Water Mist Aha-Moments

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In my career as a researcher in the field of fire protection, some moments can be described as aha-moments. Here are two of them:

1. Forgotten technology to be re-discovered - small droplets evaporate more easily than larger droplets

In the late 1980s our laboratory was heavily involved in the safety of offshore oil- and gas platforms in the North Sea. To obtain some knowledge of firefighting systems, we initiated projects on deluge systems, since this was the most commonly used systems by the oil companies present in Norway. One of the actions we took was to invite Dr. Gunnar Heskestad, then Chief Scientist at FM (Factory Mutual), USA, to be a guest tutor at our laboratory, to teach our team state-of-the-art fire development and extinguishing. FM and UL (Underwriters Laboratories) had formerly studied the effect of small droplets in firefighting, but no small-droplet technology was introduced into offshore platforms at that time.

Gunnar Heskestad has a long record of studying both the principles of buoyancy-driven fire plumes and the effect of sprinkler systems on fire development, and he had used the theory of fluid dynamics in his analyses. One paradox in water-based firefighting is that the water is normally applied from ceiling level, vertically downwards into the fire plume. This origins from practical reasons, the piping is least intrusive at this location, but most of all from the sprinkler technology, which is based on thermal activation of nozzles. The hot smoke accumulates under the ceiling, and quick response is obtained when the nozzles are at ceiling level. However, the mounting of the nozzles at the ceiling level implies that the water droplets must flow (with gravity and momentum from the exit) against the fire and smoke plume to reach the objects or the floor, since fires have a buoyancy driven direction of flow, which is vertically upwards.

Archimedes' principle *states that the upward buoyant force that is exerted on a body immersed in a fluid, whether fully or partially submerged, is equal to the weight of the fluid that the body displaces and acts in the upward direction at the centre of mass of the displaced fluid.*

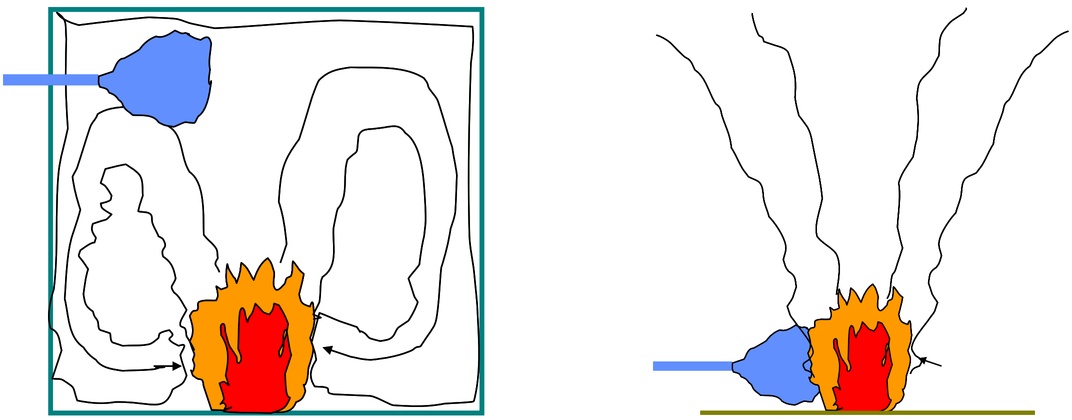

Figure 1. Principle of water mist application, in an enclosure to the left, local application to the right.

Figure 1 shows two scenarios for firefighting, with a water mist spray into an enclosure to the left, and with local application in the open to the right. The application within an enclosure shows the typical flow patterns of the combustion products, which is a recirculating movement. Upwards flow due to buoyancy occurs from the fire source, and downwards flow happen at the walls. If water mist is introduced as indicated, the water mist may follow the downwards flow at the walls and be entrained into the fire plume and will eventually lead to extinguishment of the fire. The drawing to the right shows a situation in an open environment, and one can see that the most obvious way to apply water mist is directly attacking the base of the flames.

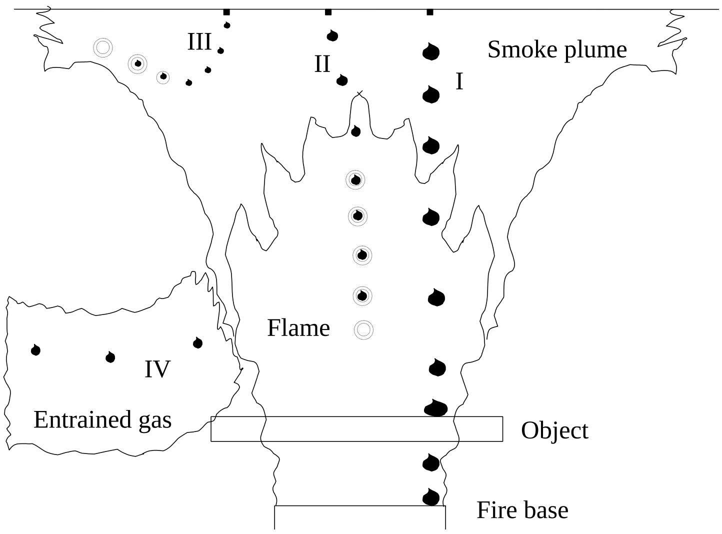

Figure 2. Illustration of the fate of droplets introduced at ceiling level into a fire. Relatively large droplets are denoted I, medium sized droplets are denoted II, very small droplets are denoted III. The situation denoted in IV is when medium sized droplets are following entrained air and combustion products into the fire plume.

Figure 2 shows patterns and fate of droplets of different size introduced into a compartment with a fire, with ceiling mounted nozzles. The largest droplets (I) will penetrate the fire plume, will be heated but not evaporated in the flames, and may cool objects and reach the fire base due to the gravity of the droplets. The smallest droplets (III) will very soon follow the smoke and may evaporate in contact with the hot smoke and may not be very efficient in cooling the base of the fire. The medium-sized droplets will be able to penetrate the fire plume, will enter the flames and may evaporate inside the flame zone. The traditional fixed firefighting systems (sprinkler and deluge systems) have utilized the cooling ability of water together with wetting of combustibles, to fight fires. In this case, it is obvious that the more water – the better effect.

Water mist systems will utilize the inerting effect of water vapour in addition to the cooling effect. The inerting effect is to utilize the water vapour to dilute the fire atmosphere, reducing the oxygen concentration to the point where the combustion is reduced or totally stopped.

The first aha-moment was when Gunnar said to me: Keep on studying the small droplet effect, this may be of great importance in marine and offshore operations, where weight and space is limited more than in land-based situations.

2. Less water leads to full extinguishment of enclosed fires, when more water leaves small confined fires burning

When IMO, the International Maritime Organization, introduced standards for the use of water mist in the 1990s, our laboratory carried out many tests for the new-born water mist industry. In addition to just carrying out qualification tests, some of our clients wanted (or were convinced by us) to carry out more extensive measurements than prescribed in the test procedures. We introduced measurement of water vapour and oxygen concentration, to better understand how the extinguishment took place in the test enclosures. Especially, the machinery space tests were challenging, since this required extinguishment of confined liquid pool- and spray fires, not hit directly by the water mist spray, in an enclosure ventilated by a large opening in one wall. This contrasted with what was required for gas firefighting systems, that were tested in air-tight enclosures with no openings in the walls except for vents to provide pressure relief. The full effect of the inerting by water vapour could not be obtained in these test scenarios, an effect that was not fully understood by the expert group of IMO formulating the test protocols.

When we measured the water vapour and oxygen concentration in these tests, we observed that the average temperature of the test enclosure often reached a level of 50 - 60° Celsius, when the confined pool fires kept burning with small flames and the main fire had been controlled and reduced to a minimum. In this situation, the study of the gas concentrations compared to basic combustion dynamics was the key to understanding better what happened.

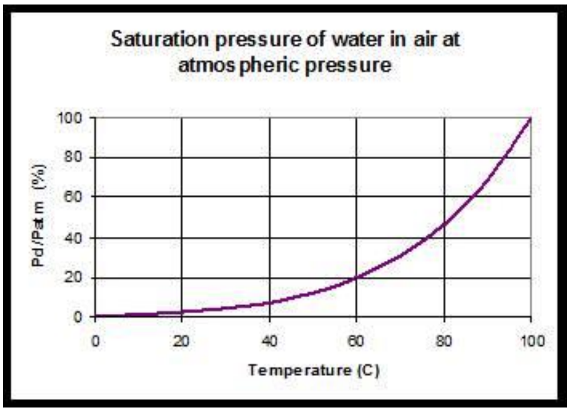

Figure 3. Saturation pressure of water in air at atmospheric pressure. The saturation pressure corresponds to the volume concentration.

Figure 3 shows the saturation pressure of water in air at atmospheric pressure. This is an important factor in how water can act as a gas system in firefighting. If water should act as an inert gas, it is necessary to have a water vapour concentration of approximately 30 per cent in the atmosphere. The graphical presentation of the saturation pressure of water in air indicates that this can only occur if the temperature of the mixture of air and water vapour is approximately 70° Celsius. At a temperature of 20° Celsius a vapour concentration can be maximum 2 per cent. This is an important fact for humans, since the normal atmosphere will never allow water vapour to occupy at concentrations that will make breathing problematic. Even at 70° Celsius, like in a sauna, humans can breathe and survive, even after water has been poured onto the oven, but it is not a pleasant atmosphere to live in for a longer stretch of time. These vapour concentrations are not to be mistaken for what is often measured: Relative humidity of air. The relative humidity is a measure for how large portion of the saturation pressure is present in the air. At a normal indoor climate, one will find that a relative humidity of 50 per cent will be pleasant, together with a temperature of 20 - 25° Celsius. In this case, only half of the saturation pressure of 2 per cent is water vapour, around 1 per cent.

To obtain inert atmosphere in a compartment, it is necessary to have about 70° Celsius in the air, corresponding to approximately 30 per cent water vapour at saturation. This is possible when a fire is started. Inside the flames, much higher temperatures will be experienced, and the only way to create an inert atmosphere with water in a fire, is to heat the water until it evaporates. To understand this, it is important to know that water evaporates at all temperatures, even below the boiling point (100° Celsius). The limit of how much water will be in the atmosphere is the saturation pressure graph, shown in Figure 3. An ideal way to evaporate water in a firefighting situation is to use small droplets, with a larger surface area compared to the volume, so that evaporation can occur inside the flames or in the hot smoke zone.

The aha-moment in this case was when we suggested to use less water when full extinguishment was not obtained. Then the average temperature of the fire compartment increased, letting more water vapour to stay without condensing into droplets, and the increased water vapour content led to full extinguishment in these cases. This is often denoted as the “paradox of water mist”, since it contrasts with what is normally considered in traditional water-based firefighting systems. It should be emphasized that this is not possible to utilize in all firefighting situations, but is limited to situations where enclosure effects are of importance, and where direct cooling or wetting of surfaces is not the extinguishing mechanism.

This explains why water mist is a perfect fire control system: if the fire grows it will be extinguished and if it does not get extinguished it will remain small and under control.