Thoughts on high pressure lines

1 Introduction

When I joined the fire service 15 years ago, I was introduced to two different systems for fire extinguishment: low and high pressure. The high pressure is typically mounted on a reel. The length of the hose line is usually 80 meters long in Belgium. The inside diameter the hose line measures 25 mm. When the pump operator selects the right settings, a flow rate of 180 liters per minute can be achieved.

In large urban areas, the high pressure is a very popular tool for extinguishment. In Brussels, an estimated 90% of the total amount of fires is put out using one or more high pressure lines .

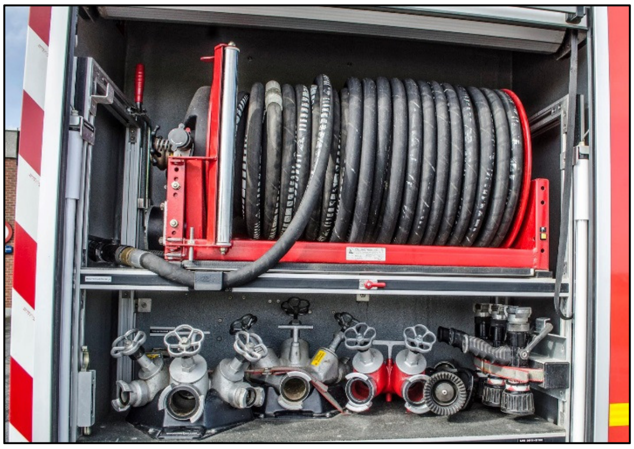

Figure 1 High pressure reel in an engine. Below the high pressure reel are the dividers as well as a number of low pressure nozzles. *(Photo: Pierre-Henri Demeyere)*

The other system for extinguishment was that of low pressure lines. In this particular system, hose line were rolled up. In Belgium, the common diameters for low pressure hose lines are 45 mm and 70 mm. The rolled up hose lines needed to be "thrown out" in order to stretch them, after which they could be connected at the couplings. In order to connect a 45 mm to a 70 mm line, a three way divider is used. The flow rate achieved by this system varies and is highly dependent on the type of nozzle that is being used.

During the past five years, a significant change was introduced to the low pressure system: the use of coiled hose packs, also known as the "Cleveland load" or "roundabout load", and the use of cassettes with a flaked hose line within. However, the introduction of this new system was met with great resistance. Many of the proponents of high pressure, remembered all the successful achievements they had accomplished using the high pressure and failed to see why they would have to change their method of operation.

In this article, several views are offered on the extinguishment systems which we use in the fire service. The goal is that everyone can form an informed opinion on the matter. An important question we need to consider is:

"Do we want a good extinguishment system for the fires of the past or a good extinguishment system for the fires of the future?"

1.1 Why is high pressure so popular?

It would be a shame to throw out the baby with the bathwater. That is why we need to think on how the high pressure became so popular. There are several reasons for this:

Figure 2 Use of a high pressure line on a car fire. *(Figure: Pierre-Henri Demeyere)*

A high pressure system is very easy to use. The hose is rolled out or stretched from a reel. As soon as the attack crew has reached the fire, the pump operator can turn on the water flow. Extinguishment can be started very quickly. This is very easy to use in outdoor firefighting. For outdoor fires, the high pressure is often stretched in a straight line from the engine to the fire. Next to that, the high pressure is also very maneuverable. A single firefighter can easily handle a high pressure line while fighting a fire in a room.

By looking at the past, we can learn some important lessons. Until recently, there was no real alternative for quickly stretching a line inside a building. Rolling out low pressure lines inside a stairwell is not really a viable option. For an apartment fire on the 3rd floor, a high pressure line is much faster than deploying rolled up low pressure lines. The introduction of coiled loads and cassettes will greatly diminish or even negate that advantage. In certain scenarios, deployment of a low pressure will now be faster than high pressure due to well thought-out systems and sufficient practice.

A high pressure line is also very easy to put away. The hose line is rolled back onto the reel. The logistical needs are very limited. No low pressure lines were used that need to be rolled up, stowed in the truck and replaced in the station. Back in the fire station, a used low pressure line would need to be cleaned. From a logistical standpoint, high pressure is a great invention.

1.1.1 Cooling capacity

The above section stated that a high pressure line flows about 180 liters per minute. In other countries, firefighters use high pressure lines with an inside diameter of 19 mm. These lines only flow 100 liters per minute. A flow rate of 180 liters per minute means that every second, 3 liters of water flows from the nozzle. This equals a theoretical cooling capacity of 9 MW, assuming each liter of water absorbs 3 MJ worth of energy.

Naturally there are some assumptions being made regarding this cooling capacity. It is assumed that all of the water, flowing from the nozzle at 20 °C, is converted into steam with a temperature of 300 °C. In reality, this will not always be the case. The steam may escape the compartment before it reaches 300 °C. But what impacts cooling capacity the most, is water that does not absorb enough energy in order to vaporize. Water that is flowing back out in liquid state, has only absorbed 11% of the 3 MJ per liter. This means that on the fire ground, the extinguishing power is a lot less than 9 MW.

The question then arises: how good are the firefighters that are handling the nozzle? This question pertains to both high and low pressure. How efficient are they? This is a question that is very difficult to answer. A lot of research has been conducted into that area and a lot depends on which equipment is being used. A good nozzle will yield a higher efficiency. Again, this is a reason why high pressure is so popular. At the time the high pressure made its first appearance, low pressure systems came exclusively with old "normalized" nozzles.

The quality of the droplets formed by these nozzles, was not good at all. A high pressure nozzle produced a significantly better droplet precisely due to the higher operating pressure. This led to a greater efficiency. Suddenly, fire crews could achieve just as much with the lower flow rate of the high pressure, than they could with the higher flow rate of the low pressure.

The efficiency will also vary depending on what kind of fire the firefighters are facing. It is much easier to achieve a high efficiency when water is being flowed into a fully developed fire, as opposed to when dealing with a small smoldering fire.

Suppose that firefighters are 75% efficient when dealing with a severe compartment fire. A high pressure line could absorb a heat release rate of 6.75 MW. This equals a burning surface area size of 27 m² (250 kW/m²). The kitchen in Figure 3 has a surface area size of 22 m². The *master bedroom* on the bottom right has a surface area size of 15 m².

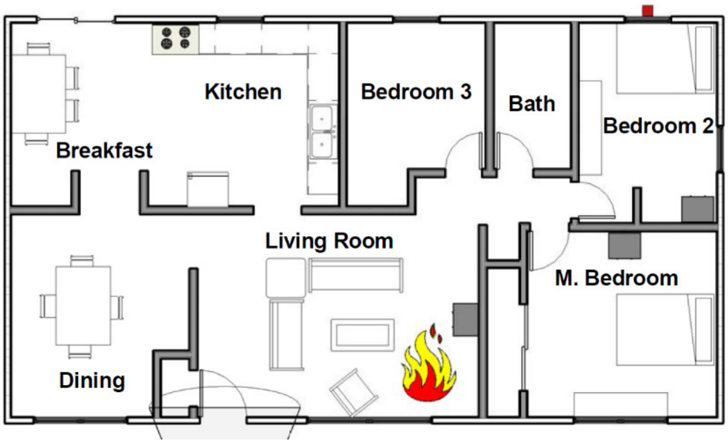

Figure 3 Floor layout of a residence with a classic room arrangement. There are many separate rooms. The surface area size of each room is limited. *(Figure: UL FSRI)*

The term "burning surface area" refers to the floor area size of the room. In any normal room, there are plenty of empty square meters. These are the *pathways* inside the house. The empty space is clearly showing in Figure 3. The figure of 250 kW/m² is a good average value for a fire in a typically furnished room. Suppose the 27 m² is filled with stacked matrasses, then the heat release rate will be much higher than 6.75 MW (provided that sufficient air is available to the fire). In such cases, a heat release rate of 1 MW/m² is quite possible.

The true reason behind the popularity of the high pressure is hidden here. The majority of the fires is smaller than 27 m², especially in residential buildings. Usually the fire is limited to a single room and most rooms are smaller than 27 m². This means that a high pressure line is a very good tool for fires in residential buildings.

Paul Grimwood has done very extensive research into the flow rates used at firefighting operations. Over a period from 2009 to 2012, he studied a total of 5401 fires. He looked at both fires in a larger metropolitan area, as well as fires in a more suburban region. The research allowed him to conclude some interesting facts relating to the fires where only high pressure lines were used. The average burning area size was 7.72 m² in the suburban area and 11.14 m² in the metropolitan area. It is extremely important to note that in these cases high pressure lines are used that only flow 100 liters per minute. When equally efficient, this would mean fires with burning area sizes between 14 and 20 m² in Belgium. So high pressure is primarily used at smaller fires. For these fires, the high pressure is very good tool… if nothing goes wrong.

2 Potential problems

Over the past years, a lot of effort has gone into training firefighters to be more efficient with their water: achieving more with less water. Because of this, the possibilities of the high pressure have increased. Then why is there a growing number of people advocating low pressure? Is there something missing in the reasoning above?

The reasoning above is mainly based on the past. People are looking to solutions for problems of the past and are justly concluding that these were good solutions. The high pressure is a good solution for the fires of the past. *Is it also a good solution for the fires of the future?*

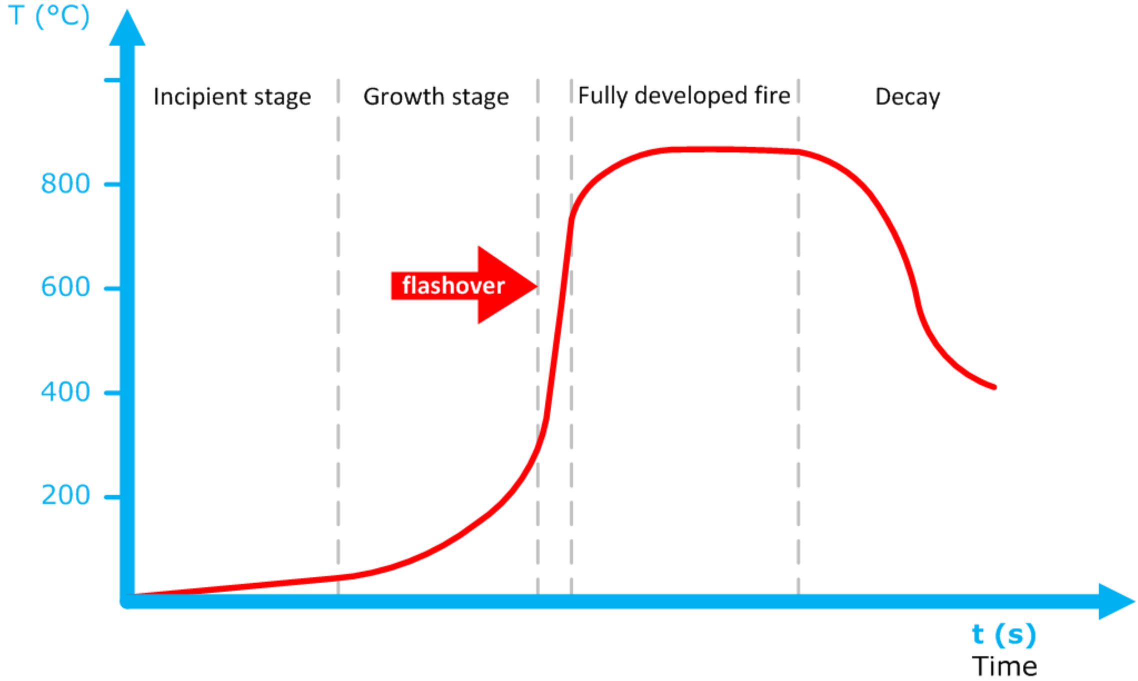

Figure 4 The ventilated fire development. The first big change in fire development to come around refers to the first two stages: incipient and growth stage. In 1950 these two stages combined took about half an hour. Now they only need two to four minutes. *(Figure: Bart Noyens)*

2.1.1 Changing fire behaviour

Everyone already knows that fire behavior has changed during the past 60 years. The introduction of synthetic materials after the second world war, led to a fire progressing much faster nowadays. In 1950 it took half an hour for a fire to reach flashover. Now, it only takes two to four minutes. Often the response of people is then: "So that would happen before the fire service arrives on the fire ground?" Of course, that is the case, but the people asking this question are forgetting that the model of the ventilated fire is referring to a single room. A fully developed fire in the kitchen will eventually cause the adjacent living room to burn as well. Two to four minutes later, flashover will occur there as well. And in that case, the fire service may have already arrived on scene. A fire attack crew may well be on its way through the living room, crawling – underneath a smoke layer

– towards the burning kitchen. When something goes wrong then, it will go wrong much faster than in the past. This is the **first major change in fire behavior**.

The introduction of double glazed windows and the evolution to more insulated housing, led to the **second major change in fire behavior**. When a room is completely shut, there is no longer sufficient oxygen available to reach flashover. Single panes of glass used to break quickly due to high temperature. This is no longer the case with double glass panes and so the under ventilated fire made its appearance. In a closed compartment, the heat release rate of the fire will be limited by the lack of air. This could still change when a window fails or when firefighters open the door to start the fire attack. Extra air means an increased heat release rate. And here as well, chances are that things will go bad in a hurry.

A research into pressure buildup at fires was published in Finland this year. Because of construction becoming more airtight, pressure builds up higher in the fire room. Fire causes an increase in temperature. Heated air will try to expand. In a closed compartment, expansion is not possible. This will cause the pressure inside to increase. In one of the Finnish experiments, pressure rose to such an amount that the entire window (glass pane and frame) was pushed out. This might well mean a third big change in fire behavior. During the fire development, suddenly a large opening becomes available, providing large amounts of oxygen to the fire. Again, this illustrates why things can go bad very quickly in modern fires.

2.1.2 Wind Driven Fires

In 2009, the American agency NIST published the first extensive research into Wind Driven Fires. Under certain wind conditions, fires can behave very erratically. The research originated from several line of duty deaths of firefighters battling fires in high rise buildings. It was demonstrated that wind can increase the fire's heat release rate considerably so that very high temperatures are generated. The wind can also cause all of this to be pushed towards the fire attack crew. When there is a strong wind blowing straight into a window, the glass pane will prevent the wind from influencing the fire. This all changes the moment the window fails. Then the fire becomes *wind driven*. A situation that was perfectly manageable, is suddenly no longer so. In the US, every fatal accident involving a firefighter is thoroughly analyzed (contrary to what happens in Belgium). During the past years, several firefighters lost their lives at wind driven fires in plain normal houses. It is therefore a risk that can happen anywhere.

2.1.3 New architecture in houses

Architecturally speaking, there have been some significant changes as well. In the past, homes were made up out of various separate rooms. There was a kitchen and a living room. Sometimes there was even a separation between the living and the dining room. Each of these rooms was smaller than 27 m². A high pressure line was an ideal tool for tackling fires in these rooms. Figure 3 illustrates this situation perfectly. When there is a fire in the living room, it will progress quickly into flashover provided there is enough air. Next, it will take a while for fire spread to occur. The fire is hindered by the walls. The doors will be a critical factor here. If the doors are shut, they will slow down the fire for some time. If the doors are open, hot smoke can flow in the adjacent rooms. The limiting effect of the walls is not as substantial in that case.

In dwellings and apartments that are being constructed nowadays, there is always an open kitchen. The living room and the kitchen are one large single room. In a lot of dwellings, the area size of that open space is larger than 27 m². This is clearly visible when comparing Figure 3 to Figure 5.

In modern housing, large open rooms are very common. This provides a more comfortable way of living for the inhabitants, but the size of the rooms increases significantly. Therefore, fires will occur that are no longer safely manageable with a high pressure line.

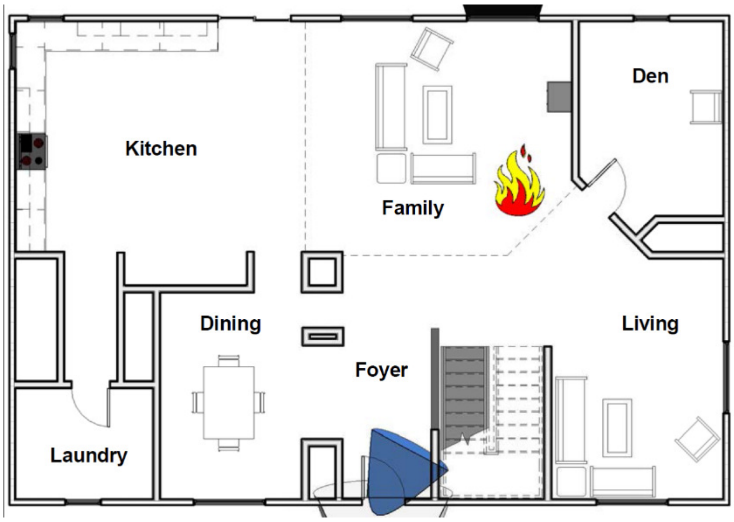

Figure 5 Floor layout of a ground floor in a modern dwelling. The kitchen and the living room are now joined into one big single room. There is a cozy sitting area (bottom right) that is connected to the family room. This all creates one large compartment. *(Figure: UL FSRI)*

2.1.4 Summarized

In summary, several different problems have arisen over the last years:

- Fire development is much faster than in the past.
- At under ventilated fires, providing a new opening can cause sudden fire spread.
- Questions are being asked regarding the effects of pressure buildup at fires.
- Wind driven fires lead to very high heat release rates.
- The use of more and more open floor plans with large open spaces, can potentially cause bigger fires.

Each one of these problems means that fires can suddenly become much larger. During an interior attack, it will take several minutes to travel the distance from the front door to a position from where the fire can be attacked. During that time frame, the fire can change drastically. A fire that could have been tackled perfectly with a high pressure, might require a lot more cooling power a few minutes later. And when that cooling power is not readily available, it becomes a very dangerous situation for the attack crew.

The fires of the future will progress much faster than the fires of the past ever did. The problems described above, were almost entirely nonexistent in the past. *A high pressure line offered a very good solution for the fires of that time.* It still offers a good solution for the fires of today <u>provided that</u> there are no big and rapid changes in the fire progress during the interior attack.

A good analogy can be made with the seatbelts of a car. Nowadays, every driver has their seatbelt on because this significantly increases his or her chances of survival in a car crash. *Fighting a fire with a high pressure line is like driving 120 km/h on the highway without a seatbelt on.* Most people will drive over highways their entire life without crashing once.

So they could just as well do this without wearing a seatbelt and they would not experience any disadvantage of doing so. A small number of people will be very unlucky and will be involved in a high speed accident. For them, wearing a seatbelt will be crucial for their survival. The same applies to firefighting. The majority of the fires can be managed with a high pressure line. Only a small portion of the fires cannot be extinguished this way and the problem is that we do not know which fires beforehand.

It will be more and more the case in the future, that the fire service arrives at a seemingly harmless situation. The initial size-up would indicate a fire which can be extinguished using a high pressure line. It is one of those many fires, that can be dealt with that way. It will only be later on during the operation, that things will start to go wrong. This could be due to one of the five scenarios described above or it could be due to some problem that has not been discovered yet. The only thing we know for sure is that there will be fires where a high pressure is not a safe choice. We just don't know up front which fires those will be.

A good example of this is a fire where the heat release rate is limited because the window is still intact and there is a small wind blowing onto the side of the building. Upon arrival, nothing will indicate a serious fire. Everything will point to the cooling power of the high pressure outmatching the heat release rate of the fire. This assessment would match reality if the burning compartment is more or less closed off. All of this will change if the window in the fire room fails. Suddenly, the wind will supply a large amount of fresh air to the fire. The heat release rate could easily double. The maximum flow rate of the high pressure line however, cannot be doubled.

So there is great concern for the safety of the firefighters executing the interior attack. Some crews are very proficient with a high pressure. They achieve a very high efficiency. But this also means that there is no safety margin. When you use an extinguishment system at the upper limit of its possibilities, you can no longer react when you would suddenly need more cooling capacity.

"Fighting a fire with a high pressure line is like driving 120 km/h on the highway without a seatbelt on."

3 Potential solutions

In the section above, a number of problems have been described which the fire service will presently face. Of course, there are also solutions. Each of these solutions requires a certain investment. Tools will have to bought or adapted. Training and practice however are also very important. Often these two are neglected. Initial training and sufficient continuing practice afterwards will have to be invested in as well if we want to implement each and any of the solutions below.

3.1 Coiled hose loads

The coiled hose loads and cassettes are already being used in large parts of Belgium. They first made their appearance in 2009 and since then have been increasingly used in more and more fire stations. The benefit of any low pressure system is that a higher flow rate is possible. Flow rates of low pressure systems using 45 mm lines are at least double of the high pressure's 180 liters per minute. The cooling power is therefor also double that of the high pressure.

Figure 6 The several different components of the system using coiled hose loads and cassettes. The 70 mm hose is connected to a three way divider. The picture shows the flaked hose line in the cassette being connected to the divider. At the point of attack, a yellow coiled hose line will be connected to the line of the cassette. *(Photo: Karel Lambert)*

In a situation where the high pressure is being pushed to its limits, the low pressure is only halfway its capabilities. Firefighters will have the option in such cases, to use double the amount of water. So, there is a safety margin that is lacking with the high pressure. Of course, it is important to realize that a low pressure line is not the answer to everything. Even the cooling capacity of a low pressure line is limited somewhere in between 15 to 20 MW.

Coiled loads and cassettes also make for easier deployment of a low pressure line. The mobility of a 45 mm hose line is still less than a high pressure line. But the speed of deployment is a lot quicker when comparing coiled loads and cassettes to the old system of rolled hose lines. An important part is that the 70 mm hose line is flaked in a zig zag pattern in the engine and already connected to the three way divider. The company officer will take the divider in hand and walk towards where he or she wants the coiled loads or cassettes connected. Especially working with a cassette inside a structure, will be faster than stretching a high pressure line. With a high pressure reel, friction will increase the further the nozzle man moves away from the reel. When deploying from a cassette, there is no friction. On the contrary: the weight of the cassette will diminish, the further the crew travels. When using a high pressure, the crew will have to provide enough extra length of hose line at the point of attack, so that interior attack is not hindered. This last bit will be hardest because friction is at its highest then. In the new low pressure system, the coiled hose loads are connected at the point of attack which immediately provides 20 to 40 m of spare hose line. The attack crew will simply put

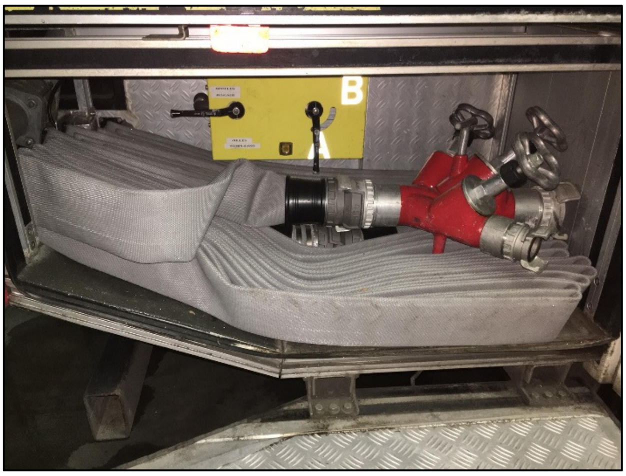

Figure 7 Flaking a 70 mm in a tight serpentine pattern coupled to a three way divider, is a significant tactical improvement that can easily be made without altering the engine. *(Photo: Steve Viaene)*

the coils down where they will be connected.

3.2 38 mm

Mobility could be increased further. In Belgium, the decision was made at some point to choose two diameters for the basis of the low pressure system: 45 and 70 mm. Other countries have made other choices. The UK often uses a 52 mm. The Australian fire service prefers 38 mm for the primary attack line.

The question is: *"Which diameter do we need?"* The diameter needed is determined by different things: the length we want to use, the flow rate we want to achieve and the pump being used. The pump has to be able to supply the needed flow rate at a pressure that is high enough to compensate for any friction losses and still have an acceptable operating pressure at the nozzle. The flow rate of a 45 mm line is somewhere in between 400 and 500 liters per minute.

A hose line with a 38 mm diameter also allows for these kinds of flow rates. Pressure losses are somewhat higher though, but these can be compensated by using a higher pressure setting at the pump. The objective is still to use 70 mm hose lines for overcoming the larger part of the distance between the engine and the fire. This will limit pressure losses.

A 38 mm hose line weighs only 71% of the weight of a 45 mm hose line while achieving a similar flow rate. Because the hose is thinner and lighter, it will be a bit more mobile. Such a line will handle more like a high pressure line. A low pressure system using 38 mm hose lines, might well offer the best of both worlds: the higher mobility of a high pressure and the flow rate of a low pressure system.

3.3 Low pressure reel

The simplicity and ease of use of a hose line on a reel, continues to be an advantage for car fires and trash fires. At outdoor fires and over short distances, the high pressure remains quicker than low pressure, even when using coiled loads and cassettes. This is an advantage we must not lose in our search for better means of firefighting. The biggest benefit of a high pressure is that a hose line on a reel can very quickly be stretched in a straight line. This is often the case in outdoor firefighting. Especially over shorter distances, a reel offers large advantages. When dealing with larger distances (40 to 80 meters), friction starts to have a larger effect.

Figure 8 Low pressure reel in the back of an engine. *(Photo: Jean-Claude Vantorre)*

Because of the quick deployment at outdoor fires, several fire stations have opted for low pressure reels to be mounted in their engines. A semi-rigid hose line of 38 mm on a reel is used. It is the same principle as a high pressure, only the diameter is larger. Then again, the length of the hose line is much shorter. The line on the reel, is limited to 40 meters. This allows for a quick deployment in case of a car fire – as is the case with the high pressure reel. Due to the larger diameter, a higher flow of 400 liters per minute can be achieved. In this case as well, the best of both worlds is combined: high flow rate and quick deployment.

4 Closing thoughts

The world around us is changing rapidly. These changes regularly cause problems. And then it is up to the fire service to go out and solve these problems. This has made the fire service very adept at thinking up solutions. Because of the rapid evolution, good solutions of the past are no longer suited to handle problems of the future.

This article has illustrated why the high pressure has become so popular. Several situations have also been described in which the low flow rate of the high pressure holds a certain risk for the attack crew.

In the coming years, the fire service will face new problems in terms of extinguishment. And as always, the fire service will come up with some good solutions for these problems. These could be one or more of the systems described above. Then again, they may well be entirely different solutions. Important is, that these solutions are fast, effective and most of all safe …

5 Bibliography

[1] *Grimwood Paul (2015) A study of 5401 UK building fires 2009-2012 comparing firefighting water deployments against resulting building fire damage, PhD dissertation, Glasgow Caledonian University*

[2] *Rahul Kallada Janardhan (2016), Fire induced flow in Building Ventilation Systems, Master's thesis, Aalto University, Finland*

[3] *Madrzykowski Daniel & Kerber Steven (2009), Evaluating firefighting tactics under wind driven conditions, NIST*

[4] *Lambert Karel (2010) Wind Driven Fires, De brandweerman*

[5] *Jean-Claude Vantorre, innovator at the fire service, personal communication, 2009-2016*