High-Expansion Foam Fire-Extinguishing Systems for Pure Car and Truck Carriers

Susumu OTA*

1. INTRODUCTION

The answer to the question of whether a fire-extinguishing system can extinguish a certain kind of fire or not is: “It may or may not be able to.” This is because fire is defined as uncontrolled combustion, and its characteristics are so diverse that the “same fire” cannot exist twice. As actual fires are not reproducible, the performance of a fire-extinguishing system is evaluated based on whether the system can extinguish a reproducible “test fire,” rather than an actual fire. On the other hand, test fires for cargo spaces of Pure Car and Truck Carriers (PCTCs), have not been established internationally.

The characteristics of fires involving electric vehicles (EVs) are discussed in “Safe Maritime Transportation of Electric Vehicles – Characteristics of EV Fires and Guidelines for Response –” in this Special Feature. However, from the viewpoint of the effectiveness of high-expansion foam fire-extinguishing systems, the detailed knowledge on fires involving automobiles and fires involving EVs is not sufficient to discuss these two types of fires separately. Therefore, this article describes the currently-available information on the effectiveness of high-expansion foam fire-extinguishing systems against fires in the cargo spaces of PCTCs, without specializing in fires involving EVs.

In recent years, there have been some reports of casualties in which high-expansion foam fire-extinguishing systems were not successful in extinguishing fires in the cargo spaces of PCTCs equipped with such systems. The details of these casualties are unknown, including whether the ignition fuels were automobiles or not, and whether the high-expansion foam fire-extinguishing system activated or not. However, following such accidents, the Japan Ship Technology Research Association (JSTRA) established the “Advisory Committee on Prevention of the Recurrence of Fire Accidents in Car Carriers” with relevant domestic stakeholders, drawing upon information from two of these accidents that occurred in 2019. The committee studied safety measures based on the structures and specifications of the ships that suffered these accidents, actual accident information, etc., and compiled a report on “Improvement Measures for Effective Use of Fixed Foam Fire-Extinguishing Systems” in March 2021 for preventing the recurrence of similar accidents. Those results were reflected in a Notice [1] of the Safety Policy Division of the Ministry of Land, Infrastructure, Transport and Tourism (MLIT). In addition, Kashiwa Tech Co., Ltd., a manufacturer of high-expansion foam fire-extinguishing systems, has been conducting experimental research to confirm the effectiveness of the equipment with the support of Nippon Kaiji Kyokai (ClassNK), etc. Moreover, there was also a possibility that fire-extinguishing foam was not supplied promptly to the cargo space in the above-mentioned accidents. Therefore, JSTRA also established a “Advisory Committee on Improvement of the Reliability of High-Expansion Foam Fire-Extinguishing Systems” in order to facilitate shipping companies in preparing better maintenance manuals, with the ultimate aim of enhancing the reliability of those systems. The following presents an overview of these research initiatives.

2. HIGH-EXPANSION FOAM FIRE-EXTINGUISHING SYSTEMS FOR CARGO SPACES OF PCTCS

2.1 Fixed Fire-Extinguishing Systems and Fireproof Structures

On a large number of PCTCs, the cargo spaces (car decks) are protected by high-expansion foam fire-extinguishing systems. Here, only cargo ships are assumed as PCTCs, and so-called Ro-Ro passenger ships are not discussed. In addition, as PCTCs generally do not have cargo spaces on exposed decks (weather decks), only enclosed cargo spaces are discussed in the following.

The previous Chapter II-2 of the annex to the SOLAS Convention had required fixed gas fire-extinguishing systems in the cargo spaces of PCTCs (ro-ro cargo spaces of cargo ships) [2]. However, the comprehensive revision [3] of Chapter II-2 of the annex to the SOLAS Convention, which entered into force on July 1, 2002, permitted the use of high-expansion foam fire-extinguishing systems instead of fixed gas fire-extinguishing systems [4]. The International Code for Fire Safety Systems (FSS Code) [5] was also

* Deputy Managing Director, Japan Ship Technology Research Association

adopted together with the comprehensive revision of the Convention. After that, as a result of the revision of the annex to the SOLAS Convention (including revision of Chapter II-2) [6], which entered into force on July 1, 2014, the cargo spaces of PCTCs, so-called "vehicle spaces," should be protected by one of the three types of fixed systems complying with the FSS Code [7], i.e., fixed gas fire-extinguishing systems, high-expansion foam fire-extinguishing systems or water-based fire-extinguishing systems.

The fixed gas fire-extinguishing systems used in the cargo spaces of PCTCs are carbon dioxide gas fire-extinguishing systems. In these systems, a volume of carbon dioxide gas equivalent to 45 % of the gross volume of the largest protected cargo space is required. Therefore, if a cargo space to be protected is excessively expanded, the required amount of carbon dioxide gas will no longer be realistic. Thus, it is necessary to divide the cargo space into multiple fire compartments. Fig. 1 shows an example of the fire protection structure of the cargo spaces of a ship using a carbon dioxide gas fire-extinguishing system, where A to G in the figure are fire compartments. In this example, one deck in 3 to 4 decks was made gastight, and bulkheads having openings with means of closure were provided near the mid-ship. To make the decks gastight, the lashing holes should also be made airtight.

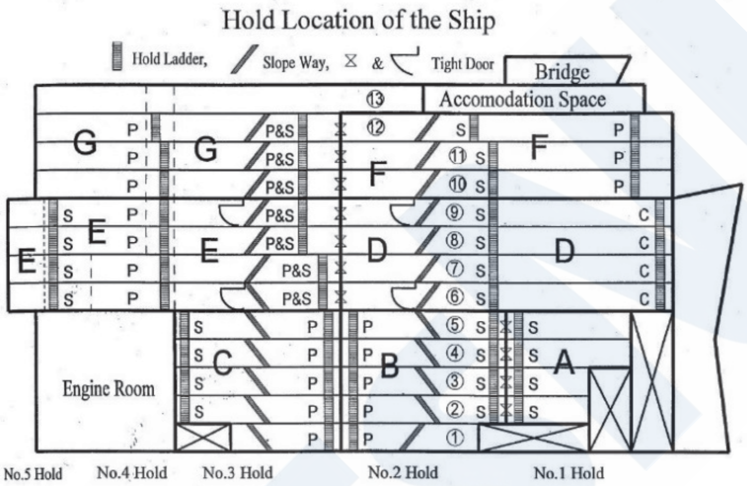

Fig. 1 Example of fire compartments in cargo space of PCTC

Previously, A-0 (A-zero) class fire integrity had been required for the fire-resisting divisions constituting a fire compartment. This means that steel structures can be used without thermal insulation for such fire-resisting divisions. However, since the above-mentioned revision of the SOLAS Convention that entered into force in 2014, A-30 class fire integrity has been required for such fire-resisting divisions. This means that thermal installation is required even for steel structures. For this reason, it is thought that high-expansion foam fire-extinguishing systems will be adopted widely as fixed fire-extinguishing systems in the future as well.

2.2 Performance Required for High-Expansion Foam Fire-Extinguishing Systems

The original FSS Code [5] prescribed foam fire-extinguishing systems, although not as systems for vehicle spaces, from the time of the comprehensive revision of Chapter II-2 of the annex to the SOLAS Convention. The major requirements, other than those for the properties of the foam (foam concentrate), were as follows:

- The nominal foam filling rate, i.e., the ratio of nominal foam production (the volume of foam produced per unit time) to the area expressed in m/min, should be 1 m/min or more.
- The quantity of foam concentrate available should be sufficient to produce a volume of foam equal to at least five times the volume of the largest protected space.

It should be noted that "Guidelines for the approval of alternative fixed water-based fire-fighting systems for special category spaces" [8] had also been referred to as a footnote to a regulation of the SOLAS Convention, but these Guidelines did not specifically mention high-expansion foam fire-extinguishing systems.

In advance of the revision of the SOLAS Convention that entered into force in 2014, Chapter 6 of the FSS Code, i.e., "Fixed foam fire-extinguishing systems," was also revised [9]. Since the revision of the FSS Code, it has been required that the foam-generating capacity should be adequate to fill the largest protected space within 10 minutes as the performance of high-expansion foam fire-extinguishing systems. The Guidelines, which is referred to in a footnote to the Code [10], also include provisions for fire tests, and in the tests, for example, the test fire is an oil spray fire having the heat release rate of 5.8 MW ± 0.6 MW plus fires in trays under (4 m^2) and on top (3 m^2) of the oil spray fire.

2.3 Types of High-Expansion Foam Fire-Extinguishing Systems

2.3.1 Types of Systems Prescribed in the FSS Code

Chapter 6 of the FSS Code contains provisions for the three types of high-expansion foam fire-extinguishing systems shown in Table 1, which are classified by the foam-generating method and the installation location of the foam generator. [11), 12)]

Table 1 Types of high-expansion foam fire-extinguishing systems

Foam-generating method	Foam generator installation location	Related section in Ch. 06 of the FSS Code
Inside air form system	Inside protected space	3.2
Outside air form system	Outside protected space	3.3
	Inside protected space	3.5

2.3.2 Inside Air Form System

As shown in Fig. 2, in this type of system, the foam solution, which is prepared by mixing the foam concentrate and water, is sprayed from the nozzle onto the foaming net to generate foam by drawing air from the surrounding space. It is called an “inside air” system because the air inside the protected space is used to generate the foam, where the foam generator is installed inside the protected space. Systems of this type are used in engine rooms and cargo oil pump rooms on ships.

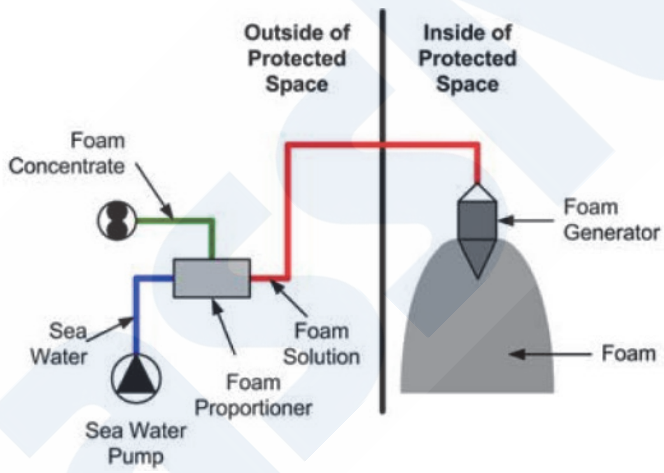

Fig. 2 Inside air form system

2.3.3 Outside Air Form System (Foam Generator: Outside Protected Space)

As shown in Fig. 3, in this type of system, foam is generated with air outside the protected space by using a mechanical fan, and the foam generator is installed outside the protected space. The foam generated at the foam generator is supplied to the protected space through a dedicated foam delivery duct. When the foam delivery duct becomes too long, the foam will collapse due to friction with the inner wall of the duct, so the length of the duct cannot be extended excessively. With the recent increase in the size of PCTCs, systems of this type of system became inefficient and are not adopted in PCTCs.

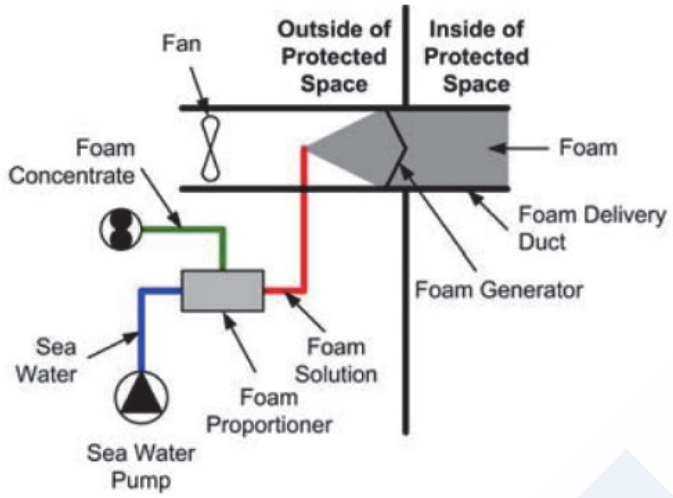

Fig. 3　Outside air form system (Foam generator: Outside protected space)

2.3.4　Outside Air Form System (Foam Generator: Inside Protected Space)

This type of system, foam is generated by the same method described in 2.3.3, where air is supplied to the foam generator from outside the protected space. As shown in Fig. 4, however, different from the above mentioned system, the foam generator is located inside the protected space. This type of system is generally adopted in the cargo spaces of PCTCs. In systems of this type, the loss of foam is minimal, even on large ships, because foam is generated inside the protected space, where air is supplied from the outside to the foam generator through a connecting duct by a mechanical fan.

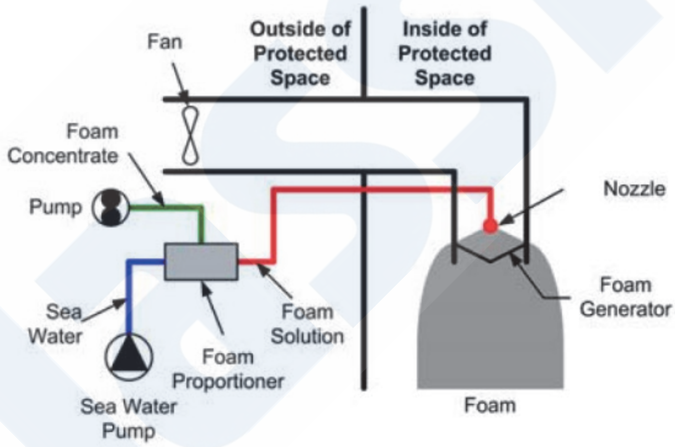

Fig. 4　Outside air form system (Foam generator: Inside protected space)

2.4　Fixed Fire-Extinguishing Systems and Response to Fire

The success or failure of fire-extinguishing activities is also related to the time from the outbreak of a fire to the start of fire-extinguishing. The fire-extinguishing system should, therefore, be activated as soon as possible.

The order of the actions when a fire occurs is sometimes expressed by the acronym “FIRE.” This means that the correct procedure is as follows: first, “Find” the fire; next, “Inform” nearby individuals, including notification; then “Restrict” the fire; and finally, “Extinguish” it. Among these, since “Restrict” includes cutting off of ventilation to the fire, the ship’s crew is trained to close openings when a fire is recognized in order to stop ventilation. In contrast to this, when using a high-expansion foam fire-extinguishing system in a cargo space of a PCTC, it is necessary to open specified ventilation ducts (including air vents). In this procedure, when a fire is recognized, the ventilation ducts are closed initially, and if initial fire-fighting attempts are unsuccessful and the high-expansion foam fire-extinguishing system needs to be activated, the specified ventilation ducts are then reopened. However, this procedure requires considerable time before the system can be activated. In this regard, it is recommended to skip the procedure for stopping ventilation in spaces protected by a high-expansion foam fire-extinguishing system. The aforementioned Notifice [1)] of the Safety Policy Division of MLIT also recommends skipping the procedure for closing the ventilation ducts (either by leaving the means of closures of ducts open or by automatic operation) in order to shorten the time until activation of the high-expansion foam fire-extinguishing system.

3. STUDY ON IMPROVEMENT OF THE RELIABILITY OF HIGH-EXPANSION FOAM FIRE-EXTINGUISHING SYSTEM OPERATION

The procedures indicated by the black circle symbol (●) in the following list are necessary before foam generation starts in the existing high-expansion foam fire-extinguishing systems with relatively low-level automation.

● Confirm the location and magnitude of the fire by the ship's crew.
● Check that all ventilation ducts to the space where foam is to be released are open.
● Press the "System standby button" on the "Control panel" (main or sub-control panel).
○ A "Foam discharge alarm" will sound automatically in the object space, and the "Ventilation fan" will stop.
● On the "Control panel," confirm that the "Water pressure lamp" and the "Foam concentrate pressure lamp" are flashing and the main power generator operation lamp is lighted.
● Press the operation button of the "Foam fire-extinguishing pump."
● Confirm that the operation lamp (green) of the Foam fire-extinguishing pump is lighted.
● Confirm that the "Water pressure normal" lamp is lighted, which means that the water pressure is raised.
○ Lamps showing that various valves such as the "Water supply valve" are open will also light automatically.
○ The "Foam concentrate pressure normal" lamp lights.
○ The "Foam discharge possible" lamp flashes.
● Check that there are no personnel in the space where foam is to be released.
● Press the "Foam discharge button."
○ The "Foam discharge" lamp lights.
○ The "Foam discharge valve" will open automatically, and the "Foam discharge valve open" lamp will light.
○ The ventilation-side openings of the "Foam damper" near the "Foam generator" on each deck will close automatically. When the air pathway to the "Foam generator" is formed, the "Foam damper open lamp" will light.
○ The "Air supply fan operation lamp" will light automatically.
⇒ "Release of foam" is started through the procedure up to this point.
(• After confirming that the fire is extinguished, press the "Stop button.")
(• Visually confirm that the foam has overflowed from the openings on the top space, and stop foam discharge.
⇒ If necessary, restart foam discharge.)

This complicated procedure cannot be executed correctly if even one switch malfunctions. Although more highly automated systems have become mainstream in recent years, the system will not function effectively if there are defects in individual parts, etc., even with progress in automation, which is similar to the case in the conventional systems. Furthermore, it is considered crucial to ensure the proper operation of the foam dampers, which are used to switch between ventilation modes for the holds and foam release. This is due to the possibility of dampers sticking and failing to operate smoothly if maintenance is poor, coupled with the difficulty of maintaining the foam damper itself. In recent years, these foam dampers have not been installed in the latest-model systems. In high-expansion foam fire-extinguishing systems, the typical procedure is to initially foam with fresh water to prevent damage to the cargo by the system's operation, and then switch to foaming using seawater. However, from the standpoint of reliability, shipping companies are exploring the use of seawater foaming from the initial stage. In any case, since maintenance is important and it is necessary to maintain manuals to be easily understood by ships' crew, JSTRA conducted research in FY 2023 and established guidelines for developing maintenance and inspection plans (to be published in the near future).

4. FIRE-EXTINGUISHING/SUPPRESSION EXPERIMENT ASSUMING FIRE OF SINGLE VEHICLE

4.1 Fire-Extinguishing/Suppression Experiment of Fire of Electric Vehicle

Kashiwa Tech, in cooperation with ClassNK and some shipping companies, carried out a fire-extinguishing experiment with an outside air-type high-expansion foam fire-extinguishing system using a battery electric vehicle (BEV) with a lithium ion battery (laminated type, 24 kWh) at the Japan Automobile Research Institute (JARI) on October 28, 2022 [12), 13), 14)]. The overall setup of the experiment is shown in Fig. 5. The BEV was covered with wire gauze, which was not permeable by the foam, and foam was supplied from the side (see Fig. 6). In the experiment, the BEV was burned for a time until the intensity of the fire was approximately constant (see Fig. 7), after which foam having a nominal expansion ratio of 900 was supplied at a nominal filling rate of 1 m/min (see Fig. 8). The fire of the BEV was extinguished under this condition (see Fig. 9).

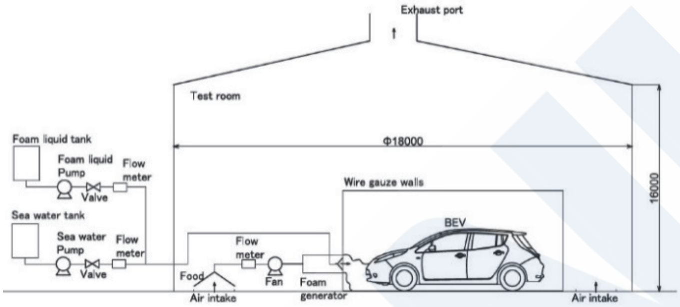

Fig. 5 Setup of experiment (overview)

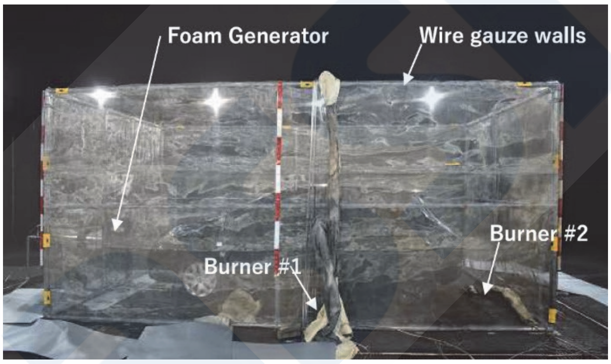

Fig. 6 BEV enclosed by wire gauze walls

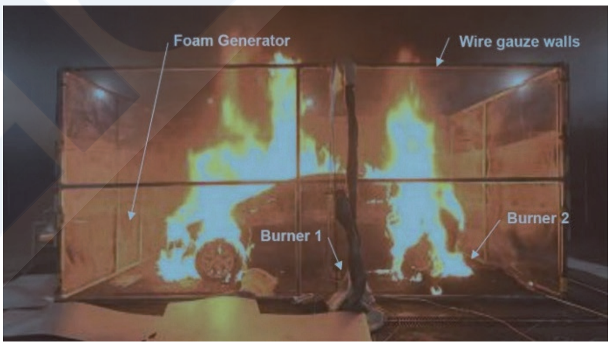

Fig. 7 Condition in burning period (before activation of fire-extinguishing system)

Fig. 8 Condition of BEV covered with foam

Fig. 9 BEV when wire gauze was removed after the fire

4.2 Fire-Extinguishing/Suppression Experiment with Test Fire Simulating Vehicle

Kashiwa Tech also conducted fire-extinguishing/suppression experiments using a test fire simulating one vehicle [15]. The fire-extinguishing limits of respective types of fire-extinguishing agents have been evaluated based on the relations between the fire-extinguishing agent supply rate (nominal foam filling rate) and time required for extinguishing (hereinafter, this relationship is called the "fire-extinguishing limit supply curve") using wooden cribs and other standardized test fires. Following this practice, in this experiment, the time required to extinguish the fire was measured with different nominal foam filling rates, and fire-extinguishing limit supply curves were plotted.

The test fire consisted of three rectangular fire trays, each measuring 1.2 m^2, with a mock-up simulating an automobile covering the fire trays. The fire trays were filled with normal heptane, and the mock-up was made of perforated metal, which was impermeable to the fire-extinguishing foam but permeable to air, in order to achieve the required heat release rate (see Fig. 10). When the heat release rate was measured without fire-extinguishing, the average values with 1, 2 and 3 trays were 2.7 MW, 4.5 MW and 6.3 MW, respectively.

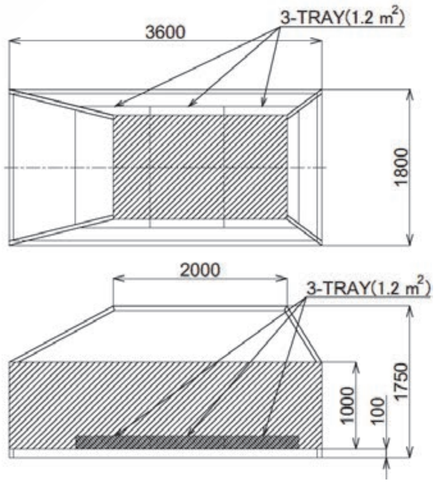

Fig. 10 Mockup of automobile (Roof: steel sheet, sides and floor: perforated metal)

In the experiments, the supply of the extinguishing foam was started after 1 minute of preliminary burning. When the foam was supplied and built up towards the front of the vehicle mockup, a flow of air from the back to the front of the vehicle mockup was formed, and the flames that had risen straight upward changed so as to burst out from the opening simulating the broken front windshield of the vehicle mockup. When the built-up foam reached the height of the windshield opening at the front of the vehicle mockup, the foam was blown away from the windshield opening by the air flow owing to the heat of the test fire. When the foam supply rate was sufficient to overcome this heat-induced air flow, the foam flowed into the interior of the vehicle mockup and covered the surface of the fire tray(s), and the fire could be extinguished or suppressed successfully. On the other hand, it was judged that fire-extinguishing/suppression was not possible when an equilibrium condition continued for several minutes, namely, when the heat-induced air flow was stronger than the foam supply rate and the foam could not flow into the vehicle mockup. The fire-extinguishing limit curves for the foam having an expansion ratio of 900 are shown in Fig. 11.

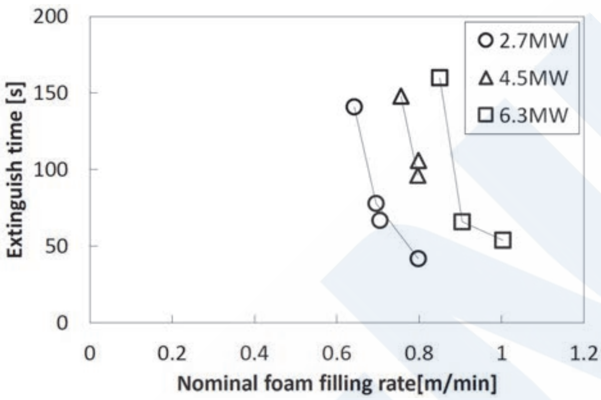

Fig. 11　Fire-extinguishing limit curves of high-expansion foam

Based on this figure, the nominal foam filling rate necessary to extinguish/suppress a one-vehicle fire, the heat release rate of which is roughly estimated as 4 MW, can be estimated to be about 0.72 m/min for the foam having the expansion ratio of 900. This implies that the fire-extinguishing systems of actual ships have a certain margin, taking into account that the systems are designed to achieve a nominal foam filling rate of at least 1 m/min. However, whether the nominal foam filling rate is sufficient to compensate for the loss of foam during spreading and build-up in the cargo space is considered to be a future subject.

5. PLAN FOR FIRE-EXTINGUISHING/SUPPRESSION EXPERIMENTS USING TEST FIRES ASSUMING MULTIPLE VEHICLES

Kashiwa Tech plans to conduct fire-extinguishing/suppression experiments using test fires and mockups of multiple vehicles in cooperation with ClassNK. The planned setup is shown in Fig. 12. These experiments aim to evaluate the effectiveness of high-expansion foam fire-extinguishing systems under conditions more closely simulating actual situations.

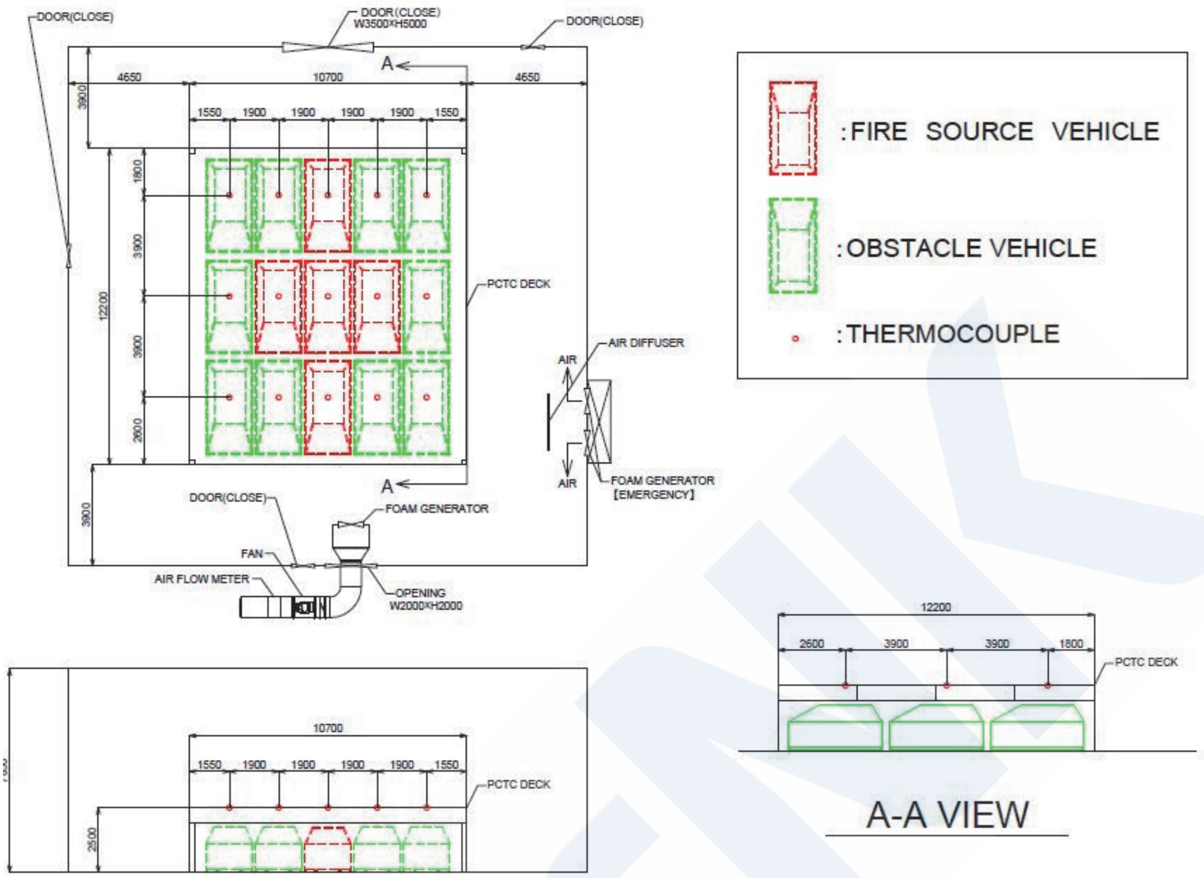

Fig. 12 Planned setup of fire-extinguishing experiment using a test fire assuming multiple vehicles

6. CONCLUSION

The timing of foam discharge in the cargo space where a fire has occurred has a dominant effect on whether fire extinguishing/suppression by high-expansion foam fire extinguishing systems is successful or not. Success, therefore, depends not only on the performance of the high-expansion foam fire-extinguishing system alone, but also on the fire detection capabilities and degree of automation of the ship as a whole. This includes securing the necessary electric power (starting power generators), preparation of ventilation equipment and ensuring operational suitability. Moreover, if all types of safety equipment, including the high-expansion foam fire-extinguishing system, are not adequately maintained and kept in a condition in which operation can start quickly, fire-extinguishing/suppression should not be expected. The author hopes that the results of the various research presented here will be utilized to enhance the fire safety of PCTCs in the future.

REFERENCES

1) Kokkaian (National Security Council, Japan) Notice No. 28 (June 10, 2021): “Improvement measures to reduce the damage generated by fire accident on large size vehicle carriers - Effective use of fixed foam fire-extinguishing systems -”
2) Former SOLAS Convention Annex, Chapter II-2, Regulation 53, paragraph 2.2.1
3) Resolution MSC.99(73) “Adoption of amendments to the International Convention for the Safety of Life at Sea, 1974, as amended,” adopted: Dec. 5, 2000, entry into force: July 1, 2002
4) Resolution MSC.99(73) SOLAS Conventional Annex, Chapter II-2, Regulation 20, subparagraph 6.1.1.2, as amended
5) Resolution MSC.98(73) “Adoption of the International Code for Fire Safety Systems,” adopted: Dec. 5, 2000, entry into force: July 1, 2002
6) Resolution MSC.338(91) “Adoption of amendments to the International Convention for the Safety of Life at Sea, 1974, as amended,” adopted: Nov. 30, 2012, entry into force: July 1, 2014

7) Resolution MSC.338(91) SOLAS Convention Annex, Chapter II-2, Regulation 20, paragraph 6.1.1, as amended
8) MSC/Circ.914 “Guidelines for the approval of alternative fixed water-based fire-fighting systems for special category spaces,” approved: June 4, 1999
9) Resolution MSC.327(90) “Adoption of amendments to the International Code for Fire Safety Systems (FSS Code),” adopted May 15, 2012, entry into force: Jan. 1, 2014
10) MSC.1/Circ.1384 “Guidelines for the testing and approval of fixed high-expansion foam systems,” approved: Dec. 10, 2010
11) IMO document FP 54/3/4 by the Republic of Korea, “Performance testing and approval standards for fire safety systems, High-expansion foam fire-extinguishing system using outside air with generator installed inside the protected space”
12) Y. Suzuki and Jiro Otagaki, “Effect of high-expansion foam fire-extinguishing systems on electric vehicle fires,” *Bull. Jpn. Assoc. Fire Sci. Eng,* “Fire,” No. 386 (Vol. 73, No. 5, 2023) Oct. 2023
13) IMO document SSE 9/INF.4 by Japan, “Any Other Business, Experimental test on lithium-ion-battery-powered vehicle fires with outside air high-expansion foam fire-extinguishing system”
14) Kashiwa Tech Co., Ltd., “Experimental study on the effectiveness of outside air high-expansion foam fire-extinguishing system on fires on battery-electric vehicles powered by lithium-ion-battery,” Feb. 1, 2023, HEA-00499
URL: https://www.kashiwa-tech.jp/doc/HEA-00499%20BEV%20Fire%20Test%20Report.pdf
15) Y. Suzuki (Kashiwa Tech Co., Ltd.), “Suppression limit of high-expansion foam fire-extinguishing system for fire of one passenger vehicle,” FY 2024 Conference of the Japan Association for Fire Science and Engineering (planned)