PyroGen: A New Chemical Alternative to Halons

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1. INTRODUCTION

PyroGen belongs to a relatively new class of fire suppression agents - pyrotechnically generated or pyrogenic aerosols.

Being environmentally friendly and three to six times more effective on a mass basis than Halon 1301, the pyrogenic aerosols have already been acclaimed as a potential halon alternative for total flooding applications.

Pyrogenic aerosol is a combustion product of a specially designed solid or gelled chemical, which contains an oxidising agent and a combustible binder. When ignited, the chemical produces fine solid particles and gaseous products that mix together into a highly dispersed aerosol. Extinguishment action of the aerosol can be compared with that of an ultra fine dry chemical powder. Micron size of aerosol particles provides an extremely high surface area for an extinguishment actions and gas-like three dimensional distribution of the aerosol. Pyrogenic mechanism of aerosol generation provides a sufficient driving force, thus eliminating need for stored pressurised cylinders and propellant gases.

At present, there are only two main products on the market of pyrogenic aerosols - "S.F.E." (also known as EMAA Encapsulated Micron Aerosol Agent) and PyroGen (also known as FEAS Fire Extinguishing Aerosol Systems in its early design).

Evaluation of S.F.E. product clearly demonstrated that while the aerosol was very effective in suppressing fires, distribution was a serious failing [1].

Since pyrogenic aerosol is a combustion product, its formation is accompanied with a significant heat release. The generation temperature has been measured to be about 2300 °C [2]. The uncooled aerosol stream, when released into enclosed area, quickly ascends due to buoyancy forces. As the aerosol dissipates and stratifies, it becomes a less effective fire suppressant due to the uneven distribution and lack of mixing. This directly contradicts to its usage as a volume filling homogeneously dispersed total flooding agent [1]. The problem of insufficient cooling has been acknowledged as a major engineering and design challenge for pyrogenic aerosol systems.

Unlike S.F.E. aerosol, PyroGen does not suffer poor distribution as its design offers an effective cooling of the aerosol stream via a specially developed chemical coolant. The coolant represents a polymer composition highly impregnated with endothermic ingredients, which decompose at 200-300 °C without melting, generating gases and absorbing not less than 400 Cal of heat per kilogram of the composition. Cooling is effected at a rate of 400 degrees per second.

The present paper describes the test program for PyroGen generators designed for Total Flooding Marine Application. The objective was to investigate the ability of PyroGen system to adequately extinguish fire that could occur within a typical small engine room of a commercial shipping vessel.

2. PRODUCT DESCRIPTION

PyroGen aerosol is a combustion product of a solid aerosol-forming composition based on plasticised nitrocellulose and potassium nitrate, and is self-generated upon ignition of the composition. The solid aerosol-forming composition, together with an electric ignition device and solid chemical coolant are contained in a small non-pressurised canister with one or two end-plate delivery nozzles. The canisters are called MAG generators and vary in size (capacity) depending on the mass of solid aerosol-forming composition contained in the generator.

When an electric current is applied to the ignition device, it ignites the solid aerosol-forming composition, which undergoes a chemical reaction of combustion to produce PyroGen aerosol. The aerosol propels itself through the chemical coolant and out of the delivery nozzle into the protected area.

The high rate of aerosol discharge, efficient agent cooling process together with the very small micron size of its particles, ensure homogeneous gas-like distribution in a few seconds.

PyroGen has the lowest extinguishing concentration known among commercially available agents as most normal fires are extinguished at the design factor of 100 grams/m^3 , compared to 330 grams/ m^3 for Halon 1301 (the "design factor" refers to the mass of unignited aerosol-forming composition per unit volume of a protected area as specified by the manufacturer or distributor).

PyroGen extinguishing action is achieved primarily by interfering chemically with the fire reaction. At the reaction temperature the main component of PyroGen aerosol - potassium compounds dissociate into potassium radicals. The chemical action of potassium radicals is similar to that of bromine radicals in Halons. Secondarily, extinguishing action is achieved by lowering fire temperature to a temperature below which the fire reaction cannot continue (thermal cooling).

PyroGen aerosol is whitish gas-like medium that is close in density to air.

PyroGen aerosol is environmentally friendly (zero ozone depleting potential, zero global warming potential), non-conductive and non-corrosive.

As PyroGen aerosol stays in suspension for extended periods, it can be removed from the protected area by any airflow. Aerosol that has settled can easily be brushed, blown or washed away.

PyroGen aerosol is suitable for the protection of a variety of potential fire hazards, including those involving flammable liquids, combustible solids, oils and energised electrical equipment. Like all total flooding agents, PyroGen aerosol is most effective when used in an enclosed risk area.

3. TEST SET-UP

3.1 Test Enclosure

The enclosure was a standard **20 ft ISO** steel container of 33.5 m^3 internal size as detailed on the enclosed drawings. The total area was **67.29 m^2.**

3.2 Leakage area

A ventilation damper fitted in the centre of the container enclosure ceiling at the far end from the doors, an existing hatch 440 mm x 130 mm in one of the doors and a number of permanent holes in the walls of the container were used to provide natural ventilation and allow supply of oxygen to the fires.

To simulate the most unfavourable situation of an enclosure with uncloseable openings and establish minimum design criteria and installation limitations for such enclosures, the ventilation damper, hatch in the door and holes remained unclosed during and after PyroGen discharge. The damper varied in size, while the size of the hatch and holes remained constant.

3.3 PyroGen installation

To meet the requirement of the maximum design limitations and most severe installation instructions, the following installation was set-up:

PyroGen system consisted of **2** or 3 MAG-4 generators, each having an extinguishing agent capacity of 1 kg. Generators were mounted **60** cm apart from each other at the centre of the soffit of the enclosure ceiling with their cylindrical axes horizontal and parallel to the doors, so that delivery nozzles were oriented away from the fire.

PyroGen design factor tested was 60-90 percent of the intended end use design concentration as specified for absolutely sealed enclosures.

Manual release of the system was effected via electrical manual means at the completion of the agreed pre-bum times and closure of the container enclosure doors.

3.4 Instrumentation

A number of "K" type thermocouples were installed to measure fire temperatures (extinguishment time), temperature of the aerosol at the nozzle (discharge time) and ambient air temperature in the enclosure. Thermocouple outputs were recorded by means of a Data Logger connected to a computer to collect data at a rate of 10 times per second and permit the subsequent print out of fire out times and enclosure temperature curves.

3.5 Fuel supply

The fuel chosen for the fire tests was commercial grade diesel as used in the majority of small Marine Applications.

Fuel trays had a minimum **25 mm** of **fuel** on top of a water base.

A spray fire was supplied with diesel fuel from a pressurised cylinder complete with quick action shut-off valve. The spray fire was ignited from an open pan of diesel fuel located below the path of the diesel spray.

Pre-burn period was **2 min** for all pan fires and 15 sec for spray fires and in all cases was sufficient to ensure complete involvement of the fuel.

After extinguishment of the spray fire the fuel supply was actuated for **15** sec for signs of re-ignition.

4. TEST PROTOCOL

4.1 Bilge Test

The aim of this test was to determine the ability of the agent to extinguish a three-dimensional tire using two trays of fuel located at different heights within enclosure, with one open tray in the machinery space section and one concealed or shielded tray in the bilge mock-up. The shielded bilge fire tray **525mm x 525mm** was located at floor level. The open machinery space fire tray 680mm x 680 mm was located on floor plates at **500** mm in height.
Uncloseable ventilation damper in the roof had dimensions **545** mm **x 400 mm** and was located close to the far left comer.

4.1.1 Bilge Test No 1 - No Agent

To demonstrate that sufficient oxygen was being provided to allow continual combustion of the test fires even with the container enclosure doors sealed, a free burn tests was conducted prior to the extinguishing agent fire tests. The procedure was as follows:

- Heptane in both trays was ignited.
- Temperature data collection was started on the computer.

- Two minutes of pre-burn period was allowed to ensure ignition and complete involvement of diesel fuel.
- Doors were closed.
- Four minutes later fires were not self-extinguished.
- Doors were opened to ensure fires were still burning.
- Doors were closed to allow diesel burned out and thus fire extinguished.

4.1.2 Bilge Test No 2 - PyroGen generators: *2* MAG-4

Test parameters:

Number of PyroGen generators:	2 MAG-4
Design factor:	59.7 g/m^3
Minimum design factor for absolutely sealed enclosures:	100 g/m^3
Leakage area, minimum:	0.275 m^2
Leakage area/ Enclosure area:	0.4 %

Schematic of the test set-up is shown in Figure 1.

Test procedure:

- Heptane in both trays was ignited.
- Temperature data collection was started on the computer.
- Two minutes of preburn period was allowed to ensure ignition and complete involvement of diesel fuel.
- Doors were closed.
- PyroGen generators were activated.
- Three minutes later doors were opened.

Test Result:

Top pan fire (open machinery space fire) was extinguished immediately after the end of aerosol discharge. Bottom pan fire (shielded bilge fire) was extinguished in 10 seconds after the end of PyroGen discharge.

Test is considered as successful.

Experimental results on temperatures plots are given in Figure 2.

4.2 Spray Fire Test

Spray jet was located at 1200 mm height at the centre line of the container 1500 mm in from the far end of the container enclosure. Schematic of the test set-up is shown in Figure 3.

The test procedure was as follows:
- Fuel in the tray was ignited
- Temperature data collection was started on the computer.
- Fuel for the spray fire was supplied and delivery volume was regulated to ensure stable jet reached the opposite wall.
- **15** seconds pre-burn time was allowed .
- Doors were closed.
- PyroGen was activated.
- Spray fire and tray fire were visually observed for the extinguishment.
- Doors were opened and extinguishment confirmed.

4.2.1 Spray Fire Test No 1 - PyroGen generators: 3 MAG-4

Test parameters:

Number of PyroGen generators:	3 **MAG-4**
Design factor:	**89.6 g/m³**
Minimum design factor for absolutely sealed enclosures:	100 g/m³
Ventilation damper	**1270 mm x 150** mm at the centre of the ceiling at the far end from the door
Leakage *area*, **minimum:**	**0.248 m²**
Leakage area/ Enclosure area:	**0.3 %**

Test results:

Spray fire was extinguished in 10 sec after the end of system discharge.
Pan fire was extinguished in **17** sec after the end of system discharge.

Test is considered successful.
Experimental results on temperature plots are given in Figure **4.**

4.2.2 Spray Fire No 2 - No Agent

Test with no agent was carried out in the enclosure having ventilation damper of **1270 mm x 150** mm to assess the effect of oxygen depletion on the **results** of Spray Fire Test No 1.

Test Result:

Spray fire was extinguished in **30** seconds after doors were closed.
Pan fire was not extinguished after **4** minutes.

5. SUMMARY OF TEST RESULTS

Table 1 gives a summary of the test results, including the generators location, the enclosure geometry, design factor and other parameters.

Table1: A **summary of test results**

Test No	Bilge No 1 *No agent*	Bilge No 2	Spray No 1	Spray No 2 *No agent*
Enclosure Volume, m^3	33.5	33.5	33.5	33.5
Enclosure area, m^2	67.29	67.29	67.29	67.29
Ceiling opening location dimension, mm	enclosure ceiling, far left corner 545 x 400	enclosure ceiling, far left corner 545 x 400	enclosure ceiling, centre, far end from the door 1270 x 150	enclosure ceiling, centre, far end from the door 1270 x 150
Min total area of unclosable openings, m^2	0.275	0.275	0.248	0.248
Opening area/ enclosure area %	0.4	0.4	0.3	0.3
PyroGen: Location		centre of the soffit of the enclosure ceiling; parallel to the front door; 600 mm apart	centre of the soffit of the enclosure ceiling; parallel to the front door; 600 mm apart	
PyroGen : Amount		2 MAG-4	3 MAG-4	
Factor g/m^3		59.7	89.6	
Extinguishment Pan Fire spray Fire	No.	Yes, in 10 sec	Yes, in 17 sec Yes, in 10 sec	No. Yes,after 30sec

6. DISCUSSION AND CONCLUSION

6.1 Bilge Fire

As PyroGen aerosol is formed at high temperature, it tends to be buoyant, rising to the top of the enclosure. Therefore, to test the system under its maximum design limitations, PyroGen generators were installed just below the ceiling level with discharge nozzles pointing away from fires.

Other test conditions were also set to be as unfavourable as possible. Specifically, presence of uncloseable opening on the ceiling and constant air flow across the enclosure, both of these resulted in a significant loss of the extinguishant. Additionally, obstructed fire in the lower region of the enclosure was expected to result in long extinguishing times.

Design factor was only 60 g/m^3, which is 40 % less than the minimum design concentration established for *sealed* enclosures.

Rapid extinguishment of fires in 10 seconds after system discharge clearly indicates that the design methodology, including design concentration, limitations and installation instructions, provides large safety margin and ensures reliable extinguishment of the above type of fire in typical small engine compartments of the commercial shipping vessels.

6.2 Spray Fire

Spray Fire as detailed in 4.2 is usually nominated as being the most difficult type of fire.

Test conditions were even more impaired by the disadvantageous ceiling installation of the PyroGen generators, orientation of nozzles away from the fres, presence of uncloseable opening in the ceiling and constant air flow across the enclosure.

Design factor was 90 g/m^3 , which is 10 % less than minimum design factor as established for sealed enclosures.

Rapid extinguishment of both spray and pan fires in less than 17 seconds after the end of system discharge clearly indicates that the design methodology, including design concentration, limitations and installation instructions, provides acceptable safety margin and ensures reliable extinguishment of the above type of fire in typical small engine compartments of the commercial shipping vessels.

7. REFERENCES

1. Sheinson, R.S., ***Fire Suppression by Fine Solid Aerosol,*** Proceesings, 1996 Halon Options Technical Working Conference, Albuquerque, New Mexico, 7-9 May, 1996.

2. Vitali, J., ***Pyrogenic Aerosol Fire Suppressants: Engineering of delivery systems and corrosion analysis,*** Proceesings, 1996 Halon Options Technical Working Conference, Albuquerque, New Mexico, 7-9 May, 1996

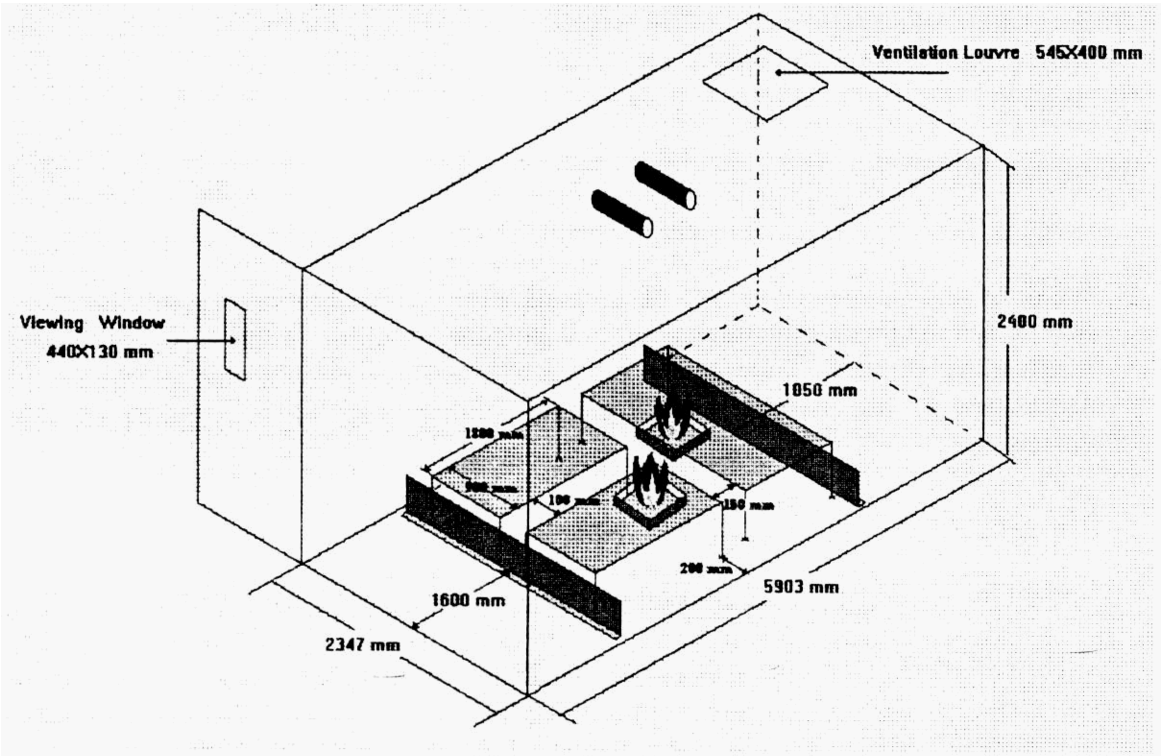

Figure 1. Bilge Test

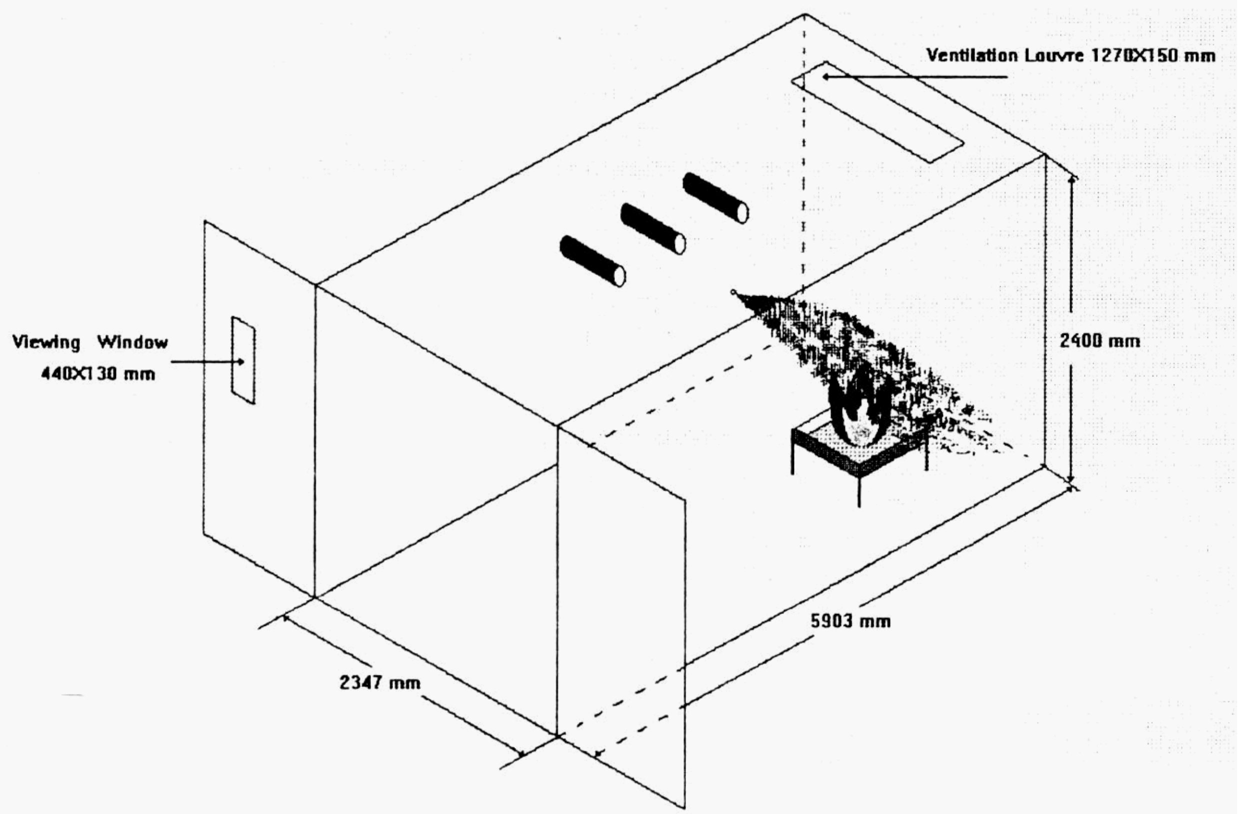

Figure 3. Spray Test

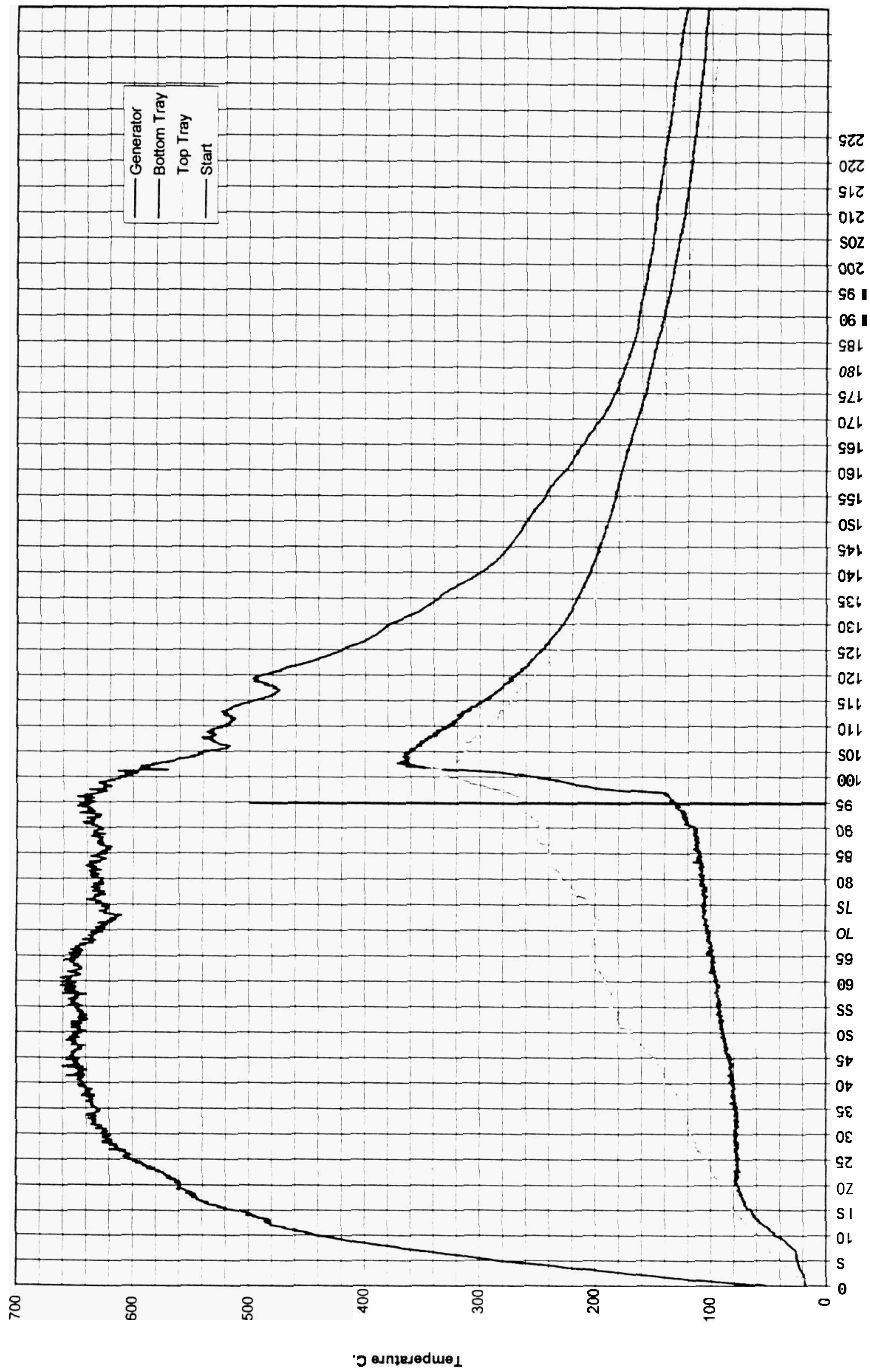

Figure 2. Bilge Fire Test : 2 g-4; opening 545x400mm

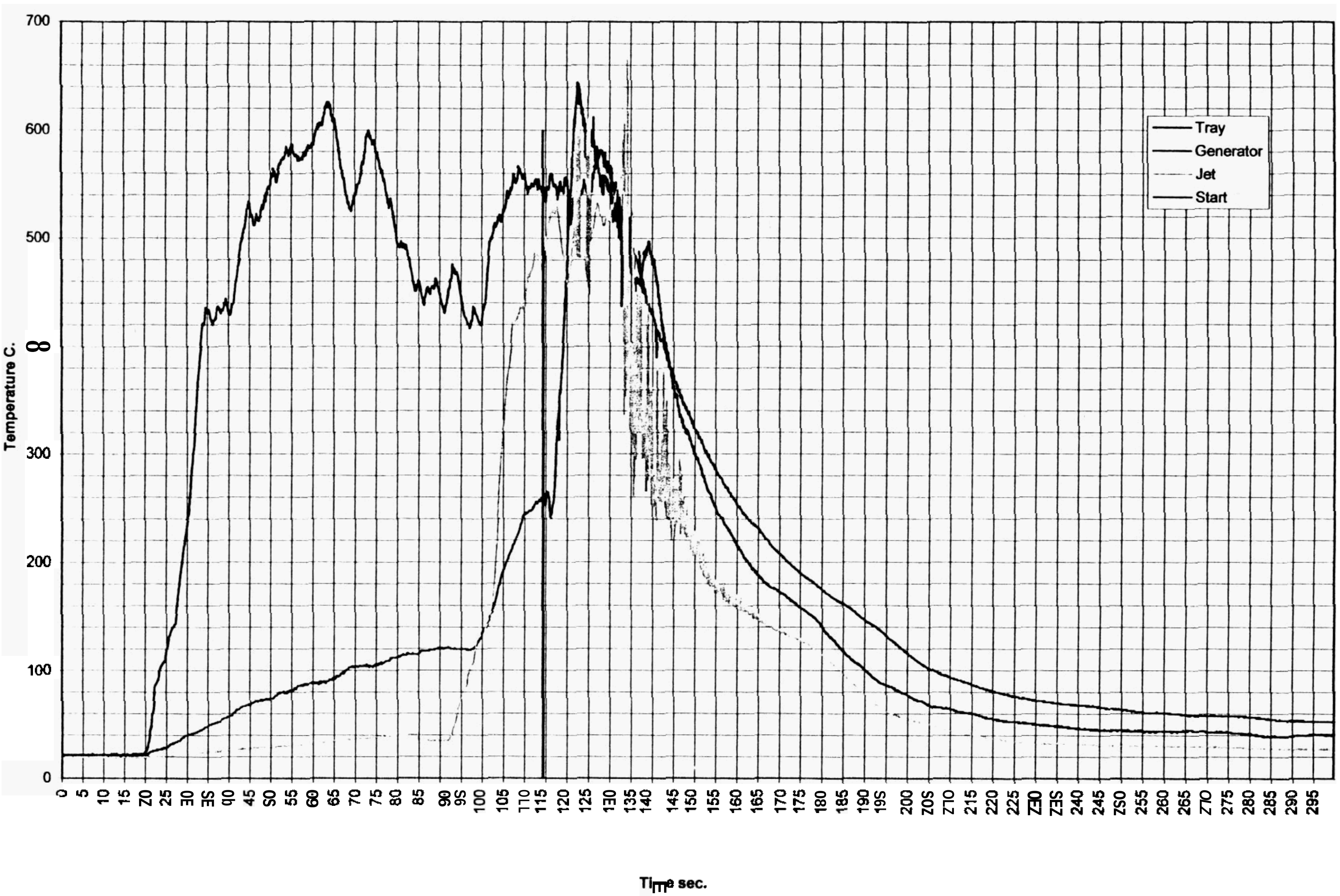

Figure 4: Spray Fire Test: 3 MAO-4; opening 1270x150mm