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Research Article

Research Progress of Instant Foods and Rapid Freeze-drying Technology

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Abstract: Aim of the study is to introduce the development of instant convenient foods and freeze-drying technology and provide technical basis for convenient foods. The instant convenient foods can meet people's requirements for food in the 21st century with nature, nutrition, safety, health and convenience and have a potential market prospect. In this study, the development status of instant convenient foods and research progress of rapid freeze-drying technology at home and abroad were described. In addition, the energy consumption and profit problems of freeze-dried foods were also discussed in this study. At the same time, the existing problems and developing trends of the convenient foods were also described briefly.

Keywords: Hot air drying, instant convenient foods, microwave drying, vacuum freeze drying

INTRODUCTION

With the development of economy and the improvement of people's living standards, people are eager to reduce the housework and unwilling to spend more time on the tedious labor of cooking, so the demand for instant convenient foods is increasing. Convenient foods are also called instant foods, quick serve meal or ready to eat foods at abroad.

In 1983, convenient foods in the US Department of Agriculture Handbook were defined as any foods that all or part of the conventional kitchen operations (such as washing, cutting, cooking, etc.) are replaced by food processing and management, especially the foods which can shorten the kitchen operating time and save energy (Zhou *et al*., 2010). While Chinese scholars defined convenient foods as those which can be kept their quality, freshness and nutrition unchanged within a certain time at room temperature through a series of process, package and proper sterilization, meanwhile, they are convenient to be stored, transported, carried and treated little or none and can change people's lifestyles (Guo, 2010). With food scientific, process industrialization, life socialization and the development of science and technology, convenient foods appeared and they were adapted to the development trend of family diet socialization and food composition nutrition (Liu and Wang, 2007). Currently convenient foods have entered the households, changing people's food consumption structure and nutrition structure and they have become a major trend of the food development.

The objective of this study is to assess the present technology of instant food and freeze drying at home and abroad, compare the energy consumption and profit problems of freeze-dried foods, highlight new approaches and offer recommendations on future research.

RESULTS AND DISCUSSION

The development status of instant convenient foods: There are many different kinds of instant convenient foods, according to statistics, at present the kinds of convenient foods reached more than 12,000 around the world, according to the processing methods and drying technologies, they can be divided into quick-frozen foods, hot air drying, microwave drying and vacuum freeze drying foods, etc.

Frozen foods are those which can go through the largest ice crystals belt within 30 min under the low temperature of -30°C, with the central temperature reaching -18°C and can be stored and transported below 18°C (Yue *et al*., 2012; Li and Guo, 2010). Due to the adoption of quick-frozen process, frozen foods go through the largest ice crystals belt quickly and avoid the mechanical damage and loss of juice successfully which may be caused by the large ice crystals in the slow freezing process, therefore, frozen foods can better maintain the original color, flavor of foods and nutrients (Anese *et al*., 2012; Delgado *et al*., 2009). At the same time, the shelf life of frozen foods is long and reaches more than one year under the refrigerated conditions of -18°C, so they are warmly welcomed by the majority of urban households, restaurants and hotels. Although frozen foods brought some convenience to people's life, frozen foods just prolong

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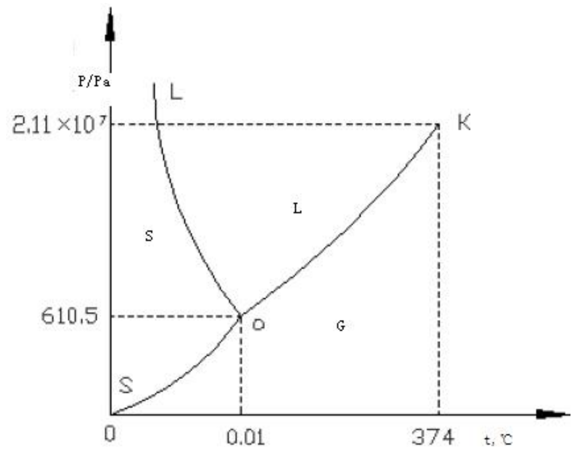

Fig. 1: The three-phase equilibrium diagram of water

the storage time and can't use instantly, meanwhile, they cannot be carried out on the go because of the frozen storage method (Zhang *et al*., 2005). Besides, as the food storage capacity increases gradually, the complex distribution system and shortcomings such as the bacteria is easily mixed with the foods make the quality and safety issues of some products still alive which can limit the use of frozen foods (Zhang and Cheng, 2014; Tang, 2014).

Hot air drying foods are dried with hot air which is blown to the oven or drying chamber by a fan, the heat from the drying medium is passed to the material and the water on the material surface is heated vaporization of water vapor to remove the moisture in foods (Ding *et al*., 2013). There is a wide range of hot air drying foods, currently hot drying foods in the market are mainly instant noodles, dried vegetables and leisure puffed foods, etc. Due to the simple operation, high efficiency, fast drying rate and low cost and high yield, hot air drying foods were warmly welcomed by consumers (Fan *et al*., 2012). However, hot air drying is operated under high temperature and aerobic conditions, if the drying temperature control is unreasonable, the oxidation of materials, surface hardening and thermal damage can easily happen which may result in the loss of nutrition, color, flavor and poor rehydration, etc. Especially for some heat-sensitive substances, hot air drying can easily lead to the loss of nutrients (Wang *et al*., 2014; Zhang *et al*., 2014).

Microwavable foods are those which are pre-processed to be suitable for the microwave or modulation by applying the modern processing technology for food materials of scientific proportions and combinations (Xu and Kong, 2006). Microwave heating can make the foods directly absorb microwave and can be heated immediately with the advantages of fast heating, efficient energy, better control, low temperature sterilization, etc (Liu *et al*., 2012). But there is still a microwave heating temperature uneven problem, mainly reflected in the edge of food overheating even coking, while the central region appears the phenomenon of the lack of heat (Wang and Lu, 2012). In addition, the microwave may not produce a color that people need on the surface of the foods, because the surface temperature of the heated materials is low enough to produce a browning reaction on the surface, which limits the rapid development of microwave foods to some extent.

Freeze-dried foods namely vacuum freeze drying foods, after the pretreated raw materials (vegetables, meat, herbs, etc.) are frozen, the ice sublimates directly into gas in the vacuum distillation, so that the water in foods is removed and we get the freeze-dried foods (Kong, 2003). Freeze-dried foods have advantages of light weight, good rehydration performance and excellent color, smell and tastes compared with canned foods and frozen foods (Zhang *et al*., 2012). Freeze-dried foods are becoming more and more favored by people with its transportation, storage and other regular low cost advantages and are bound to be a highly promising industrial processing technology. Freeze-dried foods are very popular in Europe, the United States and Japan, the proportion of freeze-dried foods in USA and Japan reaches more than 40%; while freeze-dried foods in our country are still in the early stages of development and we have made some progress in recent years, freeze-dried foods are mainly dehydrated garlic, instant coffee, freeze-dried soup and freeze-dried dumplings, etc (Jiang, 2013). Especially in the 21^{st} century, with the awareness of environmental protection and health growing and the accelerating pace of life, people created a higher understanding of the food that is processed with new technology, which will greatly promote the further development of freeze-dried foods.

The research progress of rapid freeze-drying technology:

Freeze-dried principle: Vacuum freeze-drying, also known as freeze-dried, is a drying method that when the aqueous material is frozen to a temperature below the eutectic point, the water in the material will be frozen thoroughly and then the ice sublimates directly into gas in the vacuum distillation (Zhang, 2013). Generally, the moisture in the material is converted to water vapor in the liquid state; while for freeze-drying, the moisture in the material is directly sublimated into water vapor in the solid state of ice.

Vacuum freeze-drying is a process of phases change and transfer essentially. The three-phase equilibrium of water is shown in Fig. 1. In the diagram, OL, OS, OK three curves divide the entire coordinate plane into three phases and water presents solid (ice), liquid (water) and gaseous (vapor) 3 states at different pressures and temperatures and these three states can be interdependent and transformed into each other. The three lines meet at the triple point o and the triple point pressure of water is 610.5 Pa and the triple point temperature is 0.001°C, in this condition, the three states of water reach in equilibrium. According to the principle that the pressure decreases, the boiling point drops, as long as the ambient pressure below the triple point pressure, the moisture in materials can be sublimated directly from the aqueous liquid phase to vapor without going through the liquid phase and then the water is removed (Nie *et al*., 2013). Freezing of water is an exothermic process and the sublimation of ice is an endothermic process. Therefore, freeze-drying operation is mainly composed by cooling, heating and vacuum operation (Feng *et al*., 2012).

The characteristics of freeze-drying technology: Carried out at low temperature and pressure, freeze-dried foods have many incomparable advantages compared with other frozen or dried foods:

- Dried at low temperature and vacuum state, freeze-drying technology is suitable for heat sensitive foods especially because it can prevent the foods denaturing and losing viability.
- Freeze-dried foods can maximize their original nutrients, taste, aroma and color.
- Low temperature and vacuum state inhibits the harmful effects of bacteria and enzymes to effectively prevent the food denaturing.
- In the vacuum state, some easily oxidized substances (such as vitamin C, etc.) can be effectively protected.
- In the freeze-drying process, the foods produce large pores appearing wrinkled shape and the weight reduced 70 to 90% which is not only beneficial to rehydration but also conducive to transport, particularly suitable for air transport.

The research progress of rapid freeze-drying technology at home and abroad: Freeze-drying technology first appeared in 1911, which was mainly used for dehydration of the organisms and the saving of bacteria and serums. However, freeze-dried technology of foods first appeared in the 1930s, British proposed food processing technology carried out by freeze-drying method. By the 1960s, British began the study on freeze-dried foods and announced their own experimental results on the basis of the research results at home and abroad at that time comprehensively; the results fully demonstrated that freeze-drying technology for foods is a way to get high-quality foods. Sandall *et al*. (1967) put forward a steady-state model of sublimation interface shift backwards uniformly (URIF), the experiment proved that the model can be better to calculate the sublimation drying time; Dyer and Sunderland (1968) also proposed a quasi-steady state lyophilized model on mass and heat transfer in freeze-drying process which showed that heat is transferred from the heating plate by radiation to the frozen layer and water vapor is arrived in drying chamber through the already dry layer. LItchfiedld and Lapis (1979) also proposed a adsorption-sublimation model of freeze-drying and they found that sublimation and desorption of water can be carried out simultaneously and through numerical calculation on the model, the theoretical values agree well with the experimental values which showed that the model can well describe the whole freeze-drying process. Krokida *et al*. (1998) studied the effects of freeze-drying conditions in vacuum freeze drying process on the contraction percentage of dehydrated bananas, carrots and potatoes. Bailey (1994) investigated the effects of different pre-freeze rates on the quality change of different maturity of fresh cucumbers which determined the optimal pre-freeze rate and the most suitable maturity. For a long time, freeze-drying technology at abroad developed continuously and yield of freeze-dried products increased rapidly and freeze-dried foods in many countries especially in developed countries have reached a quite high even universal level.

Freeze-drying technology started late in our country and was introduced in 1961 and there is still a technology gap to a certain extent compared with the developed countries. In recent years, more and more attention is paid to the research of freeze-drying process and theory in our country. Zhuang *et al*. (2011) studied the effects of different material maturities, thickness, freezing methods, heating temperatures and vacuum degree of drying chamber on the quality of freeze-dried banana, the results showed that when the maturity is 70~80%, thickness is 5~7 mm, vacuum degree of drying chamber is 70 pa, heating temperature is set to 20°C~60°C~60°C~40°C~40°C, every hour with L-cysteine (L-Cys) color protection and quick-freeze method, the freeze-dried banana slices obtained excellent quality and high yield; Chen *et al*. (2011) did a survey on the key technology of vacuum freeze-drying litchi, the results showed that the eutectic point and melting point temperature of litchi is -26°C and -17°C, respectively, the highest temperature in sublimation stage is 55°C and vacuum degree of drying chamber is 60~70 Pa; Ding (2011) conducted a study on the freeze-drying process of characteristic fruit HaiHongGuo in northwest, the optimum condition for the freeze-drying process of HaiHongGuo is that the loadage of unit area is 100 g/m^2, the degree of drying chamber is 32 Pa, the sublimation temperature is 48.3°C and the drying time is 14.05 h. The optimization of freeze-drying process on foods provides a theoretical basis for food production and promotes food toward the direction of high quality and high nutrition.

Compared with other drying techniques, vacuum freeze-drying technology has obvious advantages. Xu *et al*. (2014) made a comparison with the effects of vacuum freeze-drying and hot air drying on the quality of blueberry from these aspects: microstructure, rehydration ratio, color, texture, VC, total anthocyanins and total phenolics. The results proved that Vacuum

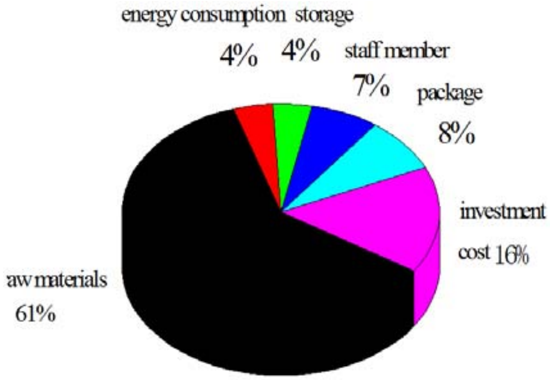

Fig. 2: Cost composition of high additional value freeze-dried foods

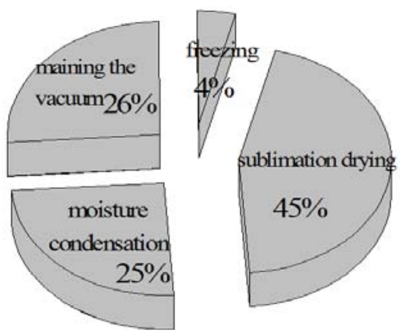

Fig. 3: Energy composition of freeze-drying process

freeze-dried blueberries have a good rehydration performance and the content of VC, total anthocyanins and total phenolic in fruit is 5.52 mg/100 g, 1.55 mg/g and 3.55 mg/g, respectively, which is significantly higher than the hot air dried blueberries.

The energy consumption and profit of freeze-dried foods: Freeze-drying technology is considered to be the best processing method to produce dehydrated foods at home and abroad. Freeze-dried foods have a high added value, but freeze-drying equipments are complex and energy consumption is large, which leads to the price of the product is several times higher than the general drying foods. In the current international market, the price of freeze-dried foods is 4~6 times of hot air drying foods and 4~6 times of frozen foods, economic benefit is very considerable (Qiang, 2013).

The cost of freeze-dried foods is composed of raw materials, energy consumption, package, storage and other components (Sunderl, 1982). Although the cost of freeze-drying process is 4~8 times of hot air drying, based on the whole machining process to analyze, such as considering the lower sales and shipping fee, the cost of freeze-dried foods is also not very expensive. According to the information provided by the United States Department of Agriculture, the processing fee of freeze-dried foods is 2 times more than frozen foods and canned foods, but the sales of storage cost is lower. From the total cost of the whole processing and circulation process, the vacuum freeze-dried foods are 1.02 times of canned foods and 1.28 times of frozen foods and the three are pretty much the same.

Ratti (2001) did an investigation and analysis about the cost components of high value-added free-dried foods and the energy composition of freeze-drying process and the result is shown in Fig. 2 and 3. It can be seen from Fig. 2 that among the cost components of high value-added free-dried foods, energy and transportation cost of the process are only 4%, respectively, not the major cost components, so for high value-added freeze-dried foods, their energy consumption and transportation cost is not very expensive compared with other dried foods. In addition, according to Judge's investigation (Judge *et al*., 1981): If the cost of transportation and energy consumption is taken into consideration, the proportion of energy consumption of freeze-dried foods is much lower compared with the frozen foods (meat or fresh fruits and vegetables). From the entire cost analysis, the energy consumption of freeze-dried foods does not occupy the most important ingredient; let's analyze the energy composition in the whole freeze-drying process. It can be seen in Fig. 2 that energy consumption of the whole process includes material freezing, sublimation drying, water vapor condensation and maintaining vacuum four parts. Among them, the energy consumption of material freezing is the lowest, accounting for only 4%; the main part of the energy is sublimated drying, accounting for 45%; the second is maintaining vacuum and water vapor condensation, which turns out that the real consumption in freeze-drying process is sublimation drying instead of freezing. Therefore, if we want to reduce energy cost of freeze-dried foods, two aspects of improving technology and equipment can be considered. Cui *et al*. (2005) studied the effects of freeze-drying process parameters of carrots on the energy consumption, he found that appropriate heating plate temperature and freeze-drying chamber pressure can significantly reduce the energy consumption in sublimation drying process. However, the technology and equipment is inseparable, if we want to meet the process requirements, the equipment needs to be operated and improved. Yao (2003) found that reasonable operation on compressors and vacuum pumps can be achieved to reduce energy consumption; Huang *et al*. (2010) put forward a kind of simple structure vacuum freezing dryer which can greatly shorten the freeze-drying cycle and reduce the energy consumption of freeze-dried foods.

The existing problems and countermeasures in development of the freeze-dried foods in our country: Freeze-dried foods can match well with the "green food", "health food", "convenient food" three major trends and have a potential market prospects with nature, nutrition, safety, health and convenience. However, the cost of freeze-dried foods is high and rehydration can't meet people's fast-paced life, so the freeze-dried foods especially in our food market are rarely seen. Aiming at the problem of the high cost of freeze-dried foods, the following aspects can be taken into consideration:

- Selecting reasonable freeze-dried materials that will make the foods have a high added value, thus the proportion of energy cost will reduce.
- Improving the freeze-drying process and equipment which will reduce the freeze-drying time so as to achieve the purpose of reducing the energy consumption.
- Improving or introducing new drying technologies, such as the introduction of microwave freeze-drying technology, adsorption freeze-drying and other new technologies which can shorten the sublimation drying time and then reduce the energy consumption. In addition, new technologies can also improve the quality of the products (Barrett *et al*., 1997).

Freeze-dried foods can maximize the original color, smell, taste and nutrition, but there is still a gap on the palate and taste after rehydration when compared with those of the fresh foods. In this view, some food additives were considered to improve the quality, taste and the rehydration performance of freeze-dried foods. Zhu (1993) found that increasing the crude protein content helped the formation of a better gluten structure and improve the taste after rehydration. In the research of thickeners improving the properties of wheat flour, Zhang and Mao (2001) pointed out that guar gum can improve the tensile properties of the dough and wrap the starch granules to form a regular structure with gluten network which will have a positive effect on moisture penetration when rehydrated.

CONCLUSION

Currently, because of the higher cost and lower rehydration performance, freeze-drying technology has not been widely used in convenient foods. However, with the increasing of attention on food nutrition, freeze-drying technology is about to become the best method to produce convenient foods and will be paid more and more attention. At the same time, as the technology is growing mature, the cost of freeze-dried foods will be reduced and the quality and performance will continue to be improved. Therefore, freeze-dried foods have a good prospect for development.

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