

An Investigation of a Novel Cooling System for Chilled Food Display Cabinets

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Abstract: The modern retail cabinets that are used for chilling and displaying food in shops are described in this paper. The deficiencies of the purely convective heat transfer mechanism used to cool food in modern cabinets are highlighted. A novel heat transfer system that provides an integrated conductive / convective cooling mechanism is then proposed.

A purposely-developed test rig and its application in the study of the novel cooling system are presented in this paper. The rig was used to evaluate the performance of the mechanism compared to the conventional convective system. The results indicate that the proposed novel system can provide improved heat transfer, which contributes to lower core food temperatures of approximately 3.5 to 5.5K. This can lead to significant reductions in energy and capital costs as well as improvements in food quality and shelf life. Furthermore, the use of this cooling system could avoid the requirement for electric defrost, which is energy intensive.

Keywords: Food display cabinet, heat pipes, food refrigeration, and food temperature control.

NOMENCLATURE

No	Number of food sample
t	Celsius temperature (°C)
T	Time (m)

1. INTRODUCTION

The supermarket is a large user of energy, consuming as much as 15,000 GWh of the UK's total consumption [1]. Of this 50% is consumed by refrigeration equipment, which provides cooling for retail cabinets used for chilled and frozen foods. The purpose of these cabinets is both to display the food products attractively and to maintain food at temperatures below that required by food hygiene legislation.

Most display cabinets in retail stores are forced-air open display cabinets. These cabinets serve contrast purpose: outstanding position opened to persuade the customers to buy the products and meanwhile have to keep low temperature for food safety. The food must be clearly visible and easy to reach, keep away from the warmer places on the shelf in the store. To cope with these requirements many technologies are applied in the cabinets. These comprise mechanical cooling, wall insulation, air circulation, air-curtains, low emissive material painted on the shelf. On the food side, most of the food is wrapped with transparent film. However it is still recognized that retail display is the weakest link in the cold chain [2]. Weight loss and high temperature lead to food spoil are the main problems. A recently research conducted by Gill et al [3] found that the maximum

temperatures of their test beef packs in six cabinets over ten were bigger than 7 °C and all these packs are 2 days old for display. To low the food temperature down, many manufacturers designed the cabinet with over cooling capacity resulted in energy waste and higher air velocity for higher heat transfer coefficient which results in weight loss and more frost on the cooling coil as well, then further decrease the energy efficiency because of lower coil heat transfer coefficient and frost removal.

These cabinets use convective cooling to cool the food, however, due to the low air velocities heat transfer rates are very low. Consequently, the air stream entering the cabinets needs to be cooled to low temperatures to compensate for the poor convective heat transfer. Achieving low air temperatures results in a large energy penalty, through increased cabinet loads, lower refrigeration system efficiency and the necessity for energy intensive defrost systems, also purely convective cooling resulted in a poor temperature distribution in these display cabinet.

2 THE POOR TEMPERATURE DISTRIBUTION

Purely convective cooling systems struggle to maintain temperatures at the warmest points without adversely freezing food at positions near the evaporator. There are large temperature ranges in cabinets with current cabinet designs, which has been cited by many authors. Gill et al. [3] measured product temperatures of between -2 and 10.6°C in the same cabinet. Willox et al. [4] found food temperatures of between 3.2 and 15 °C at different positions and times in the same cabinet in the same

week. Temperature variations occur in all directions in the cabinet. Also there are temperature swings due to control transients.

Temperature gradients from the back to the front of the shelf occur because the food at the back is cooled by the cold air entering the cabinet from the back and food at the front is more affected by thermal radiation, due to the higher shape factor. Brimelow^[7] reported that the temperatures at the back of a shelf are approximately 5 K colder than those at the front. Whereas Olsson^[8] found that packages at the back of the shelf are 2-4 K colder than at the front.

Temperature gradients from the top to the bottom of the cabinet occur because the most of the air enters the cabinet at the top point and gets progressively warmer as it flows through the cabinet. Faramarzi and Woodworth^[9] reported that the average temperature on the top shelf is approximately 2 K lower than the average temperature on the bottom shelf. Chen and Yuan^[10] found an air temperature difference of 5 K between top and bottom shelves. Temperature gradients from side to side across the cabinet are typically caused by poor distribution of air which may be partly due to random loading. Greer et al.^[5] found variations in product temperature of 4 K across the cabinet. A temperature swing at any given point will occur due to control transients and is also due to the change from day to night operation, since, the use of night blinds in supermarkets modifies the storage environment. Wilcox et al.^[6] found fluctuations due to night time temperature to be 2 K.

Work carried out by Maidment et al.^[11] with delicatessen food cabinets showed that it is possible to provide significant additional cooling to the food by positioning the food directly in contact with a cold base. This was achieved by sitting the food on a base in contact with the evaporator. Significantly increasing heat transfer to the food in this way enables the cabinet to operate more efficiently and results in significant reductions in energy consumption, as well as improvements in food quality/ safety. It was observed by Maidment et al. that chilled food cabinets would also benefit from a conductive cooling effect^[11]. However, as most chilled cabinets use adjustable shelving, utilising conductive heat transfer by sitting the food shelves onto a fixed evaporator surface is not a practical option.

A creative and novel concept able to provide significantly higher food-cooling rates is presented elsewhere^[4]. This concept uses superconductive cooling in addition to convective cooling to significantly increase heat transfer rates to the food enabling the cabinet to operate more efficiently and therefore at much higher temperatures. A test rig has been built up for this is presented in this paper.

To establish the benefits of supplementary conductive cooling to food on display, the temperature of a food sample receiving conductive and convective cooling was measured and compared with temperature measurements of food samples receiving convective cooling only.

The experiment was carried out within a typical convective multi-deck type display cabinet with heat pipes, as shown in Fig 1. The food samples receiving convective cooling only were placed directly on a cabinet shelf. The sample receiving conductive cooling in addition to convection was placed on another shelf on which the heat pipes was fixed at the back of the shelf with a space of 100 mm. The cold base temperature was achieved using heat pipes. During the experiment the average ambient conditions within the laboratory were 17°C dry bulb, 12.5°C wet bulb (sling) and 995 mbar.

Food temperatures were measured using K type thermocouples in "M-package" food samples in accordance with BS EN 441-4: 1995 (Refrigerated Display Cabinets - Part 4: General Test Conditions)^[17]. The food samples were constructed from tylose with their dimensions of 200mm x 100mm x 50mm, as shown in Fig 2. The thermocouples were spot calibrated against a NPL thermometer in an ice bath with a temperature of 0 °C. The maximum measurement error associated with the thermocouples was ± 0.15 °C after calibration.

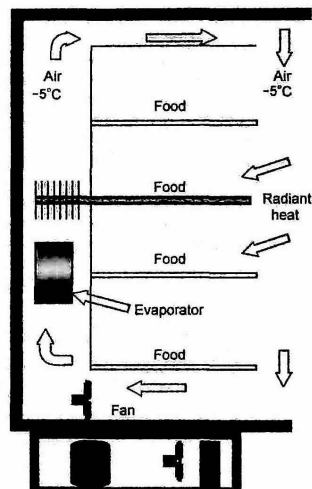


Figure 1: A typical multi-deck type display cabinet With heat pipes

3 EXPERIMENTAL INVESTIGATIONS INTO A NEW DISPLAY CABINET

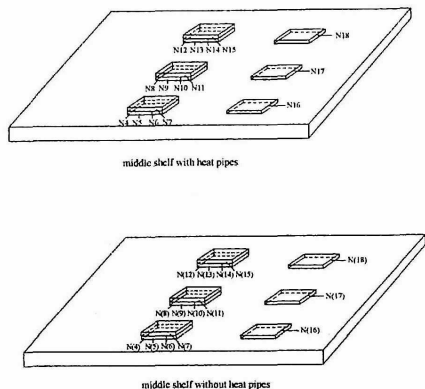


Figure 2: schematic of the food samples on the middle shelf

4 RESULTS & DISCUSSIONS

Typical results from the experiment are shown in Fig.3 to Fig. 6. This shows the temperatures measured over a test period. The No4-No18 represent the food temperatures on the same position with heat pipes and the No(4)-(No(18) represent the food temperatures on the same position without heat pipes. From figure 3, it can be seen that the temperature of the bas under food samples No4 is 5 °C lower than the temperatures of the bas under food samples No(4) and the core temperature of the food sample No6 is 3 °C lower than the core temperature of the food sample No(6). similar results can be seen from figure 4 to figure 6. The results from the test indicate that lower core food temperature of approximately 3.0 to 3.5 °C may be achieved. It also indicate that large reductions in food temperature can be achieved using supplementary conductive cooling. This could lead to reductions in energy and capital costs as well as improvements in food quality and shelf life.

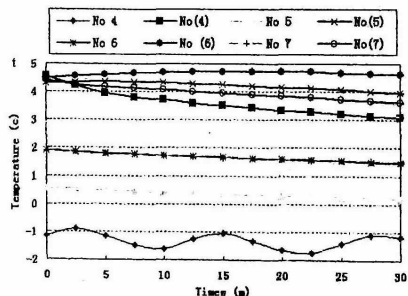


Figure 3: food temperatures on the same position with and without heat pipes

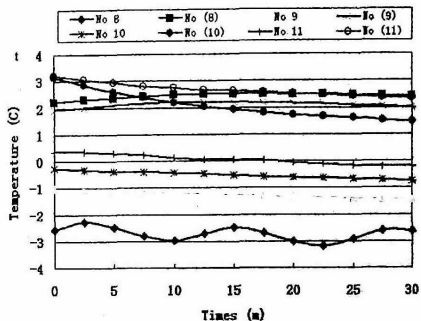


Figure 4: food temperatures on the same position with and without heat pipes

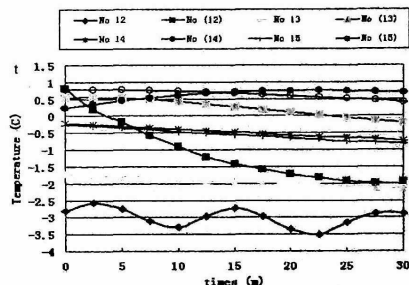


Figure 5: food temperatures on the same position with and without heat pipes

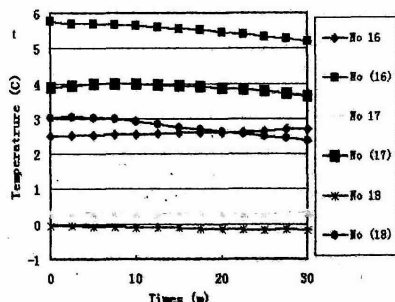


Figure 6: food temperatures on the same position with and without heat pipe

5. CONCLUSIONS

This paper highlights heat pipes were applied in a refrigerated display cabinet to produce a superconductive shelf. Experimental research carried out by the applicants has shown that large reductions in food temperature can be achieved using supplementary conductive cooling. The results from the test indicate that lower core food temperature of approximately 2.5 to 3.5 °C may be achieved. Food temperature reductions would have a

significant effect on food safety particularly if food can be kept below 4°C, the lowest temperature that common bacteria proliferate. With this system lower food temperatures can also be achieved with perhaps significantly higher air supply temperatures. This could lead to reductions in energy and capital costs as well as improvements in food quality and shelf life. Furthermore, electric defrost maybe avoided altogether with this design.

Further research is necessary to ensure that the shelf does not introduce a condensation problem or result in localised overcooling/ freezing. Furthermore, the design of the shelf requires consideration, i.e. the choice of working fluid and the design of a condenser / evaporator surfaces of the heat pipes. The above and other aspects of the novel cabinet design are the subject of continuing research.

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