Sea Fish Industry Authority

Seafish Technology

A Series Of Trials To Develop Equipment Able To Produce A Stream Of Chilled Air Below 1°C Using Ice

Internal Report No. 1428

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Contents

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Summary

From 1st April 1993, the Food Hygiene (Amendment) Regulations demand that pre-cooked and smoked products are stored and displayed below 5°C, although certain exceptions are now proposed. Retailers will find it difficult to comply with the new law as most existing display equipment is not capable of keeping products at the required temperatures. Work is currently being carried out to develop a storage/display system using trays embedded in ice for such products. It was thought chilled air could be ducted over the product to lower its temperature even further.

This report is concerned with a series of trials carried out to develop equipment which could chill air below 1°C using ice. Initial trials involved passing air through ice; further trials used metal pipes as heat exchangers with greater success. To chill air below 1°C a compact aluminium heat exchanger was built.

Several conclusions can be drawn from the work:

1. Air cannot be effectively drawn directly through flaked ice.

2. Metal pipes embedded in ice make simple effective heat exchangers capable of chilling air to 2-3°C.

3. The compact aluminimum heat exchanger fully embedded in ice proved capable of producing 8.5m^3 of air below 1°C per hour, melting 0.8kg of ice in cooling that air.

1. Introduction

From 1st April 1993, the Food Hygiene (Amendment) Regulations demand that pre-cooked and smoked products are stored and displayed below 5°C. However, it is now proposed to exempt smoked products that are not ready to eat and to introduce time limited exceptions at 8°C and 12°C. Retailers will find it difficult to comply with the new law as most existing display equipment is not capable of keeping products at the required temperatures. Work is currently being carried out to develop a storage/display system using trays embedded in ice for such products. It was thought chilled air could be ducted over the product to lower its temperature even further.

The aim of this work was to develop equipment capable of producing a stream of chilled air below 1°C using ice.

The work was carried out in the Seafish Fish Technology Laboratory during July and August 1992, and consisted of four distinct stages:-

(1) **TrialI** was carried out to investigate the possibility of chilling air by drawing it directly through ice.

(2) **Trial II** was carried out to investigate the possbility of chilling air using metal pipes embedded in ice as simple heat exchangers.

(3) **Trial III** was carried out to investigate the temperature of chilled air produced by an aluminium heat exchanger when fully embedded in ice and alternatively with the top surface only iced. The trial was also used to investigate any warming effect caused by the motor and fan blades in the air stream.

(4) **Trial IV** was carried out to determine the amount of ice melted, and the volume of chilled air produced by the aluminium heat exchanger fully embedded in ice.

2. Trials Equipment

2.1 Construction of the Fan Unit

The fan unit used in all the trials was built to suck or blow air at up to 5 m/s (*fig. 1*). It was designed to be placed directly in ice or coupled to heat exchangers and pipework by a conical adaptor on the fan housing.

The unit consisted of 14cm diameter plastic cone which tapered into a 5cm diameter outlet pipe. An RS540 motor was centrally mounted on brackets at the inlet end of the fan housing. The fan blades were made from a 13cm diameter model aircraft propeller, and a detachable mesh screen was made to fit over the inlet. Two holes were drilled into the unit to allow thermocouples to be inserted into the air stream to monitor air temperature. The first allowed a probe to be positioned 3cm in front of the fan blades whilst the other allowed a probe to be positioned 50cm behind the fan, to monitor the temperature of air leaving the system.

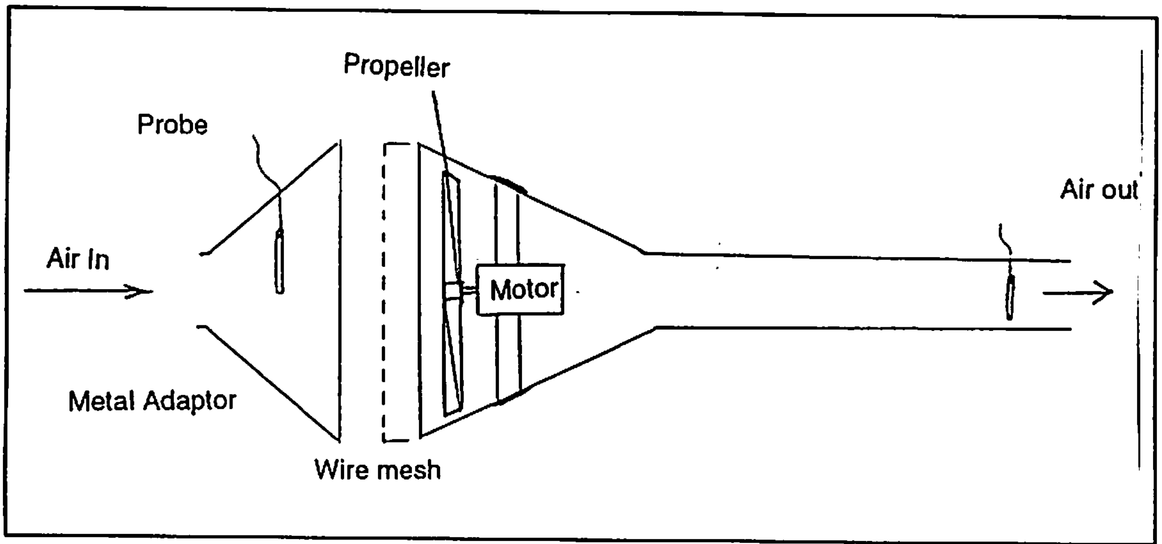

Figure 1 - Diagram of Fan Unit

2.2 Construction of the Compact Aluminium Heat Exchanger

A compact heat exchanger shown in figure 2 was used in trials 3 and 4 to improve upon the performance of simple heat exchanger pipes.

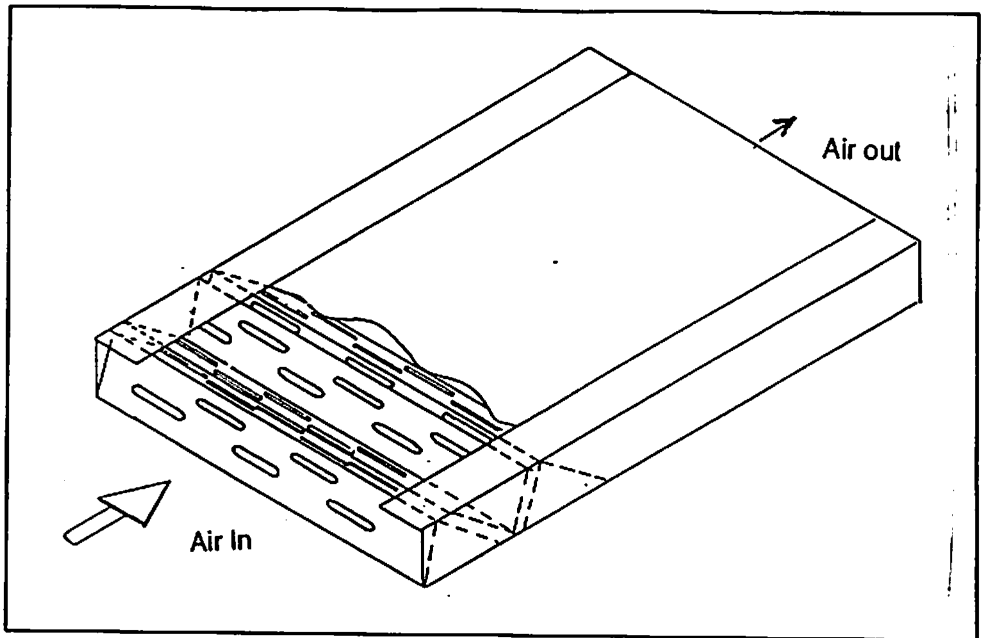

Figure 2 - Diagram of the Compact Aluminium Heat Exchanger

The 50cm x 36cm x 2.5cm deep heat exchanger was constructed by arranging strips of "V" shaped galvanised perforated steel between 2 "U" sections of aluminium. The body was then sandwiched between two 2mm aluminium plates.

3. Common Experimental Method

A 'T' type thermocouple temperature probe was inserted into the outlet pipe of the fan unit 50cm from the fan blades. With the unit fully embedded in flake ice another probe was positioned 30cm above the equipment to monitor ambient air temperature. Probes were connected to a Squirrel data logger; temperatures were recorded every minute for 30 minutes during the trial.

Outlet air speed, controlled by adjusting the voltage to the motor, was measured with a hand held anemometer. Before each trial outlet air temperature was monitored over a range of motor speeds. It was found that if air flow was increased above an optimum the temperature of the outlet air increased significantly. The optimum condition was selected for each trial.

4. Trial I - To Investigate the Feasibility of Chilling Air by Direct Passage Through Ice

4.1 Introduction

The trial was carried out to investigate the feasibility of chilling air by drawing it directly through the spaces between pieces of flake ice without using a heat exchanger.

4.2 Materials and Methods

The fan unit with the mesh screen over the inlet was embedded in flake ice, as shown in figure 3. The motor was run at 5V, 5.2A.

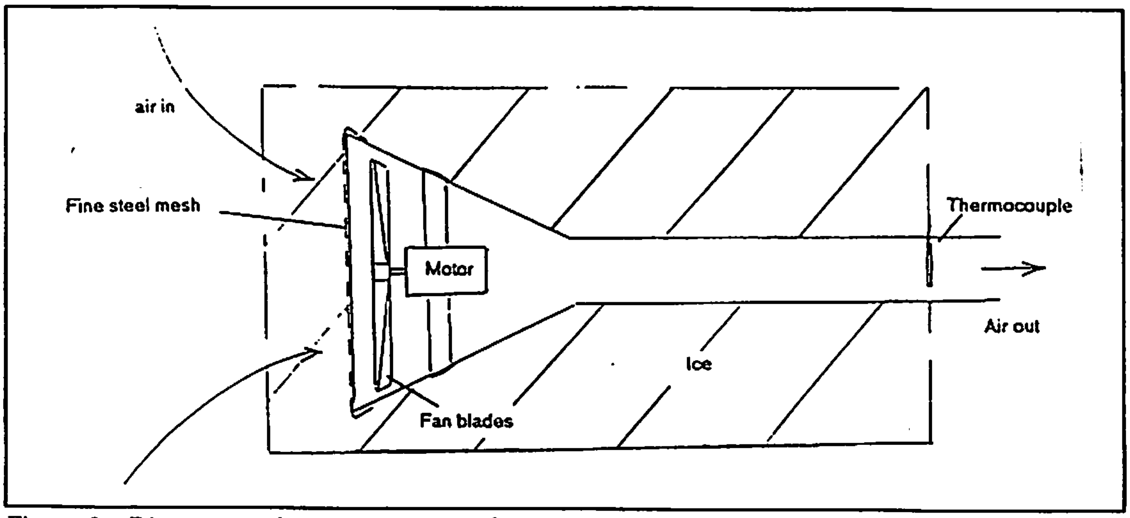

Figure 3 - Diagram to show equipment to draw air through ice

4.3 Results

With the motor running turbulent air flow was observed at the outlet between 0.5m/s and 0.8 m/s. A thin piece of paper held over the end of the pipe showed air being sucked into and blown out of the air outlet i.e. air was not being drawn through the ice.

5. Trial II - To Investigate the Effectiveness of Stainless Steel and Copper Pipes Embedded in Ice as Heat Exchangers

5.1 Introduction

This trial was carried out to see if air could be indirectly chilled by passing it through simple metal pipes embedded in ice. The trial was carried out using a short stainless steel pipe of large diameter and repeated using a long piece of copper pipe of small diameter.

5.2 Materials and Method

An 87cm x 3.5cm diameter (internal surface area $0.1m^2$) stainless steel pipe of 4mm wall thickness was attached to the inlet of the fan unit using a conical steel adaptor. The whole unit was embedded in ice leaving the air inlet/outlet unblocked, as shown in *figure 4.*

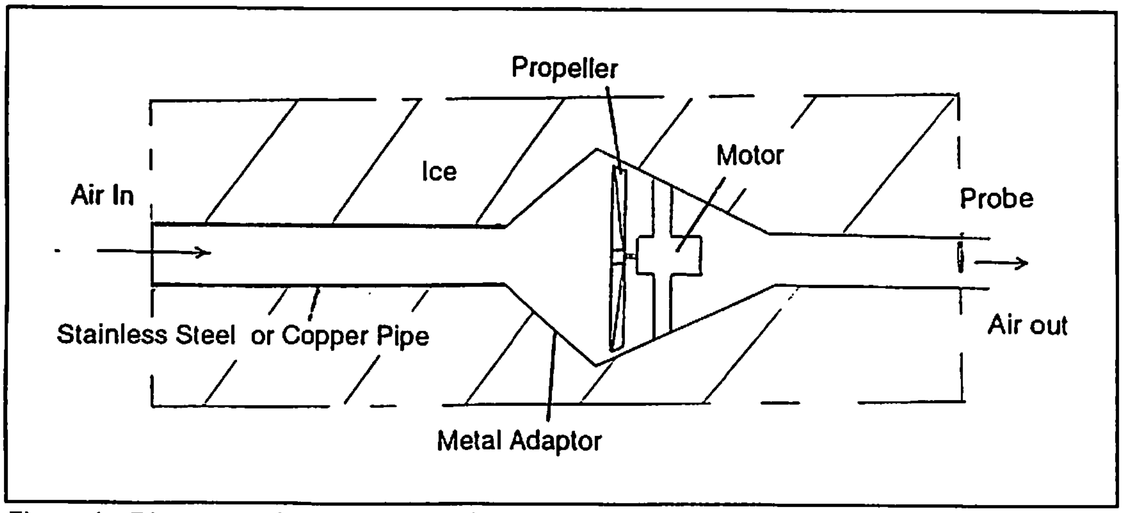

Figure 4 - Diagram to show Fan Unit with Pipe Attached

The trial was carried out with the motor running, supplied by 4V, 2.25A.

The experiment was repeated using a 350cm x 2cm diameter (internal surface area $0.2m^2$) copper pipe of 1mm wall thickness pipe to replace the stainless steel pipe.

5.3 Results

The ambient and outlet air temperature results are shown in *figure 5*. The average ambient air temperature recorded during the experiment with the stainless steel pipe was 21.3°C compared to 25.0°C with the copper pipe.

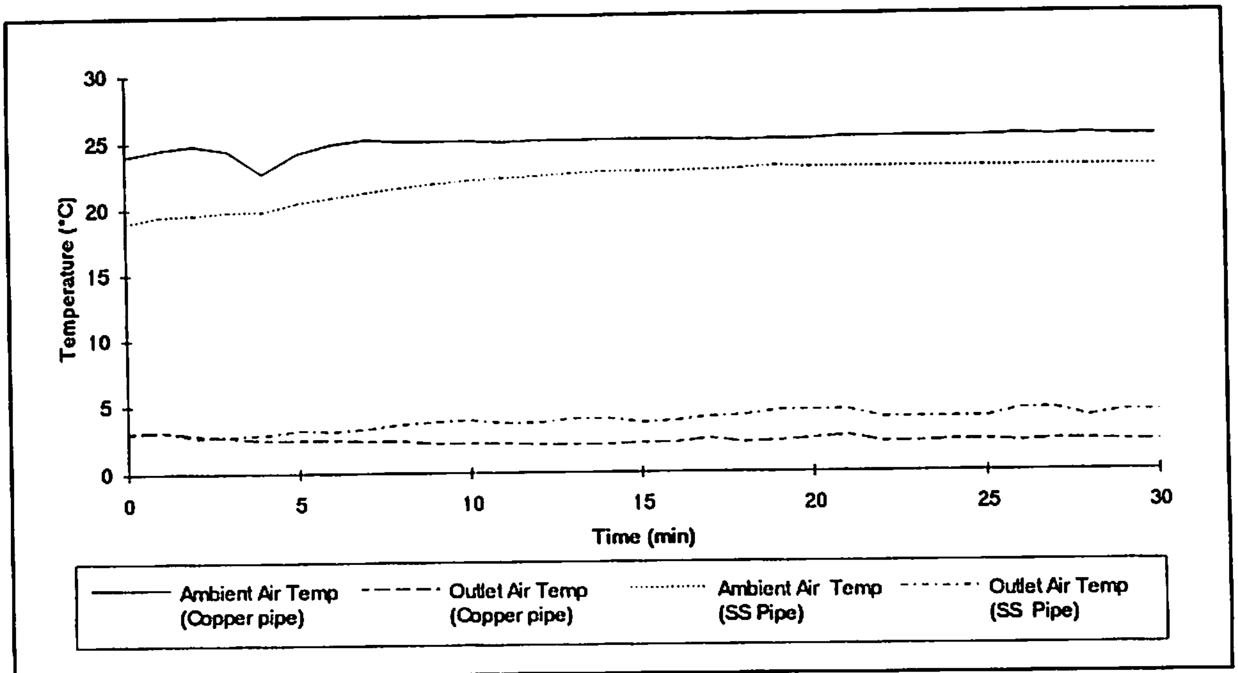

Figure 5 - Air temperature recorded when drawn through copper and stainless steel pipe embedded in ice

The average outlet air temperature was 3.8°C with the stainless steel pipe. The average outlet air temperature was 2.3°C with the air passing through copper pipe.

The average outlet air speed recorded with the unit attached to the stainless steel pipe was 1.2m/s compared to 1m/s recorded using the copper pipe.

6. Trial III - To Investigate the Performance Of An Aluminium Heat Exchanger

6.1 Introduction

The compact aluminium heat exchanger was built with the aim of chilling air below 1°C. The trial was carried out to monitor the temperature of air produced by the heat exchanger when it was fully embedded in ice; and with the top surface only in contact with ice. The trial was also used to investigate any warming effect caused by the motor and fan blades in the air stream.

The benefit of having only the top plate of the heat exchanger in contact with ice, rather than the more effective total embedding, would be that the unit could form the bottom of an ice storage bin, thus simplifying the design, construction and operation.

6.2 Materials and Method

One end of the heat exchanger was left open for air to enter, whilst a metal adaptor was fastened to the other to allow attachment to the fan unit. A temperature probe was inserted into the air stream immediately after the heat exchanger.

The compact heat exchanger was embedded in ice, as shown in *figure 6*, with the motor running, supplied by 4V, 2.25A, temperatures were recorded every minute for 1 hour.

The experiment was repeated with the bottom surface of the heat exchanger covered in 3cm of expanded polystyrene insulation before embedding in ice.

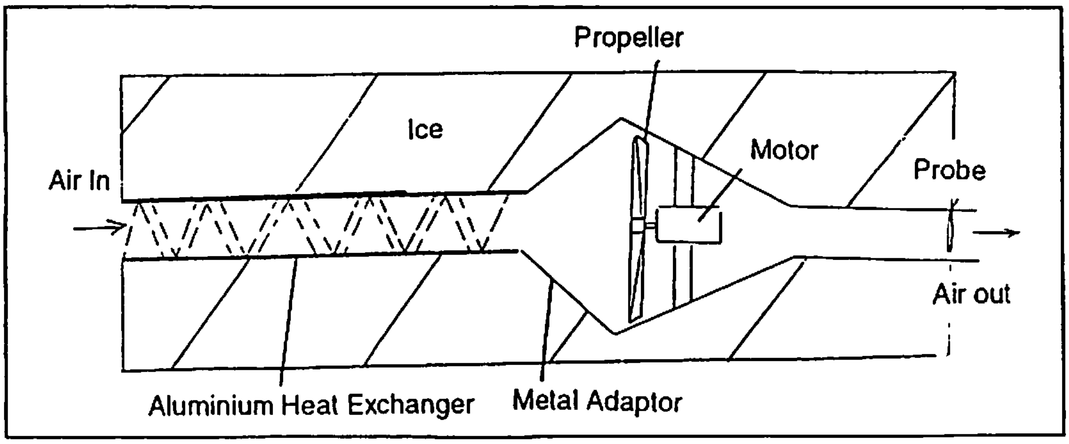

Figure 6 - Fan Unit coupled with aluminium heat exchanger fully embedded in ice

6.3 Results

The ambient and outlet air temperature results are shown in *figure 7.*

The average ambient temperature with the unit fully embedded in ice was 23.5°C compared to 23.3°C recorded with the bottom surface insulated.

The average outlet air temperature recorded with the heat exchanger when fully embedded in ice was 0.9°C compared to 1.2°C recorded with the bottom surface insulated.

The temperature of air coming directly from the heat exchanger i.e. prior to passing through the fan when fully embedded in ice was 0.16°C compared to 0.73°C with the bottom surface of the heat exchanger insulated.

The average air speed recorded at the outlet was 1.2m/s fully embedded compared to 1.1m/s with the bottom surface insulated.

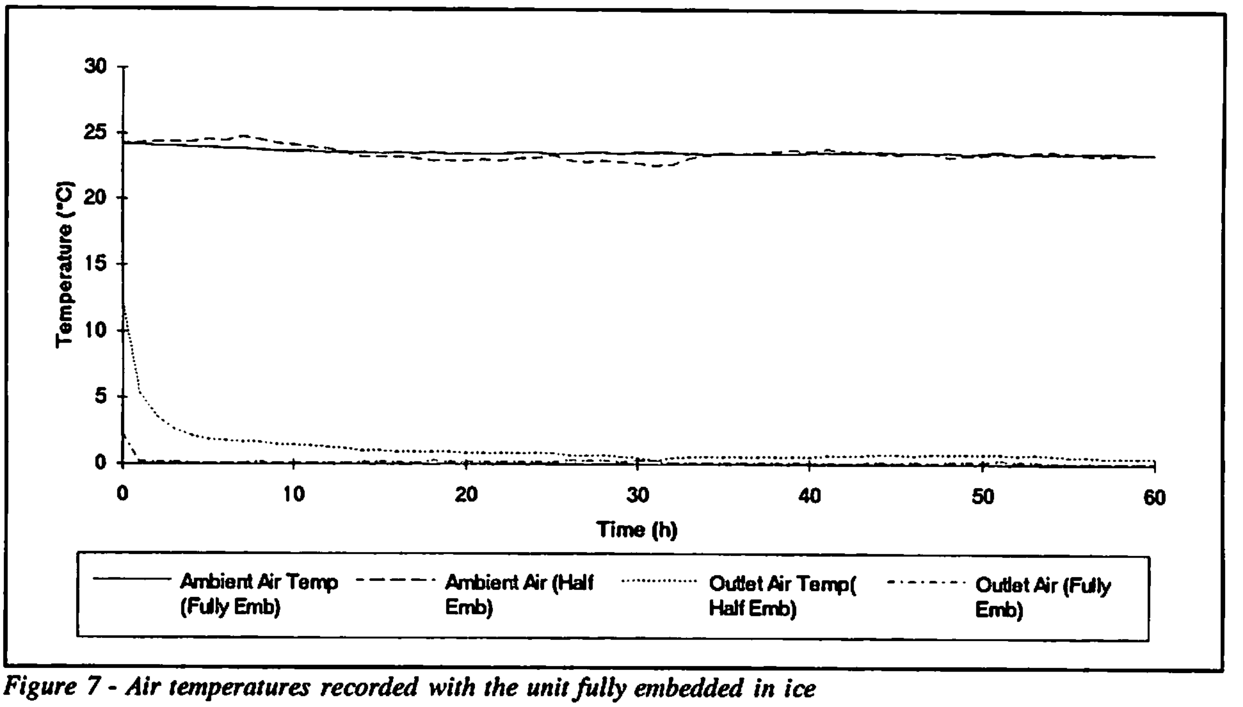

Figure 7 - Air temperatures recorded with the unit fully embedded in ice

7. Trial IV - To Determine the Amount of Ice Used, and the Volume of Air Produced by the Aluminium Heat Exchanger Fully Embedded in Ice

7.1 Introduction

Ice consumption is a major factor governing the practicality of using such a heat exchange system.

7.2 Materials and Method

The heat exchanger coupled to the fan unit was embedded in 30kg of flake ice as shown in *figure 6*. The ice was contained in a plastic tray with drainage into a bucket. The equipment was covered with a metalised insulating blanket to minimise ice loss.

With the motor switched off the melt water was weighed after 2 hours.

The remaining ice was cleared and the trial repeated with the unit in 30kg of fresh ice with the motor running at 4V, 2.25A.

7.3 Results

The average ambient air temperature with the motor off was 22.7°C compared to 23.2°C with the motor running.

With the motor running the average air temperature at outlet was 1.5°C with a velocity of 1.2m/s.

The calculated volume of chilled air produced was 8.5m^3/h.

With the motor off 2.65kg of water was collected after 2 hours, i.e. the rate of ice melt was 1.32kg/h. With the motor running, 4.25kg of water was collected i.e. the rate of ice melt was 2.12kg/h.

The working heat exchanger melted an additional 0.8kg of ice per hour.

8. Conclusions and Discussions

8.1 Trial I

It was shown that air cannot be easily drawn through flake ice. The ice quickly melted together to form an impermeable barrier.

8.2 Trial II

Not surprisingly the long, small bore copper pipe was found to be more effective at chilling air than a shorter large bore stainless steel pipe, but the chilled air temperature was still over 2°C. The copper pipe could be bent to form a more compact arrangement.

8.3 Trial III

Fully embedded in ice, the aluminium heat exchanger was capable of chilling air to below 1°C. With only the top surface of the heat exchanger in contact with ice, the air was chilled to approximately 1.2°C. The fan and motor were found to increase the temperature of the air from the heat exchanger by approximately 0.5°C by the time it reached the outlet.

A practical heat exchanger designed for commercial use is likely to be more than 4 times the size of the trial unit. Using a larger or more efficient heat exchanger lower outlet air temperatures could be achieved.

The smooth upper surface of the heat exchanger would allow the unit to form the base of an insulated ice storage container or fish display unit. The design would result in easier cleaning and operation and maximise the amount of space for ice/fish storage.

8.4 Trial IV

The rate of ice consumption of the heat exchanger unit is particularly important for a mobile retail van application, where the amount of ice carried is limited. The fully embedded compact heat exchanger producing 8.5m^3/h of air at an average 1.5°C melted a further 0.8kg of ice per hour.

Overall ice consumption could be reduced by placing the ice and heat exchanger in a well insulated container.

9. Recommendations

The fan (possibly a centrifugal unit) should be remotely driven which would remove the motor from the air stream, reducing warming of the chilled air. The air ducting from the unit should be well insulated.

Future Work

Future development could include replacing the existing fan unit with a more compact and efficient centrifugal fan and further design improvement of the heat exchanger.

Trials could be carried out in conjunction with the lidded storage/display units currently being developed. The fan unit could be activated for a period each time the lid is opened to replace the chilled air lost when serving products.

The equipment may also have value for semi-protected open fish displays where the ice bed could be used to create a stream of chilled air over the fish as an alternative to refrigeration.