THERMAL PERFORMANCE OF 70 L SINGLE WALLED FISH BOXES AND SÆPLAST INSULATED FISH CONTAINERS

Figure 1. Insulated 70 L fish container.

Figure 2. Three types of single walled fish boxes with volume capacity of around 70 L.

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Introduction

It is a well known fact that maintaining a perfect temperature control in the chill chain of perishable, fresh food can be a difficult task (Mai et al., 2012; Margeirsson, 2012). Food packaging can play a considerable role in protecting the perishables, especially at high temperature conditions. The importance of containers in fish handling has been described by Brox et al. (1984) by the following functions:

- ease the handling of small and large quantities of fish;
- simplify and increase the speed of unloading/loading and transportation of raw material;
- protect the fish against physical damage contamination and other deteriorating factors;
- offer a suitable packing unit for fish and ice;
- contain the fish under such conditions that it reaches the buyer in the best possible condition;
- help to protect the raw material against natural deteriorating effects;
- help to make maximum utilization of resources and to achieve optimum economical results through the whole system of handling from harvest to consumption.

Insulated plastic containers (also called tubs or bins, see Figure 1) outperform single walled fish boxes (totes, see Figure 2) with regard to many of the functions above. Therefore the insulated containers have replaced the fish boxes in many fish industries throughout the world. One of the main benefits is the superior thermal insulation, which results in slower ice melting, better fish temperature control and slower fish deterioration (Seafish, 2013). Considerable effort has been put in studying the insulative properties of 340–660 L containers manufactured by Sæplast (Snorrason, 2014a,b). Those containers are too large for certain conditions within the fresh fish chill chain and therefore should emphasis also be put on smaller containers.

The aim of this study is to compare the thermal performance of different HDPE single walled boxes and insulated containers commonly used for storage and transport of fish. This was done by means of ice-melt tests and the results from the tests were used to calculate the R-values of the packaging as described by Burgess (1999) and Singh et al. (2008).

Figure 3. Two 70 L PUR insulated Sæplast containers filled with ice at the beginning of the first ice melt test.

Figure 4. Single walled fish boxes filled with ice at the beginning of the second ice melt test.

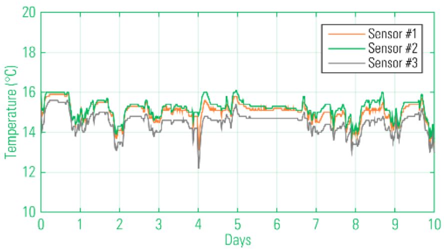

Figure 5. Ambient air temperature during 10-day storage of two 70 L PUR Sæplast containers.

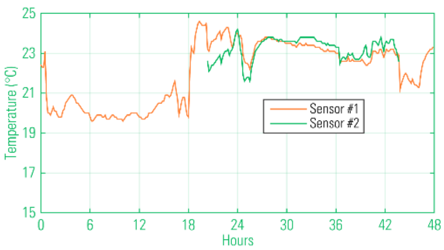

Figure 6. Ambient air temperature during 2-day storage of single walled fish boxes.

Materials and Methods

Two ice melt tests were performed. The first one was conducted by the author and three industrial- and mechanical engineering students at University of Iceland; Aðalheiður Guðjónsdóttir, Áróra Pétursdóttir and Sigurður Örn Ragnarsson. This test, which was on 70 L Sæplast containers (Figure 3), it started on 2 March 2015 and concluded 10 days later, i.e. on 12 March 2015. The latter trial, on the three types of single walled fish boxes, shown in Figure 2, was performed by the author from 20 May to 22 May 2015.

At the beginning of each trial the single standing containers were filled with ice (see Table 1, Figures 3 and 4). One 70 PUR container was closed with a lid but the other one was tested without a lid. The containers were stored inside at ambient temperatures shown in Figures 5 and 6 with no access to direct sunlight. Temperature was monitored with three CO 03.01 temperature loggers from Controlant (Reykjavík, Iceland). The accuracy of the loggers is ±0.5 °C between -20 and 40 °C, the resolution is 0.1 °C and operating range is -30 to 80 °C. The temperature loggers were factory calibrated and re-calibrated by the author in a thick mixture of fresh crushed ice and water. The mean temperatures (±standard deviations) during the whole 10-day and 2-day storage periods were 14.9±0.6 °C and 22±2 °C for the two trials, respectively.

The weights and dimensions of the packaging are presented in Table 1. The material thickness of the insulated 70 PUR container is around 40 mm compared to only around 2–4 mm for the single walled boxes.

Table 1. Weights and dimensions of the packaging types under consideration.

	70 PUR	B1	B2	B3
Weight (kg)	12.0[a]	3.5	3.7	4.7
Initial ice weight (kg)	36.5	37.2	35.8	36.1
L = inside length (m)	0.66	0.79	0.69	0.81
W = inside width (m)	0.40	0.49	0.37	0.50
H = inside height (m)	0.28	0.18	0.26	0.18
A_{in} = Inside area, (m^2)	1.07	1.23	1.10	1.28

[a] Including lid, which weighs 3.5 kg

The heat transfer rate from the ambient air to the container load can be described by the following equation (Holman, 2002):

$$q_{amb} = UA\Delta T = UA(T_{amb} - T_{load}) \tag{1}$$

where q_{amb} denotes heat transfer rate [W], U is overall heat transfer coefficient between the ambience and the container load [W/m^2/K], A is surface area [m^2] and ΔT denotes the temperature difference between the ambient air (T_{amb}) and the container load (T_{load}). This heat transfer rate can be connected to the ice melting rate as follows:

$$q_{melting} = \dot{m_{ice}} L_{ice} = UA\Delta T = q_{amb} \tag{2}$$

where $\dot{m_{ice}}$ represents ice melting rate [kg/s], L_{ice} is latent heat of fusion (melting) [J/kg]. The surface area and the overall heat transfer coefficient can be seen as constants in the temperature range applied in the current trials and thus, the ice melting rate will increase approximately linearly with ΔT according to the following equation:

$$\dot{m_{ice}} = UA\Delta T / L_{ice} \tag{3}$$

Equation (2) can also be written in the following way:

$$\dot{m_{ice}} L_{ice} = A\Delta T / R \tag{4}$$

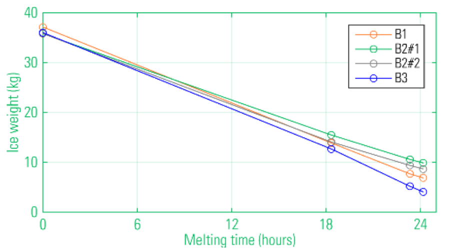

Figure 7. Ice weight in single walled boxes during 1-day storage at 20.3±0.6 °C.

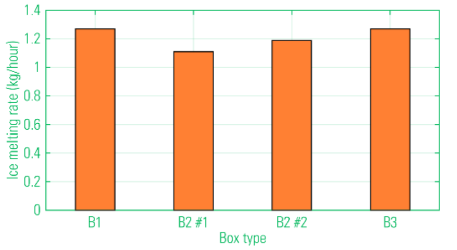

Figure 8. Ice melting rate of three single walled box types at ambient temperature of 20.3±0.6 °C.

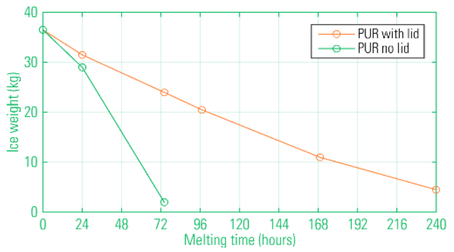

Figure 9. Ice weight in insulated PUR containers with and without lid during 10-day storage at 14.9±0.6 °C.

where R is the reciprocal of U (R=1/U) and represents the thermal resistance (R-value) of the container [m^2K/W]. This means that the R-value can be found from Equation (4) as follows:

$$R = A\Delta T / \dot{m}_{ice} L_{ice} \qquad (5)$$

Results and Discussion

Applying Equation (5) with the total inside surface areas on the results from different melting periods, the R-values shown in Table 2 were obtained. Applying the inside surface area but not the mean surface area ($S=(S_i*S_e)^{1/2}$) was done according to Burgess (1999) and Singh et al. (2008). Larger surface area yields a larger R-value but using the inside surface area makes sure that the R-value is not overestimated.

The ice melting rates in the single wall boxes were around 1.1–1.3 kg/hour at 20.3 °C ambient temperature for 18.3 hours (Figure 8), as compared to 0.2 and 0.4 kg/hour at 15.4 °C for 24 hours for the PUR insulated containers (with and without lid, respectively). Figure 9 clearly illustrates the importance of the lid with regard to thermal insulation of the container.

In order to get a fair comparison between the thermal resistances of the different packaging, Equation (5) was used for the first 18.3–24 hour melting intervals in the two trials, see the results in Table 2. Only the first melting interval in each trial was chosen because the ice melting and drainage from the containers decreases the effective heat exchange area of the containers, especially for the ones without lids. Thus, using the latter melting intervals could overestimate the R-values.

Obviously and as expected, the thermal insulation of the single walled boxes is very poor compared to the PUR insulated containers. According to Equation (3) and the current results for the multiplication UA, ice melting rate in typical single walled containers could be as high as 4.5 to 5.5-fold higher than in a PUR insulated container with a lid and around 2.5 to 2.9-fold higher if no lid is on the insulated container.

Table 2. Thermal resistance of the PUR insulated and single walled containers.

	70 PUR with lid	70 PUR without lid	B1	B2	B3
R-value (m^2K/W)	1.0±0.1	0.49±0.02	0.21±0.01	0.22±0.01	0.21±0.01
U [a] ($W/m^2/K$)	1.0	2.0	4.8	4.5	4.8
UA (W/K)	1.1	2.1	5.9	5.0	6.1

[a] U = 1/R-value = overall heat transfer coefficient between the ambience and the container load

The current results were used to predict ice melting in the different packaging under variable ambient temperature during up to one day storage, see Figures 10 and 11.

It should be noted that slower ice melting is expected when containers are stacked, especially when tightly stacked, which limits air flow around the containers. On the other side, these predictions assume that the containers are not exposed to direct solar radiation. Therefore, the melting rate could be significantly higher for containers stored outside than is predicted here.

Conclusions

Results of ice melt tests on single standing containers and boxes imply that the insulation performance of PUR insulated 70 L Sæplast containers is around 5-fold better than of typical single walled boxes of similar volume capacity. Using a lid seems to be crucial for the thermal protection because the R-value obtained for the 70 PUR container without a lid was only around half of the R-value for the same container closed with a lid.

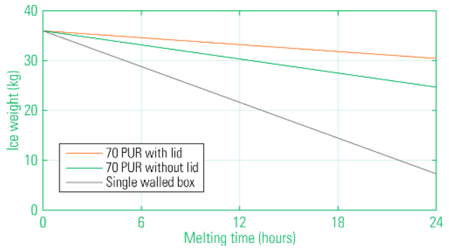

Figure 10. Predicted remaining ice stored in different containers at ambient temperature of 20 °C.

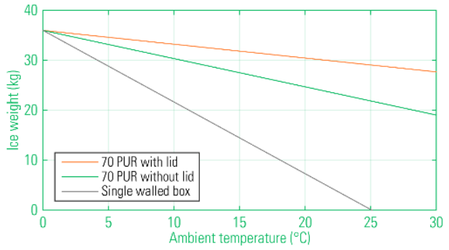

Figure 11. Predicted remaining ice stored in different containers for one day at variable ambient temperature.

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