Rapid Fire Progress: A summary

1 Introduction

Previous articles in this series talked about three groups over fire phenomena. The underlying mechanics of each phenomenon were explained. This means that the series of events of behind a phenomenon are described in detail. To better understand Rapid Fire Progress, we will now look at the different phenomena from a different point of view. Practically speaking it's more important for a firefighter to know that something can go wrong, instead of knowing exactly what is happening when it is going wrong. An example can help to clarify things. It's more important for a firefighter to recognize the conditions that can lead to flashover, than it is for him to realize he is in a flashover when it actually happens.

Figure 1 depicts a graph in which most of the Rapid Fire Phenomena have been situated. The graph illustrates the conditions which are present before a specific phenomenon occurs. It is very important for firefighters to be able to assess which phenomena can occur in the situation they are currently working in. This graph gives us an overview of the different forms of Rapid Fire Progress.

Each phenomenon will need further progress to occur before it will actually happen. After all the graph shows the circumstances before the occurrence of the phenomenon. This means that there's at least one side of the fire triangle absent. It's up to us to recognize the conditions in which a certain phenomenon can occur. The lists of warning signs of flashover and backdraft should be well known by each and every firefighter. However it is more difficult to predict when fire gas ignition (FGI) can occur.

Good observations (and good communication) by firefighters can lead to the recognition of conditions before the occurrence of a certain phenomenon. Based on these observations, several actions can be undertaken to prevent the fire from getting worse. If this isn't possible, the choice for evacuation can be made. Be increasing the distance between a fire phenomenon and firefighters, the risk for casualties drops.

The graph is a model, a means to simulate reality. Chief Ed Hartin (US) often uses the following expression when discussing models: "All models are wrong, but some are useful". This certainly applies to Figure 1. The figure illustrates the conditions of which different fire phenomena can occur. A model is an approximation of reality and is certainly not perfect. This model has been reworked over the years and could even use some further improvement. Suggestions are always welcome.

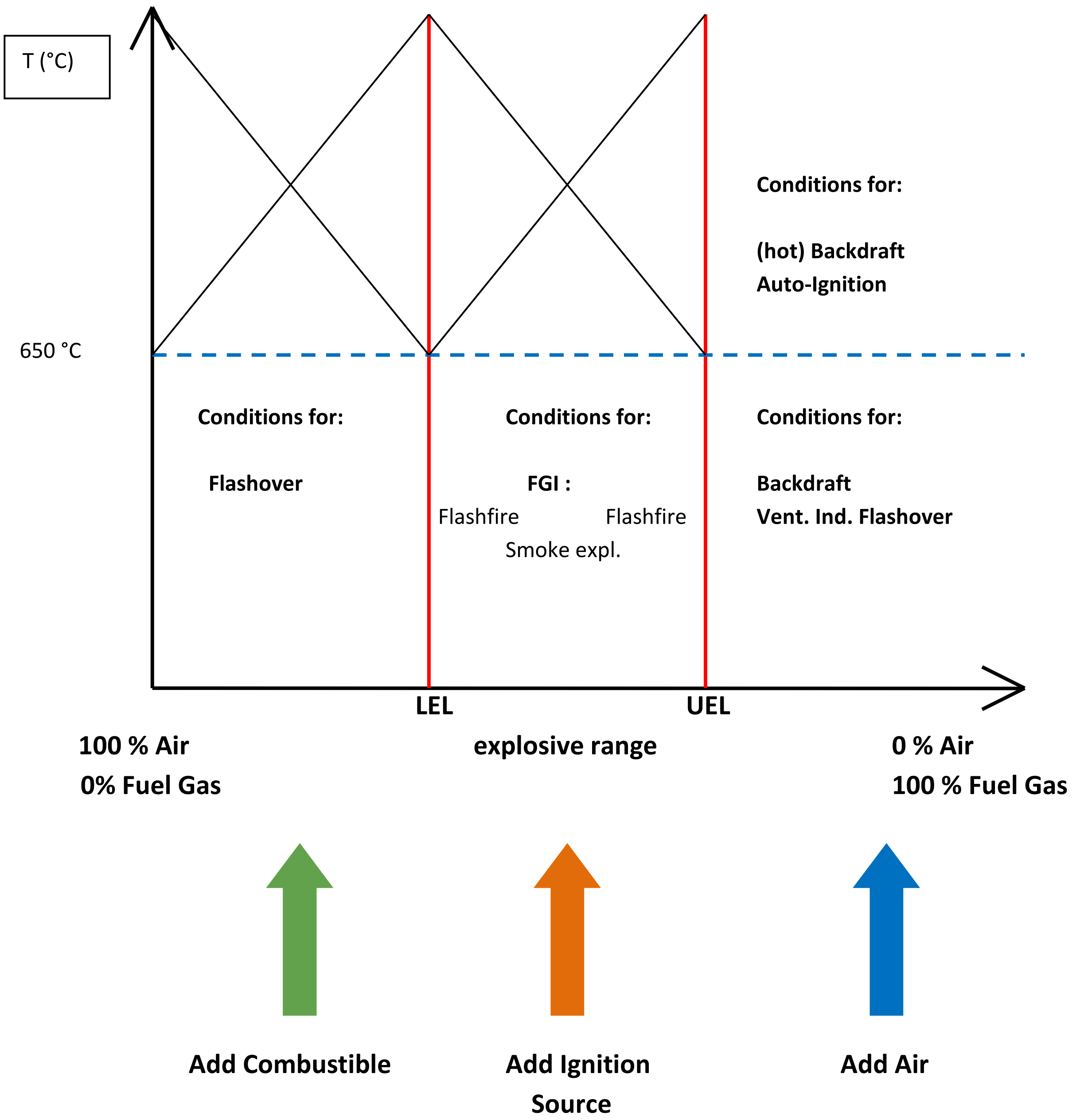

Figure 1 Overview of Rapid Fire Progress. *(Graph: Karel Lambert)*

2 Review of the different fire phenomena

2.1 Flashover

Flashover is a form of Rapid Fire Progress in which the fire transitions from a fuel controlled regime into a ventilation controlled regime. Before flashover can occur, enough heat has to build up in the room. This requires energy. The energy is released by the combustion process. In the growth stage of the fire, the surface involved by the seat of the fire will increase continuously. The amount of fuel involved will increase as well. The heat release rate of the fire will rise because of the fire growth. This means that even more energy will be released. At a certain point in time, a critical level will have been reached. Enough energy will be released to allow for flashover to happen.

Before flashover can occur, the temperature in the room is rather limited. After all, the temperature still has to be built up. The amount of fuel involved in the fire is limited as well. The fire is still local.

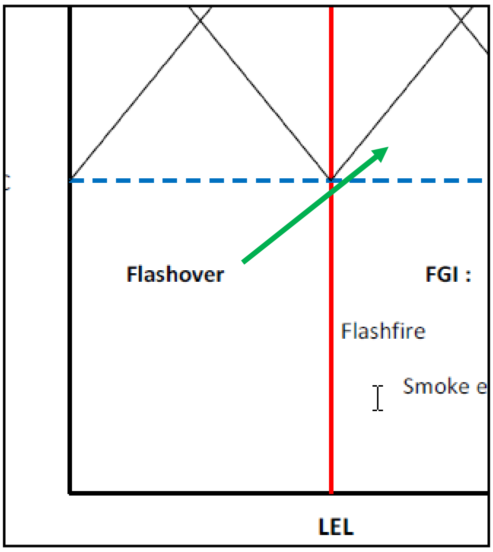

Figure 2 The green arrow indicates flashover.

The fire grows. Because of an increasing fuel load, the energy released rises as well. The smoke layer becomes thicker, drops to the floor and contains an increasing amount of flammable gases. On the graph this means a shift towards the right hand side. At the critical level, the smoke layer will ignite. This is actually a phenomenon by itself: the rollover. This will result in a massive increase in radiant heat coming from the smoke layer and directed towards the objects below. This will cause an even faster fire growth. A few seconds later the entire room will be ablaze and flashover has occurred.

On figure 2, the green arrow indicates how the situation has progressed during flashover.

2.2 Backdraft and Ventilation induced flashover.

Backdraft is a very rare phenomenon. It is however a very violent phenomenon. Because of this it is rather infamous. Almost every firemen has something to say about it.

The conditions needed for backdraft to occur are the following: A fire has to have burned in the room. This fire needs fuel and oxygen to grow. At some point in time the fire development was halted because of a lack of oxygen. This is called an under ventilated fire. Because temperature inside the compartment has already risen substantially, heated objects will continue to pyrolyze. The fire dies down. Flaming combustion ceases and what remains is a smoldering fire. Meanwhile, more and more smoke gases and especially pyrolysis gases are being produced. The atmosphere inside the room will transition from far left to far right on the graph. The concentration of flammable gases will rise so that mixture will be formed that is too fuel rich. This mixture is above the upper flammability limit (UFL).

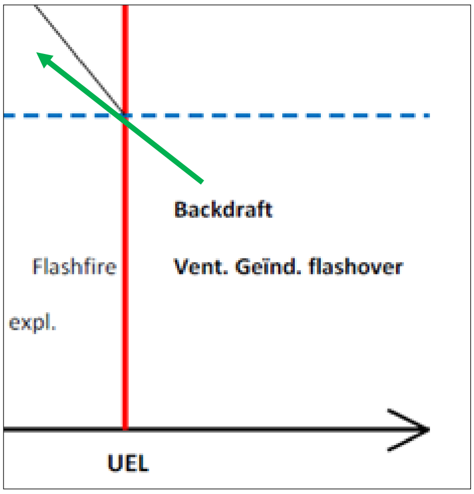

Figure 3 Occurrence of backdraft and ventilation induced flashover.

The moment the fire service opens the door of the compartment or if a window breaks, oxygen will flow back into the compartment. The fuel rich mixture will be diluted. When the fire rekindles, its flames can ignite the mixture if it has fallen between flammable limits (LFL and UFL). Backdraft will occur and a pressure wave will push smoke gas in the room outwards through the opening. This pressure wave is followed by a flame front. The result is the typical and spectacular ball of fire.

Backdraft was and always will be a rare phenomenon. After all a lot of conditions will have to be met in order for backdraft to occur. A less known phenomenon is ventilation induced flashover. A ventilation induced flashover starts from the same fire conditions. The under ventilated fire will create the conditions needed for such a fire phenomenon to occur: a fire that is being controlled by the lack of oxygen and a room filled with flammable gases.

Again, when the fire service opens the door, fresh air will flow in. The fire will rekindle. Due to the fact that a lot of objects in the room have already been heated up, the fire can progress rapidly. The fire will grow and before "the smoke has cleared", flashover can occur. This type of flashover has been caused (or induced) by the change in ventilation. A green arrow illustrates this process on figure 3.

Because the construction methods of today are different from those a few decades ago, under ventilated fires are happening more and more. It even looks like the future will have more under ventilated than ventilated fires. This means there will be an increasing risk for ventilation induced flashover. Even though backdraft is better known, firefighters need to be more careful about ventilation induced flashover.

2.3 Flashfire & Smoke explosion

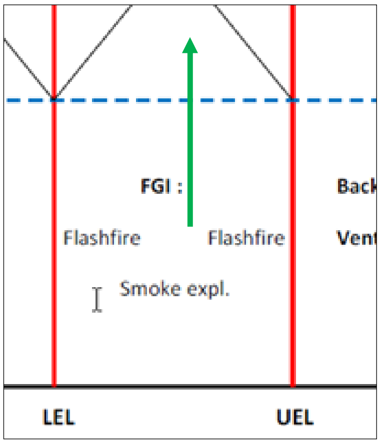

Figure 4 Occurrence of FGI

Aside from the family of flashovers and the family of backdrafts, there's also a third family: the fire gas ignitions (FGI). These phenomena happen the same way as a gas explosion caused by a gas leak in a house. For the phenomenon to happen, the following criteria have to be met: Sufficient flammable gases need to be present in the room so that the concentration is above the lower flammable limit (LFL). At a fire scene, these gases can be formed by either combustion (smoke gas) or pyrolysis (pyolyzates).

When during a fire, a lot of smoke gas is formed in a closed off room, a pressurized atmosphere is formed inside. This positive pressure will cause smoke to be pushed out through cracks and gaps. The smoke may be pushed outside, but it's also possible that the smoke ends up in neighboring or void spaces : false ceiling, elevated flooring or dry wall. The concentration of smoke gas mustn't rise above the upper flammable limit (UFL) however. Then it would be too rich to ignite.

This way a mixture of oxygen and fuel is present in the room which can be ignited. If an ignition source is added to the mixture, it will ignite. This is illustrated by the green arrow in figure 4.

Which kind of phenomenon occurs (flash fire or smoke explosion) is determined by the concentration of smoke gas. Somewhere in the middle of the flammable area is the stoichiometric ratio. That's the ideal ratio of fuel and oxygen. When igniting gases in an ideal ratio, a powerful explosion is formed. Mixtures of an ideal ratio of fuel and oxygen will form a smoke explosion upon ignition. These mixtures are in the middle of the flammable range. Closer to the outer limits of the flammable range are less ideal mixtures. They can still be ignited however. Igniting these mixtures will cause a swift combustion. The buildup of pressure in the room caused by this combustion is rather limited. Such phenomena are described as flash fires.

2.4 Auto-ignition

Auto-ignition is a phenomenon that's generally not well known. Most often it's no threat to firefighters. It may cause fire spread however. Aside from this, auto-ignition means that temperature inside the compartment is very high.

For auto-ignition to occur, smoke gas needs to be sufficiently available in the room. These smoke gases have a very high temperature, above 650°C. The value of 650°C is but a rough estimate. It may as well be 600°C or 700°C. Some texts mention a possibility for auto-ignition at even lower temperatures when the smoke is primarily made up of pyrolysis gas.

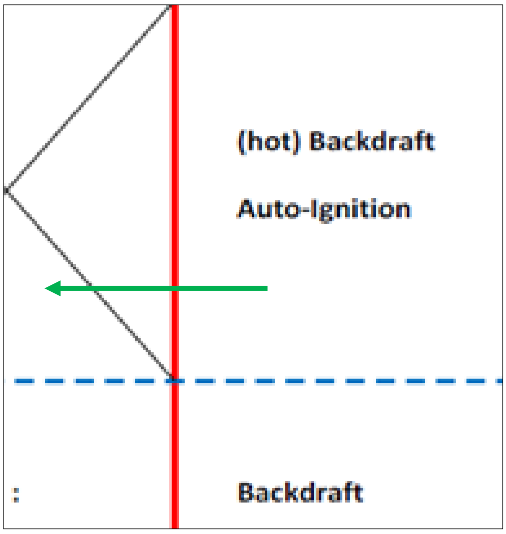

Figure 5 Occurence of auto-ignition and hot backdraft

A final condition that needs to be fulfilled is that the concentration of smoke needs to be very high so that the mixture has passed the upper flammable limit (UFL). Otherwise the smoke would ignite inside the compartment instead of outside.

The moment an opening is made, the hot smoke will exit the room. Once outside it will mix with fresh air. This dilutes the mixture. The process is represented by the green arrow on figure 5. As soon as the smoke and air have formed a flammable mixture, ignition will occur. The temperature of the smoke gas serves as the ignition source.

2.5 Hot backdraft

In a town in Wallonia the fire service was dispatched to a fully developed fire in a store with frozen food products. Upon arrival it looked like flames were exiting through the roof of the store (see figure 6). The store was closed so the firefighters had to perform forceful entry to be able to initiate fire attack. Because of the exiting flames, no one considered backdraft. In the list of warning signs for backdraft, the absence of flames is often noted as one of the main characteristics.

After a window was broken to gain entry, a large amount of air rushed swiftly into the building and shortly after a violent backdraft occurred. Luckily no one was injured. Afterwards the firefighters were clearly surprised by the fact that a backdraft had been able to happen. After all, flames were clearly visible. An important distinction needs to be made here: there were no flames visible inside the compartment. The flames seen upon arrival were probably (partially) caused by auto-ignition of exiting smoke gas.

Figure 6 The photograph shows three shades from left to right : pyrolysis gas, smoke gas and flames. The clarity of the flames indicates auto-ignition of exiting smoke gas. *(Photo: Benoît Amans)*

Figure 7 After a firefighter has created an opening in a window, a very violent backdraft occurs. *(Photo: Benoît Amans)*

A rare situation may arise when very hot smoke is built up in a compartment in which a sudden air flow is formed. At a common backdraft, fresh air and smoke (fuel) is mixed and subsequently ignited by the rekindling fire. The rekindling of the fire is determined by the supply of oxygen as well. A common backdraft therefore has two aspects which are determined by ventilation. A flammable mixture has to be formed and the fire needs to get enough oxygen to rekindle.

When however the smoke gases are extremely hot and above auto-ignition temperature, no extra ignition source is required. The smoke gas itself is the ignition source. In such cases, a "hot backdraft" can occur. This phenomenon is extremely rare and there's no general agreement on its process even amongst fire behavior experts.

2.6 Review of the graph

When looking at Figure 1 in detail, we can see that there are three different mechanisms to achieve some form of Rapid Fire Progress:

- Adding fuel (green arrow)
- Adding energy (orange arrow)
- Adding air (blue arrow)

We know that architects pay more and more attention to making housing air tight. Fires will become more and more under ventilated. Situations in which adding air leads to serious problems, will happen more and more. This doesn't mean however that the other situations can't occur (anymore). It's up to the officers to take into consideration the conditions as well as the behavior of a fire during firefighting operations. It's up to them to prevent accidents by recognizing and anticipating fire behavior.

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