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Numerical modelling of heat and mass transfer in vegetables cold storage

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Abstract

Heat and mass transfer phenomena occurring in cold storage chambers for vegetables have been modelled in the paper on the example of the experimental Chinese cabbage cold store. Special attention has been given to the problem of modelling of interrelationship between phenomena occurring in the bulk of vegetables and in the heat exchanger of a cooling unit, accomplished through User Defined Functions UDF so that the cooling capacity and the transpiration and respiration in the bed of cabbage were closely related. The comparisons between simulation and experimental results were conducted in order to indicate further improvements to the model.

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Keywords: heat and mass transfer; numerical simulation; porous medium; refrigerated storage; Chinese cabbageIntroduction

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1. Introduction

Unfavorable storage conditions in cold stores of fruit and vegetables may induce drying of the commodity or its low temperature injuries. Quantitative and qualitative losses may occur due to non-uniformity of environmental condition in the bulk. The most important factors affected the homogeneity in the bulk are velocity, temperature and humidity of air from the cooling unit, load arrangements and physical properties of vegetables and fruit. The numerical modelling of the cold storage chambers may be of great assistance in studying so complex relationships affecting the storage conditions.

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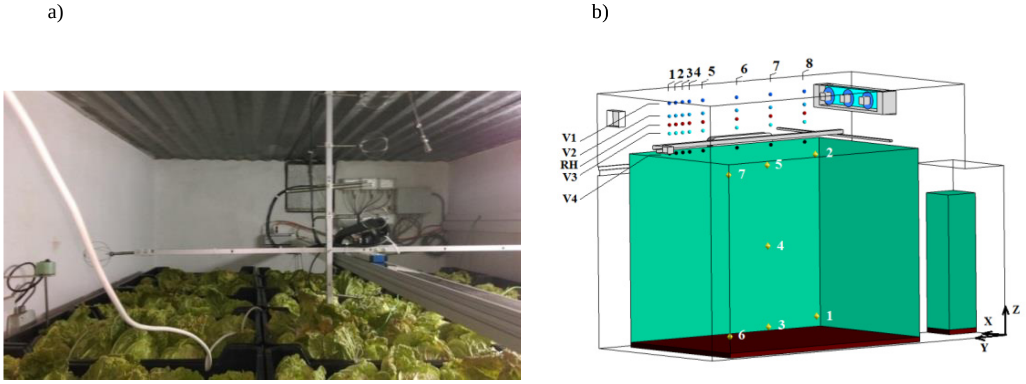
a)

b)

Fig.1. Experimental cold store of Research Institute of Horticulture in Skierniewice, Poland:the view from the cooler; (b) geometric model of the cold store

The heat transfer in the cold stores is modelled in various ways. Authors of [1] modelled only the airflow in the chamber, assuming temperature to be constant across the room. Researchers in [2] incorporated a lumped model of the heat exchange between the cooler and the air. In the papers [3, 4] the cooler was regarded as porous medium, with dominant inertial resistance, obtained taking into account losses due to wall friction, entrance and exit, acceleration and deceleration effects. Heat transfer in the bulk of produce is usually modelled using thermal equilibrium, neglecting the temperature difference between the produce and the air, as in papers [3, 4]. Thermal non-equilibrium approach, considering temperature difference between product and cooling air, was used in [2], but with the simplest heat transfer model neglecting thermal conductivity in the bulk. Recently, the authors of [5] compared both approaches (with thermal conduction in a bulk) for experimental cold store of apples with good agreement to experimental results.

The objective of our study was to model the airflow, heat and mass transfer in the storage chamber of Chinese cabbage, considering the cooling unit and the bulk of vegetables as a whole, in order to predict non-uniformity of velocity, temperature and humidity distributions inside the commodity, and consequently to determine the unfavorable storage conditions. The close relationship between the phenomena occurring in the bulk and in the cooler (the transpiration and respiration of vegetables and the required cooling rate) has been achieved through the User Defined Functions (UDF) in ANSYS Fluent. The numerical model was examined on the example of the experimental cold store of Research Institute of Horticulture in Skierniewice, Poland, shown in Fig.1a.

2. Modelling transfer phenomena

The view from the cooler side of the investigated experimental storage chamber is shown in Fig. 1a. Its geometric model is presented in Fig. 1b. The overall dimensions were 2.05 x 4.33 x 2.93m. The chamber was loaded with 2629 kg of Chinese cabbage, packed in plastic boxes, arranged in a block of dimensions 1.8 x 2.8 x 2.17m occupying most of the space. Boxes of cabbage were placed on wooden pallets. There was also a column of boxes in the antechamber to the room, seen in Fig. 1b. The nominal data of ceiling-type unit cooler operating on glycol solution were: capacity 1148W and air flow rate 1105 m3/h. The flow of air was generated by three axial fans of 20cm of diameter rotating at 1300 rpm, placed at the outflow of the cooler.

In modelling - the geometry of the cooling unit was simplified to the heat exchanger regarded as a box of porous medium and fans - being infinitely thin plates with pressure jump depending on the local normal velocity component according to the fan performance curve obtained from manufacturer data. The swirling jets of air coming from the fans to the room where visualized by means of yarn tufts and measured. The currents of air blown out by the fans took the shapes of divergent cones. The angle of divergence was measured to be 80°÷90°. The inclination angle of velocity vector with respect to the circumference of the fans was equal to 15°÷20°. These factors were used to define the radial and tangential components of velocity with the aid of UDFs. The fan motors and other solid parts of the unit were