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Scaling of fire suppression characteristics in machinery spaces

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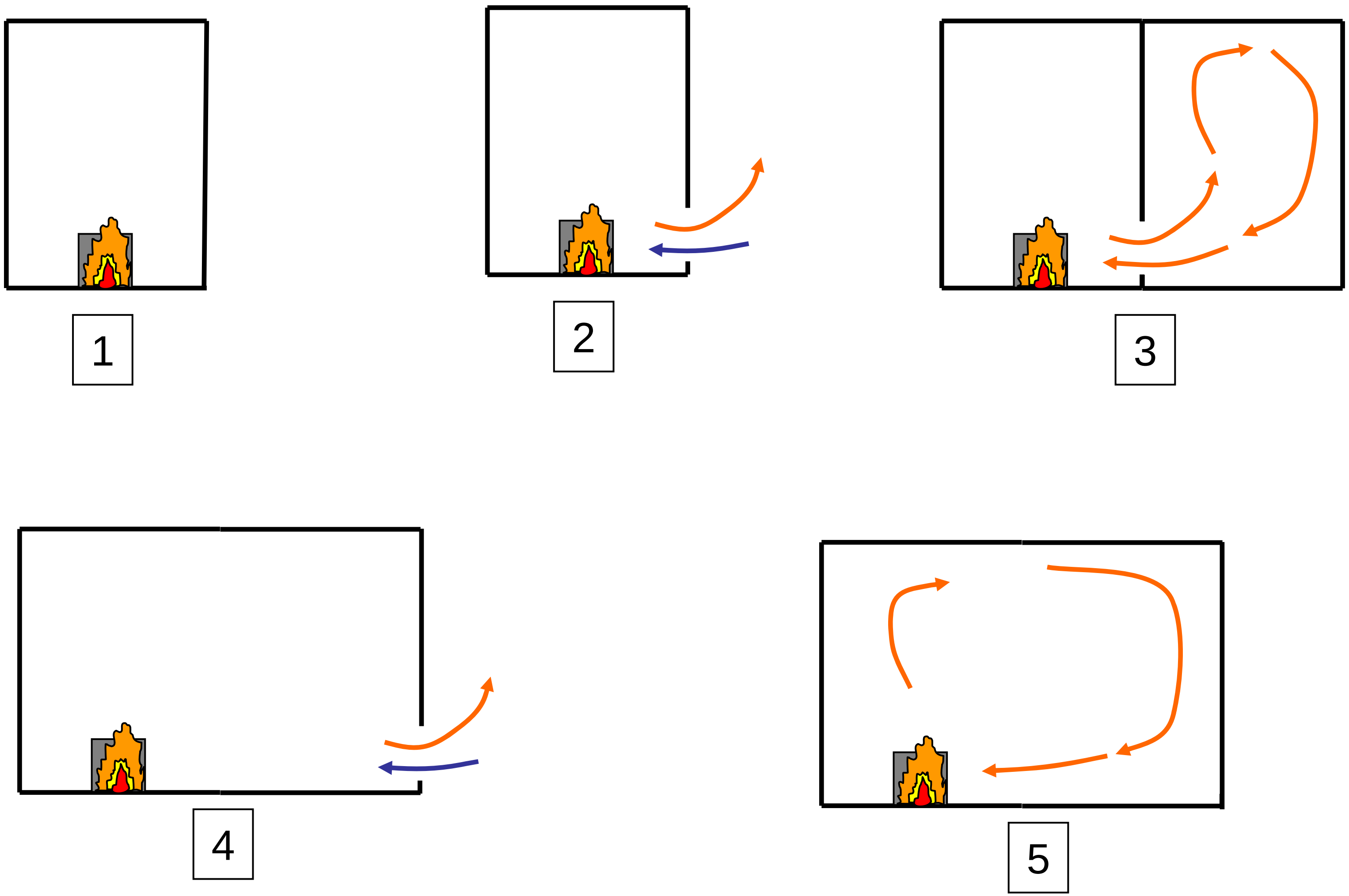
IWMA
International Water Mist Association

Background

- At the 2007 IWMA member meeting, a project was proposed with the aim to explore the possibility to develop a scheme to scale the conditions inside an enclosed space with ventilation through a doorway, as specified in IMO 1165. The project was agreed by the Board of IWMA, and was carried out by SINTEF NBL as.
- IWMA has carried out a research project with the aim to document the possibility to scale the effects of water mist into larger volumes. The primary goal is to submit a suggestion to IMO FP 53 in February 2009, for a scaling model to fulfill the requirements let out in IMO 1165:
- *The installation specification provided by the manufacturer should include maximum*
- *horizontal and vertical nozzle spacing, maximum enclosure height, and distance of nozzles below the ceiling and maximum enclosure volume which, as a principle, should not exceed the values used in approval fire test. However, when based on the scientific methods developed by the Organization*, scaling from the maximum tested volume to a larger volume may be permitted. The scaling should not exceed twice the tested volume.*
- ** To be developed by the Organization*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2
3
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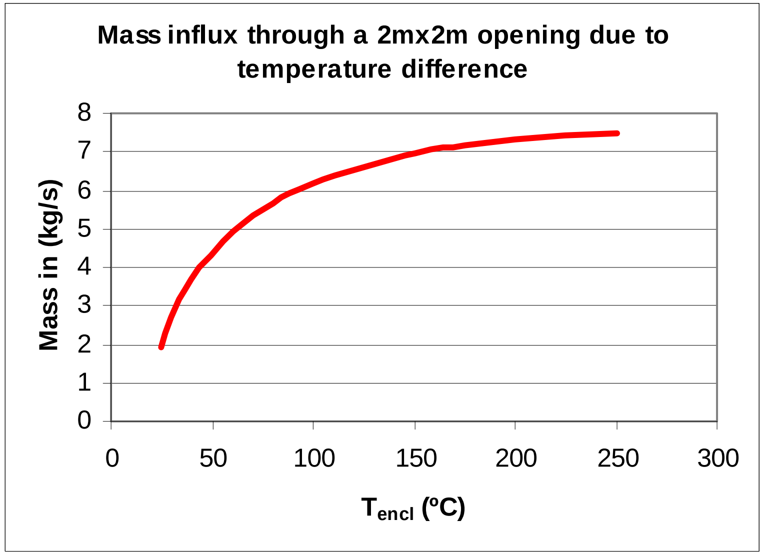
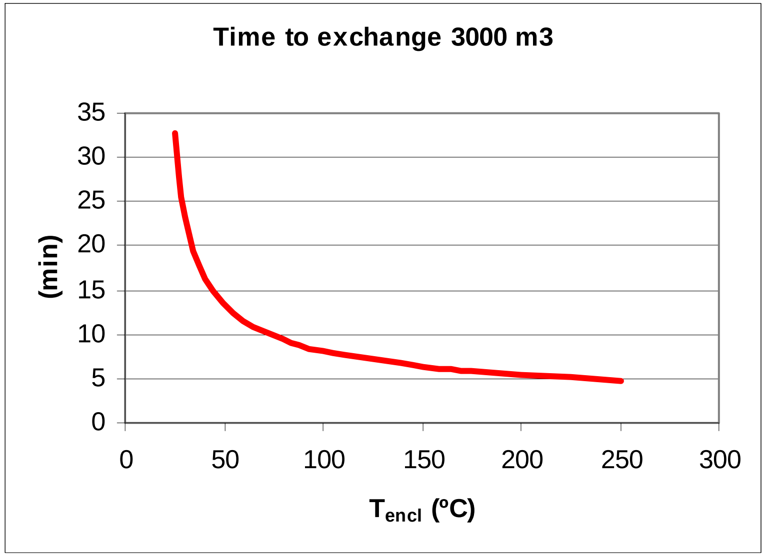
Airflow into an enclosure due to temperature difference at a door opening

$$\dot{m}_{in} = \frac{2}{3} \cdot k \cdot \rho_\infty \cdot A \cdot H^{1/2} \cdot \left[2g \frac{T_\infty}{T_{encl}} \cdot \left(1 - \frac{T_\infty}{T_{encl}}\right) \right]^{1/2}$$





Froude Number modelling

- If Froude Number is preserved at different scales, the development of temperature and gas species will be similar in space, with a defined time scale

Froude Number

$$Fr = \frac{momentum\ \ force}{buoyancy\ \ force} = \frac{\rho_g u_g^2}{(\rho_\infty - \rho_g) g L}$$

Froude Number modelling

- Doubling the volume V means an increase of linear scale with a factor of $S^{1/3} = 2^{1/3} = 1,26$. ($V=L^3$)
- Time scale: $S^{1/2}$ ($S^{1/2}=1,12$)
- The fire size and the water application scale $S^{5/2}$. ($S^{5/2}=1,78$)

- **Scaling with Froude Number similarity:**

  – Doubling the enclosure volume,using the same water mist nozzles and spacing and the water application density (Litres/m^2 min), keeping similar fire size, keeping the ceiling height constant and keeping the similar door opening:

  \+ The temperatur of similar positions outside the combustion zone will be lower at similar time

  +The concentration of species (CO, CO_2, particles) will be lower, Oxygen concentration will be higher at similar time

  \- Time to extinguishment will be longer

Scaling with IMO test conditions

- Hong-Zeng (Bert) Yu, at FM Global, USA: scaling of the IMO test fire characteristics taking into account that the test fires are kept at the same size, the door opening and the ceiling height is constant
- This study indicates a time scale relation in the order of 1,25 (15min/12min) when doubling the volume, based on the slower evaporation of water inside the enclosure when temperature is raising slower.

Qualifying the scaling scheme

- Manufacturers of water mist systems have provided results from tests to IWMA. A total of 105 tests have been utilized for the study. Results from four manufacturers of systems are included in this study. The systems and manufacturers are made anonymous in this report, but full system description and detailed test results have been studied by SINTEF NBL. Both low-pressure and high-pressure systems are represented in the database for comparison.

IMO 668/728 and 1165 fire tests

IMO 668/728	TEST No. 1	Low Pressure Horizontal Diesel Spray on Top of Mock-up
IMO 668/728	TEST No. 2	Low Pressure Diesel Spray on Top of Mock-up at a 45° Angle
IMO 668/728	TEST No. 3	Low Pressure Concealed Diesel Spray
IMO 668/728	TEST No. 5	High Pressure Horizontal Diesel Spray on Top of Mock-up
IMO 668/728	TEST No. 6	Low Pressure Concealed Diesel Spray
IMO 668/728	TEST No. 9	0,5 m^2 Heptane Pool on Bilge Plate
IMO 668/728	TEST No. 10	Flowing Heptane Fire from Top of Mock-up
IMO 668/728	TEST No. 11	Class A Wood Crib in 2m^2 Heptane Pool
IMO 668/728	TEST No. 12	Reignition Test, Heptane Spray on 5 cm Thick Steel Plate
IMO 1165	TEST No. 1	Low Pressure Horizontal Diesel Spray on Top of Mock-up
IMO 1165	TEST No. 2	Low Pressure Diesel Spray on Top of Mock-up at a 45° Angle
IMO 1165	TEST No. 3	High Pressure Horizontal Diesel Spray on Top of Mock-up
IMO 1165	TEST No. 4	Low Pressure Concealed Diesel Spray + 0,1 m^2 tray on Bilge Plate
IMO 1165	TEST No. 5	2,1 m^2 Heptane Pool on Bilge Plate
IMO 1165	TEST No. 6	Flowing Heptane Fire from Top of Mock-up
IMO 1165	TEST No. 7	Class A Wood Crib in 2m^2 Heptane Pool
IMO 1165	TEST No. 8	Reignition Test, Heptane Spray on 5 cm Thick Steel Plate
IMO 1165		Thermal Management test, Obstructed Heptane pool fire, size varied with room volume

- Figures 1-4 shows the time to extinguishing obtained with different water mist systems tested after the requirements of IMO regulations. For each figure, almost similar systems have been used, with possible smaller deviations in water application rates, positions of nozzles and other details. In some test series, AFFF is added to the water, in others no addition. The room volume is indicated for each test series. The ceiling height has been varied, but the mock-up of the engine, the fire scenarios and the door opening of 2 m x 2 m with a 0,5 m door sill is kept in all tests.

Figure 1. Time to extinguishing in tests after IMO Circ. 668/728, for room volumes of 500 m³, 1050 m³ and 1838 m³

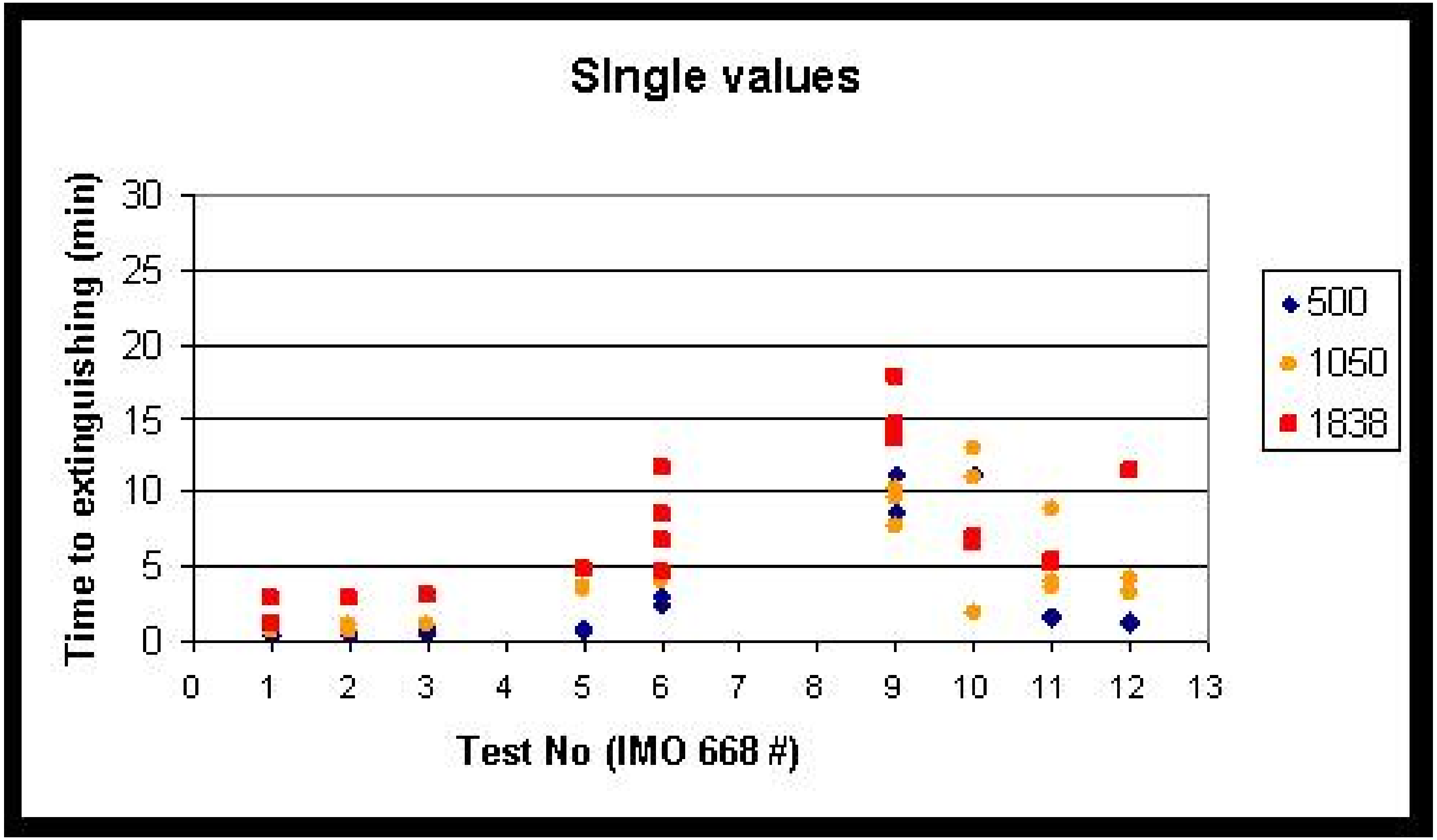


Figure 2. Time to extinguishing in tests after IMO Circ. 668/728, for room volumes of 1711 m^3 and 3348 m^3

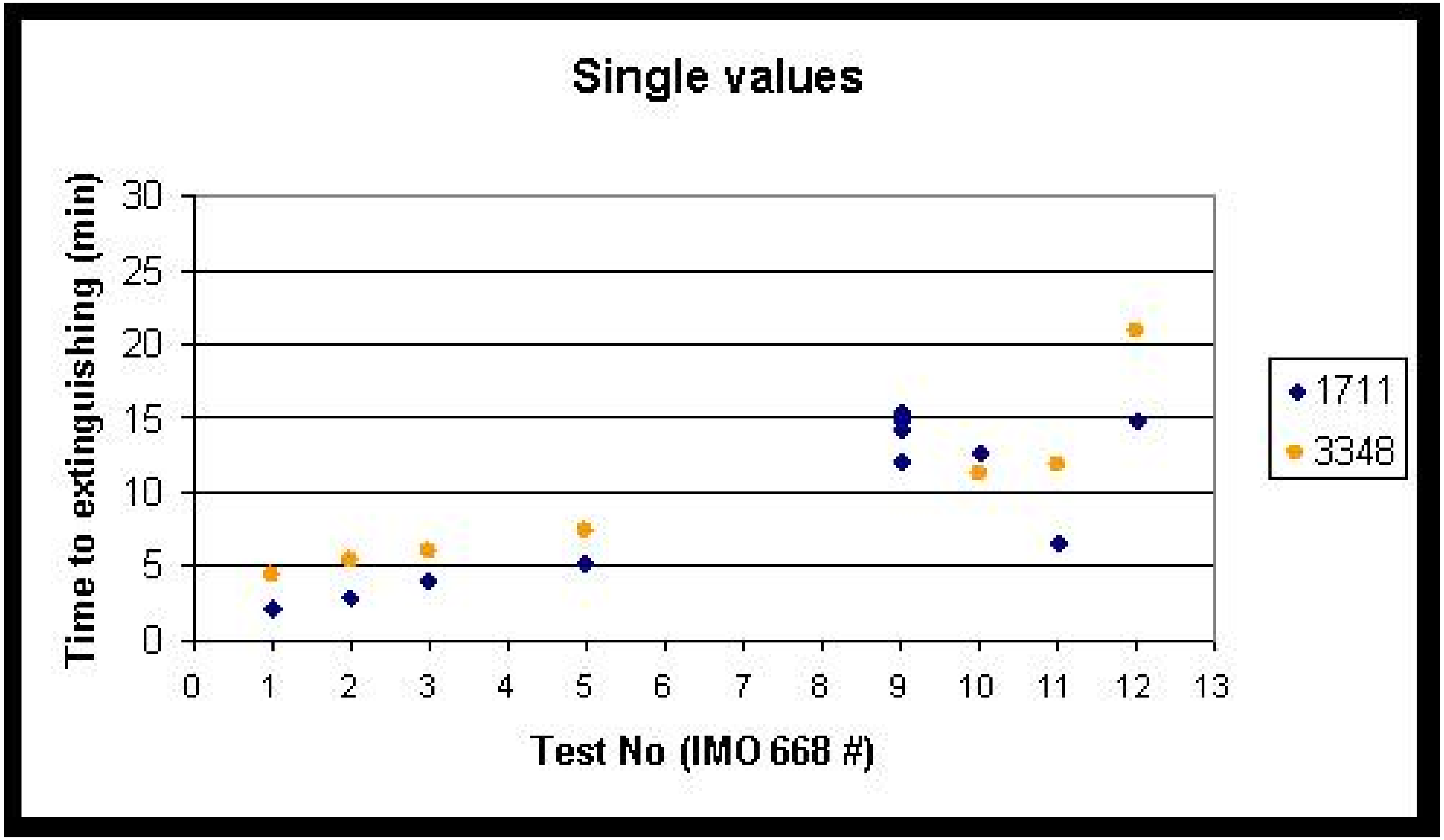


Figure 3. Time to extinguishing in tests after IMO Circ. 668/728, for room volume of 3348 m^3

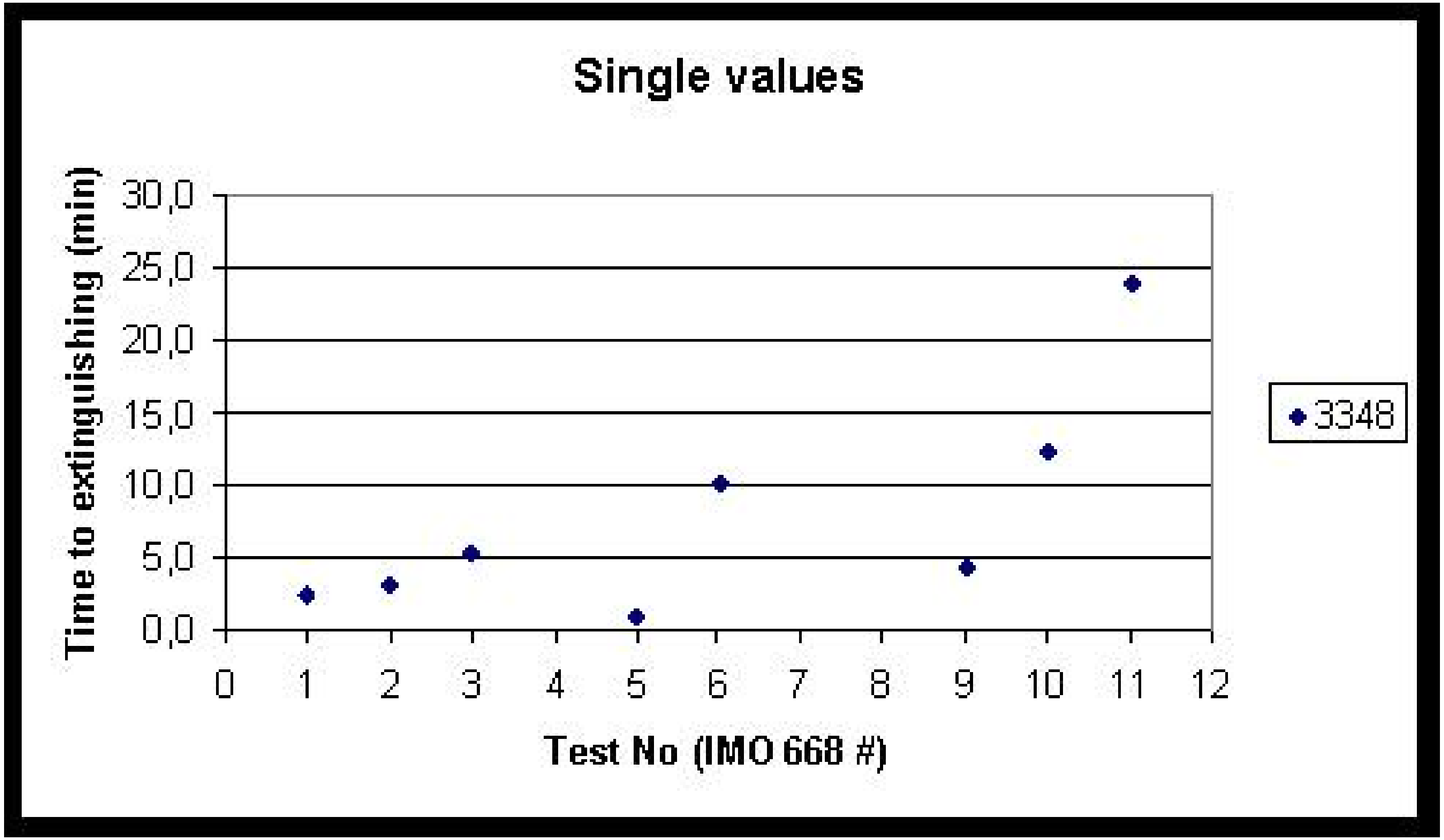


Figure 4. Time to extinguishing in tests after IMO Circ. 1165, for room volumes of 2526 m^3 and 3363 m^3

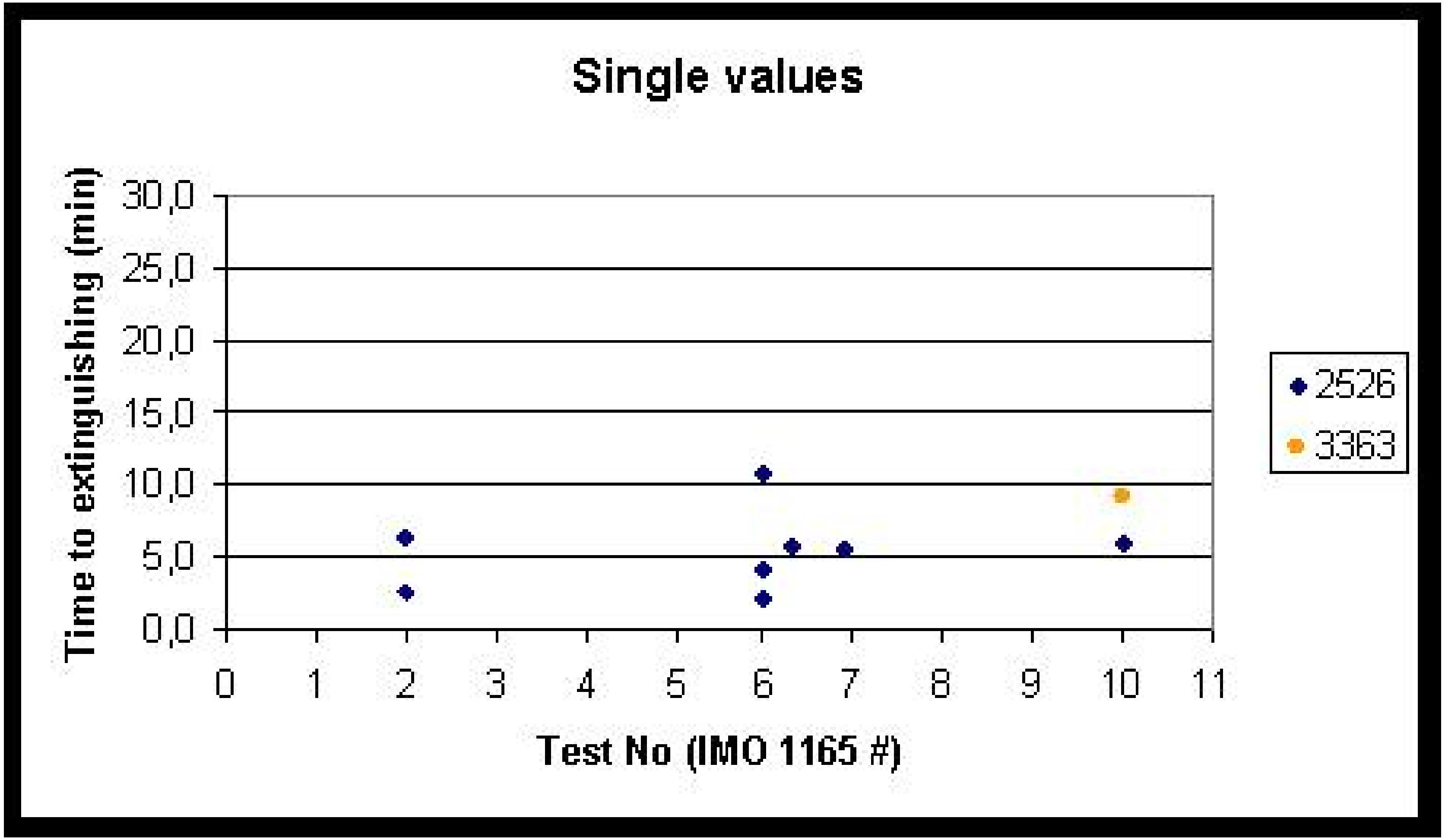


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Figure 5. Time to extinguishing in tests after IMO Circ. 668/728, for room volumes of 500 m^3, 1050 m^3 and 1838 m^3. Values of similar tests shown in Figure 1 are averaged

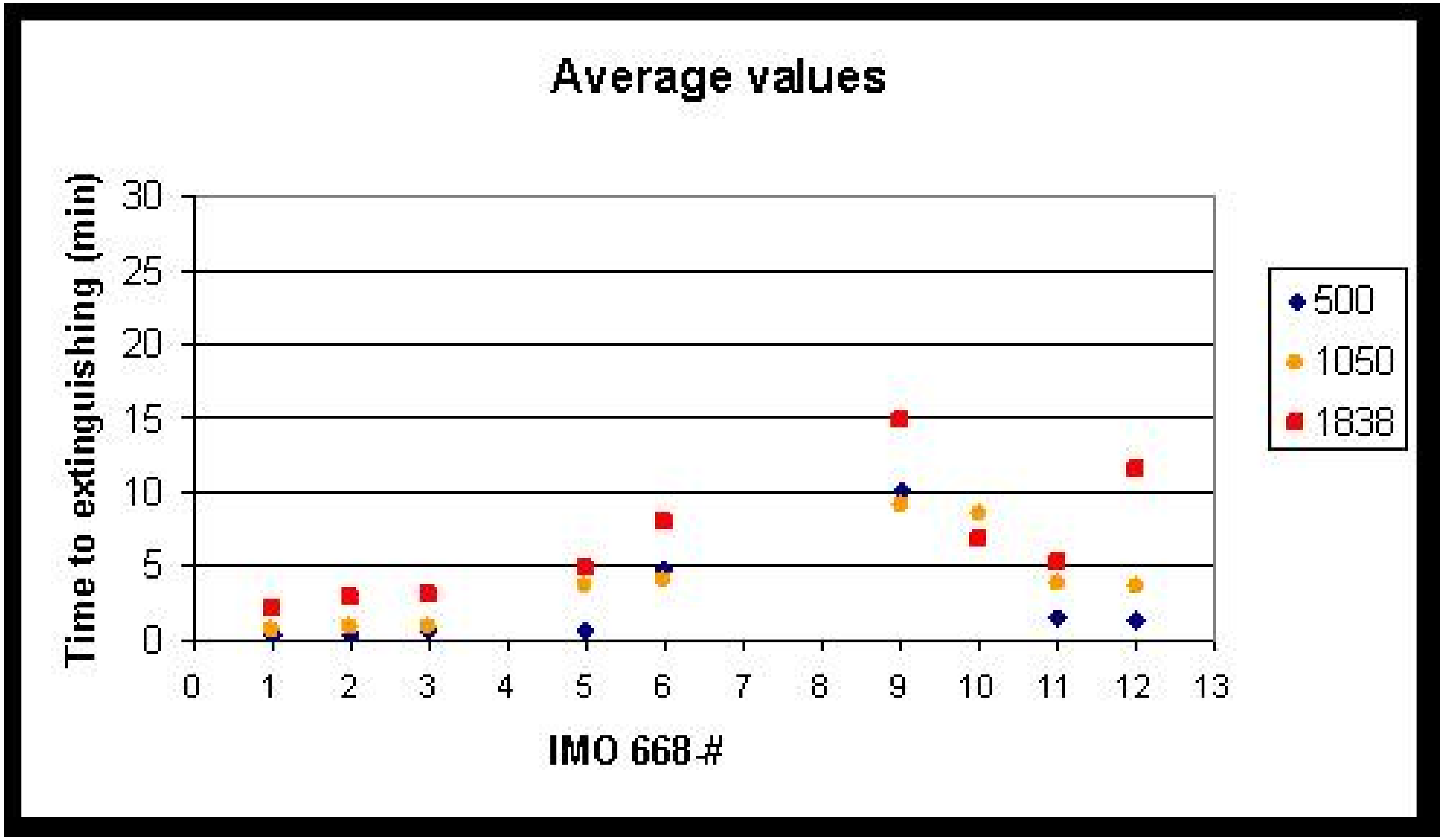

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Figure 6. Time to extinguishing in tests after IMO Circ. 668/728, for room volumes of 1711 m^3 and 3384 m^3. Values of similar tests shown in Figure 2 are averaged

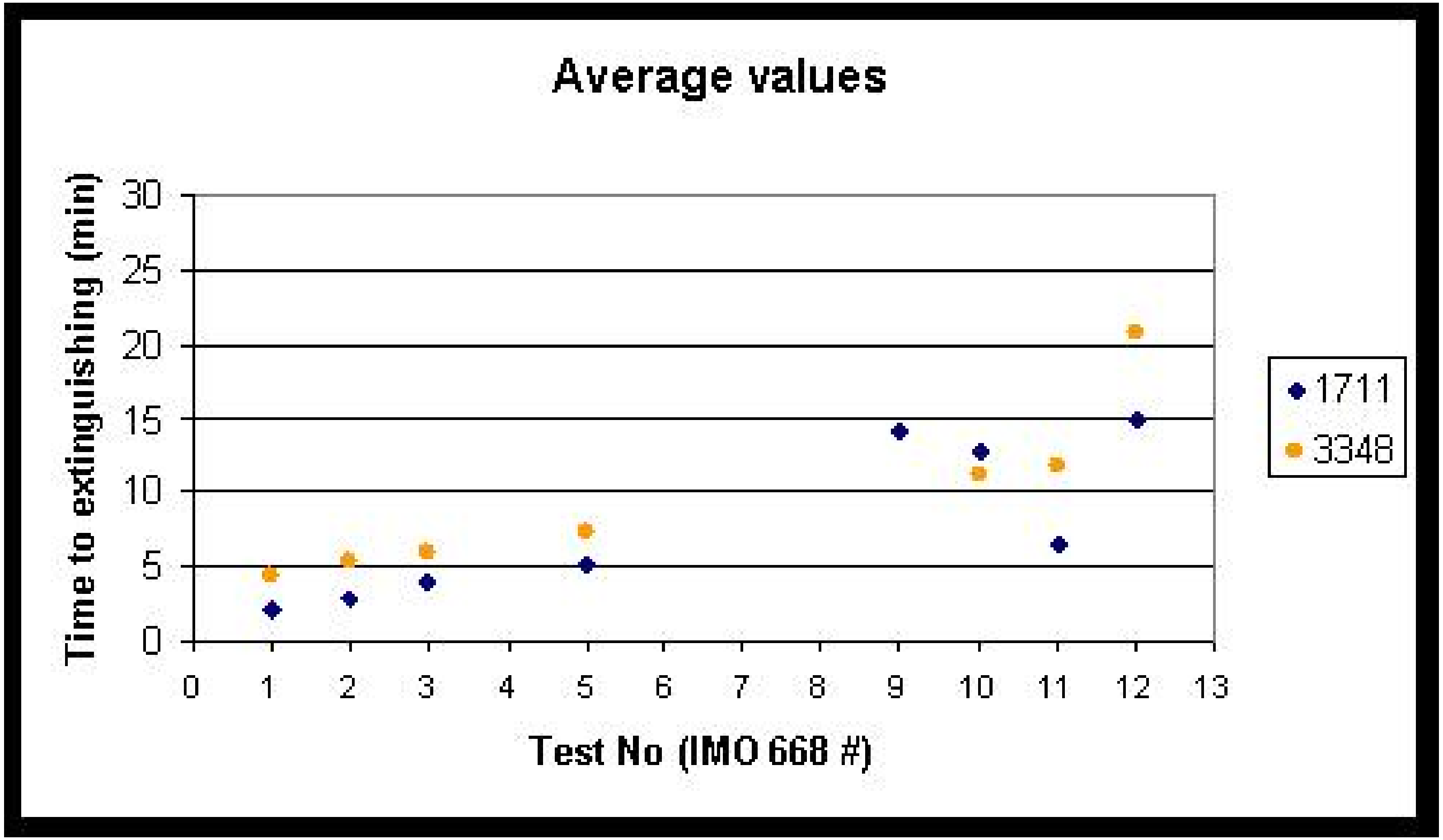

Table 3. Calculated time scales based on measured times to extinguishing from tests in room volumes of 500 m^3 and 1050 m^3, respectively. The volume scale is 2,10. The theoretical time scale (based on classical Froude Number modelling) is 1,13

IMO 668 test #	Minimum	Average	Theoretical	Ratio Minimum/Theoretical	Ratio Average/ Theoretical
1	1,88	2,15	1,13	1,66	1,90
2	2,10	2,68	1,13	1,86	2,36
3	1,83	1,32	1,13	1,62	1,16
5	4,62	4,12	1,13	4,08	3,64
6	1,67	0,87	1,13	1,47	0,77
9	0,88	0,92	1,13	0,78	0,81
10	0,17	0,86	1,13	0,15	0,76
11	2,39	2,43	1,13	2,11	2,14
12	2,63	2,80	1,13	2,32	2,47

Time scale in tests is calculated as:
(Time to extinguishing in larger scale/Time to extinguishing in smaller scale)

Table 4. Calculated time scales based on measured times to extinguishing from tests in room volumes of 1050 m^3 and 1838 m^3, respectively. The volume scale is 1,75. The theoretical time scale (based on classical Froude Number modelling) is 1,10

IMO 668 test #	Minimum	Average	Theoretical	Ratio Minimum/Theoretical	Ratio Average/ Theoretical
1	1,24	2,45	1,10	1,13	2,23
2	3,05	3,31	1,10	2,78	3,01
3	0,84	2,95	1,10	0,76	2,69
5	1,38	1,33	1,10	1,26	1,21
6	1,12	1,89	1,10	1,02	1,72
9	1,74	1,60	1,10	1,59	1,46
10	3,32	0,78	1,10	3,03	0,71
11	1,45	1,37	1,10	1,32	1,25
12	3,50	3,08	1,10	3,19	2,81

Table 5. Calculated time scales based on measured times to extinguishing from tests in room volumes of 1711 m^3 and 3348 m^3, respectively. The volume scale is 1,96. The theoretical time scale (based on classical Froude Number modelling) is 1,12

IMO 668 test #	Minimum	Average	Theoretical	Ratio Minimum/Theoretical	Ratio Average/ Theoretical
1	2,09	2,09	1,12	1,87	1,87
2	1,89	1,89	1,12	1,69	1,69
3	1,45	1,45	1,12	1,29	1,29
5	1,42	1,42	1,12	1,27	1,27
10	0,89	0,89	1,12	0,79	0,79
11	1,81	1,81	1,12	1,62	1,62
12	1,40	1,40	1,12	1,25	1,25

Table 6. Calculated time scale based on measured times to extinguishing from tests in room volumes of 2526 m^3 and 3363 m^3, respectively. The volume scale is 1,33. The theoretical time scale

(based on classical Froude Number modelling) is 1,05

IMO 1165 test #	Minimum	Average	Theoretical	Ratio Minimum/Theoretical	Ratio Average/ Theoretical
6	1,05	1,05	1,07	0,98	0,98

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Figure 7. Time scale to extinguishing in tests after IMO Circ. 668/728, for room volumes of 500 m³and 1050 m³. The volume scale is 2,10. The theoretical time scale (based on classical Froude Number modelling) is 1,13

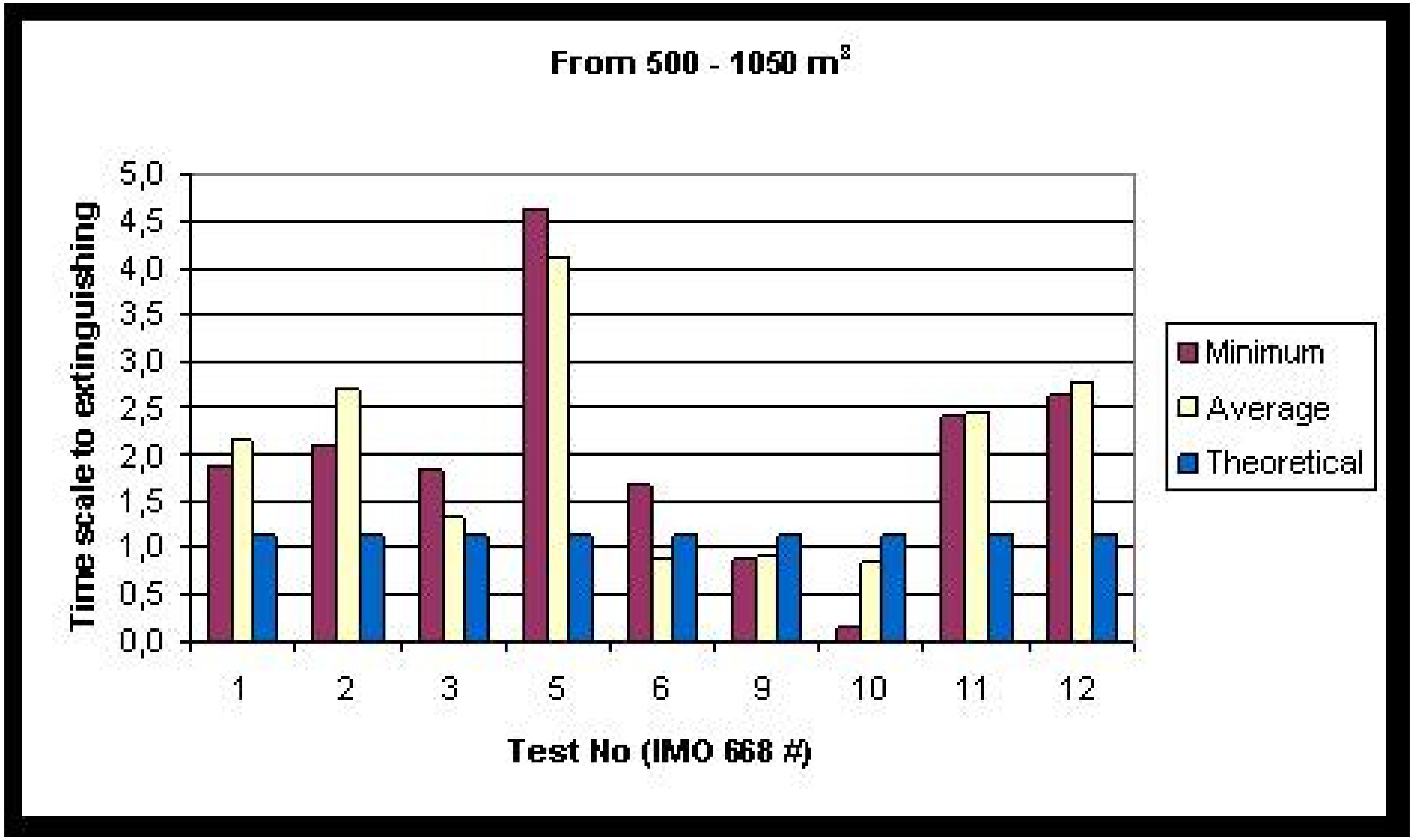


Figure 8. Time scale to extinguishing in tests after IMO Circ. 668/728, for room volumes of 1050 m^3 and 1838 m^3. The volume scale is 1,75. The theoretical time scale (based on classical

Froude Number modelling) is 1,10

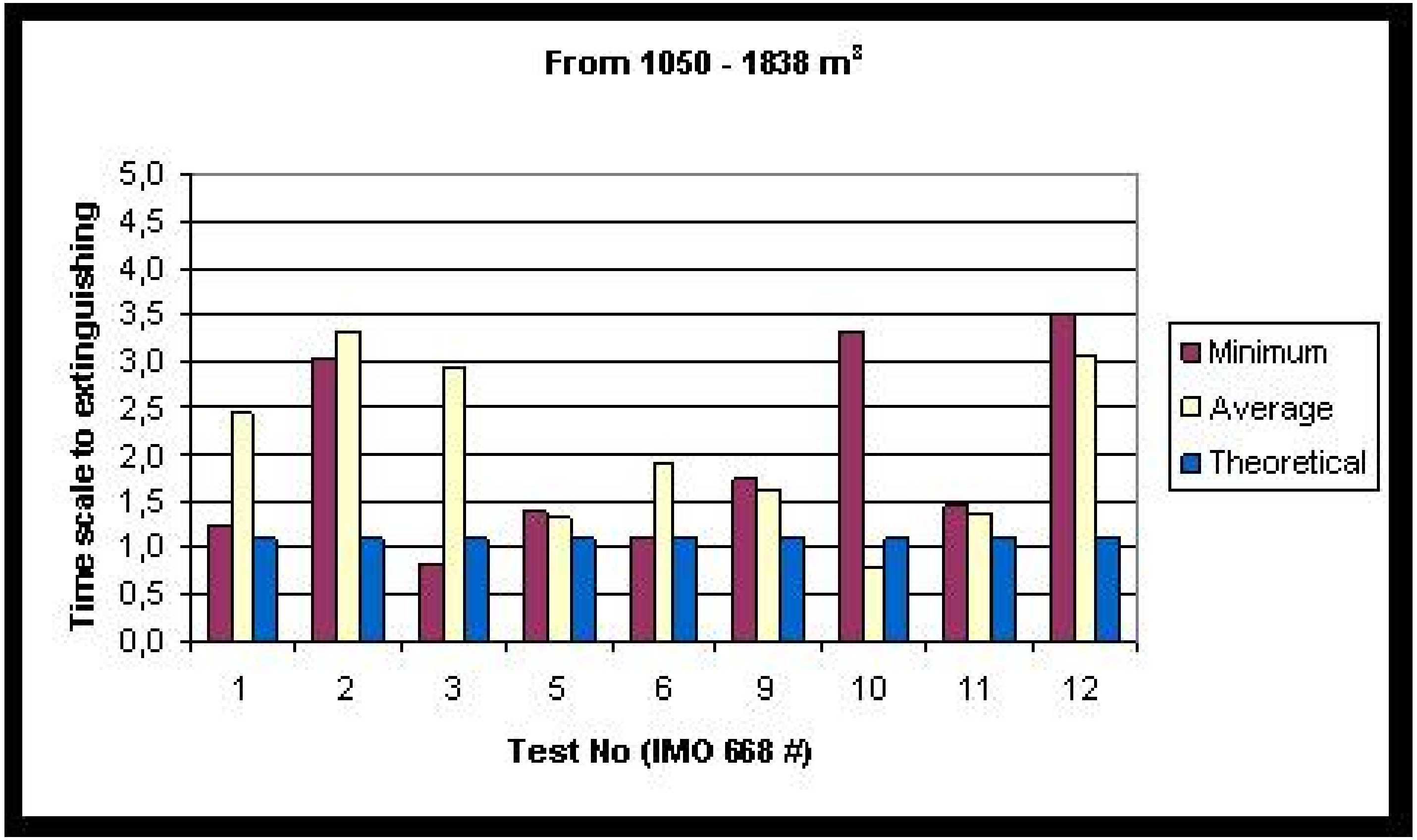
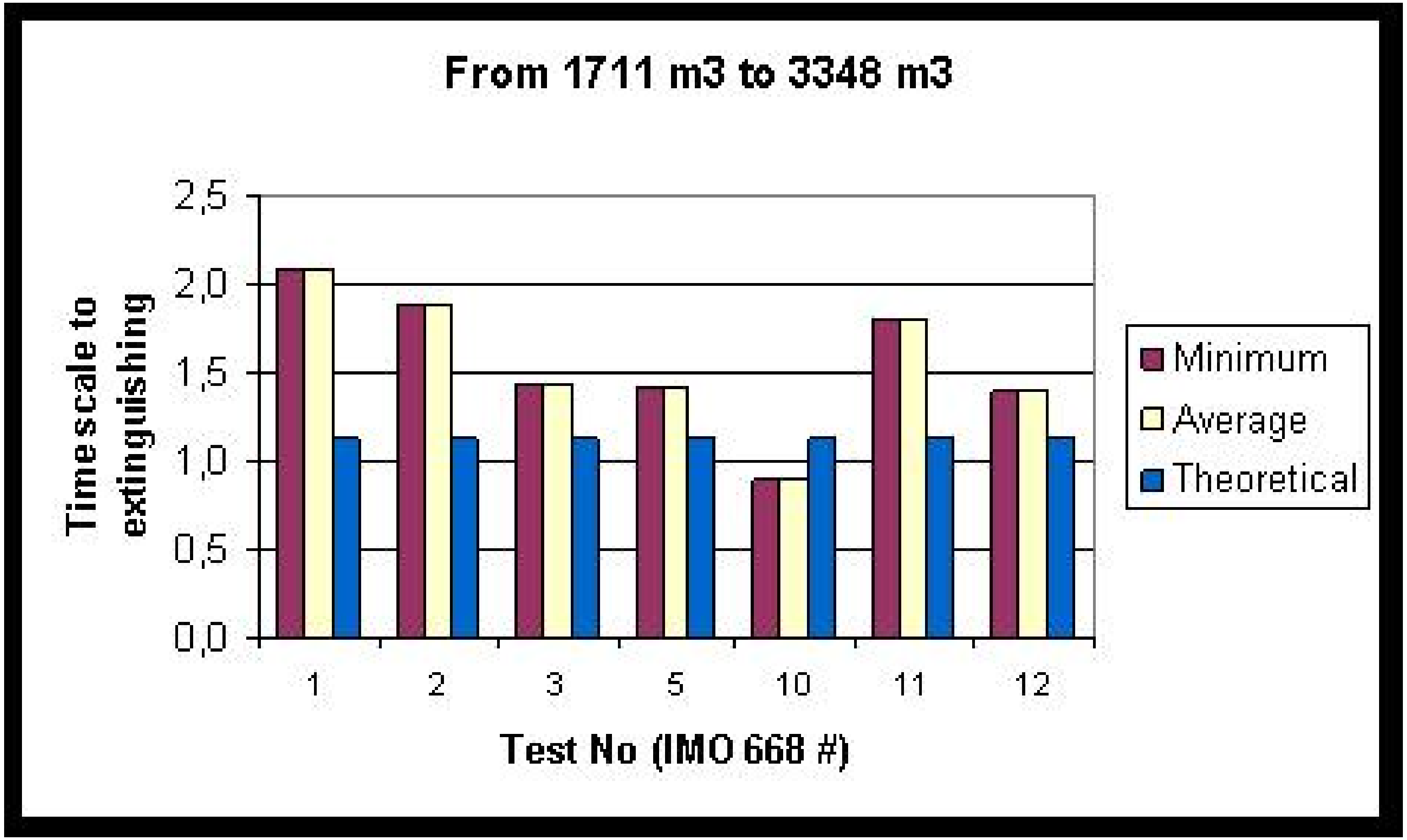


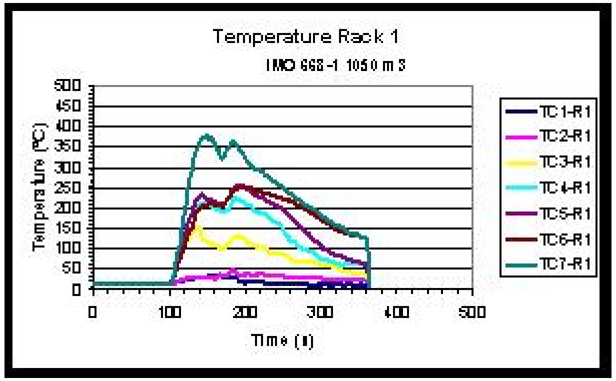
Figure 9. Time scale to extinguishing in tests after IMO Circ. 668/728, for room volumes of 1711 m^3 and 3348 m^3. The volume scale is 1,96. The theoretical time scale (based on classical Froude Number modelling) is 1,12

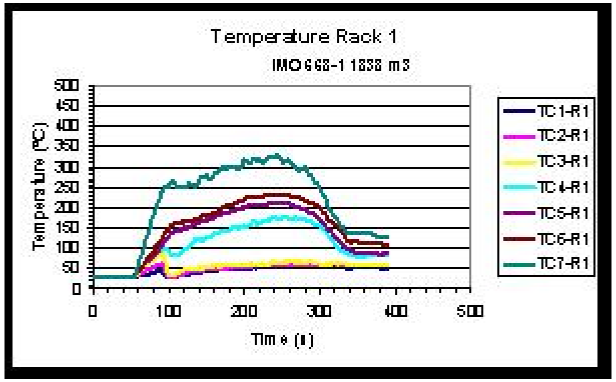


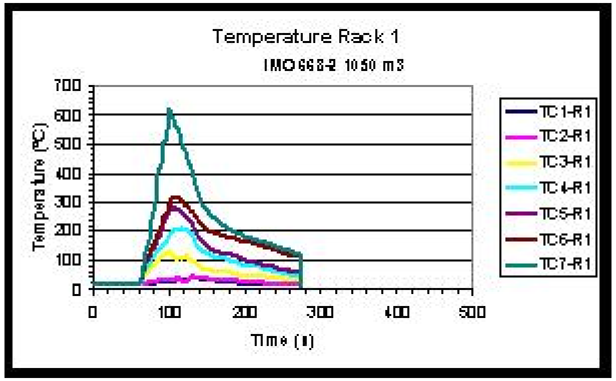
Discussion

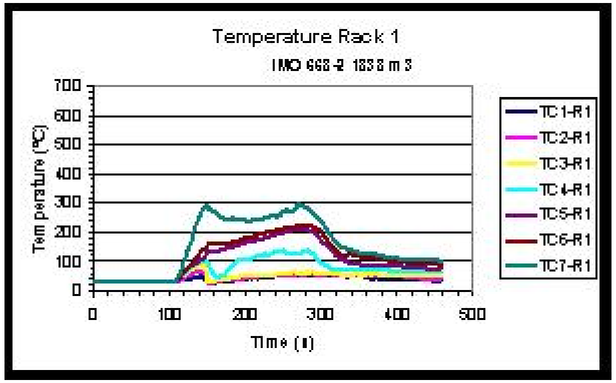
- **The overall impression looking at the time scales experienced in test compared with the theoretically based time scales is that the theoretical approach underestimates the time scale for extinguishing of the fires. This is in line with the extended study by Yu /3/, underlining that the influence of air through the open door will delay extinguishing in a way not directly scaleable.**
- **The largest deviation from theoretical value is seen for the large fire directly exposed to the water mist spray (IMO 668/728 # 5).**
- **It is also seen that in tests with concealed fires, the match between theoretical and measured times to extinguishing is better than for the fires that are directly exposed to the water mist spray. In test IMO 668/728 #1, #2 and #3, the time to extinguishing is also considerably shorter, and the scaling is not matching so well. However, this indicates that extinguishing due to the inerting of the atmosphere can be scaled well by Froude Number modelling.**
- **For other tests, the theoretical approach overestimates the time to extinguishing.**
- **In one tests carried out after IMO 1165, test #6, (flowing fire) the time to extinguishing is in line the theoretical approach.**

Thermocouples in the room









- **With the experimental data-base provided by IWMA, a check of the scaling scheme has been carried out.**
- **At true time from fire start, temperature inside the enclosure will be lower at locations away from the fire source, as the combustion products will dilute into a larger volume. Similarly, gas concentrations and the concentration of smoke particles will follow the pattern of temperature. The concentration of Oxygen will then be higher; the concentration of toxic CO will be lower**

- The main conclusion is that both the temperature and species concentration is then less severe, and the heat load towards equipment is reduced. The hazard potential to personnel that is staying inside or entering the enclosure will also be reduced. Time to extinguishment of the test fires will nominally be longer, and the smallest test fires may be of a size too small to be extinguished by inerting, as long as the door opening will provide fresh air

Safety factors

- **Current test procedures described by IMO Circ. 1165 allows water mist nozzles to be positioned in an overhead position only, and the room is equipped with a door opening of 2 m x 2 m. This has been seen as a safety factor. The door opening can also be considered to represent additional air from an increased room volume. In this case, the real installed water mist systems have already been tested in a larger room volume than tested. In a case where the door opening is closed, one should expect that time to extinguishing is decreased in comparison with the test cases.**
- **Another safety factor to installed water mist systems is the required duration of fresh water supply, 30 minutes. This is twice the maximum required time for extinguishing the test fires.**

Conclusions

- IWMA recommends that IMO allows installation of a system in an enclosure of twice the volume for which a water mist system is tested for, based on Froude Number similarity and the test results provided by IWMA. The enclosure ceiling height is not to be increased from that which is tested, and the water mist system should be installed with similar nozzle spacing and specific water application rate as tested (Litres/m2 min). This scaling is considered to be within similar or increased safety for life at sea, as formerly accepted by passing the tests of IMO Circ. 1165.
- The safety factors already included in the requirements on nozzle positions and the door opening in the test room is considered to cover the effect of the additional air of a room twice as large as the test room.
- To compensate for a possible longer duration of small remaining fires in obstructed places, it is suggested that the duration of water supply is increased to 45 minutes in the case of twice the room size.

Acknowledgements

- IWMA would like to acknowledge the work carried out by:
- (Bert) Hong-Zeng Yu, FM Global,USA, who is the Chairman of the Scientific Council of IWMA
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- Alex Palau, LPG, Spain, Chairman of the Manufacturers Council of IWMA, for commenting and carrying out CFD calculations on the topic
- Manufacturers of water mist systems, providing data from tests, showing how the effects of water mist scales with volume, that is used for verification