ANNEX E

SUPPRESSION OF METHANOL POOL FIRE: WATER MIST TEST SERIES

11/2025

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1. INTRODUCTION

The increasing adoption and integration of methanol as a feasible maritime fuel [1,2] demands a review of existing fire safety systems onboard. During a visit onboard the Laura Maersk [3,4], the world's first green methanol fuelled container ship, it was noted that within the engine room three independent fixed firefighting systems (FFFS) were installed. The machinery space containing the engine was protected with both a water mist and a total flooding carbon dioxide (CO_2) system while the bilge area was protected with an alcohol resistant aqueous film forming foam (AR-AFFF) system.

These types of certified FFFS are readily found protecting machinery spaces along with aerosols and other gaseous and water-based FFFS. All these installations would in practice address the provisions within MSC. 1/Circ. 1621:2020 section 11.7 *Provision for fire extinguishing of engine-room and fuel preparation space.* The certification fire tests that a FFFS must complete use either heptane or commercial fuel oil or light diesel oil as the target fuel to extinguish [5]. Methanol, however, does not have a burning behaviour like either of the certification fire test fuels, nor reacts to the FFFS extinguishing medium (e.g., water, CO_2, foam, etc.) in similar chemical, thermal, and molecular ways. This gap was identified from the gap analysis detailed in the main report.

The objective of this series of test was to investigate this gap of understanding. In particular, the effectiveness of a water mist system to extinguish or suppress a methanol pool fire was the focus of this investigatory test series. A comparative test of various FFFS was proposed for this gap analysis but do to project constraints only a water mist system has been investigated. To expand the gap investigation for the performance of water mist FFFS on methanol fires two different water mist nozzle types were selected. These nozzles differed in k-factors (1.43 vs. 2.75) and generally different spray patterns.

Although the test series presented in this annex is limited to an investigation into water mist FFFS, the testing approach and methodology are designed to be applicable to a broader range of fire suppression agents. The goal is to establish a repeatable and scalable protocol that may be used to preliminarily assess the effectiveness of various technologies under similar fire conditions, and to support early decision-making regarding their suitability for use in this type of hazard.

1.1. Methodology And Test Set-Up

This test series was a preliminary assessment designed for observing and evaluating the suppressive and extinguishing effect a water mist FFFS has on an open methanol pool fire. The goal was to establish a reproducible testing methodology that can assist with the development of a decision-making tool for manufacturers, designers, ship owners, and other stakeholders prior to undertaking large-scale approval or certification tests.

The tests were conducted within a custom mobile fire test laboratory termed MOBAT (Mobile Battery Testing). This concept was internally developed by DBI for the original purpose of medium scale battery fire tests. However, this modified 20-foot shipping container has been re-purposed for this test series.

(a)

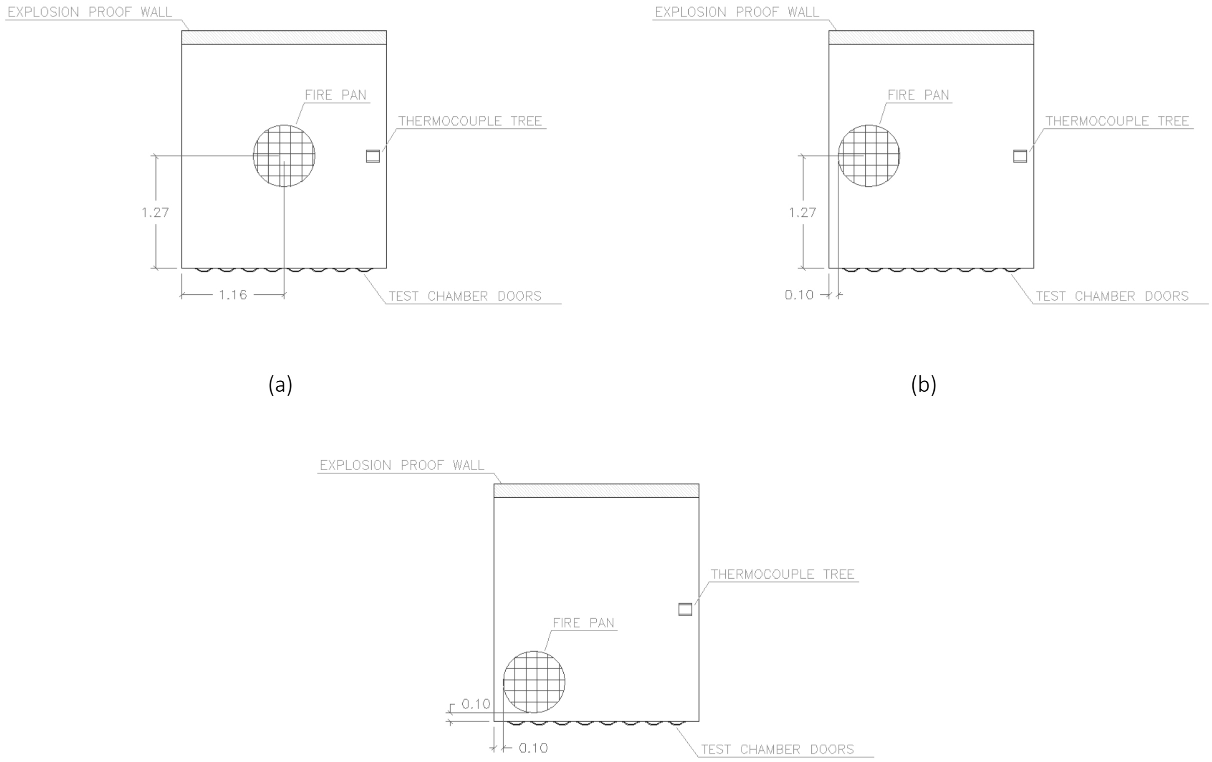
(b)

Figure 1: (a) MOBAT testing chamber preparing test specimen. (b) MOBAT testing chamber illustrating the high-pressure water mist nozzle discharge pattern.

The MOBAT test chamber is roughly 15 m^3 with a floor area of 2.34 m x 2.72 m. The MOBAT is equipped with a wide range of instrumentation capable of measuring temperature, gas species, CCTV and IR video recordings, and mass loss data within and around the MOBAT.

1.1.1. Fire Test Fuel and Positioning

A 70 cm diameter pool fire used throughout this test series. The test fuel was a 99.9% solution of fuel-grade methanol. The position of the pool within the MOBAT test chamber moved to three different locations for each water mist nozzle.



(c)

Figure 2: Different positions of the pool fire inside the MOBAT test chamber located at the center (a), along one side wall (b), and at the corner near the main opening (c).

During the tests, the pool fire burned freely for a pre-burn period of 30 seconds prior to activation of the water mist FFFS. This pre-burn time, derived from [5], ensures consistent flame development and heat feedback before the water is discharged.

The MOBAT will be operated with the test chamber door open roughly 10 cm to allow for natural ventilation of the MOBAT test chamber. The door remained open during the test series to ensure a volumetric concentration of oxygen between the range of 19-20% [6,7] throughout the 30 second pre-burn, 5-minute water mist discharge, and potential free burn of an unextinguished methanol pool fire. Finally, it is necessary to mention that active mechanical ventilation was used during the experiment.

For the definition of the heat release rate (HRR), reference values from large-scale fire tests indicate intensities in the range of 1 MW to 6 MW in open spaces of approximately 100 m^2 and 5 m in height [8]. Since the MOBAT is a scaled test environment, this test will focus on a controlled burning area and natural fire development, without forced ventilation or HRR control.

1.1.2. Water Mist System

This test campaign evaluated two types of water mist nozzles operated by the same high-pressure pump system the MOBAT is equipped with. Both nozzles were selected based on their potential applicability within a machinery space. The two nozzles selected were both 360° pendant water mist nozzles that differed in k-factor and spray pattern, but both maintained an operational working pressure of 100 bar throughout the test series. The discharge conditions (flow rate and pressure) of the water mist FFFS simulate the minimum design criteria expected at the most hydraulically remote point of a fully engineered water mist system.

1.2. Measured Parameters and Instrumentation

The overall measurement strategy for this test series focused on both quantitative and qualitative indicators of fire suppression effectiveness and operational safety.

1.2.1. Temperature Monitoring

To evaluate flame presence and behaviour, a series of Type K thermocouples were installed at specific locations corresponding to the fire source:

- Four thermocouples were positioned above the fire pan to monitor combustion behaviour.
    - Two thermocouples were installed 150 mm inward from the pan edge toward the pan center.
    - Two thermocouples were placed 250 mm and 350 mm inward from the pan edge toward the pan center. For these, an additional supporting element was added to suspend the thermocouples, which were fitted with copper conical caps to prevent direct water contact. Care was taken to ensure the caps did not touch the thermocouple junctions.
- One thermocouple was installed inside the fuel pool to measure the methanol liquid temperature.
- One thermocouple was fixed to the exterior surface of the pool fire pan to assess thermal conditions for safe post-test access and handling.

These temperature measurements served two primary purposes. First, they provided verification of flame extinction, particularly important due to the low visibility of methanol flames under certain lighting conditions [6,7]. Second, they contributed to post-test safety evaluation by indicating when it was safe to approach or manipulate the pan and surrounding structures after suppression system discharge. (See Figure 3 and Figure 4). All thermocouple data were continuously logged, and the compiled results are presented in *5.Results*.

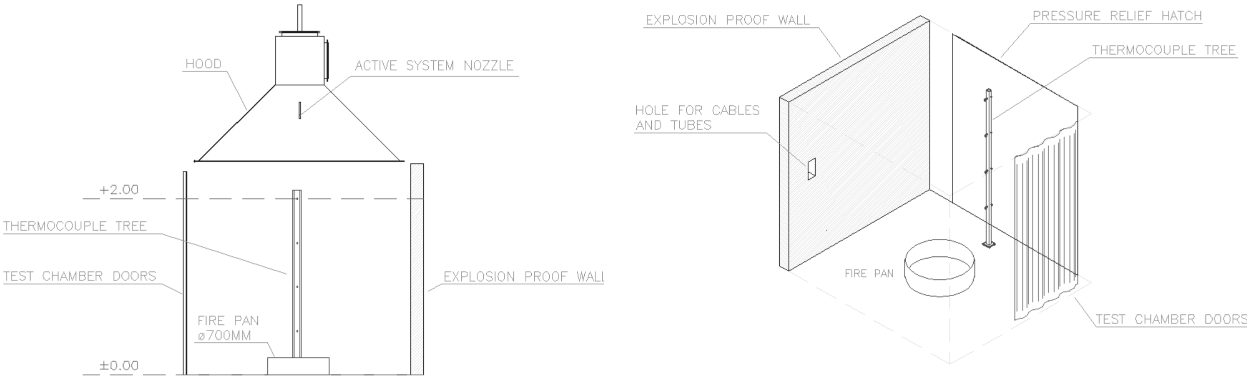


Figure 3. Layout of the devices and setup elements within the MOBAT chamber used for the water mist testing campaign.

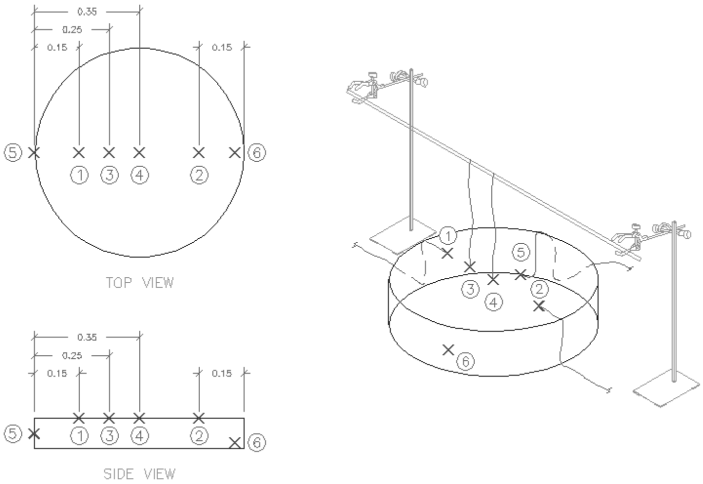


Figure 4. Arrangement of thermocouples relative to the fire pan, showing positions (1–2) at 150 mm, (3) at 250 mm, (4) at 350 mm from the pan edge toward the center, (5) inside the methanol pool, and (6) on the exterior pan surface.

In addition to the thermocouple (TC) arrangement around the fire pan, a thermocouple tree (TT) was installed at the midpoint of the MOBAT room length, positioned 15 cm from the right wall—opposite the fire location in both side and corner configurations. The TT contained thermocouples placed at heights of 0.5 m, 1.0 m, 1.5 m, and 2.0 m above the floor level (see Figure 5).

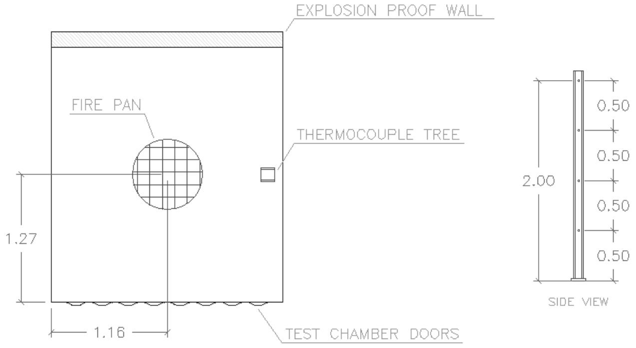


Figure 5. Thermocouple tree configuration with indicated measurement heights.

The purpose of this TT setup was to record the temperature distribution within the chamber throughout the test and to assess the influence of the suppression system inside the room.

1.2.2. Thermal Imaging

A FLIR (Forward-Looking Infrared) thermal camera was installed to monitor the methanol pool fire throughout the duration of the test. The thermal imaging data provided visual confirmation of extinguishment. In addition to this visual verification, the infrared view served as a key safety measure by allowing test personnel to confirm that the fire had been fully extinguished prior to re-entering the MOBAT unit following FFFS discharge.

1.2.3. Mass Loss Monitoring

To monitor the fuel consumption during the test, a load cell was positioned beneath the fire pan to record the fuel mass in real time. This data collection method allowed for continuous tracking the mass loss throughout the combustion and provided an additional indicator of extinguishment, based on whether the weight of the fuel remains stable following the discharge of the suppression system. Furthermore, the mass loss data was used to support post-test analysis by indicating whether the extinguishing agent successfully suppressed the fire or if the fuel was entirely consumed through sustained combustion.

1.2.4. Video Recording

A set of two fixed-position Aukey 1080p webcameras (PC-LM1E) were installed inside the MOBAT test chamber to document the fire development and suppression sequence from multiple angles. The camera placement is shown in Figure 6. These visual recordings provided valuable material for post-test review, allowing for the assessment of test quality and identification of areas for improvement.

Additionally, the video documentation supports technical communication and dissemination of results for research, operational, or training purposes.

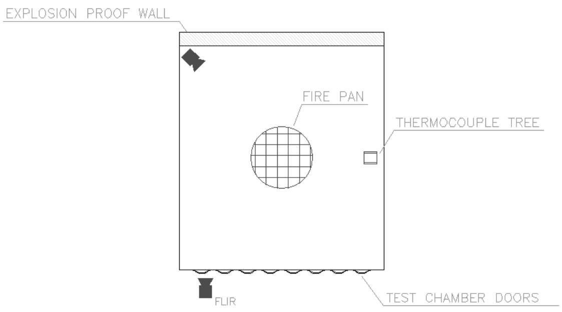


Figure 6. Camera set up inside the MOBAT unit, showing the internal recording camera and the FLIR camera mounted at the front door observation window.

1.3. Performance Criteria

Given the nature of this test series, no strict pass/fail criteria were defined. The goal of this test series was not to certify a FFFS against a standard methanol pool fire but instead to document and evaluate the observed effectiveness of a water mist system under controlled or standardized conditions.

Following each test, a qualitative and quantitative assessment was conducted, focusing on the following aspects:

- Whether the methanol pool fire was visually and thermally extinguished after the agent discharge.
- Evolution of temperature profiles (measured via thermocouples) during and after the suppression event.
- Mass loss rate of the fuel-pan during and after discharge.
- Visual confirmation from thermal imaging.

The results were recorded and reported within section 55.*Results*. For example, in the event of an incomplete suppression or continued burning, the report does not categorize the system as having "failed," but will instead show that "under the tested conditions, the agent did not achieve fire extinguishment" and will include the corresponding parameter data.

This approach is intended to maintain objectivity and allow flexibility in how different stakeholders (e.g., system designers, manufacturers, operators) interpret the results in the context of their specific use cases.

1.4. Standards and References

Although the methodology defined in this protocol represents a new approach to evaluating fire suppression effectiveness in small-scale methanol pool fire scenarios, it is fundamentally stablished in internationally recognized maritime fire safety regulations. The test structure and design considerations draw conceptual guidance from regulatory frameworks such as SOLAS Regulation II-2/10.5 [9], which outlines the requirements for fixed fire-extinguishing systems in Category A machinery spaces. These regulatory criteria help ensure that the test conditions remain consistent with the types of environments in which such suppression systems are expected to operate.

In addition to SOLAS, the protocol aligns with the technical guidance provided in the Fire Safety Systems Code (FSS Code) [10], which offers detailed design and performance expectations for fire suppression systems. While the present test is not intended for approval or certification purposes, its structure reflects the engineering intent and safety objectives outlined in the FSS Code.

Further references were considered as some IMO Maritime Safety Committee (MSC) circulars, which offer technical interpretations and application guidelines on specific systems. Among them, MSC/Circ.1387 and MSC/Circ.1165 have been considered particularly relevant for the fire suppression systems [5,8]. These circulars provide performance benchmarks and test configurations for full-scale systems, which helped to create the procedures and considerations for this new test protocol.

As the proposed testing methodology is for assessing efficiency, its results will not be interpreted under strict compliance terms. However, the objective is to establish a technically valid framework that remains consistent with the direction of international maritime safety standards.

2. SCALING THE TEST

To define the fire size used in the test, we took as reference the typical fire capacities employed in the test standards mentioned earlier. Once the dimensions of the full-scale test compartments and their corresponding fire sizes were identified, we scaled them down according to the space available within the MOBAT facility.

In low-Mach number flows, the main non-dimensional parameters are the Reynolds number and the Froude number. Using these, several scaling factors were derived to ensure that the fire behaviour in the reduced setup would be comparable to that observed in full-scale conditions (see Table 1 and Table 2).

Table 1. Resulting fire diameters for the test, based on the dimensions and magnitudes of fires in full-scale tests (MSC/Circ.1387).

Fire Size	Full-Scale (MSC 1387)	Fire Size (Scaled)	MOBAT	Equivalent Circular Pan
Q_1	1.00 MW	Q_1	0.17 MW	D_{21} = 0.65 m
Q_2	2.00 MW	Q_2	0.34 MW	D_{22} = 0.93 m
Q_3	3.00 MW	Q_3	0.50 MW	D_{23} = 1.13 m
Q_4	4.00 MW	Q_4	0.67 MW	D_{24} = 1.31 m
Q_5	5.00 MW	Q_5	0.84 MW	D_{25} = 1.46 m
Q_6	6.00 MW	Q_6	1.01 MW	D_{26} = 1.60 m

Table 2. Compartment Dimensions

Parameter	Full-Scale(MSC 1387)	Scaled (MOBAT)
Floor area	A_1 = 100.00 m²	A_2 = 5.92 m²
Height	h_1 = 5.00 m	h_2 = 2.45 m
Volume	V_1 = 500.00 m³	V_2 = 14.49 m³

Since the main purpose of this experiment was to establish an initial approach to evaluate the system's effectiveness, the tests were based on a 1.00 MW fire within a 500 m³ compartment (100 m² floor area and 5 m height). This configuration provided a manageable yet representative scenario for assessing suppression performance.

3. TEST PROCEDURE(S)

The following procedure outlines the standardized steps followed during the methanol pool fire suppression tests using the high-pressure water mist system within the MOBAT.

3.1. Pre-Burn Time

All tests shall include a pre-burn period of 30 seconds following ignition of the final fire source. This allows the fire to develop sufficient heat release and stable combustion conditions prior to the activation of the suppression system. Timing begins after confirmation that all methanol sources are ignited.

3.2. Measurements

Throughout the test, the following parameters shall be recorded:

- Fuel mass (load cell, if available)
- Temperature readings from thermocouples positioned over and around the fire
- Oxygen concentration inside the enclosure
- Visual and infrared imagery of fire behaviour

These measurements were used to determine whether extinguishment has occurred and whether conditions remain stable post-discharge.

3.3. Water Mist System Test Procedure

1. Confirm that the MOBAT unit is safe to access and that the steel trays and ignition cups are in place.
2. Fill the fire tray and ignition cups with methanol to the specified depth. Record all measurements.
3. Ignite the methanol and allow the fire to burn freely for 30 seconds.
4. Close the MOBAT door and monitor the oxygen concentration, ensuring it remains at or above 20% volume, as required by MSC/Circ.1387.
5. Openings in the enclosure may be adjusted slightly to maintain required oxygen levels during discharge.
6. Activate the water-based fire suppression system, discharging water mist for a maximum of 5 minutes.
7. Monitor fire behaviour during and after the discharge, with a minimum 300-second observation period.
8. Evaluate extinguishment status based on thermal data, flame visibility, infrared recordings, and fuel mass stabilization.
9. If fires are extinguished, monitor for re-ignition and allow conditions to stabilize before reopening the test enclosure.

10. If fires are not extinguished, and the test area is deemed safe, manually smother the flames using fitted lids.

3.4. Extinguishment Criteria

The performance of the water mist FFFS will be assessed based on the system's ability to extinguish or control the fire under the specified test conditions and within the defined performance timeframes.

3.4.1. Water-Based Systems

For water-based suppression systems, successful extinguishment shall be achieved within 5 minutes from the moment of agent discharge. The fire must remain extinguished throughout the post-discharge monitoring period (minimum 300 seconds). Any sustained or spontaneous re-ignition observed after the discharge period shall be reported in the results as unsuccessful under the tested configuration. Extinguishment shall be confirmed through thermal imaging, thermocouple data, flame visibility, and fuel mass loss stabilization. Extinguishment must occur without the need for manual intervention.

4. TEST SERIES

Two groups of tests were conducted for this campaign:

1. Free-burn series (no discharge): Methanol was burned in a steel pan and allowed to burn freely to full consumption. The objectives were to:
    a. characterise methanol behaviour in the MOBAT compartment
    b. verify the correct operation of all instruments: thermocouples (TC/TT), weigh scale, oxygen meter, and FLIR camera.
2. Water-mist discharge series: After ignition and stabilization (~30 seconds free burn), a water-mist nozzle was activated for 5 min. The fire size was held constant, while fire location (centre/side/corner) and nozzle type (2125[1] vs 2307[2]) were varied to compare performance as the primary means of suppression/extinction. Test conditions are summarized in Table 3.

Table 3: Water mist experimental test series for the methanol pool fire suppression tests

Date (YY.MM.DD)	Test No.	Nozzle Type	Fire Position	K-Factor (L/min/bar½)	Fire Pan Diameter (m)	Density (kg/m^3)	Fuel volume (kg)	Volume (m^3)	Volume (l)
25.08.20	1	2125[1]	Centre	1.43	0.70	796.00	4.50	0.0057	5.65
25.08.20	2	2125[1]	Side	1.43	0.70	796.00	3.50	0.0044	4.40
25.08.20	3	2125[1]	Corner	1.43	0.70	796.00	3.50	0.0044	4.40
25.08.20	4	2125[1]	Centre	1.43	0.70	796.00	3.50	0.0044	4.40
25.08.21	1	2307[2]	Corner	2.75	0.70	796.00	3.50	0.0044	4.40
25.08.21	2	2307[2]	Side	2.75	0.70	796.00	3.50	0.0044	4.40
25.08.21	3	2307[2]	Centre	2.75	0.70	796.00	3.50	0.0044	4.40

[1]SEM-SAFE-2125-K=1.43-100-P
[2]SEM-SAFE-2307-K=2.75-100-S

5. RESULTS

5.1. Free-burn series (no water mist)

This series focused on system shakedown and on estimating peak temperatures in MOBAT with methanol. As shown in Figures X, peak compartment temperatures typically ranged 700–800 °C, providing a baseline to quantify suppression (and, when applicable, extinguishment) during water-mist discharges.

5.2. Water-mist discharge series

Two signal sets were tracked: (i) local thermocouples (TC1, TC2, TC5, TC6 in the plume; TC3 in the fuel; TC4 on the pan) and (ii) ambient TT (TT1–TT4) for the compartment field, complemented with visible and FLIR video to mark ignition, stabilization (30 s), start/stop of the 5-min discharge, and the final state (extinguished or not).

- Fire at centre (below the nozzle): best outcomes. Average temperature dropped to ~42 °C with 2125 and ~21 °C with 2307. With 2125 there was suppression without extinguishment (temperature rose once water stopped); with 2307 extinguishment was achieved—the only full-extinguishment case of the campaign—consistent with dilution to non-flammability (see [11]).
- Fire at side: smaller temperature reductions; averages ~398 °C (2125) and ~123 °C (2307), illustrating loss of effectiveness when application does not directly impact the fire area.
- Fire at corner: reductions around 548 °C (2125) and 605 °C (2307). Two takeaways follow: (i) higher flow (higher K-factor at the same pressure) improves cooling/suppression, and (ii) spray geometry/coverage matters; distribution, not only quantity, drives performance.

Even without extinguishment, ambient cooling in the compartment was consistent: TT1–TT4 readings stayed below ~48 °C in all cases—operationally relevant for human intervention. Thus, while a given system may not ensure extinguishment in every scenario, it can meaningfully improve tenability and safety for response teams.

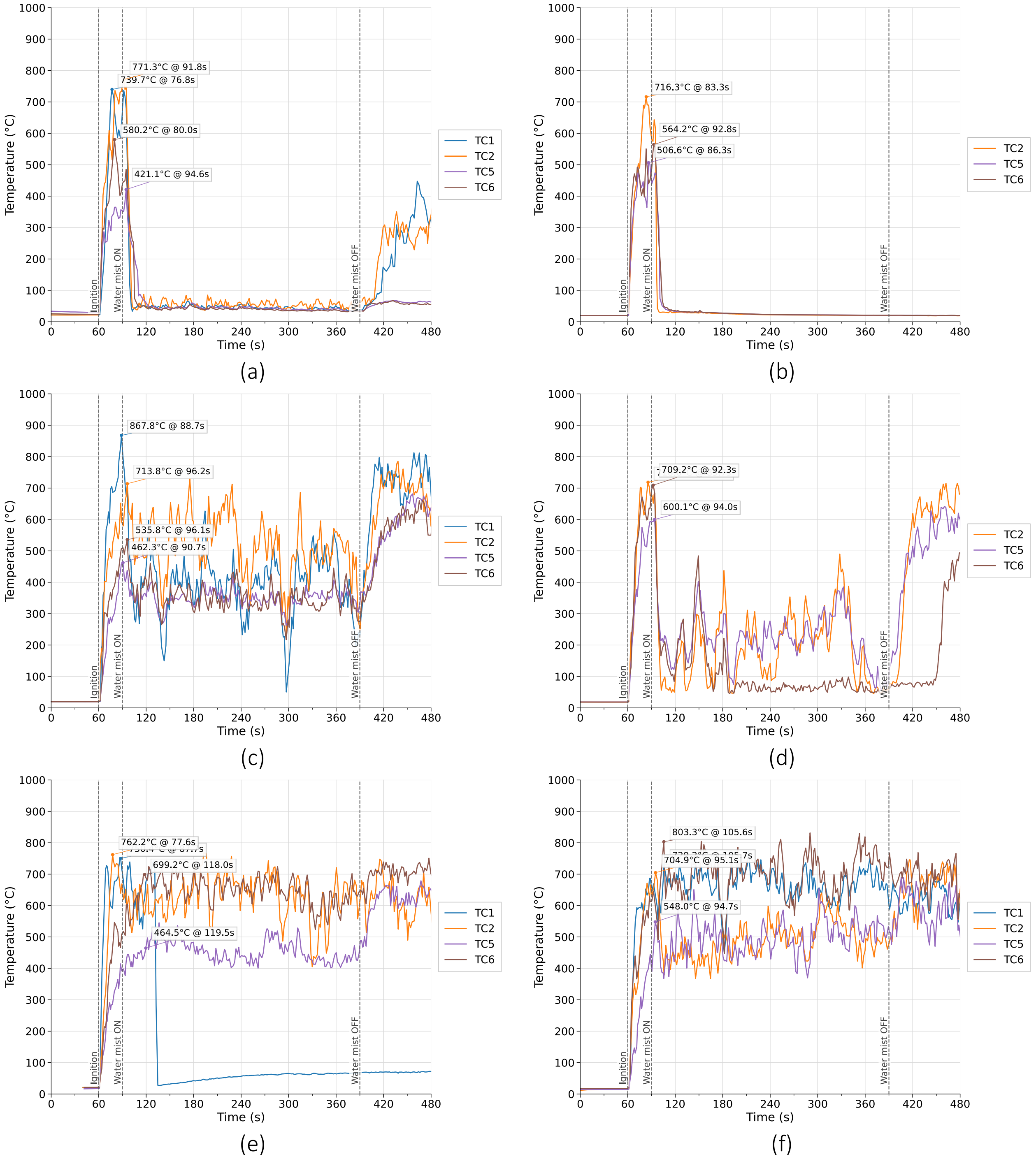


Figure 7. Set of measurements at the thermocouples near fire source for fire positions located at the centre, side, and corner, using two different nozzles. The plots in the left column correspond to nozzle SEM-SAFE-2125, while those in the right column show the results with nozzle SEM-SAFE-2307. The first row presents the results for fire at the centre (a, b), the second row for fire at the side (c, d), and the third row for fire at the corner (e, f).

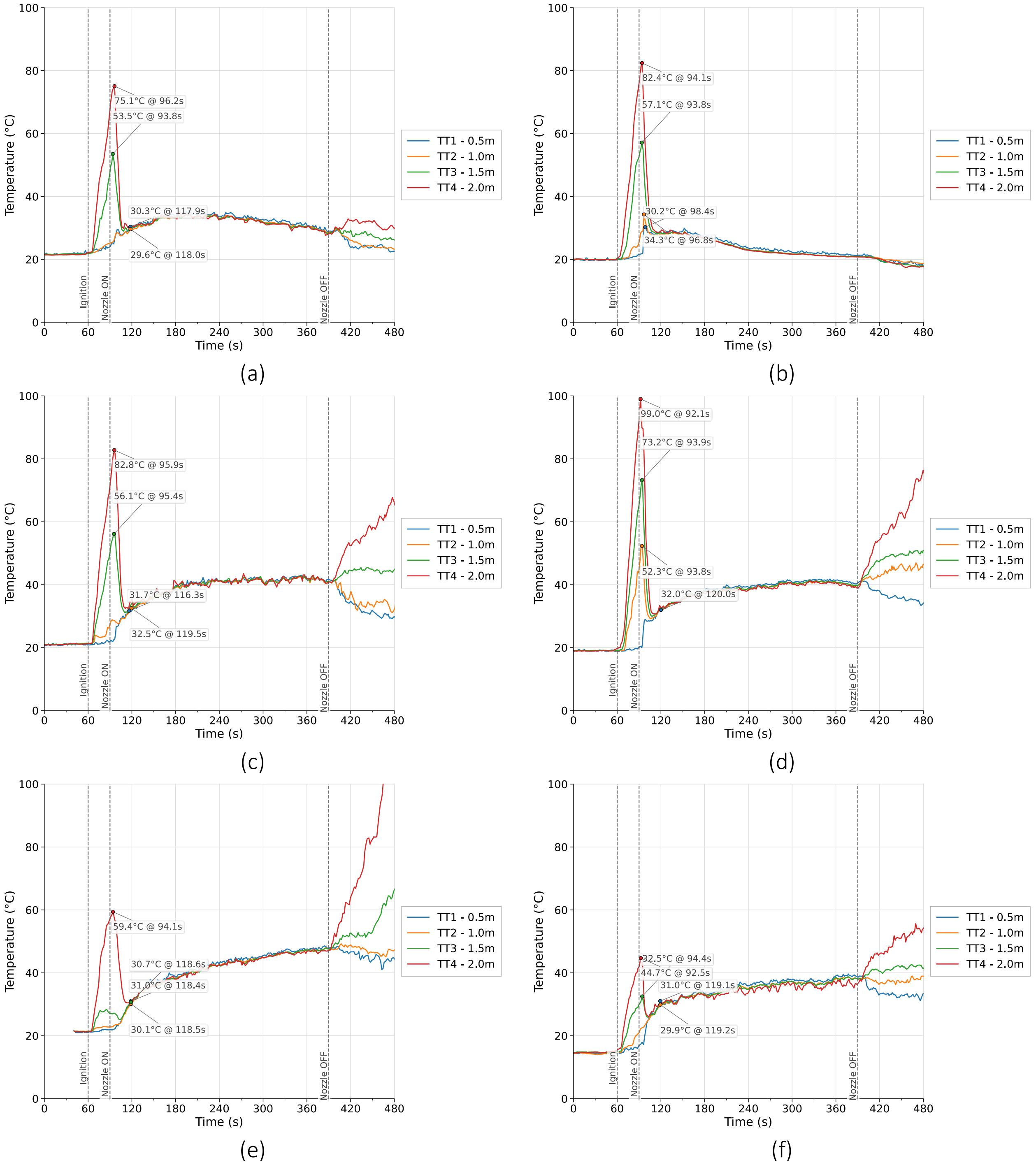


Figure 8. Set of measurements at the thermocouple trees inside the room for fire positions located at the centre, side, and corner, using two different nozzles. The plots in the left column correspond to nozzle SEM-SAFE-2125, while those in the right column show the results with nozzle SEM-SAFE-2307. The first row presents the results for fire at the centre (a, b), the second row for fire at the side (c, d), and the third row for fire at the corner (e, f).

6. REFERENCES

[1] C. Marquez, Marine Methanol: Future-Proof Shipping Fuel, (2023). https://methanolorg.wpenginepowered.com/wp-content/uploads/2023/05/Marine_Methanol_Report_Methanol_Institute_May_2023.pdf (accessed August 25, 2015).
[2] K. Andersson, C. Márquez, Methanol as a Marine Fuel Report, (2015).
[3] M. Mihajic, EU Commission President Names Landmark Methanol Vessel "Laura Mærsk," (2023). https://www.maersk.com/news/articles/2023/09/14/eu-commission-president-names-landmark-methanol-vessel-as-laura-maersk (accessed October 6, 2025).
[4] Maritime Danmark, Laura Maersk: "The beginning of a green revolution of global supply lines," Maritime Danmark (2025). https://www.maritimedanmark.dk/laura-maersk-begyndelsen-pa-en-gron-revolution-af-de-globale-forsyningslinjer (accessed October 10, 2025).
[5] International Maritime Organization (IMO), Interim Guidelines for the Safety of Ships Using Methyl/Ethyl Alcohol as Fuel, 2020.
[6] Methanol Institute, Methanol Safe Handling Guide, (2025). https://www.methanol.org/wp-content/uploads/2020/03/Safe-Handling-Manual_5th-Edition_Final.pdf.
[7] P. Blomqvist, F. Evegren, O. Willstrand, M. Arvidson, preFLASH - Preliminary study of protection against fire in low-flashpoint fuel, SP Technical Research Institute of Sweden, 2016. https://ri.diva-portal.org/smash/get/diva2:962918/FULLTEXT01.pdf (accessed October 1, 2025).
[8] International Maritime Organization (IMO), Revised Guidelines for the Approval of Fixed Water-Based Local Application Fire-Fighting Systems for the Use in Category A Machinery Spaces (MSC/Circ.913), 2010.
[9] International Maritime Organization (IMO), International Convention for the Safety of Life at Sea (SOLAS), IMO, 1974.
[10] International Maritime Organization (IMO), FSS-Code (Fire Safety Systems Code) - Res. MSC.98(73), n.d.
[11] F. Evegren, proFLASH: Methanol fire detection and extinguishment, RISE - Research Institutes of Sweden, 2017. https://www.diva-portal.org/smash/get/diva2:1094660/FULLTEXT02.pdf (accessed October 1, 2025).