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Industrial applications and potential use of ohmic heating for fluid foods

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Ohmic heating technology is generally used for processing liquids and solid-liquid mixtures (or pumpable foods) in the food industry. In ohmic processing, the product is heated volumetrically by dissipation of electrical current through it. The main advantages of ohmic heating are the rapid processing and relatively uniform heating achieved. In this review, the application and potential of ohmic heating in food industry were examined. Nowadays, the availability of novel ohmic heating systems more advanced than their predecessors makes this technology even more attractive for food processors. Ohmic technology is currently being used commercially throughout the world (USA, Japan, UK, several European countries, etc.) for the pasteurization or sterilization of pumpable foods such as fruit and vegetable products (juices, purees, pulps, etc.), milk, ice-cream mix, egg, whey, soups, stews, heat sensitive liquids, soymilk, etc. and aseptic packaging. Much research is still being carried out to improve the current ohmic systems. In recent years, industrial ohmic heating systems have been developed in different countries by companies. The potential applications of ohmic heating technique in food industry are very wide such as cooking, thawing, blanching, peeling, evaporation, extraction, dehydration and fermentation. Researchers should more investigate the potential applications and its effects on food quality and safety before its industrialization.

***Key words**: Food industry, ohmic heating, pumpable foods, current application, potential application*

INTRODUCTION

Consumers are increasingly demanding foods being safety and having improved taste and nutrition [1]. The processing of the particulate foods by conventional thermal methods could damage the food product due to slow conductive and convective heat transfer [2]. To overcome this problem, food manufacturer have begun to apply the electrical energy for food processing in the food industry in recent years [3]. The novel food technologies utilizing the electrical energy in thermal processing have been increasingly attracting the attention of food processors because of its capability of improving the quality and reducing processing costs [4]. Nowadays, ohmic heating systems are more sophisticated and cheaper than previous systems. Hence ohmic heating is more attractive for food industry [5].

Ohmic heating refers to resistive dissipation of electrical energy in the conductive food product which is in contact with electrodes (Figure 1) [6,7]. Also it is known as joule heating, electroheating, electroconductive heating, electrical resistance heating, and direct electrical resistance heating in the literature [2,4]. The uniform heat is generated within the food which allows the transition of electric current when food materials include sufficient water and electrolytes [8]. Ohmic heating

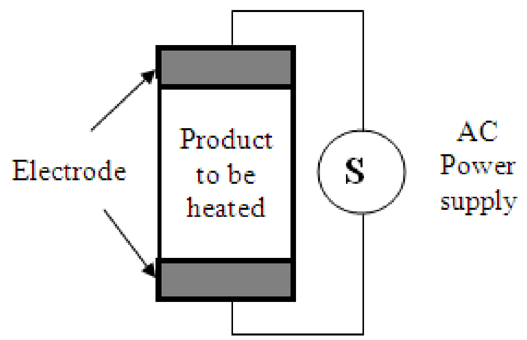

Fig. 1. Operating principle of an ohmic heating device [6].

technology is generally used for processing of liquids and solid-liquid mixtures or pumpable food in the food industry, however its use in the solid foods are still under the research [9-11]. The aim of this review is to provide a general perspective of the ohmic heating technology for currently available industrial applications and future trends in the food industry.

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INDUSTRIAL APPLICATION OF OHMIC HEATING

Brief history. Ohmic heating is investigated in several studies in the beginning of the 19th century. It was firstly used for milk pasteurization in food industry in the last century. But, it did not succeed at this time due to loss of insulation material, higher electricity prices, inadequate process regulations, and other technical restrictions. Later researches [3] declined during 1930s to 1960s. In 1980s, the Electrical Council Research (UK) was secured by a patent for continuous ohmic heating equipment. After this development, the first industrial unit is produced in 1989 in the UK [12]. Today, there are many commercial plants which are operated in food industry [13].

Ohmic heating systems. Ohmic heating systems for food processing have basically a container, a pair of electrodes, and an alternating power supply [14]. Power supply units in ohmic heating systems give electrical energy to system at low frequencies [3]. The electrodes should be made from most conductive materials and also these should have low cost and corrosion resistance [15]. Ohmic heating systems are relatively small equipments. Instant start/stop can also be made, and process temperature can be controlled accurately [3,16].

Ohmic systems can be operated to batch or continuous for processing of food [14]. They have high potential which can be designed to wide variety depending on the application [3] The typical batch ohmic systems have a horizontal cylinder with two electrodes placed at both ends [17]. Continuous ohmic heating systems can vary greatly for industrial applications [3]. They may have several designs; a simple tube with pairs of opposing electrodes mounted on the tube walls opposite to each other, coaxial tubes acting as electrodes with the food flowing between or a vertical tube with the electrodes embodied at regular intervals, etc. [14]. These systems have main parts of flow system and cooling parts. They have several columns for electrical heating. The columns include insulating materials [3].

Selection of the system depends on processing methods of foods and aims of the process. Batch and continuous systems are used for liquid (pumpable) and solid foods [11,14,17].

Current commercial applications. Ohmic heating technology is currently being used commercially throughout the world (USA, Mexico, Japan, UK, and other several European countries) for the pasteurization or sterilization of pumpable foods (viscous or liquid foods) such as fruit and vegetable products (juices, purees, pulps, etc.), milk, ice-cream mix, egg, whey, soups, stews, heat sensitive liquids, soymilk, etc. and aseptic packaging [3,12,14]. It is reported that at least 18 commercial plants were operated in Europe, USA, and Japan. Application of this technology has particularly succeeded to processing of fruits and vegetables [6].

Manufacturer companies. A great number of researches were completed for optimization of process parameters, improving of equipment materials, and design [19]. Ohmic heating systems must have effective control of heating and flow rates, as well as investment and operating costs should be low for successful commercially in food industry [17].

Nowadays, industrial ohmic heating systems are produced commercially in different countries by companies such as APV Baker Ltd. (UK)[12], C-Tech Innovation (UK) [16], Agro process (IAI Group, Canada) [20], Yanagiya Machinery Co. Ltd. (Japan) [21], Kasag (Switzerland) [22], Alfa Laval (Sweden) [23], Raztek (USA) [24], Emmepiemme SRL (Italy) [4,25]. A list of some industrial ohmic heating systems and features for processing of foods is shown in Table 1.

Leadley reported [6] that APV Baker Ltd. (UK) produced two industrial ohmic heating systems. One of these had power output of 75 kW and product capacities of 750 kg/h and the other had power output of 300 kW and product capacities of 3,000 kg/h. Approximate prices for these systems including aseptic line were £ 1,300,000 to £ 2,000,000. On the other hand, Emmepiemme SRL (Italy) produced systems in the range of 60 kW to 480 kW for production throughputs of 1,000 kg/h to 6,500 kg/h. Approximate prices estimated in 2004 were € 60,000 to € 220,000 due to the power output of systems. Tucker informed [27] that Raztek (USA) manufactured one industrial ohmic heating system which was used for pasteurizing the liquid egg at a flow rate over 11,300 kg/h.

Anderson reported [25] that the costs of industrial ohmic heating systems, including installation, can be in excess of $ 9,000,000. Although these systems have an enormous investment for a manufacturing plant, their processing costs are comparable to commercial conventional systems [3]. Costs of ohmic heating were found to be comparable to processing of low acid products [17].

Table 1. Some industrial ohmic heating systems and their features [16,21,23,26,27].

Company	Type of Technology	Type of Electrodes	Products	Heating Power, kW	Frequency, Hz	Capacity, kg/h
C-Tech Innovation	Continuous	-	Beverages, fruits and vegetables through to meat based products, ready meals*	20-240	-	300-7,200
Alfa Laval	Continuous	-	Fruits and vegetables products, prepared foods, liquid egg, ready meals, sauces*	60-300	50	-
Emmepiemme SRL	Continuous	Stainless steel Rising	Fruits and vegetables products*	60-480	25,000	1,000-6,500
APV Baker Ltd.	Continuous	Platinum coated Intrusive	Ready meals and particulate fruit product*	75-300	50	750-3,000
Raztek	Continuous	Pure carbon	Liquid egg*	-	50	11,300
Yanagiya Machinery	Continuous	-	Tofu production	-	-	-

*Pasteurization or sterilization of pumpable food.

POTENTIAL APPLICATIONS OF OHMIC HEATING

Ohmic heating is investigated on various areas in food engineering. It has a lot of potential for commercial use in food processing [18]. It has a large number of potential future applications such as cooking, thawing, blanching, peeling, evaporation, extraction, dehydration, fermentation, and online detection of starch gelatinization for food industry [2,3,8,28].

Cooking. Solid foods of ohmic heating are restricted due to the difficulty in providing good contact between the electrodes and food surface [29]. In recent years, several studies have been completed about ohmic cooking [11,14,30-32]. Studies have been conducted especially in meat processing. Although ohmic cooking has offer some advantages such as rapid cooking, energy efficiency, and food safety, it has not yet used industrially due to several limitations [14,29,30]. Icier et al. [11] reported a new method for cooking of meatball in continuous type ohmic cooking system resulting the highest product quality such as lowest hardness, maximum chewiness, and resilience and providing safety foods.

Thawing. Ohmic heating is an alternative method for thawing of frozen foods [12]. Frozen food samples must be good contact with the electrodes for efficiency of this method. The size, shape, and electrical conductivity of the frozen food should also be carefully optimized to provide higher efficiency [33]. Ohmic thawing have some advantages such as less treatment times, the less microbial growth and the better quality of the thawed product compared to the conventional methods [12,34]. Although ohmic thawing is not applied commercially in food industry due to several limitations, it has potential to use in the future [33,35].

Blanching and peeling. The ohmic heating appears to be an alternative method for blanching and peeling method for vegetables and fruits. Cell membranes of vegetables and fruits are damaged by combination of electrical and thermal effects in this method [36]. Mizrahi [37] reported that ohmic blanching considerably reduced the hot water requirement and blanching time compared to conventional method. Vegetables and fruits may be peeled efficiently without using any chemicals [13].

Evaporation. Ohmic heating is a new method for vacuum evaporation of orange juice. It can evaporate faster and gives higher quality of final product than conventional processes at the same time [12].

Extraction. Ohmic heating can be used for extraction. It affects the structure of biological tissue so that increasing of extraction yield [36].

Lakkakula et al. [38] informed that ohmic heating increased the extraction yields for sucrose from sugar beets, beet dye from beet root, soymilk from soybeans, and total percent of lipids extracted from rice bran. Wang and Sastry [39] showed the improved apple juice extraction yields with ohmic heating.

Dehydration. Ohmic heating can be used for dehydration of vegetables and fruits. It may be causes electroporation of cell membranes. Hence, it increases the permeabilization of the cell and so facilitates dehydration [8,12]. Lima and Sastry [40] showed the faster hot-air drying rate of sweet potato with ohmic heating.

Fermentation. Ohmic heating applications may be useful for fermentation in food industry. It was reported that lag period decreased when ohmic heating was used in fermentation of some foods. This technique may decrease the lag period of fermentative bacteria and so decrease of fermantation time in processing of yogurt, cheese, beer, or wine [25,41].

CONCLUSION

Ohmic heating have been used for several purposes including blanching, heating, cooking, etc.. Several manufacturers developed ohmic systems especially for processing of liquid foods. However, further studies are recommended to development of new industrial ohmic systems for the potential applications into industrialization. New industrial ohmic systems should also be convenient for processing solid food products. Nowadays, although industrial ohmic systems have high investment cost, their cost will be decreased by the time with technological developments. In future studies, toxicological and mutagenic effects should also be investigated for electrically processed foods.

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ИНДУСТРИАЛНИ ПРИЛОЖЕНИЯ И ВЪЗМОЖНОСТИ НА ОМОВОТО НАГРЯВАНЕ ЗА ТЕЧНИ ХРАНИ

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(Резюме)

В хранителната индустрия технологията на омовото отопление се използва главно при преработката на течности или смеси на твърди вещества и течности (или храни, които могат да се изпомпват). При омовата преработка обемът на продукта се нагрява чрез пропускане на електрически ток през него. Сред основните предимства на метода са бързата преработка и постигането на относително равномерно нагряване. В настоящия обзор са разгледани приложенията и възможностите на омовото отопление в хранителната индустрия. В днешно време, наличието на нови омови отоплителни системи, по-напреднали от своите предшественици, прави тази технология още по-привлекателна за производителите на хранителни продукти. В момента в световен мащаб (САЩ, Япония, Англия, някои европейски страни и др.) омовата технология е комерсиализирана и се използва за пастьоризиране или стерилизиране на храни, които се изпомпват, като например плодови и зеленчукови продукти (сокове, пюрета, каши и др.), мляко, миксове за сладолед, яйца, суроватка, супи, яхнии, чувствителни към топлина течности, соево мляко и др., а така също и при асептично опаковане. Все още се извършват много изследвания за подобряване на съществуващите омови системи. През последните години, в различни страни са разработени промишлени омови отоплителни системи. Потенциалните приложения на техниката на омово отопление в хранително-вкусовата промишленост са много широки, като включват готвене, размразяване, бланширане, пилинг, изпаряване, екстракция, дехидратация и ферментация. Учените трябва повече да изследват потенциалните приложения, като обърнат внимание на въздействие на омовото отопление върху качеството и безопасността на храните преди индустриализацията на метода.