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To: whom it may concern

Date: March 20th, 2023
Kashiwa Tech Co., Ltd.

Subject : Experimental test on lithium-ion-battery-powered vehicle fires with outside air high-expansion foam fire-extinguishing system

Dear customers,

We Kashiwa Tech Co., Ltd. appreciate for your continuous support to our products.

We are pleased to provide a brief report of a fire test using a Battery Electric Vehicle (BEV) powered by Lithium-ion battery (LIB) as follows. We have concluded that our high-expansion foam fire-extinguishing systems are considered effective to suppress the LIB-BEV fire in this test. We will proceed with further confirmation of the effectiveness of the system for other types of vehicles and/or under various conditions in corporation with related parties in Japan and provide the IMO with information on this and future test results.

1. Date: The experimental test is conducted upon October 28th, 2022 (Friday).

2. Venue: Shirosato Test Center / Japan Automobile Research Institute (JARI)

3. Purpose:

To investigate the effectiveness of outside high-expansion foam fire-extinguishing system against the fire on an electric vehicle (BEV) powered by lithium-ion battery (LIB). A standard high-expansion foam fire-extinguishing system installed on existing PCCs designed by Kashiwa Tech was used in the test.

4. Feature of BEV fires:

The root causes of fires of BEVs equipped with LIB are various, aren't clarified enough yet, however, it is assumed that a short circuit inside the battery is one of the causes because it may result in a thermal runaway which leads to a fire. When a LIB heats up, the electrolyte inside evaporates due to heat and leaks out of the vehicle. The electrolyte, liquid and gasified, become flammable materials. The electrolyte is smoldering for a long hour, and it is said this makes more difficult to extinguish a fire by BEV comparing with the case by a gasoline car.

5. Test Setup:

Figure 1 shows the test setup. The test is conducted at the test center as described above venue, with anti-explosion facility. The test vehicle was in the midst of the wire gauze walls surrounding it (Length: 5.6 m; Width: 3.8 m; Height: 2.6 m; Area: 21 m2; Volume: 53.2 m3. Construction: wire gauzes, with no ceiling). The test cell of the wire gauze is of; Floor diameter: 18 m; Height: 16 m; Volume: 4069 m3; Ventilation rate: 750 m3/min. The foam generator was located horizontally on the wall facing the vehicle's front end, 1m high from the floor.

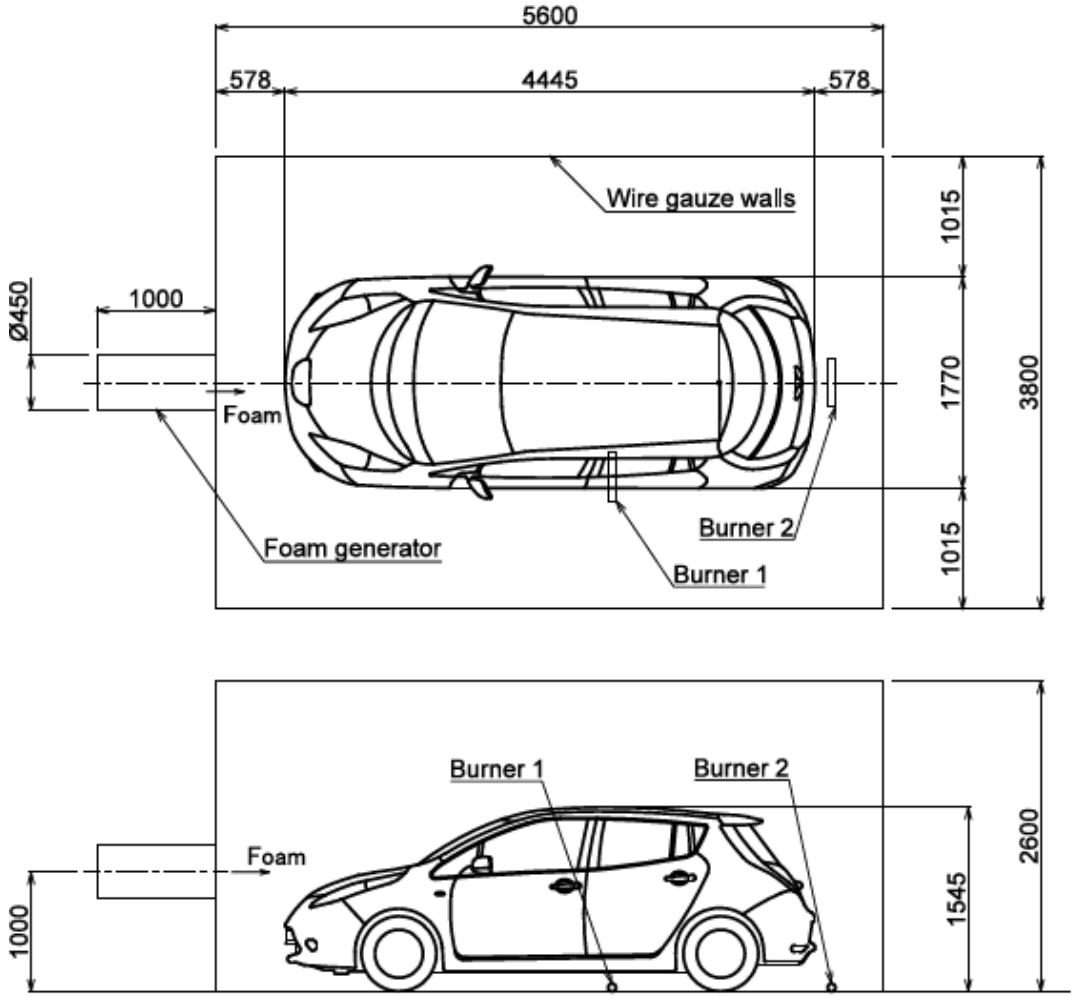


Figure 1: Test setup

6. Specifications of high expansion foam fire-extinguishing system:

The subject test is conducted with the same specifications as of the foam concentrate generated by a standard high expansion foam fire-extinguishing system installed on existing PCCs. The details are as follows:

Item	Specification
Foam generator	Discharge rate: 21 m3/min (accumulation rate: 1.0 m in height/min) Expansion ratio: 900 times; Foam solution (98% of sea water and 2% of foam liquid) supply rate: 23.3 L/min.
Sea water	Artificial sea water (prepared according to IMOs Circ.670/3.6.3)
Foam liquid	Synthetic surfactant (standard product used in Kashiwa Tech's systems).

7. Test Vehicle:

Model year as in 2011-2014. Battery installed: 24 kWh, fully charged (state of health: approximately 80%)

8. Test Summary:

In this testing the fire is caused by inducing thermal runaway with overheating a heater installed in the LIB pack. Afterwards, when the thermal runaway of LIB happened and the vehicle fire was fully intensified, the high expansion foam concentrate was discharged.

9. Test Procedure and Results:

The battery pack was heated by the heaters installed in it to bring about the thermal runaway on the first cell so that the heat could be conducted to the next cell. The original intention was to have the gaseous electrolyte blow off from the battery and get ignited by the exposure to heated surfaces or sparks with the expectation that it would develop into a whole vehicle fire. However, because this did not go as intended, a burner was used to directly ignite the gaseous electrolyte.

The high expansion foam was then discharged (Figure 3) when the fire was most intensified enough to cover the test vehicle with flames (Figure 2).

The foam started building up in the area and covering the burning vehicle and controlled the fire.

The foam discharge was stopped when the accumulated foam reached the top edge of the surrounding wall 8 minutes after the start, though the foam then partly disappeared due to the heat from the fire.

Generation of smoke and some gasses ware observed from the test vehicle in the foam (Figure 4). Steam the smoke and the gasses is supposed to be steam vapored from the moisture of the foam and the gasified electrolyte leaked from LIB, due to heat from the test vehicle.

The burner was lit again when the vehicle emerged from the foam blanket to check any flammable substances around the vehicle. Meanwhile, the front of the vehicle was ignited spontaneously just before the burner was activated this time.

Approximately 7 minutes after the re-ignition, the fire was fully developed, and the second foam discharge was made on it. The second discharge was stopped because the foam covered the vehicle in approximately 4 minutes. The burner was lit again when the foam disappeared and the vehicle emerged from the foam blanket, but no ignition occurred this time, indicating that the fire was completely suppressed.

The day after the test the battery pack was dismounted and disassembled for inspection, revealing that it was completely burnt out. Some of the cells were heated again with the flames of the burner to make sure if the flammable electrolyte still remained, but nothing happened, meaning that no electrolyte remained.

It was confirmed that the fire was suppressed so that it might successfully hinder the ignition of flammable gaseous electrolyte from the battery, to be evaporated and dismissed safely, 2hours 40minuites after the initial foam discharge, even though a burner was used to ignite.

The foam generated by our high expansion foam fire-extinguishing system not only suppressed the electric car fire during the fire intensified, but also let the electrolyte evaporate safely without ignition, led to early suppression of the fire. We can assume this is realized because of the moderate cooling effect of the foam which did not seriously disturb the evaporation of the electrolyte.
(The high expansion foam was generated from the foam concentrate with 900 times expansion ratio, mixing with the water. This makes the density of the foam water 1/900 to/less cooling effect than the pure water.)

Figure 5 shows the location of the thermocouples placed on the vehicle.
Graph 1 and Graph 2 show the temperature changes in relation to time at each measurement point.

Figure 2: Test vehicle on intensified fire

Figure 3: Test vehicle submerged in foam

Figure 4: Smoke and gasses generated

10. Test steps and observation:

No.	Time elapsed (second)	Operation	Observation
1	0:00 (0)	Heater #1 turned on	The test commenced. The battery was heated by the heater #1 attached to it.
2	1:33 (93)	Heater #1 turned off	The gasified electrolyte built up beneath the test vehicle.
3	22:00 (1320)	Heater #2 turned on	Not ignited, so heater #2 was on.
4	23:09 (1389)	Heater #2 turned off	The gasified electrolyte built up beneath the test vehicle.
5	24:00 (1440)	Burner #1 turned on	The gasified electrolyte kept blowing off but failed to get ignited. The burner was then used to directly ignite it.
6	27:00 (1620)	Burner #1 turned off	The test vehicle constantly kept burning.
7	40:00 (2400)	Fire-fighting system turned on	The fire was fully intensified. The high expansion foam system was activated and started discharge 15" later.
8	49:00 (2940)	Fire-fighting system turned off	The flame was extinguished, and the foam discharge was stopped as the foam reached the top edge of the surrounding walls.
9	1:41:00 (6060)	Burner #2 turned on	The burner #2 was activated and ignited the gasified electrolyte 1'47" later.
10	1:43:00 (6180)	Burner #2 turned off	The test vehicle constantly kept burning.
11	1:48:00 (6480)	Fire-fighting system turned on	The fire was fully intensified. The high expansion foam system was activated and started discharge 15" later.
12	1:52:00 6720	Fire-fighting system turned off	The flame was extinguished, and the foam discharge was stopped as the foam reached the top edge of the surrounding walls.
13	3:10:00 (11400)	Burner #2 turned on	The burner #2 was lit to make sure if any flammable substance still leaked, but no ignition occurred (the fire was completely suppressed).
14	3:15:00 (11700)	Burner #2 turned off	

11. Temperature Data:

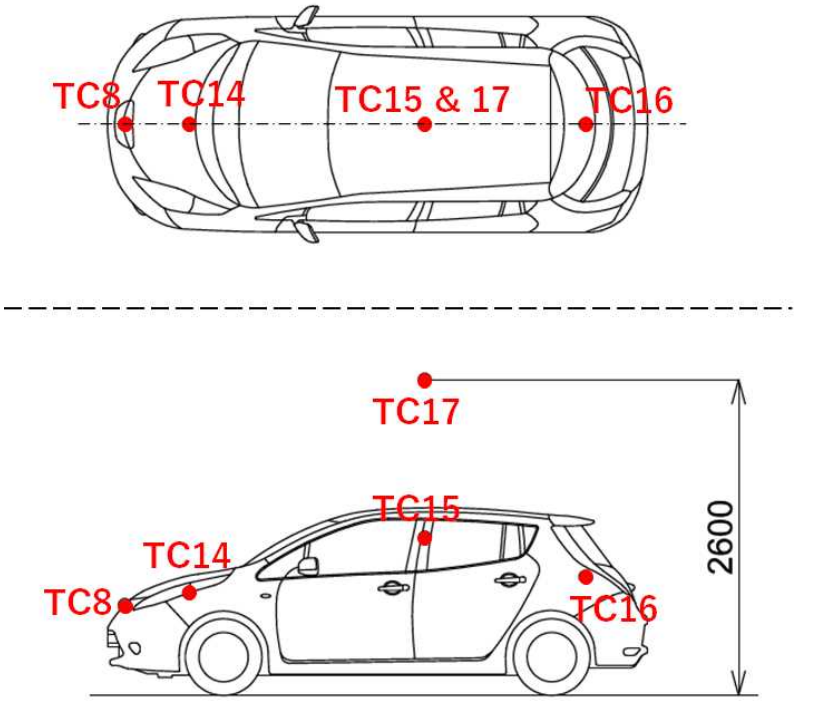
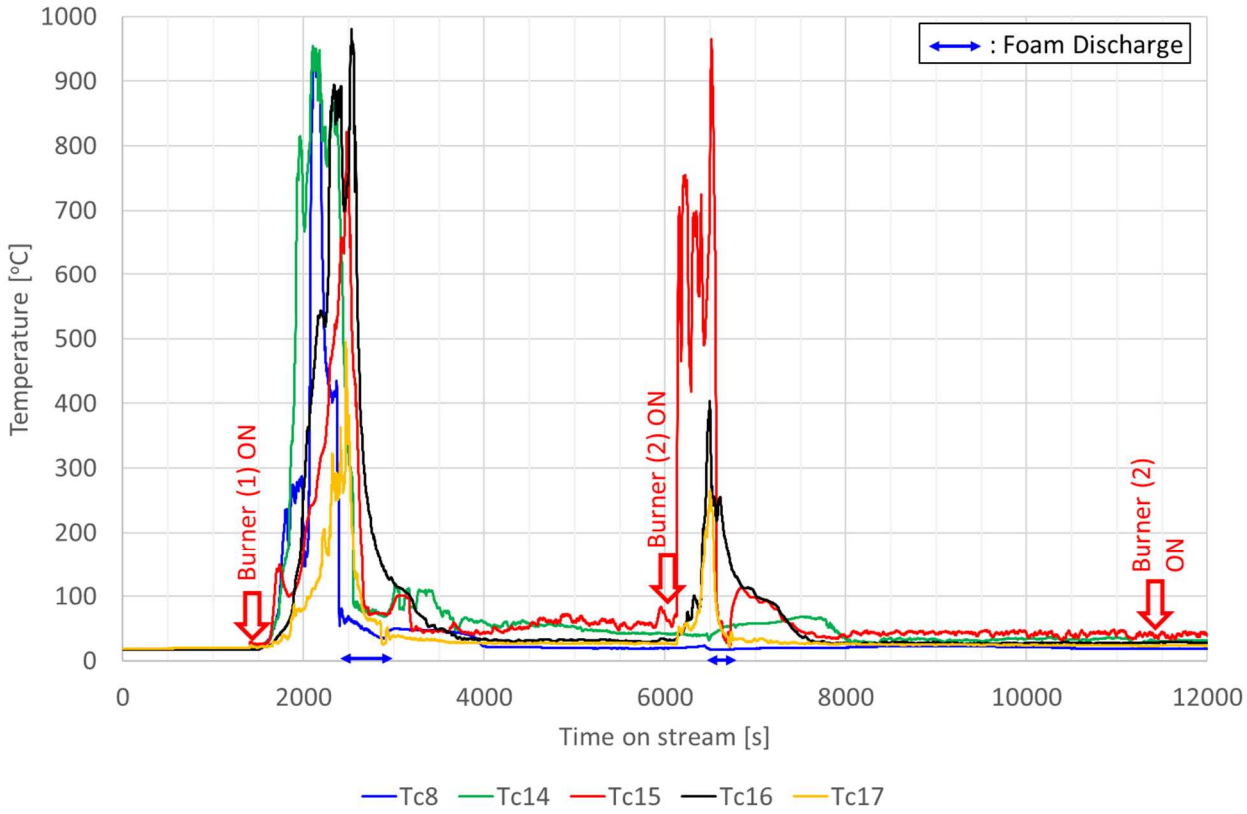
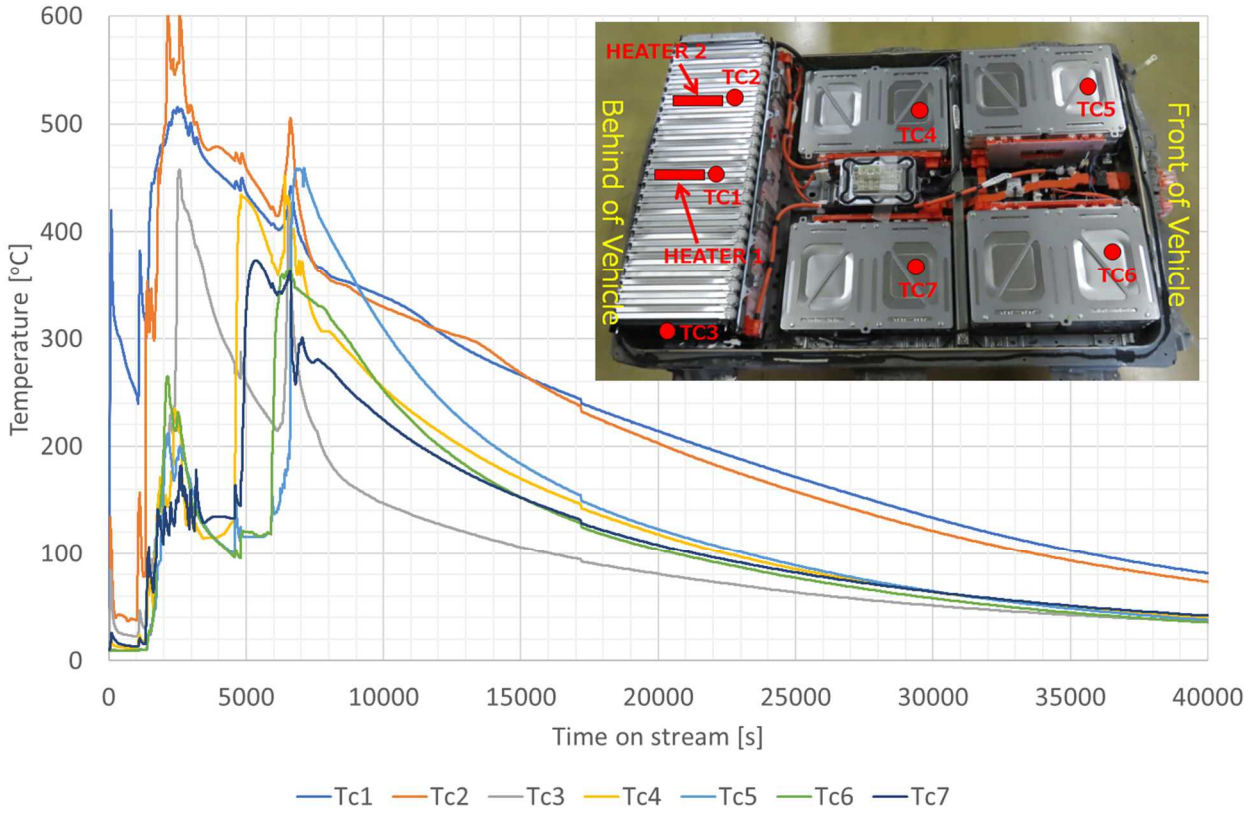


Figure 5: Thermocouple arrangement



Graph 1 Temperatures on the test vehicle



Graph 2　Temperatures in the battery pack

Please kindly contact below person if you had any inquiry related with this report.

Sincerely yours,

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End of the report