of the deposit was filmed during cleaning and heat flux changes are recorded. Images from digital camera are analysed by Leica QWin software (Leica Microsystems Imaging Solutions Ltd, Cambridge). Cleaning time is determined from heat transfer coefficient (HTC) and area curve [13, 14]. Removal of tomato deposit from stainless steel surface is done using water alone but at different flow rates (0.7 and 2.3 l/min) and temperatures (30 and 70°C). Cleaning experiments are carried out as reported by Ab. Aziz et. al. [14].

RESULTS AND DISCUSSIONS

During cleaning process, the heat transfer coefficient increases as the area covered decreases. An example, Figure 1 shows the changing of heat transfer coefficient (HTC) and the area covered through the removal of tomato. Discrete changes within the HTC curve are normally seen for cleaning of tomato deposit. However this generally not occurred for cleaning of protein deposit [13,15]. The side pictures show the individual pictures from the camera system used to determine the area covered. The tomato deposit hydrated, softened and then several large pieces of deposit are removed gradually.

Three types of removal mechanisms are discovered for tomato deposit: (1) *step*, (2) *continuous* and (3) *one step*; which are similar to Christian [13]. *Step* removal means that removal of several part of deposit step by step at certain delay time (Figure 1).

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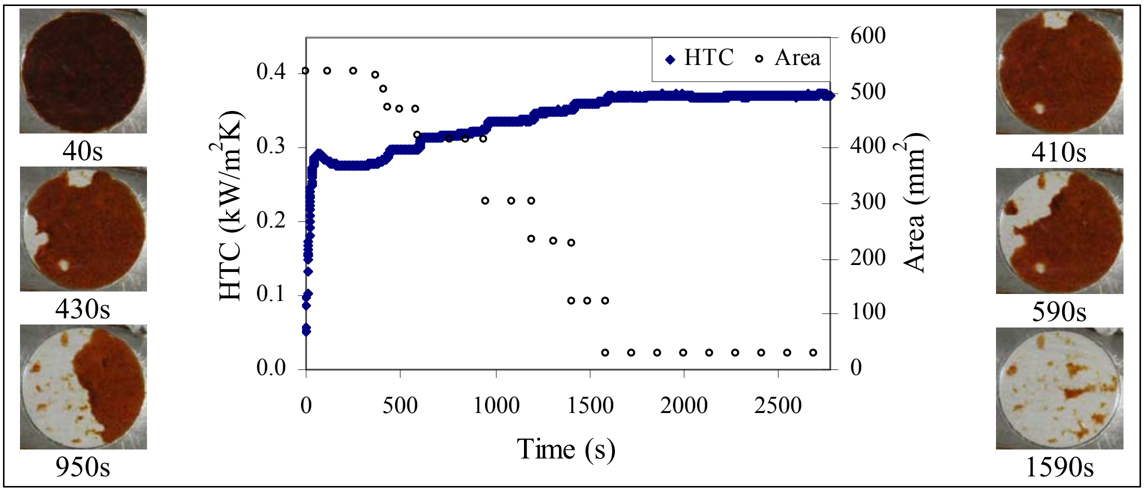

Figure 1: Cleaning profiles of step removal and some images taken during cleaning at 30°C, 2.3 l/min and on 35.08 mN/m surface (stainless steel).

When the removal of small pieces of deposit happened continuously and the decreasing of area covered not so obvious after each removal, this is defined as *continuous* removal (Figure 2).

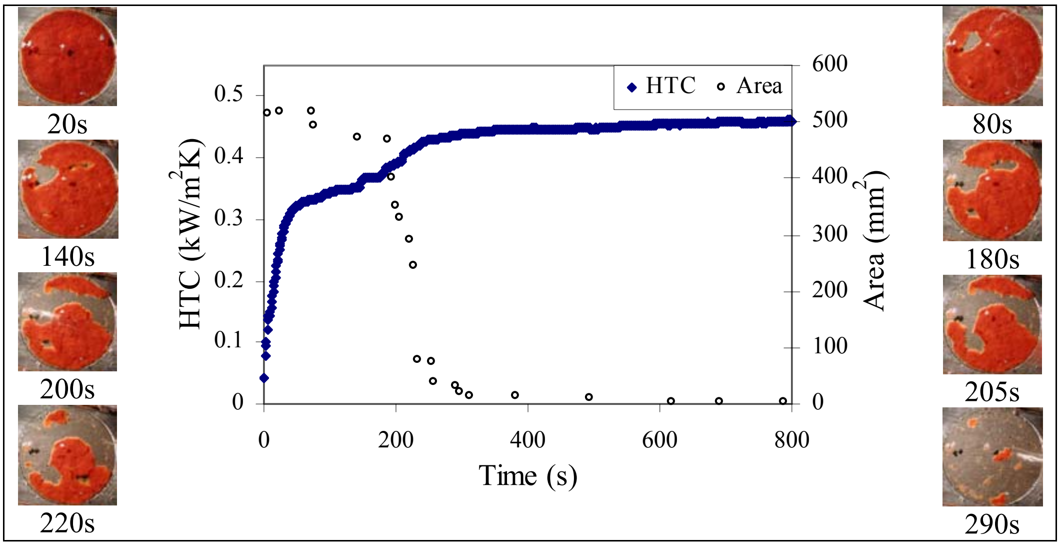

Figure 2: Results from cleaning at 70°C, 2.3 l/min and on 29.31 mN/m surface, show an example of continuous removal.

Whereas when the entire deposit is removed in one piece, this is called *one step* removal (Figure 3). *One step* removal frequently occurred at 20.11 mN/m surface (the lowest γ applied in this study) and *step* removal was generally seen at low temperature and flow rate. However combinations of high flow rate-low temperature and high flow rate-high temperature show more *continuous* removal thus reduce the cleaning time as removal occurred rapidly. From image recorded, low γ (20.11 and 21.50 mN/m) and γ of 29.31 mN/m encourage more *step* removal with removal of a few chunks of deposit, hence they consume less time to clean than normal *step* removal.

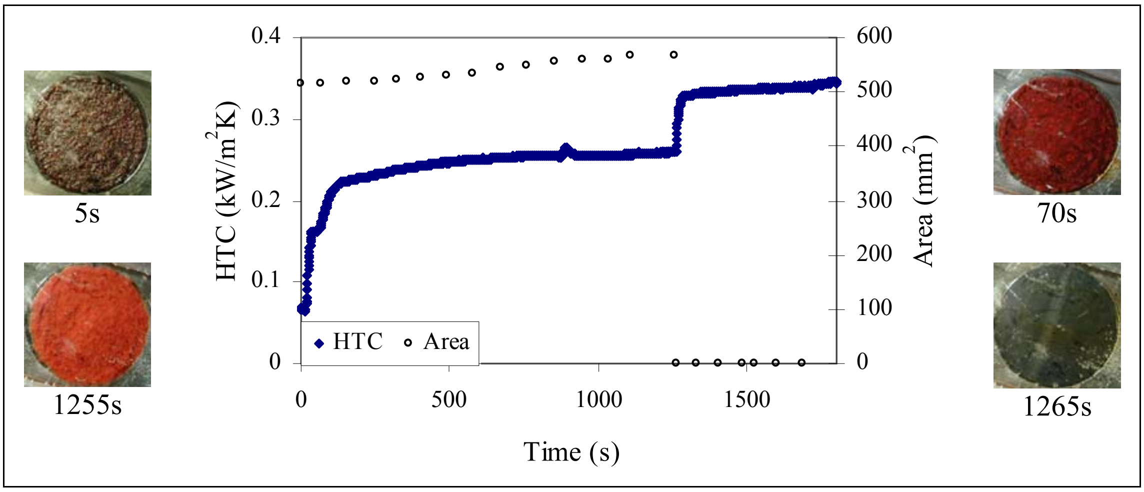

Figure 3: Result of one step removal mechanism observed during cleaning of 20.11 mN/m surface at 30°C and 0.7 l/min.

Figure 4 illustrates γ effect on cleaning duration. Shorter cleaning duration at high flow rate might cause by *continuous* removal. In which small pieces of deposit were removed continuously and with short interval time. At 30°C there are few cases where cleaning duration is longer at high flow rate than at low flow rate. This could be influenced by the γ as the mechanics effect is less; high γ provides strong adhesive bonds [14]. At 70°C cleaning duration is longer at low flow rate and *step* removal could be the reason for this. At 20.11, 21.50 and 29.31 mN/m short cleaning duration at both flow rates can be caused by γ effect and *one step* removal (sometimes occurred at 0.7 l/min).

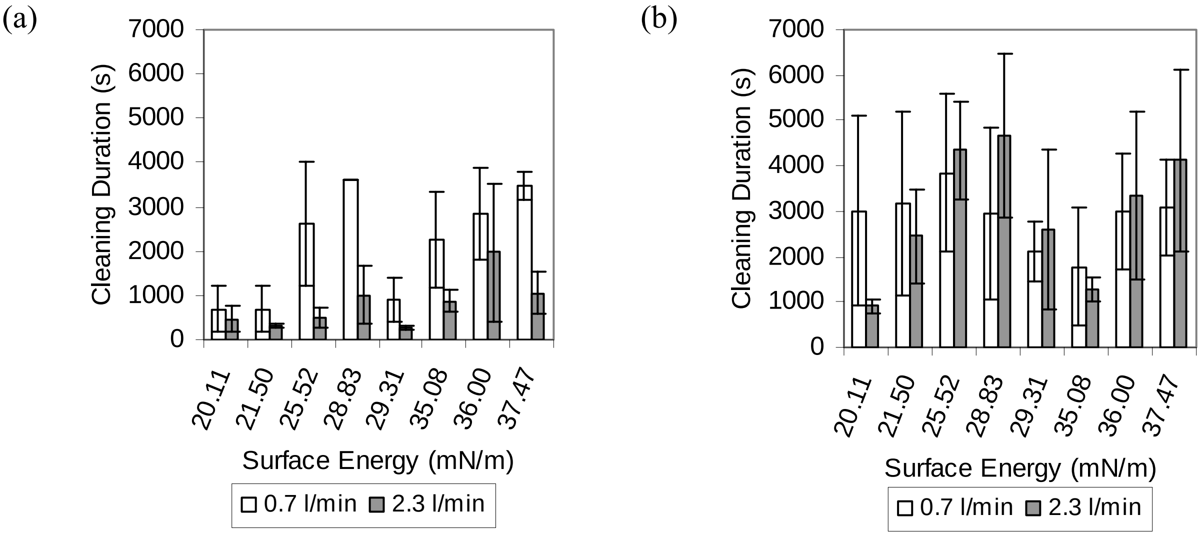

Figure 4: Effect of flow rate on cleaning duration of tomato deposit with water temperature, (a) at 70°C and (b) at 30°C.

CONCLUSIONS

Results show that γ can influence removal mechanisms but not significantly as flow rate effect. Low γ might encourage more *one step* removal to occur which assist cleaning. To enhance cleaning on high γ, application of high flow rate is needed. Ab Aziz et al. [14] discussed the effect of γ on cleaning in detail and found the effect of γ on removal of tomato deposit is not as clear-cut as would be expected from other studies, suggesting that surface effects are not always controlling in removal under these conditions. Here cleaning duration can be shorter with *one step* and *continuous* removal. Thus manipulation of bulk fluid parameters and γ can be applied to obtain the best cleaning mechanisms which assist removal.

REFERENCES

[1] Visser, H. and Jeurnink, Th.J.M (1997). General Aspects of Fouling and Cleaning. In: *Fouling and Cleaning of Heat Treatment Equipment, Bulletin of the International Dairy Federation* No. 328, edited by Visser, H., publ. IDF, Brussels, 5.

[2] Changani, S. D., Belmar-Beiny, M. T. and Fryer, P. J. (1997). Engineering and Chemical Factors Associated with Fouling and Cleaning in Milk Processing. Experimental and Thermal Fluid Science **14**: 392-406.

[3] Epstein, N. (1983). Fouling in heat exchangers. In Taborek, J. Hewitt G. F. and Afgan N. (Eds), *Heat Exchangers Theory and Practice*, Eds., (pp. 795-815). Hemisphere Publishing, New York.

[4] Holah,J.T. & Thorpe,R.H. (1990) Cleanability in relation to bacterial retention on unused and abraded domestic sink materials. Journal of Applied Bacteriology **69**: 599-608.

[5] Corrieu G. (1981) State of the art of cleaning surfaces. In B.Hallström, D.B.Lund, and A.C.Trägårdh (Eds) *Fundamentals and Application of Surface Phenomena Associated with Fouling and Cleaning in Food Processing*. Division of Food Engineering, Lund University, Lund, Sweden.

[6] Britten,M., Green,M.L., Boulet,M., & Paquin,P. (1988) Deposit Formation on Heated Surfaces - Effect of Interface Energetics. Journal of Dairy Research **55**: 551-562.

[7] Santos,O., Nylander,T., Rosmaninho,R., Rizzo,G., Yiantsios,S., Andritsos,N., Karabelas,A., Muller-Steinhagen,H., Melo,L., Petermann,L., Gabet,C., Braem,A., Tragardh,C., & Paulsson,M. (2004) Modified stainless steel surfaces targeted to reduce fouling - surface characterization. Journal of Food Engineering **64**: 63-79.

[8] Baier R.E. (1970) Surface properties influencing biological adhesion. In R.S.Manly (Ed) *Adhesion in Biological Systems*. Academic Press, New York, USA.

[9] McGuire J. & Swartzel K.R. (1987) American Institute of Chemical Engineers, National Meeting.

[10] Müller-Steinhagen H. (2000) *Heat Exchanger Fouling: Mitigation and Cleaning Techniques*. IEEE.

[11] Zhao,Q. & Liu,Y. (2006) Modification of stainless steel surfaces by electroless Ni-P and small amount of PTFE to minimize bacterial adhesion. Journal of Food Engineering **72**: 266-272.

[12] Zhao,Q., Liu,Y., Muller-Steinhagen,H., & Liu,G. (2002) Graded Ni-P-PTFE coatings and their potential applications. *Surface & Coatings Technology* 155, 279-284.

[13] Christian G.K. (2003) Cleaning of carbohydrate and dairy protein deposits. University of Birmingham, Birmingham, UK.

[14] Ab Aziz N., Fryer P.J., & Zhao Q. (2006) Effect of electroless Ni-P-based composite coatings with different surface free energies on cleaning time of tomato fouling deposit. In D.I.Wilson, J.Y.M.Chew, P.J.Fryer, and A.P.M.Hasting (Eds) Fouling, Cleaning and Disinfection in Food Processing 2006. Department of Chemical Engineering, University of Cambridge, Cambridge, UK.

[15] Liu,W., Aziz,N.A., Zhang,Z., & Fryer,P.J. (2007) Quantification of the cleaning of egg albumin deposits using micromanipulation and direct observation techniques. Journal of Food Engineering **78**: 217-224.

NOMENCLATURE

HTC	heat transfer coefficient	($kW.m^{-2}.K^{-1}$)
γ	free surface energy	(mN/m)