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Examining the degradation process of the heat/cold protecting insulation applied for construction of cooling bodies under the influence of water

Abstract

Contemporary transport of perishable food and other cargoes sensitive for temperature changes is carried out basing on specialist isothermal and cooling bodies. The reason of the deterioration of the body insulation condition is the penetration of water into the heat/cold protecting material and the further destruction of the insulation properties by moisture which in the insulating material is subject to cyclic freezing and defrosting processes depending on the temperature of the transported goods. The paper presents the test results on the destruction of the insulating material under the influence of cyclic freezing and defrosting of water introduced into the insulating material. The effects of servicing the damp insulating material were examined depending on the quantity of cycles of freezing and defrosting getting much worse deterioration of insulating properties than in case of entering water into the dry insulating material.

Keywords: degradation of insulation material, heat flux, thermovision, isothermal body.

1. Introduction

Transport of contaminated foods, pharmaceuticals, sensitive chemicals or other goods sensitive to temperature and humidity changes require the use of specialized means of transport to transport these goods which restrict the heat exchange between the interior and the environment. The limitation of heat exchange by the use of heat/cold protecting insulating materials for the construction of vehicles is not sufficient to maintain the temperature required to transport products sensitive to temperature changes. The basic problem is that the insulation material does not reduce the heat exchange between the interior of the body and the environment. Theoretically, there is an excellent insulating material - vacuum - capable to reduce heat exchange to zero, but even in the thermos, there must be a hole for loading and unloading the container so that it can be used to store the product at a non-ambient temperature and closing the hole with the element made in vacuum technology like a thermos and this causes the insulation material discontinuity. Therefore, the heat/cold insulating materials used in practice only reduce to a technically and economically justified minimum the heat flow penetrating through the baffles used to separate the space at the temperature different than the environment one. To maintain the required temperature level, they apply additional technical equipment capable the receiving heat entering the refrigerated body interior and delivering it to the environment – refrigerating units - or delivering heat to the body in place of heat penetrating from the inside to the outside of the body - heaters or refrigerating units with the heating function.

2. Description of the destruction problem

Insulation properties of heat/cold protecting materials are described by the heat transfer coefficient λ, expressed in W/mK. The less heat is conducted by the heat/cold protecting insulating material, the better are its insulating properties. Heat/cold insulation materials are environmentally sensitive materials. Under the influence of various environmental parameters - humidity, UV radiation the insulating properties of cold/heat protecting insulation materials are deteriorating. Gases in the motionless state have relatively good insulating properties. In general, insulation materials are produced with the use of stationary air or heavy gases filling the cells of the matrix material. As water conducts heat several times better than air, the insulation material must be protected from water entering into its porous structure. In order to protect the insulation material, coatings being barriers for water and other contaminants are used.

In the construction of refrigerating bodies designed to handle transport at controlled temperatures, steel sheets and plastics are used for the plating to protect the insulation material. Unfortunately, the numerous connection places of the various refrigerating body components (attaching the body to its intermediate frame, joining the body walls together, fixing the doors, fixing the refrigerating unit and so on) make the fasteners - bolts and rivets – come through the plating material, and the holes for their assembly sooner or later become the places of water penetration through the plating and reach the insulating material worsening its insulating properties. Unfortunately, the penetration of water into the insulating material is just the beginning of the destructive deterioration of the insulating properties of the material used to build the body. Water contained in the insulating material is subject to cyclical freezing and defrosting processes accelerating the destruction of the insulation material structure.

3. Description of the experiment

To measure the influence of operating factors on the deterioration of the material's insulating properties, a sample of polyurethane insulation material was subjected to a dampening process (about 10 g of water) and subjected to freezing and defrosting cycles in the climate chamber. At each stage of the experiment, the sample was mounted on a test stand equipped with a body model with a plate prepared for the assembly of the insulation material samples (1) [1] and after the stand thermal stabilization lasting 24 hours the following thermal parameters were obtained: + 32.5°C inside the body model and +7.5°C in the surroundings of the body. During the test the relative humidity of the air was kept constant at 50% RH. The Flir ThermaCAM 695 camera was used for the study. During the test, the camera was mounted on a tripod and the test and recording of the thermograms took place while the light was off.

A thermally insulated sample plate (Fig. 1 on the left) and a reference plate (Fig. 1 on the right) were observed by means of a thermovision camera to record the temperature distribution on the surface of the tested sample and the reference plate.

Fig. 1. Photo of the test stand

The thermovision photo was used to determine the density of the heat flux permeating through the operational heat bridge - a damp spot subjected to a cyclic freezing and defrosting process.

In subsequent thermovision photos, the stages of aging of the insulation material are shown from the beginning – a dry sample before injection of water into the structure of the insulation material (Fig. 2), samples after injection of about 10 g of water into the insulation material (Fig. 3) and a series of thermovision photos presenting the increase of the zone of lower insulation properties due to water freezing and defrosting cycles inside the insulation material.

As the weight of the water slab was the same throughout the study, it should be inferred that the sample soaked with water did not dry.

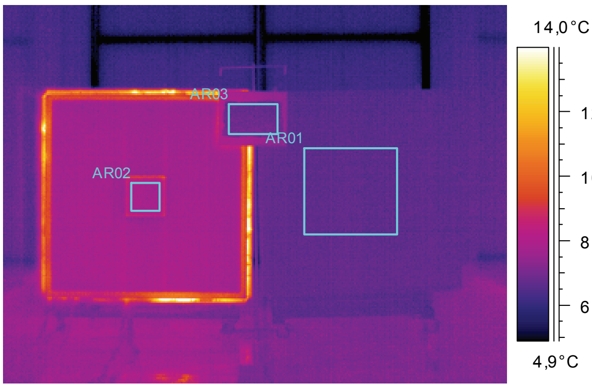

Fig. 2. Photo of dry sample of insulating material (on the left)

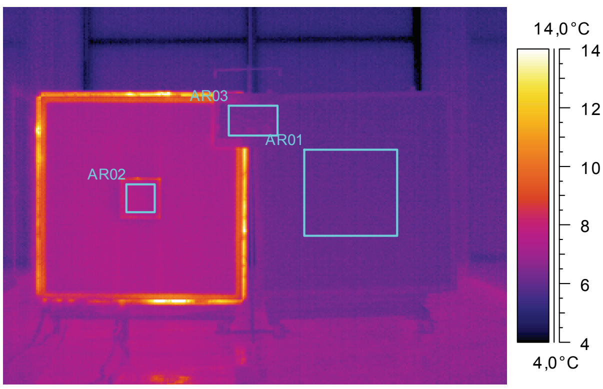

Fig. 3. Photo of the insulation material sample (on the left) after injection of 10 g of water

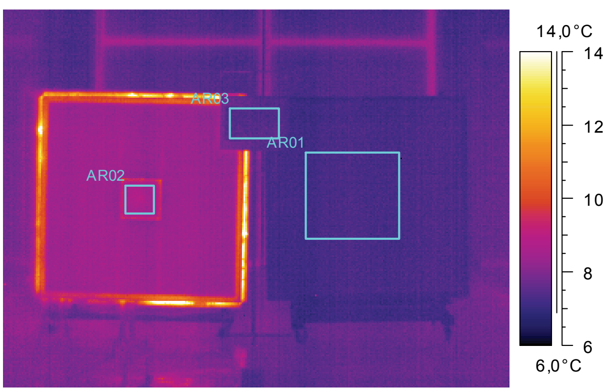

Fig. 4. Photo of a wet insulation material sample (on the left) after 75 freezing/defrosting cycles of 10 g of water

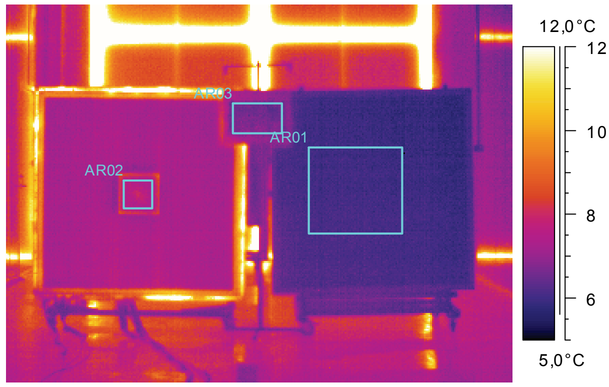

Fig. 5. Photo of a wet insulation material sample (on the left) after 200 freezing/defrosting cycles of 10 g of water

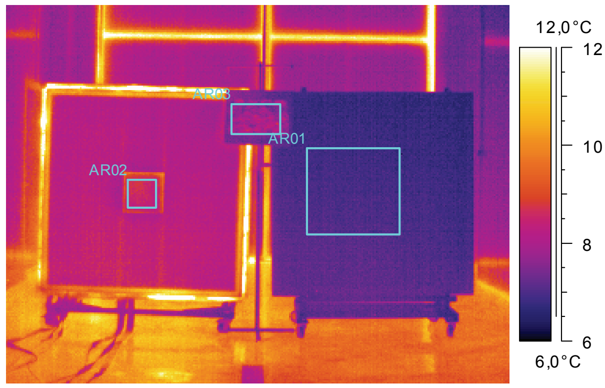

Fig. 6. Photo of a wet insulation material sample (on the left) after 385 freezing/defrosting cycles of 10 g of water

The paper [1] describes the method of determining the heat flux based on the thermovision photo, and this methodology was used to determine heat losses in the aging test. In order to compare the effect of aging over successive series of freezing/defrosting cycles, during the experiment a fragment of identical size of 19×19 pixels of thermovision photo was selected for analysis.

Table 1 shows the results of the heat flux calculation of the area under analysis it thermovision each photo. The temperature difference ΔT K was calculated basing on the average temperature of the area AR02 (damp plate) and the average temperature of the area AR01 of the reference plate - not thermally stressed. The AR02 and AR01 areas analyzed were constant throughout the study.

The heat flux was calculated from the dependency [1]:

$$\dot{Q} = (14.5\Delta T + 0.3)\ \mathrm{W}$$

The summary of the measurement results are placed in the column showing the increase in heat losses referenced to the heat loss of the dry plate prior to the process of water injection into the structure of the insulation material.

Tab. 1. Results of measurements and calculations at various stages of the experiment

Plate condition	Temperature difference ΔT K	heat flux $\dot{Q}$ W	Heat losses increase %
dry	**1.2**	**17.7**	**100%**
0 freezing cycles	1.3	19.3	109%
75 freezing cycles	1.4	20.1	114%
200 freezing cycles	1.5	22.2	125%
385 freezing cycles	1.6	23.2	131%

4. Analysis of results

As a result of the research, it was indicated that the introduction of small amounts of water (10 g into a 300 mm×300 mm×40 mm plate) reduced the insulation properties of polyurethane - the material used in the construction of refrigerated bodies, by 9%. It is surprising, however, that these 10 g of water subjected to repeated freezing and defrosting cycles in the insulating material causes even greater losses than the introduction of water itself. As described in the paper, 385 water freezing cycles in insulating material doubles the increase in heat loss in relation to increased heat loss caused by introduced water.

5. Calculation of measurement error

Temperature measurement with the use of a thermovision camera is an indirect measurement. In literature [2,3], methods for determining the measuring temperature error are presented. The following partial uncertainties were taken into account for the analysis of the temperature measurement model implemented in the thermovision camera: emissivity ε = 0.97 – 0.10; ambient temperature, T_{amb}=(280 ± 3) K, temperature of the atmosphere, T_{atm} = (280 ± 3) K, relative air humidity ω = (50 ± 10)% RH, distance of plates from the camera lens d = (9.0 ± 0.1) m.

The total error was determined by the formula given in [3]:

$$\delta_{T_{ob\%}} = \sqrt{\left(\frac{\partial T_{ob}}{\partial \varepsilon_{ob}}\delta\varepsilon_{ob}\right)^2 + \left(\frac{\partial T_{ob}}{\partial T_{amb}}\delta T_{amb}\right)^2 + \left(\frac{\partial T_{ob}}{\partial T_{atm}}\delta T_{atm}\right)^2 + \left(\frac{\partial T_{ob}}{\partial \omega}\delta\omega\right)^2 + \left(\frac{\partial T_{ob}}{\partial d}\delta d\right)^2} \quad (1)$$

After substituting the data derived from the error graphs on the individual components of the model for a temperature measurement error [2], it is:

$$\delta_{T_{ob\%}} = \sqrt{0.75^2 + (-0.15)^2 + (-0.02)^2 + (0.0002)^2 + (-0.02)^2} = 0.8\% \quad (2)$$

Ultimately, the temperature measurement error for the 281 K is 2.2 K, however, with differential measurements, the error is significantly smaller.

For homogeneous heat fluxes, more accurate measurement methods are available, but sensors are not able to correctly measure heat fluxes at places of temperature gradients, such as on operational heat bridges. The thermal imaging camera and described in [1] methodology can estimate the density of heat flux within the heat bridges.

6. Conclusions

A refrigerating body designed for transport at controlled temperatures is an object in which the operating conditions of the insulating material often change. After the transportation of frozen products, the cargo transport is often carried out, especially on the return route, and it does not need to be performed at such a low temperature, or the temperature does not need to be controlled at all. It is well known that damp insulation material loses its insulating properties, but insulation properties of the heat/cold protecting material are lost definitely faster due to cyclic water freezing and defrosting. The conclusion is that the users should take care of the means of transport and repair every minor damage to the plating as soon as possible in order to prevent the penetration of water into the insulating material causing the destruction of the heat/cold protecting insulation.

7. References

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Received: 16.11.2016 *Paper reviewed* *Accepted: 02.02.2017*

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