

Numerical Simulation on the Airflow Field and Heat Transfer in Large Cold Store

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Abstract. A steady three-dimensional CFD model was developed to investigate the flow field in cold store, including velocity, temperature, and turbulence intensity distribution. The simulation was conducted on the example of the experimental cold store, considering both the empty case and the case fulfilled with packaged pork. According to different scales between cold store and single packaged food product, special vvvvattention has been given to the mesh quality and modelling of heat transfer at the surface of single product. The comparisons between two cases were performed in order to indicate further improvements to the arrangement of products.

1. Introduction

Freezing and cooling are more effective ways to maintain superior sensory and nutritional qualities compared to other methods, such as canning and devhydration. The quality of frozen foods depends upon the control of the freezing process, which includes air temperature, velocity and turbulence intensity distribution in common case of air-blast freezer. Spatial difference of air temperature and moisture distributions are often observed at certain positions of cold store, which may lead to deterioration of food quality and safety.

The airflow inside cold store has been modelled in various ways[1-5]. Ambaw investigated the effect of storage temperature on viscoelastic properties of ice cream and correlate it with sensory quality[6]. Delele studied influence of box materials and plastic cover on the distribution of 1-MCP in cold storage using validated CFD models[7]. Laguerre developed a three-dimensional computational fluid dynamics (CFD) model to predict the storage room air velocity, temperature and humidity distributions, and fate of the water drop-lets that were sprayed for humidifying the storage room[8]. Tsevdou developed a simplified model on transfers and airflow, which described the evolution of product and air temperatures at different zones in the cold room[9].

The objective of the work was to study and model the airflow and heat transfer in the empty and loaded storage chamber and to correlate the distribution to the process of food products.

2. Method

2.1. Model formulation

In order to evaluate air distribution in cold store, coupled air flow and heat transfer has to be considered in governing equations. Since food products studied in this work was packaged products, vapor transfer was neglected during the present simulations. Following set equations governed the mass, momentum and energy conservation of airflow field in cold storage.



$$\begin{aligned} \nabla \cdot U &= 0 & (1) \\ \frac{\partial U}{\partial t} + \nabla U \cdot U &= \nabla \cdot [(\nu_l + \nu_t)(\nabla U + \nabla U^T)] \\ &\quad - \frac{2}{3}(\nu_l + \nu_t)\nabla \cdot U \cdot I - \frac{\nabla p}{\rho} & (2) \\ \frac{\partial T}{\partial t} + \nabla \cdot (UT) &- \nabla \cdot \left[\left(\frac{\nu_l}{Pr_l} + \frac{\nu_t}{Pr_t} \right) \nabla T \right] = 0 & (3) \end{aligned}$$

The air was considered as Newtonian fluid with constant properties. The gravity force caused by density difference was included in momentum equation to deal with natural convection. The turbulence of the flow is considered isotropic which is a common case of flows with heat transfer. Therefore $k-\varepsilon$ method employed for low Reynolds numbers was used for turbulence modelling.

2.2. Geometry and boundary conditions

The cold store modelled in this work is a large single room measuring 19m long, 6m wide and 4m high. Compared to other enclosed spaces such as comfort room or warehouse, it is characterized by a very cold environment and tight insulation. Moreover, the room is ventilated continuously by six air coolers mounted on the ceiling of the room. The geometries of the cold store is shown in fig. 1.

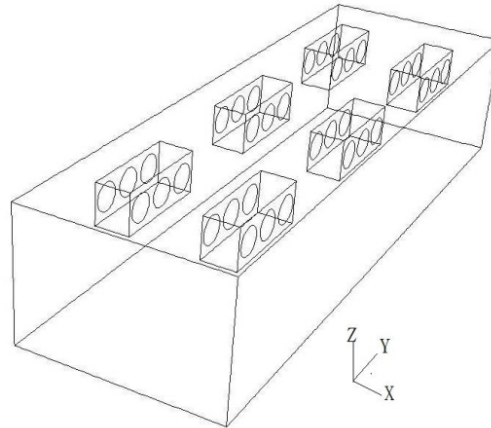


Fig. 1. Cold store dimensions and position of air coolers.

Both the empty and loaded cases were modelled to investigate the interaction between air and food products. In loaded case, the cold store was fulfilled with 1152 packaged products. The arrangement of loaded products was simplified as $18 \times 8 \times 8$ based on practicality, which is presented in fig. 2.

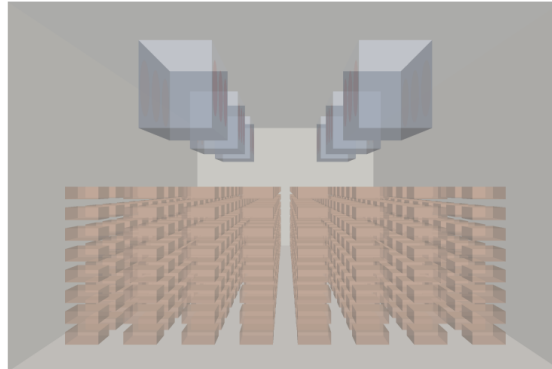


Fig. 2. Arrangements of food products in cold store.

3. Result and discussion

3.1. Empty cold store

Fig. 3 shows the velocity magnitude and flow direction in a vertical section($y=0\text{m}$) of the empty cold store. After leaving the cooler, the air was accelerated and formed into two large vortex. High air velocity was observed near the surroundings, as well as a large velocity gradient. A low velocity region was observed in the middle of the store, where most of food products will be placed. This may be likely to deteriorate the freezing condition of food products at those positions, which mainly refers to air velocity.

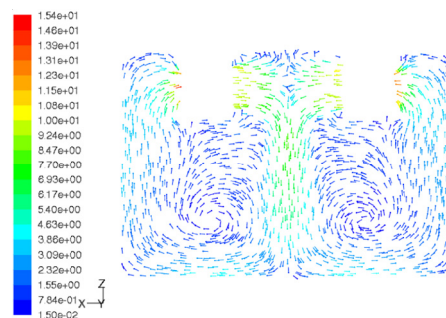


Fig. 3. Velocity magnitude and direction in a vertical cross section($y=0\text{m}$) in empty cold store.

3.2. Loaded cold store

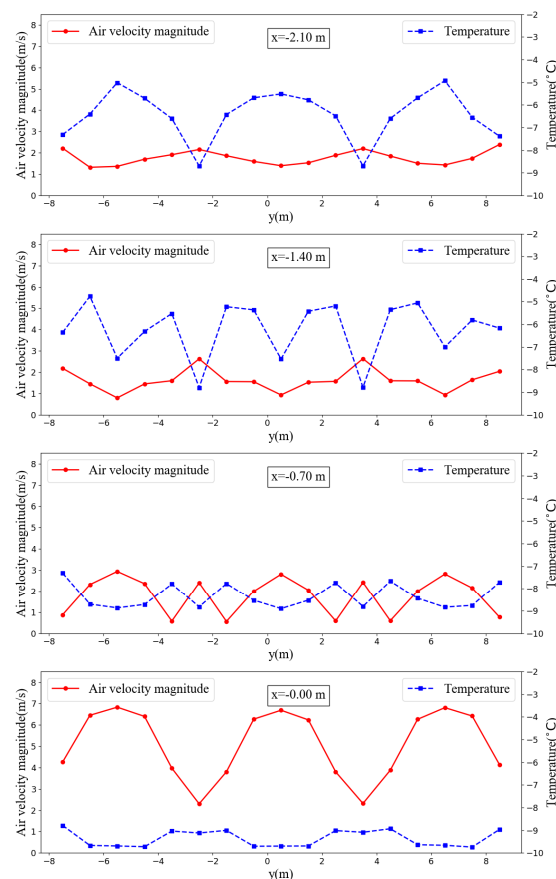


Fig. 4. Velocity and temperature profiles at $z=-0.2\text{m}$

Fig. 4 shows the velocity and temperature distributions at the plane of $z=-0.2\text{m}$, which is located at the height between the top two levels of products. Great differences on air velocity and temperature distributions are observed at the top levels, which is correlated to the location of air coolers and the arrangement of products. Greatest difference of velocity magnitude appears at $x=0\text{m}$, where air just leaves air coolers. As the air passes through products, heat transfer happens and air temperature changes. Greatest difference at difference location appears at $x=-2.1\text{m}$, where products are located near to the side wall.

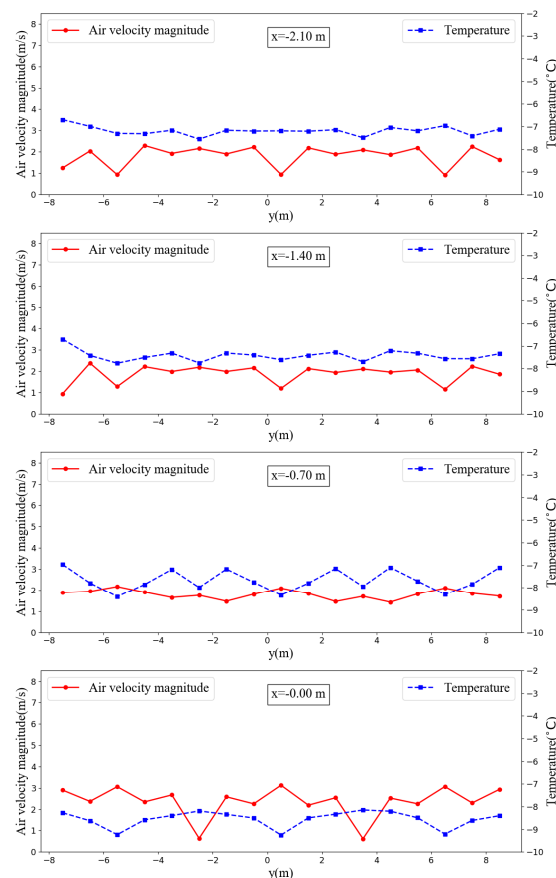


Fig. 5. Velocity and temperature profiles at $z=-1.7\text{m}$

Fig. 5 shows the velocity and temperature distributions at the plane of $z=-1.7\text{m}$, which is located at the height between the bottom two levels of products. Compared to the airflow field at top levels, velocity magnitude becomes much lower at bottom levels, due to the flow resistance as the air flows around the food products.

4. Conclusions

This research was initiated to investigate the airflow field and its influence on food processing in cold store. A simplified model for an empty as well as loaded cold store with packaged products was established to predict airflow field around products. The model was capable of calculating the velocity and temperature distributions in cold store, which indicated the occurrence of spacial differences in temperature and velocity during cooling process. Analysis shows that greatest difference appears at top level of products, as the air flows around products, distributions become more uniform. In general, these results would seem to suggest that the non-uniform distributions of airflow is the main cause for deterioration of food processing quality, in which velocity will have a greater impact than temperature. The authors wish to acknowledge the support of the National Natural Science Foundation of China (No.51508341) and the Foundation of Liaoning Educational Committee(No.L2015450) for this work.

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