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FOULING DEPOSIT FROM CHILI SAUCE PASTEURIZATION UNIT

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ABSTRACT

The formation of fouling deposit during food processing is more rapid and requires daily cleaning to ensure the quality and safety of the food products are secured. Raw materials of the food product are essential fouling factors, which food manufacturer must comprehend before processing. This paper reports a study on fouling deposit from chili sauce pasteurization. A tubular heat exchanger was applied. The chili sauce was pasteurized at flow rate of 0.712 kg/min and temperature between 90-95°C. The formation of the fouling deposit was monitored from heat transfer profile and from naked eyes observation after every one hour of the processing. The accumulation of the deposit was detected after 3 hours when the heat transfer profile was decreasing and fouling resistance profile was increasing. The chili sauce fouling deposit is categorized as carbohydrate-based fouling deposit due to the highest percentage of carbohydrate: 46.52% carbohydrate, 3.85 % fiber, 2.71% protein, 24.18% ash, 20.44% moisture and 2.28% oil.

***Keywords**: fouling deposit, chili sauce, pasteurization, heat exchanger*

INTRODUCTION

Chili sauce is a popular condiment which is broadly manufactured in Malaysia. Chili sauce is frequently consumed with variety foods to add piquant taste as well as to give better appearance and texture characteristics [1] to other food recipes. Chili puree is the main ingredients in chili sauce processing. The process involves blending, homogenization and heating under high shear condition which is at about 3000 rpm and at 90-95°C [2]. The heating process is not only for cooking but also for pasteurizing the sauce, to destroy *Clostridium botulinum* and other pathogens [3]. Heat exchanger is commonly used in pasteurization. Pasteurization process may cause formation of fouling deposit during chili sauce processing. Fouling deposit is an undesirable deposit which formed at the surface of processing equipments. It formation can cause reduction in heat transfer as the resistance is increasing by fouling thickness and the thermal conductivity of the fouling. It also can increase fluid flow resistance [4]. The formation of fouling deposit is because of foulant which is any component that contributing to the fouling formation. The behaviour of foulant depends on the fluid, which passing through the equipment's surface. Fouling problem may also cause by some form of contaminant within the fluid which frequently at very low concentration [5]. Therefore, in order to handle the fouling deposit problem, the properties of the fouling deposit must be identified so that the removal time of the deposit can be reduced.

In this research, fouling deposit from chili sauce pasteurization unit was studied. The characteristics of chili sauce were observed during pre mixing until undergo pasteurization. Although there are many previous studies on fouling deposit, there is no report on chili sauce fouling deposit. Thus there is lacking of references that can guide the chili sauce manufacturers to perform cleaning efficiently. Therefore, the objectives of this study are to determine the properties of chili sauce and its fouling deposit and finally to determine the factors that contribute to the formation of fouling deposit in chili sauce processing.

MATERIALS AND METHODS

Raw Material

The ingredients of the chili (*capsicum annum*) sauce are chili puree, vinegar, liquid sugar, salt and modified corn starch. Chili puree and modified corn starch were supplied by AJT Food Sdn. Bhd., Selangor, Malaysia. Other ingredients were purchased from a local supermarket.

Formulation of chili sauce

The formulation of the chili sauce was prepared by following the formulation from commercial chili sauce of Pegasus, Thai Roong Rueng Chili sauce Co., Ltd. [6] but garlic was not added and 2% modified corn starch was added. The modified corn starch acts as thickening agent. Other spices were also not added in the chili sauce formulation. This is to reduce the complexity of the sauce as chili sauce is categorised as complex multiphase suspensions. Table 1 provides the chili sauce ingredients.

Processing of chili sauce

130 kg of chili sauce was prepared for 3 hours operation. Firstly, the chili puree and vinegar were added into the mixer tank. The mixture was stirred for 15 minutes. Modified corn starch was pre-blended with the liquid sugar and salt before added into the mixture of chili puree and vinegar. Then the pre-blended mixture is added into the chili mixture. Then, the chili sauce was mixed for another 30 minutes. The pH and the TSS of the mixture were recorded prior to pasteurization.

Table 1: Modified formulation of chili sauce

Ingredients	Percentage (%)
Chili puree	28
Liquid Sugar	17
Salt	16
Vinegar	10
Modified corn starch	2

Physical Analysis

pH of chili sauce was determined by using pH meter. The total soluble solid of chili sauce was determined by using Digital ABBE Refractometer (AR-2008, Kruss, Germany). Both measurements were carried out 3 times. The density of the fouling deposit from each tube of the heat exchanger was measured after every one hour of pasteurization. These densities were used to calculate the thickness of the fouling deposit for every hour of pasteurization. The density was manually determined where the 500 ml beaker was used. Firstly, 200 ml of the chili sauce is taken and the weight of the chili sauce was weighed. Then, the density is obtained from Equation 1.

$$Density = \frac{mass, m}{volume, v} \quad (1)$$

Proximate Analysis

Proximate analysis was performed to determine the composition of moisture content, carbohydrate, protein, ash, fat and fibre of the chili sauce. Soxhlet method was used to determined fat content; oven method was used to determine moisture content while Kjeldahl method was used to determine protein content. Muffle furnace was used to determine ash content by drying the chili sauce up to 550°C. Proximate analysis was performed by following the standard method of AOAC (1995).

Thermal Analysis

Thermal conductivity for chili sauce during pre-mixing was measured by a thermal properties analyser (KD2, Decagon, Washington) at 28°C. The specific heat capacity of the chili sauce was determined by a differential scanning calorimeter (DSC) (DSC-7, Perkin-Elmer, USA). The temperature range for the experiment is set from 20ºC to 90 ºC with a temperature rate of 10°C/min. The data was used in order to determine specific heat capacity, Cp by using following equation [8] :

$$\text{Specific heat, Cp} = \frac{\frac{dQ}{dt}}{m\left(\frac{dT}{dt}\right)} \quad (2)$$

Where dQ/dt is heat flow, m is a chili sauce weight and dT/dt is a temperature rate. These measurements were done in duplicate and an average is taken.

Flow Behavior

Dynamic viscoelasticity and viscous flow tests were performed using a stress rheometer (Dynamic Controlled Stress 600 Rheometer, Mermo Electron Corporation, Germany) at 25°C. The experiments were carried out by using serrated plate-plate geometry (35mm, 1-mm gap) [9]. [10] stated that wide range of shear rates was tested in order to measure apparent viscosity during slow deformation involved in tipping fluid in a beaker (estimated to be 10^{s-1}) as well as the faster deformation in a normal swallow (estimated to be 100^{s-1}). Throughout testing, the temperature has been manipulated in order to observe the flow behaviour of the chili sauce at 20, 30, 40, 50, 60, 70, 80, and 90°C.

Arrhenius Equation Analysis

The Arrhenius equation, Equation 3 was used to explain the temperature effects on the flow behaviour of fresh and commercial pink guava puree [11]. A high activation energy values indicate that the viscosity is highly dependent on the temperature. Arrhenius equation analysis was also performed in this work.

$$\text{Arrhenius equation: } \eta_a = \eta_0 exp\left(\frac{E_a}{RT}\right) \quad (3)$$

Where η_a is the consistency index, η_o is empirical constant, E_a is the activation energy of flow, R is the gas constant and T is the absolute temperature in Kelvin.

Texture Analysis

The stickiness and hardness were measured according to [3]. These properties were examined by texture analyzer (TA-XT Plus, Stable Micro Systems, UK). Each test was repeated for at least five times and an average was taken. The parameter and specification of texture analyzer for executing hardness and stickiness analysis of chili sauce were stated in Table 2 below which adapted from [4].

Table 2: Parameters and specification of texture analyzer for hardness and stickiness analysis for chili sauce fouling deposit

Parameter	Value	Description
Probe	P20	The size of probe used: cylindrical; 20mm
Test- Mode	Compression	Initial probe direction and force polarity
Pre- Test speed (mm/s)	2	Probe speed while searching for trigger point
Test Speed (mm/s)	1	Speed of approach to target distance after triggering
Post test speed (mm/s)	2	Speed at which the probes returns to start point.
Target mode	Strain	Target parameter.
Strain (%)	50	Specify target strain base on trigger height
Trigger type	Auto	To define the method of the initiation of data
Trigger force (g)	4	Amount of force for TA to initiate data capture
Stop plot at	Start position	-
Break mode	off	-
Tare Mode	Auto	-
Advanced Options	On	-

Pasteurization Process

Lab scale tubular heat exchanger was used for pasteurization [12]. Figure 1 illustrates the schematic diagram of the rig. The weight of every empty tubes of the heat exchanger was measured prior to pasteurization. The heating medium was set to 90±5^{o}C and the flow rate of the sauce at 0.712 kg/min, to meet the pasteurization condition. The pasteurization unit was operated for 1, 2 and 3 hours. The temperature changes of the processing was recorded for every 3 minutes which involved temperature of product input, product output, oil input, oil output and product at intermediate which is inside tube 1, 2 and 3. Method of heat transfer analyses were based on [12].

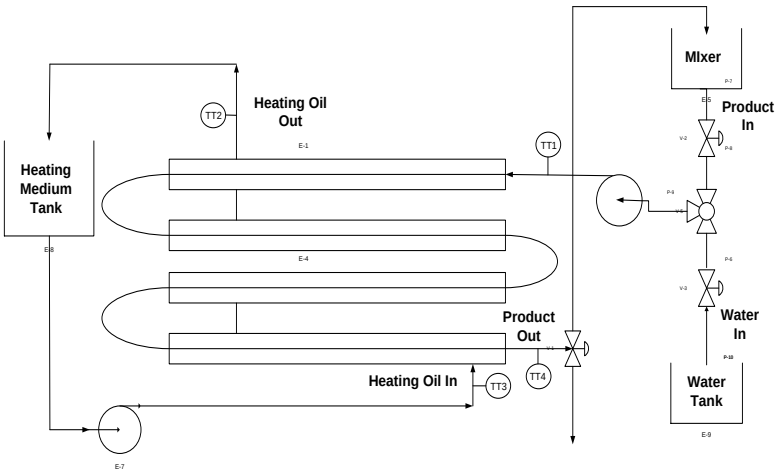

Fig. 1: PI&D of the lab scale of tubular heat exchanger.

RESULTS AND DISCUSSIONS

Chemical properties

The composition analysis helps to identify the component of the chili sauce fluid and its fouling deposit. Based on the result obtained in Table 3, the percentage of moisture is decreasing after pasteurization. It is because evaporation of chili sauce occurred during pasteurization whereby caused water loss within the chili

sauce. Chili sauce fouling deposit is categorised as carbohydrate-based fouling deposit as the percentage of carbohydrate component is the highest among the other components. Fouling deposit is classified upon its main composition [13]. The conclusion from [13] is carbohydrate-based deposit is easy to remove but the cleaning process will be harder if cameralisation occurred.

Table 3: Chemical properties of Chili sauce

Component (%)	Chili sauce	Chili sauce fouling deposit
Oil	0.2788	2.2854
Moisture	59.7051	20.4444
Ash	14.4626	24.1821
Protein	1.3723	2.71
Fibre	1.6429	3.8576
Carbohydrate	22.5382	46.5205

Physical properties

pH of chili sauce is 3.673 and it was lies in range between 3.43-3.93 which indicate an acidic characteristic. The acidic characteristic certainly results from some vinegar within recipe in Table 1. Due to sugar and salt, the total soluble solid value was 40.8 ^{o}Brix. Specific heat and thermal conductivity of the sauce was 2129 J/kg^{o}C and 0.39 W/m^{o}C respectively. Based on the results in Table 4, the density was increasing as the time increased. As the time increased, the moisture within chili sauce was vaporized during pasteurization, hence the mass of chili sauce higher than its volume.

Table 4: Density of chili sauce

Time	Density (kg/m^3)
0	1140.4
1	1150
2	1200
3	1350

From Figure 2 and 3, the stickiness and hardness of chili sauce fouling deposit were increased as the time increased. The existence of strong covalent bonding between the fouling deposits causes more strength needed to overcome the forces of the deposit. As the time was gradually increase for heating the chili sauce, the moist within the chili sauce was evaporated where make the hardness of the chili sauce increased over the time. Hardness of the chili sauce fouling deposit is depends on the raw materials used. Chili sauce mixture contains high percentage of sugar and chili purees which caused the hardening of chili sauce when contact with high temperature. So, the hardness of fouling deposit increases as the chili sauce continuously flows inside the heat exchanger for 3 hours.

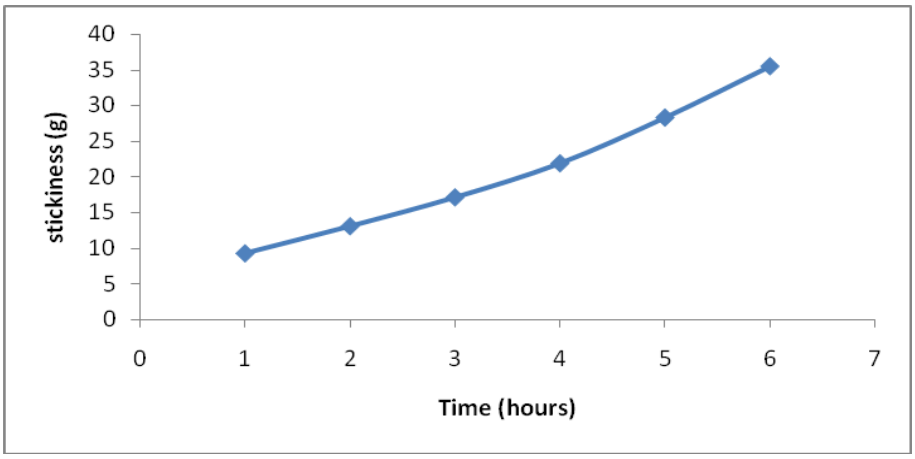

Fig. 2: Stickiness (g) as a function of time (min) for Chili sauce fouling deposit

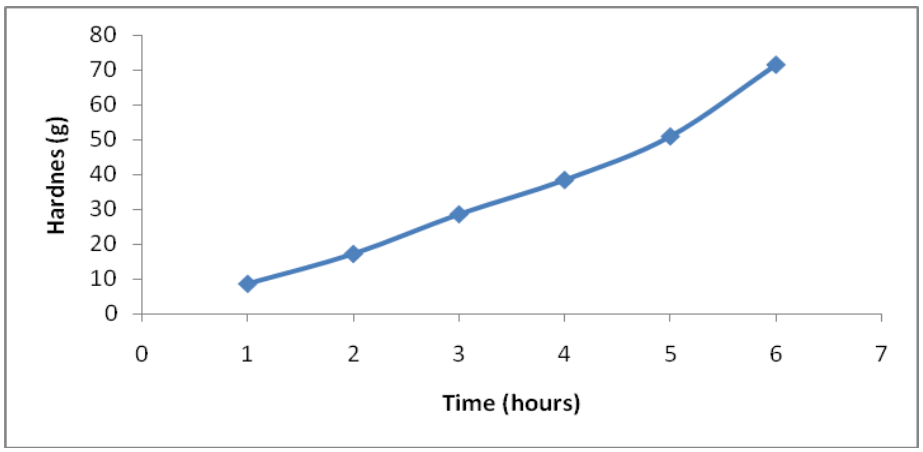

Fig. 3: Hardness (g) as a function of time (min) for Chili sauce fouling deposit

Flow Behaviour

In general, high of hydrocolloid contribute to the high of pseudo plasticity [14]. The addition of modified corn starch as one of hydrocolloids results in high viscosity of chili sauce. However, the presence of acetic acid encourages the fragmentation of starch chain into much shorter length so the gelation and disintegration of the granule occurred at low temperature. So, this phenomenon contributes to reduce in viscosity of chilli sauce. The relationship between apparent viscosity and shear rate was plotted as shown in Figure 4. The curve had shown pseudoplastic behaviour where the apparent viscosity was decreased with increasing of shear rate.

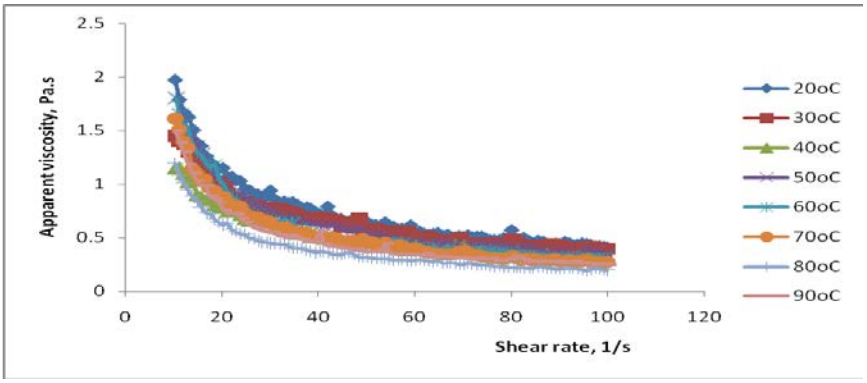

Fig. 4: Apparent viscosity as a function of shear rate (1/s) for chili sauce at different temperature

The trend of flow behaviour in Figure 5 was similar to Koocheki *et al.* (2009) which studied flow behaviour of ketchup. The parameter was obtained by fitting the data of apparent viscosity at shear rate = 30^{-1} as a function of temperature. The application of Arrhenius type model was assessed in observing the dependency of viscosity of ketchup on temperature [3]. The high value of R^2 which is 0.746 showed the relation of chili sauce viscosity to the temperature, which obeyed the Arrhenius type behaviour. Generally, the higher activation energy results in greater effect of temperature on the viscosity [15]. Activation energy, E_a of chili sauce is 7049.4 J $mole^{-1}$ was lies in the range of the activation energy of ketchup with addition of hydrocolloid which studied by [9]. The intermediate values of activation energy obtained because of addition of starch, pectin and gelatin after describing temperature effect on apparent viscosity of some food hydrocolloid with Arrhenius behaviour model which had been concluded by [16]. Even though the viscosity of the chili sauce was decreased with increased of time, the stickiness effect due to modified corn starch will maintain the chili sauce gelling structure and will lead to the formation of fouling deposit inside the tube.

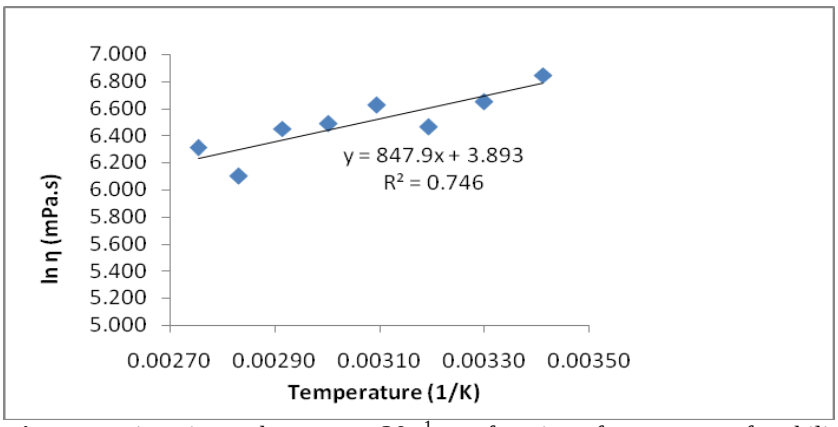

Fig. 5: Apparent viscosity at shear rate = $30s^{-1}$ as a function of temperature for chili sauce

Heat Transfer Analysis

Here only result of heat transfer analysis of tube 4 is reported, as the fouling formation in it was higher than in other tubes. The overall heat transfer coefficient gradually decreases as the chili sauce flowed into tube 4. The decreasing of overall heat transfer coefficient due to the accumulation of fouling deposit, which procides a barrier for heat transfer. The fouling resistance was high at tube 4 because the deposition rate in tube 4 was the highest among the other tubes.

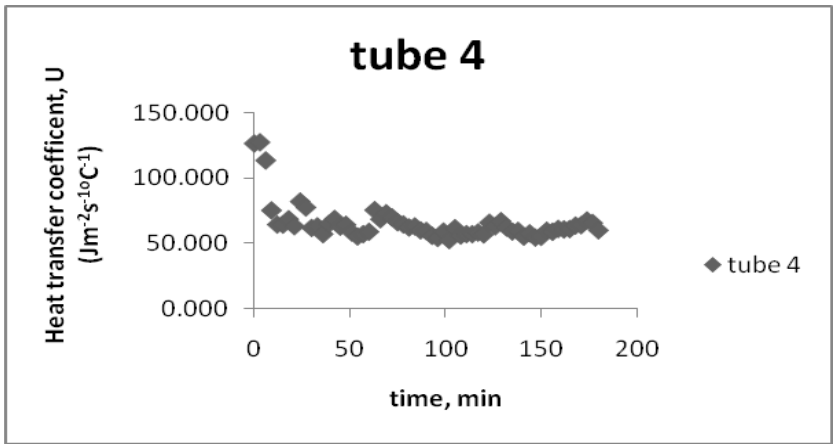

Fig. 6: Heat transfer profile of tube 4

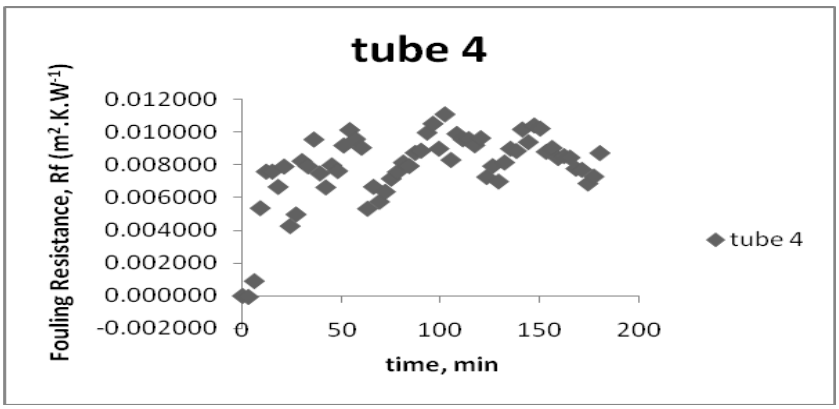

Fig. 7: Fouling resistance profile of tube 4

Fouling deposit thickness affects the fouling deposit resistance where the increasing of thickness of the fouling deposit in tube surface cause the reduction in heat transfer. Based on Figure 8, tube 4 showed the highest thickness of fouling deposit layer. It is because wall temperature at tube 4 is the highest because the heating oil was first pumped into tube 4, thus tube 4 has high temperature gradient. [17] stated that by having high wall temperature, the fouling become more severe. Figure 9 shows an accumulation of fouling deposit in the tubes after 3 hours.

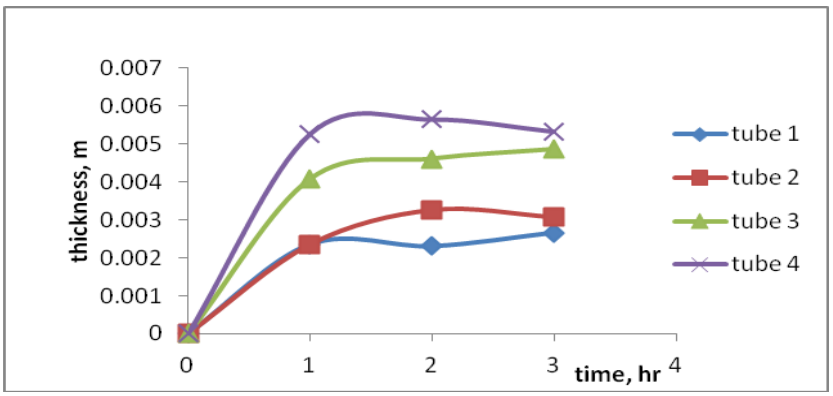

Fig. 8: Fouling deposit thickness profile at every tube.

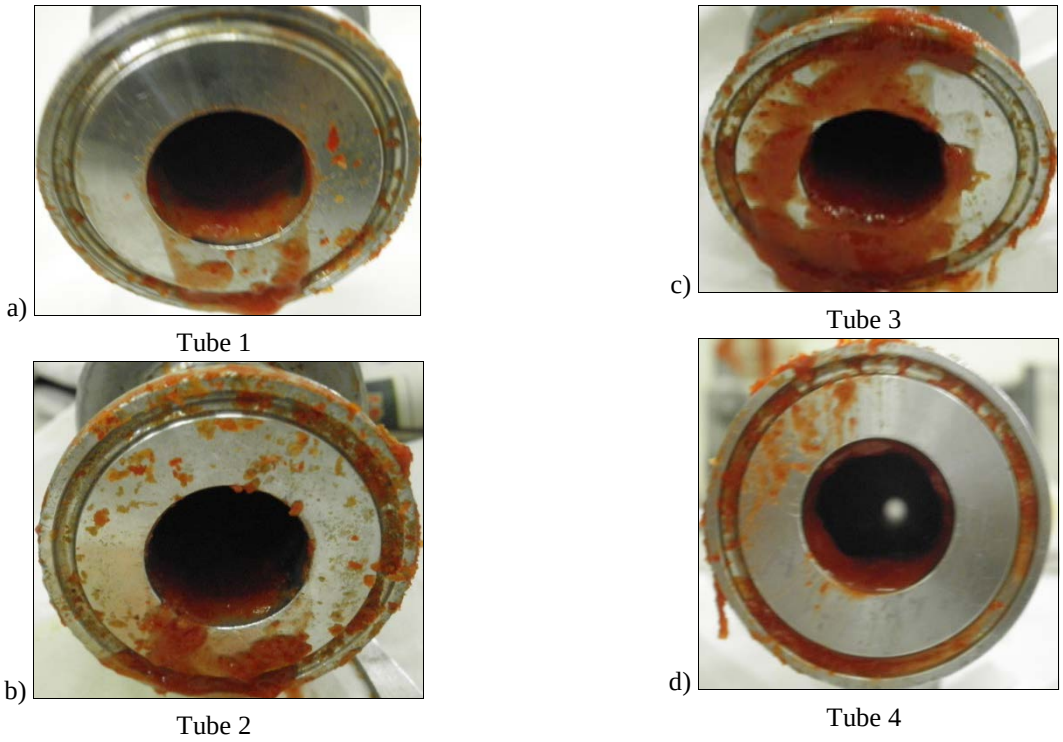

Fig. 9: Picture of chili sauce fouling deposit at a) tube 1, b) tube 2, c) tube 3 and d) tube 4, after 3 hours operating.

CONCLUSIONS

For conclusion, factors that contribute to formation of fouling deposit during chili sauce processing are temperature and its composition. The composition of chili sauce fouling deposit shows that chili sauce is carbohydrate-based fouling deposit which mostly contributed by the chili puree and modified corn starch. The molecular behaviour of the chilli sauce ingredients is also influent the hardness and stickiness of the deposit. From the study, the thickness of the fouling deposit in each tube of tubular heat exchanger was increasing by the time. Increasing of the fouling resistance was caused by the increasing thickness of fouling deposit in the tubes. While, the heat transfer coefficient was decreased by the time. Thus, chilli sauce fouling deposit is expected to form significantly and will harden with daily operating time.

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REFERENCES

[1] Ahmad, J., Shivhare, U.S., Raghavan, G.S.V. Rheological characteristics and kinetics of colour degradation of color degredation of green puree. *Journal of Food Engineering*. 2000: 44: 239-244.
[2] Gamonpilas C, Pongjaruvat W, Fuongfuchat A, Methacanon P, Seetapan N, Thamjedsada N. Physicochemical and rheological characteristics of commercial chili sauces as thickened by modified starch or modified starch/xanthan mixture. *J Food Eng*. 2011.
[3] Ho A.L., Tan V. Pink guava juice pasteurisation: Fouling deposit and cleaning studies. *The Journal*. 2010.

[4] Kukulka DJ,Czechowski.H, Kukulka PD. Factors Associated with Fouling in the Process Industry. *Heat Tranfers Eng*. 2010; 31(9):782–787.

[5] Bott, T. R. Fouling of heat exchangers. *Elsevier Science & Technology Books*. (1995).

[6] Alam M.K, Maruf Ahmed, Mst. Sorifa Akter, N. Islam, Jong B. E., Effect of carboxymethylcellulose and starch as thickening agents on the quality of tomato ketchup, *Pakistan J. of Nutrition*, 2009: 8(8): 1144-1149.

[7] Association of Analytical Chemist (AOAC), 1995.Official methods of analysis of the association of official analytical chemists. 16th ed. Arlington, Va;AOAC

[8] Bantle M.,Eikevik T.M.,Brenvall J.E. A novel method of simulation and continous determination of thermal properties during phase transition applied to Calanus finmarchius. *Journal of Food Science.* 2010:75(6):315-322

[9] Sanz T., Salvador A., Fsxman S.M. Evaluation of four types resistant starch in muffin baking performance and relationship with batter rheology, *European Food Research & Technology*, 2008:227(3):813-819.

[10] O'Leary M.,Hanson B.,Smith C.H..Variation of the apparent viscosity of thickened drinks International *Journal of Language & Communication Disorder*.2011:46(1):17-29

[11] Ken Wei Chan, Norashikin Ab Aziz*, Noraziah Muda, Rosnah Shamsuddin and Farah Saleena Taip. An evaluation of commercial pink guava puree properties as a potential model fouling fluid. *Journal of Food, Agriculture & Environment* Vol.10 (3 & 4): 60 - 66 . 2012

[12] K.W. Chan and N.A. Aziz. Pasteurization of Pink Guava Puree: Fouling Deposit Study. Proceeding of Regional Symposium on Engineering and Technology 2011, Kuching, Sarawak, Malaysia, 21-23 November 2011

[13] Grasshoff A., "Cleaning of Heat Treatment Equipment" IDF monograph, Fouling and Cleaning in Heat Exchangers, 1997.

[14] Koocheki A., A. Ghandi, S.M.A. Razavi, S.A. Mortazavi, T. Vasiljevic, The Rheological of Ketchup as a Function of Different Hydrocolloid and Temperature. *International J. Food Science and Tech.* 2009:44(1):596-902.

[15] Mohd. Nurul, I., Mohd. Azemi, B.M.N. & Manan, D.M.A. Rheological behaviour of sago (Metroxylon sagu) starch paste. *Food Chemistry*. 1999: 64(1): 501–505.

[16] Marcotte M.,Taherian Hashahih, A.R&Ramaiswamy, HS.Rheological properties of selected hydrocolloid as a function of concentration and temperature. *Food Research Journal*, 2001:34:695-703/

[17] Fryer, P.J.The use of fouling model in the design of food process plant. *J.Soc.Dairy Technolo.* 1989:42:23-39