Preliminary Work on Coconut Milk Fouling Deposits Study
Hui Yin Law, Chin Im Ong, Norashikin Ab. Aziz, Farah Saleena Taip and Noraziah Muda

Abstract — The characteristics of coconut milk fouling deposits formed during pasteurization process at temperature from 70 to 80°C were investigated. Both in-situ (using lab-scale plate heat exchanger) and ex-situ methods (using shakable water bath) were applied in preparing the fouling sample and for cleaning study. A few mini analyses such as proximate analysis, texture analysis and microstructure analysis were carried out to examine the characteristics of the coconut milk fouling deposits. Selection of raw material and determination of the optimal process parameters for pasteurization process were done to obtain a typical pasteurization condition as applied in the coconut milk product industry in Malaysia. The changes of the overall heat transfer coefficient (U) during the process were studied. The removal/cleaning of coconut milk fouling deposit was also studied at 80°C, 2 LPM and with 2 %V/V hydroxide of alkaline solution (optimal condition obtained from ex-situ method). The results indicate that fouling period was occurred during coconut milk pasteurization and it caused a resistance to heat transfer. Coconut milk fouling deposit which contains of high fat content (29.25%) can be removed by applying single stage clean-in-place (CIP) method with alkaline solution. The factors causing fouling were studied.

Index Term — coconut milk, fouling deposit, cleaning, pasteurization process, plate heat exchanger

I. INTRODUCTION
Fouling deposit generally is defined as the deposition of soils or unwanted material on the heat transfer surfaces. Despite a great technical achievement in the design and manufacture of heat exchangers in the past two decades, the problem of fouling deposit on heat exchanger surfaces still remains one of the major unresolved problems in thermal science. In food processing, fouling (i) causes increase in pressure drop through the plant, (ii) lowers the effectiveness of heat transfer, (iii) limits the operational time of the plant, and most importantly (iv) endangers plant and process sterility [1]. It also compromise product quality by cross-contamination or microbial growth [2]. Fouling condition in a heat exchanger depends on local thermal and hydraulic conditions, together with the chemistry and process history of the fluid [3]. In order to produce consistent and quality product which safe for human consumption, frequently cleaning of the plant is needed.

It is important to study the fouling deposit characteristics and cleaning mechanisms in order to get the best performance of cleaning. CIP (clean-in-place) technique is the common cleaning practice used in industry nowadays. It is used in processing plant to clean tanks, piping and workspaces between production batches by automatically recirculating cleaning chemical and rinsing liquid. There are two types of CIP treatment [4]:

1. Two-stage cleaning, using alkali commonly sodium hydroxide and acid wash (e.g. nitric or phosphoric acid).
2. Single-stage cleaning, using formulated detergents containing wetting and other surface agents as well as chelating compounds.

Coconut milk is the liquid obtained by mechanical extraction of grated coconut meat. Heating process normally takes place in a system of indirect plate heat exchangers, which consists of preheating, heating, and cooling sections. Pasteurization process has been found to be a short-term preservation process in which the coconut milk is heated to pasteurization temperature of 72-75°C for 20 min [5]. Coconut milk is a complex biological fluid, typically composed of fat, protein, carbohydrates, and minerals as a milky white oil-in-water emulsion; a percentage of fat is adjusted depending upon local requirement, between 15-40%. At high temperature, some components can lose their rheological properties and/or denature to form a fouling deposit on the heating surface. As with other food fouling, the rate of deposit build-up is quite rapid. Thus coconut milk fouling deposit can affect greatly the performance of the process.

This work aims to understand the influence of process condition and raw coconut milk properties on fouling and cleaning, which can provide a fundamental knowledge for future studies in this field. The deposit characteristics such as, strength, texture, composition, microstructure and absorption rate, are important in determining the fouling rate and cleaning performance of heat exchanger. The findings from these works provide preliminary data of coconut milk fouling deposit characteristics and its cleaning process.
II. MATERIALS AND METHODS

A. Raw Material
Raw coconut milk (purchased from wet market, \( \rho = 976.025 \) kg/m\(^3\), \( \text{Cp} = 3.494 \text{kJ/kg°C} \) at 80°C) and solution of instant coconut milk powder were used initially to find the suitable material for this work.

B. Plate Heat Exchanger (PHE) Unit
The laboratory PHE (Alfa-Laval Plate Heat Exchanger, Sweden) was used in this work. It consists of four plates at heating section, nine plates at regeneration section and four plates at cooling section. Some apparatus were connected to the PHE to increase its efficiency and lengthen the processing time, such as a temperature controller, food grade centrifugal pump, 2-way valves, water filters, feed tank, water tank, and impellers for the product and cleaning solution. The holding tube of PHE was modified to fix the fouling sample rig, for collecting the fouling deposit samples. A data logger (Monash) was used to record the temperature of inlet and outlet streams.

C. Pasteurization of Coconut Milk
60L of coconut milk was pasteurized at 80°C and 1 LPM for one hour; processing temperature used in this work was taken from the survey, which involves major producers of instant coconut milk in Malaysia. The temperature data collected from the experiments was analyzed by using a basic equation governing the heat transfer between the hot water channels and coconut milk channel:

\[
Q = U \times A \times \Delta T_{\text{Im}}
\]

The fouling resistance was calculated by the following equations:

\[
R_f = \frac{1}{U} - \frac{1}{U_o}
\]

D. Chemical & Physical Analyses
The determination of fat, protein, carbohydrate, moisture, fiber and ash in raw coconut milk and coconut milk deposits was carried out according to procedures described by AOAC, 1995 (AOAC – Association of Analytical Communities). Texture Profile Analysis (TPA) parameters of coconut milk fouling deposits were measured at 25°C using a Texture Analyzer (TA-XT2i, Stable Micro Systems, UK). Only certain TPA parameters are consider in this work, which were hardness and stickiness. The hardness value is the peak force of the first compression of the product, whereas the adhesiveness is the peak negative load attained in full cycle force required to pull probe from sample. Environmental Scanning electron microscopy (XL30 ESEM, Philips, Holland) analysis was carried out on the deposit obtained.

E. Cleaning methods
Ex-situ and in-situ methods were used during cleaning study. Ex-situ method was done by using shakable water bath, to simplified heat exchanger configuration and process, thus fewer raw materials and short experimental period were used.

In-situ method was done by using PHE, to represent a similar process to industry practice. Ex-situ experiment was conducted to provide a basis idea on fouling formation and removal behavior, due to the lack of literature on the coconut milk fouling study. The formulated cleaning chemical used in this research was Maxiclean CP6, which provided by Averax S/B, Malaysia.

For ex-situ method, coconut milk fouling deposit was prepared in stainless steel container by using shakable water bath. Cleaning of coconut milk fouling deposit was done at various combination conditions: 1) temperature: 60, 70, 80°C, 2) speed: 50, 100, 150 rpm and 3) cleaning chemical concentration: 0, 0.1, 0.5, 1.0, 1.5, 2.9, 2.5%V/V NaOH. To convert the speed used in shakable water bath into the volumetric velocity, this formula was used:

\[
v = \frac{S \times 2\pi \times r}{60}
\]

where \( v \) is velocity (m/s), \( S \) is the speed of shakable water bath (rpm) and \( r \) is the radius of rotary shaft in shakable water bath (m), which is 0.025m. The cross-sectional area between two plates is 1.253 X 10\(^{-4}\) m\(^2\). With this information, volumetric flowrate was calculated.

The optimal cleaning condition from this method was applied in in-situ experiment. Thus for in-situ method only one cleaning condition was used, to reduce the raw coconut milk usage, minimize the cleaning chemical consumption, minimize chemical discharge and labour energy.

### Table 1

<table>
<thead>
<tr>
<th>Food Components</th>
<th>Raw Coconut Milk</th>
<th>Coconut Milk Powder with 100ml Water</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture</td>
<td>66.1122 ± 0.6778</td>
<td>67.1476 ± 0.1492</td>
</tr>
<tr>
<td>Protein</td>
<td>2.5107 ± 0.2010</td>
<td>3.0358 ± 0.0092</td>
</tr>
<tr>
<td>Ash</td>
<td>0.8124 ± 0.0656</td>
<td>0.3135 ± 0.0110</td>
</tr>
<tr>
<td>Fat</td>
<td>24.75 ± 0.2500</td>
<td>19.2665 ± 0.0889</td>
</tr>
<tr>
<td>Crude fibre</td>
<td>0.00</td>
<td>0.0234 ± 0.0016</td>
</tr>
<tr>
<td>Carbohydrate</td>
<td>6.9660</td>
<td>10.2132</td>
</tr>
</tbody>
</table>

III. RESULTS AND DISCUSSIONS

The results in Table 1 show that differences do exist between the compositions of these two samples. Crude fat content of coconut milk powder solution (19.266%) is much lower than that of the raw coconut milk (24.75%); whereas, the content of protein (3.0358%) and carbohydrate (10.2132%) are higher in this sample, compared to raw coconut milk. Raw coconut milk contains of 2.5107% of protein and 6.9660% of carbohydrate. There is no crude fibre presents in raw coconut milk; on the other hand, coconut milk powder solution contains a very small amount of crude fibre which is only 0.0234%. Raw coconut milk is chosen as the raw material because it does not contain other ingredients. Coconut milk powder contains other ingredients such as whey protein product which can affect the characteristics of the coconut milk fouling deposits. Due to its
different composition, it was not suitable to be applied in this study. As this study aims to provide fundamental knowledge of coconut milk fouling deposit. Thus maintaining its original conditions can represent the typical coconut milk fouling deposit in the industry.

Monitoring the changing of U value is crucial in investigating the formation of coconut milk fouling in the PHE. At the heating section of PHE, temperature of pasteurization was controlled in the range of 70-80°C. This was the optimal temperature for pasteurization of coconut milk which was being applied in food industry. Figure 1 demonstrates the overall heat transfer coefficient (U) and the fouling resistance (R_f) as a function of time (t) which was computed for every 2 minutes during pasteurization at 1 LPM. Fouling period of heating section was started after 22 minutes of pasteurization. This means, the induction period of this section was lasted for 22 minutes. From Figure 2, the induction period of the regenerating section was lasted for a longer period compared to heating section. This is because the temperature at heating section is higher compared to regenerating section. The decrease in U after the induction period indicates that the total heat transfer through the heating section was decreased as a result of the resistance to heat transfer. The resistance was caused by the coconut milk fouling deposit (formed on the plate), which has low thermal conductivity.

Microanalysis results for moisture, fat, ash, protein and carbohydrate of the dried coconut milk deposit (in-situ) are shown in Table II. The fat, protein and carbohydrate contents of coconut milk fouling deposits were much higher compared to raw coconut milk. The fouling deposit is much concentrated than fresh coconut milk. Therefore it has lower moisture content and resulted in higher total soluble solid content. The protein has been found to be an essential factor to cow milk fouling formation since the specific protein called β-lactoglobulin can denature and lose its stability in the liquid phase [1]. For coconut milk fouling deposit, fat could be the main factor of fouling build-up. 80% of proteins in coconut endosperm can be categorized as albumins and globulins [6, 7]. Hagenmaier et al. [8] reported that approximately 30% of protein in coconut milk is dissolved in the aqueous phase. Thus the undissolved protein can be an emulsifying agent for coconut milk as fat globules are bordered by the aqueous protein solution in coconut milk [9]. The range of temperature 50-130°C can reflect the complex protein structure [5]. Heat labile proteins can be destroyed when heating coconut milk at high temperature with subsequently causing the aggregation of fat globules. Thus at pasteurization temperature, coconut milk protein and fat played the important role in coconut milk fouling.

Table II

<table>
<thead>
<tr>
<th>Sample</th>
<th>Coconut Milk</th>
<th>Coconut Milk Deposits (in-situ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture</td>
<td>66.1122 ± 0.6778</td>
<td>47.2080 ± 0.0289</td>
</tr>
<tr>
<td>Fat</td>
<td>24.75 ± 0.2500</td>
<td>29.25 ± 0.2500</td>
</tr>
<tr>
<td>Ash</td>
<td>0.8124 ± 0.0656</td>
<td>0.6293 ± 0.0028</td>
</tr>
<tr>
<td>Protein</td>
<td>2.5107 ± 0.2010</td>
<td>7.5434 ± 0.2343</td>
</tr>
<tr>
<td>Carbohydrate</td>
<td>6.9660</td>
<td>15.3693</td>
</tr>
</tbody>
</table>

Table III

<table>
<thead>
<tr>
<th>Test</th>
<th>Hardness, Force (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Sample</td>
</tr>
<tr>
<td>1</td>
<td>11.047</td>
</tr>
<tr>
<td>2</td>
<td>10.335</td>
</tr>
<tr>
<td>3</td>
<td>11.831</td>
</tr>
<tr>
<td>4</td>
<td>9.836</td>
</tr>
<tr>
<td>5</td>
<td>10.905</td>
</tr>
<tr>
<td>6</td>
<td>11.218</td>
</tr>
</tbody>
</table>

Tables III and IV display the data obtained from texture analyzer on the hardness and stickiness of coconut milk fouling respectively. The results indicate that coconut milk fouling deposit which was obtained after 45 minutes of pasteurization is harder compared to fouling which was obtained after 60 minutes of the process. Heating coconut milk at high temperature can destroy heat labile proteins. This is followed by fat globules tending to aggregate. Since Sample 1 had been heated for a longer period than Sample 2, the concentration of dispersed-oil in Sample 1 may be higher than Sample 2. The results of dispersed-oil may decrease the hardness of the fouling. Therefore, Sample 1 is less hard than...
Sample 2. While, Table III shows there is no significant changes on stickiness characteristic after different process periods.

<table>
<thead>
<tr>
<th>Test</th>
<th>Stickiness, Force (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sample 1, Fouling (60 minutes)</td>
</tr>
<tr>
<td>1</td>
<td>4.775</td>
</tr>
<tr>
<td>2</td>
<td>5.448</td>
</tr>
<tr>
<td>3</td>
<td>5.417</td>
</tr>
<tr>
<td>4</td>
<td>4.561</td>
</tr>
<tr>
<td>5</td>
<td>5.702</td>
</tr>
<tr>
<td>6</td>
<td>5.235</td>
</tr>
</tbody>
</table>

Figure 3 shows the fouled plate of heating section. From the figure, fouling deposit was observed as a brittle semisolid, yellowish-white and spongy deposit covering some part of the corrugated plates. It was quite oily due to the presence of fat globules. The plate from heating section shows more area covered by the fouling deposit, compared to the regenerating section, as shown in Figure 4. This is due to the high temperature (~80°C) at heating section. Heating coconut milk at high temperature continually causes the fat and protein molecules to agglomerate within the medium of flow, then promoting the attachment of fouling deposit onto the hot stainless steel surface. However, fouling deposit was not attached on the inner surface of the sample rig (as shown in Figure 5), as the surface was not hot. The attachment of fouling deposit could be influenced by the equipment surface configuration, roughness and temperature. Scanning electron microscopy (SEM) analysis was carried out on the fouling deposit sample, to observe the microstructure of it. The microstructure shown in Figure 6 could be due to the agglomeration of fat globule that was surrounded by a film of proteins. In general, coconut milk fouling deposit is water-in-oil emulsions, in which a continuous fat matrix surrounds the dispersed water droplets, thus the coconut milk deposit is full of water. Structure stabilization is favored by fat globules of appropriate hardness and uniform distribution, and the presence of a continuous protein matrix.

Fouling deposit formed by coconut milk cannot be removed by water alone because of the fat and protein contents. Suitable cleaning solution is needed to break the fat and protein matrix or network. Alkaline based cleaning solution is normally used to remove this type of deposit. Cleaning-In-Place (CIP) technique was used this research as it is widely used in food industry [10]. Results from ex-situ experimental approach showed that cleaning rate was greatly influenced by the chemical concentration and temperature (as shown in Figure 7). Generally high chemical concentration and temperature promise a shorter cleaning time [1, 11]. This could be due to the presence of more cleaning agents to break the fat and protein networks and the reaction increased at high temperature. However, the increase of speed was not reduced the cleaning duration significantly. The effect of the shaking technique during cleaning provides two directions of flow which is not similar to the flow profile within the PHE. Thus the shaker speed to represent the volumetric flow in PHE is not appropriate [12]. However this ex-situ experimental set-up did provide a basis idea on the best chemical concentration and temperature to be applied to in-situ experimental set-up. The shortest cleaning time was obtained at cleaning condition: 80°C, 100rpm with cleaning chemical concentration of 2.0%V/V and 2.5%V/V of hydroxide. Therefore, the suggested optimal cleaning condition is 80°C, 100rpm with 2.0%V/V of hydroxide. Figure 8 shows the stainless steel container condition during the cleaning.

The time required to clean PHE is expected to be longer than the cleaning time of ex-situ experiment (~10 minute). The effect of corrugated pattern of the plate could be the reason for this. Besides, the flow profile resulted from the shakable water bath is not similar to the flow profile within the PHE. Furthermore, the fouling deposits from the PHE were the result from continuous pasteurization process. During in-situ experiment, the cleaning process is continued until a clear,
clean alkali cleaning solution is discharged from the output of the PHE. The cleaning process was stop after 35 minutes and a clean PHE was observed. The recorded temperature during cleaning of PHE was used to observe the cleaning profile by calculating the heat transfer coefficient. Figure 9 shows the result. Initially, the heat transfer coefficient, $U$ increased when there was removal of deposit layer which promoting more heat transfer. The removal is considered complete as the heat transfer coefficient become consistent. The response of coconut milk fouling deposits towards cleaning action also can be indicated as reverse of $U$, which also known as cleaning resistance, $R_d,c$. $R_d,c$ will decrease when thickness of deposit layer decreases or when removal happens. As $R_d,c$ become constant, it is assumed that all fouling deposits had been removed.

![Graph a](image1.png)

![Graph b](image2.png)

![Graph c](image3.png)

Fig. 7. Cleaning time required to remove ~90% of coconut milk fouling deposit from stainless steel container. Cleaning condition at different temperatures and concentrations and at a) 50 (1 LPM), b) 100 (2 LPM) and c) 150 (2.95 LPM) rpm.

The understanding of coconut milk fouling deposit is crucial in selecting the correct cleaning strategy. The key roles are played by fats and proteins in the formation of coconut milk fouling deposit. The undissolved protein is an emulsifying agent for coconut milk. The proteins can be transformed when heating the coconut milk at high temperature with subsequently causing the aggregation of fat globules. Applying heat treatment on coconut milk gives the result in the aggregating of fat globules. Fat globules and protein are soluble in alkaline solution. Figure 6(b) shows the effect of alkaline solution on the deposit microstructure. Therefore, an alkaline based cleaning detergent with a desired concentration is suitable to be used to remove the coconut milk fouling deposit. The cleaning activity can be started after 60 minutes of pasteurization. It is expected that the fouling deposit which had been soften by the dispersed oil caused by the aggregation of fat globules, resulted from a longer period of thermal processing, can be removed easily.

![Image 6](image4.png)

![Image 7](image5.png)

![Image 8](image6.png)

Fig. 8. The stainless steel container condition during cleaning at 80°C, 100rpm and 2.0% V/V of hydroxide.

![Graph](image7.png)

Fig. 9. Overall heat transfer coefficient ($U$) and fouling resistance ($R_d,c$) profiles during cleaning 80°C, 2LPM and with 2.0% V/V of hydroxide (in-situ study).

IV. CONCLUSION

Fresh coconut milk had been selected as the raw material for this study because it can maintain its original conditions that
represent the typical coconut milk fouling deposit formed in the food industry. The overall heat transfer coefficient can be calculated in real time from the changes of the temperature during the study. In this study, the fouling period of coconut milk pasteurization at the flowrate of 1 LPM, was begun after 20 minutes of processing. This can be seen from the reduction of the overall heat transfer coefficient and the increment of the fouling resistance. In general, it is believed that coconut milk fouling is caused by the aggregation of fat globules due to heating treatment of the product. The coconut milk protein is also an important factor for coconut milk fouling build-up. Based on the observation, coconut milk fouling was not attached to the not-heated stainless steel surface as it was agglomerated within the medium of flow. The deposit is a sticky, smooth, soft and brittle semisolid substance, which can be removed by applying alkaline solution.

For cleaning study, there two type of experiments conducted, ex-situ and in-situ experiments. The ex-situ experiment was carried out by using the shakable water bath to represent a simple PHE. Fouling deposit was formed in stainless steel container. The shaker speed was used to represent the volumetric flowrate. However the flow profile resulted from shaker speed cannot represent the flow profile within the PHE, thus effect of shaker speed on cleaning is not appropriate. Finding from ex-situ experiment, chemical concentration and temperature, can be used to find out the optimal cleaning conditions before the real process is done by using the PHE. This minimizes the cleaning chemical usage. From the results, the optimal cleaning conditions for removal of coconut milk fouling deposits by using ex-situ method is 10 minutes cleaning at 80 °C, 100rpm (2LPM) by using 2.0% W/V (of hydroxide) alkali cleaning solution (Maxiclean CP6 from Averex Chemicals S/B). The cleaning on the PHE at same temperature and same concentration of the alkaline cleaning solution showed the increase of cleaning time to 35 minutes. The effect of corrugated pattern of the plate could be the reason for this. Besides, the flow profile resulted from the shakable water bath is not similar to the flow profile within the PHE. Furthermore, the fouling deposits from the PHE were the result from continuous pasteurization process. A future work on the application of engineering methods to investigate the effects of fluid flowrate on coconut milk fouling deposit at pasteurization temperature, is suggested. Moreover, a further study on the mitigation of coconut milk fouling deposits is also recommended.

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REFERENCES

NOMENCLATURE

\( A \) heat transfer surface area (m\(^2\))
\( Q \) heat required (W)
\( t \) time (m)
\( U \) overall heat transfer coefficient (W.m\(^{-2}\).K\(^{-1}\))
\( U_0 \) overall heat transfer coefficient of clean condition (W.m\(^{-2}\).K\(^{-1}\))
\( R_f \) fouling resistance (m\(^2\).K.W\(^{-1}\))
\( \Delta T_{in} \) logarithmic mean temperature difference (K)

CIP Clean-in-Place
LPM Liter per Minute
PHE Plate Heat Exchanger
SEM Scanning Electron Microscopy