Evaluation of thermal insulation of different Tempra EPS boxes

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1. Introduction

Temperature is a very important parameter for the quality and safety of fresh food and therefore also fresh fish. Extending the storage life would therefore reduce food waste and increase customer satisfaction (Margeirsson, 2012). Non-compliance with the cold chain leads to losses of around 20% in the world food supply and 9% in developed countries (IIR, 2015). Boxes promoting the insulation of the foodstuff can be a significant solution to the maintenance of the cold chain during transport.

The values of the EPS box of density 21 kg.m^{-3} were estimated with the different values from Al-Ajlan (2006). The influence of density on thermal conductivity is presented more precisely in the article by Gnip et al (2011). Burgess (1999) described a method to evaluate the insulation value (R-Value) of insulated packaging. Singh et al (2008) applied the method to compare the insulation of different packaging systems, including e.g. gelpacks, corrugated boxes with EPS foam panels, foil-laminated boxes, EPS boxes and polyurethane boxes.

Table 1: Thermal properties of EPS boxes (Al-Ajlan, 2006)

Density (kg.m^{-3})	Thermal conductivity (W.m^{-1}.K^{-1})	Specific heat (J.kg^{-1}.K^{-1})	Diffusivity (m^{2}.s^{-1})
21	0.035 ± 0.0006	1280 ± 50	1.32E-06
23	0.034 ± 0.0009	1280 ± 50	1.15E-06

The packaging under investigation in this study are expanded polystyrene (EPS) boxes of different sizes. They are white, made from molded polystyrene beads and composed of around 98% air (Valtýsdóttir et al, 2011). The thermal properties of the boxes are shown in Table 1.

The aim of this study is to compare the insulation of different EPS boxes manufactured by Tempra ltd in Hafnarfjörður, Iceland, and to identify the influencing factors on the insulation.

2. Materials and Methods

2.1. Equipment

Tidbit v2 loggers from OnSet Computer Corporation (Bourne, MA, USA) were used to measure the ambient temperature with 5 minutes intervals during the experiments (Figure 1). The error range of the data loggers is at ±0.21 °C between 0 and 50 °C.

Figure 1: Temperature data logger

The EPS boxes tested during the study are: Scampi box 1.5 kg, Fillet box 3 kg, Fillet box 5 kg, Fillet box long 5 kg and Fish box 23 kg (Figure 2). The tested boxes were of different densities (21 and 23 kg.m^{-3}) and with/without drain holes.

Figure 2: EPS Fish box 23 kg

2.2. Temperature logger positions

Figure 4: Experiment on temperature logger positions

In order to correctly position the temperature data logger for the experiments that will follow, different positions have been tested (around 10 cm, 30 cm, 50 cm from the short and long sides as well as at the center of the box lid), see Figure 4. To measure the ambient temperature, the temperature data logger positioned in the center of the box was eliminated because its temperature is influenced by that of the ice. Then all the other results are very close. The conclusion of this preliminary study is therefore to position the temperature data recorder at least 10 cm away from the box in all directions.

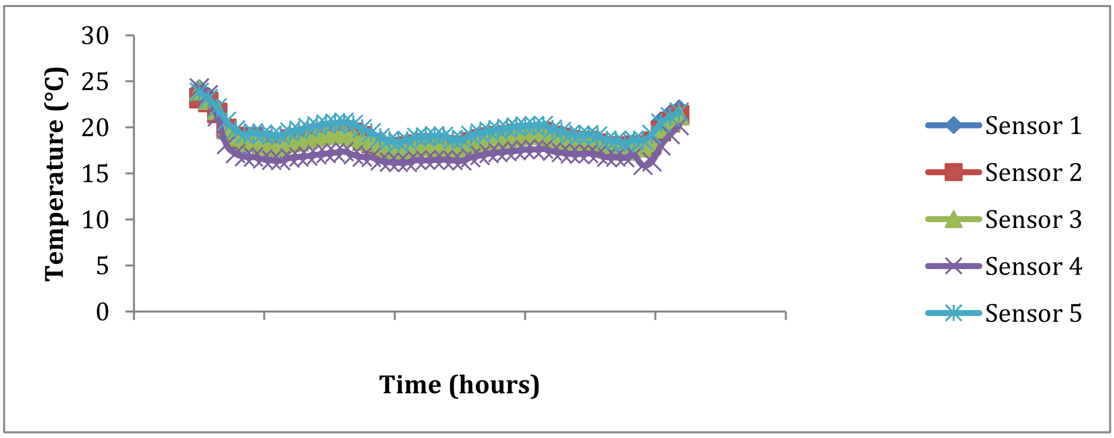

Figure 3: Temperature profiles during an ice melting experiment

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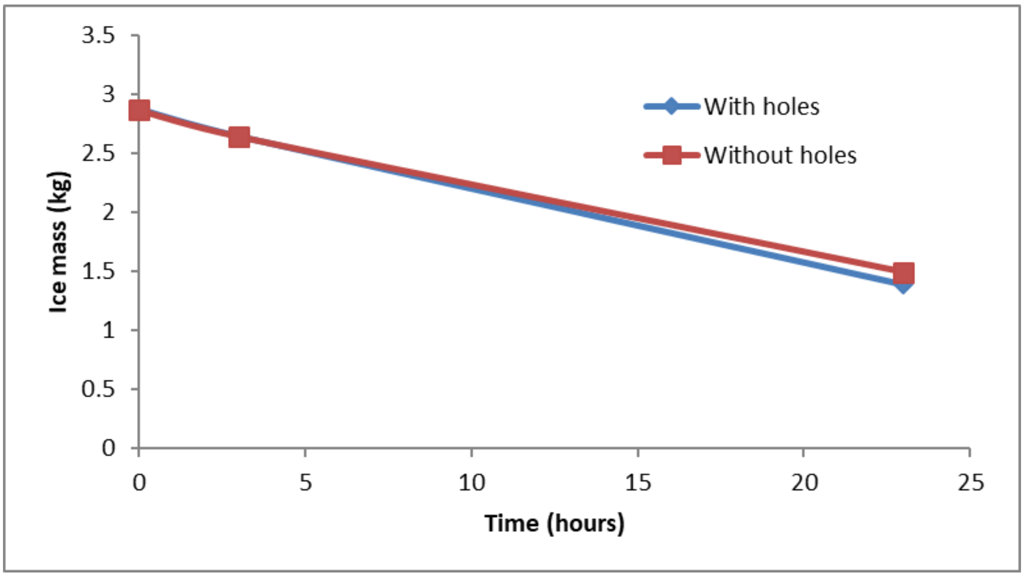

Figure 5. Ice melting at 20 °C in EPS boxes 3 kg Short Tempra with and without drain holes

2.3. Ice melting experience

The insulation is represented by R and is expressed in $m^2.K.W^{-1}$. Burgess more precisely describes the R-value formula in 1999:

$$R = \frac{A \times \Delta T}{\frac{\Delta m}{t} \times L} \qquad (1)$$

where

A: Internal surface area of box (m^2)

ΔT: Difference between ambient and internal (melting ice) temperatures (K)

Δm: Difference between the initial ice mass and final ice mass

t: Time (s)

L_{ice} = Latent heat of fusion of ice (334 800 $J.kg^{-1}$)

To calculate the R-value, certain parameters need to be known. Ice is put in the different boxes to observe the different melting rates (Δm/t), see Figure 5. The mass of ice in each box and time is registered at the beginning, at different time intervals and at the end of the experiment to be able to calculate ice melt rates. At least three temperature data loggers are placed in the ambience of the boxes in order to obtain the ambient temperature of the zone (Figure 6).

Figure 6. Ice melting experiment showing an EPS box before it was closed with a lid

3. Results and Discussion

For each ice melting experiment, ambient temperature profiles were made to calculate the R-value (Figure 3). The R-value is calculated from an average value for the ambient temperature during the corresponding ice melting period.

3.1. Influence of drain holes

Figure 5 shows the influence of the drain holes for the 3 kg short Fillet boxes stored at average ambient temperature of 20.1 °C. Ice in the box with drain holes melts faster. The drain holes reduce the R-value by 7.4%. The EPS boxes will therefore offer better insulation without drain holes (Table 2).

Table 2: Influence of drain holes on the R-value ($m^2.K.W^{-1}$) of 3 kg Fillet boxes

Box	With drain holes	Without drain holes
3 kg Short	0.75	0.81

3.2. Influence of box size

Table 3: Volume influence on the R-value (boxes without drain holes and density of 23 $kg.m^{-3}$)

Box capacity (kg)	1.5	3	5	23
R-value ($m^2.K.W^{-1}$)	0.53	0.81	0.84	0.90

The R-values for boxes ranging in fish storage capacity from 1.5 kg to 23 kg are presented in Table 3. Figure 7 shows that the insulation of the boxes increases with size (volume capacity) of the boxes until approaching a limit. It should be noted that the larger boxes generally have thicker walls, which increases their insulation capabilities.

3.3. Influence of EPS density

Table 4 shows that the density has no remarkable influence on the insulation of the boxes. The experiments were carried out on very narrow density range (21 and 23 $kg.m^{-3}$). In order to support such density vs. conductivity dependency, as noted by Gnip et al (2012), it would probably be necessary to carry out tests on boxes of a wider density range.

4. Conclusion

The ice melting experiments showed that the density had no remarkable influence on the R-value. On the other hand, the drain holes have a negative 7%-influence on the R-value (in case of 3 kg Fillet boxes). Finally, larger volumes generally yield a better R-value. The notion of limit was highlighted by cutting the results with the PUR boxes. It will take more experience to specify the volume that can reach limit.

Table 4: Influence of density and size on the R-value ($m^2.K.W^{-1}$)

	Box type			
Density	3 kg Short	5 kg Short	5 kg Long	23 kg
21 $kg.m^{-3}$	0.81	0.82	0.83	0.94
23 $kg.m^{-3}$	0.81	0.84	0.80	0.90

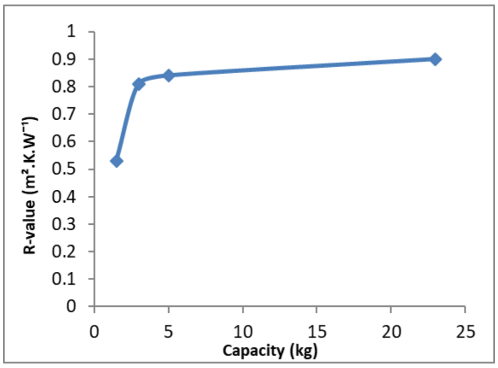

Figure 7. Influence of EPS box volume capacity on the R-value (boxes without drain holes and density of 23 $kg.m^{-3}$)

To conclude, for better insulation in the EPS boxes, it will be preferred to choose boxes without drain holes and in the largest volumes of the range. It is a choice between the practical side imposed by user's context of the EPS boxes and an optimum of insulation.

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