Research on fire fighting and emergency rescue of all-electric vehicle traffic accident

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Abstract. With the popularization of all-electric vehicles, the application of all-electric vehicles in traffic accidents is more and more. It is also difficult to solve the problems such as the selection of fire extinguishing agent for electric vehicles, the update control of high-pressure protection and emergency rescue. Based on the comparison and analysis of the normal operation of automatic sprinkling extinguishing agent and the reaction conditions inside lithium battery, this paper puts forward the updating method of selecting and controlling extinguishing agent for all-electric vehicle. And by analyzing the characteristics and danger of all-electric vehicle traffic accident, the insulation protection and power off method for all-electric fire and emergency rescue are also mentioned in this paper.

1. Introduction
In recent years, with the strong encouragement of the government, all-electric vehicle industry has developed rapidly. As shown in Figure 1, the number of all-electric vehicle in China is on the rise, and the growth rate is still increasing. From 2016 to 2019, the number of all-electric vehicle increased from 0.91 million to 3.81 million. According to the data fitting analysis, the vehicle ownership will continue to rise to 5 million in 2020. With the rapid development of all-electric vehicle, the traffic safety problems of all-electric vehicle are becoming more and more obvious. It is necessary to study the fire fighting and rescue of all-electric vehicle. The research on lithium battery fire to China is represented by the State Key Laboratory of China University of science and technology, Li Z.Y\textsuperscript{[1]}, Jiang L. R\textsuperscript{[2]}, Ke J. C\textsuperscript{[3]}, Cao W. P\textsuperscript{[4]}, Qian F. Y\textsuperscript{[5]}, Xu X. C\textsuperscript{[6]} and others studied the fire fighting tactics and methods of all-electric vehicle. Song Z. L\textsuperscript{[7]}, Cao L. Y\textsuperscript{[8]}, Huang Y. M\textsuperscript{[9]} and others have carried out different degrees of research on rescue tactics and methods of all-electric vehicle. The National Fire Protection Association (NFPA) has also described the fire fighting and rescue technologies and methods for energy vehicles in the "guidelines for emergency rescue of electric vehicles". However, there are still some problems and difficulties to be solved, such as insulation protection, power-off treatment, reburning inhibition and sewage treatment. In this paper, the thinking of fire fighting and rescue of all-electric vehicle traffic accident is put forward through analyzing the characteristics and risk of all-electric vehicle accident.
2. Characteristics and risk analysis of traffic accidents of all-electric vehicle

2.1. High voltage
The battery voltage of fuel vehicle is mostly 12–24V, which is installed in the engine cabin of the front part of the vehicle. all-electric vehicle usually are equipped with high voltage batteries of DC voltage of 100 ~ 360V or AC voltage of 650V, which is installed in the middle of the car. Structure of the system is more complicated. So there's a big difference between a all-electric vehicle and a fuel vehicle when you cut off the power. Meanwhile, the safe voltage that the human body can bear is 36V. There are great risks of electric shock in the rescue of all-electric vehicle, such as breaking down, cutting off electricity, putting out the fire and water related vehicles rescue, so that rescuers should strengthen insulation protection.

2.2. A lot of poisonous smoke
The smoke components of fuel vehicle fire include CO₂, CO, oxynitride and sulphur oxides, and the main ingredient is non-toxic carbon dioxide. However, the combustion and thermal runaway of lithium battery will produce a large number of toxic gases, such as C₆H₆, C₆H₅CH₃, C₈H₈, C₁₂H₁₀, C₃H₄O, CO, COS, HF, olefins, alkanes and ethers et al. There is more toxic than the fuel vehicle, so it is easy to cause poisoning or suffocation of trapped personnel and rescuer. When dealing with all-electric vehicle fire, rescuers should strengthen their personal protection[1].

2.3. Fast burning and heating rate
Lithium battery burns very fast. Figure 2 is the temperature change after the spark of lithium battery. The data shows that the combustion temperature of lithium battery rises very fast, reaching 1200 °C in only 210s. According to the National Fire Protection Association (NFPA), the fire spread rapidly in the power lithium-ion battery module in just a few seconds, lasting about 27 minutes. The experimental data onto Shanghai Fire Research Institute shows the maximum flame distance from lithium battery can reach 5m. So, once the lithium battery is burned, it is easy to ignite the surrounding combustibles.
2.4. Easy to reburning and explosiveness

The explosion of fuel vehicle is caused by the high temperature and High tank pressure, which will not reignite after the fire has died out. The explosion of lithium ion battery is caused by the chemical and electrochemical reaction between the active substances and electrolyte components inside the battery, which produces a large amount of heat and gas. High temperature, impact and combustion will promote the reaction. After the lithium battery fire is extinguished, it ignites easily. Li Y[10] et al. studied the reignition of lithium battery fires under the action of different fire extinguishing agents. Table 1 shows the influence of different extinguishing agents on reignition of single lithium battery. The result of the experiment shows that the fire easy to reburning and different kinds of fire extinguishing agents have different effects on the extinguishing and reburning time. Typical extinguishing agents such as water forming film foam, carbon dioxide (CO₂), ABC dry chemical could not completely extinguish the fire caused by lithium battery, and all of them appeared reignition phenomenon.

Table.1 Fire extinguishing effect of different fire extinguishing agents[10]

| Extinguishing agent          | Application time of extinguishing agent / s | fire Experimental phenomena                        |
|------------------------------|---------------------------------------------|---------------------------------------------------|
| ABC Dry chemical             | 37                                          | The open fire was put out and it reburning 8s later |
| CO₂                          | 38                                          | The open fire was put out and it reburning 10s later |
| water forming film foam      | 47                                          | The open fire was put out and it reburning 45s later |

2.5. environment pollution

Fire fighting and cooling of lithium batteries need a lot of water washing fire extinguishing agents and the combustion produces a large number of toxic compounds, which include C₆H₆, C₆H₅CH₃, C₆H₅, C₁₂H₁₀, C₃H₄O, CO, COS, HF, olefins, alkanes and ethers et al. The most toxic is electrolyte of lithium batteries (organic solvents, electrolytes LiF6 and other additives). Combustion, explosion and collision can cause electrolyte leakage, it mixes into fire-fighting sewage will cause great pollution to the environment without taking effective measures to collect and treat sewage.

3. Thoughts on fire fighting and rescue of all-electric vehicle

3.1. Personal protective equipment

All-electric vehicle accidents are more complicated than traditional vehicle accidents, Suggestions for fireman's personal protection is showed in Table II . Firemen generally wear fire helmets, protective clothing, anti-fire gloves, fire protection boots and goggles when dealing with fuel vehicle fire; when fuel vehicles are engaged in emergency rescue, rescue helmets, rescue suits, rescue gloves,
rescue boots and goggles are generally worn. The pure uses lithium batteries with high voltage for energy and lithium batteries burn quickly which will release a large amount of toxic smoke and easy to explode and reignite. Therefore, personal protection of fire fighters is extremely important in dealing with all-electric vehicle accidents. When dealing with all-electric vehicles fire, front-line combatants should wear anti-fire and chemical protective suits or simple anti-chemical suits, fire helmets, fire positive pressure breathing apparatus, insulating gloves, insulating boots and goggles, etc. When the accidents is no flame, front-line combatants shall wear electrical insulation protective suits, emergency rescue suits, rescue helmets, insulating gloves, insulating boots and goggles, etc. In dealing with accidents involving water, firefighter should take whole-body insulation protection to reduce the hazards to them, such as high voltage and toxic smoke.

Table 2 Suggestions on safety protection of vehicle traffic accident disposal

| Fuel vehicles | head | respiratory tract | body | other parts |
|---------------|------|-------------------|------|-------------|
| Fire fighting and rescue | Rescue helmet | N95 face-mask | Fire fighting protective clothing | Fire gloves, Exposure Footwear for Firemen, goggles |
| Emergency rescue | Rescue helmet | Insulating protective clothing, Rescue clothing | Insulating gloves, High voltage insulating boots, goggles |
| all-electric vehicle | Fire helmet | Fire positive pressure breathing apparatus | Anti-fire and chemical protective suits | Insulating gloves, High voltage insulating boots, goggles |

In dealing with accidents involving water, firefighter should take whole-body insulation protection

3.2. Cut off the power
Generally, fuel vehicles will stall before being dismantled. the battery is installed in the lower middle part of the car and has high voltage batteries with DC voltage of 100 ~ 360V or AC voltage of 650V, so cutting off power is complicated. Rescues should take effective measures to prevent electric shock when cutting off the vehicle circuity. During the rescue, it is forbidden to directly contact the power supply components of the vehicle and knock or puncture the battery pack. As shown in Figure 3, When the vehicle configuration and function are basically normal, rescuers can cut out the vehicle, cutting off the 12V power supply manually, and pull out the fuse of the high-voltage line; but when the vehicle body changes greatly, you have to turn over the vehicle body, and cut the car body near the control line. Then cut the control line with the insulating scissors. High-voltage wiring harness usually adopts the eye-catching red or orange, which runs through the whole body along the vehicle bottom. Low-voltage circuit is usually marked in yellow. Insulation tape can be used for winding on it to achieve power-off effect. Pay attention to insulation protection, and fix the car body when turning over to avoid vibration.

![Cut off the 12V power supply](image1)
![Pull out the high-voltage system fuse](image2)

Figure 3 Schematic diagram of power cut off

3.3. Fire fighting
Water and foam extinguishing agent are commonly used in fuel vehicle fire fighting. BC dry chemical is commonly used in initial fire fighting. There is dramatically different in the choice of extinguishing agent, because the combustion of lithium battery is accompanied by chemical reaction, and the combustion substance is different. Table 3 shows the fire extinguishing effect of different fire extinguishing agents on single lithium battery fire. Different fire extinguishing agents on the inhibition of temperature rise have extremely different effects. According to the comparison of heating rate of lithium battery under different fire extinguishing agents, it is found that water has the best effect on
inhibiting the temperature rise of lithium battery, followed by perfluorinated hexanone and hfc-277ea, and the worst is CO\(_2\) with re-burning phenomenon. Therefore, water can be used to put out the general lithium battery fire. When dealing with lithium battery fire nobody trapped, the front-line fighters should spray water-based fire-extinguishing agent at 10-15m away from the accident site to cooling and extinguishing the fire. When the fire extinguishing agent is not enough, we can strengthen the on-site vigilance to waiting for the vehicle burns out. Rather, when person is trapped, the fire fighters shall take tactical measures to control the fire according to the scene and the specific situation. By controlling the fire and spray water mist to suppress the fire. After successfully rescuing the trapped personnel, all personnel shall evacuate to the location 10 ~ 15m away from the accident site and spray water extinguishing agent to extinguish the fire. Setting up special personnel to monitor battery temperature all times. When the temperature rises abnormally or produces a lot of white smoke, firefighters must to evacuate quickly to a safe area, prevent casualties caused by explosion.

Table.3 fire extinguishing effect of different fire extinguishing agents on single lithium battery fire

| Extinguishing agent | Release time of extinguishing agent (s) | Extinguishing mechanisms | Heating rate of lithium (\(^\circ\)C/s) | Extinguished effect |
|---------------------|----------------------------------------|--------------------------|----------------------------------------|---------------------|
| HFC-277ea           | 13                                     | Isolation, chemical inhibition | 2.57                                   | Extinguished ,No reignition |
| CO\(_2\)            | 13                                     | Smothering, Isolation     | 6.14                                   | Extinguished;Reignition occurs after 10s |
| ABC dry chemical    | 12                                     | Cooling, Smothering, Isolation, chemical inhibition | 4.40                                   | Extinguished;Reignition occurs after 8s |
| H\(_2\)O             | 13                                     | Cooling, Smothering       | 2.11                                   | Extinguished ,No reignition |
| 2-METHYL-3-PENTANONE | 13                                     | Cooling, Isolation, chemical inhibition | 2.53                                   | Extinguished ,No reignition |

3.4. Cooling

The electrochemical reaction in lithium battery is slow at low temperature and basically inactive at 0 °C. Therefore, a large amount of water is used to cool the battery to reduce the electrochemical reaction rate inside the battery. If no open fire in the battery, it should be removed and transferred the battery immediately, and use plenty of water for cooling to prevent further combustion of lithium battery to aggravate fire. After the open fire is put out, a large amount of water should be used for cooling to prevent the lithium battery from re-burning when deal with the lithium battery fire.

3.5. sewage disposal

The way to spread pollution in general traffic accidents is through drainage system, which mainly includes river channels, surface drainage system and sewage system of road, irrigation channel of farmland, drainage system of plant area, surface cavity left by construction, etc. We can control the source of pollution and cut off the transmission route to prevent the sewage from polluting the environment. The way of controlling source of pollution is to adopt effective extinguishant and the method of cutting off the transmission is to take measures to prevent the spread of sewage, main measures: use leak proof pad to block the sewer to prevent sewage from flowing into sewers; Using a leak proof bag to plug the inside of the sewer, the sewer can be used as a temporary reservoir for centralized treatment of sewage after accident treatment; river channels or open ditches can be dammed to prevent the spread of sewage downstream; the surface sewage can be controlled by oil fence or sand embankment.
4. Results & Discussion
All-electric vehicle have the characteristics of high fuel efficiency, low emission or zero emission. Under the pressure of energy and environmental protection, it will become the main direction of future vehicles. And the research on all-electric vehicle is also the irresistible trend. This paper analyzes the characteristics and risk of traffic accidents of all-electric vehicle, and puts forward suggestions for fire fighting and rescue of traffic accidents of all-electric vehicle from the aspects of warning and individual protection, power failure, fire fighting, cooling and sewage treatment. Through this study, we found the following problems:

4.1. Reburning control and sewage treatment
Through the above research, it is found that the open fire of all-electric vehicle will be reignited soon after being put out, and a large amount of water is used for cooling, which is a waste of resources and the sewage produced is not easy to be treated. An effective inhibitor or method should be introduced to reduce the amount of fire sewage. It should also be the future research direction to explore the measures to reduce the environmental pollution caused by fire sewage.

4.2. The fire extinguishing agent cannot reach the ignition point
All-electric vehicle are equipped with sufficient sealing performance lithium battery pack, so the fire extinguishing agent can only act on the battery shell, and lithium battery has high voltage and explosive property, there is no technical measures to directly apply the fire extinguishing agent to the internal ignition point of the battery in case of fire, which is one of the difficulties in the research of fire fighting and rescue for all-electric vehicle.

References
[1] Li Z. Y. Research on battery car fire fighting tactics and methods [J]. Journal of the armed police academy, 2019,35 (04): 36-40.
[2] Jiang L. R. Research on tactics and methods of lithium battery fire fighting and rescue [j]. Fire fighting technology and product information, 2017 (12): 33-36.
[3] Ke J. C. Discussion on fire fighting and rescue technology of lithium battery electric vehicle [J]. Fire science and technology, 2017,36 (12): 1725-1727.
[4] Cao W. P. Research on fire fighting technology and tactics of electric vehicles [J]. Fire science and technology, 2018,37 (10): 1409-1412.
[5] Qian F. Y. Thoughts on the fire fighting of electric vehicles [J]. Fire protection (Electronic Edition), 2020,6 (02): 67-68.
[6] Xu X. C. Analysis of lithium ion battery fire risk and fire fighting methods [J]. Today's fire protection, 2020,5 (02): 78-79.
[7] Song Z. L. Study on fire risk and emergency rescue of lithium ion electric vehicle [J]. Industrial safety and environmental protection, 2020,46 (05): 16-19.
[8] Cao L. Y. Research on electric vehicle fire extinguishing and emergency rescue technology [a]. China Fire Protection Association. Proceedings of 2015 China Fire Protection Association Annual Meeting of science and technology [C]. China Fire Protection Association, 2015:3.
[9] Huang Y. M. Research on new energy electric vehicle traffic accident rescue technology[J]. Guangdong chemical industry, 2020,47 (14): 114 + 121.
[10] Li Y. Experimental study on typical lithium ion battery fire extinguishing [J]. Journal of safety and environment, 2015,15 (06): 120-125.
[11] Liu Y. J. Experimental study on extinguishing large capacity lithium-ion battery fire with various fire extinguishing agents [J]. Energy storage science and technology, 2018,7 (06): 1105-1112.