Safe Maritime Transportation of Electric Vehicles

– Characteristics of EV Fires and Guidelines for Response –

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1. INTRODUCTION

In recent years, many electric vehicles (EVs) can be seen travelling around cities and towns. Because EVs use lithium-ion batteries (LIBs) as a drive power source and do not emit CO_2 while travelling, as gasoline-powered vehicles do, EVs are considered to be superior in environmental terms. The characteristics of LIBs include high energy density, high voltage and chargeability.

Fig. 1 is a graph of the number of registered EVs published by the International Energy Agency (IEA). Internationally, adoption of EVs to achieve carbon neutrality is increasing exponentially. Transportation of EVs by vehicle carriers, including existing vessels, has begun, and the share of EVs among all vehicles being transported is currently increasing. Among potential problems, if an abnormality occurs in the LIB used to power an EV or a fire breaks out from the battery, special response methods must be applied. It is also known that much time is required to extinguish fires once a fire breaks out from an LIB. Moreover, because the vehicles transported on vehicle carriers are loaded in the vehicle spaces (car decks) with minimal distance between them, there is a risk that the fire will spread to other adjacent vehicles, and it may be difficult to approach the burning vehicles to conduct fire-fighting operations. When a fire breaks out from an EV or spreads to other EVs, special measures must be implemented in the special environment of the vehicle space. Thus, one issue is whether fire-fighting operations can be carried out, considering the special characteristics of the vehicle spaces of vehicle carriers and the characteristics of the vehicle loading condition. In other words, a special response and guidelines are necessary for the safe transportation of EVs with LIBs by vehicle carriers.

This article provides a commentary on *"Guideline for the Safe Transportation of Electric Vehicles"* issued by ClassNK (hereinafter, referred to as "the Society") to contribute to the safe maritime transportation of EVs by vehicle carriers.

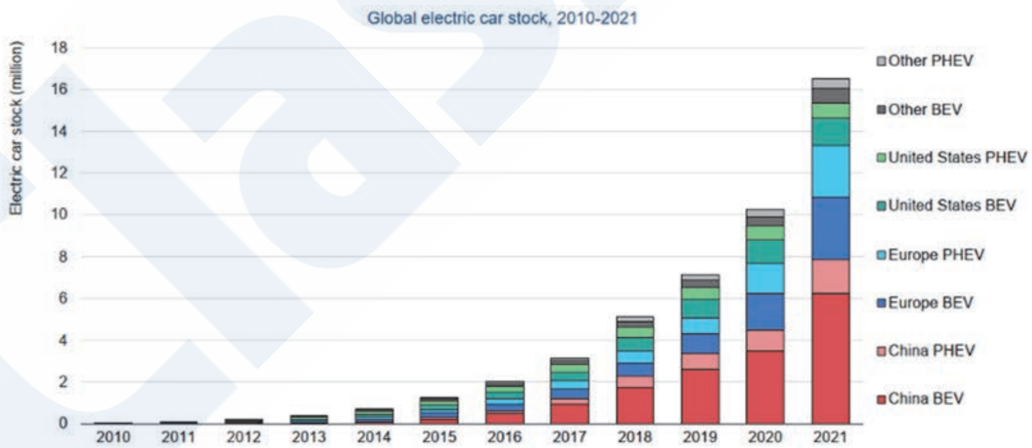

Fig. 1 Number of registered electric vehicles (EVs)[1)]

2. INITIATIVES OF THE SOCIETY

Based on the fire accidents involving vehicle carriers in recent years, the Society continuously studies fire safety measures, particularly when transporting EVs. What we wish to note here is that statistical data show that the risk of a fire occurring in an EV is low in comparison with gasoline-powered vehicles, and there are still no cases in which an EV was identified as the origin of a fire that caused a fire accident on a vehicle carrier.

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Nevertheless, unlike gasoline-powered vehicles, the power source for EVs is electricity stored in a secondary cell (LIB). If an internal short circuit occurs in an LIB, thermal runaway will begin, and a fire may break out. Moreover, once a fire occurs in an LIB, it is known that the fire is extremely difficult to extinguish.

Guidelines for responding to LIB fires on land already exists, but whether they can be implemented under the special environment of a ship is a major issue.

Therefore, in August 2023, the Society released *"Guideline for the Safe Transportation of Electric Vehicles (Edition 1.0)"* and *"List of Safety Measures for the Maritime Transportation of Electric Vehicles"* as guidelines for responding to EV fires, considering the special environment of ships and the characteristics of EV fires. It is our hope that those who own, operate or manage ships, and the shipyards, will study measures referring to these documents, and this will lead to a decrease in fire damage of vehicle carriers. From the following Chapter 3, this article will explain the details related to safe maritime transportation of EVs in concrete terms.

3. TECHNICAL EXPLANATION OF GUIDELINE FOR SAFE TRANSPORTATION OF ELECTRIC VEHICLES

3.1 Characteristics of Electric Vehicles and Characteristics of EV Fires

3.1.1 Electric Vehicles

Electric vehicles are vehicles that are powered by electricity. The types of vehicles that use electricity as a power source include pure electric vehicles (also called "battery electric vehicles" or BEVs), plugin hybrids and hybrid vehicles. In spite of differences in the types of batteries used in the respective vehicles and their systems and capacities, they can all be considered as types of EVs. However, it should be noted that the risk when a fire occurs is not completely the same because the types of battery cells and the capacities of the batteries are different.

Pure EVs have the largest battery capacity, and many use lithium-ion batteries. Many BEVs obtains the battery cells which are installed in a battery pack that extends under the entire floor of the vehicle, as shown in Fig. 2. From several 10s to several 1 000s of individual lithium (Li) ion cells may be installed in the battery pack, although the number differs depending on the type of vehicle and battery.

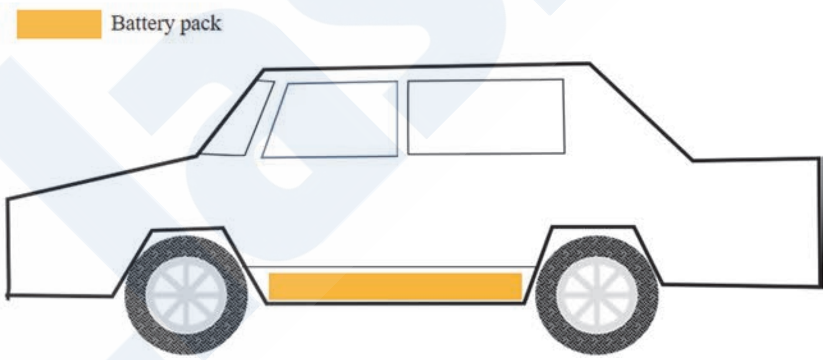

Fig. 2 Location of drive battery in an EV

3.1.2 Drive Batteries

At present, the lithium-ion battery is considered to be the only type of battery that has an energy density which makes it possible to install the power capacity necessary for vehicle travel at a practical level. LIBs achieve a high rated voltage and high energy density because electrolysis is less likely to be caused until a high potential (high voltage) due to the use of an organic solvent in the electrolyte. However, if electrolysis occurs and gasification takes place, the battery does not return to its original state. For this reason, various conditions, such as the input/output electricity, cell temperature are monitored [2].

There are three types of LIB cells, the laminated type consisting of cells in sheet form, square shaped LIBs, and the familiar cylindrical type familiar in shape of dry-cell battery. Although the battery cells have various distinctive features, which type is used differs in each vehicle model, depending on the cruising range and whether a cooling device is necessary or not. As mentioned previously in EVs, a robust case which houses the lithium-ion cells, called a battery pack, is installed, and the total capacity of the battery ranges from 20 kWh to more than 100 kWh. The voltage is extremely high, at 300 V to 400 V.

3.1.3 Safety measures of EVs

The following safety measures are taken for the passengers of EVs equipped with high-voltage LIBs [3].

1) As measures to prevent electrical shock, the drive battery is installed in a location where passengers will not come into contact with the high-voltage battery or high-voltage components during a vehicle collision. The battery is protected by a robust case and high-voltage circuits are shut down in case of a collision.

2) To prevent thermal runaway, the current, voltage and temperature are monitored and controlled by a battery management system, and high-voltage circuits are shut down if an abnormality is detected.

Nevertheless, the author hopes that all concerned will understand that the safety measures for EVs are not limited to only those mentioned here, and the safety of EVs is increasing on a daily basis.

3.1.4 Characteristics of EV Fires

Because a heavy battery pack is installed in EVs, many composite resins, etc. are used to reduce vehicle body weight. It must also be noted that more combustible materials are used in EVs in comparison with conventional gasoline-powered vehicles.

In the event of an internal short circuit in the Li-ion cells, thermal runaway will occur. Fig. 3 shows an example of the process leading to thermal runaway of an LIB. This figure shows the experimental data for a cylindrical-type cell. The temperature of the battery cell in which the internal short-circuit occurred rises due to Joule heat generation. In this process, a chemical reaction between the negative electrode and the electrolyte and meltdown of the separator occur, finally resulting in an exothermal reaction with a temperature exceeding 1 000 °C. In these experimental results, the time to reach 1 000 °C was less than a mere 28 minutes.

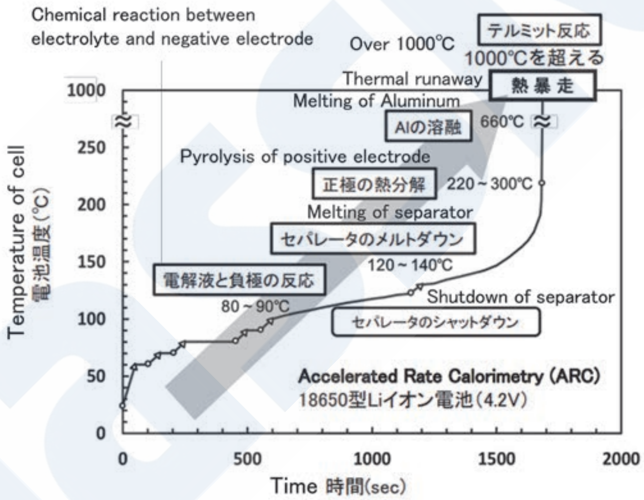

Fig. 3 Example of temperature and time to thermal runaway [4]

In addition, it must also be remembered that combustible gases are generated in the process that causes thermal runaway. The results of an analysis of the gases generated from LIBs revealed that the combustible gases include hydrocarbon gases such as methane and ethane, and hydrogen gas, among others [5]. Since this means that a combustible gas atmosphere may form in the EV loading space in vehicle carriers, attention must be paid to ignition and explosion.

Moreover, the gases generated in this process are not limited to combustible gases, but also include hydrogen fluoride (HF) as the toxic gas. HF, which is extremely harmful to human life and health, is formed by the reaction of water with the lithium hexafluorophosphate contained in the electrolyte of LIBs, or the process of pyrolysis of polyvinylidene DiFluoride, which is a binder [6]. The IDLH (**I**mmediate **D**angerous to **L**ife or **H**ealth) of hydrogen fluoride is 30 ppm, which is the upper concentration limit from which one could escape within 30 min. without a respirator and without experiencing any escape impairing or irreversible heald effects.

It is also necessary to bear in mind the danger of electrical shock. As mentioned above, high voltage LIBs, with voltages of 300 V to 400 V are used in EVs, but the risk of shock is minimal if water is sprayed on a cell where an internal short circuit has already occurred. However, considering the fact that EVs contain from several 10 to several 1 000 battery cells, and all of these cells have not necessarily suffered internal short circuits, it is important to remember that spraying water on battery cells where internal short circuits have not occurred can also cause electrical shock.

3.2 Guidelines for Responding to EV Fires

Up to this point, we have explained the characteristics of EV fires and points to note in this connection. The following explains how those concerned should respond to EV fires in concrete terms, considering the characteristics of EV fires, the environment in the vehicle spaces of vehicle carriers, and the condition of vehicle loading condition. Before explaining the individual items, please refer to Table 1, which arranges the scenarios leading up to a EV fire. Although also explained in section 3.1, thermal runaway occurs when a Li-ion cell in an EV suffers an internal short circuit. If thermal runaway occurs in a Li-ion cell, the temperature of the cell will rise due to Joule heat generation, the positive and negative electrodes will undergo pyrolysis, and the electrolyte will be vaporized, resulting in the generation of combustible gases. These gases are discharged outside the vehicle through the safety valve of the battery pack, and can be recognized as white smoke. There is a possibility that an explosive atmosphere may form in the vehicle space due to the discharge of combustible gases from the vehicle into the vehicle space. If the gas concentration reaches the Lower Explosive Limit (LEL) and ignition energy is provided by an ignition source, the gas will ignite, and an explosion and fire will occur. It is thought that the fire will ignite parts of the vehicle, and the EV itself will catch fire and begin to burn. In this case, there is a danger that the fire in that EV may then spread to adjacent vehicles, and fires may also occur in unexpected locations if combustible gases accumulate and catch fire at a location different from the burning vehicle. These events may cause the fire to spread through the vehicle loading space. The following explains the countermeasures that are thought to be effective, considering these fire scenarios.

3.2.1 Early Detection

One of the most important points when considering countermeasures for EV fires is early detection of vehicles in which a fire appears to be likely and vehicles that are actually on fire. Fig. 3 explained that the time from an internal short circuit to the final period of thermal runaway is extremely short. In other words, it is desirable to take action as early as possible to isolate vehicles in which a fire appears likely and to respond to burning vehicles. To solve these problems, as shown in Fig. 4, it is important to arrange the process leading to thermal runaway in an LIB by event, and to take effective action in each stage. These are classified in three phases, the “Temperature rise stage,” in which temperature rise is occurring in a battery cell where thermal runaway has occurred, “Combustible gas generation stage,” in which combustible gas is spewing from the battery pack, and the “Fire outbreak stage,” in which a fire actually occurs.

In the “Temperature rise stage,” one conceivable measure is to install a sensor capable of detecting temperature rise in cells near the battery. However, this involves numerous problems, such as how the signal for the temperature rise detected by the sensor is to be transmitted and received.

In the “Combustible gas generation stage,” detection of the combustible gases (HC gases and hydrogen) generated before a fire occurs is conceivable, but considering the total amount of combustible gases generated from an LIB, there are also many problems, such as what level of concentration the gas detector should be able to detect, and the possibility that the gases may spread due to the condition of ventilation in the vehicle space, making quick detection impossible.

Table 1　Scenario of fire spread in vehicle carrier

Fire escalation scenario				
Internal short circuit	Temperature rise	Emitting white vapour	Ignition to flammable gases Fire spread to vehicle parts	Fire escalation
				
Thermal runaway occur due to the trigger such as internal short circuit etc,.	Temperature of battery cell which is under thermal runaway rise.	Flammable gases and/or toxic gases are emitted and blowed off from safety valves due to the chemical reaction of battery cell.	Igniting to flammable gases and fire spread to the vehicle parts.	Flammable gas generate explosion gas atmosphere inside vehicle loading space and fire and/or explosion occur at unexpected space and fire escalation occur.

In the "Fire outbreak stage," flame detectors, heat detectors and smoke detectors are effective. However, if the flame detectors or heat detectors are not installed in locations where flames are visible or locations that receive radiant heat, they cannot fully demonstrate their functions. Therefore, installation of a remarkably large number of these detectors in the vehicle space is expected to be necessary. Furthermore, to ensure the maximum effect of smoke detectors, the smoke caused by a fire must be able to reach the detector in a timely manner. Since beams and girders are arranged in vehicle space ceiling and will restrict the flow of smoke, ingenuity is necessary when selecting the positions for installation of smoke detectors.

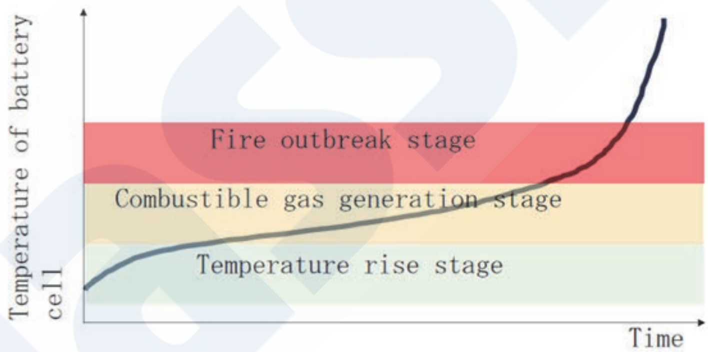

Fig. 4　Arrangement of events leading to thermal runaway of Li ion cell

Among current technologies, there is one product that demonstrates effectiveness in both the "Fire outbreak stage" and the "Combustible gas generation stage," namely, Closed Circuit Tele-Vision (CCTV). Because CCTV can recognize not only the black smoke when a fire breaks out, but also the white smoke of combustible gases as images, detection is possible from the "Combustible gas generation stage" by monitoring the vehicle space by CCTV. Fig. 5 shows a graphic representation of an image captured by a CCTV camera, which can be observed when a CCTV system is installed in a vehicle space. However, in addition to the very large number of CCTV cameras that must be installed for comprehensive monitoring of the vehicle space, full-time, image-by-image monitoring is not realistic. Adoption of a technology that recognizes smoke and issues alarms using AI-based image recognition technology is considered to be an effective solution to these problems.

Fig. 5　Appearance of vehicle captured by CCTV installed in vehicle space (image)

Up to this point, various countermeasures for early detection have been explained, but it is thought that issuance of alarms by the EV itself can also contribute to early detection. Because the battery management systems installed in EVs monitor the condition of the battery cells (temperature, voltage, etc.), it is thought that lighting the lights or honking the horn of the vehicle at a certain stage when temperature rise is detected in battery cells can make a large contribution to early detection of abnormal vehicles. The only technology capable of diagnosing abnormalities in an EV before they are visible from outside the vehicle is the battery management system installed in EVs.

3.2.2　Prevention of Secondary Fires

Concretely, the combustible gases generated from LIBs in the process of thermal runaway include hydrogen, HC gases, such as methane, ethane, propane, etc. The generated amounts of the respective gases differ depending on the type of positive electrode and negative electrode, the type and amount of electrolyte, and the charging rate [4]. If combustible gases are generated, there is concern that they may accumulate in the vehicle space and reach the LEL, and if an ignition source is present in the atmosphere and provides energy exceeding the minimum ignition energy, the gases will ignite, resulting in an explosion and fire. For example, when non-explosion-proof devices are installed in the space formed by beams and girders, as illustrated in Fig. 6, ignition and fire may occur if the accumulated combustible gases reach 100 % of LEL. Therefore, one effective measure is to determine where combustible gases may accumulate in vehicle spaces, and adopt a structure in which gases will not accumulate in the place.

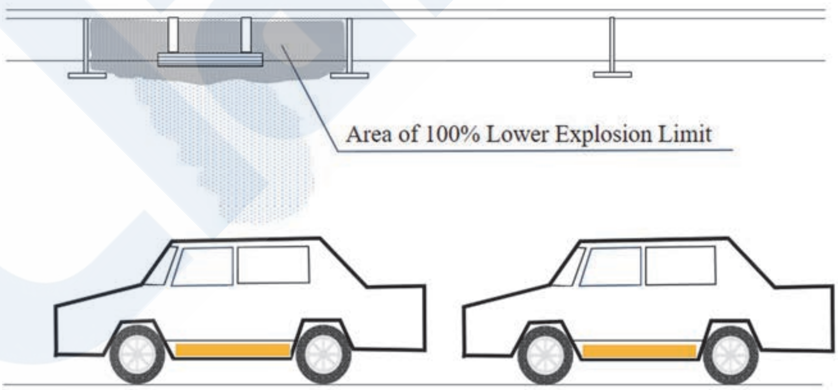

Fig. 6　Image of formation of explosive atmosphere in vehicle space

Classified broadly, the following two methods for preventing secondary fires in vehicle spaces are possible.

● Structure that makes it possible to discharge the combustible gases from the ship by ventilation so they will not form an explosive atmosphere, even if emitted from a vehicle, and prevents accumulation of gases in the vehicle space.

● Use of appropriate explosion-proof electrical devices in vehicle spaces so an explosive atmosphere will not ignite, even if formed.

Because combustible gases are emitted in the vehicle space during an emergency, the explosion-proof class of electrical devices has an explosion-proof structure suitable for use in Zone 2, as classified in IEC60079-10, and for gas vapor groups, temperature classes, gas vapor group IIC and temperature class T2 are appropriate, based on the results of an investigation of the types of gases generated during thermal runaway. It should be noted that these explosion-proof classes consider only the gas species generated from LIBs. The explosion-proof class required for other types of vehicles, such gasoline-powered vehicles, natural gas-powered vehicles, hydrogen vehicles, and vehicles carrying hazardous substances, etc., must be considered separately for each type of vehicle.

3.2.3 Prevention of Fire Spread

Because vehicles are loaded in vehicle carriers with a Door to Door spacing of 10 cm and Rear to Bumper spacing of 30 cm, it is easy to imagine that a fire which occurs in one vehicle will spread to adjacent vehicles by radiant heat during the fire. Therefore, after a fire occurs, it is extremely important to take fire-fighting action to isolate the burning vehicle from adjacent vehicles. Various means of preventing fire spread are conceivable, but two comparatively well-known methods are the water curtain and the fire blanket.

A water curtain is a curtain of water formed by water sprayed from nozzles, which can cut off the radiant heat generated by a burning vehicle. Although fixed water curtain systems exist, there is product that applies a portable-type called a water curtain hose, as shown in Fig. 7. Unlike fixed water curtain systems, the water curtain hose does not require fixed piping and nozzles, and holes with a special shape are provided in the fire hose. Because it can be placed in the location where the user wishes to form a water curtain depending on the condition of the vehicle space, it is considered to be one effective means of isolating burning vehicles.

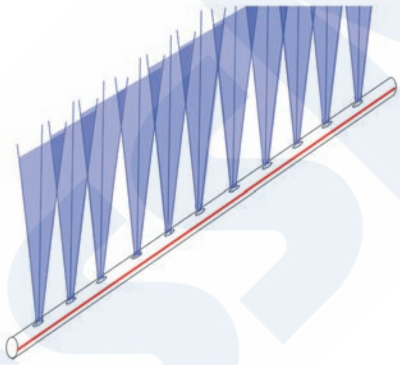

Fig. 7　Image of water curtain hose

A fire blanket is essentially a blanket which is used to enclose a burning vehicle and extinguish the fire by creating an oxygen-deficient condition inside the blanket. However, in the case of vehicle carriers, the fire may weaken, but it cannot be completely extinguished due to the presence of lashing holes. Although fire blankets are not suitable for extinguishing car fires on vehicle carriers, they can be used to prevent fire spread due to their excellent heat resistance. Fire blankets can be deployed even by two Society staff members, as demonstrated in Fig. 8, but considering the conditions in actual vehicle spaces, some ingenuity may be required when deploying fire blankets in a vehicle space.

Fig. 8　Fire blanket (photo courtesy of NIPPON TOKUSO CO., LTD.)

3.2.4 Fire-Fighting Procedures

What is important as a fire-fighting procedure for LIB fires is to understand the concept of “Burning out.” “Burning out” means that burnable fuel is no longer available and the fire burns out. For example, when a gas fire occurs, the gas will continue leaking after the fire has been extinguished, and if combustible gas fills the space and is reignited, this will cause an explosion. In this case, the fire-fighting procedure is to cut off the gas supply source and allow the remaining gas to burn up, without attempting to extinguish the fire immediately. In the meantime, efforts must be made to prevent the fire from spreading.

Battery fires are similar, in that the chemical reactions in a battery in which thermal runaway has occurred will continue until the potential difference between the electrodes is eliminated, and these reactions will continue to generate heat and gas, even if the fire from the battery is extinguished. Since it is not possible to cut off the supply of gas from the generation source, it is necessary to slow the chemical reactions by decreasing the temperature of the battery in which thermal runaway occurred, and to concentrate on continuing actions to prevent the fire from spreading to the surroundings until the chemical reactions are finished.

As one means of cooling the battery, releasing water from hydrants in the ship is effective. Because the EV batteries are arranged at the bottom of the vehicle, the battery itself cannot be cooled simply by spraying water from above the vehicle. Cooling the battery by releasing water from the vehicle bottom using a water fog applicator like that shown in Fig. 9, or directly cooling the cell by using a penetrating nozzle are effective. To prevent electrical shock, use of a penetrating nozzle is limited to cases where the nozzle can be inserted safely, at a position where it will not penetrate to a cell where internal short circuit has not occurred.

An important point when cooling a battery is the fact that the temperature will rise again, combustible gases will be generated, and the fire will be rekindled if cooling of a battery in which thermal runaway has occurred is stopped. Thus, it is also important to confirm each time that the temperature is not rising, even after battery cooling, by using a thermal camera, etc.

Fig. 9 Water fog applicator (excerpted from Marine Fire Fighting)

Although cooling the battery is extremely important, due to the high voltage of the battery, firefighters must be mindful of electrical shock when conducting fire-fighting operations. Experimental results show the necessary distance that a firefighter must take to avoid shock when using a solid stream or spraying water on an electrified grid [7]. Based on a water flowrate of 28.35 m^3/h and pressure of 0.21 MPa, a current value of 0 mA can be obtained when that distance is 11.5 ft (about 3.45 m) for a solid stream, 1.5 ft (about 0.45 m) for water spraying with an angle of 30°, and 0.5 ft (about 0.15 m) for a spray angle of 90°. In other words, when electrical shock is considered, these results show that it is important to use spraying.

3.2.5 Fire-Fighting Operations

Here, the important points for fire-fighting operations will be explained. To secure safety when conducting fire-fighting operations, the basic principle is to confront the fire with at least two firefighters per team (two buddy system). Even if one firefighter encounters some kind of danger, the other may be able to respond in some cases. Moreover, even assuming one firefighter overlooks a dangerous situation, there is a low probability that two firefighters will fail to see it.

When a fire breaks out, smoke naturally occurs. Smoke is a gas consisting of a mixture of suspended solids (soot, fibers, dust), liquid particles (hydrocarbons and water) and gases (toxic gases including carbon monoxide, hydrogen cyanide, etc.), and is harmful to human life and health. In a space where a fire has broken out, smoke is generated and visibility becomes poor. This means it is important to disperse the smoke generated by the fire, that is, perform ventilation, before carrying out fire-fighting operations. Ventilation control is explained in detail in the next section. Visibility can be secured by removing the smoke from the space where the fire has occurred by ventilation. Securing visibility contributes to identification of the source of the fire, making it possible to take appropriate action, and also makes it possible to estimate the route of fire spread. Dispersing the smoke can also secure the safety of fire-fighters. That is to say, ventilation work is one of the most important activity of fire-fighting operations.

It is known that extinguishing battery fires requires an extremely long time because it is necessary to complete the cooling of the battery. Since the time that the breathing apparatuses for firefighters specified in the SOLAS Convention can be used generally limited to about 20 to 30 minutes, it is extremely important to provide breathing equipment that makes it possible to continue fire-fighting operations for longer periods, and to perform appropriate ventilation work to secure an environment in which fire-fighting operations can be conducted even without breathing equipment.

Proper drainage of the water used in actions to prevent fire spread and fire-fighting operations is also important. If proper water drainage is not possible because the scuppers are blocked by resins or other materials melted by the heat of the fire, there is a danger that the remaining water may affect the stability of the ship. Therefore, it is necessary to check each time that there is no blockage, and water can be drained properly from the scuppers during fire-fighting operations.

3.2.6 Ventilation Control

Although the previous section explained the importance of ventilation, many people advocate shutting down ventilation systems during fires to confine the fire because of concern that allowing fresh air to flow into the vehicle space by ventilation may cause the fire to spread. However, considering the amount of oxygen consumed by a few burning vehicles in a large space like vehicle spaces , the probability that an oxygen-deficient condition can be achieved in a vehicle space is low, rather, it is possible that allowing smoke to fill the space may create an even more dangerous situation. In order to conduct fire-fighting operations using fire hydrants, it is more important to effectively remove the smoke of the fire and secure a space where fire-fighting operations can be conducted. The purposes of smoke dispersal work can be summarized as follows:

1) To improve visibility for firefighters and facilitate identification of fire sources and persons who were unable to evacuate.
2) To reduce the danger of high temperature combustible gases and toxic gases by discharging such gases.
3) To reduce the possibility of flashovers and backdrafts.

The basic rule of ventilation is to create an air flow that provides easy access to the fire by firefighters, as shown in Fig. 10. However, there are places where air stagnates, depending on the arrangement of fans, positions of slopes and the opening direction of ventilation ducts. Since smoke cannot be dispersed effectively under such conditions, it is important to investigate the condition of ventilation in each ship and identify locations where air can easily stagnate. In places where air stagnates, forced ventilation using portable fans to enable effective smoke dispersal during a fire, or PPV(Positive Pressure Ventilation) in vehicle spaces for efficient smoke discharge are considered to be effective methods.

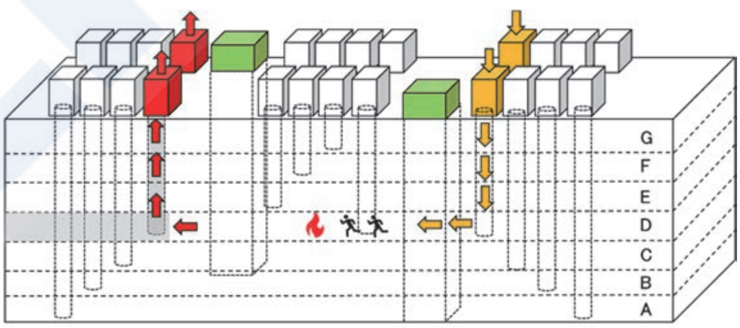

Fig. 10 Schematic diagram of ventilation system for vehicle space

3.2.7 Fixed Fire-Extinguishing Systems

As explained up to now, measures for early detection, prevention of fire spread, prevention of secondary fires and fire-fighting operations are extremely effective, but prompt activation of fixed fire-extinguishing systems is also one effective measure. The International Code for Fire Safety Systems (FSS Code) recognizes three types of fixed fire-extinguishing systems for installation in the vehicle spaces of vehicle carriers, namely, water-based fire-extinguishing systems, high-expansion foam fire-extinguishing systems, and carbon dioxide fire-extinguishing systems. Because installation of water-based systems is not realistic, high-expansion foam fire-extinguishing systems or carbon dioxide fire-extinguishing systems have become the mainstream in vehicle carriers. As a means of extinguishing fires, fixed fire-extinguishing systems are considered to be the last stronghold as a fire-fighting systems, but this appears slightly different when the object is an EV fire. Table 2 describes the effects of the respective fire-extinguishing systems in simple terms.

Table 2 Principle of fire-extinguishing by fixed fire-extinguishing systems

System	Principle of fire-extinguishing
High-expansion foam fire-extinguishing system	Extinguishes fire by the oxygen-deficient condition and cooling effect that result from covering the object of the fire in foam.
Carbon dioxide gas fire-extinguishing system	Extinguishes fire by reducing the oxygen concentration in the protected space to a level where continuing combustion becomes unsustainable.
Water-based fire-extinguishing system	Prevents generation of combustible vapor and makes continuing fire impossible by the cooling effect of water.

In thermal runaway of an electric vehicle LIB, combustion which require the oxygen occurs at the location of the fire, but the exothermic reaction of the battery is a chemical reaction which does not require oxygen. If the aim is to extinguish the flames of the fire, extinguishing the flame can be expected with any of the fixed fire-extinguishing systems shown in Table 2.

Although a water-based fire-extinguishing system cannot directly cool the EV battery because the battery is located under the vehicle, water itself is an extremely effective fire-extinguishing agent owing to its very high cooling effect, and the surrounding vehicles can be covered with a water film.

However, a cooling effect that will make the chemical reaction less severe may not necessarily be expected with high-expansion foam fire-extinguishing systems or carbon dioxide gas fire-extinguishing systems, which means it may be difficult to suppress a thermal runnway by slowing the chemical reaction simply by activating these fixed fire-extinguishing systems.

Concretely, if a high-expansion foam fire-extinguishing system is used, the foam will eventually disappear, and in this case, its smothering effect will be lost and the fire may reignite. On the other hand, the CO_2 gas used in carbon dioxide fire-extinguishing systems does not have an inherent cooling effect, and if there are openings in the protected space, the gas may leak out, allowing the oxygen concentration in the space to rise to a level where the fire can reignite.

Thus, it is necessary to understand what cannot be achieved even by a fixed fire-extinguishing system, and to study measures to compensate for those weaknesses. For example, in the case of a carbon dioxide fire-extinguishing system, this might mean sprinkling water from the carbon dioxide nozzles after the CO_2 gas has been released to provide a supplementary cooling effect.

Considering the possibility of prolonged fires, the number of times that the fire-extinguishing agent of a fire-extinguishing system can be applied is also an important factor. With high-expansion foam fire-extinguishing systems, it is possible to supply foam to the space repeatedly because ships are required to carry enough foam concentrate to fill protected spaces with foam 5 times. In comparison with high-expansion foam fire-extinguishing systems, if a carbon dioxide fire-extinguishing system is used, there is a high risk that the fire will break out again because carbon dioxide fire-extinguishing systems have only enough CO_2 gas to release into the space 1 time.

Because water-based fire-extinguishing systems use seawater, they have an inexhaustible supply of fire-extinguishing agent. However, there are high hurdles to installation of water-based systems in vehicle carriers, considering the arrangement and cost of the water feed pumps, nozzles, piping, etc.

3.2.8 Improvement of Operational Reliability of Fixed Fire-Extinguishing Systems

As described above, fixed fire-extinguishing systems, which are also called total flooding fire-extinguishing systems, are expected to have the effect of extinguishing or suppressing fires by filling the entire protected space with a fire-extinguishing agent. Since they are activated when it becomes impossible to suppress a fire through the stages of fire detection and initial fire-fighting, it is no exaggeration to say that they are the “last stronghold of fire-fighting.” If such important fire-fighting equipment cannot be activated in an emergency, there will be no choice but to evacuate the ship.

Since high-expansion foam fire-extinguishing systems use a very large number of sensors and devices to release high-expansion foam into the protected space, maintenance and management of that equipment are extremely important. For sensors, it is essential to take measures such as providing redundant sensor to ensure that the activation sequence will proceed smoothly, even if one of the sensors malfunctions.

Carbon dioxide fire-extinguishing systems are considered to have higher operational reliability than high-expansion foam fire-extinguishing systems because the CO_2 gas is released by the self-pressure in the tank when the discharge valve is opened.

Since the component elements of fixed fire-extinguishing systems differ depending on the type of system installed, understanding the sequences for activating the respective systems and identifying and strengthening the sensors and devices that are key components for releasing the fire-extinguishing agent in the protected space is one effective measure.

3.2.9 Other Considerations

As fire-fighting measures for vehicle carriers, this article has explained various facts from the viewpoint of ship equipment. However, it is also possible to avoid loading vehicles with a high risk of fire in the first place. At present, there are no indicators for judging whether a used EVs are in a dangerous condition based on the degree of deterioration of its LIB, but with future improvements in battery diagnosis technologies, it will become possible to exclude vehicles with a high risk of fire from vehicle carriers.

As one additional issue, it is not always possible to distinguish EVs from gasoline-powered vehicles. Even if someone actually witnesses a vehicle catching fire, appropriate action cannot be taken without knowing whether that vehicle is an EV or not. For example, actions such as clearly indicating where EVs are stowed in the Stowage plan and labeling or other identification of vehicles to indicate that they are EVs are considered effective.

3.2.10 Establishment of Fire-Fighting Tactics

It is important to establish the fire-fighting tactics of the response policy for EV fires, referring to the characteristics of EV fires and the points to note and response policy described up to this point.

When a fire actually breaks out, it is extremely difficult to consider various matters and take appropriate action on the spot. Therefore, it is important to compile a flowchart of fire-fighting tactics like that shown in Fig. 11, and to ensure that all crew members fully understand its content. It is also important to ensure that crew members physically master those procedures through regular training.

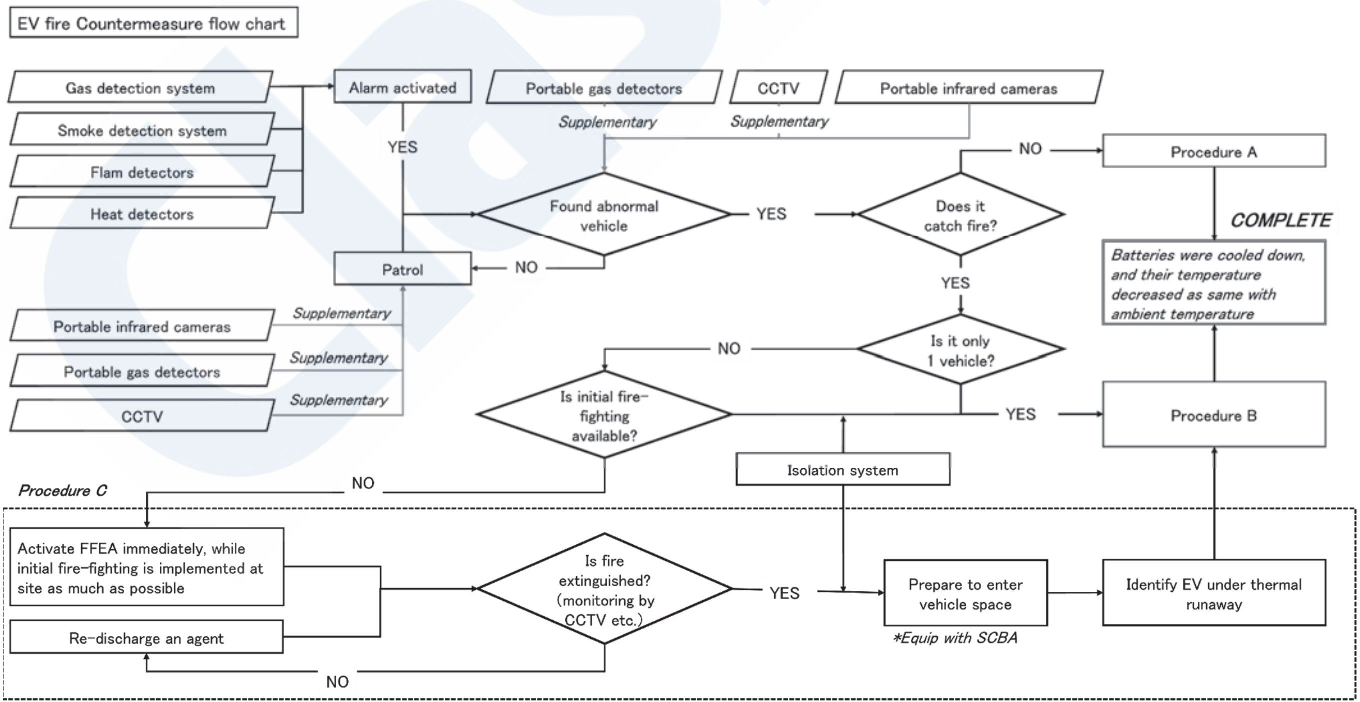

Fig. 11 Example of flowchart of fire-fighting tactics (image)

EV fires can be divided into an initial stage which is limited to only heat generation from the battery without the outbreak of a fire, a stage when a fire breaks out from a single vehicle, and a stage when fires occur in multiple vehicles. It is important to arrange the response policy corresponding to those respective stages.

3.2.11 Class Notation

Based on *"Guideline for the Safe Transportation of Electric Vehicles"* published by the Society in August of 2023, the notations shown in Table 3 can be affixed to the ship's classification characters, corresponding to the fire safety measures taken by the ship. For the following two reasons, the *Guideline* propose the types of measures that can be taken, but do not specify concrete equipment requirements.

The first reason is that it is of primary importance to understand the expected effects of various the fire safety measures and what equipment should be installed to achieve those effects, based on the purposes of the fire safety measures. Without that understanding, the system may fail to demonstrate its full effects in an emergency. Each company can best understand the purposes and importance of fire safety measures by studying those points, and this will contribute to reducing fire damage of vehicle carriers.

The second reason is because a wide range of effective technologies for EV fires is available worldwide, and technologies are also expected to be developed in the future. For this reason, the Society believes that restrictions should not be placed on the use of those technologies, and the kinds of element technologies necessary as fire measures should be conveyed by communication from the maritime industry to other industries.

It is our hope that the issuance of the *Guideline* will contribute to the development of extremely outstanding technologies and accelerated study of fire safety measures in each company.

4. FUTURE OUTLOOK AND ISSUES

The Society is promoting study of fire safety measures for vehicle carriers on an ongoing basis. We plan to refine and improve the *Guideline* based on the comments received since the publication of the *Guideline*. We also plan to continue to investigate technologies in the other industry which were not covered by studies prior to the publication of the *Guidelines*, and to study and update the kinds of effects that can be expected in fire safety measures by applying those technologies to ships.

In addition, the Society is promoting studies related to ship evacuation in the event of a fire. There may be situations where it is finally necessary to abandon ship, even if fire safety measures like those described in this article are taken on a vehicle carrier. First, we plan to conduct a risk assessment to identify the types of risks when evacuating a ship, and will then study measures for those risks that will enable the crew to safely reach lifeboats and evacuate, and reflect those results in a set of guideline.

5. RECENT TOPIC AT IMO AND INTERNATIONAL TRENDS

At present, the International Maritime Organization (IMO) has begun discussions on a revision of fire safety measures when transporting new energy vehicles, including electric vehicles, in the 10th Session of the Sub-Committee on Ship Systems and Equipment (SSE10), targeting completion in 2027. As future plans, the results of experiments conducted in each country and the views of experts concerning the characteristics of fires involving new energy vehicles will be compiled, and the systems and equipment to be required in an international convention will be studied.

Because ship owners in Japan operate a large number of vehicle carriers, even in terms of the total number of vessels in operation, we believe that Japan should actively submit safe and cost-effective measures for the transportation of EVs to the IMO, and make efforts to ensure that those measures will become the global standard.

Moreover, it is also necessary to actively exchange opinions with Japan's domestic automobile industry and take actions on this matter by the country as whole.

Table 3 Notation affixed to ship class characters for additional fire-fighting measures

Notation	Details
AFVC (FD) (EV)	**A**dditional **F**ire-fighting measures for **V**ehicle **C**arrier (**F**ire **D**etection) (**E**lectric **V**ehicle) Affixed to ships that have taken measures contributing to fire detection for vehicles with battery abnormalities.
AFVC (PS) (EV)	**A**dditional **F**ire-fighting measures for **V**ehicle **C**arrier (**P**revention of **S**econdary fire) (**E**lectric **V**ehicle) Affixed to ships that have taken measures related to prevention of secondary fires accompanying combustible gases generated by a battery fire.
AFVC (PFS) (EV)	**A**dditional **F**ire-fighting measures for **V**ehicle **C**arrier (**P**revention of **F**ire **S**pread) (**E**lectric **V**ehicle) Affixed to ships that have taken measures against the spread of a fire of a single vehicle.
AFVC (FF) (EV)	**A**dditional **F**ire-fighting measures for **V**ehicle **C**arrier (**F**ire **F**ighting) (**E**lectric **V**ehicle) Affixed to ships that have taken measures related to fire-fighting and extinguishment of electric vehicle fires.
AFVC (EFF) (EV)	**A**dditional **F**ire-fighting measures for **V**ehicle **C**arrier (**E**nhanced **F**ixed **F**ire-extinguishing system) (**E**lectric **V**ehicle) Affixed to ships that have taken measures to strengthen the capacity and improve the operational reliability of fixed fire-extinguishing systems.

6. CONCLUSION

This article has explained the characteristics and points to note concerning fires involving electric vehicles, and the fire safety measures based thereon. Persons who have studied the fire safety measures taken to reduce the damage during fires have a thorough knowledge of the use methods that make it possible to demonstrate their effects to the fullest possible extent. Ensuring that everyone understands the intentions and purposes of installing fire-extinguishing systems is the most necessary point for reducing fire accidents. If equipment requirements are specified once in an international convention or the Society's rules for ships, those concerned have a shallow understanding of the technical background for requiring that equipment, and there is a possibility that the equipment may not be able to demonstrate its full intrinsic effects. To ensure that the fire safety measures developed through repeated study over many years by persons involved in the maritime industry do not become a wasted things, the Society will continuously work to reduce fire accidents, and will provide timely information on effective methods and action guidelines for action during fires to stakeholders.

Finally, based on the fire safety measures for vehicle carriers developed independently by each company, it is our hope that all those concerned will make exhaustive efforts to ensure that the most effective and rational fire safety measures become the global standard.

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