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Heating surimi products using microwave combined with steam methods: Study on energy saving and quality

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ABSTRACT

Moisture content plays an important role in aspects of the food processing such as energy transfer, food yield, and quality. This study investigated the effects of the moisture content of surimi on its electromagnetic characteristics. At moisture contents between 78% and 80%, both the dielectric constant and the dielectric loss increased, but gradually decreased with the increase of frequency. The strongest microwave absorption appeared at a thickness of 8 mm at 2.45 GHz. A moisture content of 0.45% was supplied to surimi using steam as an auxiliary heating method. The gel strength was obviously improved by a combination of microwave treatment (35 kW) and steam heating, and scanning electron microscopy showed that the network structure was also denser. In addition, the new heating mode with medium microwave power received the highest score on the comprehensive sensory evaluation after frying. The combination of microwave and steam preparation can save 11.68% ± 1.8% of the energy used in the conventional heating method, even when taking into account the combustion of methane produced during the wastewater treatment process.

1. Introduction

Surimi products such as fish tofu use fish or surimi as a main ingredient finely chopped with soybean oil, soybean flour salt, and sugar, resulting in a low cost product with high elasticity, little fish smell, and a unique flavor after frying (Ketnawa, Benjakul, Martínez-Alvarez, & Rawdkuen, 2016). The gel property of surimi products is the most important indicator of their quality (Lin, Yang, Xu, Jie, & Liu, 2015), which depends on the process of gel formation and the processing methods, and the heating methods used will have a direct influence on the process of gel formation (Fowler & Park, 2015). The most commonly used methods in traditional surimi heating are water bath and steam (Tadpitchayangkoon, Park, & Yongsawatdigul, 2012). Usually, the slow transfer of heat from the outside to the inside of the surimi leads to greater energy consumption, a slow increase in temperature, and large quantities of waste water. The residence time of surimi gel deterioration stage (50 °C–70 °C) is too long, which exacerbates the gel's deterioration (Alvarez, Couso, & Tejada, 1999; Hu et al., 2012; Ramírez, García-Carreño, Morales, & Sánchez, 2002). A long preheating time, a large increase in material temperature, and the loss of water-soluble nutrients will also decrease the quality of surimi products.

As surimi makes direct contact with water during the traditional surimi heating process, the emission of wastewater from the heating process contains large amounts of fine surimi, water-soluble protein, fat, and inorganic salt, phosphorus, and nitrogen (Bourtoom, Chinnan, Jantawat, & Sanguandeekul, 2009; Kanjanapongkul, Tia, Wongsa-Ngasri, & Yoovidhya, 2009). If not properly treated, this sewage can lead to serious environmental pollution (Norziah, Kee, & Norita, 2014). To achieve emission standards, reasonable treatment of the wastewater produced during the processing of surimi products is an important issue in the surimi industry. Surimi sewage contains large amounts of nutrients, which can be degraded into carbon dioxide, methane, water, and other harmless substances by microbial fermentation (Bourtoom et al., 2009; Chowdhury, Viraraghavan, & Srinivasan, 2010; Ding et al., 2016). The methane can be recycled to provide heat for the production of surimi products (Shin, 1981; Sunyoto, Zhu, Zhang, & Zhang, 2016). However, the amount of recycled energy is very low compared with the energy consumed in traditional water bath heating. An alternative

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Nomenclature

E_{tw}	Total energy consumption of water bath, (MJ)
E_{tm}	Total energy consumption of microwave combined with steam, (MJ)
E_{ws}	Steam energy consumption of traditional of water bath, (MJ)
E_{ms}	Steam energy consumption of microwave combined with steam, (MJ)
E_{mw}	Energy supplied by microwave magnetrons, (MJ)
E_{we}	Required energy to heat up during water bath, (MJ)
E_{me}	Required energy to heat up during microwave combine steam, (MJ)
E_{mem}	Mechanical energy of microwave combined with steam, (MJ)
E_{mew}	Mechanical energy of water bath, (MJ)
E_{es}	Electricity consumption of sewage, (MJ)
Q_m	Thermal energy provided by methane combustion,(MJ)
C_P	Specific heat of surimi, (KJ/Kg × °C)
m	Surimi production, (Kg/h)
T_0	Initial temperature of surimi, (°C)
T_p	Temperature of the pool, (°C)
T_s	Temperature of steam, (°C)
T_w	Temperature of surimi after heating by water bath, (°C)
T_m	Temperature of surimi after heating by microwaves and steam, (°C)
T_{mb}	Temperature inside the box contains microwave and steam, (°C)
V	Volume of methane, (m^3)
ΔH	Combustion heat of methane, (KJ/mol)
η_w	Energy utilization ratio of water bath, (%)
η_m	Energy utilization ratio of microwave combined with steam, (%)
q_{ws}	Steam flow of water bath (kg/h)
q_{ms}	Steam flow of microwave combined with steam (kg/h)
r	Latent heat of vaporization, (KJ/Kg)
t_m	Heating time of microwave combined with steam, (s)
t_w	Heating time of water bath, (s)
P	The power of motor or magnetron, (kW)

processing method is thus needed to replace traditional water bath heating that can also ensure the quality of the surimi products.

Microwave is widely used in food for processes such as heating, sterilization, drying, and extraction (Chen et al., 2016; Conte et al., 2017; Kumar, Joardder, Farrell, & Karim, 2016; Resurreccion et al., 2015; Wang, Ding, & Ren, 2016), and can heat the whole material at the same time rather than using heat conduction from the outside to the inside (Acevedo, Usón, & Uche, 2014). Compared with water bath heating, microwave heating has the advantages of faster heat transfer, shorter heating time, high thermal efficiency, and no production of sewage (Chandrasekaran, Ramanathan, & Basak, 2013; Ji, Xue, Zhang, Li, & Xue, 2017). Further, microwave heating can progress rapidly through the gel cracking area, which can rapidly inactivate the endogenous proteolytic enzymes and avoid gel deterioration (Mao, Fukuoka, & Sakai, 2006). It thus has significant advantages in the processing of surimi products.

However, the process of microwave heating is often accompanied by water loss because the material is heated too quickly, which leads to the surface drying of the reactants and has adverse effects on product quality (Jouquand et al., 2015). The use of microwave heating as the only heat source causes a non-uniform temperature distribution in surimi products (H. Zhang, Wang, Wang, & Ye, 2017), and the relationship between microwave absorption and gel formation is very important for improving the quality of surimi. The use of steam heating ensures heat transfer and maintains a high-humidity environment for surimi heating, which makes up for the shortcomings of non-uniform microwave heating. Moreover, it has the advantages of preventing the loss of nutrients and retaining the food's flavor. Steam has great heat capacity and good thermal conductivity, and it will condense to water on the surface of food at the beginning of the heating process (Huang, Yang, & Lee, 2013), which can make up for the material's moisture loss and act as an appropriate buffer against the rapid heating rate of microwave heating (Chen, Cheng, & Hung, 2011; Lascorz, Torella, Lyng, & Arroyo, 2016). With the use of steam for assisted heating the internal moisture loss of surimi decreases, with the products being tender and juicy and having good sensory characteristics. Moisture makes up most of the content of surimi products and can have a significant influence on the quality and yield of the whole process. As a polar molecule, water is an important factor in a material's dielectric properties (McKeown, Trabelsi, Tollner, & Nelson, 2012). These dielectric properties can be used to predict the penetration depth and the thickness of the heating during microwave treatment (Guo, Zhu, Liu, & Zhuang, 2010; Sacilik, Tarimci, & Colak, 2007). The acquisition of these characteristics is very important for the design of continuous production and the selection of suitable materials (Fan et al., 2015).

To determine the most suitable parameters for microwave heating, it is necessary to research the influence of the moisture content on electromagnetic properties in the actual production of surimi products. The objectives of this study were thus to (1) determine suitable products for microwave heating according to the effects of moisture on the electromagnetic characteristics; (2) compare the changes in the quality and sensory characteristics of surimi heated by two different methods; and (3) analyze the energy consumption of the two heating methods. We elaborate on the advantages of microwave heating in the processing of surimi products and hope to further expand the application of microwave heating technology in the surimi processing industry. We also provide a theoretical basis and experimental evidence for the development of continuous and automatic production technology for surimi products.

2. Materials and methods

2.1. Surimi paste samples

Sea bream AAA-grade surimi paste (sucrose + sorbitol + glucose 3%–5%, sodium tripolyphosphate 0.1%–0.5%, sea bream minced fish 92–95%) was kept at −20 °C prior to use was obtained from Fujian Xiamen Anjoy Food Co., Ltd. The surimi and meat were mixed and chopped for 2 min (ZB-80, Jiaxing Machinery Co. Ltd., Shandong, China) until a stuffing was formed; salt, egg white liquid, sugar, and other ingredients were then added. The whole raw material was adjusted to 78% moisture content with the addition of ice, and the material was then chopped for another 3 min. The surimi paste was kept below 12 °C and used immediately.

2.2. Electromagnetic properties of surimi with different moisture contents

2.2.1. Moisture content measurement

The moisture content was measured in a drying oven at atmospheric pressure (Benjakul & Visessanguan, 2003; Göğüş & Maskan, 2006); samples were weighed to about 5 g and then dried to a constant weight in a 105 °C hot air circulation oven (FD115, Binder Inc., Germany). All measurements were carried out in triplicate. The moisture content was calculated with the following equation (Eq. (1)).