เอกสารวิชาการฉบับที่ ๑ /๒๕๕๐ Technical Paper No.1 /2007

การใช้ความร้อนแบบโอห์มมิกเพื่อตกตะกอนโปรตีน ในน้ำล้างจากกระบวนการผลิตซูริมิ: ส่วนที่ 1: ระบบการให้ความร้อนโอห์มมิกแบบสถิตย์

Protein Coagulation of Wash-Water from Surimi Production by Ohmic Heating: Part 1: Static Ohmic Heating System

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กระทรวงเกษตรและสหกรณ์ Ministry of Agriculture and Cooperatives

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พิสิฐ วงศ์สง่าศรี[๑]
กลุ่มนวัตกรรมผลิตภัณฑ์สัตว์น้ำเชิงพาณิชย์ กองพัฒนาอุตสาหกรรมสัตว์น้ำ กรมประมง

บทคัดย่อ

ในอุตสาหกรรมซูริมิ ปริมาณน้ำทิ้งต่อวันจะมีเป็นจำนวนมาก ซึ่งมีต้นทุนในการบำบัดน้ำทิ้งที่สูง น้ำทิ้งที่เกิดขึ้นจะมีค่าปริมาณโปรตีน COD BOD ปริมาณของแข็งทั้งหมด (Total solid) และ ปริมาณของแข็งที่ละลายน้ำได้(Total dissolved solid) ที่ค่อนข้างสูง ในการศึกษานี้ เป็นการนำวิธีการทำความร้อนแบบโอห์มมิก (ohmic heating) มาใช้ในการแก้ปัญหาดังกล่าว ระบบการให้ความร้อนโอห์มมิกแบบสถิตย์ได้ถูกพัฒนาขึ้นเพื่อใช้ในการตกตะกอนโปรตีนจากน้ำล้างปลาทรายแดง มีการศึกษาคุณสมบัติทางไฟฟ้าของน้ำล้างปลา จากผลการทดลองพบว่า ค่าการนำไฟฟ้า (characteristic electrical conductivity) แปรผันตรงกับค่าอุณหภูมิของน้ำล้างปลา (20 ถึง 70°C) และ ค่าการนำไฟฟ้าจะเพิ่มมากขึ้นเมื่อปริมาณโปรตีนเริ่มต้นมีค่าสูงขึ้น (4.26, 5.32, 6.34, 7.96, 8.60, 8.86 g/L) อุณหภูมิของการให้ความร้อนมีความสัมพันธ์แบบพาราโบลิกกับระยะเวลาในการให้ความร้อน นอกจากนี้ มีการศึกษาผลของค่า electric field strength (20, 25, 30 V/cm) และอุณหภูมิ (50, 60, 70 °C) ต่อปริมาณโปรตีน COD BOD ปริมาณของแข็งทั้งหมด และ ปริมาณของแข็งที่ละลายน้ำได้ ที่เหลืออยู่หลังจากผ่านความร้อนแบบโอห์มมิก การให้ความร้อนจนถึงอุณหภูมิ 70 °C จะทำให้ปริมาณโปรตีนตกตะกอนออกมามากกว่าที่อุณหภูมิ 50 และ 60 °C ซึ่งสามารถลดปริมาณโปรตีน COD BOD ปริมาณของแข็งทั้งหมด และ ปริมาณของแข็งที่ละลายน้ำได้ เท่ากับ 58.10%, 74.97%, 76.58%, 56%, และ 38.91% ตามลำดับ ผลการศึกษานี้เป็นการแสดงให้เห็นว่า ความร้อนแบบโอห์มมิกมีศักยภาพในการนำไปใช้ตกตะกอนโปรตีนจากน้ำล้างปลาทรายแดงในโรงงานซูริมิได้

คำสำคัญ: การให้ความร้อนแบบโอห์มมิกแบบสถิตย์ ซูริมิ โปรตีน การตกตะกอน น้ำล้าง

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Protein Coagulation of Wash-Water from Surimi Production by Ohmic Heating:

Part 1: Static Ohmic Heating System

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Abstract

In surimi industry, waste water is considerably generated every day. The industry suffers from high cost of treating the waste water which has high protein content, COD value, BOD value, total solid and total dissolved solid. In this study, ohmic heating was attempted to feasibly address these problems. A static ohmic heating system was developed to coagulate protein from fish mince (Threadfin Breams) wash-water. The electrical property of the wash-water was studied. Result indicated that the relationship between the characteristic electrical conductivity and characteristic temperature was positively linear (20-70^{o}C), and the higher the initial protein in the wash-water (4.26, 5.32, 6.34, 7.96, 8.60, 8.86 g/L), the greater the value of electrical conductivity. Heating temperature demonstrated a parabolic relationship with the heating time. Further, the effects of electric field strength (20, 25, 30 V/cm) and final temperature (50, 60, 70 ^{o}C) on remaining protein content, BOD, COD, total solid and total dissolved solid were investigated. Heating to the final temperature at 70 ^{o}C resulted in better protein recovering when compared with 50 and 60 ^{o}C which showed the reduction of protein, COD value, BOD value, TS, and TDS to 58.10%, 74.97%, 76.58%, 56%, and 38.91% of those before ohmically heated, respectively. This condition showed the promise of utilizing ohmic heating to treat the wash-water.

Key words: ohmic heating, static, surimi, protein, coagulation, wash-water

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Introduction

Waste water treatment is one of important processes in fishery industry. In order to abide by the environmental law, waste water generated from factories must be treated before being released to natural reservoirs, thereby leading to higher capital cost of processors. Amount of waste water per day from the fishery industry is significantly excessive, especially from surimi factories.

In 2004, there were 17 surimi factories in Thailand producing 145,000-150,000 tons of surimi. Forty to fifty percent of raw materials were threadfin bream (approximately 140,000 tons) (Virulhakul, 2005).Threadfin breams (*Nemipterus spp.*), a demersal fish, is one of the important raw materials in Thai surimi production for years. The surimi obtained is white, providing smooth texture with good flavor and a strong gel-formability (Holmes *et al*., 1992; Morrissey and Tan, 2000). In Thailand, 102, 121, and 113 thousand metric tons of threadfin breams were caught from the gulf of Thailand and Indian Ocean in 2000, 2002, and 2003, respectively (Department of Fisheries, 2003; 2004; 2005). These numbers reflected the rising demand of using threadfin breams in production of fish products including surimi.

Production of surimi requires a number of washing processes in order to remove undesired organic substances from fish mince such as blood, enzymes, and fat to achieve high gel strength level and exclude undesired flavor and color out of the surimi. In the waste water, Lin *et al.* (1995) reported that there were up to 80% by weight proteins (dry basis), which was waste of nutrition. Moreover, proteins, fat, and other organic substances containing in waste water result in high COD and BOD value, which not only have an impact to the environment, but also require high cost of water treatment. A general water treatment method using microorganisms is simple but requires large area and long time. This might limit the production capacity if land resource is limited.

Therefore, if proteins can be partially or considerably removed from the waste water before entering treatment system, cost of water treatment will be significantly reduced, consequently decreasing of capital cost. Also, if the recovered proteins are somehow utilized, for instance, to additionally use in surimi based products for low market or pet food, this will finally decrease processors' cost

Ohmic heating is an innovative thermal food processing, particularly in aseptic processing, that electrical energy is converted to thermal energy uniformly by applying proper formulation to avoid runaway heating even though food products are non-homogeneous. Electric field between electrodes and food resistance generate heat generation within food matrixes. Heating rate depends upon many factors such as electric field strength, cross sectional area of electrode, electrode gap, and electrical conductivity of food components. These factors determine how much electricity will pass through foods. The higher the level of electricity, the greater the heating rate.

There are many advantages of ohmic heating over conventional heating, for examples, ohmic heating is energy efficiency (86-96 %) (Huang *et al*., 1997); its heating rate is higher and faster; its system is compact, and no requirement for large production area; and it can ensure that cold spots of particulate food (liquid-solid mixture food) reach the required temperature by manipulating electrical conductivities of solid and liquid food. Due to the promise of ohmic heating, it has been studied in several aspects such as its potential to enhance dye diffusion in beet (Halden *et al*., 1990), its ability in extracting sucrose from sugar beet (Katrokha *et al*, 1984), its capability in increase the diffusion of soy milk from soybeans (Kim and Pyun, 1995), its possibility to enhance extraction of apple juice and dehydration of carrots and potatoes (Wang, 1995), its feasibility to reduce the amount of steam water used in blanching (Sensoy, 2002), and its potential to peel tomatoes (Wongsa-Ngasri, 2004).

It is known that protein in water becomes coagulated under heating. Ohmic heating is an effective heating method that uses the electrical energy to directly heat the fluid, coagulating proteins out of waste water. The advantages of using an ohmic heating to treat waste water include: it requires simple system and low capital investment; it offers clean technology since no chemical additives are used in the process;

Studying the properties of fish mince wash-water from threadfin breams by using ohmic heating became interesting since there is only little information, and perhaps the ohmic heating might be an alternative of wastewater treatment for Thai surimi production plant especially for small to medium size factory according to its simplicity and low investment.

Objectives

1. To develop a static ohmic heating system for possibility of using it to coagulate proteins in fish mince (threadfin breams) wash-water
2. To determine the relationship between the characteristic electrical conductivity and characteristic temperature of fish mince (threadfin breams) wash-water during ohmic heating

3. To determine the effect of electric field strength and final temperature on the remaining protein, Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD), Total Solid (TS), and Total Dissolved Solid (TDS) from fish mince (threadfin breams) wash-water

Materials and Methods

I. Static Ohmic Heating System Setup

A static ohmic heating system was developed which consisted of an ohmic cell, an ordinary manual on-off variable transformer (0-240 Volts), a digital recordable power meter (Yokogawa model WT110), and a thermometer. The ohmic cell made from an acrylic tube was 300 mm long, 5 mm thick, and 50 mm in the internal diameter as shown in Figure 1. Two disc-shape 316L stainless steel electrodes, 2 mm thick and 50 mm in diameter, were fixed at both ends of the cell with 75 mm of the length of gap between each other. The variable transformer was used to control voltage, resulting in generating the desired electric field strengths, and the digital meter was used to record the voltage across the cell and the electric current every 10 seconds.

The system accuracy was verified by using 170-ml standard solution of 0.1M NaCl, with initial temperature at 20±1 °C, filled in the gap between electrodes. Air bubbles were removed to ensure the precision of electrical conductivity measurement. The sample was then ohmically heated by using fixed electric field strength at 30 V/cm under pre-assigned temperature range (20, 30, 40, 50, 60, and 70 °C), and electrical conductivities were calculated as equation (1) by exerting voltage and current values recorded from the digital meter. The experiment was conducted in duplicate. The calculated electric field strengths were then compared to the valued obtained from Lobo equation (Lobo, 1984) to verify the system accuracy.

Calculation of electrical conductivity

With the assumption that there is no voltage drop across the wiring and connectors in the circuit, the electrical conductivity of wash-water (σ) can be calculated by using equation (1):

$$\sigma = \frac{I}{V} \cdot \frac{L}{A} \qquad (1)$$

Where “V”,”I”, “L”, and “A” represented the voltage drop across the cell in volts, the electric current passed through the sample in amperes, the distance between two electrodes in meters, and the cross section area of the electrode in square meters, respectively (Palaniappan and Sastry , 1991a, b).

Figure 1: Ohmic cell unit

II. Determination of relationship between the characteristic electrical conductivity and characteristic temperature of fish mince (threadfin breams) wash-water during ohmic heating

The fish mince wash-water was obtained from a surimi production plant in Samuthsakorn province (Seven lots of the wash-water). Whole threadfin breams were headed, gutted, washed, and minced through the meat-bone separator before being washed in the first washing tank, which contained high protein content, and subsequently dewatered and washed in other washing tanks. In this experiment, the wash-water from the first washing tank was collected, filled in plastic bottles, and kept cooled in a foam box containing ice during transportation to the laboratory. The experiment was performed within two hours after the sample was collected.

The wash-water samples were analyzed protein content and used as initial protein content values. Subsequently, the relationship between electrical conductivity and temperature of the samples under ohmic heating (at fixed 30 V/cm) was investigated by using the same method as mentioned above (section I). Moreover, the electrical conductivity values measured at 20^{o}C of every sample were used to find characteristic electrical conductivity and characteristic temperature and their relationship.

III. Effects of electric field strength and final temperature on remaining protein, COD, BOD, TS, and TDS

Effects of electric field strength and temperature on protein coagulation in the collected wash-water were investigated by using conditions described in Table 1. In each experiment, the wash-water of 170 ml with initial temperature at 20$\pm$1 ^{o}C was filled in the gap between electrodes. Air bubbles were removed to ensure the precision of electrical conductivity measurement. The sample was then heated under different assigned electric field strengths (20, 25, and 30 V/cm) until reaching the desired temperatures (50, 60, and 70^{o}C). Then, the variable transformer was manually turned off. Furthermore, the effects of the final temperature (50, 60, and 70^{o}C) on TS, TDS, COD, and BOD were studied only at electric field strengths of 30 V/cm.

Table 1: Experimental treatments for studying effects of electric field strength, and final temperature of fish wash-water

Final Temperature (^{o}C)	**Electric Field Strength (V/cm)**		
50	20	25	30
60	20	25	30
70	20	25	30

For every treatment, samples were analyzed the investigated values before and after ohmically heated. The samples were centrifuged at 12,000 rpm for 10 minutes. The supernatant was therefore collected and analyzed for the investigated values.

The protein content had been analyzed by Kjeldahl analyzer with the conversion factor of 6.25 according to AOAC standard methods (Cunniff, 1995). TS and TDS were measured by using standard method recommended by Clesceri *et al* (1998). COD and BOD values of the samples were measured by the methods developed by the King Mongkut's University of Technology Thonburi (Department of Environmental Engineering, 2004).

Results and Discussion

I. Static Ohmic Heating System Setup

As shown in Figure 2, the relationship between the electrical conductivity of 0.1 M NaCl solution and temperature was linear. The "σ_{exp}" and "σ_{Lobo}" represented the values of the electrical conductivity of the solution obtained from the experiment and from Lobo equation (Lobo, 1984), respectively. The "σ_{Lobo}" line was used as reference. The plot indicated that at low temperature range, the measured electrical conductivity values (σ_{exp}) were close to the reference electrical conductivity values (σ_{Lobo}). When the temperature was raised up to 70 °C, the measured value became 6.3 % lower than the reference value. The difference might come from the effect of the arising of the internal resistance in circuit wiring and connectors between the digital meter and the cell. During heating experiment, the electric current passed through the circuit, wires and connectors made by metal, resulting in heat in those electrical components. Due to the temperature increment, the internal resistance of the circuit became higher (Mott and Jones, 1958). These internal resistances caused the increase of the voltage gradient (V) across them, thereby decreasing the electrical conductivity. This might be the reason why the measured electrical conductivity values (σ_{exp}) were lower than those of the reference electrical conductivity values (σ_{Lobo}).

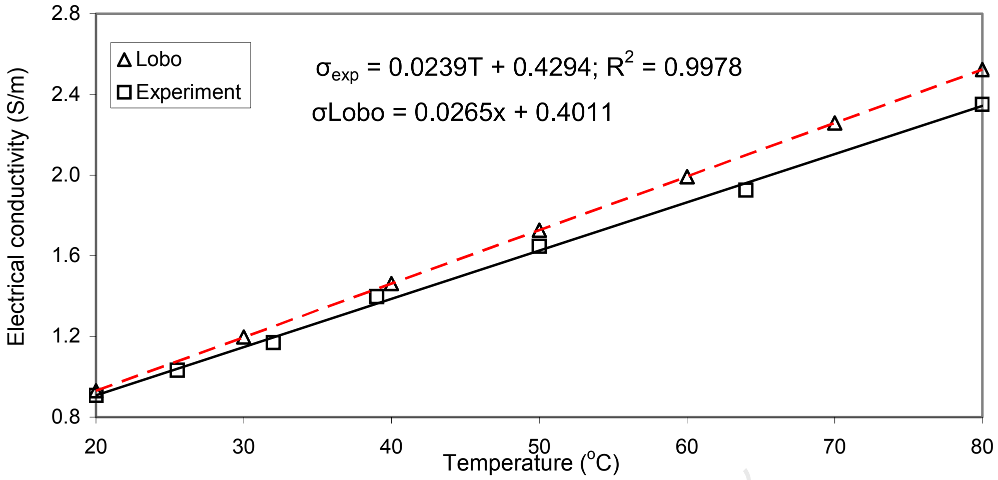

Figure 2: Electrical conductivity of 0.1 M NaCl solution at 30 V/cm obtained from: Lobo's equation, σ_{Lobo}=0.02652T+0.4011 and experiments

II. Determination of relationship between the characteristic electrical conductivity and characteristic temperature of fish mince (threadfin breams) wash-water under ohmic heating

At the same initial protein concentration, the higher the temperature, the greater the electrical conductivity (σ) (Figure 3). The mathematical models of linear relationship between σ and temperature of all samples, shown in Table 2, were agreed with the results found in several previous ohmic heating literatures using different food materials (Sukprasert, 1998; Zareifard *et al*, 2003; Castro *et al*, 2004; Palaniappan and Sastry, 1991b).

Further, at the same temperature, the higher the initial protein in the sample, the greater the value of electrical conductivity. When the protein concentration increases, the electrical conductivity would be expected to increase due to more ions from protein molecules. However, in the sample containing protein concentration of 5.32 g/L, the electrical conductivity was noticeably higher than that containing 6.34 g/L protein concentration. Also the electrical conductivity of 8.86 g/L protein concentration was lower than those of 7.96 and 8.6 g/L. A possible factor that impacts to the varying of electrical conductivity would be the different levels of water hardness being used in washing process in the factory, which is not strictly controlled in real production situation, resulting in different ion types and concentration which are greatly impacted on electrical conductivity of the wash water (Palaniappan and Sastry, 1991a).

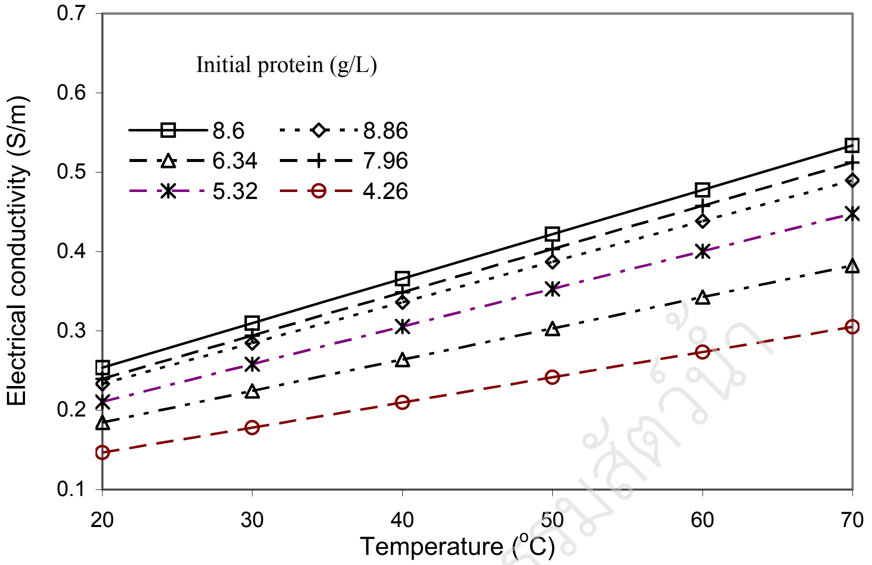

Figure 3: Relationship between electrical conductivity and temperature, treated at 30V/cm, contained the various initial protein contents

Table 2: Mathematical model of relationship between electrical conductivity and temperature of various initial protein of wash-water (T = temperature ranging from 20 to 70°C)

Initial Protein of Wash-Water (g/L)	**Relationship between Electrical Conductivity (S/m) and Temperature (°C) at 30 V/cm**
4.26	$\sigma = 0.0032T+0.0831$
5.32	$\sigma = 0.00465T+0.1155$
6.34	$\sigma = 0.00395T+0.1058$
7.96	$\sigma = 0.00545T+0.1305$
8.6	$\sigma = 0.0056T+0.1418$
8.86	$\sigma = 0.00513T+0.1307$

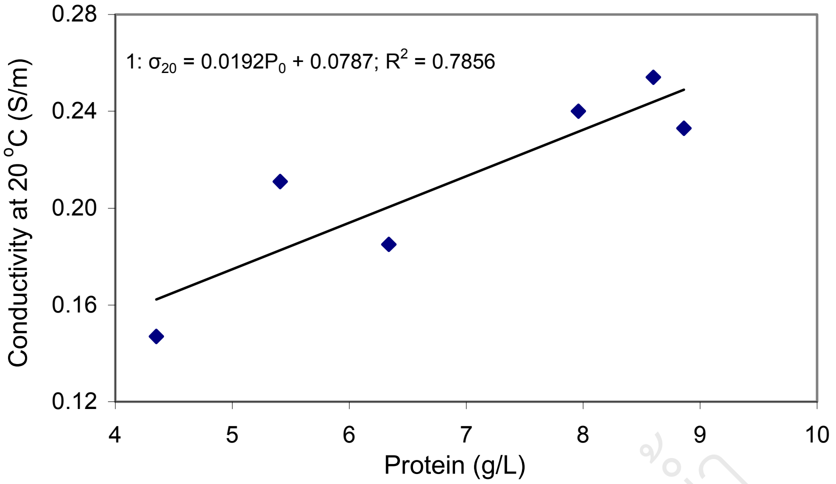

Figure 4: Electrical conductivity at 20 °C of samples contained different concentrations of the initial proteins treated at 30 V/cm.

As seen in Figure 4, the relationship between electrical conductivity measured at 20 °C and initial protein concentration was linearly established, as equation (2-a), in order to obtain one general equation representing the relationship between electrical conductivity and temperature. Characteristic electrical conductivity (σ^*) and characteristic temperature, (T^*) were defined as equation (2-b) and (2-c), respectively.

$$\sigma_{20} = 0.0192P_o + 0.00787 \qquad (2\text{-a})$$

$$\sigma^* = (\sigma/\sigma_{20}) - 1 \qquad (2\text{-b})$$

$$T^* = (T/20) - 1 \qquad (2\text{-c})$$

Where σ and σ_{20} were the electrical conductivity of the wash-water at any temperature T (in Celsius) and at 20 °C, respectively. It was found from figure 5 that no matter the initial protein concentration was, the relationship between σ^* and T^* was linear as shown in equation (3).

$$\sigma^* = 0.4485T^* \qquad (3)$$

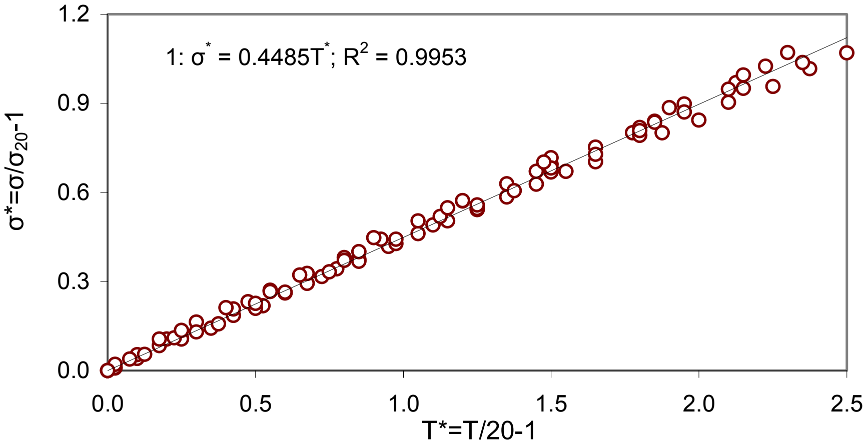

Figure 5: Relationship between characteristic electrical conductivity and characteristic temperature.

III. The effects of electric field strength and final temperature on remaining protein, COD, BOD, TS, and TDS

At the same electric field strength, the higher the treated final temperature, the lower the remaining protein in the wash-water (Figure 6). The percentage of the remaining protein after ohmically treated (calculated by comparing with the initial protein content before heating) were shown in Table 3. This could be explained by the properties of protein in the fish wash-water. Generally, protein is susceptible to heat, and at certain temperature, protein will be coagulated. When the temperature increases, more protein is coagulated. However, when temperature goes up to a point called “denaturation temperature”, most of heat-sensitive protein would be coagulated and if temperature still increases, not much more protein will be coagulated (Damodaran, 1996; Volkin and Klibanov, 1990). Haard reported that only 65-75% of the sarcoplasmic proteins from demersal fishes were coagulated under heating; namely, 25-35% of protein before heating remained in the wash-water (Haard, 1995). This was comparable to the results obtained from the experiment at 70°C (41.90 ± 3.72 %). Huang *et al.* (1997) performed the ohmic heating experiments using wash water prepared from frozen pacific whiting fish mince, and recommended that the highest heating temperature was 70 °C, which was agreed with this experiment.

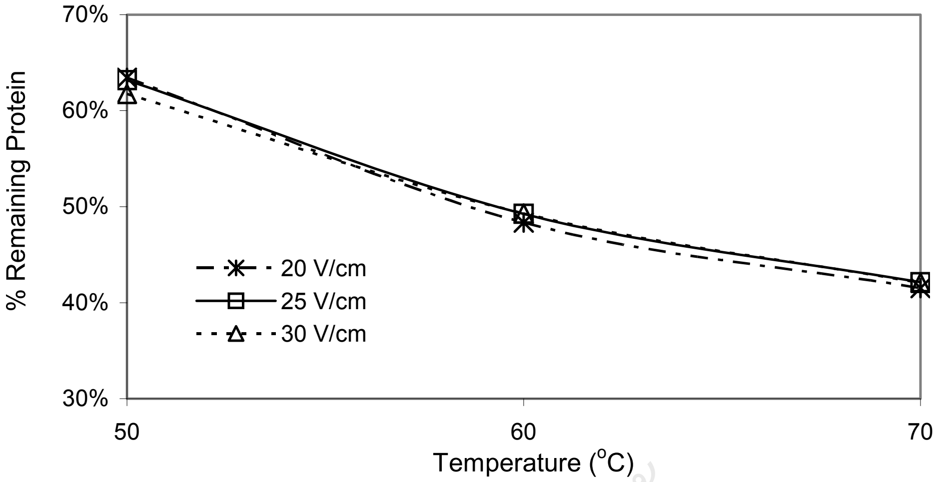

Figure 6: Relationship between the remaining proteins and final temperature at various electric field strengths

At the same final temperature, the percentage of the remaining protein would be expected to be similar value no matter what electric field strength was, due to the fact that thermal effect would have more influence than electrical effect on protein denaturation (Wongsa-Ngasri, 1999). For sample heated to 50 °C, 60 °C, and 70 °C, the remaining protein averaged from all electric field strengths was 62.59 ± 4.07%, 49.02 ± 4.07%, and 41.90 ± 3.72 % of those before heating, respectively.

Table 3: Percentage of remaining protein after ohmically treated at various electric field strengths and final temperatures

Electric Field Strength (V/cm)	**Final Temperature (^{o}C)**	**% Remaining Protein after Ohmically Treated**
20	50	61.37 ± 2.21^{a}
	60	48.34 ± 4.16^{b}
	70	41.50 ± 4.86^{c}
25	50	63.17 ± 4.72^{a}
	60	49.25 ± 4.63^{b}
	70	42.14 ± 4.14^{c}
30	50	63.78 ± 4.98^{a}
	60	49.97 ± 5.12^{b}
	70	42.02 ± 5.22^{c}

^{a,b,c} Mean values followed by the same letter are not significantly different (Turkey multiple comparison at $p < 0.05$)

Temperature also significantly affected to the remaining COD, BOD, TS (total solid), and TDS (total dissolved solid) as shown in figure 7 and 8 ($p<0.05$). The initial COD values of the samples were extremely high, in the range of 6,451 to 10,477 mg/L. After ohmically heated to 50, 60, and 70 ^{o}C, the COD value of the wash-water remained 46.20%, 31.67%, and 25.03% of those before heating while BOD value (4,854 – 7,563 mg/L) remained 50.70%, 31.87%, and 23.42% of those before heating, respectively. The thermal effect played a role in terms of subsiding amount of protein in wash-water, leading to COD and BOD reduction. The reduction of COD and BOD values should result in decreasing the wastewater treatment cost of surimi factories. Even though the 89-94% reduction of COD value from frozen fish mince wash-water could be achieved by using ultra-filtration (Lin *et al*, 1995), ohmic heating might be an alternative method for water treatment to a small surimi plant since it requires a less complicated system and less capital investment.

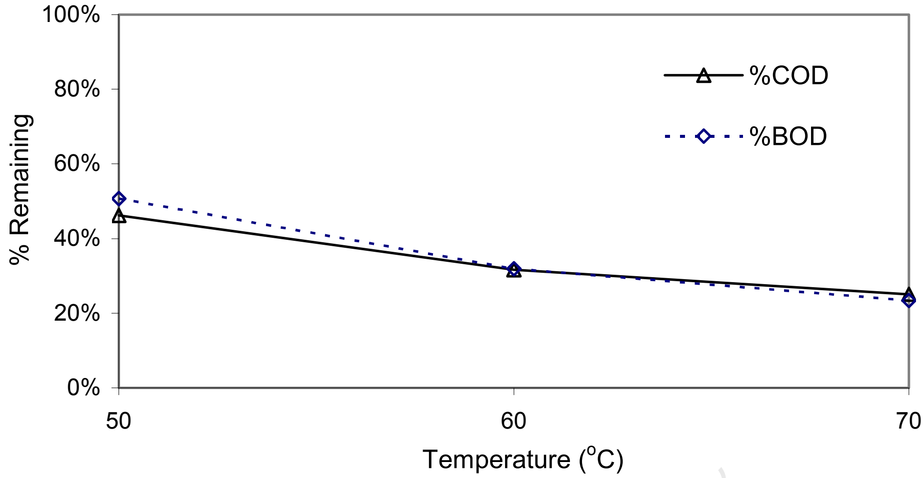

Figure 7: Relationship between percentage of COD and BOD and final temperatures

After the wash-water sample was ohmically heated to 50, 60, 70 °C, 59%, 49%, and 44% of TS before heating, and 77.42%, 67.86%, and 61.09% of TDS before heating were remained in the sample, respectively (Figure 8). This was agreed with this study as well. This indicated that there were some heat stable proteins remained in the treated wash-water. This was the reason why there still was the remaining protein in the sample after heated to 70 °C.

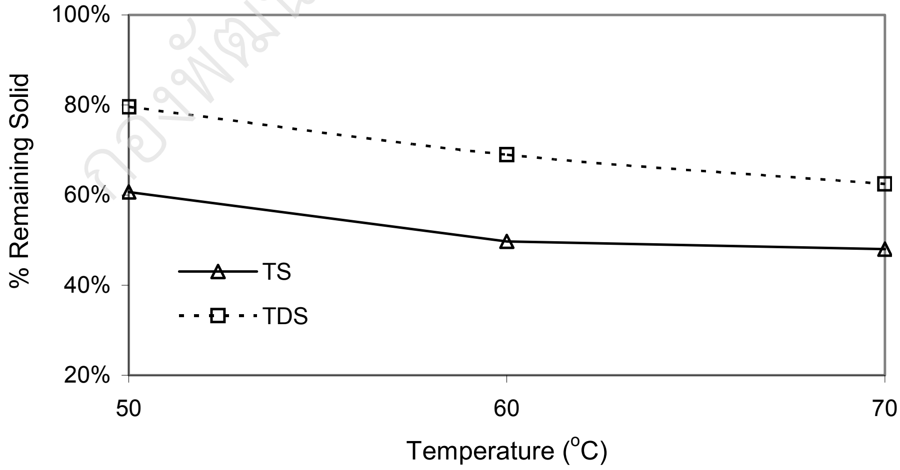

Figure 8: Relationship between the remaining Total Solid (TS) and Total Dissolved Solid (TDS) and final temperatures

Even though the electric field strength had no significantly effects on protein remaining ($p<0.05$); it affected on the heating rate which impacted to heating time. The higher the electric field strength, the shorter the heating time. The plot between the temperature of the sample under different electric field strengths and heating time was shown in figure 9. It was clearly showed that the relationship between the temperature and heating time could be explained by a parabolic model as shown in Table 4. Theoretically, with the assumption of no heat loss in the experiment, the heating rate (q) is proportional to the square of the electric field strength (∇V) as following equation (Sastry and Palaniappan, 1992).

$$q = (\nabla V)^2 . \sigma \tag{4}$$

Let q_{20}, q_{25}, and q_{30} represent the heating rate when the sample was heated under the electric field strength of 20, 25, and 30 V/cm, respectively. From equation (4), it is expected that the ratio q_{20}/q_{25} and q_{20}/q_{30} should be equal to 0.64 and 0.44. These two values obtained from the experiment were 0.61 and 0.42, which were approximately 5% lower than the theoretical values. The differences should be the result of heat loss during ohmic heating. Under lower electric field strength, heating time was longer. Longer time allowed more heat loss from the system. Consequently, the ratio of the heating rate under lower electric field to the higher one would be lower than the theoretical value.

Although higher electric field strength offered shorter period of heating time, it could give burning on electrode surface if running in the long time (Wongsa-Ngasri, 1999) or suddenly dropping of the electrical conductivity by the occurrence of electrolytic hydrogen-gas produced (Palaniappan and Sastry, 1991b). However, there was no such negative effects were observed under using of electric field strength of 30 V/cm. This indicated that this magnitude of electric field strength should be applicable for using the ohmic heating to treat threadfin breams fish mince wash-water. Also, the burn-on could be prevented by improving type and design of the electrodes.

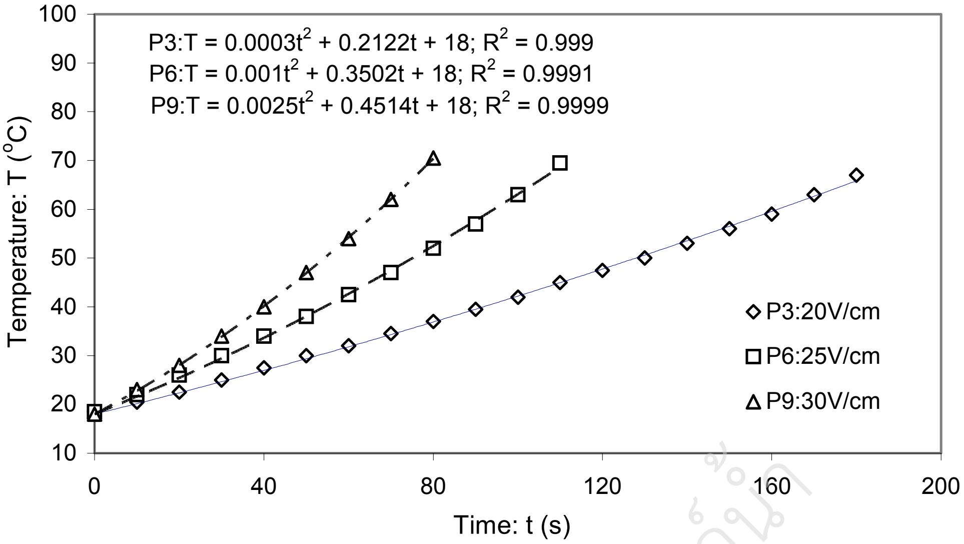

Figure 9: Relationship between temperature and heating time required from approximately 20 to 70 °C at various electric field strengths

Table 4: Parabolic model of temperature ranging from 20 to 70°C as a function of ohmically heating time at various electric field strengths

Electric Field Strength (V/cm)	**Parabolic Model**
20	$T = 0.0003t^2 + 0.2122t + 18$
25	$T = 0.0010t^2 + 0.3502t + 18$
30	$T = 0.0025t^2 + 0.4514t + 18$

Conclusions

Ohmic heating showed some promising results for protein coagulation of fish mince (Threadfin Breams) wash-water from surimi industry. For electrical property of the wash-water, at the same initial protein concentration, the higher the temperature, the greater the electrical conductivity (σ), and the relationship could be described by one general linear equation "$\sigma^*=0.4485T^*$". Further, at the same temperature, the higher the initial protein in the wash-water, the greater the value of electrical conductivity.

Ranging from 20 to 70°C, at the same electric field strength, the higher the treated final temperature, the lower the remaining protein in the wash-water. Heating sample to 70 °C resulted in better protein recovering when compared to 50 and 60 °C. Also, at the same final temperature, the percentage of remaining protein would be expected to be similar value no matter what electric field strength was, due to the fact that thermal effect had more influence than electrical effect on protein denaturation, however, higher electric field strength provided faster heating time.

After ohmically heating the fish mince (Threadfin Breams) wash-water to 50, 60, and 70 °C, 37.41±4.07%, 50.98±4.07% and 58.10±3.72% of protein before heating; 53.80%, 68.37%, and 74.97% of COD value before heating; 49.3%, 68.13%, and 76.58% of BOD value before heating; 41%, 51%, and 56% of TS before heating; and 22.58%, 32.14%, and 38.91% of TDS before heating were reduced, respectively.

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Appendix

Appendix table 1: The values of protein content in the fish wash-water before and after ohmically heating under various electric field strengths and final temperatures

Electric Field Strength (V/cm)	Final Temperature (oC)	Protein Content (g/L)	
		Before heating	After heating
20	50	8.6	5.49
		8.86	5.28
		4.26	2.59
	60	8.6	4.08
		8.86	3.96
		4.35	2.3
	70	8.6	3.45
		8.86	3.32
		4.35	2.04
25	50	8.6	5.28
		8.86	5.28
		4.35	2.98
	60	8.6	3.83
		8.86	4.38
		4.35	2.34
	70	8.6	3.45
		8.86	3.49
		4.35	2.04
30	50	8.6	5.32
		8.86	5.32
		4.26	2.96
	60	8.6	4.08
		8.86	4.13
		4.35	2.43
	70	8.6	3.36
		8.86	3.45
		4.35	2.09

Appendix table 2: The values of BOD in the fish wash-water before and after ohmically heating under various final temperatures

Final Temperature (oC)	BOD (mg/L)	
	Before heating	**After heating**
50	7563	3820
50	7563	4077
50	7563	4213
50	4854	2085
50	4854	2450
50	4854	2433
60	7563	2107
60	7563	2022
60	7563	2577
60	4854	1558
60	4854	1744
60	4854	1678
70	7563	1288
70	7563	1487
70	7563	1348
70	4854	1409
70	4854	1440
70	4854	1326

Appendix table 3: The values of COD in the fish wash-water before and after ohmically heating under various final temperatures

Final Temperature (oC)	COD (mg/L)	
	Before heating	After heating
50	10477	5524
50	10477	5486
50	10477	5714
50	6451	2342
50	6451	2554
50	6451	2688
60	10477	3530
60	10477	3371
60	10477	3962
60	6451	1805
60	6451	1805
60	6451	1958
70	10477	2724
70	10477	2895
70	10477	2819
70	6451	1459
70	6451	1498
70	6451	1574

Appendix table 4: The values of Total Solid in the fish wash-water before and after ohmically heating under various final temperatures

Final Temperature (oC)	Total Solid (g/L)	
	Before heating	After heating
50	8.42	5.11
50	8.42	5.07
50	8.42	5.03
50	6.12	3.46
50	6.12	3.6
50	6.12	3.75
60	8.42	4.24
60	8.42	4.29
60	8.42	4.39
60	6.12	2.97
60	6.12	2.97
60	6.12	3.02
70	8.42	3.87
70	8.42	3.98
70	8.42	3.9
70	6.12	2.42
70	6.12	2.68
70	6.12	2.87

Appendix table 5: The values of Total Dissolved Solid in the fish wash-water before and after ohmically heating under various final temperatures

Final Temperature (oC)	**TDS (g/L)**	
	Before heating	**After heating**
50	5.92	4.94
50	5.92	4.73
50	5.92	4.78
50	3.77	2.99
50	3.77	2.92
50	3.77	3.09
60	5.92	4.09
60	5.92	4.19
60	5.92	4.3
60	3.77	2.58
60	3.77	2.56
60	3.77	2.66
70	5.92	3.74
70	5.92	3.58
70	5.92	3.75
70	3.77	2.32
70	3.77	2.3
70	3.77	2.46