The prospects for the use of electrogasdynamic systems in dry ice-cold generators of refrigerated trucks

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Abstract. Cold sources for cooling refrigerated vans are divided into temporary ones, ensuring the maintenance of the required temperature in the body without recharging the batteries for cold cooling for a limited period, and constant, ensuring the maintenance of the set temperature without periodically renewing the supply of cold. Temporary sources of cold include ice-salt mixture, dry ice, frozen eutectic solutions, installations with liquid nitrogen. A constant source of cold is engine cooling. Dry ice cooling is devoid of the main disadvantages of other methods. It has a relatively high refrigerating effect with a relatively small volume occupied by dry ice. Dry ice cooling can be carried out by contact and non-contact methods. In the contact method, the blocks of dry ice are not separated from the product, due to which carbon dioxide pairs wash the products. With the non-contact method, dry ice is loaded into hermetically sealed containers. The authors have proposed an environmentally friendly, reliable scheme of the process of cooling the body of a refrigerator with carbon dioxide using electrophysical methods. EGD devices with moving and stationary electrodes developed by the authors were used as pathogens for the circulation of the gas mixture in an isothermal body, which allowed to reduce the consumption of solid carbon dioxide.

1. Introduction
Using machine-free cooling in refrigerated trucks used for transporting foodstuffs and their role in the formation of a continuous refrigeration chain in cities, especially in megacities, has recently increased significantly. With this cooling method, the isothermal bodies of automobiles (refrigerated containers) are cooled by eutectic ice, carbon dioxide and other cryogenic substances.

Carbon dioxide cooling systems are the simplest and most reliable. The advantages of their usage for cooling food products include a structural prostate, low cost of equipment, high reliability, environmental friendliness, a favorable effect on product quality, when passing from a solid state to a gaseous state, it occurs at a temperature of 78.5 °C without moisture formation. Dry ice per unit mass has almost twice as much cooling capacity as regular ice. The specific cooling capacity while maintaining the air temperature at −18 °C for solid CO₂ is approximately 1.7 times higher than that for liquid nitrogen N₂. Dry ice cooling is carried out in direct contact with the cooled object or using an
intermediate coolant, most often air. In the latter case, dry ice is crushed and placed in metal containers – pockets through which air circulates. Air circulation is usually controlled by fans. The atmosphere containing carbon dioxide has a bactericidal effect.

“Cearns & Brown” manufactures installations for transporting chilled and frozen food products using dry ice. The system provides the necessary mode in the temperature range from −15 to +5 °C – for up to 72 hours or more. Transportation of packaged products is provided. Thermo King SD-III CR refrigeration unit is designed for heavy-duty semi-trailers. Lowering the temperature to −29 °C is 3 times faster than a refrigeration unit with an autonomous diesel engine. For intercity transportation, the CO₂ Hybrid model refrigeration unit is used. The cooling capacity of the SD-III CR and CO₂ Hybrid refrigeration units is shown in Table 1.

| Model            | Cooling capacity (kW) at an ambient temperature of 38 °C and air temperature in the truck body |
|------------------|---------------------------------------------------------------------------------------------|
| SD-III CR        | 2 °C: 17, −18 °C: 17.6, −29 °C: 17.9                                                        |
| CO₂ Hybrid       | 9.5: 6.6, 5.1                                                                               |

2. Formulation of the problem

Despite the apparent simplicity of the implementation of the above process of cooling products with carbon dioxide, the latter has a number of disadvantages, which significantly inhibit its use. These include a significant increase in carbon dioxide consumption with a decrease in cooling temperature (on average 10–12 kg/h for transportation in the city), the inability to ensure uniform circulation of the gas mixture throughout the body volume. At the same time, it should be noted that the food delivery process, especially in cities, is characterized by frequent, long stops, during which significant heat inflows enter the body through open doors, which, as a result, leads to the formation of hydroaerosols.

The noted disadvantages can be offset by the use of new modern technologies. These include technologies developed by the authors using environmentally friendly, electrophysical methods, in particular electro-gas-dynamic systems (EGD). In the general case, an EGD system is a set of technical means that ensure the use of electrosynthesis and electroconvection controlled in time and space to influence the objects which are being processed.

3. Materials and methods

We have proposed to increase the working temperature in the body, while strengthening, in order to prevent microbiological spoilage of products, the bactericidal effect of the medium. To ensure uniform circulation of the medium, it is advisable to use highly efficient EGD systems with a power of 50–500 W creating a uniform electric wind speed of 0.5–3.5 m/s. Our studies, using EGD systems specially developed for refrigerated containers, showed that corona discharge provides stable values of air flow rates up to the entire volume of the processed chamber. The total power consumption of the system did not exceed 1.5–2.0 kW, in a wide range of negative temperatures. The kinetics of inactivation of microorganisms in the medium of a mixture of CO₂ with air formed in the atmosphere was significantly higher than in the case of carbon dioxide. In figure 1 shows the survival of microorganisms in a CO₂ environment with air and CO₂ in a corona discharge field for 90 min at a medium temperature of −18 and −8 °C.

As it can be seen from Fig. 1, the bactericidal effect of using a corona discharge with increasing ambient temperature to −12 °C is higher than the use of CO₂ in air at −18 °C.

Below fig. 2 shows a diagram of the process of cooling a truck body with granular carbon dioxide using electrophysical methods.

As the causative agents of the circulation of the gas mixture in an isothermal body, we used EGD devices developed by the authors with moving and stationary electrodes operating in the corona mode, both in static electric fields and in pulsed ones.
The survival rate of microorganisms: 1 – in a mixture of CO\(_2\) with air at \(t = -18 \, ^\circ C\); 2 – in a mixture of CO\(_2\) with air and a corona discharge field at \(t = -8 \, ^\circ C\); N\(_0\) is the initial content of microorganisms in the medium; N is the number of microorganisms in the medium after treatment.

The amount of dry ice Gl (kg) required to maintain a given temperature in the body of the refrigerator is determined by the formula:

\[
G_l = \frac{Q_k + Q_m \tau \cdot 3.6}{r_{di}},
\]

where \(Q_k\) – the amount of cold required for pre-cooling the body, kJ;
\(Q_m\) – hourly average cold consumption for the repayment of heat influx from the environment, W;
\(\tau\) – transportation duration, h;
3.6 – conversion factor;
\(r_{di}\) – specific heat of dry ice sublimation, kJ / kg;
\(r_{di} \approx 620\) kJ / kg.

The heat transfer surface (F, m\(^2\)) is determined by the formula:

\[
F = \frac{Q}{\alpha \cdot \Delta t \cdot \tau},
\]

where \(Q\) – cold reserve kJ;
\(\Delta t\) – temperature difference between air and dry ice, \(^\circ C\);
\(\tau\) – refrigerated truck duration, h;
\(\alpha\) – heat transfer coefficient between heat exchange surface and air, W/(m\(^2\)·K).

Provided that the heat exchange between air and dry ice in the installation is through a metal wall, and the air velocity varies in the range from 0.2 to 1.6 m/s, the heat transfer coefficient between the heat exchange surface and air will average 20 W/(m\(^2\)·K).

The internal volume of the box for dry ice (V, m\(^3\)) is calculated by the formula:

\[
V = \frac{Gn \cdot K_o}{\rho_{di}}
\]

where \(\rho_{di}\) – dry ice density, \(\rho_{c.c.h} = 1500\) kg/m\(^3\);
\(K_o\) – coefficient of increase in dry ice volume during crushing, \(K_o = 2.5-3\).

In the isothermal case of stand 1 made of reinforced polystyrene foam with a thickness of 100 mm, channels for the circulation of gaseous carbon dioxide are mounted on the inner walls. Circulating holes were made in the channel walls against which, inside the channels, EGD devices were mounted 7. The dry ice storage unit 2 is located outside the isothermal housing and includes a movable scraper 3, an electric motor 4 with an auger 5, for supplying ice to the dispenser 6. Process body cooling is carried out by feeding granular carbon dioxide into the dispenser, where, due to the operation of EGD devices, gaseous CO\(_2\) circulates through the internal volume of the body, ensuring its cooling, disinfection and deodorization.
Figure 2. Diagram of the process of cooling the body of a refrigerator with granular carbon dioxide using electrophysical methods

4. Conclusion
The cooling system of the refrigerator and food products developed by the authors allows one to reduce the consumption of solid carbon dioxide up to 20% by increasing the temperature of the working medium of the refrigerator and increasing the bactericidal effect due to the use of electrophysical methods, in particular, corona discharge.

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