Evaluation of IMO Fire Test Protocol for Fixed Gaseous Fire Extinguishing Systems

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ABSTRACT

Six full-scale fire tests were conducted to evaluate a gaseous agent fixed fire extinguishing system for marine applications using the International Maritime Organization's MSC Circular 776 fire test protocol, a low temperature cylinder discharge test, and a verification test for side wall discharge nozzles. The gaseous agent used was FM200® propelled by compressed nitrogen contained in the same cylinders. The tests verified that the systems met the performance requirements in terms of agent discharge time and fire extinguishment times as specified in IMO fire test protocol. The cold discharge test, in which the agent was discharged from cylinders stored at –5 °C, also met the system performance criteria. No adverse effect on the system performance was observed. Agent discharge time, cold temperature effect, and use of full-scale fire tests are discussed. Recommendations are also made to improve the IMO test protocol regarding stabilization of spray fires, use of additional telltale fires, and use of a reliable re-ignition source.

KEYWORDS: IMO, Gaseous Agent, Discharge Time, Low-Temperature Storage

1 INTRODUCTION

Halon based gas agents, together with CO_2, have been primary fire suppression agents for marine applications. A production ban on Halon due to its Ozone Depletion Potential (ODP), required industries to find new gaseous agents as replacements. In order to evaluate the effectiveness of alternative gaseous agents and their delivery systems, the International Maritime Organization (IMO) issued a fire test protocol, MSC/Circ. 776[1], under its Safety of Life At Sea (SOLAS) 74[2] regulations.

This paper attempts to evaluate the IMO fire test protocol[1] based on fire tests conducted against it to verify performance of fixed gaseous agent extinguishing systems. NFPA 2001[3], Standard on Clean Agent Fire Extinguishing Systems, mandates use of only listed equipment and devices for total flooding clean agent systems. The newly added marine chapter[4], presented at the NFPA Committee Meeting in March, 1998, also mandates that all fixed gaseous fire extinguishing systems in marine applications be approved by a listing organization. Thus, as a part of Factory Mutual Research Corporation (FMRC) Approval Process for a shipboard fixed gaseous extinguishing system, FMRC needed to conduct the IMO fire tests.

At the same time, the United States Coast Guard (USCG) had a concern for the discharge of cylinders stored at *cold temperatures* for fixed gaseous extinguishing systems. When the storage of cylinders in a vessel containing fire extinguishing agents that are mixed with pressurized nitrogen are exposed to a low temperature for a long time, the pressure inside the cylinders becomes lower than the design pressure, which is based on a room temperature. The USCG sought to find out whether the discharge of the gaseous agents from the cylinders at a lower temperature would bring any adverse effect to the system performance. This work was jointly performed between FMRC and the USCG to address these two issues from both parties.

2 PREPARATION OF THE FIRE TESTS

2.1 Test Scenarios

Currently the USCG implements the SOLAS regulations, which requires that every new fixed fire extinguishing system hardware must be tested against the IMO test protocol[1]. The hardware tested in this work used FM-200® as its gaseous agent, a chemical compound designated as C_3HF_7. A total of six tests were designed. Table 1 shows the test sequence. Details of each test are as follows:

TABLE 1. DESIGNED TESTS

Test Number	Nozzle Discharge		Design Concentration	Reference
	Total Orifice Area (mm^2)	Radial Spray Pattern		
1	2036	360°	7.2 %	IMO Fire Test # 1
2	4118	360°	7.2 %	Cold Cylinder Discharge Test
3	4118	360°	8.7 %	IMO Fire Test # 3
4	4118	360°	8.7 %	IMO Fire Test # 2a
5	4118	360°	8.7 %	IMO Fire Test # 4
6	2156	180°	7.2 %	Sidewall Nozzle Verification

Test 1 was the telltale test specified as IMO Fire Test # 1 in the protocol[1]. Eight heptane cup fires (IMO Fire A; see Ref. 1) were used to verify the extinguishing concentration of an agent and uniform mixing of the agent throughout the enclosure. Two cups were located at each corner of the test enclosure: one on the deck, the other just beneath the overhead. The concentration of the agent for the test is required to be no more than 83% of the manufacturer's recommended design concentration. The system design concentration is 8.7 volume percent at 20°C, which makes this test's concentration 7.2 volume percent at the same temperature. (Hereafter the agent concentration in this paper refers to the concentration based on volume at 20°C room temperature, unless otherwise noted.)

The volume of the IMO Fire Test enclosure was 500 m^3. A schematic diagram of piping and location of the nozzles for agent distribution is given in Figure 1. Each nozzle had eight uniformly distributed 9.0 mm diameter holes, which provided 509 mm^2 orifice area in a 360° radial discharge pattern. Four nozzles were used for the agent discharge. The agent was propelled by compressed nitrogen contained in the same cylinders. The IMO test protocol requires halocarbon agents to discharge at least 95% of the agent from the nozzles within 10 seconds, and all the fires must be extinguished within 30 seconds after the completion of the agent discharge.

Test 2 was a test to evaluate if there is any adverse effect on the performance of a gaseous extinguishing system when the cylinders containing the mixture of compressed nitrogen and FM-200® are exposed to a cold temperature for a considerable time. In order to simulate the scenario, the cylinders were stored for 48 hours prior to the test inside a walk-in freezer maintaining –5 °C. The other details of the test are identical to those in Test 1. However, as this test was not a part of the IMO test protocol, there were no regulatory time limits for discharge and flame extinguishment.

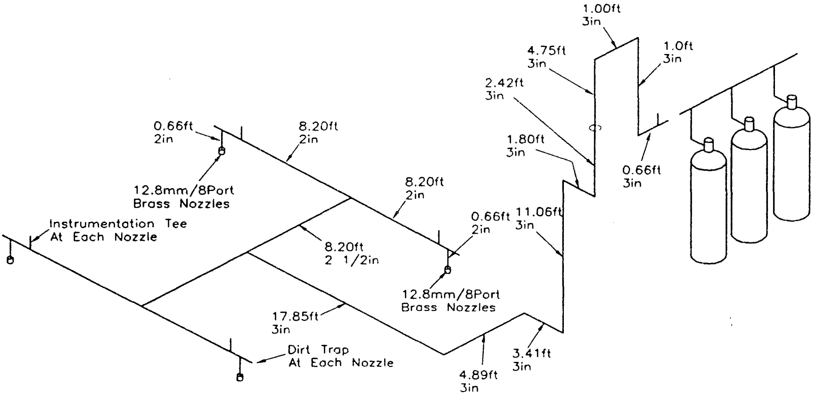

FIGURE 1. Schematic diagram of agent distribution system with 360° spray nozzles.

Test 3 was IMO Fire Test # 3. The test employed a combination of three fires with a total heat release rate of approximately 4.4 MW. They were a 2.0 m^2 diesel pan fire (IMO Fire C), a heptane spray fire (IMO Fire F), and an IMO wood crib fire (IMO Fire H). The design concentration of the agent for this test was 8.7%.

Test 4 was IMO Fire Test # 2a. This test employed a combination of three fires with a total heat release rate of approximately 7.95 MW. They were a 0.25 m^2 heptane pan fire under the engine mockup (IMO Fire B), a horizontal low pressure heptane spray fire on top of the engine mockup (IMO Fire E) and a high pressure vertical diesel spray fire on top of the engine mockup (IMO Fire G).

Test 5 was IMO Fire Test # 4. This test employs a 4.0 m^2 diesel pan fire under the engine mockup, the theoretical heat release of which was estimated to be 6.0 MW (IMO Fire D).

Test 6 was the telltale fire scenario verifying the use of sidewall nozzles with a different nozzle spacing from that of the previous tests. Because the nozzle locations were much closer to the walls than the other tests, two additional heptane cup fires were added to the eight telltale fires used in Tests 1 and 2. Both cups were located near the center of the enclosure: one on top of the engine mockup and the other below the engine mockup.

2.2 Details of the Test Preparation

Details of the test preparation are described in *TEST PLAN* by Hansen and Beene of the U. S. Coast Guard[5].

2.2.1 *Test Enclosure.* The tests were conducted in a simulated engine/machinery space at the U.S. Coast Guard test vessel STATE OF MAINE. The tests were performed in a test compartment, 10 m x 10 m x 5 m high (500 m^3), specified by the IMO test protocol.

A schematic figure of the test enclosure is given in Figure 2. It is constructed with metal bulkheads with doors and roof vents. A steel engine mockup built in accordance with the IMO test protocol is located in the center of the space. The diesel engine mockup is surrounded by a bilge plate, 6 m x 4 m, with an about 100 mm gap between inside perimeter and the engine mockup.

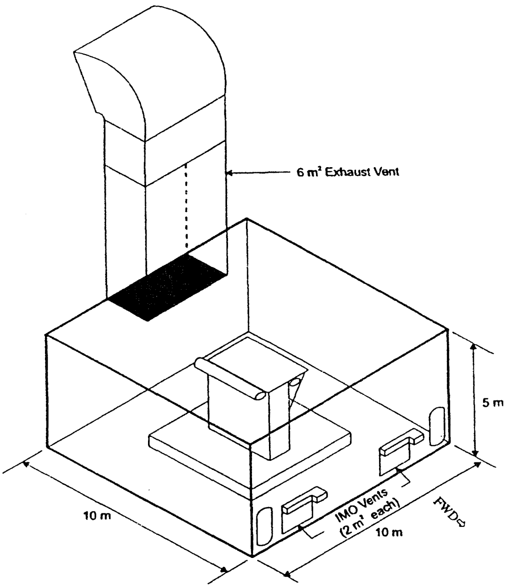

FIGURE 2. Test compartment configuration.

2.2.2 *Agent Discharge Cylinder.* The agent discharge cylinders were located outside two decks above on the main deck. For each test, three cylinders, 180 *l* each, containing mixture of compressed nitrogen and FM-200® were used.

Each cylinder was connected to a manifold through a solenoid valve so that a remote control switch in the control room could be used to actuate the agent discharge. The pressure of each cylinder was 2.5 MPa at 293K. Note that the cylinder pressure for Test 2 was noticeably lower than the others due to the low temperature that the cylinders were exposed to. The fill densities of the cylinders were 0.516 kg/*l* for Tests 1, 2, and 6, and 0.633 kg/*l* for Tests 3, 4, and 5.

3 CONDUCTING THE TESTS AND ANALYZING TEST DATA

3.1 Conducting the Tests

Tests were initiated from a remote control room. All fires had a pre-burn time prior to the agent discharge as specified in the IMO Test Protocol—15 seconds for the spray fires, 2 minutes for the pan fires, and 6 minutes for the wood crib fire. During the pre-burns, the 6 m^2 roof vent and the 4 m^2 area vent doors remained open to ventilate the fire products. Ten seconds prior to agent discharge, the vents were remotely closed from the control room. The agent distribution systems were remotely actuated from the control room. The required 15 minutes soak time was held after discharge.

3.2 Analyses of Test Data

Because of a space limitation, only a few selected test results will be discussed here. Detailed analysis and the complete test data for the whole test series can be found in Reference[6].

3.2.1 Telltale fire test (Test 1). Figures 3 and 4 show pressures and temperatures from Test 1 measured at a few selected locations on the agent distribution system. Figure 3 shows pressures at Nozzle 1, Nozzle 2, Tee 1, Tee 2, and the cylinder discharge manifold. These are denoted as Noz1, Noz2, Tee1, Tee2, and Man, respectively, in the figure. Figure 4 shows the temperatures of a cylinder on the main deck, Nozzle 1, Nozzle 2, and the cylinder discharge manifold. These are denoted in the figure as Cyl, Noz1, Noz2, and Man, respectively.

The agent discharge time in this paper is defined as *the duration from initiation of the agent discharge at a nozzle to when all the liquid portion of the agent completes its discharge.* This definition is new and different from the one[ξ] specified in the IMO test protocol[1] or NFPA 2001[3]. However, this is exactly the way industry interprets the term currently.

A possible link between the formal definition (of NFPA 2001[3] or the IMO test protocol[1]) and the industry practice can be found from the study of Elliott *et al.*[7] They conducted numerous experiments with a flow of nitrogen-pressurized Halon 1301. The experiments showed that at the end of liquid discharge from a nozzle, most of Halon 1301 (above 90%) was discharged. Actually, one test showed that at the end of liquid discharge, 96% of the total amount of Halon 1301 was discharged.

However, the test results[7] indicated that the amount of Halon 1301 discharged at the end of liquid run out at the nozzle depended upon a configuration of each distribution system. The tests, by no means, verified that 95% of the total amount of Halon 1301 would be discharged at the end of liquid run out in every case.

Even if that is true with Halon1301, there is no evidence, at least in the public domain, that the same results can be applicable to other halocarbon agents such as FM200®. In summary, there is no clear evidence showing that the current industry practice in determining the discharge time will meet the formal definition of the discharge time in every case. However, this method has been considered by many administrations within IMO as being acceptable.

[ξ] The IMO Protocol and NFPA 2001 defines the discharge time for halocarbon agents as the time to discharge from the nozzles 95 percent of the agent mass [at 70°F (21°C)] necessary to achieve the minimum design concentration.

The point of initiation of the agent discharge from nozzles can be found from the nozzle pressure curves in Figure 3 and temperature curves in Figure 4. When the liquid front of the agent (mixed with nitrogen) reaches the end of a pipe (or at the entrance of a nozzle), the pipe exit pressure would go up to the pressure of the agent, and the temperature would go down to the liquid temperature of the agent.

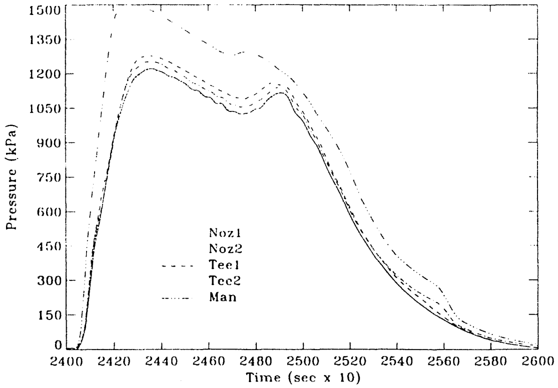

FIGURE 3. System pressure in Test 1.

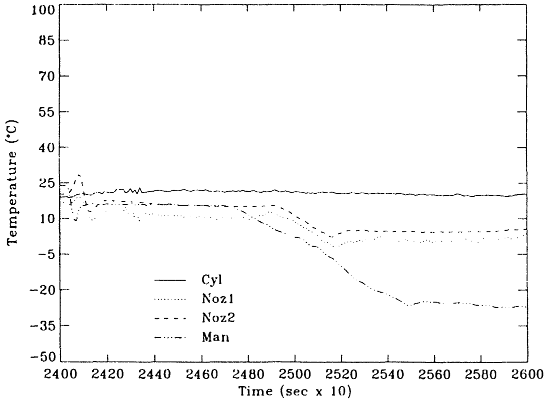

FIGURE 4. System temperature in Test 1.

However, the experimental results in Reference 7 show that the pressure rises earlier than theoretically expected as the air in the pipe was pushed ahead of the liquid.

Reference 7 also shows that there is a similar trend in temperature measurements, too. Before temperature falling down as the liquid front hits the exit of the pipe, there is a temperature spike due to a pulse of air preceding the liquid front.

The measured temperature curves in Reference 7 indicate that there could be one or more temperature pulses before the liquid front of Halon 1301 hits the nozzle entrances. Considering the above observations, t=242.0 second (2420 on the abscissa of the figures) can be regarded as an initial point of the agent discharge at Nozzles 1 and 2.

When the liquid runs out from the pipe, a sharp decrease of pressure and temperature at a nozzle is expected as only the gas portion of the mixture discharges. However, the measurements in Reference 7 again show that the slopes in pressure and temperature are not as abrupt as one should expect.

The liquid-run-out point can be determined as the inflection point in a pressure curve, though this point is not as dramatic as one might hope. The inflection point in a temperature curve is even less pronounced than that in the pressure curve. The location of the point is expected to be in the middle of the temperature fall-down curve before the minimum temperature. Figures 3 and 4 indicate that t=251.8 second (2518 on the abscissa of the figures) can be the point corresponding to the liquid run-out. This gives the agent discharge time of Test 1 as 9.8 seconds.

Oxygen concentration data collected for the test period indicate that the concentration after the completion of the agent discharge remains almost unchanged through out the whole soak time period. The compartment pressure for the test period that were measured at two locations show that there is a slight reduction of the pressure at the beginning as the agent discharges. The compartment pressure rises and then falls again until it settles to the same pressure as the original compartment pressure prior to the test. Note that there was an exhaust stack flap to keep the compartment pressure from rising higher than acceptable for the compartment structure.

3.2.2 Cold Discharge Test (Test 2). Figures 5 and 6 show the measured system pressures and the system temperatures, respectively, in Test 2. As the cylinders were stored inside a walk-in refrigerator before the test, the cylinder temperature in Figure 6 shows that it is around –5 °C, about 25 °C lower than that of the cylinders used in Test 1. The shape of the temperature curves in Figure 6 are almost identical to those in Figure 4, except that there is a shift of about 25 °C in ordinates.

Accordingly, the pressure of the system was reduced as can be seen by a comparison of Figure 5 with Figure 3. Figures 5 and 6 indicate that t=242.0 second can be the point of initiation of the agent at the nozzles, and t=252.0 second the point of liquid run out.

This gives the discharge time of Test 2 as 10.0 seconds. Compared with Test 1, a cold cylinder discharge did not seem to prolong the discharge time. The temperatures measured on the eight telltale fires also indicated that, generally speaking, there are no noticeable delays in fire extinguishment times compared with those in Test 1.

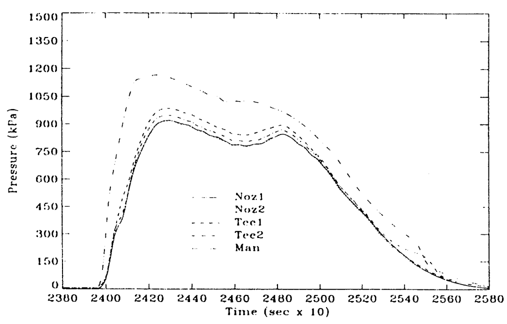

FIGURE 5. System pressure in Test 2

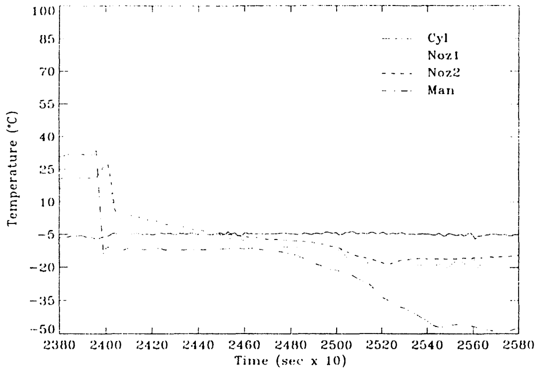

FIGURE 6. System temperature in Test 2.

4 SUMMARY AND DISCUSSIONS

A series of fire tests, Test 1 through Test 6, were conducted to evaluate a fixed gaseous fire extinguishment system for marine applications against the IMO fire test protocol[1]. All the tests met the discharge time restriction imposed by the test protocol, 10 seconds.

The agent discharge from the cold cylinders in Test 2 did not appear to prolong the discharge time compared with the other tests. The tests also verified that the systems extinguished all the fires in less than the time allowed in IMO Fire Test Protocol, which is 30 seconds after the completion of the agent discharge. No noticeable adverse effect on flame extinguishment was observed by the cold discharge in Test 2.

The extinguishment times of the telltale fires used in the tests are given in Table 2 for a reference.

TABLE 2. FIRE EXTINGUISHMENT TIME (TELLTALE FIRES)

Telltale Fire #	Location		Fire Extinguishment Time (sec. after initiation of agent discharge)		
	(x, y, z)	Reference	Test 1	Test 2	Test 6
1	(0.0, 0.0, 4.9)	Aft, Stbd, Ovhd	2	1	1
2	(0.0, 0.0, 0.2)	Aft, Stbd, Deck	12	13	10
3	(9.9, 0.0, 4.9)	Fwd, Stbd, Ovhd	22	25	12
4	(9.9, 0.0, 0.2)	Fwd, Stbd, Deck	7	13	21
5	(9.9, 9.9, 4.9)	Fwd, Port, Ovhd	18	8	22
6	(9.9, 9.9, 0.2)	Fwd, Port, Deck	12	15	12
7	(0.0, 9.9, 4.9)	Aft, Port, Ovhd	4	4	2
8	(0.0, 9.9, 0.2)	Aft, Port, Deck	11	13	11
9	(5.6, 4.5, 0.0)	Ctr, Ctr, Deck	N/A	N/A	14
10	(6.2, 5.0, 3.3)	Ctr, Ctr, Engine	N/A	N/A	4

Here Aft, Stbd, Ovhd, and Fwd under the Location/Reference column in the table stand for, respectively, aft, starboard, overhead, and forward bulkheads. Ctr and Engine in the same column stand for, respectively, center of the compartment and top of the engine mockup. Also, the origin of the (x, y, z) coordinate system is the deck at the aft starboard corner of the test compartment and the numbers correspond to the distance from the origin in meter.

There are a few items that may deserve further discussions related to the IMO fire test protocol.

4.1 Definition of Discharge Time

As mentioned in the previous section, there is a missing link between the discharge time obtained in this paper and the 95% mass discharge requirement in the IMO fire test protocol[1].

Considering that the telltale fire tests provided sufficient verifications of i) whether a system discharges a necessary amount of the agent for fire suppression and ii) whether the discharged agent achieves a uniform mixing inside the compartment, both within reasonable times, it does not seem to appear as a very significant issue. However, as the test data collected in this work could not establish the discharge time as defined in the IMO fire test protocol[1], this item still may warrant a further discussion by the protocol's drafters.

Another item of concern is the lack of a provision in the IMO protocol regarding the application of the tested hardware into a new configuration. It is very unlikely that a hardware which meets the discharge time requirement in the tests would be used in a different ship configuration in the exactly same way as tested in terms of pipe size, length, and location of nozzles. The lack of a proper provision addressing this issue makes the purpose of the elaborated measurement of and the emphasis given to the discharge time unclear.

4.2 Flame Stabilization in Test 4

The data collected in Test 4 strongly indicated that the spray fires, Fire E and Fire G, were blown out, rather than extinguished by physiochemical effects of the agent. For instance, the HF concentrations in Test 4, as shown in Figure 7, are significantly lower than those in Test 3, as shown in Figure 8, in spite of that the nominal fire size of Test 4 is much larger than that of Test 3: 7.95 MW vs. 4.4 MW. This obviously raises a concern whether the two fires in Test 4 were appropriate for testing performance of a chemical fire suppressant. It may be recommendable to stabilize the flames of the spray fires with flame holders in order to distinguish the real efficacy of the agent.

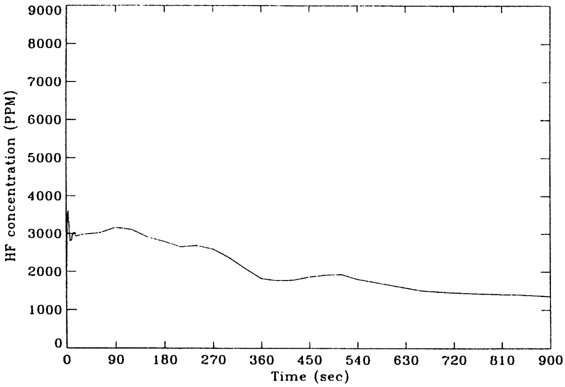

FIGURE 7. HF concentration measurement in Test 4.

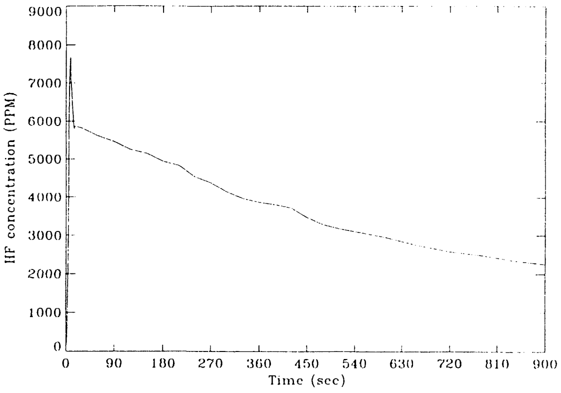

FIGURE 8. HF concentration measurement in Test 3.

4.3 Reliable Re-Ignition Source in Test 4

The IMO test protocol specifies that at the end of a soak period, the fuel spray should be restarted for 15 s prior to reopening the door and there should be no re-ignition. Thus, there was re-supply of two spray fuels in Test 4 though there was no likely re-ignition source at all. If the intent of the test protocol is to find out any re-ignition hazard at the end of the soak period, there should be a reliable re-ignition source such as a continuously energized ignition source.

4.4 Additional Telltale Fire Locations in Test 6

Once a fixed gaseous fire extinguishing system passes all the IMO Fire Tests, the current IMO standard allows the system to be modified as long as the modified system i) uses the same gas agent and ii) passes the telltale fire test, IMO Fire Test # 1. This can provide anincentive to have all of the discharge nozzles of a modified system placed very close to the four corners of the compartment where the telltale fires are located. It seems a reasonable requirement to add two more telltale fires near the center of the test room for the telltale fire test that is supposed to verify a system modification.

4.5 Cylinder Temperature of Cold Discharge Test

The cold discharge test in this paper, Test 2, manifested no adverse effect in system performance. The cylinder pressure, which was lowered due to the cold temperature, was still high enough not to make any noticeable time difference in discharging the liquid agent. The majority of the liquid agent discharged from the cylinders was still well above the boiling point of the liquid agent at the ambient pressure, –16.4 °C (see Figure 6). Thus, it can be assumed that as soon as the liquid agent discharged from the nozzles, it was vaporized immediately and dispersed throughout the test compartment.

However, if the liquid agent temperature goes down below the boiling point, it may take sometime before it starts to vaporize inside the room. In this case, the discharged liquid agent first needs a time to be warmed up above the boiling point to vaporize. There is a possibility that the effectiveness of the system can be hampered due to the slow disperse of the agent, though there is a strong indication that the discharge time may not be affected.

One more series of tests was conducted in December 1998, to verify this trend. A test cylinder that contains mixture of FM200® and compressed nitrogen (fill density of 0.678 kg/*l*) was maintained at –15 °C prior to the cold discharge test. The majority of the liquid agent discharged from the nozzles was below the boiling point, -16.5 °C, as can be seen in Figure 9. The discharge time was almost identical to that of a room temperature cylinder (12.2 s vs. 12.1 s), but there were considerable delays in extinguishment times in the telltale fires (the most significant one was 52 s vs. 26 s).

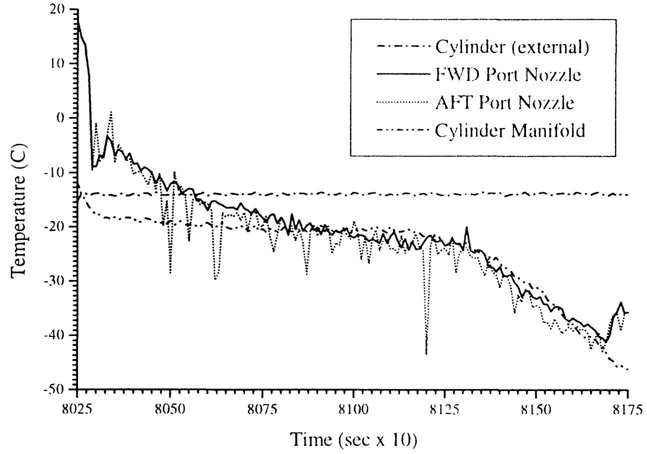

FIGURE 9. System temperature measurements in another cold discharge test.

4.6 Use of Full-Scale Fire Tests

It may be worth while reconsidering whether or not conducting the series of full-scale fire tests for every new hardware to check if it meets the IMO requirement would be necessary as required by the current regulation.

Considering that the full-scale fire tests provide much more favorable environments for a fire suppression than the telltale fire tests do (using a higher agent concentration while the oxygen depletion occurs rapidly due to large scale fires), it is very unlikely that a system would reveal any weak performance that was not manifested in the telltale tests.

A body of test results accumulated so far[8,9], also support this point. There was no system that passed the telltale fire tests ever failed in full-scale fire tests[8,9].

It may be recommendable to modify the regulation in such a way that i) only the system using untested agent has to go through all the fire tests in the protocol, while ii) any new hardware using tested agent only needs to pass the telltale fire tests.

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