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Thermal insulation requirements and new cardboard packaging for chilled seafood exports

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ABSTRACT

Three expanded polystyrene (EPS) boxes with different thermal resistance (*R*-value), a box-in-box type cardboard prototype and commercial EPS boxes were packed with fish using standard industry procedures and subjected to a simulated airfreight temperature regime replicating commercial practice. The Quality Index Method was used to assess the fish quality. The boxes with lower *R*-values did not have a measurable negative effect on the quality compared to the commercial EPS box. There was also no measurable difference in quality between fish stored in the corners or centre of all the boxes. For another experiment a double fluted cardboard prototype and commercial EPS boxes were filled with ice and subjected to a constant temperature regime to determine their *R*-value. The second prototype had slightly lower *R*-values than commercial EPS boxes. However, the double fluted wall structure might limit the foldability and manufacturability and will need to be further investigated.

1. Introduction

The annual export of chilled fresh whole and fillet fish products from New Zealand was 12,000 tonnes in 2011 (The New Zealand Seafood Industry Council Ltd., 2012 #26393). Most of the products were air freighted to Australia, Asia, North America and some EU countries. During a chill supply chain, e.g. from a New Zealand processor to a country in the northern hemisphere, the ambient thermal load can experience random fluctuations and cause temperatures to rise and fall in the product having a negative impact on the quality of the fish products. This is due to the numerous interfaces found in air logistic chains where ambient conditions are not well controlled (Mai et al., 2012).

Temperature control is the most important issue because of the large impact that it has on both microbial and chemical degradation of fish products (Giannakourou et al., 2005; Gram and Huss, 1996; Dalgaard et al., 2002). The recommended storage temperature for chilled fish is −1 to +1 °C (New Zealand Food Safety Authority, 1995 #26413). The thermal resistance (*R*-value) of packaging should be adequate to maintain the temperature of the products through the chilled supply chain. The other factors of packaging that can influence the quality of the products and customer satisfaction are: strength and shock absorbance; ability to meet various size and shape requirements; cost (including cost related to material disposal); minimal weight; adequate resistance to moisture with good sealing ability; stackability when full (not depending on the product to support the load); ease of assembly (if not pre-assembled); quality assurance approval (ISO 9000); improved end-of-life options and acceptance by consumers.

Many experimental and mathematical (Jain et al., 2005; Torrieri et al., 2011) studies have been conducted to evaluate the thermal insulation performance of packaging. The system *R*-value of an expanded polystyrene (EPS) box with various liner-in-box arrangements with and without aluminium foil was calculated by Burgess (1999). Choi and Burgess (2007) developed a mathematical model to predict the *R*-value of a multi-layered packaging wall incorporating basic heat transfer principles covering conduction, convection and radiation. They discussed several factors affecting the performance of insulation packaging and provided an example of the use of this model for determining ice requirement. Laguerre et al. (2008) and East et al. (2009) reported on the applicability and reliability of heat transfer models of different complexity for insulated boxes.

The temperature changes of fresh cod loins and haddock fillets packed in EPS boxes were investigated by Mai et al. (2012) during air transport from producers in Iceland to markets in the U.K. and France. Their work showed that variations in temperature during air freighting caused fluctuation of product temperature inside boxes, especially in those with more sides exposed to air such as those at the top corner of the pallets. Temperatures in the top layer of product inside the EPS boxes were more sensitive to environment changes than those deeper in the box. They also found that

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Nomenclature

A	surface area, m^2	r^2	coefficient of determination
c	specific heat capacity of ice, kJ/kg K	t	experimental trial time for a steady heat flow, s
d	thickness, m	ΔT	temperature different, K
h	surface heat transfer coefficient, W/m^2 K		
k	thermal conductivity, W/m K	*Subscripts*	
K coefficient	overall coefficient of heat transfer	*Ava*	average
L	latent heat of ice, kJ/kg	*out*	outside
M	mass of ice melted, kg	*i*	integer 1, 2, 3,…, *n*
n	number of layers	*ice*	ice
P	probability	*in*	inside
R-value	thermal resistance	*mel*	melting

there are several critical steps in air freighting, including the flight itself, loading/unloading operations and storage under unrefrigerated conditions. James et al. (2006) explained that the cargo hold temperature is normally between 15 and 20 °C and the product is generally unprotected if an air freight journey is relatively short. Margeirsson et al. (2011) used experimental and numerical modelling to compare EPS and corrugated plastic (polypropylene) boxes that contained fresh haddock fillets and were subjected to mean ambient temperature of 10–15 °C for 20 h. In another study by Margeirsson et al. (2012) the box types were packed with cod fillets and palletised under changing storage temperature condition. The quality of the fillets was then investigated. From these investigations the insulating property of EPS packaging was found to be suitable for a chilled fish supply chain. In other studies EPS foam has proven to be a good packaging material to protect a range of products such as vaccines, fish and meat from sudden changes in temperature (Singh et al., 2008). Froese (1998) found that the insulation property of EPS box for transporting live fish in water was adequate. However, there has been limited investigation in different thermal insulation performance of EPS packaging and its impact on fish quality. As EPS is a petroleum-based product, is not readily biodegradable or easily recyclable, and often ends up in land fill, the growing global trend is a sustainable packaging solution to replace EPS in the chilled food supply chain. Boxes made from EPS are also bulky, have structural weaknesses, are difficult to print on and the requirement to produce moulds limits product diversity.

To develop an alternative to EPS boxes for chilled seafood exports it is first necessary to identify the level of thermal insulation required to get the product to market. To address this, in Experiment 1, we prepared experimental boxes made of three thicknesses of EPS with different *R*-value plus prototype cardboard boxes and compared these with commercial EPS boxes. All boxes were packed with chilled fish replicating commercial practice. Boxes were then subjected to a temperature regime simulating actual temperatures recordings taken during commercial airfreight transport from the premises of a leading New Zealand fish exporter to arrival at a wholesale depot in Singapore. The Quality Index Method (QIM) of fish inspection (Larsen et al., 1992) was used to assess the quality of the fish. In Experiment 2, boxes of another cardboard prototype and commercial EPS boxes were compared by filling with ice and subjecting them to a constant temperature regime. From the melting rate of ice the average *R*-values of the two box types were determined and compared.

2. Materials and methods

2.1. Experimental boxes

Four boxes from each of five box types were used for Experiment 1. Those five types were: boxes made of three different thicknesses of EPS flat sheets; a prototype cardboard box and a commercial EPS box that is commonly used by the New Zealand seafood industry. Two boxes of a second cardboard prototype and the commercial EPS box were used for Experiment 2. All boxes from EPS flat sheets and the cardboard prototypes were made manually with the internal dimensions of 550 mm length, 375 mm width and 120 mm height, similar dimensions to those of the commercial EPS boxes.

2.1.1. EPS boxes

The experimental EPS boxes were made of three thicknesses of EPS flat sheets with similar density (22 kg/m^3) and thermal conductivity (*k*-value) designated EPS10, EPS15 and EPS25 purchased as having thicknesses of 10, 15 and 25 mm but measured with slightly larger thicknesses (Table 1). The EPS sheets were cut to the correct sizes and glued using a multi-purpose adhesive (Sika Nailbond, Glue Guru Industrial Products, New Zealand) to make the boxes with right angle corners. The commercial EPS boxes were obtained from a leading New Zealand manufacturer (MV100, Barnes Plastics, Auckland). Each wall thickness of the MV100 was measured at three different positions and their average values were calculated (Table 1). The average densities of the base, lid and side walls of MV100 are 22.5, 20.5 and 21.0 kg/m^3, respectively.

2.1.2. Prototype boxes

The first prototype boxes were made using a commercially available 5 mm C-fluted corrugated board. The board was made of polyethylene (PE) laminated Kraft inner linerboard, Kraft medium and white Kraft outer linerboard. The box consisted of a 25 mm thick box-in-box wall structure separated by cardboard spacers (125 mm apart) to create an approximately 15 mm air gap between two boxes as shown in Fig. 1. The spacers were placed at right angles in the side walls, base and top of the box to give equal partition and minimise air convection (Alhazmy, 2010). The second prototype boxes were made from a newly developed wall structure design as shown in Fig. 2. The wall structure (Fig. 2a) had a double fluted medium with the half wavelength of 6.6 mm that was made of a 2 mm Kraft E-fluted corrugated cardboard. The medium was sandwiched between two PE laminated and metallised Kraft E-fluted cardboard panels. Both materials were obtained from two leading Australasian manufacturers. Each wall of the box with the thickness of 25 mm was made separately and glued using a polyvinyl-acetate (Henkel Adhesives) adhesive to make the box and lid (Fig. 2b). The first and second prototypes were designated D1/25 and D2/25, respectively.

2.2. Measurement of k-value

The thermal conductivity (*k*-value) which is the measure of the ability of a box wall to conduct heat should be low as possible for