

Why does water extinguish fire?

1 Introduction

Throughout history firefighters have used water to put out fires. In past centuries people formed lines passing buckets of water to be tossed onto the fire. It goes without saying that the efficiency of this method was very limited. A leap forward was made when Dutchman Jan Vanderheyden invented the fire pump and hose lines. All of the sudden it was possible to transport water over larger distances and spray it in a jet towards the fire. By doing this, more water ended up inside the burning building thereby increasing the firefighting effectiveness. After this development a few centuries passed before the invention of the breathing apparatus (BA). This device allowed for entry into a burning structure so that water could be better applied to the seat of the fire. This again, meant an increase in efficiency. The latest great advance was made by the implementation of gas cooling. This method of firefighting was invented by our Swedish colleagues and creates a safer working environment for interior firefighting crews wearing BA's.

Fire extinguishment has evolved quite a bit since the past. Today the standard method of operation is the interior fire attack. When permitted by fire conditions, this is the most effective way of firefighting. However a lot of firefighters fail to grasp the mechanisms of interior fire attack with water. This article is an attempt to explain the different mechanisms involved.

2 How does water absorb heat?

Water can absorb heat in 3 different ways. The water used by firefighters has a maximum temperature of about 20 °C. When this water is heated up, its temperature will rise. To raise the temperature of 1 liter of water by 1 degree Celsius, 4186 Joules is needed (Joule is the unit of energy). A single liter of water will absorb 335 kilojoules (kJ) of energy when heated from 20 °C to 100 °C.

Subsequently water will absorb heat in a second way. Water with a temperature of 100 °C will transform into steam of 100 °C. This transition requires a lot more energy than the heating up from 20°C to 100 °C. The transition of water into steam will require 2.260 kJ of energy for each liter that evaporates. This means that evaporation requires roughly 7 times more energy than heating from 20 °C to 100 °C.

Water will then proceed to absorb heat in a third manner. Once the steam has been formed at 100 °C, it will absorb the heat of the smoke gases in contact with it. When the smoke's temperature is above 100 °C, heat will be transferred from the smoke into the steam until a balance in temperature has been achieved. Suppose the final temperature of the steam is 300 °C, this means the steam will have heated up 200 °C (300 °C – 100 °C) after forming. The mean amount of heat energy needed to raise the temperature of steam, formed by a single liter of water, by one degree Celsius is 2.080 J. A single liter of water transformed into steam will absorb 416 kJ of energy.

To summarize, water absorbs heat in 3 different stages:

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| 1. Water heated from 20 °C to 100 °C | 335 kJ/liter |
| 2. Water of 100 °C transformed into steam of 100 °C | 2.260 kJ/liter |
| 3. Steam heated from 100 °C to 300 °C | 416 kJ/liter |

A single liter of water transformed into steam with a temperature of 300 °C absorbs about 3 mega Joule (MJ) of energy. A more detailed explanation of this process can be found in Brandverloop by Lambert & Baaij (see [2]).

The interesting part now is to examine firefighting effectiveness when water is flowing away from the seat of the fire without evaporating. The maximum effectiveness of water being used in such a way is 11%. However it's frequently the case in firefighting that a large amount of water flows away from the fire. In such cases, 10 times the needed amount of water is used.

The above reasoning is meant to support the theory that water needs to be applied effectively. Youtube hosts quite a large number of movies showing firefighters apparently unable to comprehend the fact that the roof of a building is meant to keep water (rain) out. "The roof doesn't know it's burning." For water to achieve an adequate level of extinguishment, it needs to at least evaporate. The moment water evaporates the effectiveness level rises to 86%. Hence the saying: Good firefighting should not show water flowing back from staircases or through doors.

3 Surface cooling (direct extinguishment)

3.1 What is fire?

The answer to the question above is quite simple. *Fire is an uncontrolled chemical reaction between fuel and oxygen that produces heat and light.* A closer look upon this definition yields the following question: Which fuel are we talking about? Every fireman should know by now that it's not the solid matter itself that's burning. Flammable solid matter that is heated up sufficiently, produces flammable gases. During this process the molecules of the solid matter are broken up into smaller particles. This process can be seen. The solid matter releases fumes (see figure 4.2 and figure 4.3). Inside a CFBT container this phenomenon can be very closely examined. These fumes are called pyrolysis gases. The process itself is called pyrolysis. The output of pyrolysis gases is determined by the temperature of the fuel surface. Because of pyrolysis, solid matter is transformed into gas. These gases become fuel for the fire.

The basic firefighter course briefly touches the subject of fighting gas phase fires. Trainees are instructed that the best way to extinguish such a fire is to cut off the supply of gas (close the valve). The same reasoning can be applied to fighting interior fires. The supply of gas to the fire needs to be cut off. The best way of doing this is by decreasing the temperature of the fuel surface. This can be done by directing water onto the seat of the fire. The water will evaporate and by doing so, extract energy from the fuel surface. The temperature of the fuel will drop as a result of this. When the temperature has been decreased sufficiently, pyrolysis will reduce before halting completely. This way the supply of gas to the fire is cut off. This mechanism for putting out fires is called direct

extinguishment (see figure 4.6). It's based upon the principle of sufficiently cooling the surface of solid fuels. During each fire this mechanism will need to be applied. In order to achieve control over a fire it may be possible to use other mechanisms. The extinguishment itself however needs to be done by cooling the seat of the fire. When this isn't done, chances are that the fire will start again after a period of time.

3.2 Important points on surface cooling

When cooling burning fuel surface, several important points have to be taken in account. When a firefighter directs a water jet toward the fire, the goal is for this water to reach the seat of the fire. When the water droplets exiting the nozzle first have to pass through hot smoke, a part of the droplet will have evaporated before reaching the fire. If the droplets are too small they will evaporate completely before reaching the fire. In this case the surface temperature will not decrease and pyrolysis will not halt. When applying surface cooling, the droplets need to be sufficiently large to make sure most of the droplet evaporates on the fuel surface.

Secondly it's important the entire fuel surface is covered with water. All of the pyrolyzing surface needs to be cooled. If not, then part of the surface will have been extinguished while immediately next to it flames are still visible. In this case the radiative heat of the flames will cause the recently cooled surface to heat up again. Pyrolysis will start again shortly after this. And a bit later the released pyrolyzates will ignite which brings us back to square one. Again, this phenomenon is easily observed inside a CFBT container.

Finally it's important that the amount of water used on a single surface is limited. The quenching of fires with excessive water is a technique of the past. This method of operation dates from an era before BA's existed. In those days it wasn't possible to advance close enough to the seat of the fire. Today we still face these kind of fires. An example of this is an industrial fire which doesn't allow for entry of the building due to stability problems. However it's no longer preferable to excessively quench relatively easy fires in residential buildings which could have been easily suppressed with an interior fire attack.

When a firefighter directs water onto a burning fuel surface, the first droplets to arrive will cause the surface temperature to drop. Soon after pyrolysis will halt. All of the droplets to arrive after this point at the same surface, will flow away without being used in an effective way. This causes water damage. Fire scenes that have sustained more damage by excessive water usage than by the fire itself, are no exception. A decent nozzle control can make the difference here.

4 Producing steam (indirect extinguishment)

When steam is being used, water is applied in the form of a gaseous suppressant. This mechanism relies on the principle that the forming steam pushes out the air. This method is called indirect extinguishment. When steam is being formed, the oxygen level inside the room decreases. Once half of the room has been filled with steam, flames will disappear (see figure 4.5). This doesn't mean that the fire has been put out. At most it has been temporarily suppressed. The moment the steam is vented from the room, fresh air will return. More often than not the fire will reignite. To completely extinguish the fire, the pyrolysis will need to be halted (see above).

To achieve a maximum production of steam, hot surfaces need to be reached with water. Ideally this is done by using a fog pattern at the nozzle to direct water onto walls and ceilings. A fully developed fire will cause a lot of droplets to evaporate before reaching the walls because they have to pass through flames. After an indirect extinguishment the door to the compartment can be closed to keep the steam level up inside the room.

The use of this method is most effective in closed off rooms. The mechanism can be applied in situations where an interior fire attack is impossible or too difficult. By utilizing a cobra or a piercing nozzle it is possible to produce steam inside a compartment without entering it. In situations pertaining a high risk for backdraft, the indirect fire attack from outside can be the solution.

When using this technique with a nozzle inside a room it's important for an exit to be in place from which the excess steam can escape. If this is not the case, the door opening that was used to enter the room will serve as an exit. The excess steam will exit through there. It's inevitable for the hot steam to pass the location of the fire crew inside. This means the crew is seriously at risk of contracting burn injuries. The risk is reduced significantly when a second opening (e.g. a window) is at hand. Preferably the opening is located behind the seat of the fire. In such cases an air track can be created starting from the door and leading over the fire toward the window. This air track will carry the steam outside without bothering the fire crew.

It's important to realize that after the use of indirect extinguishment in a room that has one or more openings, the fire will rekindle the moment a new supply of oxygen is available. The fuel surface is still very hot at this point and pyrolyzates will continue to be released. To prevent these pyrolyzates from reigniting the indirect attack needs to be followed up with a direct attack (surface cooling). This will cause the fuel surface to cool down below the pyrolysis threshold (see figures 4.6 and 4.7). When oxygen returns into the room in this case, ignition will not occur because of a lack of sufficient pyrolyzates.

The next series of photos show the fire development of a live fire test. A fire is ignited inside a living room. The fire is allowed to spread and develop into the fully developed stage. After this the fire is suppressed using a massive attack. This is a combination of direct and indirect extinguishment. The emphasis is put on the indirect extinguishment. Subsequently the switch is made to direct extinguishment.



Figure 4.1 A fire is started inside this test display which represents a living room. (Photo: New South Wales Fire & Rescue Service)



Figure 4.2 The fire is developing. The smoke layer ignites. Pyrolyzates are clearly visible near the couch on the right as a result of the radiative heat. The book case is also showing signs of fire spread at the bottom. (Photo: New South Wales Fire & Rescue Service)



Figure 4.3 Flashover occurs. The entire room is engulfed in flames. Pyrolyzates released by the couch on the right are clearly visible. The carpet on the floor is also pyrolysing. (Photo: New South Wales Fire & Rescue Service)



Figure 4.4 The fire has now reached full development. The power of the fire is running extremely high for such a room because there's no front wall. This means a lot more oxygen is available for the fire than is the case with a "real" interior fire. (Photo: New South Wales Fire & Rescue Service)



Figure 4.5 The nozzle operator starts the extinguishment with a massive attack. At the time of the photograph he has completed 3/4th of a circle. He started at the upper right hand corner and has reached the bottom middle. The suppressing effect is mainly achieved by producing steam. The difference with figure 4.4 is immense. (Photo: New South Wales Fire & Rescue Service)



Figure 4.6 After the flames have been suppressed, the nozzle operator switches to a direct fire attack. He applies the painting technique. Using a very low flow rate, the fuel surfaces are cooled further to prevent reignition. (Photo: New South Wales Fire & Rescue Service)



Figure 4.7 After the steam has cleared, visibility returns in the compartment. Painting is used during the overhaul. (Photo: New South Wales Fire & Rescue Service)

5 Gas cooling

The third important method of applying water is in the safe zoning of the work area. At first the smoke gases produced by the fire accumulate against the ceiling. The temperature and density of the smoke will increase gradually. This poses a threat to fire crews. At some point in time the smoke layer will ignite (roll over). The radiative heat produced by the smoke will increase drastically (see figure 4.3). Flashover will follow.

Gas cooling can be used to prevent this scenario. By applying water in the proper form into the smoke layer, two things will happen. The inserted water will evaporate and extract heat from the smoke layer. This reduces the risk of roll over. The second part is the produced steam which (partly) remains inside the smoke layer. This will alter the flammability limits of the smoke. The smoke will be a lot harder to ignite than before.

The section above stated that droplet size needed to be large enough in order for droplets to reach the burning surface. After all water droplets will partly evaporate en route toward the burning fuel surface while passing through a hot smoke layer. When utilizing the technique of gas cooling, the goal is to avoid droplets reaching hot walls and ceilings. On the contrary: the goal is for the water to completely evaporate inside the smoke layer. Paul Grimwood described in several publications (see [4] and [5]) that this ideally requires a droplet size of 300 microns. Droplets this size are thick and heavy enough to reach the inside of the smoke layer. If they're smaller, they will be too light weight and possibly will not enter the smoke. If they're thicker, part of the droplet will evaporate in the smoke. The remaining part of the droplet will pass through the smoke onto a hot wall and evaporate there.

6 Bibliography

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