DROPLET SIZING AND CHARACTERIZATION OF WATER MIST FIRE PROTECTION SPRAY NOZZLES

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Abstract

There exist different fire-extinguishing systems. One system that is more and more of interest today is the High-Pressure Water Mist extinguishing system that is installed in many lines of business and industry, on ships and in tunnel-constructions.

The physical principle of the water mist extinguishing process depends strongly on droplet sizes. Therefore extensive investigations on droplet sizes and other spray characteristics under various conditions were done with different water mist fire protection spray nozzles. The droplet size measurement were done with a Phase Doppler Anemometer. The results of these measurements show the quality of the nozzles and lead to some additional fire-fighting tests that are done to prove the efficiency of the fire extinguishing system under realistic conditions.

Introduction

The different fire extinguishing systems that can be found on the market are mainly

- Sprinkler Systems
- Fine spray systems (work with low-pressure)
- Water mist systems (high-pressure)

Our investigations are focussed on nozzles for high-pressure water mist extinguishing systems. The facts that distinguish these high-pressure water mist systems are mainly:

- A low water consumption.
- The damage caused by water is minimized.
- The floor contamination by flowing off extinguishing water is reduced to a minimum. Also the loss of water is comparatively small.
- The large surface of the very fine water mist droplets has an adhesion effect washing out many fumes and rising soot particles.
- A possible flashover of the fire into adjacent areas is avoided as a result of the rapid cooling.

In order to develop and design good nozzles it is important to know the water mist extinguishing principles of these systems. Based on this knowledge the nozzle size, spray angle, flow rate, pressure level, spray velocity, spray behaviour, droplet size and some other parameters can be optimised.

Water Mist Extinguishing Principles:

Typically the heat absorption and vaporisation processes work relatively slowly and water often achieves only a small fraction of its full thermodynamic potential. Given that these phenomena are surface-related, the

Extinguishing system	Mean droplet diameter [µm]	Reaction surface [m²/l water]
Sprinkler / Spray system	> 1000	< 2
Fine spray system	~ 100	~ 20
High-pressure water mist	~ 10	~ 200

kinetics can be improved by maximising the surface to volume ratio. In practical terms, this is achieved by deploying the water as a fine spray with very small droplets.

Table1. Droplet size and reaction surface of extinguishing systems

Cooling effect:

As a consequence of disintegration of the water into very small droplets, a huge reaction surface is created and the heat of the fire is absorbed. Water is the extinguishing medium with the highest known heat absorption capacity which can be used in a particularly effective manner in water mist technology.

Extinguishing medium	Heat capacity [J/(kgK]	Evaporation enthalpy [kJ/kg]
Water	4,18	2250
CO2	0,85	595
N2	1,03	201
Halons		126,0 or 82,3

Table 2. Heat capacity and evaporation enthalpy of some extinguishing mediums



Figure 1. Characteristic temperature plot for a full scale fire test





Inerting effect

The water mist spray is aspirated together with the surrounding air into the fire. There the water mist is evaporating very fast due to the high temperature. A great part of the fine water mist spray that consists of extremely small droplets with a few µm only is required to follow the current movement of the air into the fire. By evaporating, the volume of the water is increased 1640-fold, which leads to a dilution of the air oxygen at the source of the fire as shown in the characteristic oxygen plot below where the normal oxygen content of approx. 21% is reduced to 16%-18%.

Separation effect

The water droplets that are between flame and fuel surface will strongly reduce the heat radiation. The burning rate goes down, and a heating up of surrounding possible fire sources is reduced.

Shielding effect

In case of the above described separation effect, the tiny water droplets clearly reduce heat radiation to surrounding objects. This counteracts a spreading of the fire, which can be put to use e.g. for fire barriers.

Figure 2. Characteristic oxygen plot for a full scale fire test in the vicinity of the fire source

Experiments

Through specifically developed nozzles, water is atomized under high pressure into very fine droplets generating water mist. The development and design of these nozzles depends on technical parameters like droplet sizes of spray, flowrate and pressure, spray angle and some other parameters that are mentioned in the following list. Below the figure 3 shows a typical nozzle head and a drawing with the main components of such a high-pressure nozzle head.



Facts to consider for development:

- Droplet sizes
- Flowrate
- Pressure
- Spray angle of nozzle head
- Spray angle of nozzles in the head
- Number of nozzles in the head
- Arrangement of nozzles
- Spray width
 - spray Behaviour of (Installation of nozzle head under roof or free)

Figure 3. Photo and drawing of fire extinguishing nozzle head with 6 nozzles

First it is important to understand that all parameters mentioned in the list above influence each other. Anyway the most important parameter is the droplet size because water mist is necessary to produce the extinguishing effects like cooling or inerting effect as mentioned above. To produce a very fine spray a pressure of about 100 bar or more is needed. The amount of water respectively the flowrate of the nozzles depends on the application that means on the size of the rooms where to use the nozzles. Therefore different sizes of nozzles and nozzle heads with different numbers of nozzles inside were investigated. The spray angle of the nozzles in the head also is of importance because there are different effects to consider like flow behaviour that can lead to an increasing coalescence of droplets. The following photos show different types of spray forms. The photos 1 and 3 show a small spray angle for the whole spray. This is due to the larger spray angle of the nozzles in the head but also depends on the flowrate respectively size of the nozzles in the head.



Figure 4. Photos of different spray forms for droplet size tests

The spray characteristic results mainly from the number of nozzles in the head, their individual spray angle, flow rate, pressure and arrangement in the nozzle head. An additional parameter is the simulation of a roof over



Figure 5. spray width diagram

the nozzles for installation of a fool over the nozzles for installation in rooms directly under a roof - but this variation did never show significant changes in the results. The following two diagrams in figure 5 and 6 show some results of spray width for several configurations with 4 and 6 nozzles in a head, different flow rates and spray height down to 5000 mm from the nozzle orifice. From these measurements you can see that configurations with 6 nozzles instead of 4 nozzles lead to smaller spray width.

A spray angle of 80° instead of 40° and a smaller flowrate of the individual nozzles in the head also



Figure 6. spray width diagram



Figure 7. Photo of droplet size measurement

causes a smaller spray width. The small droplets of the spray obviously have the tendency to follow the main stream of the spray. Only if the individual nozzles and their spray are too far away from each other the sprays remain individual for each nozzle. The knowledge of spray width is important because the extent of the spray must be known especially when several nozzles are spraying at the same time side by side.

Every configuration has advantages and disadvantages and the usage of one or another design depends on the application and some other facts like room extension and

droplet sizes. For each condition were performed droplet size measurements at pressures of 100 and 150 bar and at distances of 250 mm, 500 mm, 1000 mm, 2500 mm and 5000 mm from the nozzle head with and without roof. The droplet sizes are very important to know because the existence of fine droplets is necessary in order that the extinguishing mechanism works.

In Fig. 7 at the left side you can see a photo that shows a droplet size measurement at a spray distance of 5000 mm and gives an impression of the fine water mist spray produced by these fire extinguishing nozzles. From this photo you can see that the spray has a relative high density. Therefore it happens that the fine droplets in the spray coagulate to larger droplets and that the Sauter mean diameter increases with increasing measurement distance from the nozzle head. The following Fig. 8 shows some Sauter mean diameter curves for a nozzle head. This nozzle head consists of 6 small nozzles arranged symmetrically in the head and are spraying together at pressures of 100 and 150 bar.



The diagram in Fig. 8 shows that the Sauter mean diameter increases for all conditions from a small value at the orifice to about 150% of

nozzle head with 4 Size individual nozzles 01 2,32 l/min 4,64 l/min 02 11,36 l/min 03 8,00 l/min 04 18.00 l/min 05 14,40 l/min 06 10 1,12 l/min 11 2,32 l/min 4,64 l/min 12

Flowrate at 100 bar for

Figure 8. diagram of droplet size measurements

its original value at a distance of 5000 mm. As mentioned above is this fact mainly

caused by coagulation of the small droplets but also produced by evaporation of the smallest droplets during the flying time. The size of the nozzles respectively the flowrate of the nozzles also has an effect on the droplet

sizes. The flowrates that are typical for a nozzle range between about 1,12 l/min and 18 l/min as shown in the table above. For the smallest flowrate you get the smallest droplets. An example for a droplet size distribution of a medium size nozzle head is shown below in Fig. 9. The Sauter mean diameter is 77 μ m and the mean droplet diameter is about 50 μ m at a distance of 500 mm from the nozzle orifice.



Figure 9. Droplet size measurement of fire extinguishing nozzle head

The measurements that were performed in our laboratories were made without fire of course. Under realistic conditions the fire itself has a strong effect on the spray. The droplets sizes change very fast due to high temperature and the spray form is influenced because you have convection effects. Based on the measurements that are made at Lechler laboratories additional fire test have to be performed to verify the efficiency of the nozzles in certain applications under realistic conditions.

Concluding remarks:

As manufacturer of spray nozzles we are strongly involved into the design of high-pressure extinguishing systems. A central part of these systems are the nozzles which produce the fine sprays to extinguish a fire. The characteristics and behaviour of these sprays are investigated by us to guarantee a correct work of the extinguishing processes and effects which are typical for these extinguishing systems such as cooling effect, inerting effect, separation and shielding effect, gas scrubbing etc. ...

The spray width and even more the droplet size characteristic are of fundamental interest because the droplet size spectra of the sprays are responsible for the efficiency of all extinguishing effects mentioned above.

The spray nozzles and also the complete fire extinguishing system have to be tested under realistic conditions for example in closed rooms to be sure that the arrangement of nozzles, pressure level, flowrate level and other parameters are optimal for any given application.

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