ELABORATION OF CONCEPT OF ROAD VEHICLES TRANSPORTING DANGEROUS GOODS IN CONTROLLED TEMPERATURES

Krzysztof Bienczak, Wieslaw Zwierzycki

Poznan University of Technology, Institute of Machines and Motor Vehicles
Piotrowo 3, 60-965 Poznan, Poland
tel. + 48 61 6652655, 6652236
e-mail: krzysztof.bienczak@put.poznan.pl, wieslaw.zwierzycki@put.poznan.pl

Abstract

According to ADR rules certain self-reactive materials of the class 4.1 as well as organic peroxides of the class 5.2 require to be transported in so called controlled temperatures, with the use of cooled means of transport, for which the particular stipulations have been formulated.

This paper is an attempt to answer the question whether the mentioned stipulations can be met by vehicles applied in other specialist transport domains (for example, for cooled food transportation) and an attempt to formulate assumptions for design (and equipment) of universal categories of isothermal cooled vehicles designed only for transportation of materials of the class 4.1 and 5.2 in controlled temperatures.

The paper presents as follows: a concept of controlled and emergency temperatures being derivatives of so called self-accelerating decomposition temperature (TSR) of materials of the class 4.1 and 5.2, requirements concerning vehicles for transport in controlled temperature (including methods designated from R1 to R5), technical requirements concerning realization of cooling in methods from R1 to R5 (referring to transport chamber controlled temperature).

The summary presents ready and final technical solutions concerning transport of dangerous materials in controlled temperatures.

Keywords: *transportation, dangerous goods, controlled temperature*

1. Introduction (General characteristics of materials requiring transportation in controlled temperatures

Certain self-reactive materials of the class 4.1 as well as organic peroxides of the class 5.2 can be transported only in conditions in which the so called controlled temperature will not be trespassed. However, in case of controlled temperature trespassing, of any reasons, it could be necessary to introduce the emergency procedure. That is why, the ADR rules determine for the above mentioned materials the so called emergency temperature at which the emergency procedure should be started.

The controlled and emergency temperatures are derivatives of the self-accelerating decomposition temperature (SADT), what means the temperature in which the accelerating self-decomposition of the material being in the package applied for transport can occur (see the Table 1 [1]).

Tab. 1. Determination of controlled and emergency temperature [1]

Kind of vessel	SADT[a]	Controlled temperature	Emergency temperature
Single packages or DPPL*	20^o or less	20^oC below SADT	10^oC below SADT
	above 20^oC to 35^oC	15^oC below SADT	10^oC below SADT
	above 35^oC	10^oC below SADT	5^oC below SADT
Tanks	above 50^oC	10^oC below SADT	5^oC below SADT
a – SADT for material prepared as for transport, * - big container for transport in bulk			

Note! The real temperature during transport can be lower than the controlled one, but it should be matched so to avoid the dangerous phase division.

2. Requirements concerning vehicles for transporting self-reactive materials of the class 4.1 as well as organic peroxides of the class 5.2 in controlled temperature

General stipulations were given in the chapter 9.6 of the rules ADR [1]:

„9.6.1 → Heat insulated, mechanically or non-mechanically cooled vehicles designed for transportation of self-reactive materials of the class 4.1 as well as organic peroxides of the class 5.2 in controlled temperature should meet the following conditions:

(a) the vehicle should be so designed and equipped that its insulating properties and cooling source output guarantee that the controlled temperature determined for the transported material in 2.2.41.1.17 and 2.2.52.16 as well as in 2.2.41.4 and 2.2.52.4, respectively, will be maintained. The overall heat transfer coefficient for the cargo compartment should not exceed 0.4 W/(m^2K),

(b) the vehicle should be so equipped that vapours of transported materials and the cooling medium could not enter the driver's cab,

(c) the vehicle should be equipped in suitable monitoring and measuring devices enabling, at any time, to measure temperature in the cargo compartment from the driver's cab;

(d) in case of any risk of dangerous pressure increase in the cargo compartment, it should be equipped in ventilating holes or venting valves. If it is necessary, there should be applied countermeasures to prevent cooling effectiveness decrease caused by the holes or valves;

(e) the cooling medium cannot be flammable,

(f) in case of the mechanically cooled vehicle, the cooling installation should be arranged so that it could operate irrespective of the operation of the vehicle propulsion engine.

9.6.2 → The suitable methods preventing the controlled temperature exceeding (from R1 to R5) are given in the chapter 7.2 (see V8(3))".

The below Table 2 gives the methods preventing the controlled temperature exceeding, recommended by the ADR rules, designated from R1 to R5, presented in order from the least to the most effective one.

Tab. 2. Presentation of methods (R1 to R5) preventing the controlled temperature [1]

Designation		Remarks
R1	Thermal insulation (overall heat-transfer coefficient ≤ 0.4 W/(m^2K))	Method R1 can be applied in case of organic peroxides and self-reactive materials type C, D, E, F, if the ambient temperature planned for the time of transport is lower than the controlled one of at least 10°C !
R2	Thermal insulation and non-mechanical cooling system on the condition that: - there is transported sufficient amount of non-flammable cooling medium (e.g. liquid nitrogen or solidified carbon dioxide), taking into account reasonable delays, or there is the possibility to refill it - liquid oxygen or air cannot be used as the cooling - uniform cooling is ensured even in case when most of the cooling medium is used and - the door of the transport facility have to be provided with the warning stating that the facility has to be ventilated before going	Method R2 can be applied in case of organic peroxides and self-reactive materials type C, D, E, F, if the ambient temperature planned for the time of transport does not exceed the controlled one of more than 30°C !

Designation		Remarks
	inside;	
R3	Thermal insulation and single mechanical cooling system on the condition that in case of materials of ignition temperature lower than the emergency one increased of 5^{o}C, the electric accessories applied in the cooling chamber are of the explosion-proof execution, explosiveness group IIB, temperature class T3, in order to prevent ignition of flammable vapours released by these materials;	Method R3 can be applied in case of organic peroxides and self-reactive materials type C, D, E and F, and also in case of organic peroxides and self-reactive materials type B, if the ambient temperature planned for the time of transport does not exceed the controlled one of more 10^{o}C !
R4	Thermal insulation and complex cooling system composed of mechanical and non-mechanical systems on the condition that: - both systems are independent, and - requirements determined for methods R2 and R3 are met;	Method R4 can be applied in case of all organic peroxides and self-reactive materials!
R5	Thermal insulation and double mechanical cooling system on the condition that: - apart from the common supplying machine, both systems are independent, - each system can independently maintain the suitable controlled temperature, and - in case of materials of ignition temperature lower than the emergency temperature increased of 5^{o}C, the electric accessories applied in the cooling chamber are of the explosion-proof execution EEx, explosiveness group IIB, temperature class T3, in order to prevent ignition of flammable vapours released by these materials.	Method R5 can be applied in case of all organic peroxides and self-reactive materials!

3. Selection procedure concerning devices for temperature conditions formation in the cargo compartment of the vehicle (meeting R2-R5 rules)

The characteristics presented in the previous item show that there should be elaborated two procedures for the selection of devices forming temperature conditions in the cargo compartment:

- determining the cooling devices effect (requirements R3,R4,R5),
- defining the capacity of devices for “cool accumulation” (requirement R2-R4).

3.1. Determination of the cooling device effect

When selecting the cooling device one can make use of the guidelines given in the standard DIN 8959[2].

The mentioned standard is used for the selection of cooling devices for vehicle bodies designed for food transportation. When elaborating the standard they assumed that the cooling device has to assure:

- reception of heat penetrating through the vehicle body walls and generated in the vehicle body,
- transport of cooled air within the whole vehicle body volume.

Thus, the computational procedure has to include the heat and mass balance.

The computational concept presented in this paper assumes that the cooling device has to level losses connected with heat penetration through the vehicle body walls in the effect of temperature differences between the cargo compartment and the environment. The intensity of this process is described by the following equation:

$$Q_p = k \cdot A \cdot (t_{zew} - t_{wew}), \tag{1}$$

where:
Q_p - cooling effect demand connected with heat penetration,
k - overall heat transfer coefficient for the vehicle body [W/(m^{2}K)],
t_{zew} - mean outer temperature [^{o}C],
t_{wew} - mean inner temperature [^{o}C],
A - mean surface of vehicle body calculated as mean geometric of outer and inner surfaces [m^2].

Calculating the total demand of the cooling effect one should also take into account an additional heat load arising from: solar radiation, wind or vehicle body permeability. The standard DIN 8959 recommends determine an additional heat load (Q_{dod}) as follows:

a) long-distance transport

$$Q_{dod} = 0.75 \cdot k \cdot A \cdot (t_{zew} - t_{wew}) = 0.75 \cdot Q_p, \tag{2}$$

b) distribution – in this case the additional heat load is connected with the heat exchange in the effect of opening the door during successive unloading

$$Q_{dod} = \frac{C_1 \cdot V \cdot \Delta h}{3.6}, \tag{3}$$

where:
V - volume of the empty vehicle body (according to internal dimensions) [m^3],
Δh - air enthalpy difference between the inside of the vehicle body and its environment [kJ/m^3],
C_1 - coefficient taking into account the air exchange occurring in the effect of frequent door opening.

The value of the coefficient C_1 can be calculated as follows:

$$C_1 = \frac{a \cdot n}{z}, \tag{4}$$

where:
n - number of door openings in an hour,
z - transport time,
a - coefficient of door opening duration (to 1 min – a=0.5, to 3 min – a=0.6, to 5 min – a=0.7).

During unloading (distribution) the cooling aggregate is switched off. The operation time shortening influences the increase of the cooling effect demand in the period after restarting. The standard DIN 8959 presents this influence in the following way:

$$Q_c = C_2 \left(k \cdot A \cdot (t_{zew} - t_{wew}) + \frac{C_1 \cdot V \cdot \Delta h}{3.6} \right), \tag{5}$$

where:
Q_c- total demand concerning the cooling effect for distribution including operation breaks of the cooling device [W],
C_2- coefficient including reasonable breaks of the aggregate operation; (for two door openings in an hour C_2=1.6, for three openings - C_2=1.8).

The standard DIN 8959 contains also requirements concerning also the air fans outputs. For the loaded vehicle body this relation is as follows:

$$V_L \geq 60 \cdot V, \tag{6}$$

where:
V_L - air fans output [m^3/h],
V - empty vehicle body volume [m^3].

Making use of the above described relationships one should take into account the following matters:

- equations (1-5) take into account heat penetrating through the vehicle body walls and heat introduced with air when opening the door; the equations do not include heat connected with the load temperature change; so the computational procedures concern the case where the goods were cooled to the right temperature before loading,
- equation (3) determines the intensity of the heat exchange in the effect of the door opening, but in case where the door-way is properly protected, for example: with strip curtains; a strip curtain allows for decreasing the heat flux entering the vehicle body even of 40%,
- in accordance with information given in the standard DIN 8959 in case of distribution in the urban traffic the cooling aggregate can level the heat gains connected with the door opening only in situations where the opening time does not exceed 5 minutes.

3.2. Defining cooling capacity of devices for accumulation

The devices meeting the requirements R2 and R4 are equipped with cold accumulators.
The basic cold accumulators applied in the distribution transport are eutectic plates. Inside the plate, there is usually a coil being an evaporator of the compressor cooling installation. Around the coil there is water saline solution of eutectic character. The cooling system is used to freeze the mentioned solution.

Heat getting into the vehicle body inside when driving and unloading causes the phase change "solid-liquid". When the whole content of the eutectic mixture changes in the liquid, the penetrating heat will cause heating of liquid contained in the plate until the temperature of liquid and the vehicle cargo compartment are equal.

The heat amount getting into the vehicle body in the time unit $\Delta\tau$ can be determined from the formula (7):

$$Q = kA\Delta T\Delta\tau + \sum_{i=1}^{n}\Delta Q_i , \tag{7}$$

where:
Q – heat getting into the vehicle body,
A – mean surface of the vehicle body,
ΔT – temperature difference between the vehicle body inside and its environment,
$\Delta\tau$ – transport time,
ΔQ_i – heat entering in ith door opening,
n – number of door openings.

Heat entering in ith opening is calculated from the empirical equation (8):

$$\Delta Q_i = 2126\Delta\tau_i \, \exp(0.0484\Delta T)sh, \tag{8}$$

where:
$\Delta\tau_i$ – time of ith door opening,
s,h – width and height of the door-way.

The transport time depends on the eutectic plates cooling output and amount of heat getting into the vehicle body, it is expressed by the formula (9):

$$\Delta\tau \leq \frac{jQ_0 - \sum_{i=1}^{n} Q_i}{kA\Delta T}, \tag{9}$$

where:
Q_0 – heat capacity of one plate,
j – number of eutectic plates in the vehicle body.

4. Summary

The performed considerations show that when building vehicles applied for transportation of dangerous materials in the controlled temperatures, one can make use of experience gained during designing, building and service of vehicle bodies designed for perishable food transportation. However, one should remember about the specific requirements concerning the dangerous materials transportation. For example, electric devices have to be made in an explosion-proof version. Materials applied for the construction of the vehicle bodies must not degrade in the effect of their contact with transported goods or their vapours.

References

[1] *Rules ADR* 2007-2009.
[2] DIN 8959 *Insulated Food Carries-requirement and Testing.*