THERMAL AND RHEOLOGICAL PROPERTIES OF BRINE FROM FERMENTED AND SULFITE-PRESERVED CUCUMBERS[1]

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ABSTRACT

Pickling cucumbers may be temporarily preserved by fermentation in brine (6-8% NaCl) or without fermentation in salt-free, sulfite solution (300 ppm sulfite, pH 3.5). Brines obtained from preservation processes are often discarded. Due to environmental concerns, there is increasing consideration for further use of the brine solutions by recycling for use in bulk storage or filtration and incorporation into finished products. Thermal and rheological properties are fundamental to the reuse of the brine. The effect of temperature was determined on the rheological (5-45C) and thermal properties (5-75C) of brine. The properties of the brine samples were found to be significantly different ($P <$ *0.05) from each other and from water. Salt content was the most important factor affecting the thermal and rheological properties of brine. At the same conditions, the values of the properties (thermal conductivity, specific heat, and thermal diffusivity, viscosity) were about 5 to 23% less than the corresponding values for water.*

INTRODUCTION

Approximately 40% of the pickling cucumbers produced annually (550,000 tons) in the United States are preserved by brine fermentation (Fleming *et al.* 1995a). Fermentation of cucumbers is typically carried out with 5 to 6% NaCl.

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The salt concentrations may be increased to 15% in cold climates to prevent freeze damage, or to only 8 to 12% to ensure textural and microbial stability during extended storage. The salt concentration must be reduced to 2 to 3% during processing of the brined cucumbers into finished products. This has created disposal and environmental problems for the pickle industry. In addition, many companies cannot meet the 230 ppm chloride limit recommended by the U.S. Environmental Protection Agency for discharge of water into fresh water bodies into which processing waste is discharged (EPA 1987; Humphries and Fleming 1989).

The pickle industry currently recycles about 40% (that exogenous to the cucumber) of the salt used in brining by incorporating it into new brines for fermentation. The salt within the cucumbers must be leached from the fruit during further processing to finished products. This salt-containing leach water is too diluted to be economically reused. Strategies that are now being considered by our laboratory to alleviate this problem include: (1) controlled fermentation of cucumbers (i.e., cucumbers blanched and inoculated with a selected lactic acid bacteria culture) at lower salt levels and recycling or incorporating diluted brine into finished products (Fleming *et al.* 1987, 1995b), and (2) storage of pickling cucumbers in 300 ppm of sodium metabisulfite (McFeeters 1998). With sulfite storage, calcium chloride and HCl are added to the brine for product stability during the storage period. Fermentation does not take place and, thus, the sulfite-preserved cucumbers are free of microbial cells, salt, lactic acid, and other components that are associated with vegetable fermentation.

Brines that are to be recycled or incorporated into finished products have to be reclaimed from the stored pickles. Some of the unit operations that may be carried out on the brine samples include filtration or removal of microbial cells, pumping of the brine, and storage in appropriate containers. The thermal properties (specific heat, thermal conductivity, thermal diffusivity, and density) are needed in the design of suitable storage systems (Mohsenin 1980) due to diurnal and seasonal variations in environmental temperature during brine storage. Brine rheological properties of the brine are important in the design of pumps and handling and filtration systems (Rao 1999; Holdsworth 1971). To our knowledge, information on the thermal and rheological properties of brine from fermented and sulfite-preserved cucumbers is not available in literature. It is expected that the properties of fermentation brines will be different from those of sulfite-preserved brines.

The objective of this study was to quantify and compare the thermal and rheological properties of brines from fermented and sulfite-preserved cucumbers.

MATERIALS AND METHODS

Size 3A cucumbers (diameter of 42.0 to 45.5 mm) of unknown cultivar were obtained from a local processor. The cucumbers were washed in a reel washer and were free of obvious physical damage and disease. Brining of the cucumbers was carried out in duplicate in 1-gal (3.8 L) glass jars containing 50% cucumbers and 50% brine by weight. The cucumbers were preserved by fermentation in 6 and 2% salt levels and in sulfite solution (300 ppm of sodium metabisulfite).

In addition to salt, the cover brine for the fermented cucumbers contained 18 mM of CaOH and 53 mM of acetic acid. The brines were inoculated to contain 10^6 CFU/mL of *Lactobacillus plantarum* MOP-3 MRS broth (Difco Laboratories, Detroit, MI). The cover brines for sulfite treatment contained 30 mM of $CaCl_2$ and 100 mM of acetic acid. HCl was used to adjust the pH of the sulfite-preserved samples to 3.5.

Brined cucumbers were stored in an incubator at 30C for 2 months to allow the fermentation process to occur. Acidified samples preserved with sulfite were also stored for 2 months at 30C. The brine samples were collected after the 2-month storage period and frozen until the time for thermal and rheological properties determination. The samples were thawed and allowed to equilibrate to room temperature (~25C).

The pH, salt level and turbidity (indication of microbial cell population) of the brine samples were also determined. NaCl was measured by titration with standard $AgNO_3$ using dichlorofluorescein as an indicator (Fleming *et al.* 1992). Before rheological and thermal properties measurements, the optical density of the brine samples were determined by reading absorbance of samples at a wavelength of 640 nm in a UV-visible spectrophotometer (model 8452A, Hewlett Packard, Avondale, PA).

Thermal Properties

The measured thermal properties were thermal conductivity (k), specific heat (c_p) and density (ρ). Thermal diffusivity was calculated from the relation below:

$$\alpha = \frac{k}{\rho c_p} \tag{1}$$

Symbols are defined in the Notation section.

Thermal conductivity was determined by the line-heat source probe method. The probe apparatus, constructed according to the recommendations of Sweat

(1986), consisted of a type E thermocouple (0.051 mm diameter), constantan heater wire (0.077 mm diameter), a 23 gauge stainless steel hypodermic needle (houses the heater wire and thermocouple), and a type E thermocouple connector.

To test a sample, beakers containing the 150 mL brine samples were placed in a circulating water bath and allowed to equilibrate to the desired temperature. The probe was inserted into the sample and the power for the heater wire in the probe was turned on. The time and temperature data were recorded by a datalogger (model OM-3000, Omega Engineering, Stamford, CT) at the rate of five readings per second. Thermal conductivity was calculated from the relation (Sweat 1986):

$$k=\frac{Q}{2\pi}\frac{\ln(t/t_o)}{(T-T_o)} \tag{2}$$

The initial time, t_o, in the above equation was set equal to the time when the semi-log plot of time-temperature plot starts to become linear. The power level in the heater was 5.5 W/m. For each time-temperature plot, the slope was found using simple linear regression.

Since preliminary testing showed that the viscosity of brine was close to that of water, data collection was carried out for 25 s to minimize the development of convection currents that may arise due to probe heating (Mohsenin 1980; Sweat 1986). The accuracy of the thermal conductivity measurement procedure was verified by measuring the thermal conductivity of water at 25C. This was measured to be 0.618 W/m K. This is close to the published value of 0.606 W/m K for thermal conductivity of water at 25C (Singh and Heldman 1993).

Specific Heat and Density

Specific heat was measured by means of a Perkin-Elmer DSC 7 differential scanning calorimeter equipped with intracooler II refrigeration unit and dry box (Perkin Elmer Corp., Norwalk, CT). The DSC was calibrated with indium (temperature and enthalpy) and dodecane (temperature) before use. Samples were pipetted (55 μL) into the manufacturer's stainless steel pans and run from 5 to 45C at a heating rate of 3C/min using an empty pan as the reference. Specific heat was calculated by the software provided by the DSC manufacturer. To ascertain the accuracy of the measurements, the specific heat of HPLC-grade water was measured and found to be within 2% of published values.

To obtain density, the weight of brine sample needed to fill a 50 mL volumetric flask was measured. Density was taken as the ratio of mass to volume (50 mL).

(2) Salt content was found to be the main factor influencing the rheological and thermal properties of the brine solutions.

(3) The Arrhenius equation can be used to describe the relationship between brine viscosity and temperature. Thermal conductivity and thermal diffusivity were increased linearly with temperature, while a polynomial relationship existed between specific heat and temperature of brine samples.

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NOMENCLATURE

c_p	Specific heat (kJ/kg K)
E_a	Activation energy (kJ/kg mol)
k	Thermal conductivity (W/m K)
Q	Energy (W/m)
R	gas constant (8.314 kJ/mol K)
T	temperature (C)
T_K	Absolute temperature (K)
T_t	time (s)
p,q,v,w,x,y,z	Constants

Symbols

$\dot{\gamma}$	Shear rate (s^{-1})
ρ	Density (kg/m^3)
η	Apparent viscosity (Pa s)
σ	Shear stress (Pa)
η_∞	frequency factor (Pa s)
α	thermal diffusivity (m^2/s)

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