SMOKE SCRUBBING IN A COMPUTER ROOM

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ABSTRACT

In a computer-room-type facility the fires typically occur under the subfloor or in **a** computer cabinet, where the fire mey be caused, e.g., by an overheated capacitor or coil. **A** novel fire protection concept to specifically fight such fires is presented. Not only is the fire extinguished bur also the associated corrosive or otherwise harmful smoke is removed, hence preventing any non-thermal damages to cabinets or any other areas not directly involved in the fire.

INTRODUCTION

In a computer room fire, the flames and heat directly damage the immediate neighborhood of the ignition point. However, far more serious and widespread damages may he caused by non-thermal damage, especially by the corrosive smoke spreading all over the space: in fact, the smoke damage may paralyze a whole system of electronic data processing equipment. The damage caused by smoke may appear with a delay and hence they form an insidious danger to the operation of whole computer suites, telephone switch rooms, and the like.

The plastics applied in computer rooms with varying degrees of fire retardancy create a potential for high concentrations of smoke at an early, smoldering stage of a fire. At present, most of the cables in a computer room type facility are insulated with PVC, which generates a considerable fraction (up to 58 % of weight, depending on the actual composition) of HCI when undergoing combustion. Decomposition of PVC starts at 200 – 300 "C. HCI is the most dangerous compound in the smoke spreading around the fire area. although deposition of even non-corrosive soot may be harmful in causing short circuits.

If the chloride contamination on the surface of a circuit card is over 10 $\mu g/cm^2$, the electronics need to be cleaned [1] which may be an extremely expensive and time-consuming process if the damage is widespread. **An** upper limit for successful reconditioning has been found to be about 100 $\mu g/cm^2$. In real telephone central office fires involving PVC-based cables, contamination levels in the range of about 5 to 900 $\mu g/cm^2$ have been observed.

All the computer room fire protection systems known today are systems that do not attack the smoke problem in any way. Halon or other gas systems effectively extinguish the fires — provided that the room is sufficiently gas-tight — but they may, in fact, even worsen the smoke problem. **All** the smoke remains in the room, and the smoke together with dust is effectively distributed throughout the space.

SYSTEM DESCRIPTION

Principle of Operation

The new, widely patented Hi-fog approach to the fire protection of computer rooms is based upon the removal of smoke and the associated corrosive gases from the subfloor as part of the fire extinguishing process. The protection objectives are accomplished by a system that is essentially a high-pressure. twin-fluid. single-pipe water mist system. In addition to the extinguishing efficiency of the water mist–nitrogen mixture, the key parameters of the system are (1) the suction efficiency, and (2) the scrubbing efficiency of the high-pressure nozzles, and (3) the specific geometry of the complete system. consisting of the nozzles inside a distribution pipework and water drains.

Suction Efficiency

A water spray discharged from a nozzle entrains and imparts momentum to the air with which it comes in contact. The higher the velocity of the spray, the more energy is being transferred from the droplets to the surrounding air. i.e., the more air gets entrained into the spray. Due to the air entrainment. there is a suction flow field around the spray jet. Hence. in a fire enclosure. smoke and gases are effectively entrained into ihe spray.

Scrubbing Efficiency

Consequently the entrained smoke particles and water-soluble gases adhere to the water, and the air downstrcam of the nozzles is clean of smoke (Figure 1).

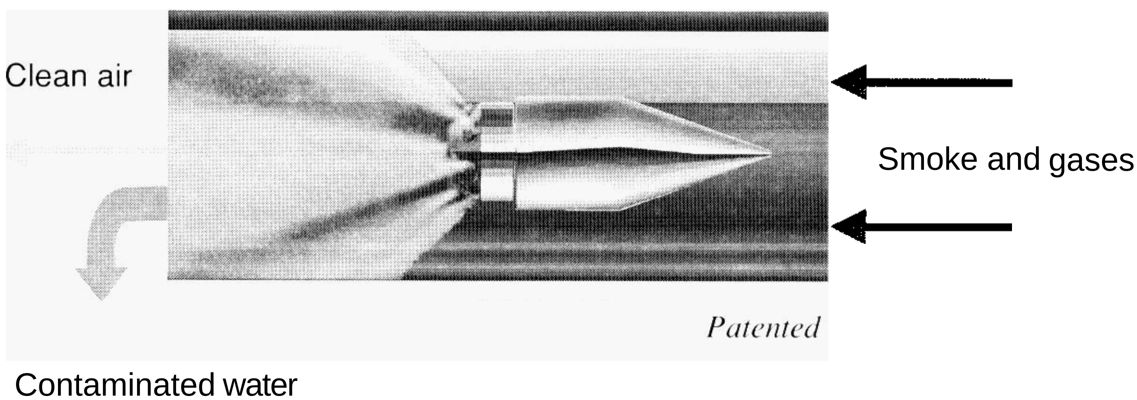
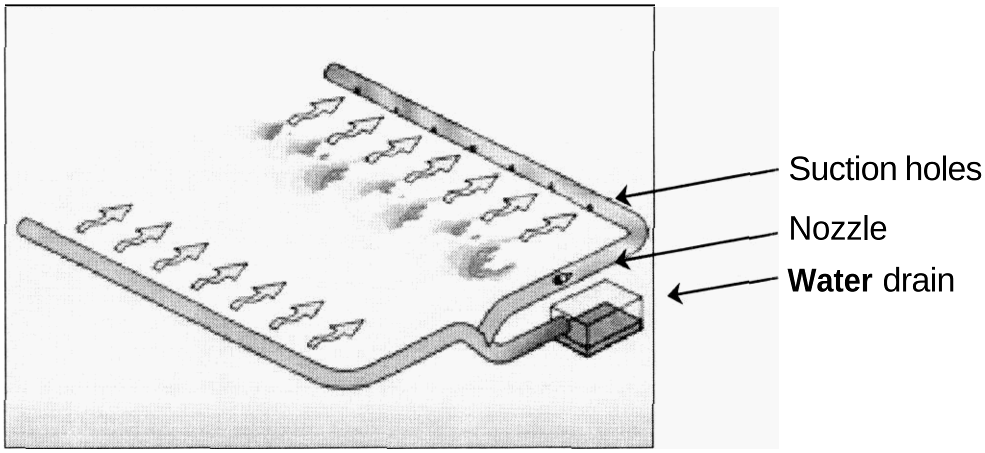


Figure 1. High-pressure spray entrains contaminated air from upstream of the Hi-fog nozzle.

Specific Geometry

The complete subfloor system constitutes a series of distribution pipes with the high-pressure nozzles inside them. The smoke is drawn into the pipes through a series of suction holes as shown in Figure 2, and is trapped with most of the discharged water in specific water drains. The cleansed air. the finest portion of the generated water mist. and the nitrogen used as the atomizing medium enter/return to the subfloor through another series of discharge holes in the pipes.

The system discharge is divided into two phases by a change in the water-nitrogen ratio in the discharged mixture. The initial discharge has a high water-to-nitrogen ratio and has a greater scrubbing efficiency. The second phase has a much lower water-to-nitrogen ratio and produces a



Patented

Figure 2. Principle of operation of the Hi-fog smoke scrubbing system.

finer, airborne mist that together with the nitrogen escapes the distribution pipes into the subfloor. This is primarily the extinguishing phase of the operation, although the two phases cannot be strictly separated: Fires do get extinguished already during the scrubbing phase, and smoke does get scrubbed until the very end of the second phase discharge.

Proper system operation requires all the key elements: Water mist is needed both as a scrubbing medium and as a suppressant. Nitrogen is used as both an atomizing medium and a suppressant. The suction is needed to accomplish the scrubbing and to maintain the high suppression agent concentration in the subfloor. It is the chimney effect that then causes the water mist-nitrogen mixture to rise into the computer cabinets and extinguish the fires also in the cabinets.

System Hardware

The system hardware consists essentially of nozzles, agent distribution piping, nitrogen and water cylinders as well as smoke scrubbing piping system with water drains under the subfloor. The whole subfloor area is covered with loops similar to those shown in Figure 2.

The two phases of operation are accomplished by a double-water cylinder arrangement with a specific adapter, powered by a single nitrogen cylinder (nominally 50-liter, 200 bar) as shown in Figure 3. The upper cylinder is initially full of water whereas the lower cylinder is only half-full. The change in the water-to-nitrogen ratio is due to the upper cylinder running out of water. The lower cylinder is pressurized by the initial flow of nitrogen into the two cylinders and continues to spray water into the nitrogen stream after the upper cylinder has run out of water.

In actual installations a control valve is opened at an alarm of an early detection system, and water starts to flow through the nozzles, initially at high pressure. A typical nozzle pressure curve measured during a discharge is shown in Figure 4. The two phases follow automatically after activation of the system.

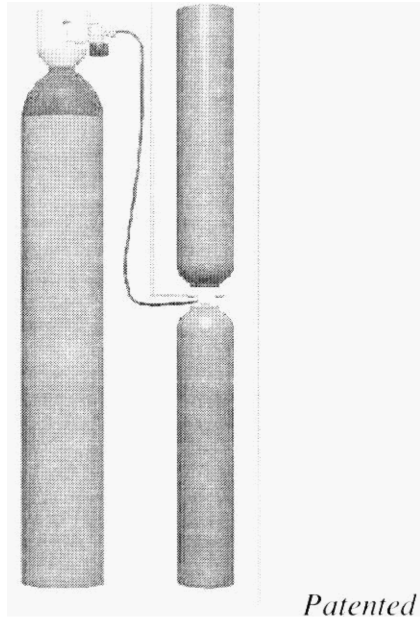


Figure 3. The Hi-fog double-water cylinder arrangement
nitrogen cylinder on the left.

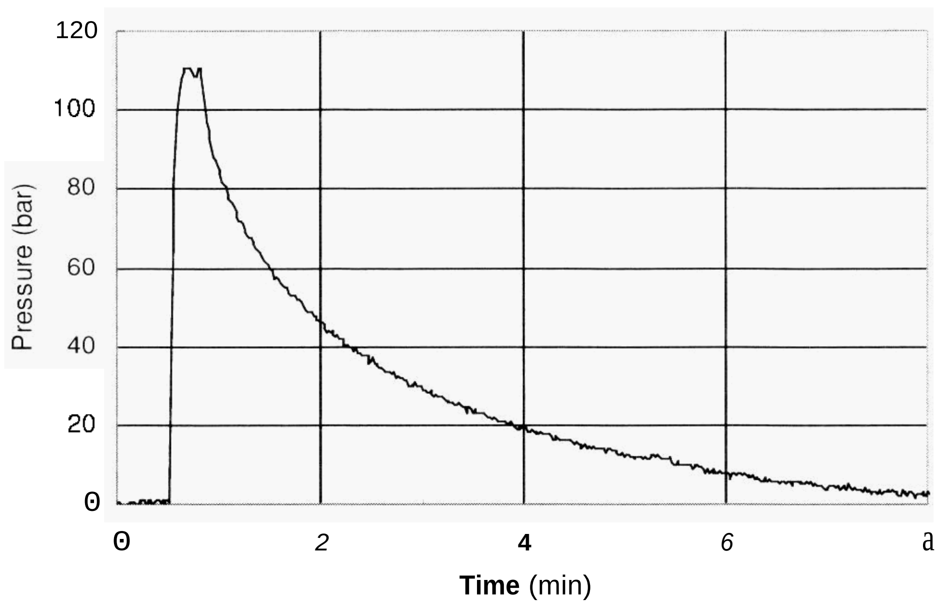


Figure 4. Nozzle pressure during discharge; first phase of operation lasts for some 30 sec

EXPERIMENTAL

Preliminary Tests

The development of the Hi-fog computer room protection system can be traced back to 1993, when Marioff conducted full-scale tests on fire suppression and smoke extraction in simulated ship's cabin and corridor [2]. Those early tests clearly demonstrated, how the Hi-fog nozzles effectively extracted smoke from the corridor and consequently washed and cooled the fire gases in the smoke extraction duct. The principal objective in that specific application was to keep the escape routes clear of smoke.

Later a more systematic study was carried out on the suction and smoke scrubbing efficiencies of different nozzles. The suction efficiency was determined according to the standard ISO 5167 *(Measurement of fluid flow by means of orifice plates, nozzles, and venturi tubes inserted in circular cross-section conduits running full).* The nozzle to be tested was installed in the same diameter (∅100 mm) pipe used in actual installations. The operating pressure of the nozzle was varied and the corresponding gas flow rate was determined. Figure 5 shows an example of the measured flow rate (V) versus pressure (p), from which follows the relationship—

$$V = const\sqrt{p}$$

The constant is nozzle specific, and the pipe length did not have any effect on it. The optimal nozzle was chosen based on these tests.

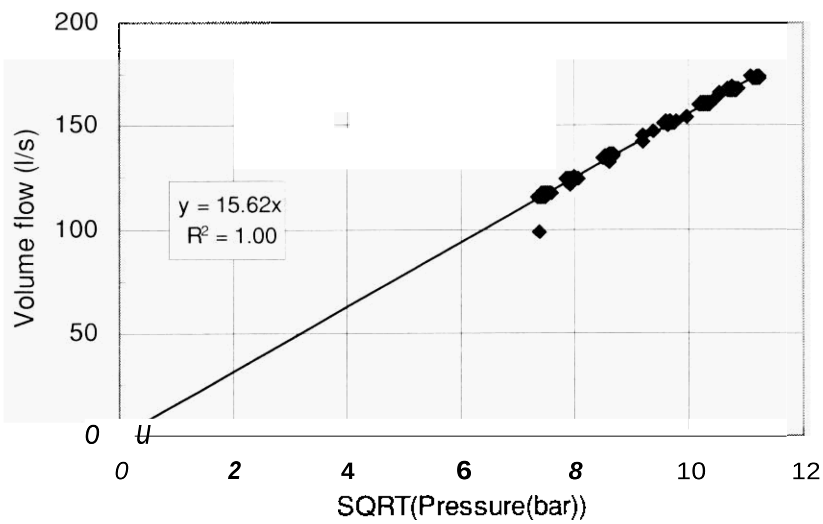


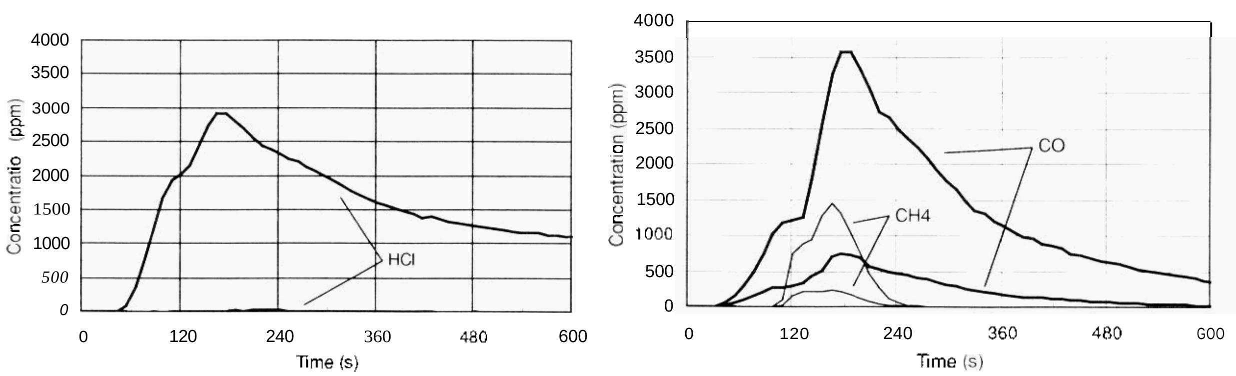
Figure 5. Entrained gas flow versus nozzle pressure for one of the tested Hi-fog nozzles.

The smoke scrubbing efficiency was verified in an arrangement consisting of a freely burning **PVC** cable crib fire in a small, ventilated enclosure of approximately 5 m^3 (2.1 by 2.1 by 1.2 m high) of volume. The nozzle to be tested was located in the enclosure's extraction duct equipped with a water drain, and the chemical composition of the gases downstream of the nozzle were determined with an FTIR multicomponent analyzer.

The crib was constructed of PVC-insulated 20-way ribbon cable, used in computers and interface units. The cables were arranged in crib form supported by a metal frame with layers 3 cm apart from each other. There were four double layers, each containing 18 strands 250 mm of length. Total weight of the crib was 0.78 kg, of which 0.52 kg was PVC. The crib can nominally generate 0.3 kg of HCl. The crib was positioned centrally on the floor of the enclosure with **a O** 9 cm pan filled with 20 ml of heptane under it. The heptane was ignited and the fire was allowed to evolve freely till **all** the fuel was totally consumed.

The test enclosure was placed in the big fire test hall of VTT, the volume of which is some 6000 m^3. During reference tests without any scrubbing, the observers could not stay in the hall due to the heavy production of irritating smoke. (A concentration of only *35* ppm already causes irritation of the throat after short exposure.) During tests with smoke scrubbing, no traces of smoke could be observed in the hall—not visually or by irritation.

Figures 6a and 6b show some gas concentrations measured in the exhaust duct (i) during a reference test without scrubbing and (ii) during **a** test with scrubbing. In both tests the crib is burning freely, and the peak production of smoke occurs some 2 min after ignition. With the scrubbing, all the HCl is dissolved in the water collected into the drain, and other gas concentrations are clearly lowered by the scrubbing spray.



(a) HCl   (b) CO and CH_4

Figure 6. ***Gas*** concentrations in the exhaust duct during free burning of the cable fire. The upper curves show the concentrations without scrubbing, the lower curves are measured with Hi-fog scrubbing initiated some 30 sec after ignition.

Full-Scale Computer Room Tests

Test Enclosure

Hundreds of full-scale R&D tests have been carried out in a simulated computer room of some 140 m^3 of volume at the Marioff site in Vantaa, Finland. The tests reported here, however, were conducted in a bigger enclosure at the Hughes Associates, Inc., in Baltimore, USA.

The schematic test arrangement is shown in Figure 7. The simulated computer room had internal dimensions of 10 by 10 by 3.54 m high. A subfloor was installed in the enclosure with 0.61 by 0.61 m steel floor tiles so that the top surface of the tiles was 45.7 cm above the floor of the enclosure. Five tiles were removed from the grid during the tests and were replaced with sections of pegboard to simulate the ventilation openings normally present in a computer room.

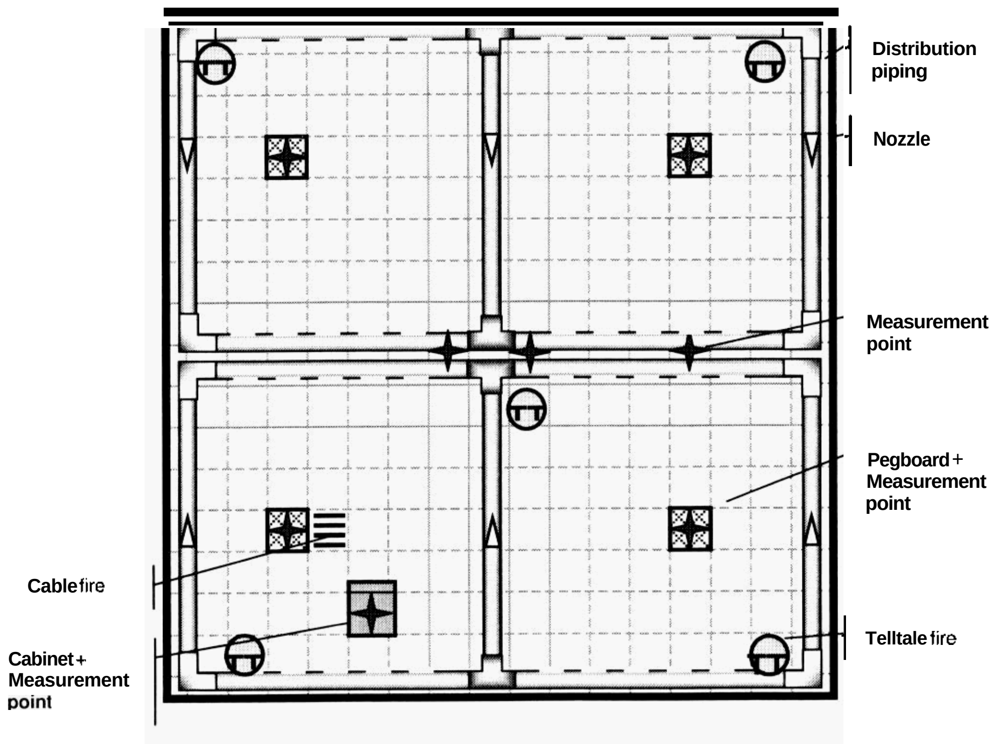


Figure 7. The large scale test arrangement. The squares represent the 0.61 by 0.61 m floor tiles covering the whole area. The schematic drawing shows the approximate locations of the eight measurement points, the five telltale fires, the cable fire, the computer cabinet as well as the Hi-fog nozzles in the distribution piping.

Computer Cabinet

An IBM Application System 400 Cabinet (64.5 by 91.4 by 157.5 cm high) was placed within the test enclosure to verify the protection of cabinet internals. The cabinet had a 12.7 by 59 cm opening in the bottom for cable passage to the subfloor. This free area was preserved throughout the height of the cabinet to act as a ventilation plenum. An outlet vent was located on top of the back wall of the cabinet. The cooling air for the cabinet was drawn from the subfloor through the cable access. The cabinet was packed with circuit cards and a processor up to the level of 92.7 cm. The space above it was empty and it was applied for test fires. In general, the level of packing of cabinets with circuit boards, racks, etc., may vary considerably. Still the flow resistance of the interiors of a typical cabinet is usually small compared to that of the vents [3]. The lower vent, i.e., the inlet vent, is the decisive choking flow hindrance.

Test Fires

In testing a firefighting system. the test fires need to be intense enough to generate measurable quantities of heat and/or smoke for validating the operation of the system. If the system was started. say, at an alarm of a sampling detector system. no visible smoke would yet be seen and no temperature rise could he measured. Therefore. in the tests, fires had to be attacked at an unrealistically late stage. Three test fire types were incorporated in the test program. The main objcctivc of *small telltale (heptane) fires* and *candle fires* was—along with verifying the cxtinguishing efficiency—to test the ability of the agent and the delivery system to reach all parts of the enclosure. The objective of the *cable fire* was to measure the scrubbing capability of the system and to test the extinguishing efficiency.

The five telltale fires in the subfloor consisted of a small steel cup (127 mm high, 76 mm in diameter) filled with 60 ml of *n*-heptane tloating on 500 ml of water. Nine candle fires were distributed in the cabinet in hidden locations at different levels.

The cable bundle fire was constructed with eight 50.8 cm lengths of PVC jacketed and insulated wire consisting of SO 24 **AWG** stranded conductors with a nominal exterior diameter of 1.2 cm. The cable lengths wcrc clamped with three hose clamps to a 650 W tubular heater. The transition to tlaming was aided by a propane ribbon burner. The cable fire was located either in the subfloor or in the cabinet (for the actual fire locations, see Figure 7).

Hi-Fog System

The subfloor system employed six Hi-fog nozzles of type 4S IMB 6MB 1000 discharging into the distribution pipes. The six nozzles were fed by three double-water cylinders (cf. Figurc 3), through 12.7 mm stainless steel tubing. **A** 1.3 m length of 9.5 mm hose was installed between the water cylinders and the stainless steel tubing.

The required nitrogen was provided from three 49-liter cylinders with initial pressures of I82 bar cach. through I m lengths of 9.5 mm hose. The flow of nitrogen was controlled by three actuation valves arranged so that a manual actuation of the first valve pneumatically triggered the other two.

The distribution piping for the tests was arranged in the subfloor in two double-loops as shown in Figurc 7. The nozzles were located 1.5 m from either the upstream elbow or Tee and 2.4 m from the downstream water traps. The inlet and outlet holes in the distribution piping were of 42 mm diameter with a spacing of 0.4 m between the centers of adjacent holes.

Instrumentation

Oxygen levels in the enclosure were measured at eight locations by Oxygen Citicel transmitters. One air sample was fed to Horiba VIR 2000 carbon monoxide and carbon dioxide analyzers. Hydrogen chloride concentrations were measured by 0 to 100 ppm Citicel transmitters **at** three locations. The **HCI** concentration in the trapped water was measured utilizing a chloride ion specific electrode. The temperatures in the enclosure were measured by K type thermocouples at the same locations with the oxygen transmitters. Stainless steel sheathed, exposed junction type K thermocouples were employed to monitor the continued burning of the telltale fires. Other pressure inside the enclosure was monitored by two Setra C264 pressure transducers. One transducer monitored the pressure differential at the top of one wall while the other monitored the pressure differential at the bottom of the same wall (in subfloor). Several other measurements were also taken, and a more detailed description of the measurements is given elsewhere [4].

Procedure

The specific procedure used in conducting the tests varied with the type of fire employed. After 15 sec of background data were collected the ignition sequence was commenced. For tests involving the telltale fires in the subfloor and the candles in the cabinet, the subfloor system was actuated 2 min after the last telltale had been lit. The candles in the cabinet were checked at the end of the test.

For tests involving the cable bundle fire, the propane igniter fire was shut off after the flame had stabilized on the surface of the cable bundle, and the subfloor system was actuated 120 sec afterwards. The tubular heater employed in the tests was shut off 15 sec after the flames were observed to have been extinguished.

Test Results

In the following section, relevant results of three different type of tests are given. In the test involving the *telltale cup fires in the subfloor and the candles in the cabinet.* the last telltale was extinguished 148 sec after the Hi-fog subfloor system was actuated (Figure **8). All** the candles in the cabinet had been extinguished when they were checked at approximately **6** min after the actuation of the subfloor system.

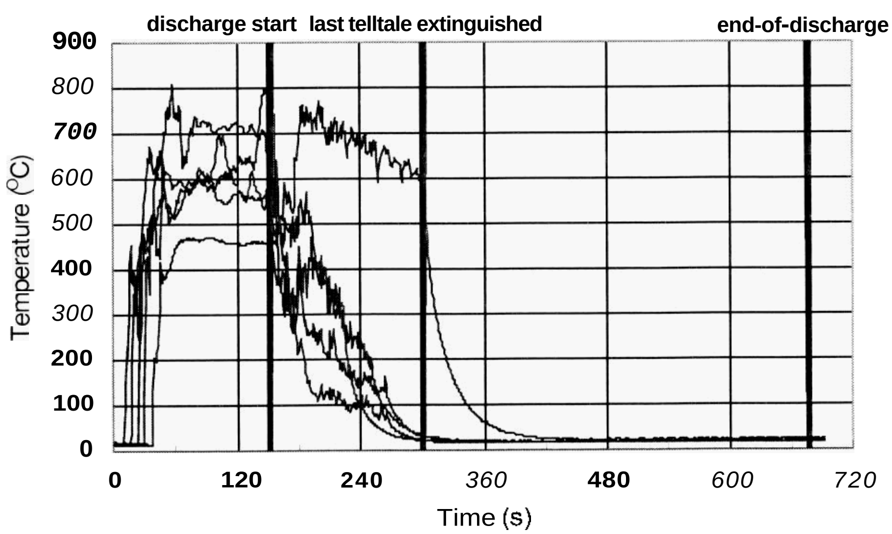


Figure **8.** Temperatures above the telltales before and during the Hi-fog discharge.

The enclosure response to the Hi-fog subfloor system discharge is shown in Figures 9-11, which present the oxygen concentration, temperature, and pressure differential across the enclosure boundaries over the course of the tests. The oxygen concentration in the subfloor and, with a delay, in the cabinet dips to approximately 15% by volume after system actuation. In the ceiling level the concentration varies around 20%. The temperature in the enclosure is largely unaffected by the discharge of the suhfloor system, and only a 12.4 Pa overpressure was measured in the subfloor. During the first **3** min of activation, an average of 1 air change/min was observed in the subfloor.

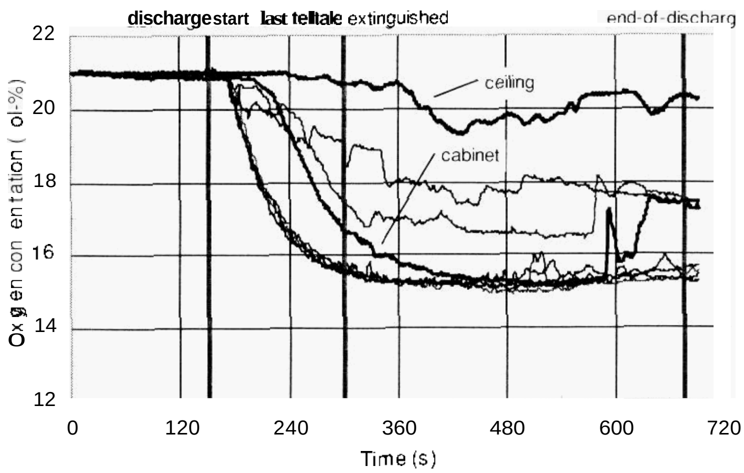


Figure 9. Oxygen concentration at different locations before and during the Hi-fog discharge.

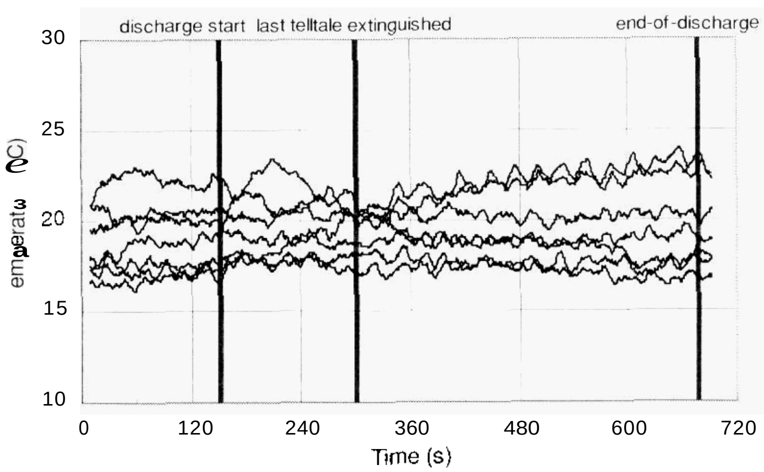


Figure 10. Ambient temperatures at different locations before and during the Hi-fog discharge.

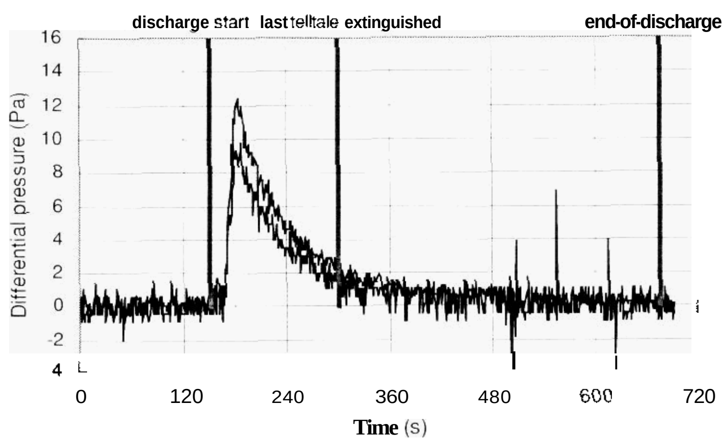


Figure 11. Differential pressure at ceiling and floor levels before and during the Hi-fog discharge.

The *cable bundle fire in the subfloor* was extinguished (end of flaming combustion) 45 sec after the Hi-fog system was actuated. The scrubbing capacity is verified with the results shown in Figures 12 and 13, where the hydrogen chloride and CO concentrations are presented. The HCI concentration measured in the cabinet is much higher than that measured in the subfloor due to the close proximity to the cable fire. The sensor in the cabinet overranged from approximately 9 min after the heater was turned on but returned to scale after less than 1 min of system discharge.

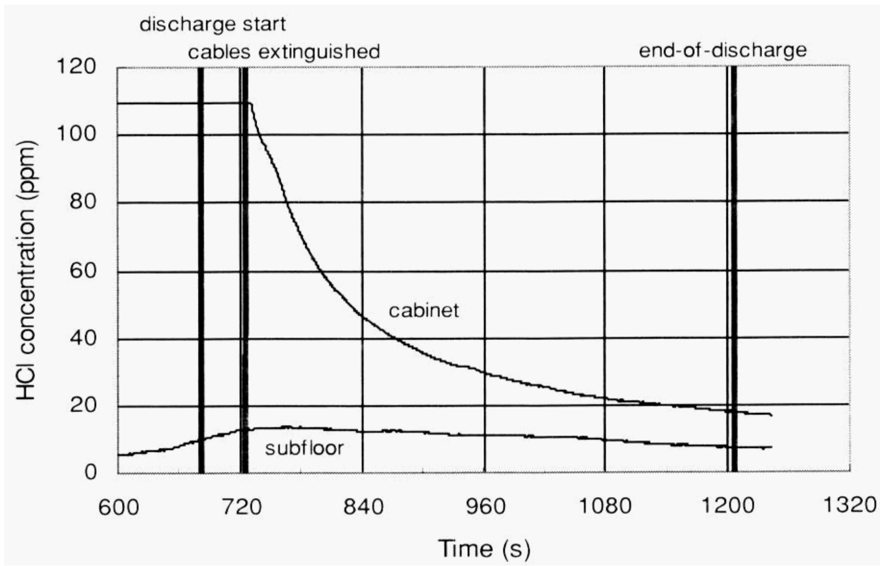


Figure 12. HCI concentration in a cable tire test before and during the Hi-fog discharge.

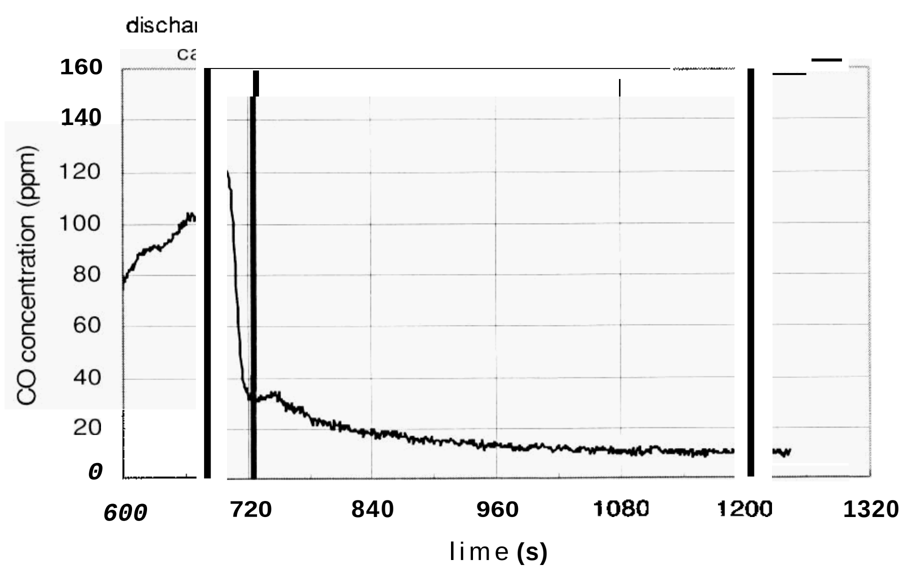


Figure 13. CO concentration (subfloor) in a cable fire test before and during the Hi-fog discharge.

Analysis of the trapped water showed chloride concentrations ranging from 47 ppm (mass) for the trap furthest away from the cable bundle fire location up to 448 ppm (mass) for the trap closest to the fire location. The collected mass of hydrogen chloride represents a change of approximately 100 ppm (volume) if distributed evenly throughout the subtloor.

When the *cable bundle was ignited inside the cabinet*, it was extinguished 94 sec after the sub-floor system was actuated. The hydrogen chloride sensor in the cabinet overranged early in the preburn of the fire, and due to the close proximity of the sensor to the fire, the scrubbing effect in the cabinet could not be tested.

CONCLUSIONS

The novel, widely patented, environmentally friendly approach to computer room fire protection has been shown to be a potential solution in new installations and in replacing existing suppression systems in electronic data processing facilities. An innovative combination of high-pressure water mist and nitrogen extinguishes fires and additionally removes harmful smoke from the protected space. System discharge poses no danger to people or equipment, neither in a fire situation nor in the event of accidental discharge.

ACKNOWLEDGMENTS

The Hi-fog concept for computer room fire protection is a patented innovation of Göran Sundholni. the Managing Director and CEO of Marioff Oy. Many employees at Marioff, in cooperation with IBM Nordic, as well as researchers in different testing laboratories have contributed in developing the system to its present form.

The system performance was first demonstrated in hundreds of tests in a simulated computer room at the Marioff site in Finland. More quantitative tests verifying the suction and scrubbing efficiency of the system were run at VTT. the Technical Research Center of Finland. The most detailed and instrumented tests have been and are being run at and by Hughes Associates, Inc., USA. in the 100 m^2 simulated computer room. Eric W. Forssell from Hughes Associates. Inc., is especially acknowledged for providing the data from the large-scale tests.

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