EXTINGUISHING FIRE IN ELECTRIC VEHICLES

Snježana Kirin, Manuela Žakula, MarjanŠarić

Abstract: Fires on electric vehicles represent a challenge and a great danger to firefighters, mainly driven by powered electric batteries that are demanding to extinguish. There are two options for extinguishing fire in electric vehicles: Put out the fire or leave the car to turn itself off. The second option creates negative effects on the local population and economy. The first fire-fighting is due to be taken into account. It is very demanding process and includes the use of modern fire extinguishing agents such as F-500 additives, Firesorb and water. Also, the effects of fire-fighting on the electric vehicle may be very serious, starting with electric and thermal shock, the occurrence of burns on the body or the inhalation of toxins. The issue of fire-extinguishing requires analysis, testing and attention of the professional public as the exceptional increase in the purchase of electric vehicles on the market has been observed. One key step in the successful extinguishing fire in electric vehicles is the education of firemen but also cooperation with distributors and manufacturers of electric vehicles. However, manufacturers of electric vehicles use a number of safety features to raise it to the larger level, as the creation of its own markings, safety and security elements in the manufacture of electric vehicles.

Key words:fire, electric vehicle, modern fire extinguishing agents, health consequences, safety measures, education

1. INTRODUCTION

Interest in electric vehicles has increased significantly in recent years, and this trend will undoubtedly continue. From a safety point of view, significant progress has been made, but special care should still be taken due to the amount of energy stored in propulsion electric batteries. The biggest problem for firefighters is the propulsion batteries when they catch fire. The previous experiences of firefighters, but also the conducted research, show that large amounts of water are needed to extinguish and cool the propulsion batteries themselves.Modern extinguishing agents have proven to be very good if there is access to the battery (which is otherwise enclosed in its own armor and is located at the base of the vehicle).

The voltages present in electric cars are significantly higher (currently up to 650V DC) than those used in other vehicles (12 / 24V - DC). In dry conditions, accidental contact with parts above 120V DC can be dangerous and even lethal [6]. The history of electric vehicles dates back to 1834, when Robert Anderson constructed the first electric vehicle (1832-1839) [1].

But Faraday's discovery spurred the development of DC Law. Two years later, the battery powers an electric vehicle. For many years, seventeen years to be exact, the battery has driven an electric vehicle at a speed of up to 31 km/h. It took eight years for rechargeable lead-acid batteries to be developed.

Excellent discoveries follow.Then in 1838, William H. Taylor (the United States) was credited with the further development of the electric motor. He records the discovery of an electric motor to power a ship on the Neva River in St. Petersburg, Russia.

Davenport did not give up. He developed a more advanced construction of Faraday's DC motor for commercial purposes. With respect, it is used in printing and machine tool operation. However, the high cost of battery power sources has been observed, so there is very little demand for this type of motor [6]. Camille Alphonse Faure (France) constructed higher quality lead batteries of higher electrical capacity in 1881.

This is a prerequisite for the further development of electric cars. In 1881, Frank Julian Sprague constructed the first "practical DC motor that was able to keep constant speed at variable loads." William Morrison made an electric cell in 1891. In the same year, Peugeot established its first car factory at the end of the 20th century. So, in the 20th century, there were several hundred electric vehicles on the roads. Electric vehicles have become the future. But for the shortest time, due to the low-cost fuel, electric vehicles were suppressed in the 1920s. The renewed interest in electric vehicles has grown after the first environmental problems in the 1960s [8]. Countries such as the US, France, and Germany cooperate with electric vehicle manufacturers and exchange experiences with firefighters. In that way, they improve vehicles.

In addition, sorts of electrrical vehicles are shown in Table 1.

Table 1. Sort of electrical vehicles

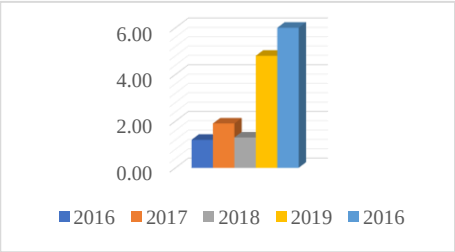
Sort of electrical vehicles (EV)	Short description of the vehicle
SERIES HYBRID	It's powered by an electric motor. This hybrid shows up in urban traffic, first of all, when the car is idling
HYBRID	May be propelled either with an internal combustion engine either an electric motor or both combined
POWER-SPLIT HYBRID	Can switch between serial and parallel modes to so can take advantage of each
MICRO HYBRID	Uses renewable energy to recharge a 12V battery, which reduces fuel consumption from internal combustion engines and thus reduces CO2 emissions
MILD HYBRID	Equiped with electrical motor
FULL HYBRID	It can only be powered by electricity, and the only limiting factor is the capacity of the battery.
PLUG-IN HYBRID	Generates the lowest CO2 emissions of any of the hybrid technologies described above

Electric vehicles are defined all vehicles that in some way use electricity to start a propulsion machine. They are divided into six basic groups: traditional electric vehicles, hybrid vehicles, [1]- [6], fuel cell vehicles or metal-air batteries, electric vehicles powered by overhead lines, electric vehicles powered by solar cells and electric vehicles powered by flywheels and super capacitors [1] - [6].

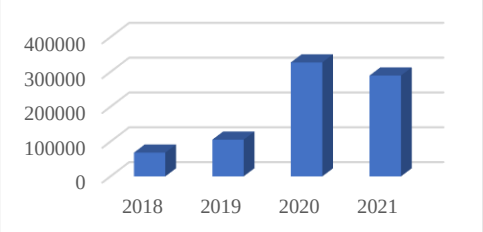
Graph 1 refers to the number of electric cars globally, while Graph 2 refers to the number of electric vehicles in the European Union, what are shown below.

Graph 1 refers to the number of electric cars globally, while Graph 2 refers to the number of electric vehicles in the European Union, what are shown below.

Graph 1. The number of electrical vehicles (globally)



Graph 2. The number of electrical vehicles in EU



Source: Statista, 2021Source: Statista, 2021

Graph 1 shows data about the number of electric vehicles in the world, from 2016 to 2020.The number of electrical vehicles is expressed in millions. In 2016, there were 1.2 million vehicles worldwide, while in 2020 there were 6.8 million electric vehicles worldwide [2]. Thus, the number of electric vehicles increased by 5.6 million in four years [2]. It indicates an exceptional increase in the number of vehicles globally. At the same time, the number of electric vehicles in Europe grows (graph 2).In April 2018, there were 68,276 thousand vehicles in the European Union while in 2021 (February) the number of vehicles was 289,625 thousand electric vehicles. So, there has been an increase in the number of electric vehicles of 221,349 thousand in the European Union in four years.

Additionally, there are a lot of advantages because of electrical cars's usage as it is shown in Sheme 1.

Sheme 1. The advantages of electrical cars's usage

In accordance with Sheme 1., there are a lot of advantages for electrical cars. One of the key advantages is caring about the environment. The second important issue is safer traffic and decreased VAT and fossil fuels.

It is essential to know the legal regulations related to fires, especially fires in electric cars. The Fire Protection Act states that the fire protection system includes fire protection planning, prescribing fire protection measures for buildings, organization of fire protection entities, implementation of fire protection measures, financing of fire protection and training, and authorization to perform fire protection activities. fire [13]. Fire protection is carried out, in addition to natural and legal persons prescribed by this Act, also by legal persons and associations performing firefighting and protection and rescue activities, and local and regional self-government units, in accordance with regulations about rescue and protection [13].

Do we need to be concerned about fires in electrical vehicles? As many people buy electrical vehicles (EV), there is more concern about what will happen if these vehicles fire [4].

Despite the unquestionable benefits of electrification of electric vehicles, from reducing air pollution to making a reduction in the consumption of fossil fuels, there is a growing sense of concern about the dangers and apparent spontaneous combustion of electric vehicles. Electric vehicles use rechargeable lithium-ion batteries. The first lithium-ion battery was invented in the 1990s, and it was used to drive cars in the early 2000s. Basically, electric vehicles are extremely safe, but the main hazard arises when the lithium-ion battery is damaged.

What could happen if it's exposed to a large hot tub or something penetrates the wall of a battery? Professor Paul Christensen, of the University of Newcastle, is an expert in the field of fire with electric motors, and explained that lithium-ion batteries are incredible because they can store a huge amount of energy in a very small space. However, if the battery is exposed to excessive heat or incursions into the battery, then you will have an internal short circuit. This short circuit causes what's called Joule warming. That's when the electricity that goes through causes heat and you can't get rid of heat as quickly as you create it. Then, because of this heat, a chemical reaction produces more heat, which then causes the chemical reaction to go even faster. This is a process called a thermal release and can lead to ignition, or in some cases, even explosions. [4]

2. TYPES OF FIRE HAZARDS IN ELECTRIC VEHICLES

In the case of a fire in electric or hybrid vehicles, the main danger is the electric battery in the vehicle.

The arising dangers are the risk of electric shock, toxic and thermal risk. Besides these dangers, electric vehicles pose additional dangers and challenges for firefighters. [3]. Electric vehicles have operational features that firefighters are not familiar with, such as the fact that electric vehicles do not produce any sound [3].

Therefore, firefighters must always assume that the vehicle is turned on and take the necessary actions to secure the vehicle.The voltages in electric batteries range up to 650 V DC, while in conventional vehicles they are 12/24 V. The hazards of electric shock in electric vehicles come from the power outlets, the battery itself, power cables, and plug service. In electric vehicles, we encounter direct and alternating current.

Another hazard is toxic risk.

During a fire in an electric vehicle, ie when a fire affects high voltage batteries, toxic and corrosive gases and vapors such as hydrogen fluoride (HF), hydrogen chloride (HCl), hydrogen cyanide (HCN) are released, while the last two gases are explosive.The release of toxic substances pollutes the air, soil and water.In the case of extinguishing a fire, the use of personal protective equipment and respiratory protection devices is mandatory [12]. There is also a risk of heat generated by the electric battery due to ignition, box battery damage or its destabilization.

Electrothermal burns also occur due to the passage of current through the human body [3]. Burns are usually found on the hands [3].In addition, most electric vehicle manufacturers have their own markings, safety and security features.Standardizing them would be of great help to firefighters. External markings and safety measures mostly serve to protect firefighters themselves, as there is a high risk of electric shock if care is not taken.

Also, external electric vehicle marking symbols serve for easier identification. The symbols are marked in blue or marked as EV, Hybrid, or Plug-in hybrid. The charging socket can be located anywhere on the vehicle, depending on the manufacturer.

In addition to these symbols, there are other features of easier identification, which are: electric vehicles do not have exhaust gases or do not produce exhaust gases [3]. When talking about safety, electric vehicles, manufacturers of electric vehicles apply a number of safety features to raise them to a larger level.

In addition to these symbols, there are other features that make easier identification, which are: electric vehicles do not have exhaust gases or do not produce exhaust gases [3]. When talking about safety, electric vehicles, manufacturers of electric vehicles apply a number of safety features to raise them to a larger level

Some of the main measures are [3]

- Location of high voltage cables outside the usual cutting places. They are orange (usually placed at the base in the middle of the vehicle),
- The position of high voltage batteries is usually located in the center of the vehicle or between the rear wheels, depending on the manufacturer,
- Impact on the resistance, water penetration into the battery box.

3. THE BASIC PRINCIPLES FOR EXTINGUISHING FIRE IN ELECTRIC VEHICLES

In the case of a fire in an electrical vehicle, firefighters face hazards and situations which are quite different from conventional vehicle fires. The hazards represent high voltage batteries and cables which are located in the vehicle. Firefighters use different methods with the aim of simplifying their work. For example, thermovision cameras, modern technology (applications) and extinguishing fire methods.The firefighters lay the basis for their own experience from previous fires, conventional vehicle intervention, as well as individual interests in the firebrigade station. They collect experience from their European Union colleagues. It exposes a question: „How to be prepared for that vehicle for that sort of intervention? The point is that there is little chance to get an electrical vehicle for tests and drills, presentations or situation simulations. It would be desirable to improve cooperation with manufacturers or electrical vehicle distributors. It would make it much easier for firefighters to take actions during interventions. [3] For firefighters, what specifically did they do? Extinguish the fire in the car or leave it to be extinguished after several hours. But it's not that simple. Account should be taken of the environment, people and property found at the place where the car was burned. For example, if a car is on the road, it should close the road for several hours. This has a negative impact on the local population and the economy. Therefore, the best option is to extinguish a fire in an electric vehicle. [4] The basic settings for fire-fighting of electric fires are based on the fact that fires in electric vehicles can occur on the battery itself or extend/transfer from the rest of the vehicle. Electric batteries can have different burning characteristics and can react differently when exposed to heat.

Fire department experts prescribed the following procedures and useful information for firefighters [3].

- The use of water for extinguishing fires on electric vehicles does not pose a danger to firefighters.

- If the battery is affected by fire, there is a possibility of re-ignition after extinguishing and cooling, so constant monitoring by a thermal camera is required. The igniting
- of the electric battery is accompanied by blowing sounds, then white smoke, sparks and constant flames,
- Re-ignition can occur in the range of several hours to 24 hours after extinguishing,
- After extinguishing, and when the towing service takes the vehicle, it is necessary to control the vehicle at the landfill and meet the towing service with the problem,
- As the electric batteries are in an insulated box, it is impossible to reach the extinguishing agent directly, and for this reason, a large amount of water is required (estimated at about 15,000 liters of water),
- Cooling is continued even when there is no visible flame. The batteries have cooled down properly and pre-ignition has been prevented.
- If the electric batteries are not yet affected by the fire, the vehicle is extinguished in the traditional way.
- The cover of the electric battery box must not be opened or removed due to possible injuries due to high voltage,
- All those within 15 meters of the fire vehicles must use personal protective clothing and footwear, as well as respiratory protection devices, as they emit toxic gases during combustion.

A sufficient number of respiratory protection devices must be provided. Use standard equipment found in fire trucks. It is very important to adhere to all the given steps in order not only to protect the environment but also to protect human lives. The analysis of extinguishing agents starts with their basic division. The basic means are water, foam and powder.New means, such as the F-500 and Firesorb, are increasingly represented when extinguishing fires in electric vehicles. Mostly, water is used, while foam and powder can be used until the fire catches the electric batteries. [5] When testing fire extinguishing with water, an AWG CM nozzle (DIN 14365) and hydrant water can be used, while the nozzle flow can be set to 100 l/min at a pressure of 8 bar (Figure 3).

It is so important to follow all prescribed steps with the aim of environmental protection as well as human being protection.

4. FIRE EXTINGUISHERS

The firefighters' tests with AWG CM(Fig. 1) have shown that 3 hours after the fire, the electrical battery (immersed in the pool) has stillvented the smoke ballons. Also, it turned out that after the water quenching, the battery began to heat up again, which is why it reginited. It can therefore be expected that after 24hrs or 48hrs, it can ignite which particular attention should be paid [5].

Figure 1. AWG CM nozzle

A second means is F-500, which is usually added to water and works in a way that neutralizes burning and cuts the chain reactions of free radicals. So it results in rapid flame down, more permanent resistence to combustion and the removal of vapor, soot and smoke. It also reduces the surface tension of water, which results in better heat absorption and better penetration into the pores of combustible materials, and reduces evaporation and improves visibility, which is extremely beneficial for firefighters themselves [12].

Figure 2.WG Turbo-nozzle 2000 venturi 75-C2L

WG Turbo-nozzle 2000 venturi 75-C2L (Fig. 2) showed that when extinguishing the flame immediately disappeared in contact with a mixture of water and additives F-500, it took 14 seconds and 15 liters of mixture to extinguish the vehicle.Unlike water, the temperature of the battery did not rise after it was turned off.Also, with a few more sprays, it was extinguished to reduce the amount of smoke.In total, about 80 liters of the mixture were consumed [9]

The third agent is Firesorb is an additive that also mixes with water, and when applied to the flammable surface, forms a gel that sticks. It creates a layer 10 centimeters thick, and can be used on smooth, vertical surfaces and ceilings.Due to its chemical-physical properties, the rate of water evaporation is significantly reduced even at high temperatures, leading to a reduction in water consumption.For the Firesorb test, a WG Turbo-nozzle 2000 venturi 75-C2L was used. For testing purposes, hydrant water and a 200 l/min flow mixer (Fig. 3) dosed at 1.8% were used.

Figure 3. Stirer

The fire-fighting test on an electric vehicle, with a mixture of water and Firesorb to extinguish flames, with the aid of a mixer, was required for 6 seconds and 40 litres of the mixture. The temperature of the electric battery didn't grow back. For the total fire fighting, 120 litres of the mixture had been consumed while the levels of toxic vapour concentration were negligible. The final test results showed that the temperature of Litii-ion batteries was rising up to 800 ° C, while the fire spread within a radius of about 2 m. The temperature of the rest of the vehicle and the concentration of toxic gases should also be increased. In the event of a fire, water may be extinguished, but a greater quantity of water should be provided. It should also be borne in mind that the battery in the vehicle will not be directly accessible. In parallel to water, additives F-500 and Firesorb showed very good wear properties. The F-500 is highlighted by easier and deeper penetration of the vehicle structure and the battery itself. It is recommended that, according to the possibility, the batteries be caught by fire or the whole vehicle be sunk in water or a mixture for the next 24 to 48 hours. [11]

Table 2. The comparision of fire extinguishing fire means

	Water	*F-500*	*Firesorb*
Baterry		Identična	
Weight		175 kg	
Water quantity	400l	80 l	120 l
Additive		F-500	Firesorb
Percentage of mixture		1%	1,8%
Time for fire extinguishing			
Flame	40s	7s	6s
New burn	YES	NO	NO
Turned off	1050s	689s	456s
Temperature	460°C	577°C	409°C

5. CONCLUSION

Fires of electric vehicles are very demanding and dangerous, both for the fire and for the environment. Although fires in electric vehicles occur, in relation to the number of vehicles on the road, the percentage is quite small, which shows that electric vehicles are quite safe. This paper presents modern-day extinguishing agents that have proved far more efficient than water. But because of their price and the inability to penetrate the electric batteries themselves, they are rarely used. Therefore, firefighters remain in the water as the main extinguishing agent. The testing of fire-extinguishing agents has shown that F-500 and Firesorb are adequate resources, as the battery shuts down faster until the water is optimal, as there is a possibility that the battery in the electric vehicle is reignited and if it is not under control, it can be a serious problem. Fire causes in electric vehicles are the most common technical characteristics, such as overheating of electric batteries or short circuits. But the education of firemen and co-operation with the conductors with the appropriate legal regulations can be of great help in situations where fires on electric vehicles occur. Adapting to modern life trends, such as driving electric vehicles, changes the safety frameworks of EU citizens.

6. REFERENCES

[1] H. Glavaš, M. Antunović i T. Keser, *Dvadesetšesti skup o prometnim sustavima s međunarodnim sudjelovanjem,* KoREMA, 2018.

[2] Statista, *The number of electrical vehicles,* EU: Statista, 2020.

[3] M. Šarić, *Gašenje električnih automobila,* Karlovac: VUKA, 2021.

[4] P. Neill, *Electric Vehicle Fires should we be concerned?,* A. Q. News, Ur., London: Air Quality News, 2020.

[5] MBS Fire, *AWG CM-Strahlrohr nach DIN 14365 mit C-Storz Kupplung,* 2021.

[6] M. Šipuš, »Gašenje požara električnih automobila,« *Vatrogastvo i upravljanje požarima ,* svez. III, br. 1-2, pp. 45-57, 2018.

[7] Ministarstvo rada i mirovinskoga sustava, *Pravilnika o zaštiti radnika radnika o izloženosti opasnim kemikalijama na radu NN 91/2018,* Zagreb: Narodne novine, 2018.

[8] M. Stojkov , »Električni automobil : povijest razvoja i sastavni dijelovi,« *Proceedings PLIN,* svez. 2, 2014..

[9] AWG Sales, *System solution,* Njemačka: AWG, 2020.

[10] Vatropromet, *Vatrogasna i zaštitna oprema,* Vatropromet, 2021.

[11] Hazard Control Technologies Inc., *Why F-500 EA is Economical?,* Hazard Control Technologies Inc., 2021.

[12] F. Emde, *Control Technologies INC.*, FRITZ EMDE – Mechanical and vacuum engineering, 2021.

[13] Zakon.hr, *Zakon o zaštiti od požarima NN 92/10,* Zagreb: Narodne Novine , 2010.

[14] Fire Protection Research Foundation, »Best Practices for Emergency Response to Incidents Involving Electric Vehicles Battery Hazards: A Report on Full-Scale Testing Results,« Fire Protection Research Foundation, Massachusetts SAD, 2014.