International Refrigeration and Air Conditioning Conference

School of Mechanical Engineering

1996

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ABSTRACT

Refrigerated display cases are now commonplace in food stores in order to display products in an attractive manner to the customer. An increasing variety of chilled and frozen foods has also added to the demand for more chilled display area but despite this, most modifications to the way supermarket refrigeration systems are designed has come on the high pressure side with little or no regard for what is happening within the display case on the sales floor. The aim of this paper is to present the results of some experimental work carried out at Brunel University on a vertical dairy display case. It is envisaged that this work will help us to understand in greater detail what happens inside the case and how it interacts with its environment.

INTRODUCTION

Vertical multideck refrigerated display cases are now seen merchandising a multitude of supermarket products from fresh produce and meat to dairy products and frozen food. Despite this growth in their use through the last two decades, their design has remained virtually unchanged.

A cross section through a typical design is shown in figure 1. The display unit consists of a shelving system with an evaporator mounted in it's base. Air is drawn into the base through a return air grille located in the top of the front upstand by propeller fans and is passed over the evaporator. The cold air now enters the back panel which is perforated and allows air to diffuse through over the stored product. The remainder of the air then enters the canopy from which it is ejected in the form of an air curtain across the front opening of the case. The primary purpose of the air curtain is to effectively segregate the chilled display volume from the store's ambient environment whilst still allowing customers to access the products on display without any physical barrier.

The air curtain takes the form of a negatively buoyant, submerged, plane jet, a characteristic of which is that it entrains air from it's surroundings. This entrainment of still air is a characteristic of a submerged jet largely dependant on the velocity gradient and as such, the effect cannot be eliminated totally. The nature of the initial turbulence of the flow means that at the top of the curtain, warm air from the store is drawn towards the air barrier and forms a parallel air stream. As the plane jet of air develops, small eddies begin to cascade into larger ones and mixing begins between the two air streams increasing the mass flow rate of the curtain. At the return air grille, air is thus returned to the evaporator at a higher temperature than at the top of the curtain. Meanwhile, a mass balance across the fans means that the remaining mass of air must be spilt back into the aisle of the supermarket at a lower temperature than the air which was initially entrained into the air curtain.

The process outlined above has several consequences on both the refrigeration system and the operation of the retail store. As shown by Howell et al. in 1976 sensible and latent heat transfer will occur across the air curtain. This in turn will add a refrigeration load to the evaporator and also dictate the defrost load of the case which will be largely dependant on the temperature and relative humidity in the store, (Howell 1993). The amount of heat and moisture transfer occurring between the store and the display case can be controlled to a certain extent by limiting the turbulence intensity of the air curtain. Reducing this mixing obviously limits the amount of heat transfer, keeping the curtain cooler and the overspill air warmer. Efforts have been made to limit the amount of initial turbulence intensity of the air curtain by placing honeycomb sections in the air outlet of the canopy. An investigation was carried out in 1976 by Loerke & Nagib into the effectiveness of honeycombs in reducing turbulence intensity. They found that the resultant effect of the honeycomb was to reduce the transverse fluctuating velocity components which decayed along the length of the porous section resulting in a largely unidirectional flow at the exit. As the air flow from each of the holes in the honeycomb rejoined at the exit from the section, small scale, high frequency turbulence was regenerated but was quickly dissipated resulting in a net reduction in the turbulence intensity across the honeycomb. They recommended that to gain a useful reduction in turbulence intensity, the length to diameter ratio of the honeycomb should be of the order of ten. Despite the positive advantages of the honeycomb in reducing turbulence intensity, it does require periodic cleaning or replacement to avoid the accumulation of dirt. These requirements increase the maintenance costs and for this reason some manufacturers omit the honeycomb from their display case designs.

Secondly, the cold air overspill from the front of the case results in an increased heating load to the store. Thirdly, cold floors and sharp temperature gradients between the floor and knee level lead to complaints of discomfort from customers and staff alike. Cold air overspill has long been recognised as a problem in supermarkets and in recent years there have been several attempts to counter this and thereby reduce the thermal discomfort felt by customers and staff. Such measures have included underfloor heating and return air grilles in the front of the base of the cabinet in order to extract the cold air from the aisle. In 1994 Taylor and Adams suggested a system whereby cold air could be drawn into the case, reheated and then supplied at low level through an air terminal device at the base of the cabinet. However, all of these methods require an additional energy supply in an attempt to rectify a problem which is inherent in the design of a vertical display case.

These problems indicate that changes are required to the design of vertical multideck display cases in order to make them more energy efficient and user friendly whilst still allowing the customer unhindered access to the product.

BACKGROUND

The results presented in this paper form a small part of a larger ongoing project at Brunel University investigating the performance characteristics of refrigerated display cases using Computational Fluid Dynamics (CFD). In order to validate the computer model an experimental facility has been set up at the university so that refrigerated cases may be tested to international standards.

Before any modifications of present cases can be carried out it is essential that the fluid dynamics of the design is understood so that educated design decisions can be made. As explained above one of the most critical factors in the successful operation of a vertical display case is the design of the air curtain. Van & Howell (1995) investigated the influence of the initial turbulence intensity on the development of the air curtain which is indirectly related to the heat and moisture transfer across it. Another characteristic of the curtain which is less well understood is its tendency to move towards the shelves on exiting the air outlet. It is thought that this could be due to one (or a combination) of three things. Firstly, the effect of gravity on the denser, cold curtain could be responsible for its deflection from the projected centreline on the outlet. Secondly, there is the thought that surface viscous forces draw the air towards the shelves a phenomenon commonly known as the Coanda effect. The third theory is that the flow from the back panel strikes the back of the curtain outlet and is deflected down to form a secondary air curtain. It could then be that the air from the main air barrier is being entrained into this secondary curtain. In order to try to understand this effect better, it was decided to test a display case varying three parameters, namely cold and ambient temperature curtains, with and without shelves and with and without back panel air flow.

EXPERIMENTAL FACILITY

The case forming the subject of the present investigation was a 2.5 metre (8 ft) long refrigerated vertical dairy case operating as described previously with four shelves and a single evaporator in its base. The case was loaded with packages filled with water to add thermal mass to the case. Velocity profiles were taken parallel to and downstream of the air curtain outlet at distances of 100, 200, 300 and 400mm. The location of this velocity profile plane was at 610mm from one end of the case in order to limit any boundary effects from the flow divider located in the canopy half way along the length of the unit.

The case was run overnight to allow the packages to come down to temperature before air velocities were measured using a temperature compensated thermal probe with an digital display. In an attempt to even out fluctuations in the measured velocity due the turbulent nature of the curtain, five velocities were logged at each position and their average taken.

DISCUSSION OF RESULTS

The baseline was taken to be the cold case with stacked shelves and an air flow diffusing through from the back panel. The profiles from this case are shown in figure 2. Measured velocities are plotted against a parameter x/b_o describing the position of the measured point in relation to the projected centreline of the air curtain. In this dimensionless parameter, x indicates a horizontal distance and b_o is the width of the outlet. A negative value of x/b_o indicates the case side of the centreline and a positive value indicates the store side.

From the profiles in figure 2, two things immediately become apparent. Firstly, is the fact that the air curtain spreads and the peak velocity increases as the profile is moved downstream indicating an increase in mass flow rate. One would normally expect the peak velocity in a turbulent jet to decay as the profile moves downstream. The effect observed in this particular case could be due to the air flow from the back panel combining with the air curtain. Secondly, is that the curtain moves towards the shelves as discussed previously. In order to investigate this phenomenon, similar profiles were taken for the following combinations of geometry, temperature and air flow. Each combination is given a name in an attempt to avoid confusion.

	Cold or Warm Curtain	Shelves	Back Panel Flow
Baseline	C	✓	✓
Curtain 1	C	✓	×
Curtain 2	C	×	✓
Curtain 3	W	✓	×
Curtain 4	W	✓	✓
Curtain 5	W	×	×
Curtain 6	W	×	✓

Figure 3 shows the projected paths of the air curtain for each of the tests detailed in the above table where the lines drawn indicate the path of the peak velocity within the air curtain. Lines are drawn from the bottom of the air curtain outlet as this is the area where the velocity of the air issuing from it was measured to be the greatest. The projected path of curtain 3 is not shown as it follows virtually the same path as the baseline and would confuse the diagram. However, comparison between this and the baseline alone shows that far from drawing the air curtain closer to the shelves, the tendency is for the flow from the back panel to push the curtain away from the product. This assumption is supported by comparing like cases where the variation between the two is only whether the back panel is blocked or not, e.g. comparing baseline and curtain 1, curtains 3 and 4, or curtains 5 and 6. Having, established the significance of the back panel air flow it is now necessary to look at the contribution of the other two factors on the movement of the air curtain.

It can be seen that the path of curtain 2 is directly into the case. This made the actual measurement of the velocity profile impractical and so the path drawn in figure 3 is an approximation based on smoke tests carried out for each curtain. It is believed that what is happening in this example is that cold air issuing from the back panel is sinking down immediately it enters the display area due its higher density compared to the slightly warmer air in the case. This generates a lower pressure behind the air curtain drawing the air flow quickly into the case.

Comparison between the warm and cold air curtains shows that the former tend to follow the projected centreline of the outlet more closely. This suggests that the effect of gravity has a large part to play in the deflection of the air curtain. That is, unless the surface viscous forces become more predominant at lower temperatures. Increasing the temperature of the air curtain from 2 °C (35.6 °F) to 20 °C (68 °F) represents an increase of 6% in the viscosity of the air. Although this could effect the attachment of the air to the shelves, it is doubtful whether such a small change could have such a dramatic effect.

It seems that the effect of the shelves has little influence on the initial deflection of the air curtain although viscous surface forces do have a profound effect once the air curtain finds itself in the region of the product packages. Comparing the baseline with curtain 1, a cold air curtain with and without back panel flow, the process of viscous attachment seems more predominant where the curtain is allowed to move nearer to the shelves without being diverted by a horizontal air flow. This would seem to be a better design than is currently in use as the air is allowed to fall naturally over the product without being forced in two directions simultaneously. It could be argued that product temperatures would suffer towards the back of the shelf.

However, as the air curtain is penetrating further into the case good mixing of air around the product should occur maintaining its temperature although this remains to be seen.

The process which seems most feasible to the authors whereby the air curtain is deflected towards the shelves is that initially gravity acts on the cold air drawing it into a vertical path. It would seem that then viscous forces, namely the Coanda effect takes over ensuring that the flow of air remains close to the profile of the shelves.

CONCLUSIONS

As a part of an ongoing investigation into the performance of refrigerated display cases, experimental data has been collated in order to try to understand better the dynamics of the air curtain used on many designs of vertical temperature controlled display cases. The following conclusions may be drawn:

- The horizontal flow from the back panel of the case has a significant effect on the direction of the vertical air curtain.
- Gravity and surface viscous forces combine to deflect the air curtain in towards the shelves of the case.
- A better design than at present may be to omit the flow from the back panel thus allowing the air curtain to fall naturally over the product. The authors realise that there are cases on the market currently which adopt this principle but in the UK at least, their use is the exception rather than the norm.
- It is clear that much more work is required in this area before reaching any firm conclusions but the results presented herein will form an essential part of the ongoing work at Brunel University.

ACKNOWLEDGEMENTS

Acknowledgements are also due to the following companies who have provided equipment for the construction of the experimental facility at Brunel University:
Elm Ltd., Glasgow
Polymeters Response International Ltd., Winchester, Hampshire
Hussmann Refrigeration, Uxbridge, Middlesex
Hussmann Manufacturing, Glasgow
Liebert Europe, Marlow, Buckinghamshire
Reycol SVC Ltd., Watford, Hertfordshire

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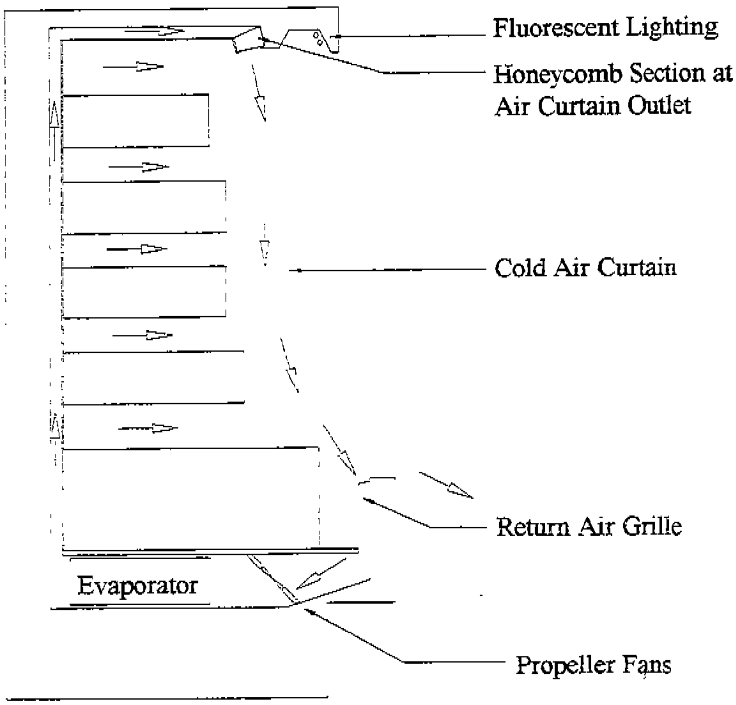

Figure 1 - Typical operation of refrigerated multideck case

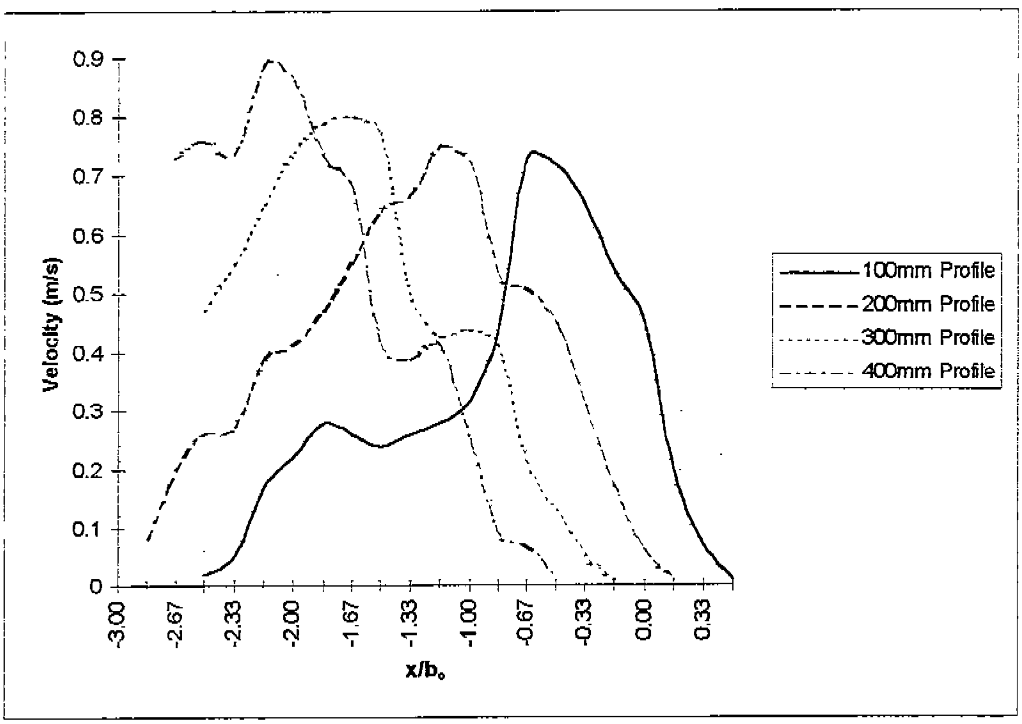

Figure 2 - Velocity profiles taken for baseline case 610mm from left hand end of unit

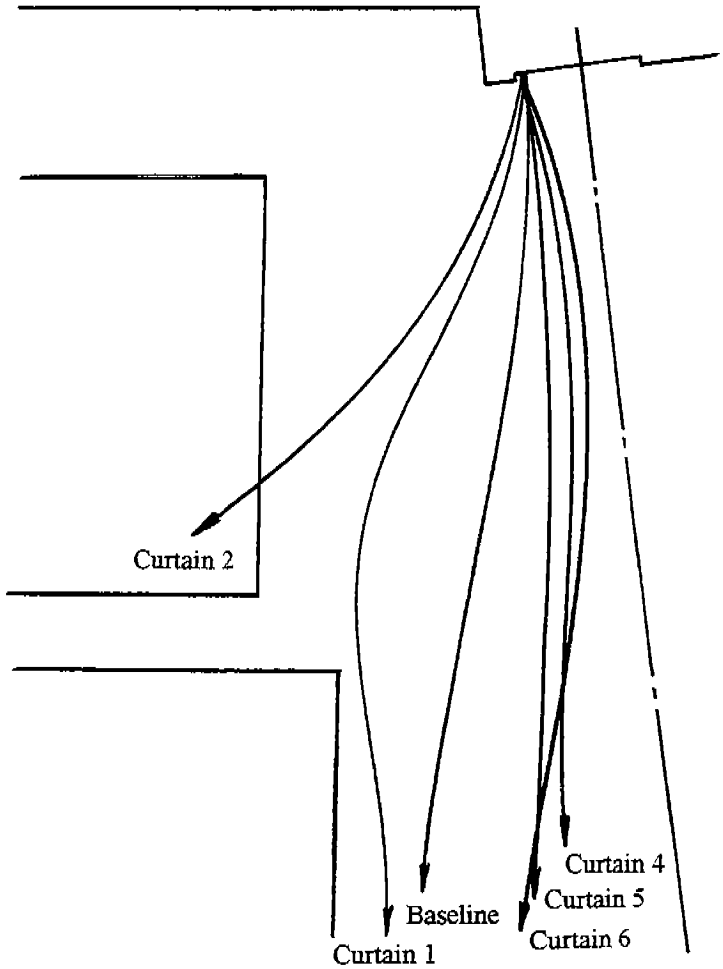

Figure 3 - Projected paths of air curtain peak velocities