Issues of operational and environmental safety in the aftermath of an accident of vehicles with high-voltage components

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Abstract. The authors raise the issue of safety of operation and elimination of consequences of road accidents of vehicles with high-voltage components. The elimination of the consequences of road accidents is often associated with the elimination of the harmful effects of damaged lithium-ion batteries on the environment and human health. The world experience of identification of this type of vehicles equipped with a system of accumulation and storage of electricity in the form of a high-voltage traction battery based on NiMH or Li-ion is considered. The rationale for the use of a universal identifier with a description of the world practice of solving this issue is given. The ways of implementation in relation to the legislative and regulatory documents of the Russian Federation are proposed. The reasons and practical significance of the introduction of identification of electric vehicles and vehicles with combined power plants are described. Additional problems have been identified, the solution of which requires timely solutions in order to ensure operational and environmental safety.

1. Introduction
Since July 25, 2017, definitions of new types of ground vehicles - electric vehicles and hybrid vehicles - appear for the first time in the Road Traffic Rules (RTR). These types can be categorized as energy efficient vehicles, which is highlighted by their low or no CO₂ emissions. The main characteristics of such vehicles are high-voltage components: traction electric drive and rechargeable energy storage system (RESS).

The global fleet of electric vehicles has already approached the 6 million mark. At the same time, the growth rates are very high, since 143 models were introduced to the market in 2019 and it is planned to bring the number of models to 450 by 2022.

As of July 1, 2020, the fleet of electric vehicles is 7925 vehicles and 450 buses with electric traction drive [1]. Based on the statistical data provided by the analytical agency Avtostat every six months (Figure 1) [2], a preliminary calculation of the fleet increase can be made: by the end of 2025 - about 35,000 electric vehicles. It should be noted separately that there is no statistics on the number of vehicles with combined power plants.
2. Results

Currently, several types of vehicles with high-voltage systems are produced and sold in the world [3-5]:
- electric vehicles
- vehicles with combined power plants based on electric drive and internal combustion engine
- vehicles with combined power plants based on electric drive and fuel cells

In the world there are already a fairly large number of cases of high-voltage battery ignition [6, 7]:
- manufacturing defects
- failure of a component of the cooling system
- thermal runaway when charging conditions are violated
- insufficient level of diagnosis after an accident
- mechanical damage in an accident.

In addition to the reasons described above, the subject of spontaneous fire of lithium-ion batteries has been repeatedly raised when studying the fire safety of lithium-ion storage and accumulation systems in transport. Examples of spontaneous fire of lithium-ion batteries are known in the digital gadgets, portable personal vehicles and even automobiles.

Since 2010, there have been quite a few incidents with rechargeable hybrids and electric vehicles related to the thermal runaway of lithium-ion batteries, which led to the fire of the traction battery on such vehicles as: Zotye M300 EV, Chevrolet Volt, Fisker Karma, Dodge Ram 1500 Plug-in Hybrid, Toyota Prius Plug-in Hybrid, Mitsubishi i-MiEV and Outlander P-HEV.

A large number of vehicles with high voltage components offered earlier on the market used nickel metal hydride batteries, which do not pose the same thermal runaway hazard as lithium-ion batteries, however, lithium-based batteries currently show the best specific performance.

Initially, let us look at the design of a lithium-ion battery (Figure 2). Lithium-ion batteries consist of an anode and a cathode, which are separated by a porous polymer separator. In the cathode, an active material is most often used in the form of transition metal oxides, in the crystal of which lithium ions are embedded. The anode, in turn, is represented by graphite. The electrolyte used in this type of batteries is an organic solution of lithium salts. The first charging of the battery is accompanied by the process of embedding lithium into the anode, which creates an electrically protective ion-conducting layer that protects the electrodes from harmful interactions with the electrolyte.
Scientists investigated various causes of spontaneous fire of high-voltage storage batteries. These main reasons are: internal short circuit, overheating of the battery, exceeding the maximum permissible voltage, charging with high currents, too deep discharge. All these reasons lead to one result - thermal runaway and decomposition of the electrolyte when interacting with the electrodes with the difference only in the reaction rate.

A short circuit inside can be caused by a large number of factors, which may depend on the following reasons: mechanical damage to the cell, violation of production technology, presence or ingress of metal particles between the anode and cathode, formation of chains of lithium dendrites (metallic lithium).

The formation of lithium dendrites occurs if lithium ions do not have time to integrate into the anode crystal at low temperatures or high charging rate, as well as provided that the capacity of the active material of the cathode is higher than of the anode. The consequence of this is the appearance of deposits on the surface of the anode, which grow over time (Figure 3).

Manufacturers of batteries and electric vehicles pay particular attention to the development of systems that prevent spontaneous fire, for example: a porous separator that prevents the growth of dendrite, safety valves that allow excess gases to be discharged into the atmosphere or fuses that disconnect electrodes from the circuit.

Figure 2. Diagram of a lithium-ion battery [wikimedia.org].

Figure 3. Dendrites of lithium.
Lithium-based energy storage devices, in addition to high voltage, in case of violation of operating conditions, can be a source of high temperatures and fire, as well as caustic thick smoke. Also, if lithium-ion batteries are damaged, hydrofluoric acid may be released.

It is known that the release of gas to the outside, when interacting with oxygen, leads to a fire. Thus, even with the presence of protective systems and mechanisms, with external mechanical impact on the battery, there is a high risk of fire. Similar cases have been repeatedly recorded in road accidents involving electric vehicles.

Back in 2011, Chevrolet, together with the National Highway Traffic Safety Administration (NHTSA), trained more than 1,600 emergency workers using the example of Chevrolet Volt in rescue operations. This electric vehicle safety training project is a nationwide program in the United States to help firefighters and emergency responders to be prepared for the growing fleet of vehicles with high-voltage storage and accumulation systems. As part of the preparation of this training, a number of provisions were developed on carrying out work in the elimination of the consequences of accidents with the participation of vehicles with high-voltage components.

Elon Musk commented on the elimination of the consequences of one of the first accidents of the electric vehicle Tesla, which caused the ignition of a high-voltage battery, pointing out that firefighters began to work according to the usual scheme – in order to get to the source of the fire, that is, to the battery, rescuers damaged the fireproof bulkheads between the battery modules, which led to further spread of fire.

Thus, the need to designate the type of vehicle for rescuers and emergency workers is once again emphasized, and car manufacturers shall work more closely with emergency response services in order to increase efficiency in eliminating the consequences of accidents of vehicles with high-voltage components, since the issue of the specifics of rescue operations has been raised more than once [8-10].

Thus, with the appearance of vehicles with new types of power plants on public roads, a number of problems arose that can be combined in two directions:
1. Fire and operational safety, including:
   - elimination of the consequences of road accidents;
   - operation and maintenance of the vehicle;
   - certification and testing of vehicle components.
2. Disposal of high-voltage battery components.

Elimination of the consequences of road accidents is directly related to the identification of the vehicle by design, since the choice of appropriate methods and approaches is especially important in order to ensure the complete safety of personnel during rescue operations [11].

Detection and identification of vehicles with high-voltage components in the Russian Federation has not been worked out before. The problem is that the registration documents of most of these vehicles do not contain any information about the presence of a high-voltage battery designed for driving, just like electric vehicles do not have an environmental class defined in the main documents - in the vehicle passport. The procedure for introducing a new ecological class or the mandatory indication of HVB in special marks is rather inertial, and the changes that will be introduced now, can be implemented not earlier than in 3-5 years. During this time, the safety problem may become so acute that it will require the introduction of emergency measures. Consequently, the problem of identifying energy efficient vehicles (electric vehicles and hybrid vehicles), which includes a high-voltage traction battery, has long been relevant.

A large number of ways to identify vehicles with high-voltage components were proposed in the world, but the main ones are:
   - identification sticker;
   - registration plates.

Most countries use a registration plate, which has a specific color for identification (Figure 4). At the same time, the European Union has a number of regulatory documents that regulate the format and location of the identification sticker on buses and trucks, according to the type of fuel and the way it is stored [10].
Figure 4. License plates for energy efficient vehicles.

Based on international practice [13,14], the authors propose a format for an identification sticker for vehicles with high-voltage components, which will inform others about the presence of a high-voltage source and the need to take appropriate measures. A variant of the identification sticker is shown in Figure 5. Also GOST R Electric vehicles and automobile with combined power plants is developed. Identification, which regulates the location of this identifier.

Figure 5. Type of identification sticker of type "A" of an electric vehicle.

3. Conclusions
The issue of ensuring safety during the elimination of the consequences of accidents with vehicles with high-voltage systems is one of the most urgent at the present time and its solution is a multifaceted and multifactorial task that is available only with an interagency response. The variant of the identifier presented by the authors is one of the first steps in the field of systematization of safety assurance during operation and elimination of the consequences of accidents of vehicles with high-voltage systems.

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