Determination of the Thermophysical Properties of Tuna Using the Heat Pulse Method

Manuscript received March 26, 2025; revised April 27, 2025

Ho Thi My Phong
Faculty of Chemical Engineering
Ho Chi Minh City University of Industry and Trade
Ho Chi Minh City, Viet Nam
hothimyphong0580@gmail.com

Lu Thi Mong Thy
Faculty of Chemical Engineering
Ho Chi Minh City University of Industry and Trade
Ho Chi Minh City, Viet Nam
thyltm@huit.edu.vn

Hoang Thi Nam Huong
Thermal and Refrigeration Technology Department
Ho Chi Minh City University of Technology
Ho Chi Minh City, Viet Nam
htnhuong@hcmut.edu.vn

Do Huu Hoang*
Faculty of Chemical Engineering
Ho Chi Minh City University of Industry and Trade
Ho Chi Minh City, Viet Nam
hoangdh@huit.edu.vn

***Abstract*—Although the tuna industry plays an important role in supporting the economy and local communities, it remains underdeveloped and faces several challenges, according to reports from the Ministry of Industry and Trade and the Vietnam Tuna Association. This study focuses on examining the heat-related physical properties of tuna—specifically, how well it conducts heat (thermal conductivity), how quickly heat spreads through it (thermal diffusivity), and how much heat it can store (specific heat capacity). These properties were measured using the heat pulse method within a temperature range of -15°C to 20°C. The results showed that thermal conductivity ranged from 0.394 to 1.103 W/m·K, thermal diffusivity from 1.11×10^{-8} to 2.60×10^{-7} m²/s, and specific heat capacity from 3,377.21 to 52,948.54 J/kg·K.**

Keywords*—Density, Heat Pulse Method, Specific Heat Capacity, Thermal Conductivity, Thermal Diffusivity, Vietnamese Tuna.

I. Introduction

Vietnam, a Southeast Asian nation, possesses a 3,260 km-long coastline and an exclusive economic zone of 1 million km² in the East Sea. According to the Vietnam Association of Seafood Exporters and Producers (VASEP), the total export value of Vietnamese tuna reached $733 million in 2021, accounting for 21.56% of the country's total seafood export value. Among this, tuna products classified under code 160.414 generated over $280 million, representing 8.24% of the total seafood export value [1]. Currently, Vietnam has favorable conditions for developing its tuna fishing industry due to its extensive coastline and the subtropical monsoon climate of the East Sea, which is ideal for tuna fishing [2].

Despite its significant role and contributions to the socio-economic landscape, the tuna industry has generally remained underdeveloped and encounters various constraints and challenges, as noted by the Ministry of Industry and Trade and the Vietnam Tuna Association. These challenges have resulted in outcomes that fall short of the industry's potential [2]. In the fishing sector, vessels are predominantly of low capacity, and tuna fishing and preservation technologies remain traditional. Additionally, the relatively long duration of fishing trips adversely affects the quality of tuna upon landing [3].

To ensure sustainable long-term export potential, it is imperative to control product quality and minimize energy consumption during processing. Achieving this requires determining the thermal load and freezing time-based on calculations of key physical parameters such as specific heat capacity (c), density (ρ), thermal diffusivity (a), thermal conductivity (λ), and enthalpy (h). Among these parameters, establishing a model for the thermal conductivity (λ) is the most challenging due to food products' complex, heterogeneous, and anisotropic structure. Numerous mathematical models have been developed to determine the thermal conductivity λ(t) and thermal diffusivity a(t) of food products [4]–[10], [11]–[16].

However, applying these models requires detailed knowledge of the physicochemical composition of the food, which poses significant challenges in sample analysis. Therefore, in this study, the thermophysical properties, including the thermal conductivity (λ), thermal diffusivity (a), and specific heat capacity c_p of Vietnamese tuna, were determined using the heat pulse method within the temperature range t = (-15 ÷ 20) °C.

II. Materials and Methods

A. Materials

The Vietnamese tuna samples were purchased in Ho Chi Minh City and were rectangular blocks with dimensions of (140×100×70) mm, and a weight range of M = (1400÷1800) g. The physicochemical composition of the tuna samples, averaged from three replicates, was analyzed at Khue Nam Science and Technology Service Co., Ltd., and is presented in Table 1.

B. Measurement equipment

Determining thermophysical properties using the heat pulse technique, also known as the dual-needle probe method, is widely applied in food processing technology. This technique offers significant advantages, including a short

 EISSN: 2961-872X ● PISSN: 2961-8924 ● DOI: 10.56741/IISTR.esl.00902

experimental duration and suitability for small-sized samples [17]–[22].

TABLE 1. PHYSICOCHEMICAL COMPOSITION OF VIETNAMESE TUNA SAMPLES

No.	Component	Unit	Result			
			Sample 1	Sample 2	Sample 3	Average
1	Protein	%	15.6	24.3	21.9	20.6
2	Total fat	%	0.84	0.64	0.84	0.77
3	Carbohydrate	%	0.00	0.00	0.00	0.00
4	Total ash	%	0.76	1.36	1.36	1.16
5	Moisture content	%	82.8	73.7	75.9	77.5

As such, it is well-suited for measuring the thermal conductivity of tuna. Using this method, the thermal conductivity and the thermal diffusivity are determined simultaneously based on the line heat source principle. The line heat source is created using a resistance wire with an extremely small diameter embedded in the sample, which is treated as a "thermally infinite medium" (Fig. 1).

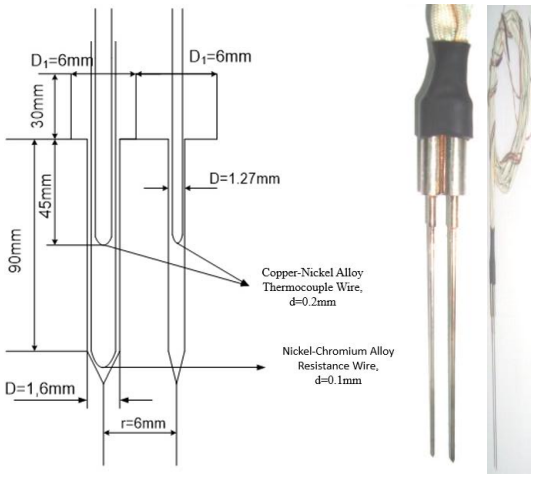


Fig. 1. Equipment for measuring thermal conductivity and thermal diffusivity

A summary of the estimated uncertainties associated with experimental instruments and derived parameters is presented in Table 2.

TABLE 2. MEASUREMENT UNCERTAINTY AND INSTRUMENTATION ACCURACY

Parameter	Instrument / Specification	Estimated Uncertainty
Temperature control	Thermally controlled chamber	±0.3 K
Air velocity	Internal flow: 0.2 ± 0.02 m/s	±0.02 m/s
Time resolution (data logging)	Automated system, $\Delta\tau$ = 5 s	±0.5 s (sampling precision)
Sample temperature stabilization	Pre-conditioned in chamber for 2–24 h	Negligible
Thermal conductivity	Dual-needle probe (L = 9 cm, d = 0.16/0.127 cm; L/d ≥ 25)	<1%
Thermal diffusivity	Derived from pulse method and modeling	±5 ÷ 10%
Current stability	Current range: 0.1–4 A, controlled	±0.05 A (estimated)

When maintaining a constant power output from the heat source, a defined thermal field is generated within the sample. In this process, heat flux propagates cylindrically from the source along the oz-axis, representing the heat conduction process. The temperature field within the sample is a function of time t and radius r from the source. The mathematical model describing the heat conduction process is given as follows Equation (1).

$$\begin{cases} \dfrac{\partial T}{\partial \tau} = a\left(\dfrac{\partial^2 T}{\partial r^2} + \dfrac{1}{r}\dfrac{\partial T}{\partial r}\right) \\ T(r, \tau = 0) = T_0 = \quad \text{const} \\ T(r \to \infty, \tau) = T_0 = \quad \text{const} \\ \lim\limits_{r \to 0} 2\pi\lambda \dfrac{\partial T(r, \tau)}{\partial r} = -q' = \quad \text{const} \end{cases} \tag{1}$$

The solution to Equation (1), as determined by Carslaw and Jaeger [23], was expressed as follows Equation (2).

$$\Delta T = \frac{q}{2 \times \pi \times \lambda} \int_{\beta}^{\infty} \frac{\exp(-\beta^2)}{\beta} d\beta \tag{2}$$

where:

β: Dimensionless parameter, defined in Equation (3);

$$\beta = \frac{r}{2\sqrt{(a \times \tau)}} \tag{3}$$

r: The distance between the two probes (m);
a: Thermal diffusivity ($m^2.s^{-1}$);
t: Time (s).

To determine the thermal diffusivity (a), Nix et al. (1967) [18] solved Equation (3), yielding the result expressed in Equation (4).

$$\Delta T = \frac{q}{2 \times \pi \times \lambda}\left[-\frac{C_e}{2} - \ln(\beta) + \frac{\beta^2}{2 \times 1!} - \frac{\beta^4}{4 \times 2!} + \ldots\right] \tag{4}$$

where:

$\theta = t_1 - t_0$: Temperature difference relative to the initial temperature;
$\ln\gamma = C_e = 0.57721$: Euler's constant.

Equation (4) is utilized to determine the thermal diffusivity (a). According to Nix et al. [18], for convergence when solving the equation, the first 40 terms must be considered if 0.16 < β < 3.1; otherwise, if β < 0.16, only the first two terms are sufficient. The parameter β is obtained using the Goal Seek function in Microsoft Excel. From the experimentally obtained β value, substituting into Equation (3) allows for calculating the thermal diffusivity (a).

The thermal conductivity is determined based on the temperature increase in the probe measuring thermal conductivity during the heating period. According to B. K. Kumbhar, R. S. Agarwal, and K. Das [20], the thermal conductivity is calculated from the temperature variation over the time interval τ_1 to τ_2 using Equation (5).

$$\lambda = \frac{q_1}{4\pi(t_2 - t_1)} \ln\left(\frac{\tau_2 - \tau_o}{\tau_1 - \tau_o}\right) \tag{5}$$

where:

λ: Thermal conductivity, $W.m^{-1}.K^{-1}$;
q_1: Heat flux density, $W.m^{-1}$;
t_1 và t_2: Temperatures (°C) corresponding to times τ_1 and τ_2 (s);
τ_o: Correction time (s).

III. Experimental Determination of the Conductivity and Thermal Diffusivity

A. Experimental setup

The thermal conductivity and thermal diffusivity were determined using the heat pulse method. Experiments were conducted on three different tuna samples with identical geometric dimensions and mass within the temperature range t = (-15÷20) ºC. The experimental samples, along with the measuring equipment, were placed in a thermally controlled chamber for (2÷24) hours to achieve and stabilize the sample temperature before measurement.

The experiments to determine the thermal conductivity and thermal diffusivity were conducted at the Department of Refrigeration and Air-Conditioning Technology, Ho Chi Minh City University of Technology.

The experimental chamber was a thermally insulated closed space with dimensions: Length×Width×Height (407×279×298) mm, operating within a working temperature range of t = (-75÷200) ºC with a temperature control error of $\overline{\Delta T}$=±0.3[K]. The air velocity inside the experimental space was maintained at $\overline{\omega}$=(0.2±0.02)m.s^{-1}.

Data acquisition for all measurements was automated, with data recorded at time intervals of Δτ = 5s. The experimental setup and the connection of measurement devices are shown schematically in Fig. 2.

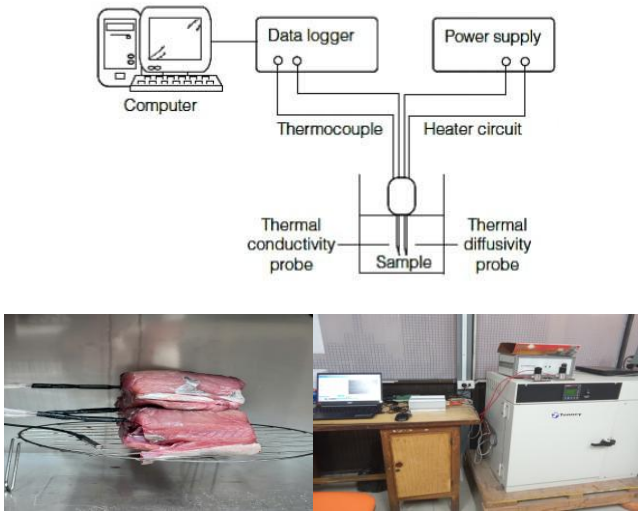


Fig. 2. Schematic of the measurement device connection

B. Experimental results

The experimental results for thermal conductivity λ(t) and thermal diffusivity a(t) of tuna within the temperature range t = (-15÷20) ºC, obtained from three samples with identical dimensions and mass, are presented in Table 3.

Based on the experimentally determined values of λ(t) and a(t), the specific heat capacity of tuna was indirectly calculated using the following Equation (6).

$$c_{exp}(t) = \frac{\lambda(t)}{a(t)\cdot\rho(t)} \quad (6)$$

For density, experimental determination was not performed within the scope of this study. Instead, the formula proposed by Choi and Okos [10], which is based on the physicochemical composition of tuna, employed the following Equation (7).

$$\rho = \frac{1-\varepsilon}{\sum_{i=1}^{n}\frac{x_i^w}{\rho_i}} \quad (7)$$

Table 3. Experimental Results for Thermal Conductivity and Thermal Diffusivity of Tuna

No.	Temperature t (ºC)	Thermal conductivity λ_{exp} (W.m^{-1}K^{-1})	Thermal diffusivity a_{exp} (m^2.s^{-1})	Density ρ (kg.m^{-3})	Specific heat capacity c_{exp} (J.kg^{-1}.K^{-1})
1	20	0.394	1.04E-07	1055.27	3590.04
2	15	0.406	1.120E-07	1056.19	3432.15
3	10	0.413	1.157E-07	1056.96	3377.21
4	5	0.427	1.160E-07	1057.55	3480.72
5	3	0.462	1.22E-07	1057.74	3580.17
6	0	0.476	1.120E-07	1057.98	4017.08
7	-2	0.495	1.30E-07	1058.10	3598.62
8	-3	0.601	1.111E-08	1021.66	52948.54
9	-5	0.826	3.55E-08	1006.57	23115.74
10	-7	1.028	7.812E-08	1002.40	13127.74
11	-10	1.103	1.420E-07	999.77	7769.39
12	-15	1.103	2.60E-07	997.96	4250.98

C. Evaluation of experimental resutls

Based on the experimental results presented in Table 3, the errors between experimental outcomes and established theoretical models were evaluated. According to Fricke [24], thermophysical property models are highly reliable for predicting food properties. These include: (1) thermal conductivity (λ) calculated using the Levy model [7]; (2) thermal diffusivity (a) determined using the model by Choi and Okos [10]; and (3) specific heat capacity (c) calculated based on the Schwartzberg model [5].

Levy [7] developed a model for determining the thermal conductivity, which considers two components, as shown in Equation (8).

$$\lambda = \frac{\lambda_2\left[(2+\Lambda)+2(\Lambda-1)F_1\right]}{(2+\Lambda)-(\Lambda-1)F_1} \quad (8)$$

where:

Λ: The ratio of the thermal conductivity of two components (Λ=λ_1/λ_2);

λ_1: Thermal conductivity of component 1;

λ_2: Thermal conductivity of component 2;

F: A parameter established by Levy (1981) and calculated using Equation (9).

$$F_1 = 0{,}5\left\{\left(\frac{2}{\sigma}-1+2R_1\right)-\left[\left(\frac{2}{\sigma}-1+2R_1\right)^2-\frac{8R_1}{\sigma}\right]^{0,5}\right\} \quad (9)$$

where:

x_1: Mass fraction of component 1;

ρ_1: Density of component 1;

R_1: Volume fraction of component 1,

$$R_1 = \left[1+\left(\frac{1}{x_1}-1\right)\left(\frac{\rho_1}{\rho_2}\right)\right]^{-1};\ \sigma = \frac{(\Lambda-1)^2}{(\Lambda+1)^2+\frac{\Lambda}{2}}.$$

Choi and Okos [10] proposed a model for determining the thermal diffusivity a, expressed in Equation (10).

$$a = \sum a_i x_i^w \quad (10)$$

where:

a_i: Thermal diffusivity of component i;

x_i^w: Mass fraction of component i.

 EISSN: 2961-872X ● PISSN: 2961-8924 ● DOI: 10.56741/IISTR.esl.00902

According to Schwartzberg [5], specific heat capacity is calculated as follows in Equation (11).

$$c_p = c_{pu} + (bX_s - X_{wo})\Delta c_p + EX_s\left(\frac{Rt_0^2}{18(t_{cr}-t)^2 - 0.8\Delta c_p}\right) \quad (11)$$

where:

c_p: Specific heat capacity;

c_{pu}: Specific heat capacity above the freezing point;

X_s: Dry matter fraction;

X_{wo}: Water fraction;

$M_s = \frac{x_s RT_{cr}^2}{-(x_{wo}-x_b)L_0 t_f}$: Molecular weight of the dry matter;

$x_{ice} = \frac{x_s RT_0^2}{M_s L_0}\frac{(t_f - t)}{t_f t}$: Ice fraction;

$x_b = 0{,}4x_p$: Non-frozen water fraction;

$E = \frac{M_w}{M_s}$: Ratio of molecular weight of water to the molecular weight of the dry matter;

$\Delta c = c_w - c_{ice}$: Difference in specific heat capacity between water and ice;

$x_i^v = \frac{x_i/\rho_i}{\sum_{i=1}^{n}(x_i/\rho_i)}$: Volume fraction.

The calculated thermophysical properties of tuna, based on theoretical models, are presented in Table 4.

TABLE 4. THERMOPHYSICAL PROPERTIES OF TUNA BASED ON THEORETICAL MODELS

No.	Temperature t (°C)	Thermal conductivity λ (W.m^{-1}K^{-1})	Thermal diffusivity a (m^2.s^{-1})	Density ρ (kg.m^{-3})	Specific heat capacity c_p (J.kg^{-1}.K^{-1})
1	20	0.419	1.079E-07	1055.27	3683.99
2	15	0.424	1.092E-07	1056.19	3682.25
3	10	0.429	1.1034E-07	1056.96	3680.70
4	5	0.433	1.1139E-07	1057.55	3679.35
5	3	0.435	1.1179E-07	1057.74	3678.86
6	0	0.437	1.133E-07	1057.98	3678.19
7	-2	0.435	1.127E-07	1058.10	3652.28
8	-2.2	0.435	3.839E-09	1058.12	107229.50
9	-3	0.622	1.038E-08	1021.66	58676.04
10	-5	0.864	3.818E-08	1006.57	22502.09
11	-7	0.984	7.850E-08	1002.40	12510.45
12	-10	1.083	1.513E-07	999.77	7160.037
13	-15	1.184	2.790E-07	997.96	4208.36

Based on the experimental results (Table 3) and theoretical calculations (Table 4), the error between the experimental and theoretical results was determined using Equation (12).

$$E(\%) = \frac{1}{n}\sum_{i=1}^{n}\left|\frac{V_{exp} - V_m}{V_{exp}}\right| \quad (12)$$

where:

n: Number of experiments;

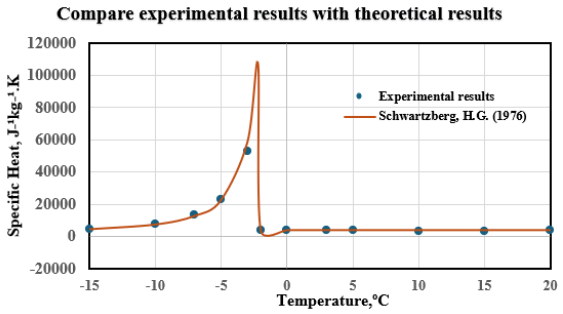
V_{exp}: Experimental result;

V_m: Result from the theoretical model.

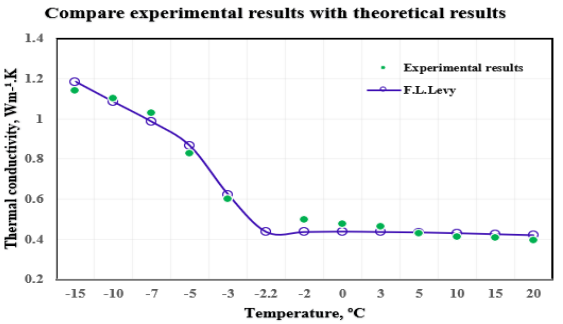
Using Equation (12), the errors between theoretical and experimental results are shown in Table 5 and Fig. 3.

TABLE 5. THE ERRORS BETWEEN THEORETICAL AND EXPERIMENTAL RESULTS

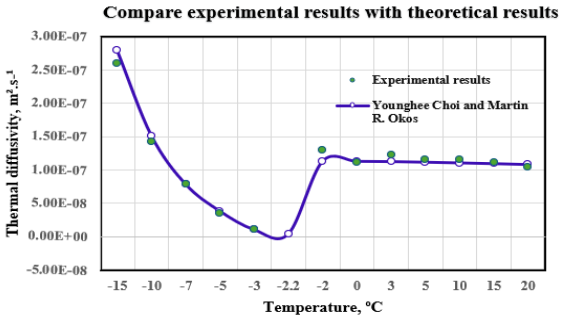
No.	Temperature t (°C)	Thermal conductivity (%)	Thermal diffusivity (%)	Specific heat capacity (%)
1	20	-5.9	-3.6	-2.6
2	15	-4.3	2.6	-6.8
3	10	-3.7	4.8	-8.2
4	5	-0.02	3.9	-5.4
5	3	6.2	9.1	-3.0
6	0	8.8	-1.1	9.2
7	-2	13.7	15.3	-1.5
8	-2.2	---	---	---
9	-3	-3.4	7.0	-9.7
10	-5	-4.4	-7.0	2.7
11	-7	4.5	-0.5	4.9
12	-10	1.8	-6.2	8.5
13	-15	-3.7	-6.8	1.1



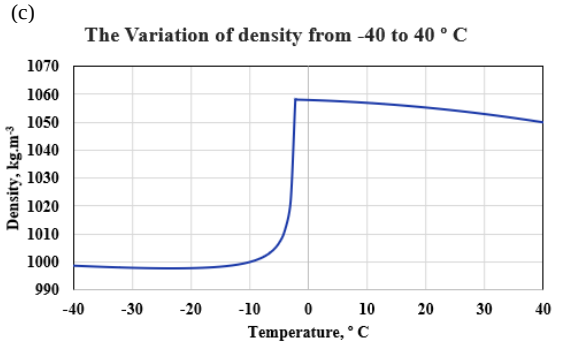
(a)



(b)



(c)



(d)

Fig. 3. Compare experimental with theoretical results of (a) specific heat, (b) thermal conductivity, (c) thermal diffusivity; and (d) the variation of density from -40 to +40 °C

IV. Discussion

Based on the results presented in Table 5, the discrepancies between theoretical and experimental data for the thermal conductivity range between (1.8÷13.7) %, thermal diffusivity (0.5÷15.3) %, and specific heat capacity (1.1÷11.4) %. However, these results are deemed acceptable considering the structural and compositional complexity of food materials and especially in the freezing zone, this result is acceptable. At the freezing point, due to the limited sensitivity of the measuring device, the physical parameters at this point could not be determined.

Furthermore, prior research conducted by our team on Pangasius hypophthalmus using the same dual-needle heat-pulse sensor method supports the adaptability of this approach to other seafood types [22]. This indicates promising potential for comparative studies across species.

Additionally, the incorporation of phase-change energy measurements, such as through Differential Scanning Calorimetry (DSC), is anticipated to significantly enhance the modeling of freezing dynamics. This integration is considered for future studies to enable direct quantification of latent heat and further improve the precision of thermal property estimation.

V. Conclusion

Based on the line heat source method, the thermophysical properties of Vietnamese tuna were determined using a dual-needle heat pulse sensor. Due to the complex composition and structure of food materials, the deviation between experimental results and theoretical models is considered acceptable. Across the temperature interval t = (-15 ÷20) ^{o}C, the thermophysical properties of tuna were determined as follows:

- Thermal conductivity λ= (0.394÷1.103) W.m^{-1}.K^{-1};
- Thermal diffusivity a = (1.111.10^{-8}÷2.60.10^{-7}) m^{2}. s^{-1}; and
- Specific heat capacity c_p = (3377.21÷52948.54) J. kg^{-1}.K^{-1}.

These are the first thermophysical property data for tuna obtained using the dual-needle heat pulse method. Based on the data obtained, these properties can be applied in calculations for the freezing and cold storage processes of tuna products in Vietnam. Moreover, we intend to incorporate Differential Scanning Calorimetry (DSC) to directly measure enthalpy changes during freezing. This will complement the dual-needle heat-pulse technique and provide more comprehensive data for optimizing freezing processes in dynamic systems.

References

[1] T. V. Nguyen, M. Simioni, C. Le Quyen, and H. P. Valtýsson, "Productivity, technical efficiency, and technological change in Vietnamese oceanic tuna fisheries," *Fish. Res.*, vol. 248, p. 106202, Apr. 2022.

[2] K. A. Thi Nguyen and C. M. Jolly, "Balancing interests of actors in the ocean tuna value chain of Khanh Hoa province, Vietnam," *Mar. Policy*, vol. 98, pp. 11–22, Dec. 2018.

[3] T. V. Nguyen and T. Q. Tran, "Management of multispecies resources and multi-gear fisheries: The case of oceanic tuna fisheries in Vietnam," *Reg. Stud. Mar. Sci.*, vol. 63, p. 103021, Oct. 2023.

[4] K.-I. Hayakawa and A. Bakal, "New Computational Procedure for Determining the Apparent Thermal Diffusivity of a Solid Body Approximated With an Infinite Slab," *J. Food Sci.*, vol. 38, no. 4, pp. 623–629, 1973.

[5] H. G. Schwartzberg, "Effective Heat Capacities for the Freezing and Thawing of Food," *J. Food Sci.*, vol. 41, no. 1, pp. 152–156, 1976.

[6] G. Tchigeov, "Thermophysical processes in food refrigeration technology," *Food Ind.*, pp. 19–2, 1979.

[7] G. Tchigeov, "Thermophysical processes in food refrigeration technology," *Food Ind.*, pp. 19–2, 1979.

[8] F. L. Levy, "Calculating the thermal conductivity of meat and fish in the freezing range," *Int. J. Refrig.*, vol. 5, no. 3, pp. 149–154, May 1982.

[9] B. H. Han and M. Loncin, "Thermal diffusivities of fish products," *Leb. Technol. 18*, pp. 159–163, 1985.

[10] Y. O. M. R. Choi, "Effects of temperature and composition on the thermal properties of foods," *Transp. Phenom.*, pp. 99–101, 1986.

[11] V. Latyshev, "Scientific thermophysical fundamentals of refrigerated processing and storage of foods," *Dr. Diss. D. Sc. Thesis, SPTIHP, St. Petersbg.*, p. 44, 1992.

[12] K. A. Fikiin, "Ice content prediction methods during food freezing: A survey of the Eastern European literature," *J. Food Eng.*, vol. 38, no. 3, pp. 331–339, 1998.

[13] K. A. Fikiin and A. G. Fikiin, "Predictive equations for thermophysical properties and enthalpy during cooling and freezing of food materials," *J. Food Eng.*, vol. 40, no. 1, pp. 1–6, 1999.

[14] D. T. L. Pham, Q. T., H. K. Wee, R. M. Kemp, "Determination of the Enthalpy of Foods by an Adiabatic Calorimeter," *J. Food Eng. 21*, vol. 1, pp. 137–156, 2014.

[15] Q. T. Pham, "Calculation of Bound Water in Frozen Food," *J. Food Sci.*, vol. 52, no. 1, pp. 210–212, 1987.

[16] Q. T. Pham, "Prediction of thermal conductivity of meats and other animal products from composition data," *Eng. food 1*, pp. 408–423, 1990.

[17] E. F. M. Van der Held and F. G. Van Drunen, "A method of measuring the thermal conductivity of liquids," *Physica*, vol. 15, no. 10, pp. 865–881, 1949.

[18] G. H. Nix, G. W. Lowery, R. I. Vachon, and G. E. Tanger, "Direct determination of thermal diffusivity and conductivity with a refined line-source technique," no. 67, 1967.

[19] G. H. Nix, R. I. Vachon, G. W. Lowery, and T. A. McCurry, "The line-source method: procedure and iteration scheme for combined determination of conductivity and diffusivity," *Proc. 8th Conf. Therm. Conduct. Plenum Press. NY.*

[20] B. K. Kumbhar, R. S. Agarwal, and K. Das, "Thermal properties of fresh and frozen fish," *Int. J. Refrig.*, vol. 4, no. 3, pp. 143–146, May 1981.

[21] E. G. Murakami, V. E. Sweat, S. K. Sastry, and E. Kolbe, "Analysis of various design and operating parameters of the thermal conductivity probe," *J. Food Eng.*, vol. 30, no. 1–2, pp. 209–225, Oct. 1996.

[22] D. H. Hoang, N. V. Dung, and H. T. N. Huong, "Determining the Thermal Properties of the Pangasius Using a Dual Needle Heat-Pulse Sensor," *Appl. Mech. Mater.*, vol. 907, pp. 79–87, 2022.

[23] H. S. Carslaw and J. C. Jaeger, "Conduction of heat in solids," 1959.

[24] P. Taylor, B. A. Fricke, and B. R. Becker, "Evaluation of Thermophysical Property Models for Foods," no. November 2013, pp. 37–41, 2011.

 EISSN: 2961-872X ● PISSN: 2961-8924 ● DOI: 10.56741/IISTR.esl.00902