

Ex-Situ Experimental Set-Up for Pink Guava Juice Fouling Deposit Study

Ong C. A., Abdul Aziz, N.* , Taip, F. S. and Ibrahim M. N.

*Department of Process and Food Engineering,
Faculty of Engineering, Universiti Putra Malaysia,
43400 Serdang, Selangor, Malaysia
E-mail: shekeen@eng.upm.edu.my

ABSTRACT

A study has been conducted on pink guava juice (PGJ) fouling deposit. Several ex-situ experimental rigs were set-up to obtain PGJ fouling deposit, while the best ex-situ experimental rig was also selected. PGJ was heated at 93°C and its fouling deposit was obtained after 1 hour of heating. Then, it was used for the ex-situ cleaning study at 1 litre min⁻¹, at several temperatures (70, 80 and 90°C), and in some chemical concentrations (1.6 v/v% of Maxiclean CP6 or 0.325 % OH⁻; 1.8 v/v% of Maxiclean CP6 or 0.369 % OH⁻; 2.0 v/v% of Maxiclean CP6 or 0.44 % OH⁻). The best cleaning combinations were investigated. Carbohydrate is the main content in the fouling deposit. The morphology of the deposit was studied using SEM and it showed an aggregated structure. The cleaning process improved as the temperature increased with the increasing of the chemical solution concentration. The shortest cleaning time was 40 minutes, for cleaning using 2.0 v/v % of Maxiclean CP6 (0.44 % OH⁻) at 90°C.

Keywords: Pink guava juice, fouling deposit, cleaning, ex-situ method

INTRODUCTION

In many processing industries, fouling deposit is an unwanted by-product that attaches to the inner surfaces of processing equipment (Bott, 1995). Fouling deposit can hamper the process performance, both technically and economically. It is important to note that fouling deposit can reduce equipment performance and product output, as well as increase maintenance cost, energy cost and affect the environment. The formation of fouling deposit is caused by the effect of processing condition and processing raw material properties. In food industries, the formation of fouling deposit is common because food substances are heat sensitive and heating process is a typical technique to preserve the food. Thus, it is almost impossible to terminate formation of fouling deposit in the food industry.

Pasteurisation is a common technique used to preserve food products in the food industry. High temperature is required to deactivate enzyme and kill harmful bacteria. However, food substances are heat sensitive. Exposure to high temperature will denature food substances and promote formation of fouling deposit. Heat exchanger is a common unit operation use in the food industry to pasteurize and sterilize food products (Earle, 1983). As formation of fouling deposit is presumed to occur, most heat exchanger designers take into consideration the fouling factor in designing it to ensure that its usage can be prolonged (Saunders, 1988). Meanwhile, the application of fouling factor is one of the precaution methods to delay the fouling removal procedure. Each material should have its own fouling factor as it depends on the raw material properties and the

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*Corresponding Author

fouling deposition mechanism (Krause, 1993). Nonetheless, only few fouling factors have been discovered, and these are mostly for the petroleum industry (Müller-Steinhagen, 2000). Therefore, an in-depth empirical study is required to quantify the fouling factor of undefined fouling deposit.

Cleaning-in-place (CIP) is a common method used in food plants to remove fouling deposit and regain the original condition of heat exchanger. Cleaning procedure needs to be done frequently as food fouling deposit reduces processing performance, and product quality, as well as provides a medium for bacteria growth. Meanwhile, cleaning agent, procedure and condition are generally dependent on the type of food substances; for instance, alkaline-based cleaning agent is best suited with protein-based and fat-based fouling deposit (Watkinson, 2008). However, an empirical study is still needed to set the right duration for cleaning, to ensure short downtime and less consumption of water and chemical during the cleaning process. Many studies on fouling and cleaning have been focussing on dairy-based products (Fryer & Bird, 1994; Changani *et al.*, 1997; Chen *et al.*, 2004; Swartzel, 1983), which provide important knowledge for mitigating the fouling problem. Thus, studies on fouling and cleaning are still limited, particularly on tropical-based food products.

Therefore, this study investigated pink guava juice (PGJ) fouling deposit, which is an undefined fouling deposit. Pink guava is also among the main natural resources of tropical countries. Furthermore, Malaysia is among the main producers of pink guava puree. Zainal *et al.* (1999) studied the effect of temperature on pink guava juice, but the researchers did not include the aspect of fouling deposit formation in their work. The objectives of this study were to set-up a simple ex-situ experimental rig to obtain PGJ fouling deposit in a short processing time and to provide basic knowledge on cleaning requirement. The reason to use an ex-situ experimental set-up was to reduce the consumption of raw material, labour work and processing time. The findings from this work are essential for further investigations on the fouling factor of the PGJ fouling deposit and the best cleaning procedure for the PGJ industry.

MATERIALS AND METHODS

Preparation of Pink Guava Juice (PGJ)

Pink guava juice was prepared according to the basic formulation provided by Sime Darby Food and Beverages Marketing Sdn. Bhd. Filtered water and sugar were added to the puree at the ratio of 1:3:7 (sugar: pink guava puree: water) to produce PGJ. The puree was sponsored by Sime Darby Food and Beverages Marketing Sdn. Bhd. This PGJ had the viscosity of 11.2 mPas and the pH value ranging from 3.8 to 4.5, which is classified as acidic food. The total soluble solid tested with refractometer is 11° Brix.

Preparation of Ex-Situ PGJ Fouling Deposit

The ex-situ PGJ fouling deposit was prepared by adapting the method proposed by Chen *et al.* (2004), in which the ex-situ milk fouling deposit was prepared by boiling the milk. A small stainless steel plate was placed at the bottom of heated beaker to form milk fouling. In this study, the juice was heated at 93°C inside a stainless steel petri dish by using hot plate, static water bath (Heidolph, Germany) and shakeable water bath (Hotech 903D, Taiwan) until the ex-situ fouling deposit was formed. The heating temperature is a recommended temperature for pasteurising foods in acidic class (Lewis & Heppell, 2000). The speed for the shaker of the shakeable water bath was set at 50 rpm. Equation 1 was used to convert the rotation-based speed, S (unit is rpm), of the shaker to distance-based speed, v (unit is ms^{-1}). The distance-based speed was used to represent the velocity flow of the PGJ.

$$\text{Velocity of liquid flow, } v \text{ (ms}^{-1}\text{)} = \frac{25\pi r}{60} \quad [1]$$

The radius, r , of the rotary shaft in shakeable water bath was 0.025 m. Meanwhile, the cross sectional area of the flow was $1.253 \times 10^{-4} \text{ m}^2$. Thus, the flow rate of the PGJ on the moving shaker (at 50rpm) was equivalent to 1 litre min^{-1} .

Heating by hot plate and static water bath represents non-flowing system while shakeable water bath represents flowing system. *Fig. 1* illustrates the experimental set-up for obtaining fouling deposit and cleaning using hot water bath. The ex-situ fouling deposits from each method were then compared and the best method was selected to obtain the samples of the ex-situ fouling deposit, which were then used for finding their cleaning requirement.

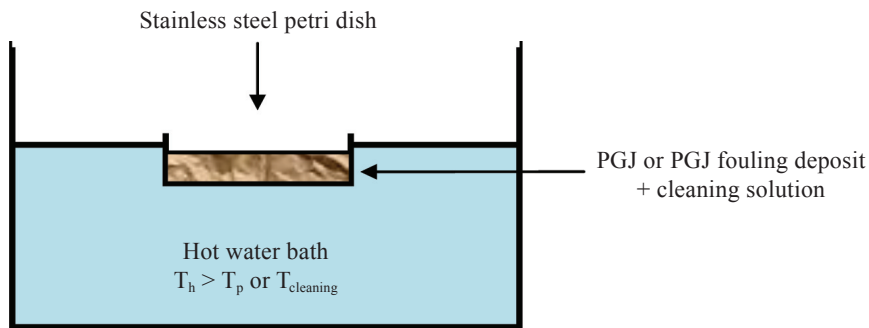


Fig. 1: Experimental set-up for obtaining fouling deposit and for cleaning

Analyses of the PGJ Samples

Proximate analyses were done to obtain PGJ and the ex-situ PGJ fouling deposit compositions. Water content was measured using the oven method, while the fat content was determined using the Soxhlet method and the protein content was examined using the Kjeldahl method (AOAC, 1990). The determination of ash was measured by drying the sample in a muffle furnace up to 550°C . Environmental scanning electron microscopy (ESEM - Philips XL30) was used to observe the microstructure of the fouling deposit surface.

Cleaning

Cleaning chemical or detergent was used to remove the deposit. The food industrial detergent, Maxiclean CP6 was donated by Averex Chemicals Sdn. Bhd. The detergent is an alkaline based-chemical solution. The main components in the detergent are NaOH and KOH. The detergent was diluted prior to use (1.6 v/v% of Maxiclean CP6 or 0.325 % OH⁻; 1.8 v/v% of Maxiclean CP6 or 0.369 % OH⁻; 2.0 v/v% of Maxiclean CP6 or 0.44 % OH⁻). The ex-situ cleaning method was done by using shakeable water bath at different temperatures (namely, 70, 80 and 90°C) and at 50rpm (equivalent to 1 litre min^{-1}). The diluted detergent was preheated to the required temperature, and it was later added into the fouled stainless steel petri dish. The petri dish was placed into the shakeable water bath that had been heated to the desired cleaning temperature. The liquid inside the petri dish was drained and refilled after every 5 minutes to observe the remaining of the fouling deposit. This particular step was repeated until the petri dish was clear from the fouling deposit. Photographs were taken and the cleaning time was also noted.

RESULTS AND DISCUSSION

Ex-situ PGJ Fouling Deposits

Table 1 shows the characteristics of the ex-situ PGJ fouling deposits from different methods, which were using hot plate, static water bath and shakeable water bath, respectively. The hot plate method is not a suitable method because the direct heating concept can cause overheating process and promote dehydration. Thus, any experiment carried out cannot be done for a period of more than 20 minutes. The hot plate method can be classified as a rapid fouling deposit preparation. Fig. 2 shows the ex-situ fouling deposits gained from the hot plate, static water bath and shakeable water bath method. The fouling deposit from the hot plate method appeared to be slightly burned in colour, which is not appropriate to be a physical model for the cleaning study. This could be due to the caramelization effect (non-enzymatic browning of sugar) as the preparation was done at high temperature and the moisture was decreasing with time. According to Ab. Aziz (2007) and Christian (2003), there is a weakness in the rapid preparation of fouling deposit; for instance, using an oven to dehydrate the fluid of study. One of the weakness is the structure of the fouling deposit is not fully developed as compared to the fouling deposit obtained from industrial environment. The fouling deposit from industrial environment is gradually formed due to the effect of the process condition (i.e. temperature, flow rate, pressure) on its compound (Müller-Steinhagen, 2000; Bott, 1995). Meanwhile, the concept of heat transfer between hot and cold fluid is the best as it can mimic the heat transfer in commercial heat exchanger. The application of water bath to set-up the simple fouling deposit preparation was done to revamp the weakness of the hot plate method. However, the fouling deposit obtained from the static water bath could be due to the sedimentation of the PGJ solid compound. The fouling deposit from this particular method had a weak attachment as it could be easily removed by rinsing with water alone. On the contrary, shakeable water bath is preferred due to the motion condition, which approximates the flowing system in commercial heat exchanger. However, the deposit was not evenly formed on the surface and the covered area was not similar after each preparation of the fouling deposit. This could be due to the unstable rotation effect which further creates vortex within the medium of study, and thus promoting rapid de-attachments of the fouling deposit. For Ab. Aziz (2007) and Christian (2003), their samples of the fouling deposits were evenly spread on the surface and the covered areas were similar for every preparation. It is crucial to highlight that this particular standard is important for a repetitive study. Thus, the tests in this work were not repeated. Despite the fact that the repeated tests were not performed, the findings from this work have provided a basis for future studies on PGJ fouling deposit, particularly in term of the experimental set-up to obtain a physical model of the PGJ fouling deposit, their characteristics and the cleaning requirements.

TABLE 1
Comparison of ex-situ PGJ fouling deposits characteristics obtained from different ex-situ methods

Characteristics of Different Ex-situ PGJ Fouling Deposits		
Hot plate	Static water bath	Shakable water bath
1. Direct heating process	1. Heat transfer between hot and cold fluids, simulation of simple heat exchanger condition	1. Heat transfer between hot and cold fluids, simulation of simple heat exchanger condition
2. Fast heating process and can get overheated easily	2. Less prompt to overheat	2. Less prompt to overheat
3. Non-flowing system	3. Non-flowing system	3. Flowing system
4. "Batch" processing	4. "Batch" processing	4. "Batch" processing

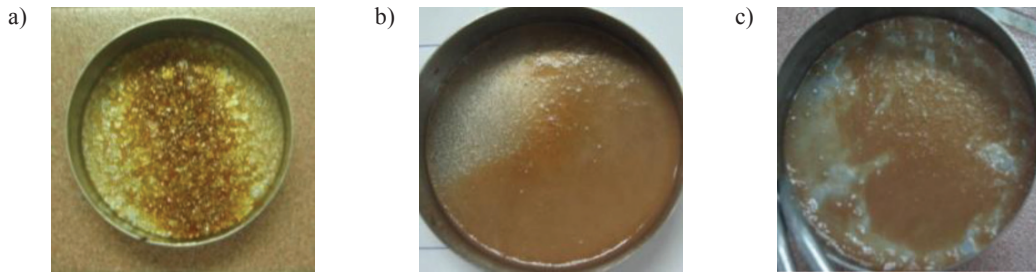


Fig. 2: Ex-situ PGJ fouling deposit obtained from: a) hot plate, b) static hot water bath, and c) shakeable hot water bath methods

PGJ and Its Fouling Deposit

Table 2 shows the components in PGJ and its fouling deposit. PGJ differs from dairy-based fouling deposits because their main component is protein, while PGJ consists of mainly carbohydrate. Thus, the formation of the PGJ fouling deposit is due to the deformation of the carbohydrate configuration at high temperature which forms carbonised deposits that are difficult to remove (Tamime, 2008). Alkaline-based detergent is required to remove protein-based fouling deposit in normal practice (Watkinson, 2008), while for carbohydrate-based deposit, water alone can be used as a cleaning agent, although it is not efficient. The existence of dispersed particles, which are also known as “seedstone” in PGJ, can also harden the PGJ fouling deposit, and hence, a suitable cleaning procedure is required. The dispersed particles in the PGJ are referred to as insoluble solids (fibres). These particles are the ruptured seeds of pink guava fruit that were produced after the filter press operation during the production of the pink guava puree. The size of the dispersed particles ranged from 168 to 200µm (Ho *et al.*, 2010). The surface microstructure of the ex-situ PGJ fouling deposit is shown in Fig. 3. The deposit consisted of small groups of 10-50µm aggregates. Each group comprises smaller aggregates in the sizes of 2-5µm. Table 2 shows that the main solid composition of the PGJ deposit is carbohydrate. Thus, it is presumed that the carbohydrate constitutes the aggregates. The formation of the aggregates is due to the heat-denaturation of the carbohydrate structure. The distribution of these aggregates can be further validated by performing elemental map analysis.

TABLE 2
Results from the proximate analysis of PGJ and its fouling deposit

Component (%)	Pink guava juice	Ex-situ deposit
Moisture Content	88.64	48.825
Ash	0.568	0.750
Protein	1.112	0.886
Fiber	0.972	1.684
Fat	0.112	0.094
Carbohydrate	8.602	47.761

Cleaning

The ex-situ cleaning method was utilized in this study. Fig. 4 shows the influences of temperature and detergent concentration on cleaning time. The result has shown that short cleaning time can be obtained when the cleaning condition is set at high temperature and at high chemical concentration.

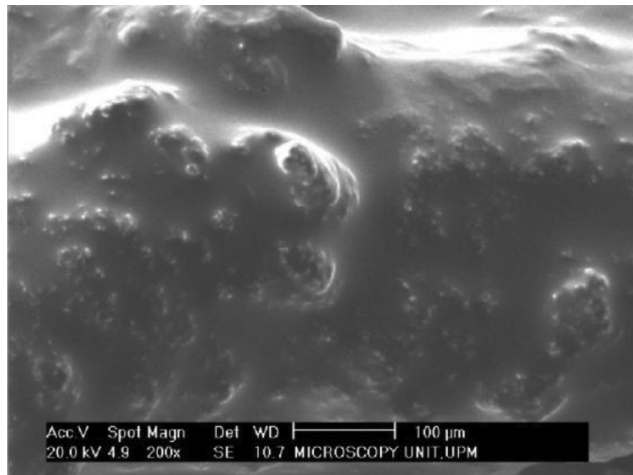


Fig. 3: SEM micrograph of the ex-situ PGJ fouling deposit

This finding is in agreement with the findings of Fryer and Bird (1994), Changani *et al.* (1997), Ab. Aziz (2007), and Christian (2003). Meanwhile, the shortest cleaning time (i.e. 40 minutes) was obtained for the cleaning at 90°C and 2.0 v/v% of Maxiclean CP6, in which alkaline detergent was used as it is one of the agents for dissolving organic compound. Tables 3 to 5 illustrate the changes on the fouling deposit that occurred during cleaning in different conditions. From the series of the pictures, the removal of the fouling deposit was started with the wetting process, which softened the deposit to further assist the next removal action. The effect of rotation was also contributed to the removal, as there were sequences of the removal of pieces of the deposit. It is presumed that for the in-situ cleaning, the cleaning time is shorter than that found in this study due to the effect of the existing high flow rate. According to Eggleston and Monge (2007), a study on cleaning time required for each food processing plant is important as it can affect the production performance which further contributes to economic losses.

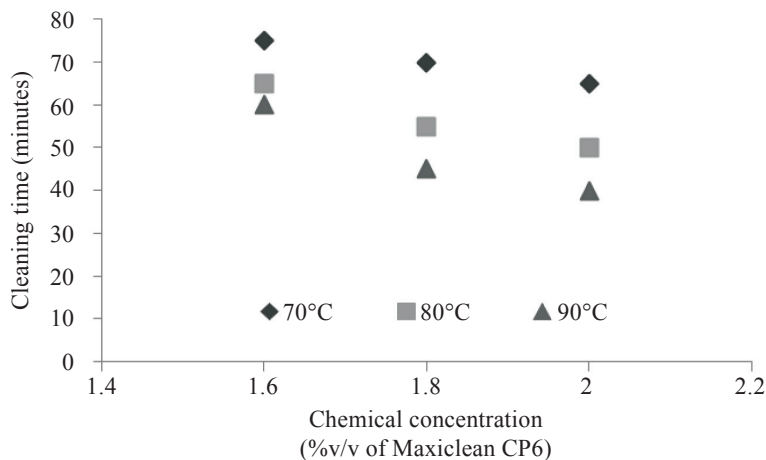


Fig. 4: Cleaning time profile for the removal of PGJ fouling deposit at different chemical concentrations and temperatures

TABLE 3
Cleaning progress during cleaning at 70°C

































Time (minute)	Concentration of the cleaning solution		
	1.6 v/v% Maxiclean CP6 (0.352% OH ⁻)	1.8 v/v% Maxiclean CP6 (0.396% OH ⁻)	2.0 v/v% Maxiclean CP6 (0.44% OH ⁻)
0			
10			Not significant
20			
30			
40			
45			
50			
55			
60			
65			
70			
75			

TABLE 4
Cleaning progress during cleaning at 80°C
















































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0			
10	Not significant		
20			
30			
35		Not significant	Not significant
40			
45			
50			
55			
60			
65			

TABLE 5
Cleaning progress during cleaning at 90°C

Time (minute)	Concentration of the cleaning solution		
	1.6 v/v% Maxiclean CP6 (0.352% OH ⁻)	1.8 v/v% Maxiclean CP6 (0.396% OH ⁻)	2.0 v/v% Maxiclean CP6 (0.44% OH ⁻)
0			
10			
20			
30			
35	Not significant		
40			
45			
50			
55			
60			

CONCLUSIONS

This work has shown several simple experimental set-ups to form PGJ fouling deposit, which can be used as a physical model for further studies on fouling and cleaning. In this study, the shakeable water bath method was found to be the best method to obtain the PGJ fouling deposit samples. This particular ex-situ method was observed to require less raw material and short processing duration (i.e. within 1 hour). However, some improvements on the method need to be done for future studies

as it is quite difficult to obtain similar covered area of fouling deposits for each preparation. It has been proven that the PGJ fouling deposit would form on the heat transfer surface and the deposit is carbohydrate-based deposit. Thus, the preliminary cleaning study was performed using the ex-situ cleaning method. Cleaning can be done using alkaline detergent to shorten the cleaning time. The best ex-situ cleaning process was obtained at the concentration of 2.0 v/v% Maxiclean CP6 (0.44% OH⁻) and at the temperature of 90°C. The effect of rotation may also promote the removal of the deposit, due to shear stress flow effect. Therefore, the findings of this work have provided essential basic knowledge of PGJ fouling deposit, which can assist future work on the reduction of PGJ fouling deposit formation and finding the optimum cleaning procedure. However, more work is still needed to characterize the PGJ fouling deposit in order to obtain its fouling factor and to formulate a better cleaning procedure.

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