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Empirical Modeling of Fouling Rate of Milk Pasteurization Process : A case study

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Abstract

Fouling in heat exchanger becomes a major problem of dairy industry and it increases the production cost. These are lost productivity, additional energy, additional equipment, chemical, manpower, and environmental impact. Fouling also introduces the risk of food safety due to the improper heating temperature which allow the survival of pathogenic bacteria in milk, introducing biofilm formation of pathogenic bacteria in equipments and spreading the pathogenic bacteria to milk. The aim of this study is to determine the fouling rate during pasteurization process in heat exchanger of pasteurized milk produced by Village Cooperative Society (KUD) "X" in Malang, East Java Indonesia by using empirical modeling. The fouling rate is found as 0.3945 ^{o}C/h with the heating process time ranged from 0 to 2 hours and temperature difference (hot water inlet temperature and milk outlet temperature) ranged from 0.654 to 1.636 ^{o}C. The fouling rate depends on type and characteristics of heat exchangers, time and temperature of process, milk type, age of milk, seasonal variations, the presence of microorganism and more. This results will be used to plan Cleaning In Place (CIP) and to design the control system of pasteurization process in order to maintain the milk outlet temperature as standard of pasteurization.

Keywords*: empirical modeling, fouling, heat exchanger, milk, pasteurization.*

1. INTRODUCTION

Fouling on the surface of plate heat exchanger during pasteurization of milk, a complex process formed by protein and minerals, may reduce the efficiency of heat transfer and increase the dropping of pressure. The run time of heating process may be decreased because of the graduate blockage of milk that passed into

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the heater. Several costs due to the presence of fouling might rise in plants such as additional energy, additional equipment, lost productivity, additional manpower, additional chemicals, and environmental impact [1]. Moreover, the possibility of deterioration in product quality might increase because the process fluid could not be heated up to the required temperature such as in pasteurization of milk. In pasteurization milk process, the improper heating might not kill the pathogenic bacteria which might release into the process stream and contaminate the milk product [2]. The presence of pathogenic bacteria in pasteurized milk introduced the health risk to human health [3].

Commonly, milk fouling is formed rapidly. This evidence caused heat exchangers in milk plants required to be cleaned every day or more frequent to ensure the production efficiency, production capability, strict hygiene standards. For comparison this evidence, the heat exchangers in petrochemical or other plants was cleaned every year or every semester to remove the fouling [2]. According to Gillham *et al*. [1] rapid fouling might lead the frequent interruptions of production for cleaning-in place (CIP). The cost of production interruption might be more compared with those of reduction of efficiency [2]. Approximately 80% of total production costs in milk processing industry might be announced by cleaning due to the presence of fouling in process equipments [4]. Furthermore, meeting the quality and safety aspects of milk product are placed in the top list of milk industry due to its importance to human health. The aim of this study is to determine the fouling rate during pasteurization process in heat exchanger of pasteurized milk produced by Village Cooperative Society (KUD) “X” in Malang, East Java Indonesia by using empirical modeling.

2. MATERIAL AND METHODS

Raw fresh whole milk was collected by milk tanker from dairy farms in Dau collection area of the KUD “X”, Malang, East Java, Indonesia. About 8000 L of fresh raw whole milk was chilled at 4^{o}C, preheated, homogenized, separated, pasteurized at 72^{o}C for 15 seconds and chilled to 4^{o}C. The whole milk was standardized to maximal 2.8% of fat content and minimal 2.5% of protein content. The data were collected during 2013. Prior to pasteurization, analysis of protein was carried out to know protein content of milk by using Kjeldhal method [5]. Fat content of milk was also analyzed using Babcock method [6].

The pasteurization plant controlled the pasteurization temperature (up to 80^{o}C). The heat exchanger (Alfa-Laval Sweden) comprised of two sections. The first section consisted of cooler and pre-heater. This was followed by second section which was pasteurizer heater and final cooler. The heaters were controlled automatically using cooling and heating water circuits. The flowing of water and milk at plate heat exchanger was countercurrent. Each section was equipped with temperature sensors to measure the inlet and outlet temperatures of the milk and water. The holding tubes of pre-heater and pasteurization heater were located each other for 4 m.

The milk heating were started on water, and this switched to milk once temperature control had been established. The start of the fouling run was taken as the time at which the milk, displacing the water, reached pasteurization heater. Mean fouling rates varied among the different season and different milking time (morning and afternoon). The pasteurization plant was thoroughly cleaned-in-place prior to every run. The hot water inlet temperature and the milk outlet temperature in heat exchanger (Alva Laval, Lund, Sweden) of pasteurization process were recorded. This was calculated by using formula of Srichantra *et al*. [7] as below:

$$\Delta T = TW_2 - TM_1 \qquad (1)$$

where : TW_2 = hot water inlet temperature
TM_1 = milk outlet temperature

$$y^* = mt + C_3 \quad (2)$$

where y^* = predicted ΔT
m = fouling rate (°C/h)
t = time from start of run (h)
C_3 = Best fit ΔT at start of run

Statistical analysis

The differences in fat and protein contents of pasteurized milk during dry and wet season were determined by using Student's two tailed paired t-test (SPSS version 13.0) at a significance level of $P<0.05$. This was also carried out for analyzing the difference of fat and protein milk content of pasteurized milk of morning and afternoon milking.

3. RESULTS and DISCUSSION

The basis of calculating fouling rate in pasteurized milk process was presented in figure 1. This calculation was based on the data obtained from heat plate exchanger (stage 2) which carried out the pasteurization process at KUD "X" at Dau, Malang, East Java, Indonesia. The fouling rate among milk collected during different season (dry and wet season) and different milking time (morning and afternoon) were shown in figure 2 to 4.

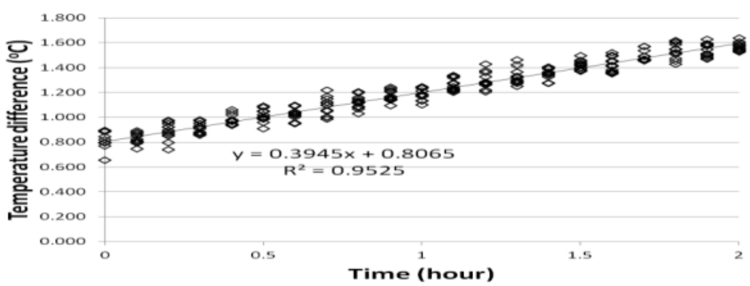

Figure 1. Fouling rate of pasteurization heating at KUD "X" at Dau, Malang, East Java, Indonesia

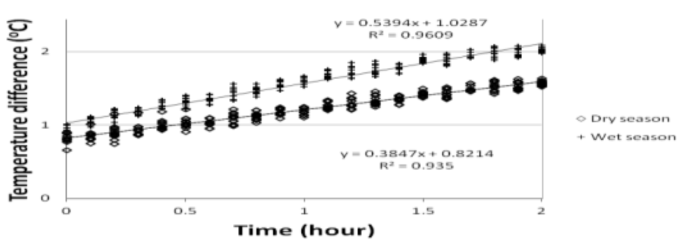

Figure 2. Fouling rate of pasteurization process during wet and dry season at KUD "X", Dau, Malang, East Java

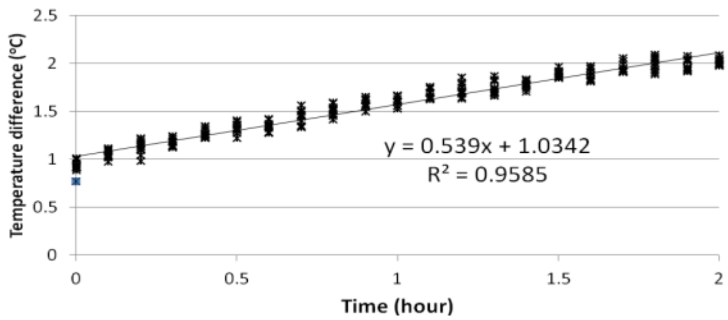

Figure 3. Fouling rate of pasteurization process using milk of morning milking at KUD "X" at Dau, Malang, East Java, Indonesia

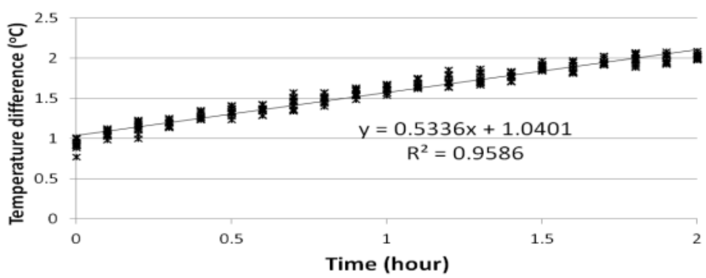

Figure 4. Fouling rate of pasteurization process using milk of afternoon milking at KUD "X" at Dau, Malang, East Java, Indonesia

Fouling rate could be measured by using deposit weight measurement [8], pressure loss measurement [9], heat transfer coefficient measurement [10] and temperature difference measurement [11]. In this present study, temperature difference (hot water inlet temperature and milk outlet temperature) in heat exchanger of pasteurization process is used to determine the fouling rate. The temperature difference is ranging from 0.654 to 0.896 °C at t_0. This increases after 2 hours which is ranging from 1.524 to 1.636 °C.

In this present study, fouling rate of pasteurized milk is observed to be relatively higher on wet season (0.5394) compared to those of dry season (0.3847) as shown in Figure 2. According to Bansal and Chen [2] and Bansal *et al*. [12] a seasonal variation could attribute to milk composition. De Jong [13] revealed that whey protein -lactoglobulin, constituted about 0.32% in whole milk, has initiated milk fouling. The constituent of milk was influenced by the feed [12, 14]. In this present study, the farming cows are fed by grass. Hidayati [15] reported that grass, as energy source and high of fiber, were planted in many kind area. This author also reported that grass production in dry season was lower up to 50% than those in wet season. This present study observes that protein and fat content are relatively higher in pasteurized milk during wet season than those during dry season (Figure 5). There is significant difference between protein content of pasteurized milk during wet and dry season ($P < 0.05$). No statistically significant difference in fat content of pasteurized milk during wet and dry season is observed ($P > 0.05$). In KUD "X" Dau, Malang, pasteurized milk was set by using homogenization and cream separation to meet the standard such as protein content (minimal for 2.5%) and fat content (maximal for 2.8%).

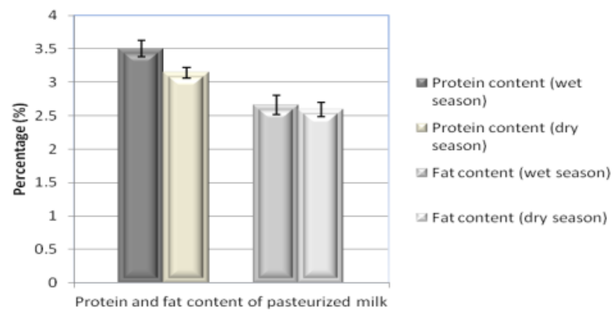

Figure 5. Protein and fat content of pasteurized milk during dry and wet season at KUD "X" at Dau, Malang, East Java, Indonesia

Besides seasonal variations, the variation of fouling rate was influenced by different milking time. In this present study, the fouling rate of pasteurized milk is observed to be slight higher in milk of morning milking (0.539) compared to those of afternoon milking (0.5336) as shown in Figure 3 and 4. The interval between milking might influence to composition of milk nutrient. According to Klopčič *et al*. [16] longer milking intervals did not change protein content as much as fat content. This present study observes that protein content of milk is not significantly different between those of morning milking and afternoon milking ($P>0.05$). The protein content of milk is almost similar between those of morning milking and afternoon milking. However, this present study observes that fat content in pasteurized milk of morning milking is relatively higher than those of afternoon milking (Figure 6). Fat contents of milk is significantly different between those of morning milking and afternoon milking ($P<0.05$). Frank O'Mahony [17] revealed that shorter interval of milking may decrease the fat contents of milk.

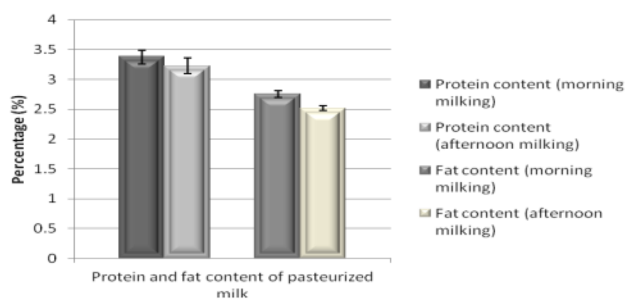

Figure 6. Protein and fat content of pasteurized milk of morning and afternoon milking at KUD "X" at Dau, Malang, East Java, Indonesia

According to Bansal and Chen [2], heating the milk might lead native proteins (β-Lg) denaturation, reacted with other denaturated protein and introduce the presence of fouling. Fouling was classified as type A (protein) fouling and type B (mineral) fouling which was formed different temperature. These authors revealed that type A (white, soft, and spongy) was formed in the range of 75°C to 110°C and type B (hard, compact, and grey in colour) was formed at temperature above 110°C. The deposits of type A were composed by 50-70% proteins (mainly β-Lg), 30-40% minerals, 4-8% fat and the deposits of type B were composed by 70-80% minerals (mainly calcium phosphate), 15-20% proteins, and 4-8% fat. In this present study, temperature of water inlet in pasteurization process ranged from 75 to 77 °C with the temperature difference ranged from 0.654 to 2.088°C. Thus, the fouling form can be classified as type A and is caused mainly by protein. Besides seasonal variations and time milk collection, the fouling rate was influenced by age of milk, time and temperature of process, milk type, the presence of microorganism, type and characteristics of heat exchangers and more [2, 18].

The cleaning in place (CIP) was carried out to ensure the cleanliness of pasteurization heating section. In this present study, CIP was done immediately when fouling rate reach 0.8 °C/h. Srichantra *et al*. [7] reported that CIP was done to ensure the cleanliness of plate heat exchanger.

4. CONCLUSION

The fouling rate in plate heat exchanger of pasteurization process at KUD "X" plant, Dau, Malang, East Java, Indonesia is found as 0.3945 °C/h with the heating process time ranged from 0 to 2 hours and temperature difference (hot water inlet temperature and milk outlet temperature) ranged from 0.654 to 1.636 °C. Fouling in milk pasteurization process can be initiated by composition of milk which depend on seasonal variation and time collection of milk. Cleaning in place was done to ensure the cleanliness of plate heat exchanger and the temperature required by pasteurization process to kill vegetative especially pathogenic bacteria.

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