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OPERATIONAL STATES OF INSULATION IN REFRIGERATED TRANSPORT OF GOODS

In the paper are presented operational states of thermal insulation occurring during exploitation. The analysis of processes devastating thermo-insulation systems during operation was conducted. Also the criteria of the borderline condition of those insulations were described.

Keywords: *insulation board, refrigerating bodywork, borderline condition of insulation boards, criteria of the borderline condition of insulation boards.*

1. Introduction

Exploitation of refrigerated means of transport for transporting foodstuff is an essential issue in the system of transport. The technical conditions of the system decide about the ability to fulfill ordered tasks. Failure to meet the assumed technical requirements by particular vehicle results in various negative consequences such as e.g. damage of forwarded goods can cause high financial losses, as well as ecological threat forcing the carriers and recipients to troublesome and usually expensive procedures associated with elimination of not suitable for eating foodstuff. The problem is even bigger if it concerns food products for which conditions, such as temperature, humidity and often also atmospheric composition, are precisely specified. Another limitation while transporting foodstuff is usually short expiration date of those articles, which is associated with the tendency of cutting off the amount of chemical substances for food conservation, so the time of transporting goods from manufacturer to customer is also considerable limited.

In this paper an attempt was made to present issues considering maintaining refrigerated of transport in operational state; that is operational, nonoperational and intermediate states are described. It was also attempted to determine criteria of reaching the borderline state by a vehicle, which causes temporary or even permanent exclusion of the particular vehicle from operation.

2. Scope of research

The object of research of this paper is cooling means of transport used for transporting foodstuff. Described means of transport consists of:

- o thermal bodywork,
- o devices responsible for shaping microclimate in the loading chamber,
- o measuring devices controlling values of characteristic parameters.

In the paper are considered just borderline states of part of the vehicle – of the thermal cover. Its task is to limit the heat exchange between the interior of the loading chamber and the environment. Moreover, the bodywork should guarantee: [1]:

- o protecting the load from humidity and light,
- o sanitary transport conditions,
- o protecting the load against theft,
- o proper location and protection of the load against undesirable movements during transporting.

The classification of means of transport is given, among other things, also ATP Agreement (Agreement on international transportation of quickly decaying foodstuff, on special means of transport for transporting such goods). The basic criterion classifying a vehicle to particular group is the value of overall heat-transfer coefficient '*k*', which describes the intensity of heat exchange between interior of the chamber and the environment. According to ATP agreement, the vehicles can be divided into the one with:

- o normal insulation – $k \leq 0{,}7$ W/(m^{2}K),
- o strengthened insulation – $k \leq 0{,}4$ W/(m^{2}K).

For constructing cooling bodyworks are used laminated boards. They consist of two layers (metal or plastic), which guarantee appropriate rigidity of the boards, and of the core (usually made of polyurethane foam), which protects the interior of the bodywork from penetration of the heat from the environment.

Such boards can be made in two ways – either in the process

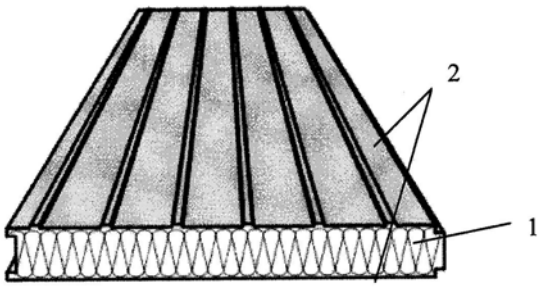

Fig.1 Laminated board (1 – core insulation, 2 – material of the layers)

of gluing particular layers composing the board, or by foaming the polyurethane foam between the two layers.

In the core of thermo-insulation board, used for constructing cooling bodyworks, have to be placed elements of construction for mounting e.g. hinges, locks and reinforcements under the refrigerating unit. In such places occur so-called heat leakage bridges that are places of actual reduction of thickness of the insulation. One of the tasks of the bodyworks' designers is to reduce the number of those bridges.

Cooling bodywork during exploitation is exposed to deterioration of its insulation parameters e.g. change of the overall heat–transfer coefficient due to impact of operational parameters. So it is essential to monitor the technical condition of the vehicle continuously in order to ensure the best conditions of transportation, so that any changes of the parameters will not influence negatively the quality of transported goods.

3. Operational states of insulation systems

Faults resulting in deterioration of reliability of cold insulations may come into being on three stages of existence of the cooling unit: during designing, production and while operation. Unserviceabilities formed on the designing stage generate structu-

ral defects, and faults on the production stage – cause technological defects. Faults occurring while operation are called damages. Structural and technological defects do not eliminate particular unit from operation, just cause the deterioration of its quality understood as the level of satisfying the needs of the user. They can occur as visible defects or hidden ones, which reveal after some time of operation or in particular operational conditions.

Deterioration of technical unit reliability can cause a change of its physical condition. Notion standard, quoted earlier in this document, presents following definitions essential for the discussed issue:

- Operational state – state of reliability in which the unit can perform its task in comply with the requirements,
- Nonoperational state – state of reliability, in which the unit cannot perform its task in comply with the requirements,
- Damage – event consisting in transition of the unit from operational to nonoperational state,
- Criteria of damage – requirements concerning a feature or group of features, on the basis of which the fact of occurring damage is established.

Another notion necessary to define for further proper consideration of the issue is 'condition'. It can be presented as a set of particular values of physical quantities accepted for describing material unit or phenomena, occurring simultaneously and inseparably.

Examples of routing diagrams illustrating different cases of technical unit transition from operational to nonoperational states are presented in Fig. 2.

The above definitions present a situation, in which particular

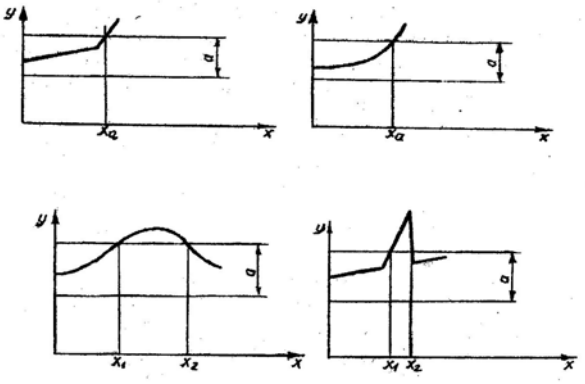

Fig 2. Examples of routing diagrams of transition of the unit from operational to nonoperational state; x – operational parameter, y – value of measured feature, a – tolerance region for operational state, a) irreversible changes – stepping process, gradual process, b) reversible changes - stepping process, gradual process

unit can be just in two extreme states. It can exist just as 'operational' on 'nonoperational'. Transition between those states is radical and is called 'damage'. Such situations occurring in reality are considered breakdowns or catastrophes. In practice it is possible to generate a sequence of intermediate states between operational and completely nonoperational state. Those states can be named in following way:

- Operational state – desired state of ideal unit. The insulation board already produced, as long as it meets the quality requirements, is in the fully operational state and can be used for exploitation.
- A sequence of consecutive accepted states – a sequence of states, in which the basic insulation functions carried out are in comply with assumed criteria, e.g. damage of lacquer layer covering the layers of cold insulation does not influence the task realised, it can just influence the esthetical requirements for the insulation.
- A sequence of consecutive tolerated states – a sequence of states in which the basic unit functions are disturbed, but because of different reasons such a situation must be tolerated. During transporting foodstuff on short distances such little damages of insulation influence the overall heat-transfer coefficient, but do not cause the deterioration of the quality of food transported. Such state can be called a tolerated state.
- State of menace – a state, in which the unit carrying out its function can pose a menace of deterioration of the quality of protected goods, ecological risk, increase the energy- and time-consumption of the functions realised. Such state, when identified, can be treated as tolerated one in some operational conditions despite of deeply disturbed some of the functions of the unit, or as an inadmissible state for further unit exploitation. Such a situation can be often observed for cooling vehicles. During food transportation, the vehicle is exposed to frequent damages of the external body panelling due to external factors or of the internal panelling – due to securing the goods improperly. Particular vehicle has to get to the delivery point, so despite of the threat of goods' quality deterioration posed by the damage, it must be treated as a tolerated state.
- Nonoperational state – a state, in which the unit is eliminated from exploitation because of impossibility to carry out the imposed functions. Such a state can be reversible if the unit is reparable, or irreversible, if the repair is impossible. Reparability is dependent of the technical potential (in terms of repairing technologies) and costs (the repair can be cost-effective or not). If the impossibility of carrying out the imposed functions is of physical character, the reason of this can be called damage; in other cases nonoperational states, as well as other states, have decisive character (that is, it does not ensue just from technical condition of the unit). An example of such nonoperational cold insulation is disturbance of the insulation core of the board. Damaged panelling causes intensive propagation of moisture inside the board, increasing the overall heat-transfer coefficient. Such insulation does not meet the imposed criteria, so it has to be excluded from operation.

Depending on the decisive criteria selected, it is possible to qualify the unit to the proper state.

4. Analysis of damaging processes of thermo-insulation systems of refrigeration bodyworks

During the 'life cycle' of the refrigeration bodyworks occur many situations, in result of which the unit can achieve nonoperational state by not fulfilling the assumed operational parameters. The specification of operational conditions of the bodywork is the reason for wide variety of working conditions. This is the reason for wide diversity of damaging processes. On figure 3 is presented classification of processes damaging insulation boards, describing the reason, consequence and symptoms of particular damage.

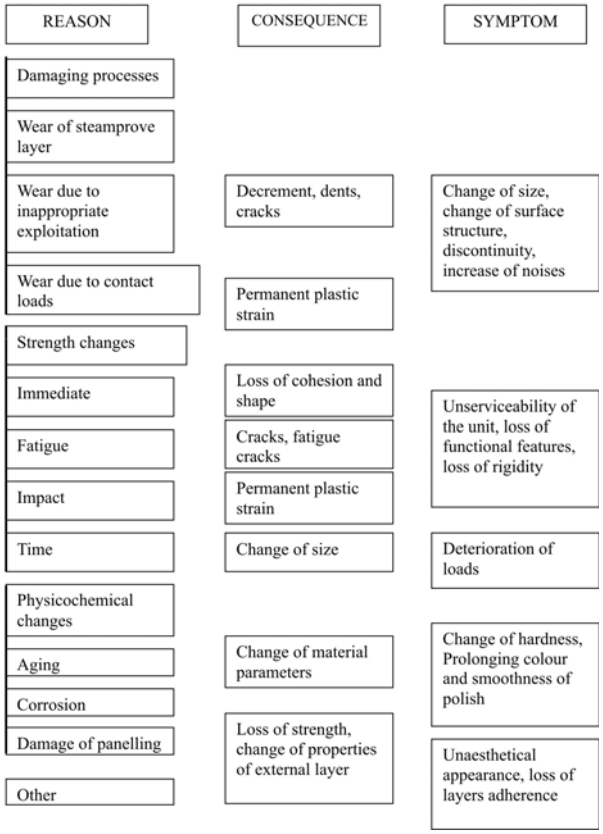

Fig. 3 Classification of processes damaging insulation boards

Assumptions influencing deterioration of quality of discussed thermo-insulation systems can occur, as previously mentioned, on different stages of existence of the unit.

On the designing stage, deterioration of the assumed durability can ensue from mistakes of constructors – designers. It can be the result of personal lack of knowledge or purposeful decision of resigning from the optimal parameters of design, ensuing from reasons other than technical.

Both on the designing and production stage, defects can appear on two levels:

- during production of laminated board,
- during mounting the laminated boards composing particular technical unit.

Proper quality of thermal insulation can be achieved by appropriate realisation of particular technological processes during production of boards, especially during preparing adequate proportions of particular components of foam, mixing them and during pouring the combined components into the form. On the stage of mounting the boards it is recommended to pay attention to proper tightness of joints, as accurate insulation of joints is the basic factor influencing reliability of the produced unit.

Exploitation stage is the most essential in existence of every technical object. During this time the cooling bodywork fulfils functions for which it was designed, produced and prepared for use that is transporting goods in appropriate climatic conditions. On this stage appear most of the dangers causing loss of values of parameters deciding about its usability for exploitation.

Damages to the cooling bodywork are caused by impact of forcing factors, which can be divided into two groups:

- factors ensuing form functions carried out by given unit, in this case – by cooling chamber (working media),
- factors characteristic of the environment in which particular chamber functions (external factors).

Working media stop operating the moment, when the unit stops fulfilling its function, that is transporting and storing foodstuff, while external factors influence the unit whether it is exploited or not.

The cooling bodywork during operation usually suffers damages caused by improper exploitation. The damages are most often caused by external factors and occur accidentally e.g. influenced by the force causing plastic strains. Another example of damages is scratches. Both examples are usually the result of insufficient qualifications of the drivers servicing particular vehicle or lack of caution while operating the vehicle. Many of the damages of the boards are cracks of the layer of varnish of the insulation panelling. Such type of damage has little influence on overall heat-transfer coefficient, as it does not disturb the insulation layer (the core) of the board, but ignoring it might cause corrosion of the panelling and the moisture penetrating the core can cause increase of this coefficient.

Damages of the bodyworks can also be caused by influence of environmental factors, such as intense solar radiation causing cracking of the varnish layers of the panelling, acid rains speeding up processes of corrosion of metal panelling and introducing moisture into the core through crevices, high temperature speeding up, among other things, also corrosion processes. Essential influence on the insulation condition has also atmosphere pollution and microorganisms (fungi, mildew, algae). Damages of the car bodyworks usually embrace the external or internal panelling of the insulation (depending on which part of the chamber they were initiated) and possibly the area of insulation core adherent directly to the panelling.

5. Criteria of the borderline of thermal insulation

Technical objects, including thermal insulations, can be in two states: operational and nonoperational. As previously mentioned, transition between those two states is racidal and called ‘damage’. For the need of this paper it was accepted that operational state is not only lack of damages and limitations in the quality of operation, but also such state of the unit, in which all the functions are realised in the best way from the point of view of all criteria that can be specified for estimating the quality of this realisation. Those criteria can be divided into three groups:

- Technical and structural criteria – most important here are criteria of functionality associated with operation of the unit.
- Economic criteria – used to determine the borderline state in case, when due to technical changes of the element the efficiency of using it drops.
- Environmental criteria – used to estimate the influence of the device on natural environment.

Among technical and structural criteria can be established the physical parameter – certain physical quantity – the value of which will determine usability of given insulation in the process of exploitation. Such a parameter is the heat transfer coefficient already mentioned above. Any exceeding of a specific level of this quantity implies that the operation of the facility should be discontinued.

The very important group are technical criteria, ensuing form the structural characteristic of insulation boards. As the insulation during exploitation in different of conditions is exposed to various loads, it can be damaged, or at least the mechanical or compression strength can deteriorate. While exploiting the unit there is steady deterioration of the properties of the boards. It is caused e.g. by aging, corrosion or fatigue. Despite the fact that materials for insulation boards, in the moment of introducing them into operation, have some determined mechanical strength or resistance to development of microorganisms, low hygroscopicity and absorbability, of course, during exploitation those parameters deteriorate. Exceeding the determined limitations can cause withdrawal of the unit form further use.

Economic criteria – used to establish the borderline conditions of the insulation board in case when there is a change of its technical condition, which causes lowering the effectiveness of using it. The example here might be increase of overall heat-transfer coefficient due to mechanical damage of the board. With the increase of the coefficient increases also the amount of energy supplied to refrigerating unit. On the basis of economic calculation should be determined the borderline for wear or degree of damage of the insulation boards working in particular operational conditions. While settling the economic criteria for thermal insulation, the technical requirements and economic efficiency of exploiting it should be taken into account. When further exploitation, due to change of the values of condition parameters, requires higher investments than those settled, and prime-costs are higher than planned, it is pointless.

Because of growing environmental pollution, the importance of environmental criteria in estimating the borderline conditions of cold insulation is growing. Their aim is to protect both natural and influenced by people environment. Those criteria include also legal standards, market laws, trends and aesthetics. Legal standards regulate acceptable amount of pollution and noise both during exploitation and production. They also include hints for further use of materials composing insulation boards (recycling of wastes). Every departure from the legal standard is a measure of insulation failure.

In case of estimating the borderline conditions of insulation board (on the basis of the above criteria), the decision about reaching the borderline condition depends on a person responsible for withdrawing the board from exploitation. Often it occurs that temporary loss of usability of the board does not have to result in withdrawing it from operation, as it is not equivalent to reaching the borderline condition. An example here might be increase of costs of energy required to ensure proper conditions during exploitation of the refrigerator, when the external temperature is higher due to hot weather. Taking into account longer period of time, then costs of maintaining the refrigerator made of boards in exploitation will not exceed the determined economic criteria.

6. Conclusions

Determination of operational and nonoperational states of thermal boards composing thermo insulation system is an essential issue during exploitation. To estimate the borderline condition of insulation boards the importance of every factor for determining the condition should be taken into account. While estimating state of boarders working in different conditions might occur little deviations of particular parameters. The rule is that in every case analysis of the issue of borderline condition estimation is effective, which takes into account the rule of priority of the functional criteria – influence of the physical factors, then economic factors and finally – environmental factors. Next, other criteria might be considered.

Because of the structure of the unit, the technical control of the bodywork might be difficult during operation, so every carrier should have the system of stationary diagnostics implemented and operating in the transport base. The system should determine the type of diagnosed damages, methods of diagnosing them and time intervals between the inspections.

Technical condition of the cooling bodywork determines safety of goods transported, so fulfilling all the criteria should by the priority task of every carrier.

7. References

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