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Winterization strategies for bulk storage of cucumber pickles☆

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Cucumbers are commercially fermented and stored in bulk in outdoor open top fiberglass tanks. During winter, snow and ice that accumulates around and on top of tanks influence heat transfer in an unpredictable manner, often compromising quality. This study evaluates the performance of inexpensive and resilient fermentation tank insulation and provides an estimate of heat loss associated with strategies for storage and preservation of fermented cucumbers during winter. Three insulation configurations were explored: conical top-cover, flat top-cover, and perimeter insulation. Changes in temperature during storage were experimentally studied in different tank configurations. A mathematical model was developed to simulate temperature profiles and heat loss in an idealized fermentation/storage vessel. Comparisons of the insulated tank configurations suggested a significant difference in temperature between a flat cover and uncovered tank when exposed to temperatures characteristic of the spring season in Pinconning, MI.

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1. Introduction

In the pickle processing industry, storage is essential to preserve quality of the product and provide availability throughout the year. Cucumbers are brined with 5–8% sodium chloride (NaCl), potassium sorbate, and vinegar and held in open top tanks, so that the brine surface is exposed to ultraviolet rays of sunlight to prevent growth of mold and yeast. To maintain year round processing operations, NaCl concentration is increased up to 14% after fermentation to prevent growth of spoilage microorganisms, minimize freezing damage in open-top tanks during winter conditions, and guarantee long term storage and preservation (Fleming et al., 1987). Emerging technologies, such as cucumber fermentation brined with calcium chloride ($CaCl_2$), can reduce the amount of salt needed during fermentation and storage of brined cucumbers while diminishing chloride concentrations in the wastewater (McFeeters and Pérez-Díaz, 2010; Pérez-Díaz et al., 2015). However, maintaining the quality of pickles stored at freezing temperatures without salt and at low levels of $CaCl_2$ during winter represents a challenge. Thermal performance of low salt fermentations has not been explored. Different winterization approaches to preserve the quality of pickles have been used, including burying of tanks, to provide insulation and geothermal heat, and covering the top of the tanks with fiberglass domes to decrease convection losses. However, adoption of these techniques is currently cost prohibitive for pickle processors (personal communication). Experimental studies have shown that brines prepared with 1.1% $CaCl_2$ have a freezing point of 29 °F (unpublished). In order to match the freezing point of the 6% (wt.) NaCl cover brines (14 °F), about 18% (wt.) $CaCl_2$ or 14% v/v glycerin is needed. Increasing the $CaCl_2$ and glycerin content to maintain the temperature of cover brines above the freezing point during storage through the winter are neither cost efficient nor environmentally sustainable.

We theorize that modifying the exposed tanks may help in reducing in-tank freezing, salt levels, environmental footprint, and processing cost. Visual observations indicate that ice is mainly formed at the top and the internal perimeter of the tanks, impeding the removal of fermented stocks and increasing processing costs. To overcome these problems, a new winterization strategy is needed to prevent water and snow intrusion, capture heat from solar radiation at the top, and reduce heat transfer by convection at the top of the tanks. A removable greenhouse cover is a potential solution to keep the surface of brine in the tanks at temperatures above the freezing point of the cover brines by trapping solar heat and

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protecting the top surface area from wind, thereby minimizing heat dissipation. Polycarbonate, fiberglass, glass, acrylic, vinyl, and polyethylene have been widely used as greenhouse covering materials. The choice of material will mainly depend on the application, ambient conditions, and budget. In Michigan, where temperatures during winter are below freezing, evaluating the impact of insulation and thermal behavior of the tanks is crucial.

This study aimed at designing and building inexpensive and resilient insulation tank covers to prevent or ameliorate freezing, monitoring in-tanks temperature changes as a function of time and insulating design, and developing a heat transfer model using a mathematical computational fluid dynamic tool (COMSOL Multiphysics v5.2) to simulate cold weather fermented cucumber bulk storage and calculate heat losses. The collective new knowledge serves as a tool for providing recommendations for processors on effective enhancements for outdoor tank insulation used for bulk storage.

2. Materials and methods

2.1. Brining of cucumbers

Cucumbers were fermented in 10,000 gallon fiberglass tanks. Each of the tanks contained 3B (1.75″–2″ diameter) cucumbers that were brined to give a 60:40 pack out ratio (by weight of cucumbers to cover brine). The composition of cover brines used in the study are presented in Table 1.

2.2. Experimental protocol and data collection

Seven commercial cucumber fermentation tanks, four buried and three exposed tanks (one with a greenhouse conical top-cover), were examined in Pinconning, MI from January 18^{th}-25th, 2016. Also, three commercial exposed tanks (uncovered, flat top-cover, and insulated perimeter) were examined in Mount Olive, NC from March 1^{st}-29th, 2016 to test the potential to extend the pickle processing season later into the fall/winter and earlier in the spring in the South. The conical top-cover, flat top-cover, and perimeter insulation prototypes were constructed with a commercial 5 mm high density polyethylene (Solexx) material (Solexx Greenhouse and Greenhouse Covering, GSR-240-4, Salem, OR). The conical structure (12′ diameter and 2.5′ tall) was constructed on an untreated pine frame and installed in Pinconning, MI (Fig. 1A). The flat top-cover structure (12′ diameter) was constructed on a PVC frame and installed in Mount Olive, NC (Fig. 1B). The covers were placed on top of the tanks and the insulated perimeter was wrapped with Solexx material around the tank and held in place with PVC rings. To determine temperature inside the tanks, 15 thermocouples were mounted at five different radial locations, 2 feet away from the walls of the tank, and three heights from the surface (2, 5, and 9 feet) inside PVC pipes (three thermocouples per PVC pipe) and placed inside the tanks. The cover brine temperature was monitored using type K thermocouples. Temperatures were recorded every minute using a computer-based data acquisition system (TempScan/1100, iOtech, Cleveland, OH). Average cover brine temperatures during the most extreme weather conditions were used for modeling.

2.3. Numerical model

Heat transfer under varying environmental conditions in outdoor fiberglass tanks containing fermented cucumbers in winter conditions was modeled. Four tank models were created (buried with $CaCl_2$ cover brine, buried with NaCl cover brine, exposed tank without cover and with NaCl cover brine, and exposed tank with Solexx conical top-cover with NaCl brine) with a cylindrical geometry (10′ tall, 12′ in diameter, and 2″ thick) in 3D interface. The remainder of the model geometry was a rectangle whose material properties were defined as air (turbulent flow). The boundaries between the tank and air were defined as a continuous boundary. The computational domain included the brine, tank walls, and insulation material. The properties of the cover brine were as follows: $\rho = 1040$ kg/m^3, $k = 0.64$ W/m°K, and $cp = 4230$ J/kg°K. Material properties of the tank walls (fiberglass) was used as listed in COMSOL's material library. Thermal conductivity values were obtained from experimental data using a KD2 pro thermal analyzer (Decagon Devices, Inc., Pullman, WA) and the density and specific heat were obtained from the literature (Humphries and Fleming, 1991; Fasina and Fleming, 2001).

The temperature changes in cover brine were simulated using heat transfer with surface-to-surface radiation module in COMSOL Multiphysics, which considered external radiation using the coordinates of Pinconning, MI (latitude 43° N, longitude 83° W), time zone, and day of the year to compute the direction of incident solar radiation. In the energy equation, the external ambient temperature and the superficial heat transfer coefficient have been imposed on the tank's walls, the top, and the base, considering the radiation heat transfer between the tank and the ambient. The modes of heat transfer considered in the heat loss calculations were conduction, convection, and surface-to-surface radiation. Thermal losses from the tank to the environment were analyzed and minimized in order to improve insulation efficiency.

The simulation was set up as a time-dependent study to examine the temperature inside the tank as a function of time (3 h during the most extreme weather conditions observed, 8 °F and 37 °F). The model was meshed, solved, and then analyzed. For this analysis, all of the elements were free triangular meshed.

The following assumptions were made: mass transfer and volume changes are negligible and properties (density, porosity, permeability, dynamic viscosity, diffusion) do not change with temperature. The model created was verified by comparing predicted time-temperature history throughout the tank to existing experimental data. The data points for each thermocouple were averaged to create an average temperature history to compare with the results of the COMSOL model.

3. Results and discussion

The experimental data collected at Pinconning, MI showed that cover brine temperatures during the coldest night (ambient temperature 8 °F) were on average 22, 23 and 25 °F for exposed, top-covered, and buried tanks, respectively (Fig. 2 and Table 2). The

Table 1
Equilibrated cover brine composition observed at the locations included in this study.

Location	Cover brine composition
Mount Olive, NC	NaCl cover brine: 5.8% wt. NaCl, 6 mM potassium sorbate
Pinconning, MI	NaCl cover brine: 8% wt. NaCl, 6 mM potassium sorbate and 15 mM acetic acid as vinegar
	$CaCl_2$ cover brine: 1.1% wt. $CaCl_2$, 6 mM potassium sorbate

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