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Calculation of Heat Damage Losses of Cooling Bodies

Abstract

This paper presents the calculation results of heat amount increase being typical for isothermal and cooling bodies where body plating has been broken causing the open way for water penetration into the insulating material and thus deteriorating the insulating properties of the damaged body fragment. During the service of the isothermal and cooling bodies the damages of their different fragments take place. A typical damage is abrasion of the side walls, damage to the joints of walls and walls with the roof and damage to the door edges. Using the thermovision camera and the algorithm described in [1], heat loss can be calculated for a fragment of the body that includes damage - an operational heat bridge that generates a variable heat flux being difficult or even impossible to be measured with heat flux density sensors. On the example of typical damages occurring in the serviced refrigerated body, they have calculated the amount of additional heat which may lead to the disqualification of the refrigeration body from refrigerated transport of sensitive goods, such as food and medical goods, bringing losses to transport companies.

Keywords: isothermal and refrigerating bodies, heat bridge, heat losses.

1. Introduction

In order to ensure the continuity of the cooling chain, the restrictive requirements as to the storage conditions of perishable food and other goods being sensitive to temperature changes translate correspond with the requirements of transport conditions of these goods. In order to meet the requirements that should be ensured during the transport of goods sensitive to temperature changes, isothermal and refrigeration bodies are constructed. These are highly specialized constructions. Generally, it can be said that bodies of this type are chambers adapted to move on roads with a structure that ensures minimal heat exchange between the interior and the environment. Because the heat loss of the isothermal or refrigerating body cannot be reduced to zero, the occurring heat exchange causes an increase / decrease in the temperature of the transported load which must be compensated by the operation of the refrigerating or heating device in order to maintain the required temperature. The insulating properties of the new isothermal and refrigerating bodies are affected by the type and amount of insulating material, structural solutions of reinforcements called structural heat bridges, assembly errors most often related to human errors made during the assembly, i.e. technological heat bridges.

The service of isothermal and refrigerating bodies is associated with deterioration of the technical condition. Damages to the isothermal and refrigerating body cause an increase in heat losses to / from the cooling body. Increased heat losses of the cooling body cause a transport hazard at temperatures higher than the transported product requires. Transport at a higher temperature than required for a given load results in an increase in the rate of microbial growth and deterioration of the quality or even the product spoiling, and this creates a threat to consumer safety. If the cooling unit is properly selected, serviced and maintained in good technical condition, it has a reserve of cooling power to compensate the increase in heat loss penetrating through the damage to the body, but it is at the cost of the unit operating time (and the increase in fuel expense for the operation of the combustion engine driving the cooling unit).

Because mechanical damages of isothermal and refrigerating bodies and the associated penetration of water into insulating material are random (size and shape of damage, nature of damage), it is generally not possible to calculate in the analytic way the heat losses caused by damages.

Heat fluxes measuring methods basing on heat meters are based on sensors measuring concerning the area of sensor size - usually it is a diameter in the range of several tens of millimetres. The sensor averages the value of the measurement result and when it is mounted on a surface that emits a homogeneous heat flux, the measurement result can be considered as correct. Unfortunately, the irregular shape of the damage in connection with the effect of deterioration of insulating properties of the cold material under the influence of penetrating water which additionally by repeated freezing and thawing damages the structure of insulating material [2], creates gradients on temperature fields and accurate measurement with heat meters is fraught with risk of a big error.

In order to be able to measure the heat flux penetrating through the damage of the refrigerating body (commonly known as service thermal bridges), a method for determining heat losses based on the thermogram [1] was developed. Quantitative analysis of heat losses of the damaged fragment of the body allows to qualify the body for further operation, repair or withdrawal of goods sensitive to temperature changes.

To assess the operational damage, they have chosen several of the most common occurring failures of refrigerating bodies, such as:
- damage with perforation of the plate,
- damage within the slats covering the joining of walls,
- damage to the door edges.

A typical damage is abrasion of the side walls, damage to the joints of walls and walls with the roof and damage to the door edges. Although each of these damages arises from various causes and concerns various parts of the body, these damages have an important common feature - water penetrates through the damage into the insulating material causing deterioration of insulating properties at the damage place and due to the specific service conditions of cooling bodies being associated with frequent changes in the conditions of transported loads, additional deterioration of insulation properties and the expansion of areas with deteriorated insulating properties.

2. Description of the experiment

The purpose of the experiment was to determine heat losses for typical damages occurring in refrigerating bodies. Thanks to the quantitative analysis of damages, it will be possible to indicate which damages and in what places of the body generate the greatest heat losses. This will enable presentation of guidelines for the users of isothermal and refrigerating bodies regarding the repair work of the damaged refrigerating bodies.

Due to the characteristics of thermovision tests - a large environmental impact on the measurement results, the thermovision tests of heat bridges were carried out in the ATP test chamber located at the Poznan University of Technology. The conditions for testing the body are set out in the ATP agreement (Agreement on the International Carriage of Perishable Foodstuffs and on the Special Equipment to be Used for Such Carriage, Geneva, 1 September 1970, with later changes) and on its basis the heat losses of the isothermal or refrigerating body as a whole are determined. Thermograms allowed to mark off and subject the thermal examination to a fragment of the body with damage. The thermovision tests of body damages were carried out "by the way" of certification tests for the compliance of vehicles with the requirements of the ATP agreement.

The ATP agreement specifies conditions for testing isothermal and refrigerating bodies during the test, these conditions are: temperature inside the isothermal or refrigerating body t_w = 32.5°C, temperature in the test chamber i.e. outside the refrigerating body t_z = 7.5°C, air velocity flowing over the test body (1- 2) m/s. Under the same conditions, the tests with the use of the thermovision camera ThermaCam 695 manufactured by FLIR were performed.

Several types of the most common body defects were selected for the analysis. The most common damages occurring in the body are:

- dampness of insulation due to perforation of the plating (e.g. abrasion with interruption of the plating continuity, leakage of cutting off rivets),
- damage to the joints of walls, walls and roofs being associated with the presence near the traffic lane of elements such as branches of trees, advertising boards, buildings, bridges),
- damage to the door edges (e.g. mechanical damage to the edges created when reversing to the loading dock, mechanical damage related to the low durability of the structure).

These are the most frequently occurring service damages in vehicles operated in the range of 6-12 years. Newer vehicles do not show numerous damage yet, and older vehicles (over 12 years) due to a significant deterioration of the technical condition of insulation are resold or intended for other types of transports where maintaining heat loss through the body is not a critical requirement.

3. Measurements results and calculations

In order to analyse the heat loss of the cooling body damage, fault depictions were selected as well as a reference fragments that insulating properties did not raise any objections. The selected areas were exported using software for processing thermovision material (ThermaCAM Reporter, FLIR Quick Report) to Excel where it was subjected to further analysis. For the exemplary analysis, a fragment of the side wall of the body was chosen in which it was damaged by tearing the plating and penetration of water into the insulating material (Fig. 1).

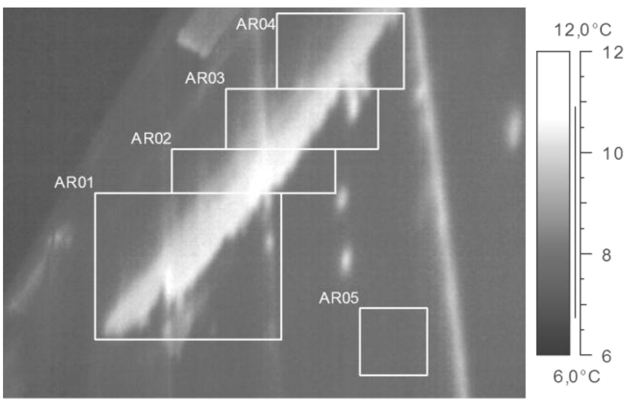

Fig. 1. Thermogram of service heat bridge with perforation of the plate on the side wall

Because in this type of analysis the difference between the area without damage and the area with damage is important - that is, the determination of additional heat losses in the area of damage, the heat loss method developed within the previous tests and described in [1] allows to determine the increase in heat loss caused by the damage of the isothermal and refrigerating body. To minimize temperature errors with a thermovision camera, the method is based on differential analysis in relation to the reference area.

After selecting and exporting to Excel the temperature measurement results on the surface of the heat bridge, the mean temperature of the reference area was determined basing on the thermovision processing program. This average temperature was used to calculate the increase in the surface temperature of the heat bridge (i.e. the difference in temperatures between the individual pixels of the heat bridge and the temperature of the reference area). This difference was substituted for the formula (1) in [1] for the heat flux density emitted by each fragment - the area of the heat bridge observed by means of individual detector pixels. After calculating the area of the area observed by individual detector pixels from the geometrical relations of the lens, the heat quantities of particular fragments of the heat bridge were obtained. After adding up the heat amount of the heat bridge, this value was compared to the heat loss of the body fragment with the same area as the analysed heat bridge fragment, where global heat loss coefficient is K = 0.40 W/(m^{2}K) with temperature difference Δt = 25 K. Table 1 contains the results of the heat loss analysis introduced by the fragment of the heat bridge presented in the picture from Fig. 1.

Tab. 1. Summary of the heat loss analysis of the damage presented in the Fig. 1

	AR_{01}	AR_{02}	AR_{03}	AR_{04}	$\sum ARi$
Heat bridge area m^2	0.114	0.030	0.039	0.040	0.223
Heat losses of body fragment without heat bridge Q,W for K=0.40 W/(m^{2}K), Δt=25 K	1.1	0.3	0.4	0.4	**2.2**
Calculated increase of heat losses for heat bridge Q_{HB} W	1.3	0.5	0.6	0.4	**2.8**
Relative heat loss increase of area AR0x Q_{HB}/Q %	116%	163%	159%	102%	127%

Another analysis was carried out for a fragment of the damaged joining of the side wall with the body roof. This type of damage is particularly dangerous for the deterioration of insulating properties because water from atmospheric precipitation can penetrate the damage site and further into the insulating material.

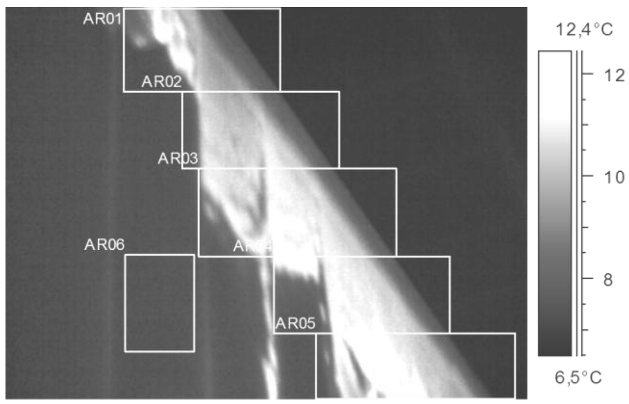

Fig. 2. Thermogram of service heat bridge occurred in the effect of damage in joining of a side wall and a roof

Tab. 2. Summary of the heat loss analysis of the damage presented in the Fig. 2

	AR_{01}	AR_{02}	AR_{03}	AR_{04}	AR_{05}	$\sum ARi$
Heat bridge area, m^2	0.109	0.101	0.145	0.113	0.109	0.577
Heat losses of body fragment without heat bridge Q, W for K=0.40 W/(m^{2}K), Δt =25 K	1.1	1.0	1.5	1.1	1.1	**5.8**
Calculated increase of heat losses for heat bridge Q_{MC} W	1.9	2.4	4.5	3.1	3.4	**15.4**
Relative heat loss increase of area AR0x Q_{MC}/Q %	175%	241%	312%	274%	313%	266%

A fragment of the body susceptible to damage is the door leaf. The driver, before the ride to the loading dock opens the rear door with an angle of 270° and having so prepared the isothermal or refrigerating body for loading or unloading the body, arrives to the dock. Open doors are the first to be damaged. The picture in Fig. 3 shows the fragment of the door leaf damaged at the driveway to the dock and Table 3 presents the results of the analysis of this heat bridge.

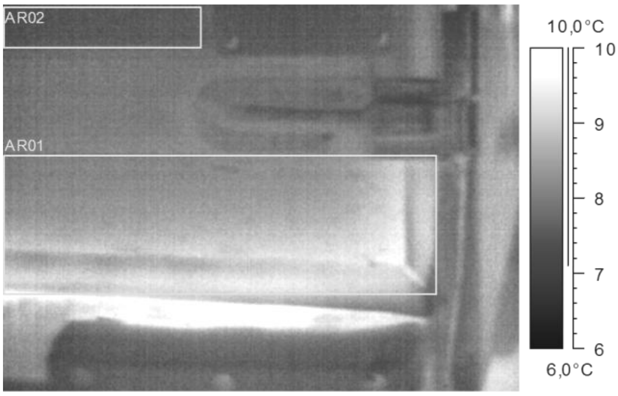

Fig. 3. Thermogram of service heat bridge occurred in the effect of damage in open door leaf when approaching the loading dock

Tab. 3. Summary of the heat loss analysis of the damage presented in the Fig. 3

	AR_{01}
Heat bridge area m^2	0.094
Heat losses of body fragment without heat bridge Q W for K=0.40 W/(m^{2}K), Δt=25 K	**0.9**
Calculated increase of heat losses for heat bridge Q_{HB} W	**1.6**
Relative heat loss increase of area AR0x Q_{HB}/Q %	172%

4. Analysis of measurement results

It should be clearly emphasized that this is not the final result of the impact of heat losses generated by the heat bridge to the thermal balance of the isothermal or refrigerating body.

The article [2] showed that the cyclical freezing and thawing of insulation material (containing small amounts of water) associated with the characteristics of the refrigerating body work (frequent changes related to the type of transported cargo) causes degradation of the insulation material and the heat loss increase in the heat bridge.

Heat bridges with perforation of the plating, damage of the edge of the door leaf or the side walls joining with the roof, open the road for water condensing on the bridge and supplied during the rain, causing further deterioration of the insulating properties of the heat or cold protecting material.

In today's isothermal and refrigerating bodies there is a tendency to minimize the "stock" or even the production of bodies on the limit of the insulation requirements ($K \leq 0.40$ W/(m^{2}K), for bodies designed for transporting goods at sub-zero temperatures and $K \leq 0.70$ W/(m^{2}K), for bodies designed for transporting goods in a refrigerated state to 0°C. Therefore, it may turn out that a few heat bridges together with a fragment of the damaged strip connecting the walls and a slight damage to the door introduce additionally (50-80) W of heat, causing exceeding the permissible heat loss for the body class and preventing the body to transport food and other goods sensitive to too high temperatures.

5. Calculation of uncertainties

Temperature measurement with a thermovision camera is an indirect measurement. Literature [3, 4] presents methods for determining the temperature measurement uncertainties. The following partial uncertainties of the temperature measurement model implemented in the thermovision camera have been used for the analysis: emissivity ε_{ob}=0.97±0.10; the apparent reflected temperature T_{amb} = (280±3) K, the atmosphere temperature T_{atm} = (280±3) K, the relative air humidity ω=(50±10)% RH, the distance of the bodies - camera lens d = (3.0 ± 0.1) m.

The total uncertainties has been determined on the basis of the formula given in [3] and after substituting the data from the error influence graphs for individual components of the model on the temperature measurement error [4], it is:

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

where: ε_{ob} - emissivity, T_{amb}, K - apparent reflected temperature, T_{atm}, K - atmosphere temperature, ω,%RH - relative air humidity, d, m - distance of the bodies - camera lens

$$\delta_{T_{ob\%}} = \sqrt{(-0{,}75)^2 + (-0{,}15)^2 + (-0{,}02)^2 + (0{,}0002)^2 + (-0{,}02)^2} = 0{,}8\% \quad (2)$$

Since the test conditions affecting the uncertainty of measurement have been constant and in accordance with the methodology for testing isothermal and refrigerated bodies described in the ATP agreement, the uncertainty analysis presented in [4] is valid for numerical tests and analyses described in the article.

Ultimately, the temperature measurement uncertainty for the 281 K is 2.2 K, however, with differential measurements, the uncertainty is significantly smaller. For homogeneous heat fluxes, more accurate measurement methods are available, but sensors are not able to measure correctly 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

On the examples of small fragments of the damaged body presented in the article, it is evident how important it is to repair damage to an isothermal and refrigerating body being used. Repairs should be carried out in workshops capable of ensuring quality similar to that of the bodybuilder, otherwise the repair may only aggravate the insulating properties of the body.

7. References

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Received: 12.12.2018 *Paper reviewed* *Accepted: 04.02.2019*

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