EXTINGUISHING FIRES ON ELECTRIC VEHICLES

Aleksandar Majstorović[1], Mladen Todić[2], Tihomir Latinović[3]

1. Faculty of Technical Studies, University of Travnik, Bosnia and Herzegovina
2. Faculty of Mechanical Engineering, University of Banja Luka, Bosnia and Herzegovina
3. Faculty of Information Technology, University “VITEZ”, Bosnia and Herzegovina

ABSTRACT

We are witnessing a time in which the lack of energy sources (various types of fossil fuels) is felt, which is caused by irrational consumption, but also the impossibility of using and distributing crude oil or natural gas (as the leading energy sources) due to the consequences of war, which are felt in all types of industry, especially in the automotive industry. Naturally, in the last few years, this has affected the development and expansion of both passenger and cargo electric vehicles, which are primarily presented as more environmentally friendly and technologically advanced, compared to conventional vehicles. With the introduction of electric-powered vehicles into use, their shortcomings have started to manifest when compared to conventional vehicles both in terms of supplying electricity and in terms of fire protection, i.e., fire extinguishing.

Keywords: electric vehicles - classification, charging, deficiency, firefighting

INTRODUCTION

Due to the increasing environmental awareness and the “green focus,” which primarily aims to reduce pollution and improve air quality in large cities caused by exhaust emissions from motor vehicles worldwide, there is an idea for complete electrification of mobility (full adoption of electric cars) in the European Union. Additionally, there are plans to completely cease the production of gasoline and diesel engines by the end of 2035. Leading global passenger car manufacturers, such as the German automaker BMW, have announced the cessation of gasoline and diesel engine production at their central European facility based in Munich, starting as early as 2024. However, engine production will continue in facilities located in Austria and the United Kingdom. Recently, the Swedish automaker Volvo also joined this trend by completely discontinuing diesel engine production for passenger cars, which they had been producing continuously for 45 years. Volvo’s plan is to produce only electric vehicles by 2030. Meanwhile, the management of the world’s largest car manufacturer, Toyota, has announced that diesel engines will remain in use for several more years.

In the Netherlands, a significant problem has recently emerged due to the mass use and charging of electric vehicles during specific time periods (between 5 PM and 8 PM). This has led to frequent disruptions in the electricity supply to major cities (such as Utrecht, Rotterdam, Amsterdam, and The Hague) due to overloading of both low-voltage and high-voltage grids.

HISTORY OF ELECTRIC VEHICLES

The first electric vehicle, characterised by limited range and a speed of 12 km/h, appeared back in 1839 (credited to Robert Anderson). It used non-rechargeable primary energy cells. In 1861, Otto Nikolaus constructed the first internal combustion engine as an alternative to steam engines. By 1864, he began serial production of internal combustion engines ICE[11] [11]. Another notable electric vehicle was designed by our renowned inventor and scientist, Nikola Tesla, in 1931. He modified a standard Pierce-Arrow automobile by replacing its ICE with an electric motor. This vehicle operated based on wireless transmission of electrical energy and is believed to have reached a maximum speed of 144 km/h.

[1] Hereafter referred to as ICE

TYPES OF ELECTRIC VEHICLES

Electric vehicles can be categorised into four groups:

1. **Hybrid Electric Vehicle** (HEV[21]): HEVs have both an internal combustion engine (ICE) and an electric motor. The ICE is used for driving and charging the battery, while the electric motor reduces CO2 emissions or enhances ICE performance during driving. The HEV battery is not charged from an external power source; instead, it relies solely on regenerative braking to recover energy.

2. **Plug-In Hybrid Electric Vehicle** (PHEV[3]): PHEVs also have both an ICE and an electric motor, similar to HEVs. However, PHEVs offer two operating modes:

- **Pure electric mode**: In this mode, both the electric motor and battery provide energy to the vehicle.

- **Hybrid mode**: Both the ICE and electric motor are utilised.

This type of vehicle uses an ICE engine and an electric motor in a similar way as an HEV, the difference being that electric propulsion[4] is the main driving force. The ICE engine is used for driving and charging the battery, and is supplied with fuel from the tank, while the electric motor is used to reduce CO2 emissions or to increase the performance of the ICE engine while driving, and supplies electricity from the battery. The PHEV battery can be charged from an external power source and by recuperating the electrical energy obtained by deceleration or braking.

3. **Battery Electric Vehicle** (BEV[5]) – fully electric vehicles that are powered exclusively by an electric motor from a battery power source. The battery is charged from an external power source (electrical network), and its power is transferred to one or more electric motors of direct current or alternating current, which are characterised by high torque and at lower speeds. These vehicles have DC to AC converters, while the range of these vehicles depends solely on the battery capacity. By decelerating or braking, the electric motor/motors recover electrical energy, i.e., charge the battery.

4. Electric Vehicle With Fuel Cells (Fuel Cell Electric Vehicle, FCEV[6]; Fuel Cell Electric Vehicle, FCEV) - use "fuel cell technology" to produce electricity through a chemical reaction by combining hydrogen (from the vehicle's tank) and oxygen (from the air), where electricity is generated to start the electric motor and water, which is discharged from the car through the exhaust pipes.

According to their configuration, electric vehicles, compared to vehicles with ICE engines, are much more flexible in terms of the simplicity of the mechanical systems because the electric motor is their only moving part, while the power supply is made possible by connecting batteries that can be placed in different places in the vehicle provided that there is an electrical connection between them, and due to the very nature of flexibility, different types of configuration are possible, for example: front- or rear-wheel drive, all-wheel drive, etc. [1, 2].

BATTERIES FOR ELECTRIC VEHICLES

The range of electric vehicles is determined by the capacity of the batteries, which depends on the vehicle's load, terrain configuration, driving style, and power consumers. Several types of batteries are used in operation. Previously, lead-acid, NiCd, and NiMH (nickel-metal hydride) batteries were used, while lithium-based batteries such as LiS (lithium-sulphur), LiCoO2 (lithium-cobalt-oxide), LiMnO2 (lithium-polymer), and LiFePO4 (lithium-ion-phosphate) are used nowadays. Li-ion batteries have proven to be the best in practice due to their capacity and very good energy retention, characterised by a self-discharge of 1-5% per month (which is 15% less compared to NiMH batteries). However, their tendency to overheat is their main drawback.

The Chinese battery manufacturer for electric vehicles, BYD, has developed a new generation of LiFePO4 (lithium-ion-phosphate) batteries, which are smaller in size and weight. Compared to previous batteries of the same type, they are cheaper to produce, and the range of electric vehicles has increased to 1000 km.

Lithium (from Greek lithos - stone), chemical symbol Li, is the lightest of all known metals (alkaline metal), and due to its reactivity, it is not found in its elemental state in nature. It is stable in dry air at room temperature for a long time, slowly reacting to form lithium nitride[71], while in moist air, it oxidises very quickly, creating lithium hydroxide[8]. Like all alkaline metals, in contact with moisture on the skin, it can cause severe burns due to corrosion, which clearly indicates the dangers and harmfulness it can cause.

[2] Hereafter reffered to as HEV
[3] Hereafter reffered to as PHEV
[4] Propulsion (lat. propulsus – pushed forward) a device that takes over the power of a drive device (in this case an electric motor), [15]
[5] Hereafter referred to as BEV
[6] Hereafter referred to as FCEV

[7] a compound of lithium and nitrogen Li3N
[8] Hydroxides - compounds in which hydroxide anions are present, and bases or alkalis are aqueous solutions of hydroxides

FIRES IN ELECTRIC VEHICLES

In comparison to ICE vehicles, extinguishing fires in electric vehicles presents several types of dangers, such as toxic and explosive products (hydrogen fluoride, hydrogen chloride, hydrogen cyanide), thermal and light emissions from the combustion of lithium batteries, chemical reactions caused by water penetration into lithium battery casings, and the danger of high-voltage system shocks (ranging from 400 to 650 V depending on the manufacturer).

Fires in electric vehicles can occur due to:

- Cracking of lithium battery casings due to mechanical damage and short circuits caused by traffic accidents or mishaps.

- Charging batteries with too strong or too weak currents, leading to rapid heating of the batteries and their ignition.

- Discharging batteries with too strong currents, heating them up and leading to their ignition.

FIRE EXTINGUISHING TACTICS FOR ELECTRIC VEHICLES

When extinguishing fires, firefighters must use protective equipment (protective clothing, footwear and, insulating devices at a distance of 15 m from the vehicle). Since there is no adequate tactic for extinguishing this type of fire in our region, it is necessary to apply developed tactical models and approaches of French and American firefighters, which are based on two modes of extinguishment:

1. If the fire has not reached the electric batteries, an offensive attack is recommended, applying extinguishing tactics as for ICE vehicles.

2. If the fire has reached the electric batteries, a defensive attack is recommended.

PROCEDURES FOR EXTINGUISHING FIRES ON ELECTRIC VEHICLES

Considering that a fire in an electric vehicle can occur on the battery itself or can spread to the battery from the rest of the vehicle, and that batteries can react differently when burning or exposed to heat, firefighters are prescribed the following procedures:

• Extinguishing fires on electric vehicles with water does not pose a danger to firefighters;

• Inspection of the extinguished battery with a thermal imaging camera is necessary due to the possibility of reignition within a few hours to 24 hours;

• The burning of the battery is accompanied by the sound of rushing air, intense white smoke, sparking, and a constant flame;

• Batteries are located in an insulated housing, and it is impossible to reach the seat of the fire with extinguishing agents, which is why a large amount of water is needed for extinguishing (up to 15,000 litres), so a water supply must be planned;

• After extinguishing a fire on batteries, it is necessary to continue cooling them to prevent reignition;

• It is forbidden to remove the cover of the electric battery housing due to the possibility of high-voltage electric shock;

• During extinguishing, use the available equipment from fire vehicles;

• Electric and hybrid equipment does not require special extinguishing equipment.

FIRE EXTINGUISHING AGENTS FOR ELECTRIC VEHICLES

The primary agents for extinguishing fires are water, foam, and powder. In the case of electric vehicles, water is mainly used until the fire reaches the electric batteries, after which foam and powder are utilised.

In a deliberate fire caused for experimental purposes by DEKRA[9] on a Lithium-ion battery vehicle to test the effectiveness of extinguishing agents, the first signs of burning due to a short circuit and damage to the electric battery appeared after eight minutes. This was accompanied by visible deformations on the battery casing, release of toxic gases, the appearance of a bright flame (up to 2 metres long), and the spraying of a small amount of aluminium (within a 2-metre diameter), while the measured temperature on the electric battery was 750° C.

• **Water**: The effectiveness of water as an extinguishing agent for electric vehicle batteries during the initial extinguishing was proven within a 40-second interval, using approximately 70 litres of water. After 140 seconds, self-ignition occurred, consuming about 200 litres of water, with the extinguishing interval lasting 4 minutes. To completely extinguish the electric battery, approximately 500 litres of

[9] DEKRA - Deutsche Kraftfahrzeug-Überwachu-ngs-Verein e.V. (German Motor Vehicle Monitoring Association) was founded in 1925 in Berlin and is focused primarily on car safety. More recently, it has been engaged in the testing and certification of electric vehicles.

water were used over a 17-minute interval. After extinguishing, the electric battery was submerged in a water pool and continued to release smoke bubbles for the next three hours, indicating that due to water extinguishing, the electric battery began to reheat, leading to its reignition. It was found that it could reignite within 24 to 48 hours.

• **F-500**: An additive (not foam) that is added to water to reduce its surface tension for more efficient penetration into the pores of the combustible material. It is used as a fire extinguishing agent with a cooling effect, a wetting agent, and for controlling the release of hazardous liquids and gases, with possible dosages of 1%, 3%, and 6%. During the extinguishing of fires on electric vehicle batteries, its effective properties were demonstrated by rapidly removing heat, neutralising combustion and reducing flame intensity and evaporation, thereby increasing visibility. A specially designed nozzle (turbo nozzle with a self-mixer) set to a water flow of 75 litres and an additive dosage of 1% was used, with the flame disappearing after just 14 seconds and 15 litres of the mixture used. To completely extinguish the electric battery, approximately 80 litres of the mixture were consumed, and unlike water, the battery temperature did not rise during or after extinguishment.

• **Firesorb**: It is also an additive mixed with water when extinguishing fires on electric vehicle batteries, characterised by forming a gel that adheres to the combustible surface, rapidly removing heat, and significantly reducing the rate of water evaporation, thus decreasing its consumption. Water from a hydrant was used for extinguishing, with a Z2 mixer and an additive dosage of 1.8%, with the flame disappearing after just 6 seconds and 40 litres of the mixture used. To completely extinguish the electric battery, approximately 120 litres of the mixture were consumed, and like with F-500, the battery temperature did not increase during or after extinguishment.

FIRE SUPPRESSION EQUIPMENT FOR ELECTRIC VEHICLES

For extinguishing fires in electric vehicles, the usual firefighting equipment available to fire brigades can be used, but attention must be paid to the extinguishing agents. Recently, several models of fire suppression equipment specifically designed for electric vehicles have emerged, including:

1. **Fire Blanket** (VLITEX Fire Blanket): This fire blanket is designed to prevent the inflow of air, suppress flames, and contain toxic products until safe extinguishing begins or until the vehicle can be safely moved after fire suppression. The blanket's base is made of glass fibres coated on both sides with a layer of silicone. It is reusable and can withstand temperatures up to 1100° C for 50 hours. It can be used on all vehicle models, including off-road vehicles and motorcycles.

2. **Low-Pressure Water Mist System** (VLITEX SprayJet HV): This system consists of interconnected low-pressure nozzles. It efficiently generates a water mist to dissipate heat from the fuel material and cool it down. Additionally, it helps displace air from the combustion zone. The system is suitable for installation in hard-to-reach areas, such as underneath vehicles (for cooling electric vehicle batteries, braking systems, etc.) using an adiabatic process. It has proven to be highly effective in practice.

3. **Emergency Plug**: In critical situations, the emergency plug connects to the vehicle's charging socket and simulates the charging process. This automatically shifts the electric vehicle's transmission to the "P" position (activating the electric brake), preventing sudden movement. Integrated LEDs in the plug housing indicate whether the vehicle is deactivated.

CONCLUSION

Environmentally friendly, electric-powered vehicles (BEVs) do not produce harmful products from the operation of their engines, such as CO or CO_2, nor soot particles, nor do they make noise like ICE engines, and they do not make any sound when idle. Based on research, as well as experience from practice, it can be said that this type of vehicle does contribute to environmental pollution to some extent, given that the increase in their number in some European countries has also increased the production of electrical energy (operation of thermal power plants), while electricity produced from "renewable" energy sources for this type of vehicle is insufficient and negligible. Additionally, the movement of these vehicles, under the effect of friction, wears out the tires, as well as in vehicles with auto and diesel engines, which continues to pollute the environment with small rubber particles, since those in electric vehicles wear out faster due to greater mass and torque, compared to ICE engines.

Of course, when braking, electric vehicles, as well as vehicles with ICE engines, use the same braking systems, in which, due to the increase in friction during braking, brake linings made of plastics (Bakelite)[101] and asbestos[11] wear out, which pollutes the environment with microplastics. and asbestos fibres, pollutants that are very dangerous for health.

Chinese companies, under the slogan "Electricity is cheaper than oil", lowered the prices of the electric cars they produce in order to be as competitive as possible on the European market, which will put an additional burden on the power systems of the European Union countries [17]. Although electricity is a cheaper energy source than oil, electric vehicles are still more expensive than vehicles with ICE engines.

[10] Bakelite - a type of plastic with very wide application, is obtained from a crystalline mass of phenol and formaldehyde gas.
[11] Asbestos – natural fibrous mineral, resistant to high temperatures. Asbestos fibres are very dangerous for human and animal health, causing malignant diseases.

Some German political parties advocate an analysis that would prove the advantages, but also the disadvantages, of ceasing the production of ICE engines, noting that customers still have difficulty accepting electric cars and that the infrastructure for charging electric vehicles is inadequate, which resulted in a decline of electric car sales in Germany and influenced the reduction of the ambitious goals of the Mercedes manufacturer, [5].

Information comes from the Stellantis group that the mass of batteries in electric cars represents a significant obstacle in increasing environmental protection, and that in the next decade, efforts will be made to reduce the mass of batteries in electric cars by up to 50%. The very method of obtaining lithium for batteries, taking into account its extraction from the earth's crust, up to chemical processing and negative consequences during use, also contributes to the adverse effect on environmental protection [4]. Batteries for electric vehicles, as well as other types of electric batteries, lose their capacity over time or after a certain number of charging and discharging cycles, and their range and reliability in exploitation decrease, which indicates the need for their replacement. Bearing in mind the toxicity of lithium, as well as other components (electrolytes) that make up an electric battery, the methods and places of their proper disposal, as well as the possibility of recycling, must be seriously approached, which would avoid additional pollution of the environment that is already damaged by a large number of pollutants in our area.

Fires on electric vehicles, i.e., fire products caused by the burning of lithium batteries and insulation on the electrical installations of electrically powered vehicles are major pollutants, as extinguishing them also consumes large amounts of water that pours onto the surrounding terrain or into the storm water sewerage. Additionally, these fires should be approached carefully, knowing that the tactics for extinguishing this type of vehicle (if the electric battery is on fire) are different from the usual tactics for extinguishing vehicles with ICE engines.

Water, as the most widespread, cheapest, and most frequently used means of extinguishing fires, is not recommended as a means of extinguishing batteries on electric vehicles due to its interaction with lithium, resulting in increased burning intensity, but should only be used as a means of cooling (battery or other electronic vehicle components). For extinguishing fires on electric vehicle batteries, use water only with the addition of additives such as F-55 or Fire-sorb.

Special attention should be paid in accidental situations during technical interventions (traffic accidents or accidents) or fires in which at least one electric vehicle was involved, and emphasis should be placed on turning off the main switch (if possible) due to the interruption of the vehicle's supply of high-voltage electricity with additional securing of the vehicle with stabilisation blocks in order to avoid its sudden start.

Regular training of firefighters should indicate that they never touch, damage or cut the orange high-voltage cables, which are normally located in well-secured and protected parts of the vehicle, and that when intervening on this type of vehicle, they must wear protective equipment, including equipment for protection against electrical energy shocks. They should also be educated on electric vehicle firefighting and regularly informed about innovations on non-electric vehicles, as well as the method of application and effectiveness of both existing and new means of extinguishing fires on them. Unfortunately, many firefighting units in the territory of Republika Srpska and the Federation of Bosnia and Herzegovina are not in the financial capacity to purchase the above-mentioned and very effective means, but are forced to extinguish this type of fire with the most commonly used means - water.

REFERENCES

Books and scientific and professional sources:

1. D. Knezevic. (2023). Research on the experience and training of firefighters for intervention on electric and hybrid vehicles. Final paper, Karlovac University of applied Sciences. Karlovac.

2. M. Saric. (2020). Electric vehicle fire. Final paper. Karlovac University of applied Sciences. Karlovac.

3. M. Sipus. (2018). Extinguishing electric car fires. Firefighting and fire management. Zagreb.

Other sources:

4. https://autoblog.rs/blog/auto/vesti/2024/04/ 06/masa-baterija-u-automobilima-mora-biti-prepolo-vljena [Retrieved 7 April 2024].

5. https://www.b92.net/automobili/aktuelno/ 11 698/veleobrt-sada-bi-da-ukinu-zabranu-di-zelasa-i-be-nzinaca-u-eu/vest [Retrieved 7 April 2024].

6. https://autorepublika.com/2024/04/03/toy-ota-veruje-da-je-i-dalje-dug-zivot-pred-dizelmotorom/?fbclid=IwAR0gFe0OfcBkJlZW4XynXsn1KqCsOShFtvhc68MrMJIjViESb_pmkvLb9jY [Retrieved 6 April 2024].

7. https://hr.fluorined-chemical.com/fireexti-nguishing-agent/f-500-foam-fireextinguishing-agent.html [Retrieved 16 April 2024].
8. https://www.jutarnji.hr/autoklub/aktualno/ elektricna-mreza-na-rubu-kolapsa-ova-zemlja-eu-u-obz-ir-uzima-izbacivanje-elektricnih-auta-iz-gradova-15440928 [Retrieved 26 March 2024].
9. https://www.klprotektion.hr/proizvod/eme-rgency-plug-h1/ [Retrieved 17 April 2024].
10. https://revijahak.hr/2021/10/25/dolaze-el-ektricna-vozila-bmw-uskoro-prestaje-s-proi-zvodnjom-benzinskih-i-dizelskih-motora-u-glavnom-pogonu/ [Retrieved 26 March 2024].
11. https://smart-ri.hr/znate-li-da-je-prvo-ele-ktricno-vozilo-proizvedeno-prije-vise-od-100-godina/ [Retrieved 11 March 2024].
12. https://smartlife.mondo.rs/e-zivot/mobi-lnost/a53942/byd-blade-baterija-1000km-bez-punjenja.ht-ml [Retrieved 28 March 2024].
13. https://srpskainfo.com/kraj-jedne-ere-vo-lvo-dizel-otisao-u-istoriju-otkrijte-sta-ce-sve-djani-proi-zvoditi-u-narednih-6-godina/ [Retrieved 28 March 2024].
14. https://sr.wikipedia.org/wiki/Litijum, [Retrieved 9 April 2024].
15. https://tehnicki.lzmk.hr/clanak/propulzija-elektricna, [Retrieved 8 April 2024].
16. https://www.telegraf.rs/auto/auto-vesti/ 3364889-nikola-tesla-elektricni-automobil; [Retrieved 5 April 2024].
17. https://ubrzanje.telegraf.rs/nauka-i-privre-da/3865796-pojeftinili-kineski-elektricni-auto-mobili-a-prodaja-skocila-za-skoro-50-odsto-evo-cime-su-se-vodili, [Retrieved 4 April 2024].
18. https://www.vecernji.hr/barkod/stellantis-postao-cetvrta-auto-grupacija-na-svijetu-s-godisnjom-prodajom-vise-od-8-milijuna-vozila-1467833, [Retrieved 4 April 2024].
19. https://vlitex.fr/en/, [Retrieved 17 April 2024].

GAŠENJE POŽARA NA ELEKTRIČNIM VOZILIMA

SAŽETAK

Svjedoci smo vremena u kojem se osjeti nedostatak energenata (razne vrste fosilnih goriva) koji je prouzrokovan neracionalnom potrošnjom, ali i nemogućnosti korištenja i distribucije sirove nafte ili zemnog gasa (kao vodećih energenata) zbog posljedica ratnih dejstava koje se osjete u svim vidovima industrije, a naročito u autoindustriji. Naravno, ovo je u posljednjih nekoliko godina uticalo na razvoj i ekspanziju električnih vozila, kako putničkih tako i teretnih, koja su prezentovana prvenstveno kao ekološka i tehnološki naprednija u odnosu na konvencionalna vozila. Uvođenjem u upotrebu vozila na električni pogon, počeli su se ispoljavati i njihovi nedostaci u odnosu na konvencionalna vozila, kako u pogledu opskrbljivanja električnom energijom tako i u pogledu zaštite od požara, odnosno gašenja požara na istim.

Ključne riječi: električna vozila – podjela, punjenje, nedostaci, gašenje požara

Correspondence to: Aleksandar Majstorović
Faculty of Technical Studies, University of Travnik, Bosnia and Herzegovina
E-mail: aleksandar.majstorovic@eftfts.edu.ba