Advance Journal of Food Science and Technology 11(12): 848-855, 2016
DOI:10.19026/ajfst.11.2803
ISSN: 2042-4868; e-ISSN: 2042-4876

Submitted: October 16, 2015 Accepted: January 13, 2016 Published: August 25, 2016

**Research Article**

# Internet of Things based Real Time Computation on the Thermophysical Properties of Classical Foods in Wuhan City using Choi-Okos Model

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**Abstract:** This study aims to investigate the thermophysical properties of classical foods in Wuhan city using the internet of things (IoF) based real time computation method. The Choi-Okos model was employed to compute and analyse the thermophysical properties of the *Wuhan hot noodles with sesame paste* and *Zhou-Black duck*. The internet of things (IoF) based real time computation was proposed to deal with the Choi-Okos model. Experimental analysis was carried out to calculate the relationships between the thermal conductivity, thermal diffusivity, density and specific heat and temperature. The analysis results demonstrate that the thermal conductivity and thermal diffusivity were influenced significantly by the temperature for *Wuhan hot noodles with sesame paste* and the thermal diffusivity was influenced significantly by the temperature for *Zhou-Black duck*. The findings of this study can provide theoretical support for reasonable food storage and preservation.

**Keywords:** Food thermophysical properties, internet of things (IoF), *numerical computation*

## INTRODUCTION

Wuhan city locates in the central China. There are lots of famous classical foods in Wuhan city. Two of the most welcome foods over the country are the *Wuhan hot noodles with sesame paste* and *Zhou-Black duck*. A large amount of these two foods are consumed every day. Several fast-food storing styles of the *Wuhan hot noodles with sesame paste* and *Zhou-Black duck* are used to preserve and transport them to every city in China. People can enjoy the *Wuhan hot noodles with sesame paste* and *Zhou-Black duck* in the morning or afternoon even in the northern China (Fang, 2011). However, due to improper storage or preservation methods, the *Wuhan hot noodles with sesame paste* and *Zhou-Black duck* may spoil. Once poisonous foods are eaten by people, it may be harmful for people's health and even cause serious accidents (Wang *et al*., 2009). In order to prevent spoilage of the *Wuhan hot noodles with sesame paste* and *Zhou-Black duck*, it is very urgent to investigate the proper and useful storage and preservation methods.

In order to obtain the proper storage and preservation methods for the *Wuhan hot noodles with sesame paste* and *Zhou-Black duck*, it is required to investigate their thermophysical properties. This is because the thermophysical properties, including the heat transfer parameters and thermophysics indexes, can be used to computer the processing time and cost for refrigerating, freezing and transporting of the *Wuhan hot noodles with sesame paste* and *Zhou-Black duck* (Fricke and Becker, 2001). The composition and temperature of the foods are strongly involved with the thermophysical properties. Many mathematical models have been developed to calculate the thermophysical properties of the foods with different chemical compositions and temperatures (McCance and Widdowson, 1991). Ebrahimnia-Bajestan *et al*. (2012) investigated the thermophysical properties of a vegetable sponge during the freezing processing and discovered that the food heat transfer process was dependent on temperature, moisture and ice content. Quirion *et al*. (2012) showed that the thermal behavior of the leafy vegetables was useful for correct package design. Rojas *et al*. (2013) indicates that the temperature should be considered in the food thermophysical parameters calculation. Monika and Peter (2013) adopted the hot wire method and dynamic plane source method to measure thermophysical parameters in food materials. Experimental analysis results show that the selected thermophysical parameters can be used to design suitable food storage strategy. Tirado *et al*. (2014) developed the theory models to calculate the thermophysical properties in foods and used the experimental data of tilapia to verify the models. Tirado *et al*. (2015) proposed the food

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thermal behavior analysis method during frying. The *Tilapia* and *Pan fruit* were used in their experimental tests for validation of the proposed analysis models. In these models, the food compositions often include *protein*, *fat*, *carbohydrate*, *fiber* and *water*. The temperature and moisture were found to be significantly important for the food thermophysical properties analysis. But they were rarely considered in studies on the *Wuhan hot noodles with sesame paste* and *Zhou-Black duck*. One of the most applied calculation models is the Choi-Okos model (Choi and Okos, 1986). It is very suitable for the thermophysical properties calculation of the *Wuhan hot noodles with sesame paste* and *Zhou-Black duck* using the Choi-Okos model because the calculation temperature range of this model is between -40°C to 150°C. However, literature review indicates that very limited work addressed the thermophysical properties calculation of the *Wuhan hot noodles with sesame paste* and *Zhou-Black duck* using the Choi-Okos model. To design suitable storage and preservation strategy for the *Wuhan hot noodles with sesame paste* and *Zhou-Black duck*, it is crucial to investigate their thermophysical properties using the Choi-Okos model.

In order to investigate the thermophysical properties of the *Wuhan hot noodles with sesame paste* and *Zhou-Black duck* using the internet of things (IoF) based real time computation method, the Choi-Okos model was adopted in this study. The relationships between the temperature and the thermophysical properties (i.e., thermal conductivity, thermal diffusivity, density and specific heat) were analysed. Experimental data of the *Wuhan hot noodles with sesame paste* and *Zhou-Black duck* were used to validate the Choi-Okos model.

## MATERIALS AND METHODS

In this study, the Choi-Okos model was employed to calculate the thermophysical properties of the *Wuhan hot noodles with sesame paste* and *Zhou-Black duck*. The basic mathematical equations for different food compositions presented in the Choi-Okos model are listed in Table 1 (Choi and Okos, 1986).

Literature review indicates that the temperature plays an important role in the Choi-Okos model. If the temperature is below the initial freezing point, significant differences will be found when calculating the thermophysical properties of the same food. This is because the freezing process is very complex due to food crystallization. The ice and water fractions in the freezing process are influenced by the temperature. Hence, the effect of initial freezing point should be considered in the calculation of the thermophysical properties of the *Wuhan hot noodles with sesame paste* and *Zhou-Black duck*.

Since the Choi-Okos model involves with the food compositions, chemical test was carried out to obtain the compositions of the *Wuhan hot noodles with sesame paste* and *Zhou-Black duck* on 10 July, 2015 in Wuhan city. Table 2 lists the compositions of the *Wuhan hot noodles with sesame paste* and *Zhou-Black duck*. According to the compositions in Table 2, the thermophysical properties of the *Wuhan hot noodles with sesame paste* and *Zhou-Black duck* can be calculated using the Choi-Okos model.

Table 1: The mathematical equations for Choi-Okos model

| Thermophysical property | Composition | Mathematical equations |
|---|---|---|
| Thermal Conductivity W/(m·K) | Protein | $k = 1.7881\times10^{-1}+1.1958\times10^{-3}t-2.7178\times10^{-6}t^2$ |
| | Fat | $k = 1.8071\times10^{-1}-207604\times10^{-3}t-1.7749\times10^{-6}t^2$ |
| | Fiber | $k = 1.8331\times10^{-1}+1.2497\times10^{-3}t-3.1683\times10^{-6}t^2$ |
| | Carbohydrate | $k = 2.0141\times10^{-1}+1.3874\times10^{-3}t-4.3312\times10^{-6}t^2$ |
| | Water | $k = 5.7109\times10^{-1}+1.7625\times10^{-3}t-6.7036\times10^{-6}t^2$ |
| | Ice | $k = 2.2196-6.2489\times10^{-3}t+1.0154\times10^{-4}t^2$ |
| Thermal Diffusivity $m^2/s$ | Protein | $\alpha = 6.8714\times10^{-8}+4.7578\times10^{-10}t-1.4646\times10^{-12}t^2$ |
| | Fat | $\alpha = 9.8777\times10^{-8}-1.2569\times10^{-10}t-3.8286\times10^{-12}t^2$ |
| | Fiber | $\alpha = 7.3976\times10^{-8}+5.1902\times10^{-10}t-2.2202\times10^{-12}t^2$ |
| | Carbohydrate | $\alpha = 8.0842\times10^{-8}+5.3052\times10^{-10}t-2.3218\times10^{-12}t^2$ |
| | Water | $\alpha = 1.3168\times10^{-7}+6.2477\times10^{-10}t-2.4022\times10^{-12}t^2$ |
| | Ice | $\alpha = 1.1756\times10^{-6}-6.0833\times10^{-9}t+9.5037\times10^{-11}t^2$ |
| Density $kg/m^3$ | Protein | $\rho = 1.3299\times10^{3}-5.1840\times10^{-1}t$ |
| | Fat | $\rho = 9.2559\times10^{2}-4.1757\times10^{-1}t$ |
| | Fiber | $\rho = 1.3115\times10^{3}-3.6589\times10^{-1}t$ |
| | Carbohydrate | $\rho = 1.5991\times10^{3}-3.1046\times10^{-1}t$ |
| | Water | $\rho = 9.9718\times10^{2}+3.1439\times10^{-3}t-3.7574\times10^{-3}t^2$ |
| | Ice | $\rho = 9.1689\times10^{2}-1.3071\times10^{-1}t$ |
| Specific heat J/(kg·K) | Protein | $c_p = 2.0082\times10^{3}+1.2089t-1.3129\times10^{-3}t^2$ |
| | Fat | $c_p = 1.9842\times10^{3}+1.4733t- 4.8008\times10^{-3} t^2$ |
| | Fiber | $c_p = 1.8459\times10^{3}+1.8306t-4.6509\times10^{-3}t^2$ |
| | Carbohydrate | $c_p = 1.5488\times10^{3}+1.9625t-5.9399\times10^{-3}t^2$ |
| | Water | $c_p = 4.0817\times10^{3}-5.3062\times10t +9.9516\times10^{-1}t^2$ (-40°C to 0°C) |
| | | $c_p = 4.1762\times10^{3}-9.0864\times10^{-2}t+5.4731\times10^{-3}t^2$ (0°C to 150°C) |
| | Ice | $c_p = 2.0623\times10^{3}+6.0769t$ |

Table 2: The compositions of the two foods

| Food name | Composition | Percentage (%) |
|---|---|---|
| Wuhan hot noodles with sesame paste | Protein | 8.27 |
| | Fat | 4.72 |
| | Fiber | 0.39 |
| | Carbohydrate | 56.1 |
| | Water | 30.51 |
| Zhou-Black duck | Protein | 43.78 |
| | Fat | 55.64 |
| | Fiber | 0.01 |
| | Carbohydrate | 0.56 |
| | Water | 0.01 |

## RESULTS AND DISCUSSION

The thermophysical properties of the *Wuhan hot noodles with sesame paste* and *Zhou-Black duck* were calculated using the Choi-Okos model in this study. Figure 1 to 5 show the thermophysical properties of the *Wuhan hot noodles with sesame paste*. It can be seen in

Fig. 1 and 2 that the thermal conductivity curve was very similar in shape to the thermal diffusivity curve and in Fig. 3 and 4 the density curve was very similar in shape to the specific heat curve. The thermal conductivity and thermal diffusivity were influenced significantly by the temperature. In Fig. 1 and 2, an influence degree of 9.4% was found in both the thermal conductivity value and thermal diffusivity value from the initial temperature 22.5°C to the highest temperature 40°C. In Fig. 3, the influence degree of 0.3% was found in the density value from the initial temperature 22.5°C to the temperature 35°C and in Fig. 4 the influence degree was 1.2% for the specific heat value.

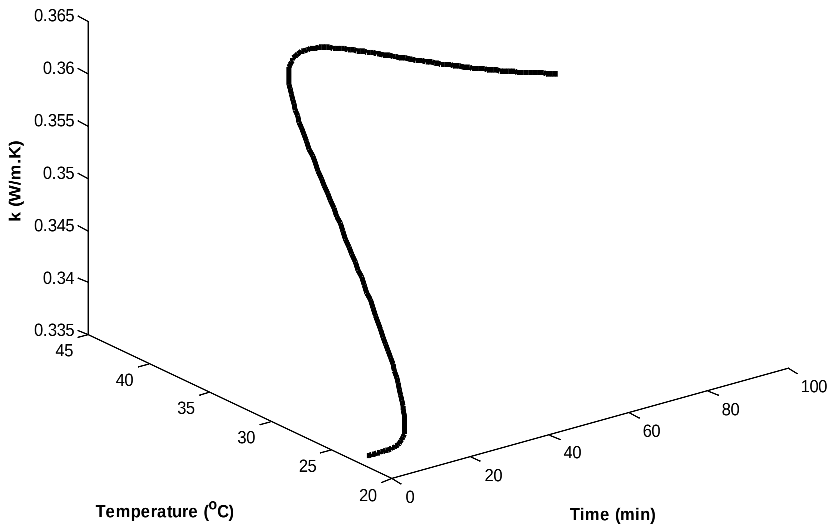


Fig. 1: The thermal conductivity of the *Wuhan hot noodles with sesame paste*

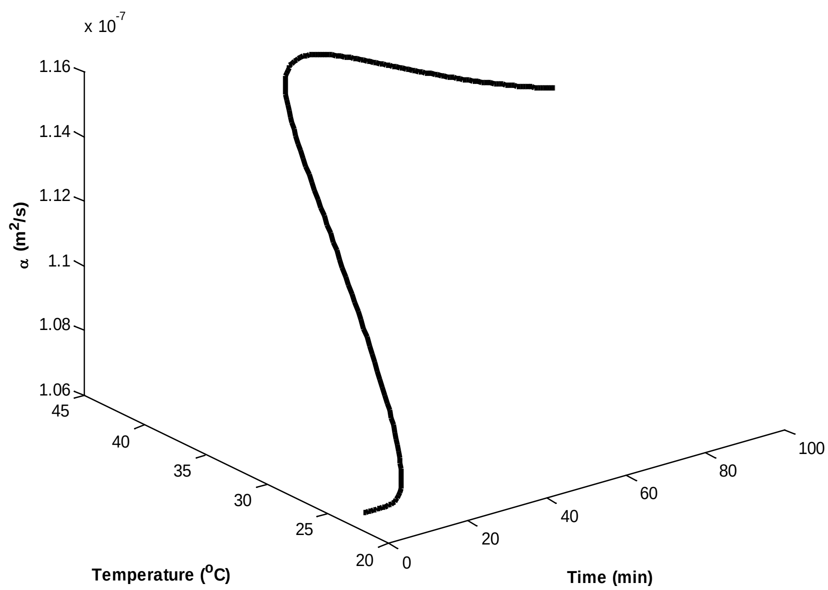


Fig. 2: The thermal diffusivity of the *Wuhan hot noodles with sesame paste*

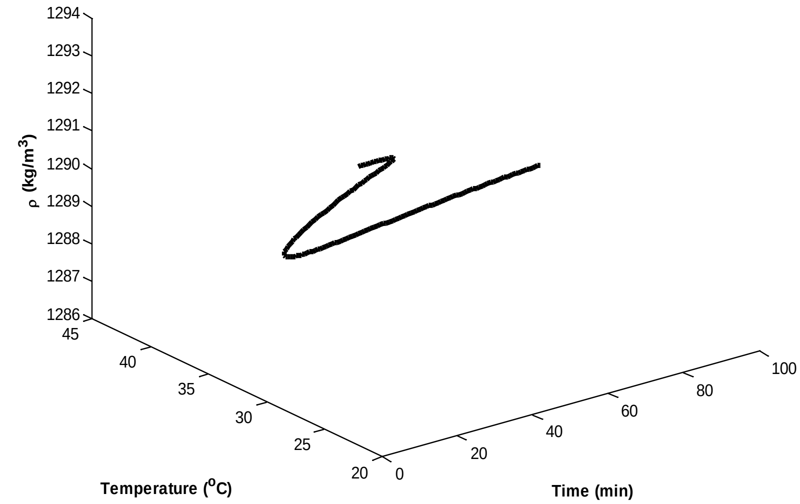


Fig. 3: The density of the *Wuhan hot noodles with sesame paste*

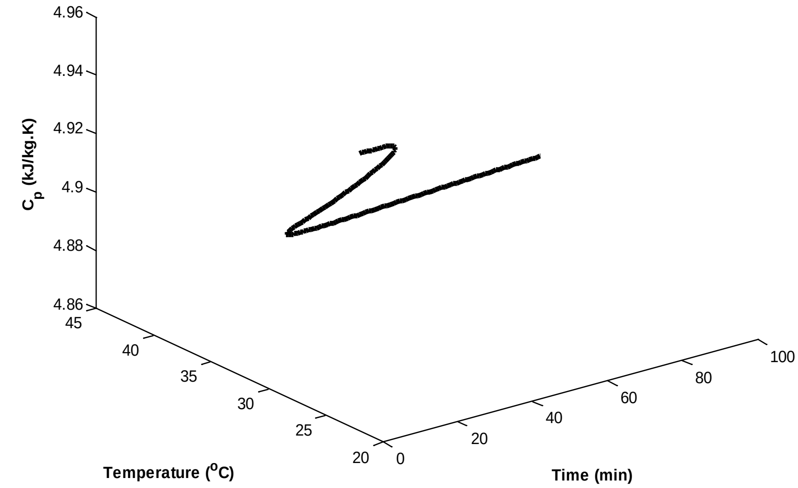


Fig. 4: The specific heat of the *Wuhan hot noodles with sesame paste*

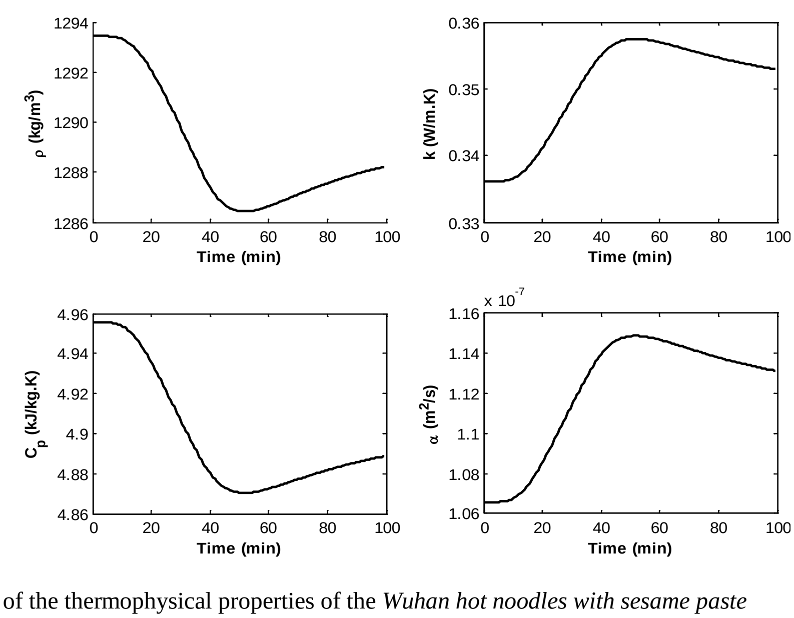


Fig. 5: The 2-D curves of the thermophysical properties of the *Wuhan hot noodles with sesame paste*

Figure 6 to 10 show the thermophysical properties of the Zhou-Black duck. It can be seen in Fig. 6 to 9 that the thermal conductivity curve was very similar in shape to the density curve and specific heat curve. One can be noticed that there were two inflection points in Fig. 6 to 9. These two inflection points indicates the complex freezing process. It can infer from the observations in Fig. 6 to 9 that the thermophysical properties were influenced significantly by the temperature.

It can be seen from Fig. 1 to 10 that the computation on the thermophysical properties of the *Wuhan hot noodles with sesame paste* and *Zhou-Black duck* reflected the dynamics of the thermophysical properties to the environmental changes. Especially, one can be noticed from the analysis results in Fig. 1 to 10 that the thermophysical properties of the *Wuhan hot noodles with sesame paste* and *Zhou-Black duck* were dependent on temperature. These results were consistent with the observations in Ebrahimnia-Bajestan *et al*. (2012) and Tirado *et al*. (2014, 2015). Since litter work addressed the thermophysical properties analysis of the *Wuhan hot noodles with sesame paste* and *Zhou-Black duck*, the findings of this study extended and supported the recent reports in the food thermophysical properties analysis (Ebrahimnia-Bajestan *et al*., 2012; Tirado *et al*., 2014, 2015).

Moreover, in order to monitor the storage and preservation states of the *Wuhan hot noodles with sesame paste* and *Zhou-Black duck* in the transport process, the IoF based real time computation method was proposed to calculate their thermophysical properties. The framework of the IoF is shown in

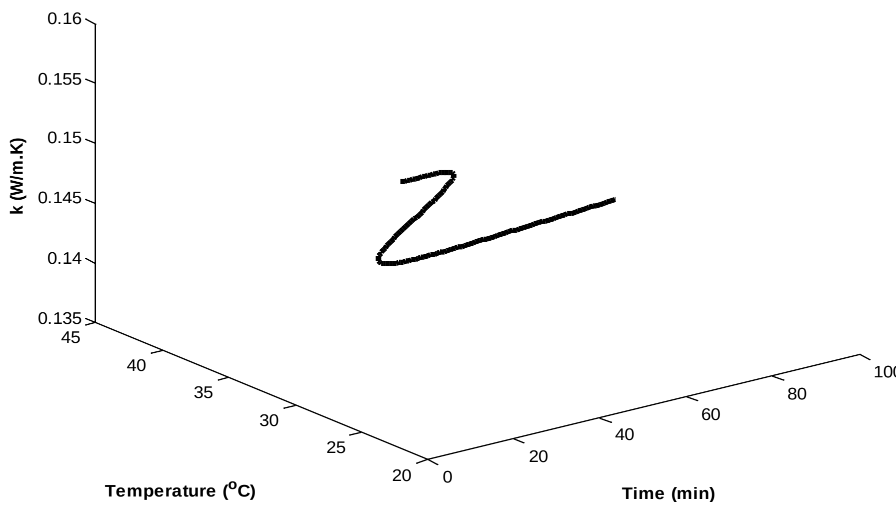


Fig. 6: The 3-D curve of the thermal conductivity of the *Zhou-Black duck*

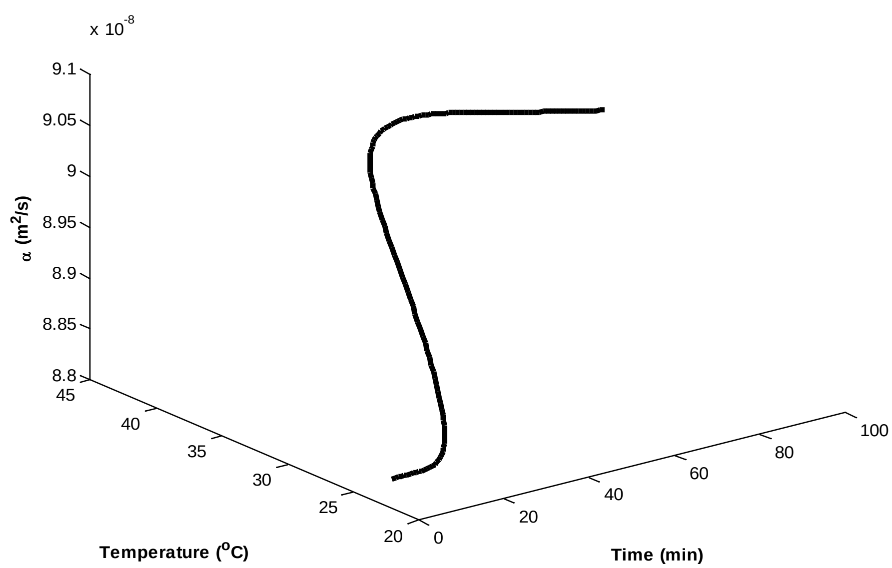


Fig. 7: The 3-D curve of the thermal diffusivity of the *Zhou-Black duck*

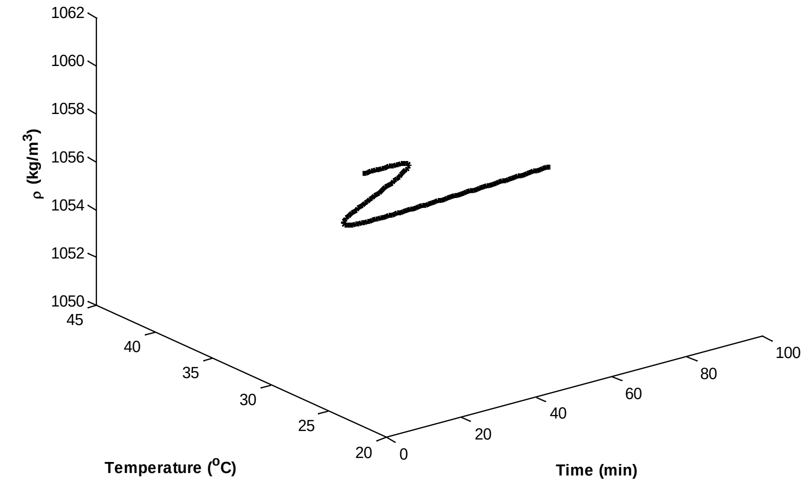


Fig. 8: The 3-D curve of the density of the *Zhou-Black duck*

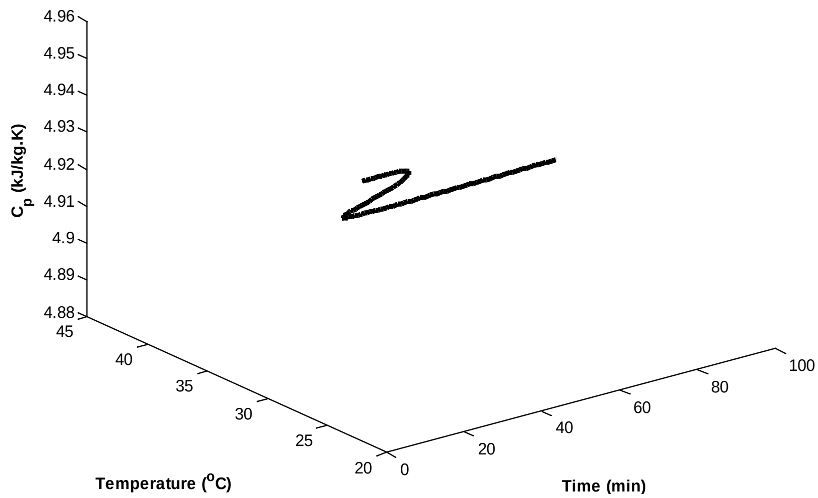


Fig. 9: The 3-D curve of the specific heat of the *Zhou-Black duck*

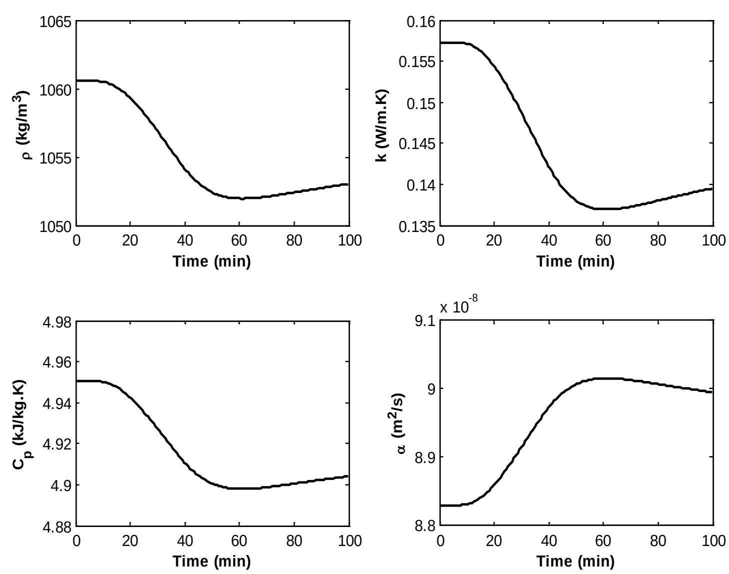


Fig. 10: The 2-D curves of the thermophysical properties of the *Zhou-Black duck*

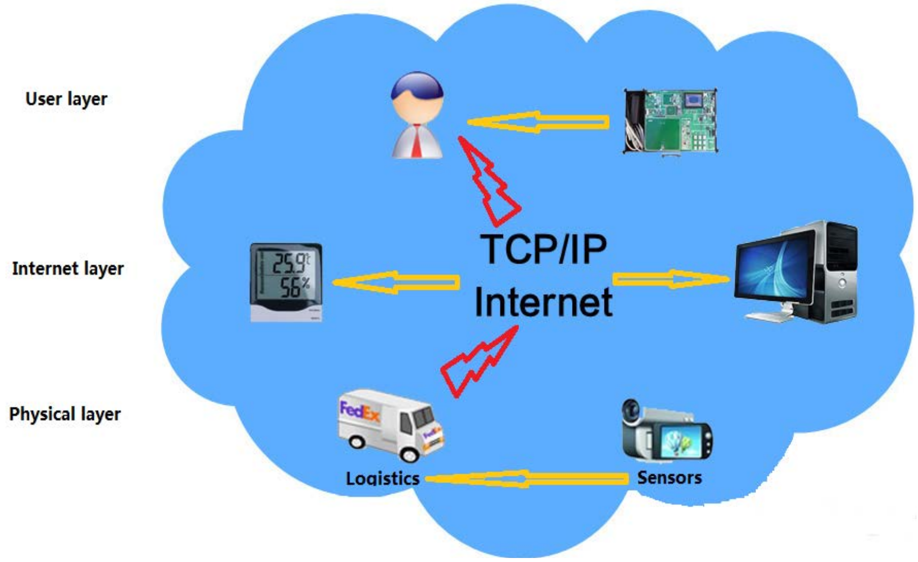


Fig. 11: The IoF based real time computation framework

Fig. 11. The IoF framework consists of three layers, namely, the user layer, the internet layer and the physical layer. In the physical layer, the sensors are applied to measure the temperature change and the water/ice change in the foods and transmit the data to the internet layer via wireless internet. Then the data is stored in the internet layer and transmitted to the user layer. In the user layer the data analysis is carried out and the calculation output is reported to the users. Lastly, the users make proper decisions for the food storage and preservation. Compared with the recent publications on food thermophysical properties analysis, the advantage of this IoF framework is that it can provide real time computation of the food thermophysical properties according to the temperature. As a result, the storage and preservation strategy can be adjusted in a timely manner.

## CONCLUSION

The thermophysical properties of a food can be used to guide the proper strategy for food storage, preservation and transport. In this study the thermophysical properties of the *Wuhan hot noodles with sesame paste* and *Zhou-Black duck* were investigated using the Choi-Okos model. Experimental analysis was carried out to calculate the relationships between the temperature and the thermophysical properties (i.e., thermal conductivity, thermal diffusivity, density and specific heat). The analysis results demonstrate that the thermal conductivity and thermal diffusivity were influenced significantly by the temperature for the *Wuhan hot noodles with sesame paste* and the thermal diffusivity was influenced significantly by the temperature for the *Zhou-Black duck*. It can be concluded that the presented analysis methods using the Choi-Okos model is a rational tool for thermophysical properties of the *Wuhan hot noodles with sesame paste* and *Zhou-Black duck*. The observed relationships can be used to achieve reliability storage and preservation.

## ACKNOWLEDGMENT

The authors gratefully acknowledge the financial support by the PHD Foundation of HBUT with the No. BSQD12027 and the Scientific Research Project of Hubei Provincial Education Department with the No. D20131403.

**Conflict of interest:** Authors claim that there is no conflict of interest in this study.

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