

FOG FIREFIGHTING SYSTEMS IN ENGINE TEST CELLS

Dirk Odenbrett, Dirk K. Sprakel, Lars Tober
FOGTEC Fire Protection GmbH
D - 51063 Koln GERMANY

ABSTRACT

Due to the serious disadvantages of gaseous fire extinguishing methods in terms of toxicity and environmental impact, an international search for alternative extinguishing methods is underway. Fog is an alternative extinguishing technology now on the market that has positive extinguishing features similar to gases without the above-mentioned disadvantages.

Numerous 1:1 combustion tests have been carried out in the recent years to investigate applications for fog technology by various manufacturers and institutes. The paper describes a series of full-scale fire tests for the protection of engine test cells, which in the past were almost always equipped with gas extinguishing systems. The tests were planned in conjunction with ISV, the Institute for Safety Technology in Rostock, Germany, and performed in their laboratories using a fixed FOGTEC high-pressure fog extinguishing system.

It is accepted that fog systems can be used as a local application for test engines, the described test series shows that fog systems, properly designed, can also be used as total-flooding systems for such applications. In the tests hidden fires were shown to be extinguished safely and effectively.

The characteristics and basic working mechanisms and other theoretical aspects of fog used as an extinguishing medium are explained in the first part of the paper. The second part describes the methodology, the tests and the conclusion.

CURRENT PROTECTION FOR ENGINE TEST CELLS

To comply with strict requirements for safety and reliability, engines and similar technical aggregates undergo intensive testing in so-called test cells. Those tests, often carried out unsupervised, present a high fire **risk** due to combustible fuels and high surface and exhaust temperatures, accompanied by excess air due ventilation systems.

In the past, engine test cells were protected against fire mainly through the use of gas extinguishing systems that used agents such as halon or CO₂. It is well known that those extinguishing gases pose severe problems in terms of environmental impact or toxicity.

The use of halons was banned in many countries following the Montreal Protocol because of their ozone depletion potential. Although other chemical gas alternatives exist, most of them have a global warming potential. In addition to CO₂ inert gases are also used. In Germany, CO₂ is primarily used to protect engine test cells.

One major disadvantage of CO₂ extinguishing technology is that the CO₂ concentration required to extinguish a fire is toxic and would kill any personnel in the area. As is common knowledge on activation the CO₂ concentration in the air quickly rises to 20% by volume. A CO₂ level that

exceeds 8% by volume can cause severe damage to health, and a level over 12% by volume presents a serious risk to human beings. Therefore, an appropriate warning time is required before a CO₂ extinguishing system is activated to ensure that the area at risk can be safely evacuated. In turn, this delays timely firefighting. The fire will develop during the delay. The resulting fire is much larger and more difficult to control. More damage is caused [1].

Studies have shown that CO₂ in the required concentration has a negative effect on the availability of combustion engines, which often means that cost-intensive test programs must be interrupted when CO₂ is used to fight even small fires. Comparative tests have shown that the effect of fog on engine operation is negligible, allowing testing to continue [2].

The cooling effect of most extinguishing gases is negligible. Even during the early stages of a fire, a high heat stress on the enclosure and the aggregate cannot be prevented.

DESCRIPTION OF HIGH-PRESSURE FOG TECHNOLOGY

To achieve a sufficient extinguishing effect or to control of a fire by using water fog systems, it is most important that the quality of the fog meets the requirements given by the particular application. That quality is a function of numerous parameters, such as pressure, flow rate and nozzle design.

The fog extinguishing mechanism makes use of several extinguishing effects:

Appropriate nozzles are used to atomise the water so finely that, when compared with other water-based extinguishing methods, the surface area of the water is much greater and therefore the uptake of the heat energy produced by the fire is much more rapid. The heat capacity and the very high enthalpy of vaporisation of the water immediately provide a considerable cooling effect. In addition, the fog droplets hold back the radiant heat from the area surrounding the seat of fire. A large portion of very small water droplets also cause the fog to remain suspended, which up to a certain extent allows obstructed fires to be successfully fought [3].

However, by far the most important effect for extinguishing is the inerting capacity. The 1640-fold volume increase that occurs when the water vaporises into steam, displaces the oxygen in the air. In other words, the O₂ concentration is reduced in the proximity to the fire, causing the fire to be smothered. The thermal current produced during a fire creates a partial vacuum, which draws O₂ to the seat of the fire. This is countered by inerting due to vaporising of extremely fine droplets in the µm range, which are drawn in with the air stream [4].

In addition to cooling and inerting, the two primary extinguishing effects that have been described, the following three ancillary extinguishing effects also play a role:

The dilution effect is produced by diluting the concentration of combustible gases required for burning (vapour/air mixture) in the reaction zone of the flame, due to conversion of water into steam and the water droplets that are applied to the flame.

The separation effect prevents radiant heat feedback to the immediate surroundings and the fuel surface thanks to the fog's high density of water droplets.

The catalytic effect is characterised by the generation of chain branching and chain termination reactions in the combustion process due to heterogeneous inhibition (wall effect) of the water drops in the extinguishing agent stream with the free radicals from combustion. This permanently disrupts the reaction process [5].

The following sections describe in greater detail the parameters that influence the individual extinguishing effects.

To take full advantage of those extinguishing effects, FOGTEC firefighting systems provide a class 1 fog (for fog classification, see NFPA 750). A relatively high level of energy is required to produce the high degree of splitting of the water into small droplets, as well to give them sufficient kinetic energy to transport them. In that regard an operating pressure of about 100bar has proven to be effective by providing sufficient energy at the nozzle.

THEORETICAL CONSIDERATIONS FOR EXTINGUISHING WITH HIGH-PRESSURE FOG

When considering the "inerting" extinguishing effect, opinions vary concerning the area to be used as a basis for the calculation. Whereas some models require inerting of the entire enclosure (enclosure model), others consider inerting of the atmosphere in direct proximity to the seat of the fire by "enveloping the seat of the fire" with water fog to be sufficient (cylinder model).

Calculations of the main extinguishing effects according to both models have shown that successfully extinguishing a fire does not depend exclusively on cooling or exclusively on inerting with fog.

If we **look** at the inerting process on in isolation, Covelli [4] states that the O₂ content of the air surrounding the seat of a fire must be reduced to about 11–12% by volume. In the extinguishing area, vaporisation of the droplets must produce a vapour volume that displaces most of the air. Assuming a homogeneous mixture of vapour and air, the following result is obtained when using the displacement formula:

$$E_0 = E_{0 \text{ Air}} \cdot \exp (- V_{\text{Steam}} / V_{\text{Enclosure}})$$

with the values

$$E_0 = 0.12$$

E_0 = Extinguishing concentration

$E_{0 \text{ Air}}$ = O₂ concentration (air)

$$E_{0 \text{ Air}} = 0.21$$

V_{Steam} = **Steam** volume

$V_{\text{Enclosure}}$ = Enclosure volume

the necessary steam volume V_{Steam} :

$$V_{\text{Steam}} = V_{\text{Enclosure}} \cdot 0.56$$

The air drawn in by the fire should therefore contain approximately 60% saturated water vapour that is not in the form of drops. Subject to those requirements, at 100% relative humidity the necessary air temperature would be 85 °C.

In normal cases, air at temperatures between 20 °C and 40 °C flows at low level to the seat of fire. If it is assumed that correspondingly atomised water droplets are carried along by this incoming air, it can be estimated that those droplets in the area near the reaction zone will be heated to approximately 50 °C. In that fashion, the oxygen concentration in the incoming air can be reduced to levels ranging from 16-18% by volume [6].

Numerous tests have shown that a reduction in the O₂ concentration in the air flowing to the seat of fire to 16-18% by volume, combined with the cooling effect and the described ancillary extinguishing effects of the fog, is sufficient to extinguish a fire.

It would not be possible to extinguish the fire merely through inerting or solely due to the cooling effect. The synergy of the two primary extinguishing effects and the ancillary extinguishing effects (separating, diluting, and catalytic effects) is required to extinguish the fire.

In addition to the characteristics of the water fog itself, the development of the primary and ancillary extinguishing effects also depends on the generated heat of the fire. For the development of the primary and ancillary extinguishing effects, three energy ranges can be distinguished of which all three have to be present to achieve all extinguishing effects simultaneously:

- Range 1: Energy \leq 400 kW
- Range 2: Energy $>$ 400 to \leq 1000kW
- Range 3: Energy \geq 1000kW

The two primary extinguishing effects, cooling and inerting, are formed to different extents as a function of the heat flow. The portion of local inerting increases from Range 1 to Range 3. In Ranges 1 and 2, the cooling effect in the flame zone and on the fuel surface is more important for extinguishment than in Range 3. Local inerting can cause a brief oxygen concentration of 12-14% by volume at the seat of fire in heat flow Range 3 [5].

CHARACTERISTICS OF WATER DROPLETS AS A FUNCTION OF DROPLET DIAMETER

Different droplet sizes produce different characteristics that contribute to the extinguishing effect. Small water droplets ranging from approximately 10–50 μm remain suspended due to Brownian molecular motion and the occurrence of natural convection, so that this portion of the droplets to some extent has the property of an extinguishing gas. The proportion of larger droplets ensures the necessary droplet velocity by providing sufficient kinetic energy.

- Droplets \leq 150 μm occur when the energy of the fire is approximately above 400 kW in interaction with the rising flame column and hot gases.
- Droplets $>$ 150 μm still occur depending on the height of the energy flow in interaction with the fuel surface.
- The greatest possible absorption of the heat radiation occurs at droplet diameters from $>$ 50 μm to \leq 100 μm .
- Droplets with diameters $<$ 50 μm have a higher incidence of reflection of heat radiation compared with a lower incidence of absorption [5].

To achieve extinguishment or control of a fire, it is necessary to provide a mixture of different droplet sizes with the above characteristics.

Knowledge of the fuel, ventilation, room size, etc., provides the details that define the suitable quality of the water fog for the particular application. The use of the best droplet size distribution must be accompanied by concise design of the fog extinguishing system, e.g., the position and number of nozzles as well as the discharge time.

Knowledge of the flow properties and physical and thermodynamic characteristics of the water fog will enable the individual extinguishing effects of the finely dispersed water to be formed quickly and effectively by applying the smallest possible total quantity of extinguishing water.

OBJECTIVE OF THE TESTS AND DESCRIPTION OF THE TESTS

The objective of the tests was to demonstrate that fires in engine test cells can be extinguished in a very short time using high-pressure fog and that this technology provides an effective alternative to the gas extinguishing systems often used for this application.

Consequently, a test procedure was developed that simulated the sizes and structure of a real engine test cell.

The simulated fire scenario was a complex dynamic fire as a result of a broken fuel injection line (spray fire) together with fuel that collected in the bilge (Pool 1 and Pool 2), which was ignited. A concealed fire is simulated in Pool 1, which is located under the engine and the grid. Petrol and diesel were used as fuel. The fires in Pools 1 and 2 were ignited manually, and the spray fire was ignited electrically.

The following constants and variables were used when performing the tests.

Constant conditions:

- Enclosure geometry
- Test set-up
- Operating pressure of the high-pressure fog extinguishing system
- Activation temperature 100 °C under the ceiling of the enclosure

Variables:

- Number of nozzles
- Nozzle type
- Flow rate
- Nozzle positions

Test Set-Up

The dimensions of the test enclosure and the test set-up are shown in Figure 1

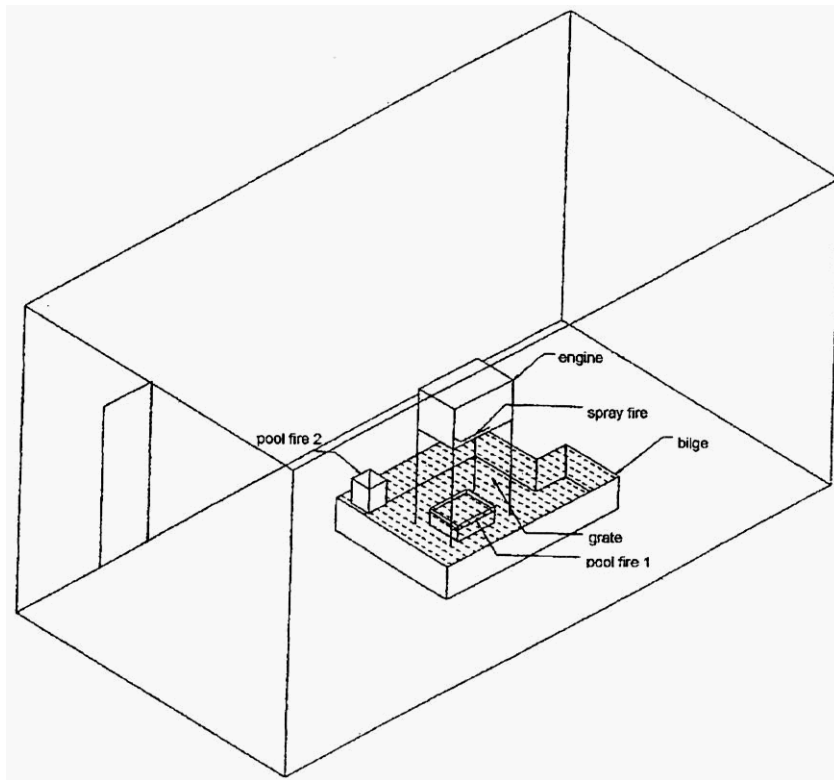
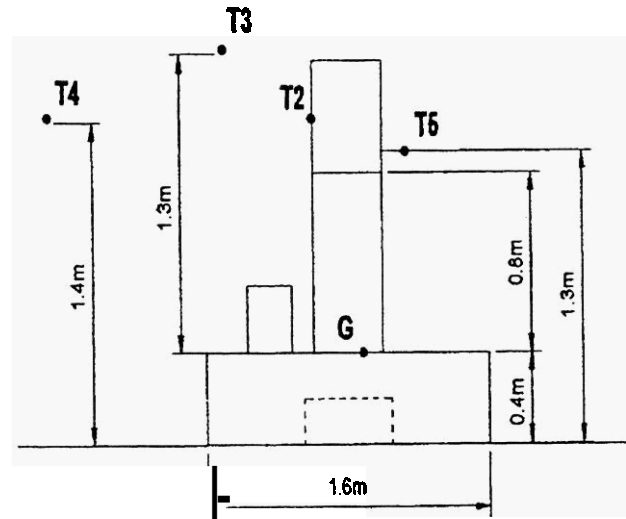
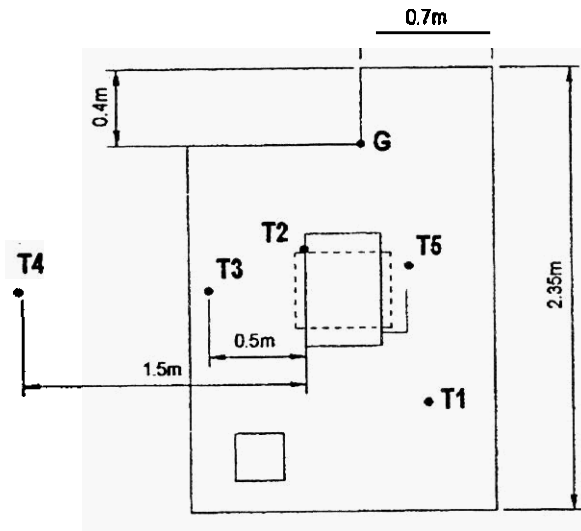


Figure 1. Test enclosure with engine mock up.

Test enclosure:	Height	3.8 m
	Width	3.9 m
	Length	1.65 m
	Volume	113m ³
Engine mock up:	Volkswagen car engine	
Fire sources:	Pool 1:	Size 40 x 50 x 5 cm
		Fuel Petrol
		Quantity 5 litres
	Pool 2:	Size 25 x 25 x 30 cm
		Fuel Petrol
		Quantity 5 litres
	Spray fire:	Flow 57 ml/min
		Fuel Diesel

During the test, the gas concentrations (CO₂, CO, **and** O₂) and temperatures were measured at **various** points in the test enclosure and recorded. The arrangement of the measuring equipment that was used (thermocouples and gas measuring point) is shown in Figures 2 and 3.



Figures 2 and 3. Arrangement of measuring points,

- T1: Gas temperature at ceiling (h = 3.35 m)
- T2: Surface temperature of engine
- T3: Temperature at respiration level 1
- T4: Temperature at respiration level 2
- T5: Temperature of spray fire
- G : Gas measuring point (CO, CO₂, O₂)

Water fog system:

- Pressure: 100bar at the hydraulically most demanding nozzle
- Pressure source: Three-plunger pump with electrical motor
- Nozzle arrangement: **All** nozzles under the ceiling with one nozzle at wall directed at mock up
- Additives: None

Room conditions before test start:

- Enclosure temperature: 25 °C
- Oxygen concentration: 20% by volume
- Carbon dioxide concentration: 0.04% by volume
- Carbon monoxide concentration: 0 ppm

After ignition of all three fires, the high-pressure fog extinguishing system was activated when the temperature at the ceiling reached 100 °C. The temperature curve at the ceiling and at respiration level, as well as the described gas concentrations, were recorded using the arrangement shown in Figures 2 and 3.

RESULTS

In total more than 40 tests with different nozzle arrangements have been carried out. For the purpose of this paper, one test has been chosen to demonstrate results achievable with an optimised arrangement.

All fires were extinguished after an extinguishing time totalling 3:47 min and application of 24.4 litres water. The following diagrams show the temperature curve and concentrations of measured gas components during the test.

	Absolute time, min:s	Relative time, min:s
Pool 1 ignited	1:41	
Pool 2 ignited	1:41	
Spray fire ignited	1:41	
System activation	2:03	0:00
Pool 1 extinguished	5:40	3:37
Pool 2 extinguished	5:50	3:47
Spray fire extinguished	3:20	1:17
System deactivated	6:20	4:17

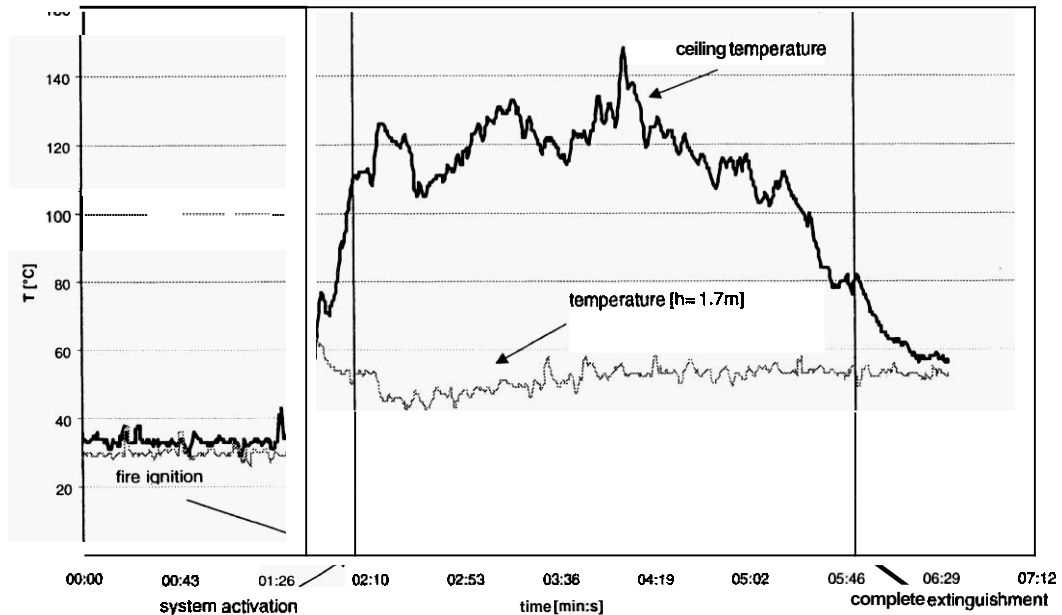


Figure 4. Temperature curve during the test.

Figure 4 shows that immediately after activation of the fog extinguishing system the temperature at respiration height [h = 1.7 m] reduced to a level that is not hazardous to people and property. The temperature measured under the ceiling could not be reduced until water was applied for approximately 2 min, due to the use of a very low water flow rate [6.72 liters/min]. Other tests

have shown that increasing the water flow rate allows the temperature in the test enclosure (beneath the ceiling) to be reduced much more quickly, but the aim of the tests was to apply as little water as possible. A temperature level of 100 °C under the ceiling for a period of approximately 2 min is acceptable.

The content of CO remained (as Figure 5 shows) during all tests well below a level that would cause danger to human beings.

Figure 5 shows also that the oxygen concentration in the enclosure dropped to 17.5% during the test, which means that sufficient inerting was achieved. This, in combination with the cooling effect of the fog, resulted in successful extinguishing. At no time was the O₂ level too low for normal human respiration.

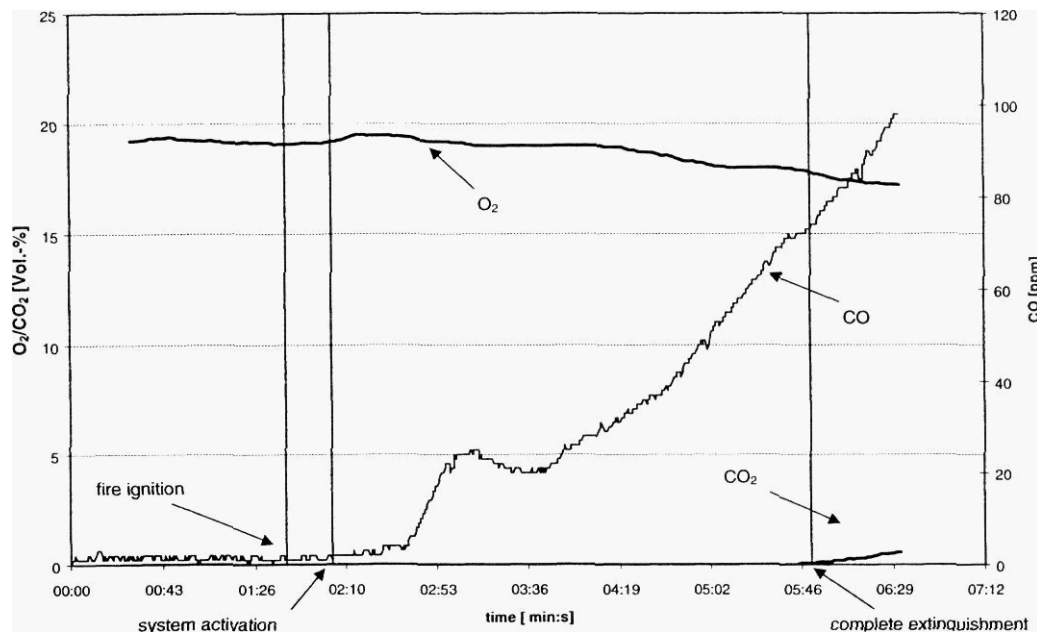


Figure 5. Concentration of measured gas components during the test.

The variations of the nozzle type and their flow rates have shown that the nozzle configuration has a major influence on extinguishing time and the required water flow rate. It became clear that when nozzles with low flow rates were accompanied by an improved droplet size distribution, much better extinguishing results were obtained than when nozzles with higher flows were used. This means that more extinguishing media do not mean faster extinguishment.

During the tests it was obvious that to a large extent the smoke was washed out immediately after the fog system was activated. During the discharge of the fog system, the dark **smoke** was turned into white fog. The small smoke particles had been bound by the fog particles and, therefore, the contamination of a ~~real~~ test cell could have been reduced compared to a gaseous extinguishing system.

CONCLUSION

The tests showed that the use of fog for the protection of engine test cells represents an efficient and environmentally friendly alternative to gas extinguishing methods. The water fog extinguishing media do not cause danger to human beings and the temperature is quickly lowered to a safe level. In addition the washing out of smoke particles and water soluble gases is an advantage. In the tests it was also shown that the careful design of the system and the choice of the right droplet size distribution are critical for the effectiveness of water fog systems.

Based on guidelines for installation of fog firefighting systems issued by the National Fire Protection Association, potential users of the technology have with water fog an efficient and reliable alternative to conventional systems.

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