UNIVERSITI PUTRA MALAYSIA

FOULING DEPOSIT ANALYSIS OF HEAT INDUCED PINK GUAVA PUREE

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MASTER OF SCIENCE

UNIVERSITI PUTRA MALAYSIA

2012

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By

CHAN KEN WEI

Thesis Submitted to School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirements for the Degree of Master of Science

October 2012

Specially thanks to….

My parents….

My siblings….

My friends….

For their support and encouragements….

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirement for the degree of Master of Science

FOULING DEPOSIT ANALYSIS OF HEAT I NDUCED PINK GUAVA PUREE

By

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October 2012

Chairman : Norashikin Abdul Aziz, PhD

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Fouling deposit phenomena are common in industrial heat exchangers. It can accumulate during heat treatment and cooling process. The objectives of this work were to investigate the characteristics of pink guava puree (PGP) fouling deposit and to predict the effect of fouling deposit on tubular heat exchanger. The similarities of fresh and commercial PGP were investigated prior to fouling study. The properties (pH, total soluble solid, thermal conductivity, specific heat capacity, composition and rheology) of both purees were compared to determine the suitability of the commercial PGP as PGP fouling fluid model. Most properties of both purees behave similarly except for pH, total soluble solid (TSS) and rheology properties. There is a significant different for the pH and TSS for both puree ($P<0.01$). However, this may not affect the fouling rate significantly as the puree is carbohydrate based deposit. The rheology properties of both

PGP showed significant difference only at low temperature, which will not affect the fouling study for heat induced deposit. The findings confirmed the suitability of commercial PGP for PGP fouling studies. In this work, pasteurization process is applied to obtain heat induced PGP fouling deposit. Heat transfer analysis of the heat exchanger during the pasteurization process was carried out. The PGP has accumulated to form fouling deposit and reduced heat transfer efficiency by 10.76% or 8.4661 $W/m^2°C$ during 360 minutes pasteurization process and the fouling deposit thickness in tube 4 was 2.4 mm in heating tube 4. The fouling deposit is classified as a carbohydrate-based deposit because it contains 28.5% of carbohydrate content. The fouling deposit has irregular structure that causes further fouling adhesion. The hardness increased by 59 % while its stickiness increased by 49% after 360 minutes operating time. The prediction on the effect of the fouling deposit on the heat exchanger was carried out by using empirical model and COMSOL Multiphysics software. The empirical model which has a coefficient of determination of 0.9562 prove that is can be used to predict the heat transfer coefficient of heat transfer during pasteurization for 24 hours. COMSOL Multiphysics software was used to simulate the effect of fouling deposit thickness on the temperature of the PGP. The prediction result shows that the fouling deposit is increasing with time. The economical lost due to PGP fouling was calculated in terms of energy and the chemical solution used to performed cleaning-in-place (CIP). The PGP fouling was found to cause an energy lost of RM1599.41 and RM52378.69 yearly in chemical solution respectively.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

ANALISA MENGENAI HABA TERARUH MENDAKAN KOTORAN PURI BAGI JAMBU BATU BERWARNA MERAH JAMBU

Oleh

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Kejadian mendakan kotoran biasanya dijumpai pada permukaan mesin penukar haba di industri. Ia boleh berkumpul semasa rawatan haba dan proses penyejukan. Ojektif bagi kajian ini adalah untuk mengkaji ciri-ciri mendakan kotoran puri bagi jambu batu berwarna merah jambu (PGP) dan meramalkan kesan mendakan kotoran pada mesin penukar haba berbentuk tiub. Kesamaan bagi puri segar dan komersial disiasat sebelum kajian mendakan kotoran.. Ciri-ciri (pH, jumlah pepejal larut, kekonduksian terma, muatan haba tentu, komposisi dan rheologi) bagi kedua-dua puri dibandingkan untuk menentukan kesesuaian puri komersial sebagai model bendalir PGP bagi mendakan kotoran. Keputusan dari kerja pembandingan dianalisis dengan menggunakan analysis of variance (ANOVA). kebanyakan ciri-ciri bagi kedua-dua puri adalah hampir serupa kecuali pH, *total soluble solid* (TSS) dan rheologi. Terdapat perbezaan bagi pH dan TSS bagi kedua-dua puri (P<0.01). Walaubagaimanapun, ini tidak akan menjejaskan kadar pembentukan mendakan kotoran kerana puri ialah mendakan jenis karbohidrat. Bagi ciri-ciri rheology, terdapat perbexaan semasa suhu tinggi. Ciri-ciri rheologi bagi kedua-dua hanya menujukkan perbezaan pada suhu rendah. Ini tidak menjejaskan kajian mendakan kotoran bagi mendakan jenis haba. Keputusan dari kajian menunjukkan komersial puri sesuai untuk menjadi model bendalir dalam kajian mendakan kotoran bagi PGP. Dalam kajian ini, process pempasteuran dijalankan untuk mendapat mendakan kotoran PGP. Analisis pada pemindahan haba dalam mesin penukar haba semasa proses pasteurization dijalankan. PGP membentuk mendakan kotoran dan mengurangkan kecekapan pemindahan haba sebanyak 10.76% atau 8.4661 W/ m^2°C semasa proses pempasteuran selama 360 minit. Ketebalan mendakan kotoran juga didapati adalah 2.4 mm dalam tiub pemanasan keempat. Mendakan kotoran dikasifikasikan sebagai mendakan berdasarkan karbohidrat kerana ia mengandungi kandungan karbohidrat sebanyak 28.5%. Mendakan kotoran mempunyai bentuk yang tidak teratur yang menyebabkan rekatan mendakan kotoran. Kekerasan bagi puri meningkat sebanyak 32.149 g dan kelekitan meningkat sebanyak 10.54 g selapas proses pempasteuran sebanyak 360 minit. Ramalan pada kesan mendakan kotoran pada mesin penukar haba dijalankan dengan menggunakan model empirical dan perisian COMSOL Multiphysic. Model empirical yang mempunyai pekali penentu sebanyak 0.9562 membuktikan ia boleh digunakan untuk meramal pekali pemindah haba dalam mesin penukar haba semasa pasteurization dalam masa 24 jam. Perisian COMSOL Multiphysic digunakan untuk mensimulasikan kesan ketebalan mendakan kotoran pada suhu PGP. Hasil dari ramalan menunjukkan mendakan kotoran menjaid lebih serius dengan peningkatan masa pempasteuran. Kerugian ekonomi yang disebabkan oleh mendakan

kotoran dikira dari segi tenaga dan larutan kimia yang digunakan untuk melakukan CIP. Mendakan kotoran didapati menyebabkan kerugian sebanyak RM1599.41 dari segi tenaga dan RM52378.69 dari segi larutan kimia setiap tahun.

ACKNOWLEDGEMENTS

I would like to thank my supervisor, Dr. Norashikin Abdul Aziz, for her guidance, helpful advice, encouragement, patience, kind attention and willingness to assist me throughout the research. I have learn a lot of useful knowledge from her throughout this research. Thank you also my supervisory comitee members, Assoc. Prof. Dr. Mohd. Nordin Ibrahim and Dr. Farah Saleena Taip, for their guidance.

I also grateful to Encik Kamarulzaman Dahlin, Encik Mohd. Zahiruddin Daud, Encik Rahman Morat, Encik Shahrulrizal Zakaria and Puan Siti Hajar Zakaria for providing technical support and guidance throughout my laboratory works. I would like to thank you other individuals whom I have not mentoned but helped me in various possible ways.

Last but not least, I would like to express my heartfelt gratitude and love to my parents, family and friends for their love, encouragement and support.

I certify that a Thesis Examination Committee has met on August 2012 to conduct the final examination of Chan Ken Wei on his thesis entitled "**Fouling Deposit Analysis of Heat Induced Pink Guava Puree**" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U(A) 106] 15 March 1998. The Committee recommends that the student be awarded the degree of Master of Science.
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DECLARATION

I declare that the thesis is my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously, and is not concurrently, submitted for any other degree at Universiti Putra Malaysia or at other institution.

CHAN KEN WEI

Date: 5 October 2012

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LIST OF ABBREVIATIONS

PGP	Pink Guava Puree
TSS	Total Soluble Solid

NOMENCLATURE

W	Weight of sample
W_d	Dry weight of sample
W_a	Weight of ash
W_c	Weight of crucible
I_s	Volume of NaOH to titrate HCL
I_b	Volume of NaOH to titrate blank
N	Normality of NaOH
M	Weight of the fat
S	Total weight of crucible, filter paper and dried residue
K	Weight of filter paper without ash
A	Weight of crucible with ash
η_{app}	Apparent viscosity
η_0	empirical constant
k	Consistency coefficient
y	shear rate
n	Flow behaviour index
τ	Shear stress
τ_0	Yield stress
$\tau^{0.5}$	Square root of shear stress
K_0	Constant for Arrhenius equation

E_a	Activation energy of flow
R	Gas constant
k_{OM}	Square root of yield stress
k_M	Consistency index
Q	Total heat energy transferred
U	Overall heat transfer coefficient
ΔT	Logarithmic mean temperature difference
R_f	Fouling resistance
U_f	Overall heat transfer coefficient after fouling occurred
U_0	Overall heat transfer coefficient for a clean heat exchanger
m_f	mass of fouling deposit
v_f	volume of fouling deposit
ρ_f	density of fouling deposit
r_1	radius of tube with fouling deposit
r_2	radius of tube without fouling
h_f	length of fouling deposit
T	Absolute temperature in Kelvin.
$T_{OIL,in}$,	Inlet temperature of heating oil
$T_{OIL,out}$,	Outlet temperature of heating oil

$T_{PGP,in}$	Inlet temperature of PGP
$T_{PGP,out}$	Outlet temperature of PGP
m	Mass flow rate
C_p	Specific heat capacity
y_i	ith observation of the heat transfer coefficient
x_i	ith pasteurization time,
a, b	Correlation coefficient for empirical model
k	Thermal conductivity
ρ	Density
u	Velocity field
F	Volume force (N/m^3)

CHAPTER 1

INTRODUCTION

Thermal processing is a major operation in food processing because it is the cheapest and most efficient method to ensure pathogen free foods (Hui et al., 2007). Foods usually undergo heat treatment to maintain food quality and extend the shelf-life by destroying harmful bacteria which are often present in non-processed food (Eisenbrand, 2007). However, fouling deposit problems may occur in heat treatment equipment during processing and result in extra expenses in dealing with this issue. The presence of the fouling deposit problem results in an increase in the production, capital and maintenance costs.

In Pink guava production, usually it will be processed into pink guava puree (PGP) and needs to undergo heat treatment such as sterilization and pasteurization to maintain its quality. Pasteurization is a heating process which increases the product shelf life by reducing most of the harmful microorganisms and pathogens that cause disease. PGP processing is also not excluded from the fouling deposit problems. Therefore, it is necessary to study the fouling behavior of PGP during food processing.

1.1. Food Fouling Deposit

Fouling deposit is the formation of unwanted material on the surface of a heat exchanger during heat treatment (Bott, 1995). The dairy industry started to face fouling problems when plate heat exchangers were introduced for pasteurizing and sterilizing milk from 1930 onwards (Visser and Jeurnink, 1997). Even up to today, fouling deposit is an unsolved problem in the food industry. The fouling deposit itself can be a solid material caused by coagulated protein from milk, caramelized sugars from fruit juice, scorched pulp from tomato paste or solutes that have reached their limit of solubility as the material is heavily concentrated such as calcium in milk or hesperidin in orange juice (Berk, 2009).

Fouling deposit in the food industry is more critical than in other industries such as petroleum and waste water treatment. This is because food is heat sensitive, hence fouling deposit will develop rapidly. Fouling deposit formation is a complex phenomenon which involves unsteady states, momentum, mass and heat transfer problem with chemical, solubility, corrosion and biological processes occuring at the same time (Awad, 2011). Fouling deposit becomes an issue because the deposition of fouling on the heat exchanger will reduce the heat transfer efficiency due to the low thermal conductivity of the fouling material (Berk, 2009). In addition, the increase in thickness of the fouling deposit thickness will restrict the fluid flow and increase the pressure drop in the heat exchanger. During heat processing, fouling will cause the food product to lose its quality because of the many heat sensitive components in food that will be deposited on the heat transfer surface to form the fouling layer (Singh and Heldman, 2009). The adverse effect of the fouling deposit on the heat exchanger surface leads to the growth of bacteria and microorganisms which results in hygiene problems. Frequent cleaning of the food processing equipment using a cleaning in place (CIP) technique has been used to remove the fouling deposit formed on the surface of the equipment (Changani et al., 1997). However, the best formulation and regime of CIP for a specific fouling deposit material needs to be identified in each case to ensure optimum food processing. Currently many CIP regimes are designed for dairy based fouling deposit, which is a well-known and well-defined deposit. Thus, it is important to investigate the properties of other fouling deposit material properties to formulate the best CIP regime for a specific heat process.

1.1.1. Impact of Fouling on the Economy

Fouling causes a negative impact in the economy of the industrial world. This is shown in Table 1.1. In 1992 alone, fouling caused US$45 million worth of lost revenue in the industrialized countries and the cost of fouling keeps on increasing every year (Dynamic Descaler, 1992). The occurrence of a fouling problem causes an increase in the cost and expenses of operating a food processing plant. In order to mitigate the potential fouling areas, higher capital cost is needed. Capital expenditure is needed to make the processing plant oversized by providing excess surface areas, extra space, and includes transportation and installation costs (Awad, 2011). In addition, extra cost is also necessary for additional pipe work and larger pumps to perform cleaning when severe fouling occurs in the heat exchanger (Bott, 1995).

Table 1.1. Total of fouling costs per annum in 1992, calculation based on percentage of Gross National Product (GNP) (Dynamic Descaler, 1992)

Country	Fouling Costs as % of GNP	1992 GNP (US$billion)	Fouling Costs (US$million)
UK	0.25	1000	2500
US	0.25	5670	14,175
New Zealand	0.15	43	64.5
Australia	0.15	309	463
Germany	0.25	1950	4875
Japan	0.25	4000	10,000
Total industrialised world	0.2	22,510	45,020

Fouling can also cause degradation of the food product quality. This is because the high temperature of the heat transfer surface may cause the deposition material to burn and impart a 'burnt' taste and unsightly black specks in the final product (Berk, 2009). The operating cost of the food processing plant will also increase when the fouling problem occurs as unwanted material deposit on the heat exchanger surfaces, and consequently the efficiency of the heat exchanger is reduced and there is a loss of pressure. Thus, additional heat and pumping energy is required to maintain the temperature and flow rate of the process. The presence of fouling deposit also increases the maintenance cost of the plant because the heat exchanger needs to be constantly cleaned to maintain machine efficiency and to ensure the processing is running under hygienic conditions. The cleaning process requires a large quantity of chemicals and high labour cost (Bott, 1995). Moreover, fouling problems lead to large production losses due to the planned and unplanned shut down of the plant for cleaning (Steinhagen, 2000). The cleaning process, which involves dismantling and reassembly of the equipment will cause damage to the heating equipment that could shorten the useful life of the heating equipment (Awad, 2011). Therefore, a clear understanding of the fouling formation process is necessary to solve the fouling problem.

To date, much research has been carried out to study the fouling problem in processes for milk and dairy products. This has resulted in a clear understanding of the dairy based fouling deposit. However, a there exists a lack of knowledge of the fouling mechanism for other food products exists due to the complexity of each food production processes and a lack of research studies. Therefore, much more research needs to be carried out on food products other than milk and dairy products. A detailed description of fouling deposits is discussed in Chapter 2.

1.2. Problem Statement

The major producer country of guava in the world is India (Zainal et al., 2000). In South-East-Asia, Malaysia is the largest pink guava producer as nine million kilograms of pink guava are harvested annually and this represents 15% of the world pink guava puree. Common practice for pink guava fruits is processed into puree due to its short shelf life. Then, the puree is supplied to other industry like beverage and baby food industries. Main business of Sime darby Beverages Sdn. Bhd. is manufacturing PGP, which the fruit are mainly from their plantation. To lengthen the shelf life of the puree, sterilization process is applied. During the heat and chill processing of pink guava puree, a fouling deposit is formed on the surface of the heat exchanger surface. Thus, cleaning has to be performed regularly to remove the fouling deposit. However, most of the cleaning procedure is based on dairy based fouling. There is a lack of procedure on a cleaning program that is specifically designed for the fouling deposit of PGP. Without a tailored cleaning procedure, this may cause ineffective cleaning of the heat exchanger and economic loss as an improper technique and/or chemical may be used. Currently, there is no previous research had been carried out to investigate the cleaning of PGP fouling deposit. Therefore, it is necessary to carry out such an investigation into this problem. The findings from this study is useful to other fruit puree and juices industries which process puree and juices that have similar properties as PGP.

As the PGP is not well defined fouling deposit, it is essential to understand the PGP fouling behavior. However, a preliminary study is needed to check the best fouling fluid model to substitute the fresh PGP, which is not practical to be used in this work due to its delicate condition and logistic limitation. In this work, commercial PGP is used as model fouling fluid. The pasteurization process is applied instead of applying sterilization due to difficulty in applying high temperature short time processing condition as in the sterilization process. This is because sterilization condition carried out by Sime Darby requires a more advance and large scale heat exchanger. Besides, sterilization also needed to be carried out in a controlled processing area with specific requirement to ensure the hygiene and safety of the process. This becomes a limitation for the study to perform sterilization in the faculty laboratory. Thus, pasteurization is chosen to perform the fouling study instead of sterilization. Even though pasteurization applied, the pasteurization condition can be use to represent the sterilization condition because the pasteurization temperature which is 90°C is similar with the sterilization temperature performed by the industry which is 90°C to 95°C. Another limitation for this work was the heating time of the pasteurization process. In this work, PGP is heated for 90 s instead of 40 s as in the sterilization process. This is because 90 s is the time required by the laboratory scale heat exchanger to heat the PGP to 90°C.

1.3. Significance of the Study

Every year, a large amount of PGP is produced and simultaneously the fouling problem occurs as well. This causes a great economic loss to a processing company. Thus, it is necessary to investigate the PGP fouling formation mechanisms and find suitable ways to reduce and remove the fouling deposit. This study will provide knowledge concerning changes in the properties of PGP during the heating process, which then results in the formation of a fouling deposit. Thus, the critical process parameters which form the fouling deposit will be identified. The fouling formation rate can be reduced through these findings when suitable processing parameters are implemented during the heating process. The findings in this study can also provide fundamental knowledge for the pink guava puree industries in terms of improving their process parameters.

As a result of this study, knowledge of the fouling rate can be obtained. Thus, a suitable cleaning procedure that is specifically designed for PGP can be devised. A suitable chemical that can effectively clean the fouling deposit can also be chosen through the findings of this study. Therefore the economic loss can be reduced as ways to deal with the fouling deposit can be determined.

1.4. Objectives

The general objective of this work is to investigate the fouling behavior of the PGP. The specific objectives are:

i. To investigate the similarities between the properties of fresh and commercial PGP, as a fluid model for a PGP fouling study.
ii. To investigate the characteristics of the fouling deposit obtained from similar industrial conditions as the PGP pasteurization process.
iii. To predict the effect of fouling deposit on the heat exchanger to evaluate the changes in heat transfer efficiency and economical lost as fouling occurs by using empirical model, simulation software and engineering calculation.

1.5. Thesis Outline

In this chapter, a brief introduction to the problem of fouling in the food industry and the significance of the work are discussed. Chapter 2 begins by introducing the properties of PGP, the pasteurization process, types of heat exchangers, hygiene and cleaning of a heat exchanger. Then, the heat transfer mechanism during heat treatment is discussed. A review of the fouling problem in the food industry, factors that affect fouling and previous work on PGP fouling are presented.

Chapter 3 reports the raw materials, equipment and experimental procedures used in this study. The experiments were performed in three stages. In the first stage, a comparison work between fresh and commercial PGP is carried out. This is followed by an investigation into the fouling behavior of PGP. Finally, a prediction of the effect of the fouling deposit on the heat exchanger is undertaken. In this chapter, all experimental designs and method of analysis are stated.

Chapter 4 presents a discussion of the results obtained from the experiment. In this chapter, the properties of PGP are discussed and the fouling behavior of PGP is explained. Then, the data obtained from the prediction analysis is discussed. Finally, chapter 5 concludes the findings on this work and gives suggestions for further research.

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