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Continuous Flow Experimental Set-Up for Fouling Deposit Study

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***Abstract*—**The study of the fouling deposition of pink guava juice (PGJ) is relatively new research compared to milk fouling deposit. In this work, a new experimental set-up was developed to imitate the fouling formation in heat exchanger, namely a continuous flow experimental set-up heat exchanger. The new experimental set-up was operated under industrial pasteurization temperature of PGJ, which was at 93°C. While the flow rate and pasteurization period were based on the experimental capacity, which were 0.5 and 1 liter/min for the flow rate and the pasteurization period was set for 1 hour. Characterization of the fouling deposit was determined by using various methods. Microstructure of the deposits was carried out using ESEM. Proximate analyses were performed to determine the composition of moisture, fat, protein, fiber, ash and carbohydrate content. A study on the hardness and stickiness of the fouling deposit was done using a texture analyzer. The presence of seedstone in pink guava juice was also analyzed using a particle analyzer. The findings shown that seedstone from pink guava juice ranging from 168 to 200μm and carbohydrate was found to be a major composition (47.7% of fouling deposit consists of carbohydrate). Comparison between the hardness and stickiness of the deposits at two different flow rates showed that fouling deposits were harder and denser at higher flow rate. Findings from this work provide basis knowledge for further study on fouling and cleaning of PGJ.

***Keywords*—**Pink guava juice, fouling deposit, heat exchanger.

I. Introduction

NOWADAYS, most of food products such as milk, fresh juices and ice cream, are safe to consume although after several days of storage. Without pasteurization process we will not be able to enjoy such a convenient food product like these. Pasteurization, a process taken place at high temperature (>50°C) enables harmful bacteria to be killed and thus increase the shelf life and safety of the product. The temperature required to meet this is depending on the type of raw food materials that involved in the process. It is an essential step required in most food industries [1]. Heat exchanger is the common unit operation use for pasteurization.

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Most process of beverages and dairy products in food industries are operated for 24 hours a day and for almost every day. The heat exchanging mechanisms are taken place between the product and the heating medium. The primary objective of heating process is to kill the harmful bacteria. Even though the bacteria are being killed during this process, chemical reaction and the properties of the product changes as well. Very often, these changes produce scaling or precipitation on the inner surface of processing equipment which is known as fouling deposit.

Fouling deposit, a term use to describe the deposition of unwanted material formed on solid surfaces of processing equipment. It formation can reduce the efficiency of the heat exchanger and consequently affect the pasteurization process [2]. Fouling layer formed on the wall acts as a barrier to heat transfer. Besides that, it can reduce the pipe flow area, thereby resulting in pressure drop and inefficiency of heat transfer. As a consequence, this may affect the industry's productivity and economy.

In this study, pink guava juice (PGJ) was used as the model fluid of the research. Pink guava is tropical fruit and Malaysia is among the top in the world that producing pink guava puree for PGJ and as ingredient for other food products. Furthermore, currently there is no publication on PGJ fouling deposit. A simple experimental set-up for obtaining pink guava juice fouling deposit was constructed and its enable the study in continuous flow condition. The obtained deposit can be a physical model for fouling deposits from industrial scale heat exchanger. Fouling characteristics study was performed on the fouling deposits obtained from the constructed rig. The influences of different operating conditions on fouling formation were investigated while characterization of the fouling layer such as texture, composition and microstructure were performed to analyze the fouling deposit. The finding from this study can provide basis knowledge on PGJ fouling deposit, hence the formation rate of it can be understand and the formulation for cleaning can be predicted..

II. Materials and Methods

A. Pink Guava Juice

Pink guava puree was supplied by Golden Hope Food & Beverages Sdn. Bhd., Sitiawan, Malaysia. It was diluted with distilled water. Distilled water was added to the puree at the ratio of 1:3:7 (sugar: pink guava: water), to produce pink guava juice. The percentage of Brix used was in the range of

7.0-11.0 and the Brix set for this experimental study was 11° Brix and the Brix percentage of the pink guava juice was determined using the refractometer.

B. Concentration, Temperature and Time for Pasteurization

Normal practice in food industry, pink guava juice is pasteurized at temperature range of 93°C-97°C and with holding time for 30s. This information was obtained from Golden Hope Food & Beverages Sdn. Bhd and it provides a benchmark for the lab scale study.

C. Proximate Analysis

This analysis was carried out to determine the compositions of moisture, fat, ash, fiber, protein and carbohydrate contents. Moisture content was determined by using the oven method, fat content was determined by using the Soxhlet method while protein content was examined using the Kjeldahl method. Determination of ash was measured by drying the sample in a muffle furnace up to 550°C. The fiber content analysis was carried out according to the procedures described by AOAC, 1995 [3].

D. Microstructure Analysis

Critical point drying was chosen as the choice of fixation technique for pink guava juice fouling deposit. Standard critical point drying (CPD) protocol was used for preparing the samples. After fixation with 4% glutaraldehyde in 0.1 M cacodylate and 2% buffered osmium tetroxide, the samples were dehydrated through a graded series of acetone (30%, 50%, 75% and 95% - once for 10min at each step), and then immersed in 100% acetone three times for 15 min each. The samples were then transferred to Bal-Tec CPD 030 critical point dryer (BAL-TEC AG, Switzerland) using liquefied carbon dioxide as transitional fluid before coated with gold by a sputter coater (Bal-Tec SCD 005, BAL-TEC AG, Switzerland). Then the dried sample was transferred to ESEM (XL30 Environmental Scanning Electron Microscopy, Philips, Holland) chamber, to obtain the ESEM micrograph for microstructure analysis.

TABLE I
PARAMETERS AND SPECIFICATION OF TEXTURE ANALYZER FOR HARDNESS AND STICKINESS ANALYSIS OF PINK GUAVA JUICE FOULING DEPOSIT.

Parameter	Value	Description
Probe	P20	The size of the probe used: cylindrical; 20mm
Test Mode	Compression	Initial probe direction and force polarity
Pre-test speed (mm/s)	1	Probe speed while searching for trigger point
Test-speed (mm/s)	2	Speed of approach to target distance after triggering
Post-test speed (mm/s)	2	Speed at which the probe returns to start point
Target mode	Strain	Target parameter
Strain (%)	30	Specify target strain base on trigger height
Trigger type	Auto	How the initiation of data is defined
Trigger force (g)	5	Amount of force for TA to initiate data capture
Trigger distance (mm)	2	Pre-travel distance before initiating data capture

E. Texture Analysis

For texture analysis, the hardness and stickiness of pink guava juice fouling deposit were examined by using the texture analyzer (TA-XT Plus, Stable Micro Systems, UK). The parameters and specification of texture analyzer for performing hardness and stickiness analyses were stated in Table I.

F. Particle Analysis

The presence of seed-stone in pink guava juice was analyzed for the size distribution. Pink guava puree was filtered with cheesecloth to separate the seedstone from other fibrous compositions. The filtered residue was then laid flat and distributed evenly on a thin layer of aluminium foil before brought into the oven to be dried at 40°C for 24 hours. The dried residue was scrapped with spatula and kept in petri dish. The sample was stored in the desiccators prior to particle analysis. In analyzing the particle size of the seedstone, particle analyzer (Scirocco 2000, Malvern, UK) was used

G. Continuous Flow Experimental Set-Up

A rig constructed of 304 stainless steel pipe with the outer diameter of 22mm and was joined by Type A/ non manipulative, British standard compression fittings. These fittings were utilized in developing the rig that resembles a concentric tube exchanger.

The design of this heat exchanger (Figure 1) was based on the concept that the heat from the heating medium will transfer heat to the stainless steel pipe and eventually to the pink guava juice in the pipe in order to pasteurize the pink guava juice to the desired temperature. The pink guava juice was prepared and stored in a tank (20L) before being pumped to the tube that immersed in glycerol. The heat exchanger contains 3 passes with length of 0.17m for each pass to provide a sufficient holding time for heating. One K-type thermocouple was placed near the outlet of the heat exchanger and another was placed in the heating medium to monitor the temperature of the pink guava juice and heating medium, respectively. Pink guava juice is then recycled back to the tank.

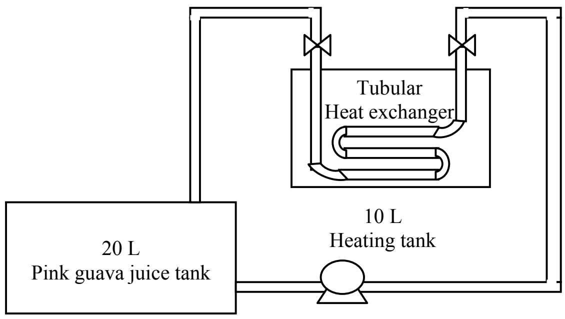

Fig. 1 Continuous Flow Experimental Set-Up

III. RESULTS AND DISCUSSIONS

Fouling deposit from continuous flow experimental set-up (the simple heat exchanger) seems different physically compared to fouling deposit from shakable water bath system

[4]. Figure 2 shows the heat exchanger tubes with the fouling deposit, which were obtained at different conditions. In the simple heat exchanger, the controlled parameter was the flow rate. The flow rates used were 0.5 liter/min and 1 liter/min, which were the same flow rates used in the shakable water bath system (the flow rate is equivalent to the shaker speed) [5].

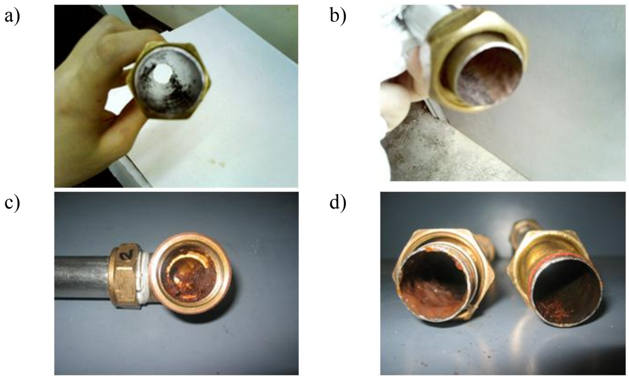

Fig. 2 PGJ fouling deposit after heating process at flow rate of: (a)-(b) 0.5 liter/min and (c)-(d) 1.0 liter/min.

From Figure 2, the amount of fouling deposit formed was more at flow rate of 1 liter/min compared to fouling deposit formed at 0.5 liter/min. The area of deposition was mainly at the lower tube, which was the result of sedimentation and non-fill tube. The amount of deposition through the tube was not uniform. The top deposit texture was soft and soggy, resembled semi-solid. While the lower deposit texture was hard and quite dry. Generally different textures of the deposit are influent by the temperature and the duration of heating, which then promotes ageing [6]. The fouling deposit from this experimental set-up is more appropriate to represent the fouling deposit from industry than the deposit from shakable water bath system. This is due to the experimental condition that includes the effect of flow rate and continuous flow.

TABLE II
COMPOSITIONS OF PGJ AND ITS FOULING DEPOSIT.

Component (%)	Pink Guava Juice	Fouling Deposit
Moisture Content	89.085 ± 1.2465	50.298 ± 1.5709
Ash	0.544 ± 0.0216	0.832 ± 0.2034
Protein	0.927 ± 0.1002	1.215 ± 0.1996
Fiber	0.733 ± 0.0297	1.298 ± 0.1725
Fat	0.204 ± 0.0083	0.092 ± 0.0029
Carbohydrate	8.507	46.265

Table II shows the results of proximate analysis of PGJ and PGJ fouling deposit. From the table, the solid content of PGJ is about 10.92%. The solid content consists primarily of carbohydrate, which is 77.94% of solid content. While the major composition of PGJ fouling deposit is carbohydrate (46.265%). Thus PGJ fouling deposit is carbohydrate-based deposit. Grassoff (1997) [7] classified fouling deposit base on its main composition and has concluded that carbohydrate-based deposit is easy to remove but if cameralisation occurred, the removal could be harder. Other researches study on carbohydrate-based fouling deposit is using tomato paste [8], [9].

Table III and IV show the hardness and stickiness of pink guava juice fouling deposit that obtained from the continuous flow experimental set-up. The hardness of the fouling deposit from heating process at 1 liter/min is 60% higher than the fouling deposit from the heating process at 0.5 liter/min. Thus, the velocity of the flow has a major effect on the hardness of the fouling deposit. A faster flow rate resulted in a harder fouling layer. According to [2], a biofilm/ fouling layer can be more compact and dense under high velocities. At low velocity, the structure can be more open and fluffy, result in fouling deposit structure that was not dense and hard. The open structure enables more air to be trapped within the structures. Same trend was also observed for stickiness, in which fouling deposit formed at 1 liter/min was stickier than the deposit formed at flow rate of 0.5 liter/ min (Table IV).

TABLE III
HARDNESS OF PGJ FOULING DEPOSIT

Test	Hardness, Force (g)	
	Fouling Deposit, 0.5 liter/min	Fouling Deposit, 1 liter/min
1	23.9021	70.8240
2	30.3161	71.3198
3	28.8171	68.3017
4	27.6751	69.8121
5	29.5616	70.2205
6	26.7268	69.1772
Mean	27.8331	69.9426
Standard Deviation	2.3162	1.0997

TABLE IV
STICKINESS OF PGJ FOULING DEPOSIT

Test	Stickiness, Force (g)	
	Fouling Deposit, 0.5 liter/min	Fouling Deposit, 1 liter/min
1	15.2568	32.3685
2	20.8214	33.5813
3	20.108	33.9749
4	20.4647	34.4659
5	18.0391	34.9702
6	19.0736	35.5021
Mean	18.9606	34.1438
Standard Deviation	2.0795	1.1071

Microstructure of PGJ and PGJ fouling deposit is not similar. Figures 3 show the ESEM micrograph for pink guava juice. The micrograph shows that pink guava juice contains very fine sacs of carbohydrates and networks of fibers. Seed-stones were not observed in the micrograph. Most probably they were covered by the sacs and network of fibers. There was a distinct characteristic between the juice and the fouling deposit. In the fouling deposit as shown in Figure 4, the sacs were no longer be seen. A dough like structure was observed. Besides, the fouling deposit looked dense, hard and porous to some extent. The observation may lead to the conclusion that heat treatment of pink guava juice has led to the denaturation of some of the organic matters, which is mostly carbohydrates as shown by the proximate analysis results in Table II. The sacs of carbohydrate burst due to retrodegradation and form aggregates which settle with the seed-stones that were entrapped in the network. The microstructure of fouling deposit from this experimental set-up was developed gradually due to the continuous flow and thermal effect, which differ for those deposits from shakable water bath system [5]. Thus the microstructure is comparable to other fouling deposit obtained from similar flow system, such as milk fouling deposit [8]. Thus the fouling deposit from this experimental set-up can represent the industrial-based fouling deposit.

a) b)

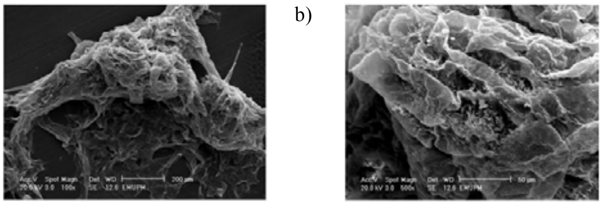

Fig. 3 ESEM micrograph of pink guava juice at: a) 100x and b) 500x magnification.

a) b)

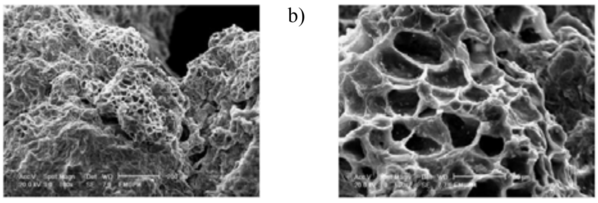

Fig. 4 ESEM micrograph of PGJ fouling deposit at: a) 100x and b) 500x magnification.

The uniqueness of PGJ fouling deposit is on the presence of seed-stone, which is insoluble in water. The sedimentation of the seed-stone might influence the hardness of the fouling deposit. This characteristic is not present in well defined milk fouling deposit. Figure 5 shows the micrograph for the seed-stone. The size of the seed-stone is ranging from 168 to 200μm.

a) b)

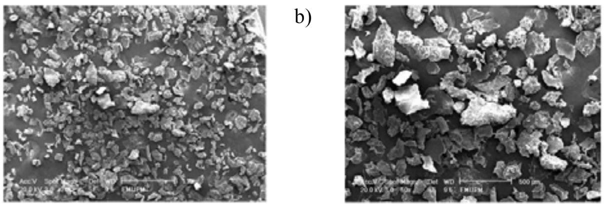

Fig. 5 ESEM micrograph of the particles, ‘seed-stone’ at: a) 25x and b) 50x magnification

When discrete and fine particles like seed-stones present in a fluid, they cannot take part in any deformation that the fluid may undergo. The result is an increasing resistance to shear, which is greater than a pure fluid [2]. Therefore the suspended solid will resulted in an increased resistance to shear and hence suspended on the wall of the heat exchanger in which fouling deposit was eventually formed.

IV. CONCLUSIONS

This study used PGJ as a model fluid to obtain PGJ fouling deposit, which has not been studied by previous researcher. PGJ fouling deposit is classified as carbohydrate-based deposit, due to its main composition. PGJ fouling deposit is unique compared to milk fouling deposit. Due to it is not only containing carbohydrates but also some particles, which are known as seed-stone. These fine particles (168 to 200μm) were embedded in the fouling deposit and were observed only on the fouling deposit, as heating process denatured some of the components that hiding the seed-stone. The presents of the seed-stone might influence the hardness of the fouling deposit. A continuous experimental set-up was developed to ensure the deposit is similar to industrial-based deposit. Thus findings from this work can benefit PGJ industry and the country economy. The texture of the fouling deposit at different flow rates revealed that fouling deposit formed during a faster flow rate process has a harder and stickier texture compared to fouling deposit formed during a slower flow rate due to the fouling layer may be more compact and dense under high velocities. While in the presence of low velocity, the structure may be more open and fluffy. In conclusion, this work has discovered some important characteristics of PGJ fouling deposit and the continuous experimental set-up has worked successfully in producing the PGJ fouling deposit that has typical microstructure to the industrial-based fouling deposit. Findings from this work provide basis knowledge for future study on properties of PGJ fouling deposit and on cleaning aspects.

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