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Heat transfer characteristics of cucumbers during blanching ☆

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Abstract

The possible use of blanching in combination with controlled fermentation is being considered as a means to reduce the salt levels needed in the storage of brined cucumbers. To be commercially feasible, the use of heat should be optimized for economic and product quality considerations. This study reports basic information on the heat transfer characteristics of cucumbers needed to optimize the blanching process.

Two-dimensional (cylindrical coordinates) heat diffusion equations were used to simulate the heat transfer characteristics of cucumbers during rapid water heating (blanching). The equations were solved by explicit form of the finite difference method. Thermo-physical properties (thermal conductivity, specific heat and density) of cucumbers needed to solve the heat transfer equation were also measured. Temperature (20–95°C) did not significantly affect the thermal conductivity (0.62 W/m K) or specific heat (4.03 kJ/kg K) of cucumber. The maximum standard error of simulated temperatures of the cucumbers from experimental data was 4.5°C. There was no significant change in the moisture level of the cucumber during blanching. Simulation results showed that heat transfer coefficients between 500 and 6000 W/m^2 K had no significant effect on the surface and center temperatures of cucumbers during blanching.

Keywords: Cucumber; Thermal properties; Heat transfer; Blanching

1. Introduction

The US production of cucumbers (*Cucumis sativus*) for pickling is about 590,000 t, which are preserved by brine fermentation (40%), pasteurization (40%), or refrigeration (20%) (Fleming, Kyung, & Breidt, 1995). Brine fermentation is the oldest method for cucumber preservation and was the only commercial method used before the introduction of pasteurization in the 1940s (Etchells & Jones, 1942, 1944; Monroe et al., 1969).

Brine fermentation remains an important method for temporary preservation of cucumbers because of sensory traits desired in certain products, processing strategies, and economic reasons (Fleming, 1982; Fleming & Moore, 1983). However, the need to use relatively high concentrations of salt for preservation necessitates removal of some of the salt during processing of the brined cucumbers into finished products, which results in disposal problems associated with both the salt and consequent organic matter. Environmental problems exist within the pickle industry because many companies cannot meet the 230 ppm chloride limit set by the US Environmental Protection Agency for discharge of their wastewater into fresh water bodies (Anonymous, 1987; Humphries & Fleming, 1989).

It is possible that salt levels needed to assure the microbial and textural storage stability of brined cucumbers can be reduced (or even eliminated) by heating the cucumbers before brining to inactivate undesirable microorganisms and softening enzymes on the cucumber surface, followed by the addition of a desired culture of lactic acid bacteria (Fleming et al., 1995). The optimum heat process necessary to adequately preserve cucumbers brined at low levels of salt has not been established.

Considerable research has been done in establishing the optimum heat process necessary to preserve pasteurized cucumbers contained in glass jars and submerged in acidified liquid (Anderson, Ruder, Esselen, Nebesky, & Labbee, 1951; Esselen & Anderson, 1957;

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Esselen, Anderson, Ruder, & Pflug, 1951; Esselen, Anderson, Fagerson, & Labbee, 1952a; Esselen, Fagerson, Pflug, & Anderson, 1952b; Etchells & Jones, 1942; Labbee, Esselen, & Anderson, 1952; Monroe et al., 1969; Nicholas, Pflug, & Costilow, 1957; Nicholas & Pflug, 1962; Rodrigo & Alvarruiz, 1988). The industry-accepted standard for pasteurization is to heat the cucumbers in acidified cover solutions to an internal (of the cucumber) temperature of 74°C.

Blanching was compared to irradiation and pasteurization as a means of inactivating naturally occurring microorganisms for use in inoculation with pure cultures of selected species of lactic acid bacteria (Etchells, Costilow, Anderson, & Bell, 1964). Blanching of fresh, whole cucumbers is a common commercial practice to increase flaccidity of the cucumbers so as to facilitate their packing into jars. The effect of blanching on the quality of fresh cucumber pickles has been studied (Nicholas & Pflug, 1962). The texture, as measured by a mechanical pressure tester, was significantly lower for the heat-processed pickles than for the raw cucumbers. Blanching was carried out at temperatures of 65.6–95.6°C for 7–166 min. In addition, internal damage, largely carpel separation, was obtained for heating regimes exceeding equivalent temperature and time of 82.2°C and 2 min, respectively.

The possible use of blanching in combination with controlled fermentation has been considered. The pure culture fermentation studies of Etchells et al. (1964) had implications in that direction. However, at the time, heating of cucumbers for bulk fermentation was not considered practical. Salt was inexpensive, and the use of excess concentrations to assure stability of the brine-stock was not as serious a concern as it is today. To be commercially feasible, however, the use of heat should be optimized for economic and product quality considerations. Evidence indicates that, by far, most microorganisms are located on or near the surface of the whole cucumbers (Etchells, Bell, Costilow, Hood, & Anderson, 1973; Breidt & Fleming, 1998), although some occasionally may occur within the fruit (Samish, Etinger-Tulczynka, & Bick, 1963; Meneley & Stanghellini, 1974). Also, most microbially produced softening enzymes are thought to be located on/near the surface, since washing of cucumbers prior to brining has been shown to reduce enzyme activity and result in firm salt-stock cucumber (Etchells, Bell, & Jones, 1955). We wish to determine if a blanching process can be optimized to be commercially applicable to fermentation and storage of whole cucumbers in bulk containers.

To optimize such a blanching process, basic information on the heat transfer characteristics of cucumbers is needed. Although research has been published on heat penetration into cucumbers contained in liquid in glass jars, we are unaware of studies relating specifically to the blanching process. In addition to obtaining a general understanding of the heat transfer characteristics of cucumbers during blanching, we were particularly interested in quantifying the rate of temperature increase within the first 100 s of heating, since most of the microorganisms are suspected to be located at or near the surface of whole cucumbers (Breidt & Fleming, 1998). The objective of this paper was to simulate the transfer of heat into cucumbers during blanching and to use experimental data to verify the simulation model.

2. Materials and methods

2.1. Heating experiment

Fresh pickling cucumbers were obtained from local growers or pickle companies. Only hand-washed cucumbers free of obvious physical damage and disease were used. Cucumbers with diameters of about 25, 37, and 45 mm were used for model verification. A digital vernier calipers (Digimatic, model no. CD-S6″CP, Mitutoyo, Japan) with precision of 0.01 mm was used to measure the actual dimension of each cucumber. Two small diameter (0.432 mm) needle probe thermocouples (model 08505-93, Cole Parmer Instrument, Vernon Hills, IL) were inserted into a cucumber from the axial (stem) end. The intent was to have the tip of one of the thermocouples at the geometric center of the cucumber, while the other thermocouple tip resided close to the surface of the cucumber. In most of the cases, these could not be achieved because of the soft nature of cucumber tissue. Therefore, the actual locations of the thermocouple tips were obtained by cutting the cucumbers after heating and measuring with the vernier calipers.

A DaqBook Data Acquisition system (IOtech, Cleveland, OH) was used to collect temperature readings from the thermocouples placed inside the cucumber during heating. The data acquisition system consists of a signal conditioner (DBK 19), an analog to digital converter – ADC (DaqBook 100), and a personal computer.

To carry out a test, a cucumber fruit with the thermocouples inserted was placed in a 10-l heated water bath set to a desired temperature. The temperature of the water in the bath did not deviate from the desired set point by more than 0.5°C. Temperatures from the thermocouples were read and stored by the data acquisition system at every second for 1000 s. The heated fruit was, thereafter, removed from the blanching water, cut and the actual axial and radial locations of the tips of the two thermocouples were measured. Heating of the 37 mm diameter cucumbers was carried out in water heated to constant temperatures of 50°C, 65°C, 80°C, and 95°C. The effect of cucumber size was studied by heating 25 and 45 mm diameter cucumbers in water at