THERMOPHYSICAL PROPERTIES OF SNAKEHEAD FISH (*Channa striata*) MUSCLE CHANGE DURING CHILLING PROCESS

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ABSTRACT

This study was conducted to identify the initial freezing point temperature (t_f) of water and to investigate the changes of thermophysical properties of snakehead fish muscle during the chilling process. The temperatures of snakehead fish muscle during the chilling process and t_f identification decreased from 25.7°C to 0.5°C, and from 28.3°C to -8.2°C, respectively. The result indicated that the initial freezing point temperature (t_f) of water in the snakehead fish muscle was -1.3°C. The temperature of snakehead fish muscle affected considerably the thermophysical properties of snakehead fish muscle. The density (ρ) and specific heat (*c*) increased with decreasing temperature during the chilling process. Inversely, the thermal conductivity (k), thermal diffusivity (α) and enthalpy (h) decreased with decreased temperature. The results obtained from this study could be applied in calculating the energy requirements and equipment used in snakehead fish processing industry.

Keywords: *Chilling, freezing point temperature, snakehead fish, thermophysical property.*

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1. INTRODUCTION

For several decades, aquaculture in the Mekong Delta region of Vietnam has played an important role to the delta communities through improvements in the provision of animal protein, creation of jobs, and generation of income, as well as contribution to the domestic consumption and exports of aquatic products of Vietnam. There is an increasing growth in freshwater aquatic production that includes catfish (Tra and Basa catfish), tilapia, anabas, snakehead fish, and freshwater prawns. The farming area of snakehead fish, especially striped snakehead fish (*Channa striata*), has rapidly increased [1]. Snakehead fish is mainly cultured in small-scale farms with high stocking density and fed by low-value fish or trash fish, which can help reduce poverty [2]. Snakehead fish is considered as a source of high-quality protein because of the fine flesh and flavor, and traditional remedy of sickness [3]. Snakehead fish muscle contains a high protein content (78.32±0.23% dry matter), lipids (2.08±0.08% wet matter), and vitamin A (0.265±0.013 mg/100g fish muscle). It also has high contents of arachidonic acid (AA) 20: 4ω6 (8.2±0.1% total lipid), docosahexaenoic acid (DHA) 22: 6ω3 (13.0±7% total lipid) and eicosapentaenoic acid (EPA) 20: 5ω3 (0.6±0% total lipid) [4]. These components vary depending on species, sex, size, harvest season, feed composition and habitat conditions [5].

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Knowledge of thermophysical properties of foods is thought to be useful in new product development and design of processing equipment, in process calculations of heating and cooling rates of times, and in calculating the process energy requirements as well as in the development of new processing techniques [6]. Thermophysical properties of foods commonly used in calculating heat and mass transfers include density (ρ), specific heat (c), thermal conductivity (k), thermal diffusivity (α) and enthalpy (h) [7]. Thermophysical properties of foods strongly depend upon the chemical composition [8] and temperature [9, 10], thus, using mathematical models which account for the effects of chemical composition and temperature is the most common method used to predict the thermophysical properties of foods [11, 10].

To date, there have been no reports on the changes in the thermophysical properties of snakehead fish muscle during chilling process. Therefore, the objective of this study was to determine the changes in thermophysical properties of snakehead fish muscle during chilling process, including the density (ρ), specific heat (*c*), thermal conductivity (k), thermal diffusivity (*α*) and enthalpy (h). The initial freezing point temperature (t_i) of water in the snakehead fish muscle was also determined.

2. MATERIALS AND METHODS

2.1. Snakehead fish

Snakehead fish used for this research were bought from the local fish farm in Nha Trang city, Khanh Hoa province. The average weight of the fish was 700-800 g. The fish were then transported to the labs of Nha Trang University alive in water containers. Fish were recovered for 2 h before bleeding and gutting in following the procedure described in Nguyen *et al.* (2021) [12].

2.2. Chilling process

The gutted snakehead fish were chilled using slurry ice (crushed ice : water ratio of 1 : 1) in Styrofoam boxes at a ratio of fish to slurry ice of 1 : 2 (w/w). The changes in temperatures of fish muscle were recorded using a 12-channel Thermocouple (Data logger TM500, Extech Instruments, Boston, Massachusetts, USA). Three sensors were inserted into the fish muscle by piercing the loin to varying depths with a 12-gauge stainless steel needle. The thermocouple wire was inserted into the holes; one in the skin, one beneath the skin and another one in the center of the dorsal muscle to indicate the rate of cooling (temperature reduction) in different geometrical locations in the fish body.

2.3. Initial freezing point temperature determination

The initial freezing point temperature of water in the snakehead fish muscle was determined by the freezing curve method described by Rahman *et al.* (2002) [13]. Snakehead fish samples were frozen in a freezer at temperature of -20°C (Sanaky VH-6699W3). The temperature-time of snakehead fish muscle was recorded by using a 12-channel Thermocouple. The freezing point was derived from the time-temperature data plot.

2.4. Thermophysical properties determination

The thermophysical properties of snakehead fish muscle including density (ρ), specific heat (*c*), thermal conductivity (k), thermal diffusivity (α) and enthalpy (h) were measured according to the mathematical models developed by Choi and Okos (1986) [8] (Table 1).

Table 1. Mathematical models for thermophysical properties determinations

Thermophysical property	Food Component	Thermophysical property model
Density (ρ), (kg/m^3)	Protein	$\rho = 1.3299 \times 10^{3} - 5.1840 \times 10^{-1} \times t$
	Fat	$\rho = 9.2559 \times 10^{2} - 4.1757 \times 10^{-1} \times t$
	Carbohydrate	$\rho = 1.5991 \times 10^{3} - 3.1046 \times 10^{-1} \times t$
	Fiber	$\rho = 1.3115 \times 10^{3} - 3.6589 \times 10^{-1} \times t$
	Ash	$\rho = 2.4238 \times 10^{3} - 2.8063 \times 10^{-1} \times t$
	Water	$\rho = 9.9718 \times 10^{2} + 3.1439 \times 10^{-3} \times t - 3.7574 \times 10^{-3} \times t^{2}$
	Total	$\rho = \frac{(1-\varepsilon)}{\sum \frac{x_i}{\rho_i}}$
Specific heat (c), kJ/kg.K	Protein	$C_P = 2.0082 + 1.2089 \times 10^{-3} \times t - 1.3129 \times 10^{-6} \times t^{2}$
	Fat	$C_P = 1.9842 + 1.4733 \times 10^{-3} \times t - 4.8008 \times 10^{-6} \times t^{2}$
	Carbohydrate	$C_P = 1.5488 + 1.9625 \times 10^{-3} \times t - 5.9399 \times 10^{-6} \times t^{2}$
	Fiber	$C_P = 1.8459 + 1.8206 \times 10^{-3} \times t - 4.6509 \times 10^{-6} \times t^{2}$
	Ash	$C_P = 1.0926 + 1.8896 \times 10^{-3} \times t - 3.6817 \times 10^{-6} \times t^{2}$
	Water	$C_p = 4.1289 - 9.0864 \times 10^{-5} \times t + 5.4731 \times 10^{-6} \times t^{2}$
	Total	$C = \sum C_i \times X_i$
Thermal conductivity (k), W/m.K	Protein	$k = 0.17881 + 1.1958 \times 10^{-3} \times t - 2.7178 \times 10^{-6} \times t^{2}$
	Fat	$k = 0.18071 - 2.7604 \times 10^{-3} \times t - 1.7749 \times 10^{-7} \times t^{2}$
	Carbohydrate	$k = 0.20141 + 1.3874 \times 10^{-3} \times t - 4.3312 \times 10^{-6} \times t^{2}$
	Fiber	$k = 0.18331 + 1.2497 \times 10^{-3} \times t - 3.1683 \times 10^{-6} \times t^{2}$
	Ash	$k = 0.32962 + 1.4011 \times 10^{-3} \times t - 2.9069 \times 10^{-6} \times t^{2}$
	Water	$k = 0.57109 + 1.7625 \times 10^{-3} \times t - 6.7036 \times 10^{-6} \times t^{2}$
	Total	$k = \sum x_i^V . ki$
Thermal diffusivity (α), m^2/s	Protein	$\alpha = 6.8714 \times 10^{-8} + 4.7578 \times 10^{-10} \times t - 1.4646 \times 10^{-12} \times t^{2}$
	Fat	$\alpha = 9.8777 \times 10^{-8} - 1.2569 \times 10^{-11} \times t - 3.8286 \times 10^{-14} \times t^{2}$
	Carbohydrate	$\alpha = 8.0842 \times 10^{-8} + 5.3052 \times 10^{-10} \times t - 2.3218 \times 10^{-12} \times t^{2}$
	Fiber	$\alpha = 7.3976 \times 10^{-8} + 5.1902 \times 10^{-10} \times t - 2.2202 \times 10^{-12} \times t^{2}$
	Ash	$\alpha = 1.2461 \times 10^{-8} + 3.7321 \times 10^{-10} \times t - 1.2244 \times 10^{-12} \times t^{2}$
	Water	$\alpha = 1.3168 \times 10^{-7} + 6.2477 \times 10^{-10} \times t + 2.4022 \times 10^{-12} \times t^{2}$
	Total	$\alpha = \sum \alpha_i . X_i^V$
Enthalpy (h), kJ/kg	Unfrozen water	$h_f = 9.79246 + 405.096 \times x_w$
		$h = H_f + (t - t_f) \times (4.19 - 2.3 \times x_S - 0.628 \times x_s^{3})$
		$h = \sum H_i . X_i = \sum \int_{t1}^{t2} C_i . X_i \, dT$

2.5. Proximate analysis

Proximate analysis was performed according to the AOAC (2000) [14] standard methods. Moisture and ash contents were determined using the AOAC method 976.05 and 942.05, respectively. The protein content was determined using nitrogen determination by the Kjeldahl method from AOAC method 954.01. The conversion factor used to calculate crude protein content was 6.25. To determine the lipid content of the samples, Bligh and Dyer (1959) [15] method was used.

2.6. Statistical analysis

Data analyses were done using Microsoft Excel 2019 (Microsoft Inc. Redmond, Wash., USA). One way analysis of variance (ANOVA), Duncan's test (Post-hoc) and Pearson correlation analysis were performed on means of the variable values in the statistical program NCSS 2000 (NCSS, Kaysville, Utah, USA). The significance of differences was defined at the 5% level ($p<0.05$).

3. RESULTS AND DISCUSSION

3.1. Chemical composition of fresh snakehead fish muscle

Table 2. The chemical compositions of fresh snakehead fish muscle

Component	Value
Water (%WB)	77.6±0.13
Protein (%WB)	18.2±0.24
Lipid (%WB)	2.71±0.12
Ash (%WB)	1.09±0.02
Carbohydrate (%WB)	0.34±0.03

The chemical compositions of fresh snakehead fish muscle are presented in Table 2. Moisture, protein, lipid, ash, and carbohydrate in snakehead fish (*Channa striata*) muscle were of 77.6±0.13%, 18.2±0.24%, 2.71±0.12%, 1.09±0.02% and 0.34±0.03%, respectively.

The results revealed that snakehead fish is a medium-fatty fish species. Osman *et al.* (2001) [16] reported that low-fat fish have higher water content, as observed in this study. The proximate composition of the snakehead fish reported by Chedoloh *et al.* (2011) [4], Rahman *et al.* (2018) [17] and by Zuraini *et al.* (2006) [18] showed some degrees of differences, especially for the fat content. Such variations in the chemical composition of fish are closely depended on the age, size, sex, environmental conditions and season [19]. The farmed fish generally have a higher lipid content compared to wild fish [20].

3.2. Freezing point temperature of water in the snakehead fish muscle

Initial freezing point temperature is one of the most important properties of food that is used in prediction models of thermal properties, freezing and thawing times in order to optimize the process and the product quality. It is also used for determining the food's proper processing and storage conditions [13]. The initial freezing point of water in the snakehead fish muscle was determined using the freezing curve method. From the time-temperature data plot (Figure 1), the initial freezing point temperature of water in the snakehead fish muscle was practically found to be -1.3°C (point B) and the undercooled temperature was -2.8°C (point A). The initial freezing point temperatures of water in the fish muscle are different from different species, mainly due to the disparity between methods applied, and variation of fish species in terms of chemical composition and freezing point depressants. However, the result from this study was found to be correlated with the initial freezing point temperature of -1.4°C for long tail tuna (*Thunnus tongol*) [21] and -1.5°C for salmon (*Salmo salar*) [22].

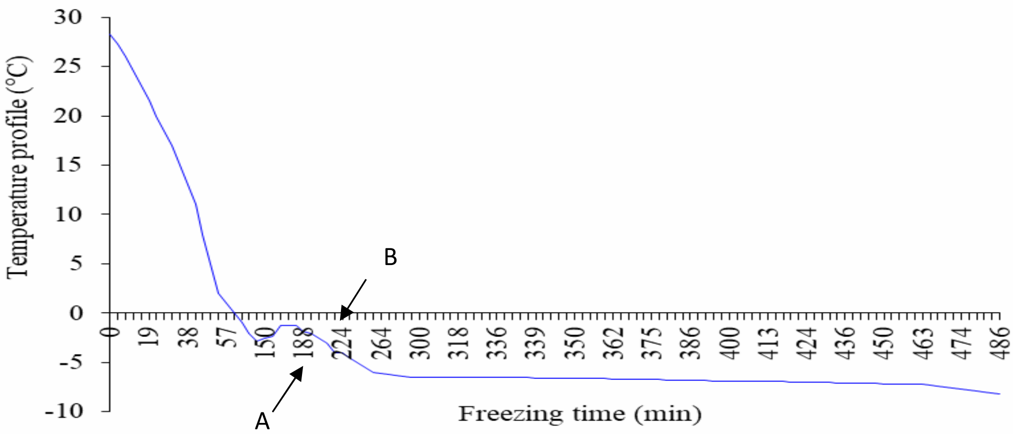

Figure 1. The initial freezing point temperature of water in the snakehead fish muscles

3.3. Changes in density (ρ) of snakehead fish during chilling process

Although the mass density of the fish is not involved with the group of thermal properties, however, it was determined along with the other properties due to its significance in heat transfer calculation. The changes in density of snakehead fish as a function of temperature are presented in Figure 2. It is obvious to see that the density increased slightly (from 1,042 kg/m^3 to 1,046 kg/m^3) with decreasing temperature over this range of temperature applied in the chilling process. It is well-known that the fish muscle is composed mainly of water, therefore, the behavior of water constituent will dominate the density behavior. The results of this study were in agreement with those published by Abbas *et al.* (2009) [23] for Malaysian yellowtail catfish.

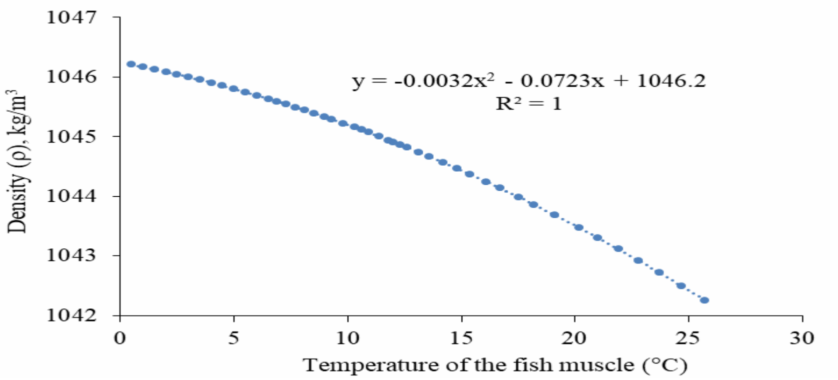

Figure 2. Variation of the density of snakehead fish muscle with temperature

3.4. Changes in specific heat (c) of snakehead fish during chilling process

Specific heat is a measure of the energy required to change the temperature of a kg of food by one degree. Therefore, the specific heat of foods can be used to calculate the heat load imposed on the refrigeration equipment by the cooling or freezing of foods. Generally, the specific heat of snakehead fish muscle increased slightly from 3.653 kJ/kg.K to 3.662 kJ/kg.K during the chilling process (Figure 3). The pattern of changes in specific heat agreed with that noted by Kreith and Bohn (1993) [24]. The results from the present study were in accordance with those published by Radhakrishnan (1997) [25] for bluefish, salmon, seabass, tilapia, trout and tuna. The author reported the specific heat of these fish species ranged from 3.1 kJ/kg.K to 3.8 kJ/kg.K. The specific heat of fresh seafood at a temperature of 17°C varied from 3.29 kJ/kg.K to 3.79 kJ/kg.K [26].

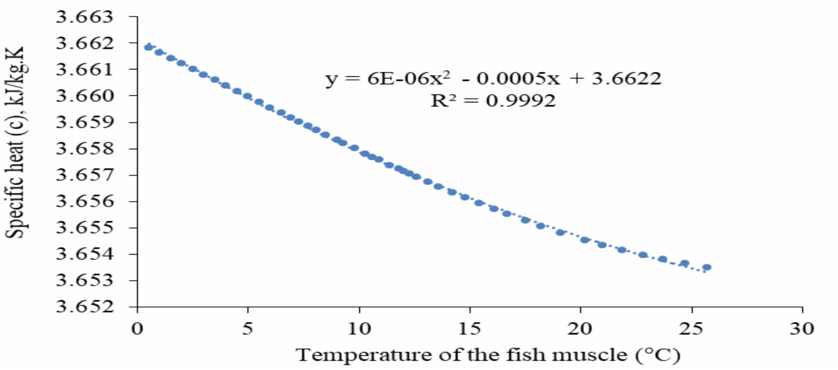

Figure 3. Changes in specific heat of snakehead fish muscle during chilling process

3.5. Changes in thermal conductivity (k) of snakehead fish during chilling process

Thermal conductivity (k) measures the heat conducting ability of a material. Materials with low thermal conductivity have a lower rate of heat transfer compared to materials with high thermal conductivity. The thermal conductivity of snakehead fish muscle decreased linearly with decreasing temperature of the fish muscle over the range of experimental temperature with R^2 = 0.9997 (Figure 4). The thermal conductivity of snakehead fish muscle in general ranged from 0.498 W/m.K to 0.539 W/m.K at temperatures 0.5 to 25.7°C. Kumbhar *et al.* (1981) [27] reported that the k values of mackerel were in the range of 0.416 to 0.459 W/m.K at temperatures 0 to 30°C. The k value of 0.502 W/m.K was reported for salmon (*Salmo salar*) at a temperature of 4°C. Radhakrishnan (1997) [25] demonstrated the k values for bluefish ranged from to 0.424 to 0.628 W/m.K with a temperature ranging from 6.7 to 29.47°C and for tilapia the k values ranged from 0.442 to 0.548 W/m.K. The thermal conductivity of Tuna (*Katsuwonus pelamis*) of 0.57±0.01 W/m.K at ambient temperature and 71.6% moisture content. It is well-documented that the thermal conductivity is much dependent on the temperature and chemical composition of food muscle [11, 28]. In general, it could be concluded that the thermal conductivity of snakehead fish muscle agreed well with the values found in the literatures for fish.

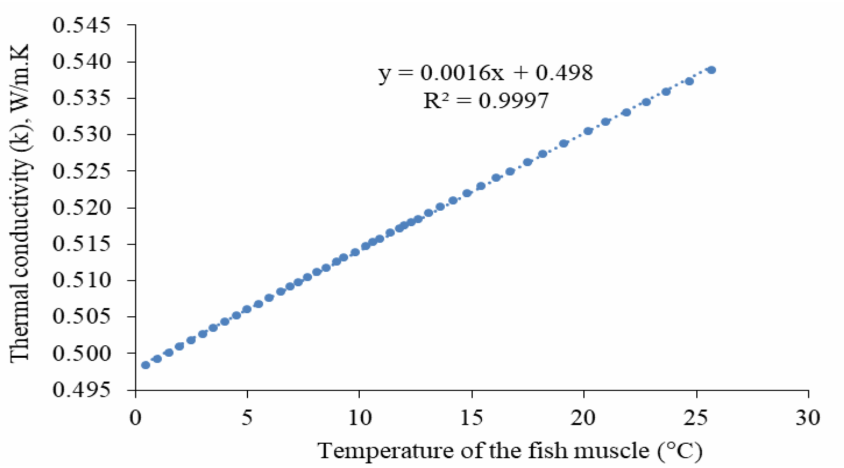

Figure 4. Thermal conductivity changes during chilling snakehead fish as a function of temperature

3.6. Changes in thermal diffusivity (α) of snakehead fish during chilling process

Thermal diffusivity (α) is a physical property associated with transient heat flow. It measures the ability of a material to conduct thermal energy relative to its ability to store thermal energy. Materials with large thermal diffusivity will respond quickly to changes in their thermal environment while materials of small thermal diffusivity will respond more slowly, taking longer to reach a new equilibrium condition. In this study, the thermal diffusivity of snakehead fish muscle decreased from 1.35×10^{-7} m^2/s to 1.22×10^{-7} m^2/s during the chilling process (temperature of the fish muscle decreased from 25.7°C to 0.5°C) (Figure 5). The α values obtained for snakehead fish muscle were in the ranges reported for bluefish, salmon, seabass, tilapia, trout and tuna by Radhakrishnan (1997) [25]. Kumbhar *et al.* (1981) [27] also reported the thermal diffusivity values for 12 different fish species were in the range of 1.086×10^{-7} m^2/s to 1.875×10^{-7} m^2/s.

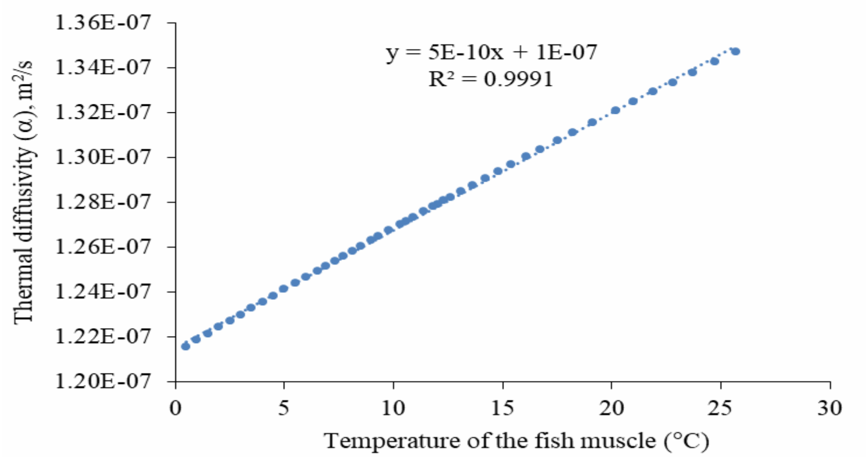

Figure 5. Changes in thermal diffusivity of snakehead fish muscle as a function of temperature

3.7. Changes in enthalpy (h) of snakehead fish during chilling process

The change in a food's enthalpy can be used to estimate the energy that must be added or removed to affect a temperature change. It is obvious to see that the enthalpy of snakehead fish muscle was a function of temperature. The enthalpy decreased well-linearly (R^2 = 1.00, from 423.36 kJ/kg to 330.91 kJ/kg) with decreasing temperature during the chilling process (Figure 6). The trend of enthalpy variation obtained from the present work was in agreement with that reported by Hobani and Elansari (2008) for four different types of meat. However, the results showed some degrees of differences. The enthalpy values ranged from 291.36 kJ/kg to 428.50 kJ/kg for Noemi meat at 40°C reported by Hobani and Elansari [29]. The differences might be due to the differences in chemical composition of the samples and different temperatures used for enthalpy measurements.

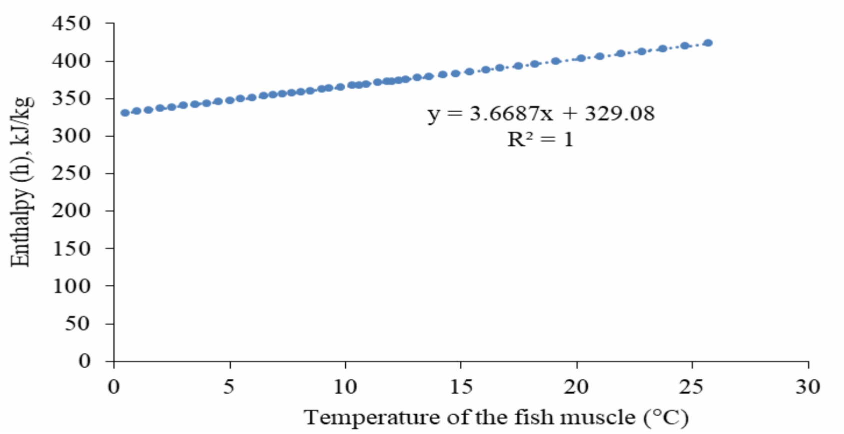

Figure 6. Changes in enthalpy of snakehead fish muscle during chilling process

4. CONCLUSION

The initial freezing point temperature of water in the snakehead fish muscle was -1.3°C. Thermophysical properties of snakehead fish muscle depended on the temperature of the fish muscle during chilling process. The density (ρ) and specific heat (*c*) increased from 1,042 kg/m^3 to 1,046 kg/m^3 and from 3.653 kJ/kg.K to 3.662 kJ/kg.K, respectively when the temperature of the fish muscle decreased from 25.7°C to 0.5°C.

Inversely, the thermal conductivity (k), thermal diffusivity (α) and enthalpy (h) decreased from 0.539 W/m.K to 0.498 W/m.K, from 1.35×10^{-7} m^2/s to 1.22×10^{-7} m^2/s and from 423.36 kJ/kg to 330.91 kJ/kg, respectively. The results obtained from this study could be applied in snakehead processing industry.

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