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SEARCH FOR INNOVATIVE SOLUTIONS IN BUILDING ISOTHERMAL BODIES FOR FOOD CARRIAGE

Summary

This paper outlines the research area of new heat-insulating materials useful for the production of sandwich plate for building isothermal bodies. It also presents the inappropriate solutions of construction nodes causing the occurrence of heat leakage bridges, and thus the increase of the value of overall heat-transfer coefficient (of the whole body). The last part of the paper presents the advancement procedure for the prototype isothermal body. Information obtained on the basis of the analysis of the thermovision photographs (as well as local measurements of heat-transfer coefficient values) is very important for this procedure. The presented information is connected with the realisation of the research project PBS1/B6/6/2012 "Elaboration of production technology for complete semi-trailer for food transport in refrigeration conditions of improved technological parameters" (a leader – the firm Wielton from Wielun, consortium members: Poznań University of Technology and Industrial Institute of Agricultural Machines in Poznan [2]).
Key words*: food carriage, isothermal vehicles, heat-insulating materials, sandwich plates, thermovision photographs analysis*

POSZUKIWANIE INNOWACYJNYCH ROZWIĄZAŃ W BUDOWIE NADWOZI IZOTERMICZNYCH DO PRZEWOZU ŻYWNOŚCI

Streszczenie

W artykule zarysowano obszar poszukiwania nowych materiałów termoizolacyjnych przydatnych do produkcji rdzeni płyt warstwowych w budowie nadwozi izotermicznych. Pokazano również niewłaściwe rozwiązania węzłów konstrukcyjnych prowadzące do powstania mostków ciepła, a tym samym do wzrostu wartości globalnego współczynnika przenikalności cieplnej (całego nadwozia). W ostatniej części artykułu zaprezentowano procedurę doskonalenia prototypowego nadwozia izotermicznego. W procedurze tej bardzo istotne są informacje uzyskane z analizy zdjęć termowizyjnych (oraz wyniki pomiarów lokalnych wartości współczynnika przenikania ciepła). Przedstawione informacje mają związek z realizacją projektu badawczego PBS1/B6/6/2012 „Opracowanie technologii produkcji kompletnej naczepy do przewozu żywności w warunkach chłodniczych o ulepszonych parametrach technicznych" (lider – firma Wielton z Wielunia, konsorcjanci: Politechnika Poznańska i Przemysłowy Instytut Maszyn Rolniczych w Poznaniu [2]).
Słowa kluczowe*: przewóz żywności, pojazdy izotermiczne, materiały termoizolacyjne, płyty warstwowe, analiza zdjęć termowizyjnych*

1. Introduction

All over the world people use nearly one million isothermal vehicles (insulated, refrigerated, ice generators, cold stores and heated vehicles) and about half million containers with thermal insulation. The value of goods transported in the cooled and frozen state is about 1200 billion dollars. The important trend in this sector of transport is constant costs reduction and at the same time increasing requirements concerning maintaining high quality of food during transport. This forces a constant search for modern materials meeting high requirements concerning thermal conductivity and creates development of new design solutions for isothermal bodies.

An insulated body should be characterised by:
- lack of negative influence on transported goods,
- applicative performance,
- durability and required strength in service conditions,
- low own mass,
- adequacy to maintain good sanitary conditions,
- low heat-transferability,
- low costs of purchase and service.

Law acts which should be taken into account when designing bodies are:
- Agreement on the International Carriage of Perishable Foodstuffs and on the Special Equipment to be Used for such Carriage (ATP) [3],
- Directive 2007/46/WE of European Parliament and Council of 05.09.2007 on accepting entry into service of vehicles,
- standards DIN EN 12640 and DIN 12642 concerning load fastening and protecting.

ATP Agreement determines requirements which have to be met by an insulated body for carriage of food staff in controlled temperatures. The basis for the bodies classification is the value of the overall heat-transfer coefficient k:
- $k \leq 0.4 W/(m^2K)$ – bodies with heavy insulation,
- $k \leq 0.7 W/(m^2K)$ – bodies with normally insulation.

Construction of bodies of such low heat-transferability requires:
- application of construction materials of low thermal conductivity,
- avoiding heat bridges.

This paper discusses research directions concerning new materials useful in building isothermal bodies, methods to eliminate heat bridges when designing and improving a prototype of isothermal body.

2. Research directions for new constructional materials

Insulated bodies are at present made as self-supporting constructions of laminated boards where the laminated core is covered by lining made of (steel, aluminium) sheet or plastic. The metal lining is made of some combined metal sheets. In places where the sheets are combined the heat bridges can occur which does not take place when the lining is made of plastic as the lining is a uniform surface with no connections.

The heat-insulating core of sandwich plates - limits the heat-transport to the body inside through conductivity.

In the actually built bodies the heat-insulating cores are usually made of polyurethane or foamed polystyrene.
The advantages of polyurethane are as follows:
- low thermal conductivity,
- low moisture absorptivity,
- no brittleness even in very low temperatures,
- good adhesion to construction materials.

Polyurethane conductivity strongly depends on the applied foaming substance. The best foams were obtained with the use of the refrigerant R11. Due to the negative influence of halogen like agents on the environment (ozone hole effect and greenhouse effect) the refrigerant R11 has been withdrawn from use. Polyurethanes produced with the use of other foaming agents characterise with higher thermal conductivity and quicker undergo the process of ageing.

Foamed polystyrene feature is low thermal conductivity (however, it is higher than in case of polyurethane), it is foamed with air so it is ageing resistant. The disadvantages of foamed polystyrene are susceptibility to organic solvents and necessity to apply special additives to achieve self-extinguishing.

In order to build bodies of possible best heat-insulating properties it is necessary to look for new materials of low thermal conductivity.

The aim is to search for new insulating materials of very low thermal conductivity but also of high adhesion so that they could be bound with various construction materials of high physiochemical parameters enabling to maintain the body durability in different difficult conditions. The new material should be safe from the point of view of human health and environment protection.

The best medium reducing heat transport through conductivity is vacuum. Vacuous boards applied in passive building industry have considerable mass so in practice for this reason they are not useful for building isothermal bodies. Additional disadvantage of such boards in case of different traffic events causes decompression which is against their application.

Therefore, looking for new heat insulating materials, it is worth paying attention to aerogels. Aerogels are microporous silica consisting of: light molecules of silica (below 10%) and air (above 90%). Aerogels characterise with very small thermal conductivity as nanopores are filled with air.

It is worth considering the possibility of application aerogels when building isothermal bodies what is proved by their following properties:
- very low thermal conductivity,
- possibility to apply in a very wide range of temperatures (from -270^{o}C to 649^{o}C),
- no chemical danger for the environment,
- low density,
- hydrofobic (highly resistant to humidity), high durability (good adhesion, low deflection, short recovery time of the deformed material to its original dimensions, considerable durability).

Owing to the above mentioned properties aerogels are already applied in:
- fuel and power industry as insulation for tankers, tank systems and pipes,
- building drilling platforms on sea, as insulation of pipes,
- military and cosmic installations,
- transport, as truck screening,
- household equipment, as insulation of appliances doors and walls.

The above mentioned examples show that properly modified aerogels can be in prospect a material for building heat insulating cores of laminated boards applied in isothermal bodies building.

3. Elimination of heat bridges

Heat bridges can occur during the stage of designing, production and service of the isothermal body. This subject was widely discussed in the elaboration [1]. This article pays attention to the problem of heat bridges occurring when constructing the body.

Tables 1 and 2 present reasons of heat bridges occurrence in the process of construction.

Table 1. Structural reasons of the heat bridges [1]
Tab. 1. Konstrukcyjne przyczyny mostków cieplnych [1]

Item	Reasons – categories of elements
1.	**Strengthening sunk in insulation, used for fastening:** - aggregate (eutectic plates), - door hinges, locks, - hooks (in “hook bodies” – bodies designed for transporting half carcass of pork), - walls, - side doors, - strengthening for load protecting system (in ceiling and on walls and floor)
2.	**Elements fastened on surface of board plating:** - strengthening for load protecting system (on walls), - aggregate casings, - floor guard strips, - shifting wall ways, - distributors of air from aggregate (catcher of air from evaporator and sleeve), - biburner installation shields, - additional door locks (coded locks)
3.	**Tailgate:** - connecting inner and outer body panelling (door edges), - clearance necessary for seals operation, - seals, - door frame, - threshold strengthening, - decompression holes (in tailgate and front wall)
4.	**Floor supporting structure**
5.	**Wall boards:** - connecting body panelling, - laminate ribbing
6.	**Decreasing insulation thickness** for: - sunk locks, - sunk lighting fittings, - wings
7.	**Side doors:** - sunk locks and casements (max. thickness limited due to wall thickness)

Table 2. Other structural defect worsening an insulating power of refrigerating settlement [1]
Tab. 2. Inne wady konstrukcyjne pogarszające izolacyjność zabudowy chłodniczej [1]

Item	Kinds of actions (disadvantages) – examples
1.	**"Savings" on insulation:** - too thin board, - replacing polyurethane foam by foamed polystyrene (styrodur), - making floor without insulation
2.	**Change when choosing fittings** – other spacing of inner strengthening and outer fastening for: - aggregate, - closures/locks
3.	**Specific design solutions:** - special shelves for aggregate (so called "leaves catchers") in the front wall, - single/double side doors, ice generators, - halved doors, - multichamber semi-trailers (so called " multitemperature" ones), - problems with insulating cars having tin load chamber
4.	**Disadvantages of refrigerating building fittings:** - connecting shielding sheets of inner and outer parts of refrigerating aggregates, - massive casings of temperature sensors (non-electric)

The further part of this paper presents thermovision photos with typical heat bridges caused by reasons presented in the tables 1 and 2. The heat bridges occur in places of brighter colour (higher temperature) as in order to take a thermovision photos, the method of heating the inside of the installed body was applied causing the temperature difference between the inside and the environment $\Delta T = 25^oC$ (Tinner= +32.5°C, Touter= + 7.5°C).

The next figures present heat bridges caused by:

- Strengthening in the front wall for the refrigerating aggregate (fig. 1). Solutions of this type are necessary evil, mass of semi-trailer aggregates reaches 900 kg. The strengthening construction should be sunk in the insulating material. Similar situation takes place in case of eutectic boards.
- Strengthening for fastening tailgate hinges (fig. 2). Sheet plates welded on the door leaf frame are used most often.

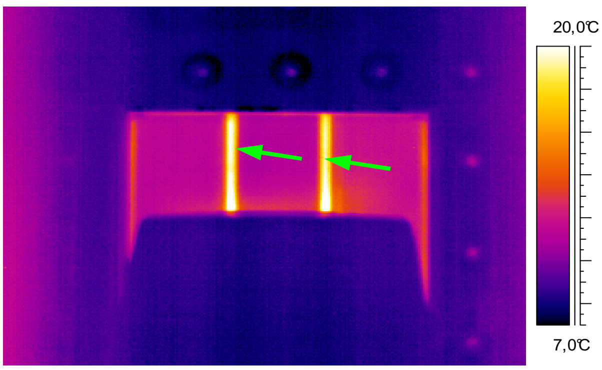

Fig. 1. Thermovision photo of the front wall where strengthening for the refrigerating aggregate is applied (places of strengthening are marked with a green arrow) [1]
Rys. 1. Zdjęcie termowizyjne przedniej ściany, w której zastosowano wzmocnienia dla agregatu chłodniczego (zieloną strzałką zaznaczono miejsca wzmocnień) [1]

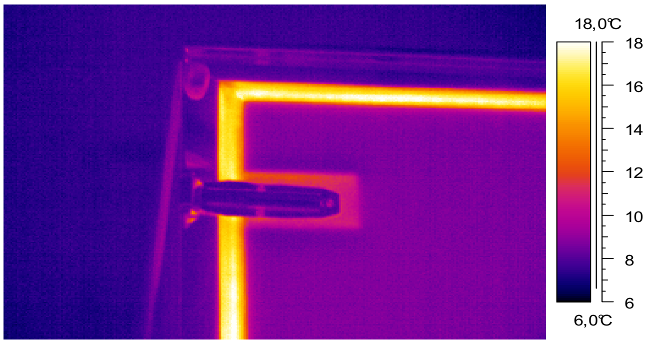

Fig. 2. Thermovision photo of the door leaf with strengthening for hinges fastening (green arrow) [1]
Rys. 2. Zdjęcie termowizyjne skrzydła drzwi ze wzmocnieniami do mocowania zawiasów (zielona strzałka) [1]

- Strengthening door closures/clocks (fig. 3). Fastening strengthening require both the door lock and closing rods (outer and inner).
- Hanging meat equipment i.e. bodies designed for transporting half carcass of pork, (fig. 4). To strengthening sunk in the roof insulation the hook guides are fastened. This construction requires also strengthening in side walls.

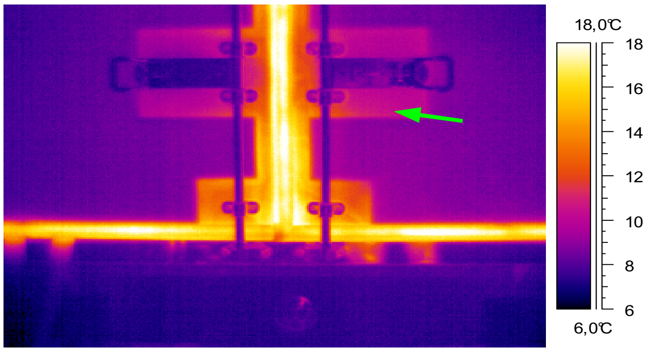

Fig. 3. Thermovision photo of the door leaf with strengthening for fastening the door closure (green arrow) [1]
Rys. 3. Zdjęcie termowizyjne skrzydła drzwi ze wzmocnieniami do mocowania zamknięcia drzwi (zielona strzałka) [1]

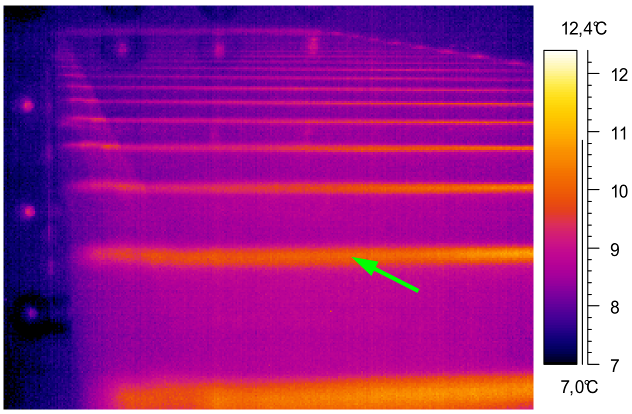

Fig. 4. Thermovision photo of the refrigerating body of hanging meat equipment type designed for transporting half carcass of pork. Strengthening in the body roof is marked with a green arrow [1]
Rys. 4. Zdjęcie termowizyjne nadwozia chłodniczego typu „hakówka" do przewozu półtusz wieprzowych. Strzałką koloru zielonego zaznaczono wzmocnienia w dachu zabudowy [1]

- Strengthening of walls and roof connection places (fig. 5 and 6). Stiffness of the refrigerating building can be obtained among others through the application of strengthened edges of walls, roof and floor (steel profiles closed – connected with strengthening of the aggregate or eutectic boards).

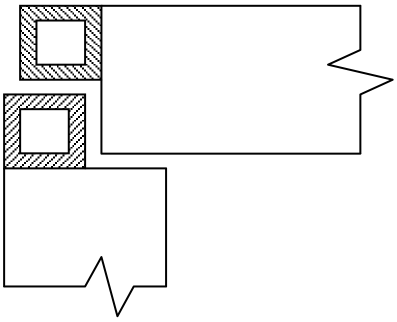

Fig. 5. Scheme of strengthening in connection of the wall and roof [1]
Rys. 5. Schemat wzmocnień w łączeniu ściany i dachu [1]

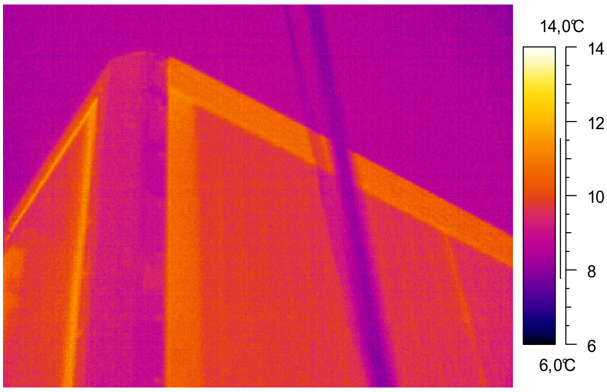

Fig. 6. Thermovision photo of walls connection [1]
Rys. 6. Zdjęcie termowizyjne łączenia ścian [1]

- Strengthening for load protecting system (fig. 7 and 8). One version of solutions provides for situating the strengthening inside the walls, ceiling and floor. This requires local decreasing of insulation thickness, very often there is no possibility to protect the node against moisture penetration.

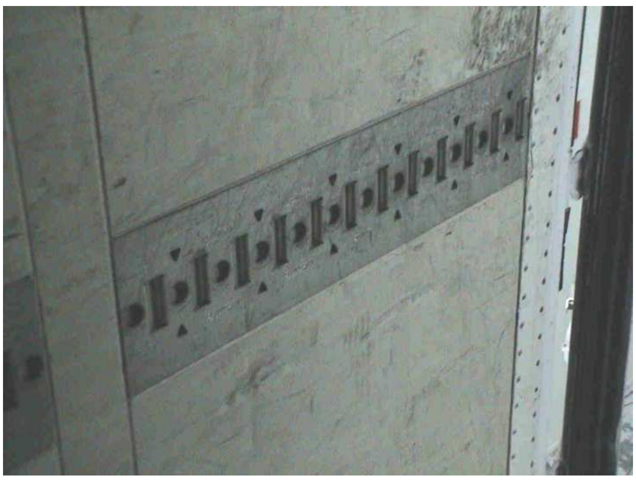

Fig. 7. Strengthening for the load protecting system sunk in the wall [1]
Rys. 7. Wzmocnienie do systemu zabezpieczenia ładunku wpuszczone w ścianę [1]

Fig. 8. Strengthening for the load protecting system sunk in the floor
Rys. 8. Wzmocnienie do systemu zabezpieczenia ładunku wpuszczone w podłogę

- Strengthening enabling side doors fastening (fig. 9). The side doors thickness is limited by side wall thickness as the doors can stick out neither outside nor inside. The loss of insulating power caused by strengthening for the doors can be compensated through the application of the thicker side wall (of 10 to 20 mm).

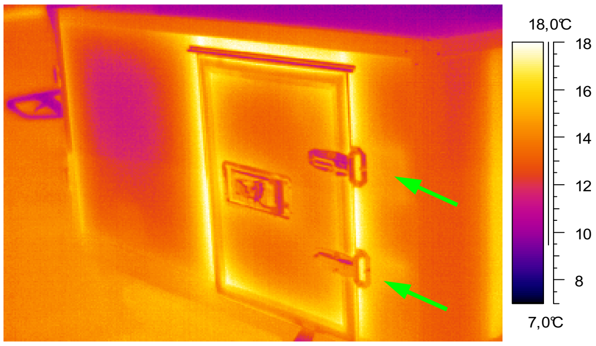

Fig. 9. The side wall with the door in infrared. Strengthening is marked with green arrows
Rys. 9. Ściana boczna z drzwiami w podczerwieni. Strzałkami koloru zielonego zaznaczono wzmocnienia

In case of the tailgate the situation is much better. The effect of heat bridges caused by constructional strengthening can be partly compensated through the application of thicker doors (20 to 40 mm thicker than the side walls).

4. Improvement of prototype refrigerating body

New constructions of bodies, after making a prototype, should be improved. The improvement process is, among others, the elimination of weak points – so called "heat bridges". The location of heat bridges, after making the temperature difference between the body inside and the environment, should be done best with the use of the thermovision camera. Analysing thermograms you can determine the number of bridges, the surface of each of them and their location. If the surface of Ai of i^{th} bridge contains in the circle of the area Akr, you can assume that the bridge is of point character. Quantitative evaluation (local heat-transfer coefficient) for this bridge can be made with the use of the auxiliary wall method. The value of Akr area depends on the diameter of the "auxiliary wall" type sensor. If there is no mentioned relation (Ai Akr), one should use a heating box [1] for the bridge evaluation.

The above analysis should be done for all found bridges, meeting this condition means that the real relation i = I, where i – the successive number of the analysed bridge, I – the highest number assigned to the bridge. After making the quantitative analysis of all the registered bridges, the reason of their occurrence should be established. During this process, it is very useful to have the scheme of the body and description of the body components production technology as well as the their assembly. The performed analysis should determine the reasons of the bridges occurrence, i.e. if they are caused by:

- necessary construction solutions (for example, due to strength reasons),
- constructional mistakes, for example, incorrectly designed strengthening for the aggregate,
- technological mistakes (for example, foam misruns occurred in the foaming process due to the lack of vents on the boards plating).

After the elimination of bridges being the effect of design and technological mistakes, the overall heat-transfer coefficient should be determined with the exact method. If the value of the coefficient „k" does not exceed the boundary value (inequality 1 is met), the body gets the class confirmation. Otherwise, the proposal of design changes should be made, for example, roof or floor thickening. The discussed actions are presented in the form of the block scheme in the fig. 10.

$$k \le k_{gr}, \qquad (1)$$

where:

k – overall heat-transfer coefficient,

k_{gr} – boundary value of overall heat-transfer coefficient,

The boundary value of the overall heat-transfer coefficient, depending on the body class, is:

$$k_{gr} = \begin{cases} 0.4\ \mathrm{W/(m^2K)} \text{ – strengthened insulation,} \\ 0.7\ \mathrm{W/(m^2K)} \text{ – common insulation.} \end{cases}$$

5. Summary

This paper outlines the area of looking for new isothermal materials useful for the production of cores of heat-insulating laminated boards applied for building isothermal bodies.

The paper presents also the incorrect solution for the construction nodes causing the occurrence of heat bridges and thus the increase of the value of the overall heat-transfer coefficient.

The last part of the paper presents the improvement procedure of the prototype isothermal body. Information obtained from the analysis of the thermovision photos are of great importance.

Summing up, one can state that the presented actions will be helpful when designing innovative isothermal bodies.

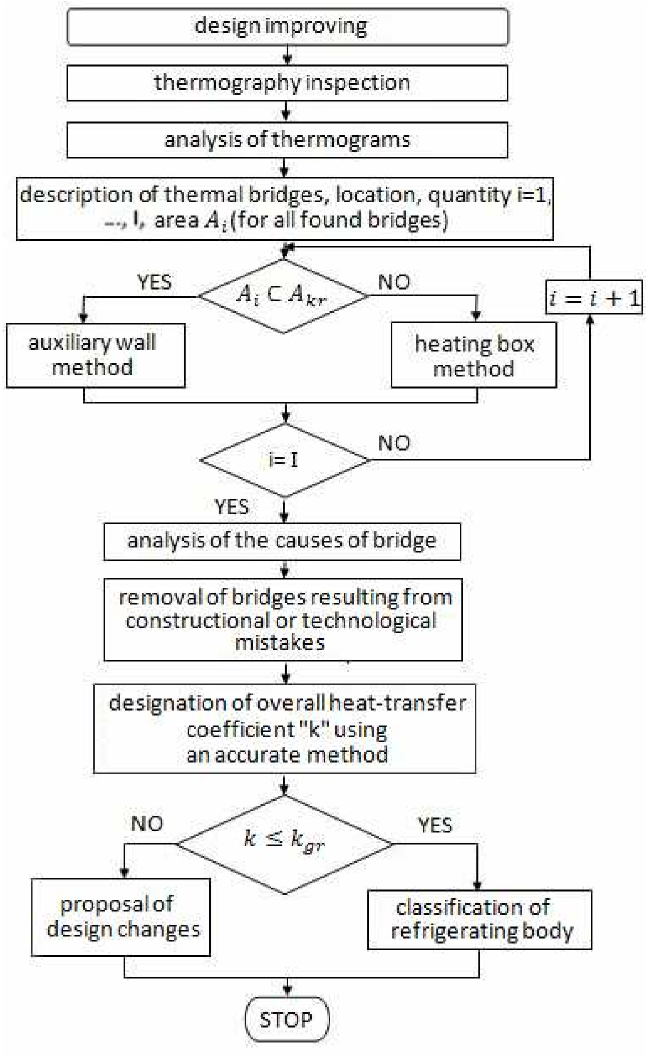

Fig. 10. Research supporting the process of construction improving [1]

Rys. 10. Badania wspomagające proces doskonalenia konstrukcji [1]

6. References

[1] Fizyczne podstawy diagnostyki układów termoizolacyjnych do transportu żywności. Praca zbiorowa pod red. K. Bieńczaka, Radom: Wyd. ITeE.

[2] Projekt badawczy: „Opracowanie technologii produkcji kompletnej naczepy do przewozu żywności w warunkach chłodniczych o ulepszonych parametrach technicznych" (PBS1/B6/6/2012).

[3] Agreement on the International Carriage of Perishable Foodstuffs and on the Special Equipment to be Used for such Carriage. United Nations Economic Commission for Europe New York and Geneva, 2013.

This work realized during the research project PBS1/B6/6/2012 "Elaboration of production technology for complete semi-trailer for food transport in refrigeration conditions of improved technological parameters".

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