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Optimizing the Air Distribution of Large Space Cold Store Based on Numerical Methods

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Abstract: This research employs numerical methods to simulate three-dimensional numerical flow field of large-scale low-temperature cold store. With help of analysis on different cooler layouts, the research shows that Staggered layout for coolers shall be adopted, under which the air flow has low velocity and even distribution in most of the space. The research method of numerical simulation is simple and convenient in comparison with experimental method which could provide conductive advice to optimization of the design of large space low-temperature cold storage.

Key words: Air distribution, cold store, numerical simulation, large space

INTRODUCTION

With development of agriculture, husbandry and fishing industry in China, there is increasing demand for cold stores. With regard to design of cold stores, air distribution is a major issue; the reasonable layout ensures even distribution of cool air in cold stores, lower energy consumption and better quality of stored articles. Information about air flow is normally acquired through either laboratory or numerical methods. The former is more reliable but with higher cost and inability to obtain complete and intact data. The latter which makes up flaws of the former is able to establish mathematical model of cold store based on analysis of physic properties of the research object, simulate design parameters of the entire velocity field and pressure field thereof with help of high performance computer and accordingly improve design capacity and quality of cold store.

In recent years, numerical calculation technique has received in foreign countries wide applications and satisfying results in food and cooling programs. According to research results its application in design of cold store is highly feasible (Scott and Richardson, 1997; Cortella *et al*., 2001; Wang and Touber, 1990). Domestic and foreign researches on numerical calculation of cold store though large in quantity focus mainly on numerical simulation of flow field and temperature field of small food stores. Research on flow field of small cold store has been done by two dimensional simulation hereof (Xie and Qu, 2005; Yu and Lu, 2001); so do air distribution of low temperature quick freeing apparatus (Lu *et al*., 2006) and numerical research on air distribution of tall plant buildings (Zhou *et al*., 1998). Three dimensional research on flow field of cold store is at its initial stage. Three dimensional simulation calculation and laboratory measurement have been completed with regard to minicold store (Liu, 2003). Thousand tons have been built in recent years, As a Hu *et al.* (1998) has established three dimensional simulation and conducted laboratory research on temperature and oxygen density of fruit air conditioning room. With rapid development of quick freezing and cold beverage industry in China, a great many cold stores of capacity of a dozenresult, design of large space cold stores becomes increasingly demanding task and analysis of air flow distribution is more and more imperative which is highly constructive to design of cold stores.

MATHEMATIC MODEL

Low temperature cold stores in the research are mainly used to store quick frozen plate foods in cold store of dimension 72 m (L)×50 m(W)×10 m (H). The air flow model is forced air circulation of ceiling cooler. The main issue of the research is fluid interchange of large space turbulent flow. Part of the space of dimension 14 m (L)×50 m (W)×10 m (H) has been chosen as the research object as per requirement for cold store and cooler layout and to facilitate research and main properties of the flow field. The following assumptions have been made to describe the numerical simulation.

Boussinesq hypothesis has been adopted considering small variation of air flows in the cold store.

Effects of shelves in the cold store on the flow field have not been taken into consideration.

Effects of temperature on the flow field have not been taken into consideration.

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In previous researches on numerical simulation of the flow field, many complicated models have been designed such as k-ε model and Reynolds' stress model owing to significant improvement of computation capacity of modern computer and profound understanding of turbulent flow. These models contain time consuming three dimensional problems and are difficult to meet engineering requirement of accuracy and speed. Moreover, simple model could achieve better results for some issues (Chen and Xu, 1998; Said *et al*., 1995). As a result it has become prevailing strategy of research staff in recent years to use zero equitation to solve the issue of large space air flow (Zhao *et al*., 2001). LVEL zero equation model has been employed in the research to study air flow field in enclosed space of cold store. The model is satisfactory owing to its simpler design compared with k-ε model, less computation time and better simulation of air flow within buildings (Mumovic *et al*., 2004).

Computation method and analysis of computation results: Air distribution in low temperature cold store is aimed to maintain steady and even distribution of air flow and controls the air flow velocity over non packed frozen foods below 0.5 m sec to help reduce drying loss. Cold Store Design Standards of China Considering large cooling space in terms of the length and width, ordinary coolers could not meet the requirement and coolers of 25 m range are selected. Hence, four layout schemes for coolers have been designed, face to face blowing layout, back to back blowing layout, parallel and staggered layouts. Refer to Fig. 1 for the layouts. Simulation calculations of the four models hereinabove have been conducted under stable working conditions Fig. 2 and 5 for results of the flow fields.

According to Fig. 2 it could be seen that air flows at both ends of the store are even at both high and low levels and the air velocity is below 0.5 m sec. However, there are large high velocity zones at the middle which are mainly formed due to back flow at the middle.

Figure 3 indicates that air flow at the middle of the store is good with air velocity below 0.5 m sec. However, the velocity rises sharply in large area near the wall. In addition, air distribution is in opposite direction with low velocity area which is harmful to food drying loss. This phenomenon occurs because of properties of coolers which has good back flow within the range scope. Besides, the back to back blow layout affects the installation, maintenance, defrost and drainage.

Figure 4 it could be learnt that the horizontal velocity is below 0.5 m sec at the height of 5.5 in staggered layout which shows the proper moment to form good air flow distribution with even speed and distribution and is good for both low temperature storage and reduction of drying loss.

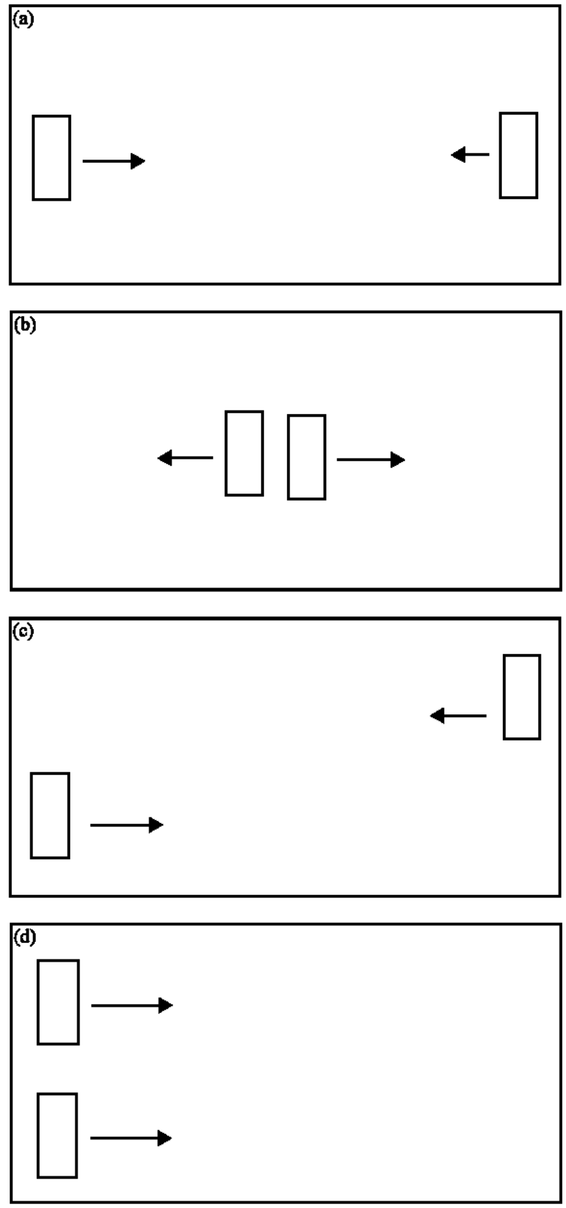

Fig. 1(a-d): (a) Face to face blowing layout, (b) Ack to back blowing layout, (c) Staggered layout and (d) Parallel blowing layout

From flow charges of paralleled layout in Fig. 5 it could be seen that a ir velocity exceeds 0.5 m sec at the height over 1m and back flow occurs in most storage space. This layout, thought fails to meet the requirement for cold store, suits cooler and freezing stores.

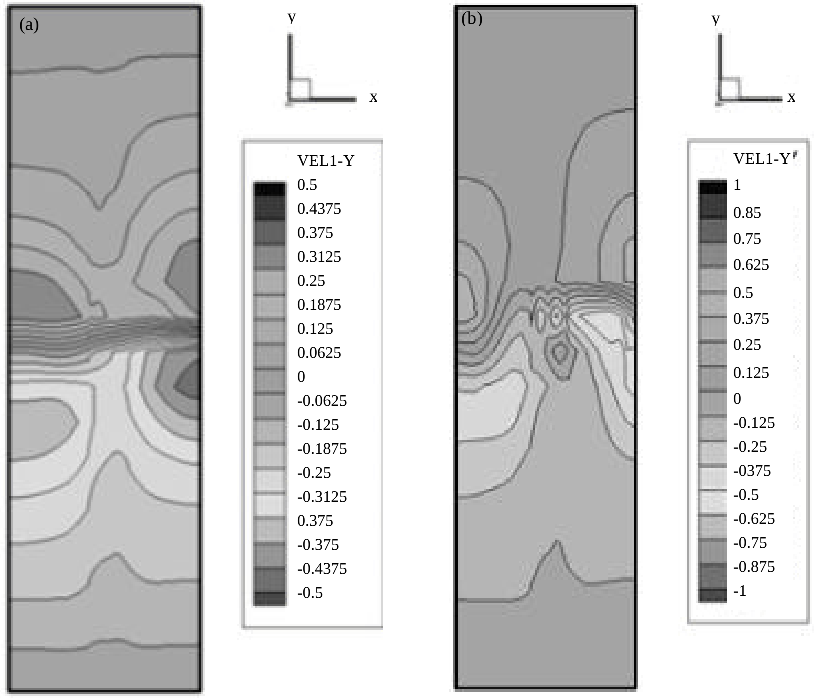

Fig. 2(a-b): (a) Horizontal flow fields for face to face layout at the height of 1 m and (b) Horizontal flow fields for face to face layout at the height of 3.5 m

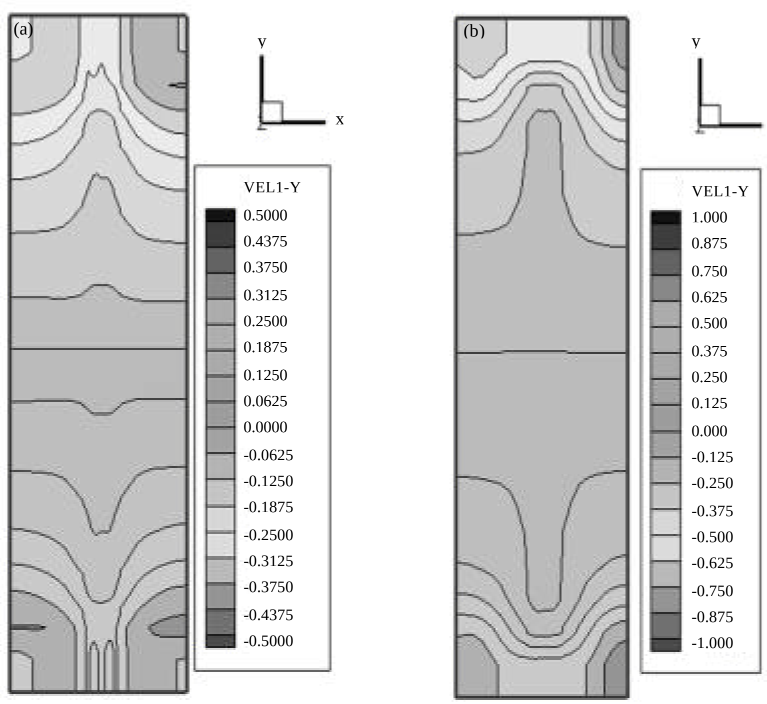

Fig. 3(a-b): (a) Horizontal flow fields for back to back layout at the height of 1m and (b) Horizontal flow fields for back to back layout at the height of 3.5 m

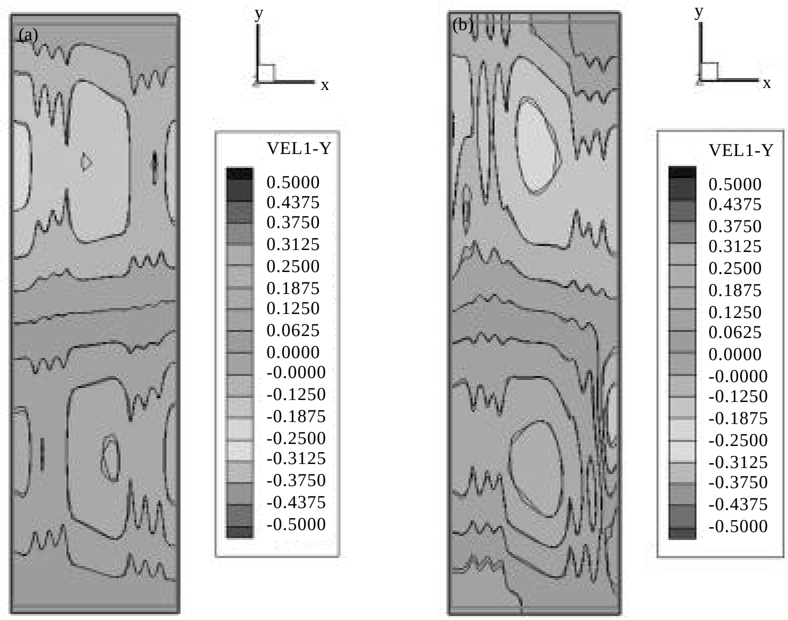

Fig. 4(a-b): (a) Horizontal flow fields for staggered layout at the height of 1 m and (b). Horizontal flow fields for staggered Layout at the height of 5.5 m

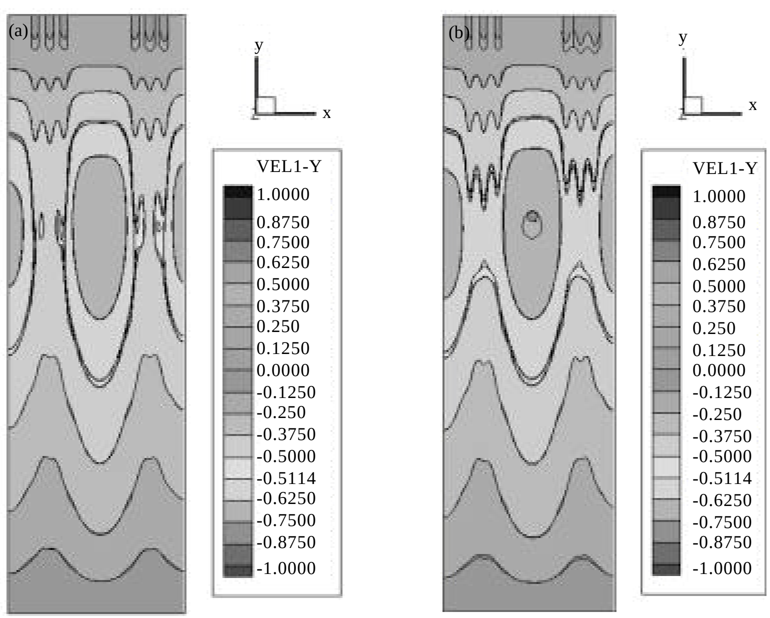

Fig. 5(a-b): (a) Horizontal flow fields for parallel Layout at the height of 1 m and (b) Horizontal flow fields for parallel Layout at the height of 3.5 m

CONCLUSION

The research employs zero equation model to establish numerical simulation of large space low temperature cold store. According to calculation and analysis results, the research shows that four cooler layouts are appropriate for extra long and super large low temperature cold store which include face to face, back to back, staggered and paralleled blowing layouts. Velocity fields in the four layouts are obtained which demonstrates that staggered layout is appropriate for it provides low velocity and even air distribution in most space of the store. The research also shows that the calculation could better facilitate the optimization of the store design which if combined with traditional method could improve the design and storage quality.

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