Engineering Letters, 25:4, EL_25_4_12

The Effect of Moisture Content, Temperature and Variety on Specific Heat of Edible-Wild Mushrooms: Model Construction and Analysis

Soraya Saenmuang, Arpassorn Sirijariyawat, and Nattapol Aunsri*, *Member, IAENG*

Abstract—**Specific heat is a property of foods materials needed for analysis and design processes involving heat transfer. The specific heat of edible-wild mushrooms as affected by moisture content, temperature and mushroom variety was investigated in this paper. The ranges of moisture content and temperature studied in this paper were 0.05-0.80 kg water/kg sample and 10-90°C. The significant of the studying factors was analyzed and the regression analysis was then performed to determine the best model for predicting specific heat. The statistical analysis and software were performed and used for the judgment of the degree of accuracy of the fitted models. A linear function of specific heat with moisture content and temperature was proposed and model efficiency was evaluated statistically. The obtained model obviously outperformed the other conventional models and was found to be successful in much better specific heat prediction of mushroom varieties which will be very useful in practical use of mushrooms in industry**.

Index Terms—**Edible-wild mushrooms, specific heat, thermal properties, mathematical models, food engineering.**

I. INTRODUCTION

Specific heat, defined as the amount of heat gained or lost by a unit mass of material to accomplish a unit change in temperature, is a property of foods materials needed for analysis and design processes involving heat transfer. These processes include cooling, freezing, heating and drying as found in post-harvest handlings and product processing, storage and distribution. The accurate specific heat data will allow food scientists and engineers to calculate the heat transfer precisely leading to the effective food process design including equipment design and implementation. Eventually, the energy used in the food processes can be optimized to provide the best food products quality.

Due to a limit number of specific heat data of foods available in literatures, hence, the specific heat of foods is normally obtained by predictive models. Work reported in [1] provided the comprehensive models to predict specific heat of foods based on compositions (i.e., moisture, protein, fat, fiber, ash and carbohydrate) and temperature. However, since structure of foods is different among various food materials, the specific heats of foods are still different even they have the same composition. Therefore, the predictive models for a particular food have been presented recently. Furthermore, because water is a major component of foods and it has the highest specific heat in comparison to the other components; to simplify the predictive model but still keep the most influent factors, most of those models, therefore, described the specific heat as a function of moisture content and temperature [2], [3], [4], [5], [6], [7], [8], [9], [10], [11], [12], [13], [14], [15].

Mushroom is known as a food with unique taste and high nutritive values. Due to the increase in demand of the healthy food recently, the mushroom market is growing continuously, not only the well-known common mushrooms but also the edible-wild mushrooms from many countries. This stems from the fact that they deliver subtle flavor and are known as the alternative sources of nutrients and bioactive compounds [16], [17], [18], [19], [20]. However, mushroom is a perishable food, the suitable handling and processes are, therefore, required in such a way that the extension of its shelf-life can be achieved effectively. These handling processes normally involve heat transfer such as cooling, freezing, sterilizing, and drying, in which thermal properties as specific heat are needed for the design of these processes.

For the specific heat of mushrooms, nevertheless, only a few sources of data of common mushrooms were published [21], [22], [23]. However, the study in specific heat of edible-wild mushrooms is not yet available in literatures. The high demand of mushrooms in food industry and the small number of studies about edible-wild mushrooms reported recently brought to the importance of this work. In this study, the effect of moisture content, temperature and variety on specific heats of selected edible-wild mushrooms was investigated and the empirical models were developed. The obtained data from the study will definitely be useful for proper design of the processes of mushrooms related to heat transfer, i.e., good products quality and the efficient use of energy resources.

The rest of the paper is organized as follows. Sect. II provides the materials and methods used in this work including sample preparation, proximate analysis, and the determination of specific heat. In Sect. III, it discusses the

---

Manuscript received June 1, 2017; revised November 1, 2017. This work was supported by Kasetsart University Research and Development Institute, Thailand.

S. Saenmuang is with the Faculty of Natural Resources and Agro-Industry, Kasetsart University, Chalermphrakiat Sakon Nakhon Province Campus, Sakon Nakhon, 47000, Thailand (e-mail: csnsry@ku.ac.th)

A. Sirijariyawat is with the Faculty of Natural Resources and Agro-Industry, Kasetsart University, Chalermphrakiat Sakon Nakhon Province Campus, Sakon Nakhon, 47000, Thailand (e-mail: csnaps@ku.ac.th)

N. Aunsri is with the School of Information Technology, Mae Fah Luang University, Chiang Rai, 57100, Thailand (e-mail: nattapol.aun@mfu.ac.th)

* Author to whom correspondence should be addressed.

experimental design and analysis for our work. Results and discussion are presented in Sect IV. Finally, the conclusions of the paper can be found in Sect. V.

II. MATERIALS AND METHODS

A. Sample Preparation

Four edible-wild mushrooms, i.e., *Lentinus polychrous*, *Astraeus hygrometricus*, *Termitomyces globules* and *Amanita hemibapha*, were collected from local markets in North-Eastern area of Thailand. The fresh mushrooms were cleaned by running tap water and dried out by placing on screen to remove excess water on the surfaces. The cleaned mushrooms were then sampled for proximate analysis. For the specific heat determination purpose, the cleaned mushrooms were cut into small pieces and dried at 70°C in a hot air oven in order to get the samples with different moisture contents of 0.05, 0.20, 0.40 and 0.80 kg water/ kg sample. These samples were then packed in hermitical seal aluminum foil bags and kept at 4°C overnight for equilibrating the moisture contents before operating the specific heat determination.

B. Proximate Analysis

Since the specific heat of foods is reported to be affected by their compositions, hence, in this study, proximate composition of the studying mushrooms was analyzed. The proximate analysis was carried out by AOAC methods [24] described as follows. The moisture content was analyzed by hot air oven method at 105°C; protein was analyzed by Kjeldahl method in which the conversion factor of 4.38 was used to quantify the protein content [19]; fat was analyzed by Soxhlet extraction method using petroleum ether; fiber was analyzed by ceramic fiber filter method; ash was analyzed by muffle furnace method at 550°C; and carbohydrate was calculated by the following equation,

$$\begin{aligned}&\%(carbohydrate) = \%(dry\ matter)\\ &- [\%(protein) + \%(fat) + \%(fiber) + \%(ash)]\end{aligned} \tag{1}$$

where *%(carbohydrate)* is the percentage of carbohydrate, *%(dry matter)* represents the percentage of dry matter; *%(protein)*, *%(fat)*, *%(fiber)*, *%(ash)*, represents the percentages of protein, fat, fiber, and ash, respectively.

C. Specific Heat Determination

Practically the specific heat of a mushroom is determined by differential scanning calorimeter (DSC) (Mettler Toledo STARe System DSC 1 Module, Mettler Toledo, Switzerland). In DSC, the difference of the amount of heat required for increasing the temperatures of a sample cell and a referent cell to the same temperature must be measured. For this study, in order to determine the specific heat of samples, three measurement settings have been made: blank (empty crucible) in which a base line was recorded, standard with known specific heat where a sapphire (α-Al_2O_3) was used, and samples with different moisture contents. The three measurements were subjected to heat from 5°C to 105°C with heating rate of 5°C/min. The heat flow against temperature was recorded from 10-90°C and the specific heats of samples were calculated as follows:

$$C_p = \frac{D}{D_s}\frac{m_s}{m}C_{ps}, \tag{2}$$

where C_p stands for specific heat of sample in kJ/kg°C, C_{ps} represents the specific heat of sapphire in kJ/kg°C, m is mass of sample in kg, m_s is mass of sapphire in kg, D is the deflection from baseline due to sample in W and D_s is the deflection from baseline due to sapphire in W.

III. EXPERIMENTAL DESIGN AND DATA ANALYSIS

A three factors factorial design was conducted to investigate the effects of moisture content (0.80, 0.40, 0.20 and 0.05 g water/ g sample), temperature (10, 30, 50, 70 and 90°C) and mushroom variety (*Lentinus polychrous*, *Astraeus hygrometricus*, *Termitomyces globules* and *Amanita hemibapha*) on the specific heat. Statistical significance was analyzed by the analysis of variance (ANOVA) at 95% confident interval (P<0.05) (STATISTICA 10.0 Trial Version, StatSoft, Inc., Tulsa, OK, USA).

Once the influenced factors to the specific heat were identified via ANOVA, the relationship of the specific heat to the studying factors was determined by regression analysis (STATISTICA 10.0 Trial Version, StatSoft, Inc., Tulsa, OK, USA) and the best fit model was chosen based on the coefficient of determination (R^2).

After obtaining the fitted model, the accuracy of the fitted model was tested and compared with the general models in literatures. The quantity that is used for interpreting the difference between the predicted and the measured values of specific heat is the root mean square error (RMSE) as given by (3); this quantity is one of the most common quantities widely used for the judgment of the performance of the fitted model or predictor as seen in [25],[26]. The lower values of the RMSE indicate better agreement and vice versa [27].

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(C_{p_{exp}} - C_{p_{pred}})^2} \tag{3}$$

The quantity *RMSE* is a root mean square error, $C_{p\ exp}$ stands for the measured value of specific heat (kJ/kg°C), $C_{p\ pred}$ represents the predicted value of specific heat (kJ/kg°C) and n is number of data points.

IV. RESULTS AND DISCUSSION

A. Effect of Moisture Content, Temperature and Variety

The ANOVA results showed that specific heat of the mushrooms was significantly affected by moisture content, temperature and mushroom variety. And among these factors, moisture content was found to be the most influenced factor to the specific heat with P<0.001, followed by temperature (P<0.01), while mushroom variety had the least effect (P<0.05). Fig.1 illustrates that the specific heat

TABLE I
SPECIFIC HEAT OF MUSHROOMS AT DIFFERENT RANGES OF MOISTURE CONTENT AND TEMPERATURE

Mushrooms	Moisture content (kg water/ kg sample)	Temperature (°C)	Specific heat (kJ/kg °C)
Lentinus polychrous	0.05-0.80	10-90	1.48-2.85
Astraeus hygrometricus	0.05-0.80	10-90	1.15-3.59
Termitomyces globules	0.05-0.80	10-90	1.08-3.19
Amanita hemibapha	0.05-0.80	10-90	1.36-2.99
Volvariella volvaceae [23]	0.30-0.90	50-80	2.28-4.01
Pleurotus florida [22]	0.10-0.90	40-70	1.72-3.95

TABLE II
PROXIMATE COMPOSITIONS OF MUSHROOMS

Mushrooms	Proximate compositions (kg/100 kg dry solid)				
	Protein	Fat	Fiber	Ash	Carbohydrate
Lentinus polychrous	28.7±2.0	4.3±0.5	25.2±3.8	3.9±0.5	37.8±1.9
Astraeus hygrometricus	24.8±0.2	7.4±2.2	35.2±8.8	7.6±0.6	24.9±6.9
Termitomyces globules	31.2±0.3	0.9±0.1	11.4±1.2	4.7±0.9	51.8±0.1
Amanita hemibapha	26.7±0.9	2.4±0.4	14.7±1.1	5.6±0.0	50.5±0.6
Edible-wild mushrooms [19]	14.0-24.2	2.1-2.9	8.3-16.8	6.7-27.6	41.6-65.2
Common mushrooms [16]	4.6-34.8	0.2-8.0	1.4-27.9	0.4-12.6	40.0-92.6

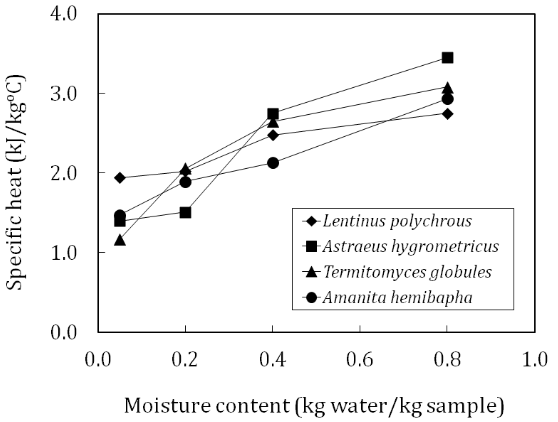

Fig. 1. Average specific heat of mushrooms as a function of moisture contents for temperature range of 10-90°C.

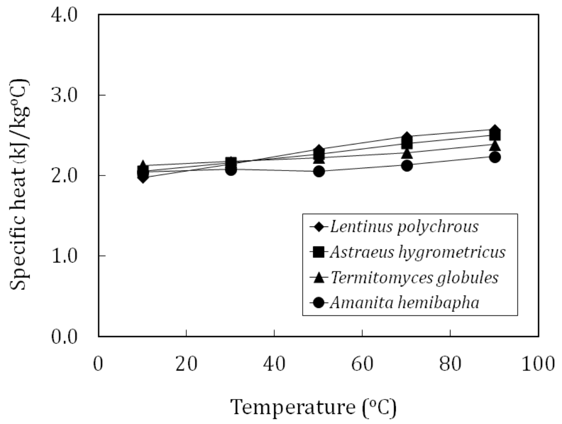

Fig. 2. Average specific heat of mushrooms as a function of temperatures for moisture range of 0.05-0.80 kg water/ kg sample.

of the four mushroom varieties showed marked increase with increasing of moisture content and this is from the fact that water has high specific heat; while Fig.2 reveals that the specific heat of all mushrooms is slightly increased with temperature and this results from the fact that higher energy is needed for rising temperature at higher temperature [1]. Although both factors affect the specific heat, as suggested by the results, the influence of moisture to the specific heat of the edible wild-mushrooms is actually greater than that of the temperature.

In comparing to the specific heat of two common mushrooms previously reported by [22] and [23], it was observed that, as presented in Table I, the four studying mushrooms had lower specific heats than those from the two common mushrooms. This is from what we have mentioned previously that the specific heat is increased with the increment of moisture content and the range of moisture content in this study is lower than those of the previous studies. In addition, it should be noted that for the ranges of moisture content and temperature in the present study, the specific heat values were different with each variety. This implied that the specific heat was significantly affected by different proximate compositions of mushroom varieties. The proximate compositions of the studying mushrooms and compositions ranges of 13 edible-wild mushrooms [19] and common mushrooms, i.e., button mushroom (*Agaricus bisporus*), straw mushroom (*Vovariella volvacea*) and white mushroom (*Pleurotus ostreatus*) [16] are presented in Table II. The table demonstrates the proximate compositions for the wide ranges of compositions depending on types of mushrooms. This allows us to be concerned that the specific heat of mushrooms could be affected by variety due to different compositions.

B. Specific Heat Model Selection

As mentioned that the specific heat of mushrooms was significantly affected by the three factors, however since the mushroom variety is a qualitative factor, hence, this factor should be removed from the model. Consequently, number of empirical equations of specific heat as a function of moisture and temperature for each mushroom variety were then developed. This set of equations is responsible for capturing both the linear and nonlinear structural models of the specific heat as functions of the independent variables mentioned previously. Table III summarizes the results from the regression analysis, a linear function was found to be the best model for all four mushroom varieties as it delivered the highest R^2, and it is the simplest model. It should be observed that although one or two of the nonlinear models also deliver exactly the same R^2 as the linear model does, but the complexity of the nonlinear model exhibits its disadvantage in analysis and practical use. We can conclude that the linear model which is the simplest one is the most effective model as it gives a greatest fitting performance compared to the others. Therefore, a general governed equation describing the relationship between the specific heat and these two parameters that provides the best fit is given by

$$C_p = \mathrm{a} + \mathrm{b}X_w + \mathrm{c}T \tag{4}$$

Quantity X_w is moisture content of sample (kg water/kg sample), T is temperature (^{o}C), and a, b and c are model coefficients. All the fitted coefficients for each mushroom are provided in Table IV. As researches conducted by [22] and [23], it should be observed that the fitted models from them are also linear functions coinciding with the developed model of the four mushrooms in this study.

TABLE III
REGRESSION MODELS OF EACH MUSHROOM

Mushrooms	Models	R^2
Lentinus polychrous	$C_p = 1.5038 + 1.1388X_w + 0.0077T$	0.90
	$C_p = 1.6537 + 1.1388X_w + 0.00007T^2$	0.89
	$C_p = 1.6676 + 1.1821X_w^2 + 0.0077T$	0.82
	$C_p = 1.9976 + 0.0167X_wT$	0.61
	$C_p = 1.9166 + 0.0149X_wT + 0.0023T$	0.63
	$C_p = 1.8882 + 0.6566X_w + 0.0096X_wT$	0.71
	$C_p = 1.3310 + 1.6156X_w + 0.0111T + 0.0095X_wT$	0.90
Astraeus hygrometricus	$C_p = 0.9258 + 2.9464X_w + 0.0057T$	0.92
	$C_p = 1.0325 + 2.9464X_w + 0.00005T^2$	0.92
	$C_p = 1.6676 + 1.1821X_w^2 + 0.0077T$	0.82
	$C_p = 1.6388 + 0.0353X_wT$	0.59
	$C_p = 1.9939 + 0.0432X_wT - 0.0100T$	0.66
	$C_p = 1.2114 + 2.5646X_w + 0.0076X_wT$	0.90
	$C_p = 0.8200 + 3.2384X_w + 0.0078T - 0.0058X_wT$	0.92
Termitomyces globules	$C_p = 1.2245 + 2.3660X_w + 0.0031T$	0.86
	$C_p = 1.2779 + 2.3660X_w + 0.00003T^2$	0.86
	$C_p = 1.5975 + 2.3013X_w^2 + 0.0031T$	0.67
	$C_p = 1.7299 + 0.0279X_wT$	0.54
	$C_p = 2.0822 + 0.0357X_wT - 0.0099T$	0.65
	$C_p = 1.3785 + 2.1089X_w + 0.0051X_wT$	0.86
	$C_p = 1.2168 + 2.3873X_w + 0.0032T - 0.0004X_wT$	0.86
Amanita hemibapha	$C_p = 1.3190 + 1.8732X_w + 0.0022T$	0.98
	$C_p = 1.3526 + 1.8732X_w + 0.00002T^2$	0.98
	$C_p = 1.5751 + 2.0080X_w^2 + 0.0022T$	0.92
	$C_p = 1.7149 + 0.0217X_wT$	0.60
	$C_p = 1.9981 + 0.0280X_wT - 0.0079T$	0.72
	$C_p = 1.4287 + 1.7173X_w + 0.0031X_wT$	0.97
	$C_p = 1.2873 + 1.9607X_w + 0.0028T - 0.0018X_wT$	0.98

TABLE IV
COEFFICIENTS VALUES BASED ON THE FITTED MODEL FOR EACH MUSHROOM

Mushrooms	a	B	c	R^2
Lentinus polychrous	1.5038	1.1388	0.0077	0.90
Astraeus hygrometricus	0.9258	2.9464	0.0057	0.92
Termitomyces globules	1.2245	2.3660	0.0031	0.86
Amanita hemibapha	1.3190	1.8732	0.0022	0.98
Volvariella volvaceae [23]	1.3078	2.6913	0.0043	0.99
Pleurotus florida [22]	1.1027	2.4700	0.0092	0.99

TABLE V
RMSE OF PREDICTED SPECIFIC HEAT VALUES CALCULATED BY DIFFERENT MODELS

Mushrooms	*RMSE*		
	$C_p = \mathrm{a} + \mathrm{b}X_w + \mathrm{c}\,T$	$C_p = \sum_{i=1}^{n} C_{pi} X_i$ [1]	$C_p = 1.5400 + 2.6270\,X_w + 0.0002\,T$ [21]
Lentinus polychrous	0.194	0.568	0.534
Astraeus hygrometricus	0.245	0.516	0.364
Termitomyces globules	0.273	0.498	0.394
Amanita hemibapha	0.062	0.576	0.463

C. Specific Heat Model Validation

Typically, the specific heat of foods can be estimated by the general models based on composition [1], [28], [29] or composition and temperature [1], [21]. Since the temperature presented a significant effect for the range of temperature that we studied, therefore, in this study, the models based on composition and temperature given by (5) [1] and (6) [21] were used to compare with (4) in order to verify an adequacy of the fitted model. The two baseline models are given as

$$C_p = \sum_{i=1}^{n} C_{pi} X_i \tag{5}$$

$$C_p = 1.5400 \;+\; 2.6720\,X_w \;+\; 0.0002\,T \tag{6}$$

Equation (5) is a model that describes the specific heat of foods as a function of compositions, where C_{pi} is a specific heat of the i^{th} component, viz., moisture, carbohydrate, protein, fat , ash and fiber (kJ/kg^{o}C), X_i is a fraction of the i^{th} component (kg/kg sample), n represents number of components in food. It must be noted here that the specific heat of each component, C_{pi}, is also a function of temperature. A simpler model is presented by (6), this model describes specific heat, particularly for most common mushrooms, as a function of moisture content and temperature. Here X_w is moisture content of sample (kg water/kg sample) and T is temperature (^{o}C).

The comparisons of specific heat values calculated from the fitted model of (4) and the two general models of (5)-(6) are presented in Figs. 3-6. For each figure, the specific heat from the fitted model of (4) is illustrated via the solid line; the dash line indicates specific heat from the model given by (5) while the dot line demonstrates the specific heat obtained by (6). We can see clearly from the results that the fitted model delivered the greatest agreement, followed by (6), while the values obtained from (5) introduced the highest error. Table V demonstrates, via root mean square error, how the fitted model outperforms the models of (5)-(6) for all mushrooms varieties, emphasizing the adequacy of our fitted model. Regarding to the models verification result, it could be explained that although (5) is a comprehensive model for foods accounting of all compositions into the model, however, this model was constructed based on the assumption that each composition has the same specific heat, which is not always practical for different structures of composition in different food materials. As a result, the highest errors are obviously observed in Table V. For (6), this model describes specific heat particularly of common mushrooms, the effects of the other compositions except water were neglected, that is, the model was generated based on the assumption that the effect of variety was not significant. Because this model aimed to use for the prediction of specific for mushrooms, consequently, it provides better prediction results than that from the general model for foods of (5). Nonetheless, as described before, the ANOVA result suggested previously that the specific heat of mushrooms is significantly affected by variety in this study, thus the effect of this factor should be considered.

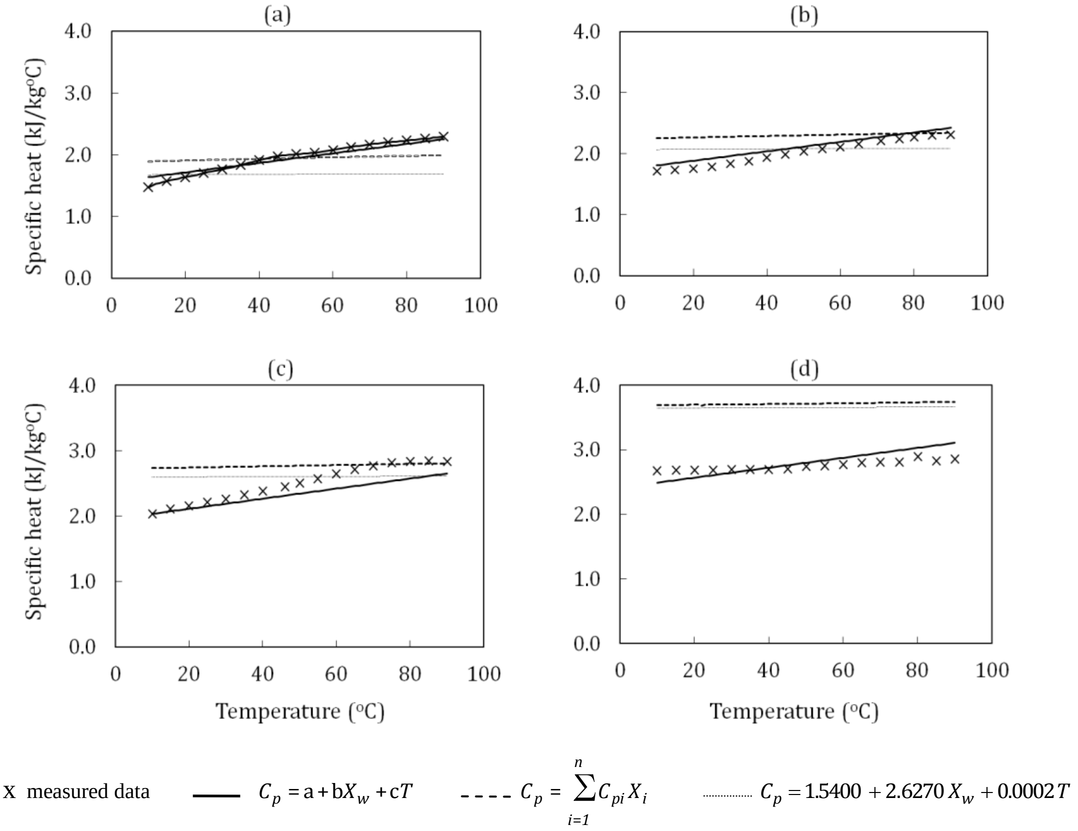

Fig. 3. Predicted and measured specific heats of *Lentinus polychrous* at different moisture contents and temperatures: (a) $X_w = 0.05$ (b) $X_w = 0.20$ (c) $X_w = 0.40$ and (d) $X_w = 0.80$.

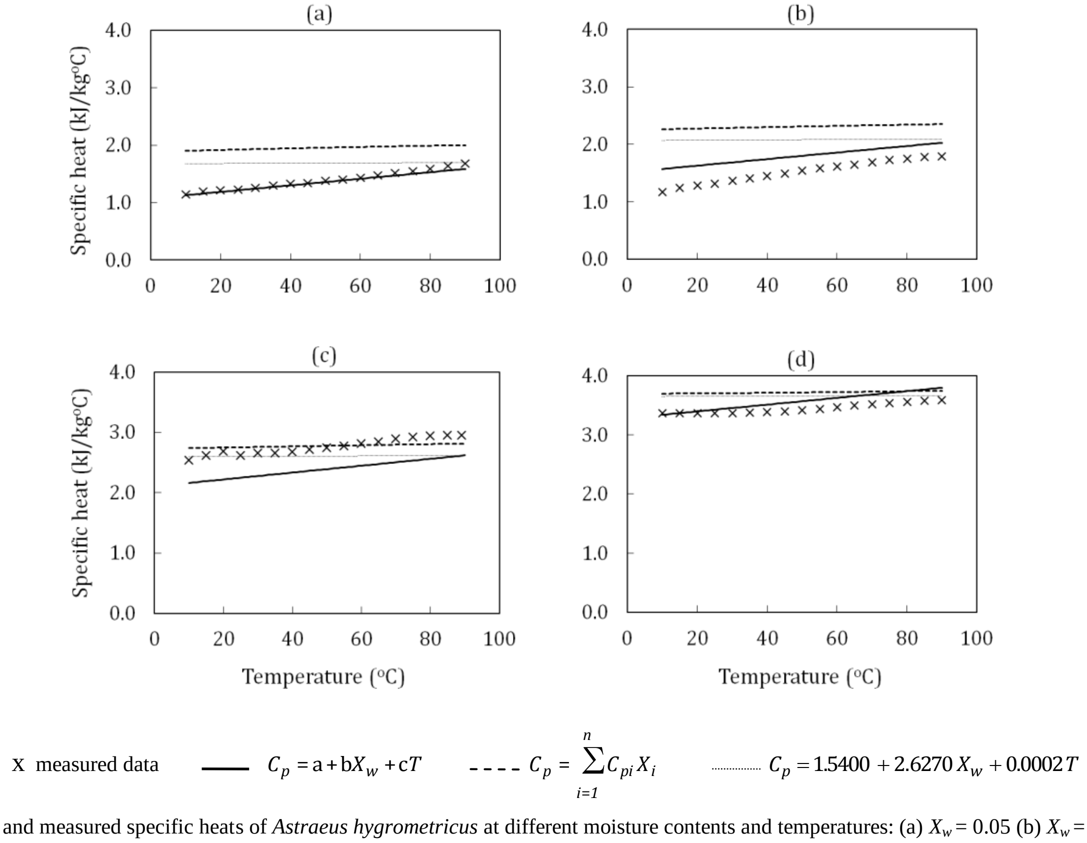

Fig. 4. Predicted and measured specific heats of *Astraeus hygrometricus* at different moisture contents and temperatures: (a) $X_w = 0.05$ (b) $X_w = 0.20$ (c) $X_w = 0.40$ and (d) $X_w = 0.80$.

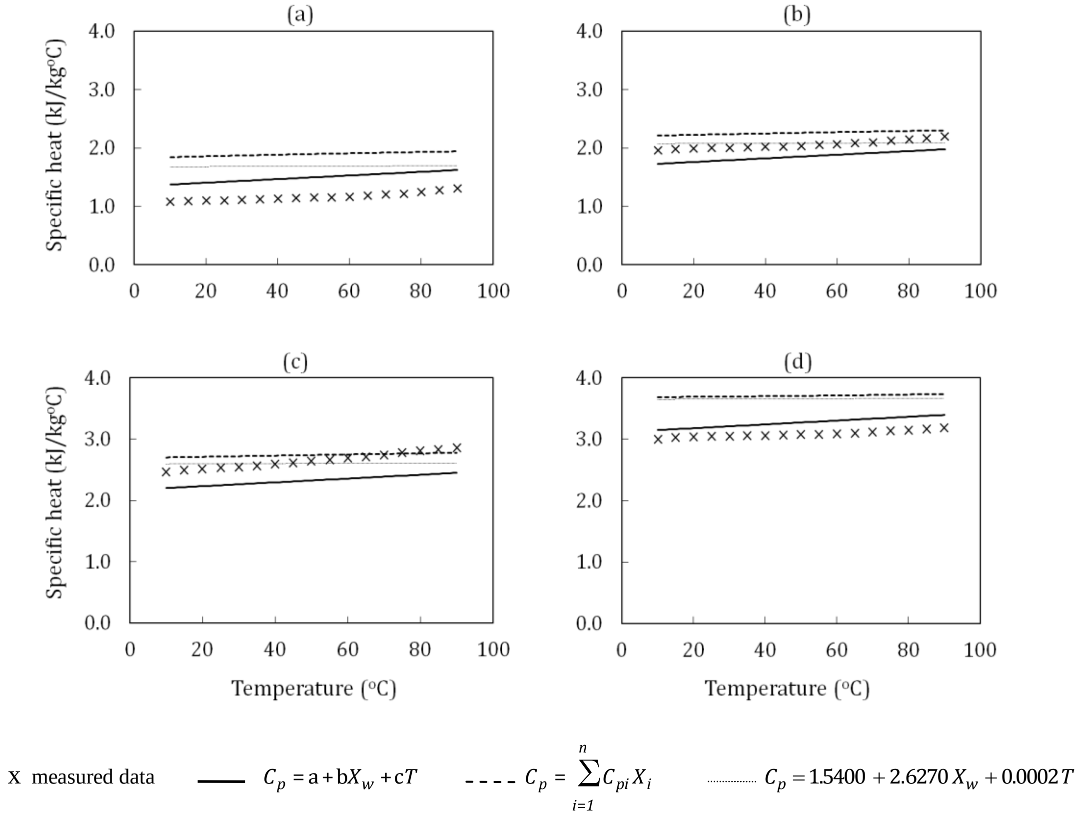

Fig. 5. Predicted and measured specific heats of *Termitomyces globules* at different moisture contents and temperatures: (a) $X_w = 0.05$ (b) $X_w = 0.20$ (c) $X_w = 0.40$ and (d) $X_w = 0.80$.

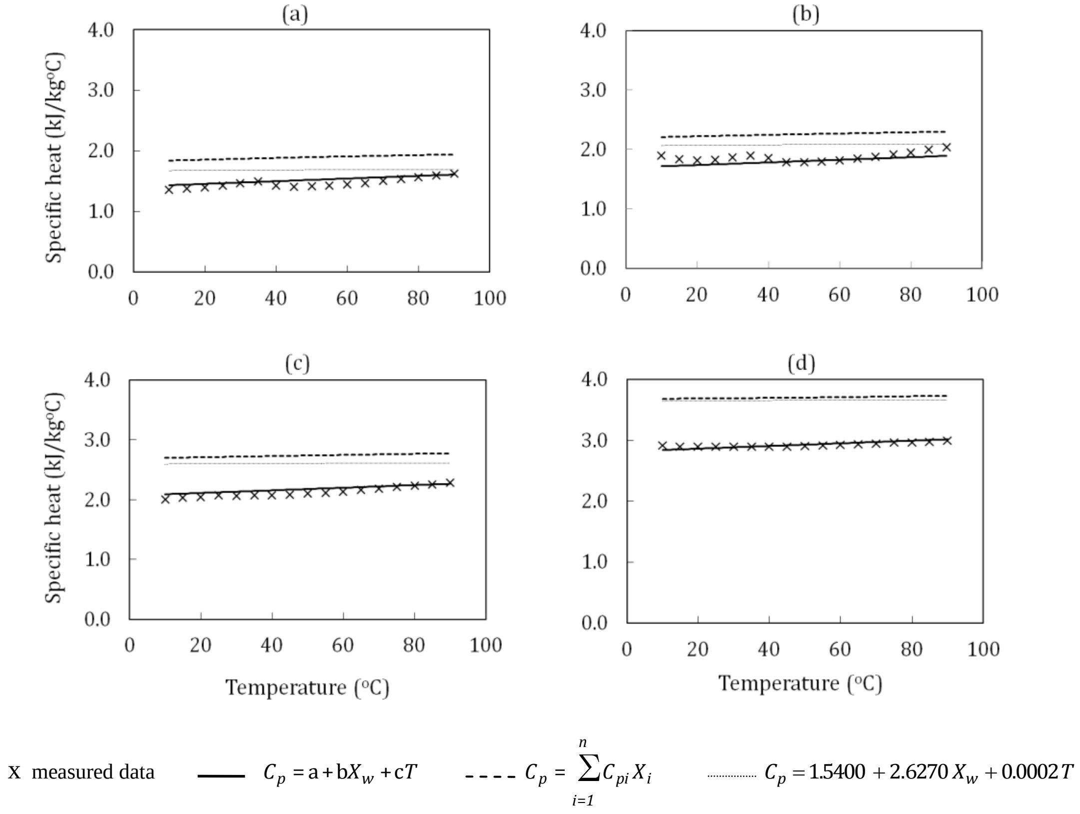

Fig. 6. Predicted and measured specific heats of *Amanita hemibapha* at different moisture contents and temperatures: (a) $X_w = 0.05$ (b) $X_w = 0.20$ (c) $X_w = 0.40$ and (d) $X_w = 0.80$.

The specific heat models of fresh produces as functions of moisture content and temperature have been proposed in several studies. These models are either linear functions as found in berberis fruit, sweet potato, chilli, canola seed, pumkin seed and moringa seed [2], [3], [5], [8], [9], [10], [21] or non-linear functions such as exponential, polynomial, etc. depending on kind of produces, as applied the models for soy bean, mucona seed, saponaria seed, radish seed, alfafa seed, borage seed, red lentil seed [3], [5], [12], [13], [14], [30]. For some kinds of produces, the models are also different among varieties, pistachio nut for example [31] and ranges of moisture and temperature such as canola seed and apple [9], [15], [32]. The diversity of models among produces is mainly due to the difference of proximate compositions. And through these compositions, water is known as the most effect on specific heat, not only amount of water, but also water structure. Work from [32], who studied the effect of moisture content on specific heat of apple, found that the water dependence of specific heat was linear at water content above 0.10 kg water/kg sample, but non-linear at water content lower than 0.10 kg water/kg sample. This can be explained that the water in foods has heterogeneous structure and is divided into free water and bound water. Regarding to different specific heat of the two structures of water and because the water in foods is mostly free water at high moisture content but is bound water at low moisture content; therefore, different ratio of the two structure at different ranges of moisture content must be observed. Consequently, this results in different dependency of specific heat with different moisture content. Fat is another composition highly affect specific heat next to water [28], [29], especially, at low water content. In [33], they investigated the effect of fat content and temperature on specific heat of milk and found that for low fat content of 0.1 kg/100 kg sample, specific heat increases linearly with temperature, but the deviation from linear relationship is increased with the increasing of fat content from 3.5 to 35 kg/100 kg sample due to the phase change of fat. As described above, we can say that for mushrooms, the foods that have low fat content and moderate to high moisture content, the specific heat linearly increases with moisture content and temperature, in which, level of the two factors dependency are different with variety due to different compositions. The fitted model of (4) can be effectively applied for the prediction of specific heat of various mushroom varieties without significant errors.

V. CONCLUSIONS

In this paper, we have investigated the effect of moisture content and temperature on specific heat of selected edible-wild mushrooms. For the ranges of the factors studied, the specific heat of the mushrooms markedly increased with moisture content but slight increased with temperature. This is a significant evidence of the influence of the moisture content and temperature to the specific heat of the mushrooms and this finding plays an important role in analysis and design of the food post-harvesting and processing in order to achieve the highest food production industry involving edible-wild mushrooms. The empirical linear and nonlinear models for specific heat of the mushrooms were then constructed to capture the effect of the moisture content and temperature to the specific heat of the mushrooms. We found that a proposed linear function of specific heat with moisture content and temperature obtained a best performance compared to those of the models previously reported. Finally, we applied the proposed model to predict the specific heats of the mushrooms and then compared the efficiency of the model with the general specific heat models of foods widely used in literatures. Based on the root mean square error, RMSE, the results showed that our model performed excellent agreement to predict the specific heat of various varieties of mushrooms.

ACKNOWLEDGMENT

This work was supported by Kasetsart University Research and Development Institute, Thailand. The authors would also like to thank the School of Information Technology, Mae Fah Luang University for providing its facilities to this work.

REFERENCES

[1] Y. Choi and M. Okos, M. R. “Effect of temperature and composition on the thermal properties of food,” edited M.L. Maguer and P. Jelen. London: Elsevier Applied Science Publishers, 1986.

[2] M. Aghbashlo, M. H. Kianmehrand, and S. R. Hassan-Beyg, “Specific heat and thermal conductivity of Berberis Fruit (*Berberis vulgaris*),” *American Journal of Agricultural and Biological Sciences*, vol.3, no.1, pp. 330-336. 2008.

[3] N. A. Aviara, S. E. Ehiabhi, O. O. Ajibola, S. A. Oni P. P., Power, T. Abbas and O. A. Onuh, “Effects of moisture content and temperature on the specific heat of soya bean, *Moringa oleifera* seed and Mucuna flagellipes nut.” *International Journal of Agricultural and Biological Engineering*, vol.4, no.1, pp.1-6, 2011.

[4] S.D. Dashpande and S. Bal, “Specific heat of soybean,” *Journal of Food Process Engineering*, vol. 22, no. 6, pp. 469-477, 1999.

[5] A. Farimu and O. Baik, “Thermal properties of sweet potato with its moisture content and temperature.” *International Journal of Food Properties*, vol.10, no.4, pp.703-719, 2007.

[6] A. L. Gabas, W. D. Marra-Júnior, J. Telis-Romero and V. R. N. Telis, “Changes of density, thermal conductivity, thermal diffusivity, and specific heat of plums during drying,” *International Journal of Food Properties*, vol. 8, pp. 233–242, 2007.

[7] B.M. Ghodki and T.K. Goswami, “Thermal and mechanical properties of black pepper at different temperatures.*”* *Journal of Food Process Engineering*, vol. 40, no. 1, pp.1-11, doi:10.1111/jfpe.12342, 2017.

[8] M. A. Hossain and B. K. Bala, “Geometric dimensions, density, and specific heat of chilli as a function of moisture content.” *International Journal of Food Properties*, vol.2, no. 2, pp. 175-183, 1999.

[9] F. Jian, D. S. Jayas, and N. D. G. White, “Specific heat, thermal diffusivity and bulk density of genetically modified canola with high oil content at different moisture contents, temperatures and storage times.” *Transactions of the American Society of Agricultural and Biological Engineers*, vol. 56, no. 2, pp. 1077-1083, 2013.

[10] H. Kocabiyik, B. Kayaisoglu and D. Tezer, “Effect of moisture content on thermal properties of pumpkin seed.” *International Journal of Food Properties*, vol. 12, no. 2, pp. 277-285, 2009.

[11] W. Phomkong, G. Srzednicki and R. H. Driscoll, “Thermophysical properties of stone fruit.” *Drying Technology*, vol. 24, no. 2, 195–200, 2006.

[12] B. L. Shrestha and O. D. Baik, “Thermal conductivity, specific heat and thermal diffusivity of *Saponara vaccaria* seed particles.” *Transactions of the American Society of Agricultural and Biological Engineers*, vol.53, no. 5, 1717-1725, 2010.

[13] J. Yang and Y. Zhao, “Thermal properties of radish and alfalfa seeds.” *Journal of Food Process Engineering*, vol. 24, no. 5, pp. 291-313, doi: 10.1111/j.1745-4530.2001.tb00545.x, 2001.

[14] W. Yang, S. Sokhansanj, J. Tang and P. Winter, “Determination of thermal conductivity, specific heat and thermal diffusivity of borage

seeds." *Biosystems Engineering*, vol.82, no.2, pp.169-176, doi:10.1006/bioe.2002.0066, 2002.

[15] D. U. Yu, B. L. Shrestha and O. D. Baik, "Thermal conductivity, specific heat, thermal diffusivity, and emissivity of stored canola seeds with their temperature and moisture content." *Journal of Food Engineering*, vol.165, pp. 156–165, 2015.

[16] P. C. K. Cheung, "Mini–review on edible mushrooms as source of dietary fiber: Preparation and health benefits." Food Science and Human Wellness, vol.2, no.3-4, pp. 162-166, 2013.

[17] R. C. G. Correa, T. Brugnari, A. M. Bracht, R. Peralta and I. C. F. R. Ferreira, "Biotechnological, nutritional and therapeutic uses of *Pleurotus* spp. (Oyster mushrooms) related with its chemical composition: A review on the past decade findings." *Trends in Food Science and Technology*, vol.50, pp. 103-117, 2016.

[18] T. Islam, X. Yu and B. Xu, "Phenolic profiles, antioxidant capacities and metal chelating ability of edible mushrooms commonly consumed in China." *LWT-Food Science and Technology*, vol.72, pp. 423-431, 2016.

[19] R. Sanmee, B. Dell, P. Lumyong, K. Izumori and S. Lumyong, "Nutritive value of popular wide edible mushrooms from northern Thailand." *Food Chemistry*, vol. 82, no. 4, pp. 527-532, 2003.

[20] M. Sari, A. Prange, J. I. Lelley and R. Hambitzer, "Screening of beta-glucan contents in commercially cultivated and wild growing mushrooms." *Food Chemistry*, vol. 216, pp. 45-51, 2017.

[21] G. K. Vagenas, A. E. Drouzas, D. Marinos-Kouris and G.D. Saravacos, "Predictive equations for thermophysical properties of plant foods." In: Spiess, W.E.L., Schubert, H. (Eds.). New York: *Engineering and food, vol. 1*. Elsevier Applied Science Publishers, 1990.

[22] M. Shrivastava and A. K. Datta, "Determination of specific heat and thermal conductivity of mushrooms (*Plerotus florida*)." Journal of Food Engineering, vol. 39, no. 3, pp.255-260, 1999.

[23] A. Tansakul and R. Lumyong, "Thermal properties of straw mushroom." *Journal of Food Engineering*, vol.87, no. 1, pp. 91-98, 2008.

[24] AOAC. *Official methods of analysis of the Association of Official Analytical Chemists Vol. 1*, 15th ed. Arlington: AOAC, Inc., 1990.

[25] R. Uzupyte, K. L. Man, T. Krilavicius, I. Zliobaite, and H. Simonavicius, "Predicting position of a functional target from an external marker in radiotherapy," *Engineering Letters*, vol. 23, no. 4, pp. 318-325, 2015.

[26] N. Aunsri, "A bayesian filtering approach with time-frequency representation for corrupted dual tone multi frequency identification," *Engineering Letters*, vol. 24, no. 4, pp. 370-377, 2016.

[27] T. Chai and R. R. Draxler, "Root mean square error (rmse) or mean absolute error (mae)-arguments against avoiding rmse in literature," Geoscientific Model Development, vol. 7, pp. 1247-1250, 2014.

[28] S. E. Charm, *The Fundamental of Food Engineering*, 3rd ed. Westport: AVI Publ. Co., 1978.

[29] D. R. Heldman and R. P. Singh, *The Fundamental of Food Engineering*, 2nd ed. Westport: AVI Publ. Co., 1981.

[30] S. M. T. Gharibzahedi, M. Ghahderijani, and Z. S. Lajevardi, "Specific heat, thermal conductivity and thermal diffusivity of red lentil seed as a *function of moisture content," Journal* of Food Processing and Preservation, vol. 38, no. 4, pp. 1807-1811, 2008.

[31] S. M. A. Razavi and M. Taghizadeh, "The specific heat of pistachio nuts affected by moisture content, temperature, and variety*," Journal of Food Engineering*, vol. 79, no. 1, pp. 158-167, 2007.

[32] V. Mykhailyk and N. Lebovka, "Specific heat of apple at different moisture contents and temperatures," *Journal of Food Engineering*, vol. 123, pp. 32-35, 2014.

[33] J. Hu, O. Sari, S. Eicher, and A. R. Rakotozanakajy, "Determination of specific heat of milk at different fat *content between 1°C and 59°C using micro DSC," Journal* of Food Engineering, vol. 90, no. 3, pp. 395–399, 2009.

Soraya Saenmuang received the B.Sc. degree in Food Technology and M.Eng. degree in Food Engineering from Khon Kaen University and King Mongkuts University of Technology Thonburi, Thailand in 1995 and 2001, respectively. She obtained Ph.D. degree in Biological and Environmental Engineering from The University of Tokyo in 2011. Currently, she is a Lecturer at the Faculty of Natural Resources and Agro-industry, Kasetsart University Chalermphrakiat Sakon Nakhon Province Campus, Sakon Nakhon, Thailand. Her research interests include food process engineering, and engineering properties of food materials.

Arpassorn Sirijariyawat received the B.Sc. and M.Sc. degrees in Food Technology from Khon Kaen University, Thailand in 2001 and 2005, respectively. She obtained Ph.D. degree in Food Science from Kasetsart University, Thailand in 2012. Currently, she is a Lecturer at the Faculty of Natural Resources and Agro-industry, Kasetsart University Chalermphrakiat Sakon Nakhon Province Campus, Sakon Nakhon, Thailand. Her research interests include food science and technology.

Nattapol Aunsri (M'14) received the B.Eng. degree and M.Eng. degree in Electrical Engineering from Khon Kaen University and Chulalongkorn University, Thailand in 1999 and 2003, respectively. He obtained M.Sc. degree in Applied Mathematics and Ph.D. degree in Mathematical Sciences from New Jersey Institute of Technology, Newark, NJ, in 2008 and 2014, respectively. The author became a Member (M) of IAENG in 2014. Currently, he is a Lecturer at the School of Information Technology, Mae Fah Luang University, Chiang Rai, Thailand. His main research interests include ocean acoustics, Bayesian filtering, signal processing, and mathematical and statistical modeling.