Archimedes in practice

Fire fighting and the Archimedes principle of buoyancy, by Ragnar Wighus.

Traditional fixed fire-fighting systems such as sprinkler and deluge systems use the cooling ability of water and the wetting of combustibles to fight fires; the more water, the better the effect. In contrast, water mist systems use the inerting effect of water vapour in addition to the cooling effect. Ceiling-mounted nozzles result in water droplets flowing (with gravity and momentum from the nozzle exit) against the buoyancy-driven flow of the fire and smoke plume.

However, the local environment and the size of the water droplets in the extinguishing media both have a big impact on fire-fighting effects.

A water-mist fire-fighting system within an enclosure shows the recirculating movement found in the typical flow pattern of combustion products. The fire source causes an upward flow due to buoyancy as well as a downward flow at the sidewalls. Here, the fine water mist spray follows the downwards flow at the sides and is entrained in the fire plume, eventually leading to fire extinguishing. In an open environment, where there is no downwards flow, the most effective way to apply the water mist is directly onto the base of the flames.

As would be expected, fire-fighting effects are also dependent on the size of the water droplets. In a compartment fire with ceiling-mounted nozzles, the largest droplets will penetrate the fire plume; there they will be heated but not fully evaporated, cooling objects and reaching the fire base due to the effect of gravity. The smallest droplets, however, will rapidly follow the hot smoke and they will probably evaporate without cooling the base of the fire. The medium-sized droplets, in contrast, can penetrate the fire plume, enter the flames and may also evaporate inside the flame zone.

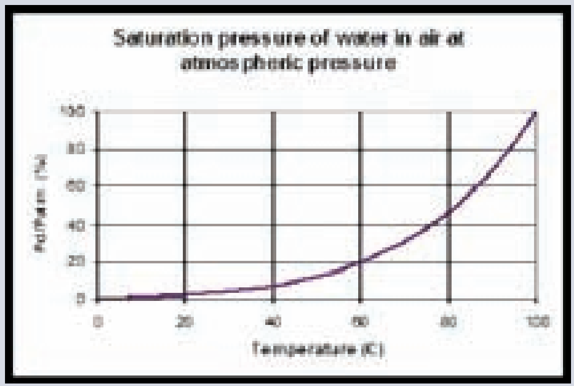
Medium-sized droplets are considered the most efficient or water-mist applications because of the combined effect of cooling and inerting, which is obtained when the droplets evaporate after being entrained into the combustion zone.

For water to act as an inerting gas a concentration of approximately 30% water vapour concentration is required in the atmosphere. The graph below shows that this can only occur if the temperature of air/water vapour mixture is approximately 70°C; at a temperature of 20°C, vapour concentration can be a maximum of 2%.

This vapour concentration is not the same as the oft-quoted relative humidity of air, which is the ratio of the partial pressure of water vapour to the equilibrium vapour pressure of water at a given temperature.

To achieve an inert atmosphere in a compartment, therefore, an air temperature of around 70°C is necessary, which is perfectly possible in a fire situation. Water evaporates at all temperatures, even below the boiling point (100°C), but the limit of how much water will be in the atmosphere is as per the saturation pressure graph, shown below.

It is also worth noting that a medium-sized droplet flowing upwards along with the gases inside the plume will be in contact with the hottest part and therefore will evaporate the fastest. Once upwards momentum inside the fire plume is lost, the droplet will again fall down, effectively leading to the 'recycling' of the non-evaporated part of the water droplet.



Ragnar Wighus, chief scientist at SP Fire Research Norway, is also chair of the International Water Mist Association.

The Archimedes Club is an informal gathering of the International Water Mist Association. A prospective member has to have used the principle of buoyancy to improve the performance of a water-based fire-fighting system. Archimedes' principle states that the upward buoyant force exerted on a body immersed in a fluid (ie liquid or gas), 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.