FIRE BEHAVIOUR

INSTRUCTORS AID MEMOIRE

DEVON FIRE
&
RESCUE SERVICE

RÄDDNINGS
VERKET
Swedish Rescue Service Agency

Fire Behaviour
Instructors Aide Memoire

PREFACE

The following notes where compiled by Members of Devon Fire and Rescue Service and The Swedish Rescue Service Agency as an aide memoire for students who have successfully undertaken a Fire Behaviour Instructors Course. The course is held in Devon by members of the Swedish Rescue Service Agency in their partnership with Devon Fire and Rescue Service.

This aide memoire should not be considered as a definitive note, but should be used as a foundation for further learning. Much of the operational experiences originate from Sweden, but this aide memoire is intended to place this experience in the appropriate United Kingdom Firefighting context.

As we know, the fireground offers a multitude of challenges to Firefighters. The skills you have been taught will equip you to fight fires more effectively and safer than before.

The importance of regular training in the techniques you have been taught cannot be over emphasised.

The definitions of “Flashover” and “Backdraught” in this note are based on the state of knowledge in 2001, rather than the British Standard 4422:1987.

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Notes made by Roger Williams. Devon Fire and Rescue Service

Fire Behaviour
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SECTION I – INTRODUCTION

During the early 1980s following a flashover where two Swedish Firefighters were killed, Stockholm Firefighters began to practice techniques developed by Gisselson & Rosander that were aimed at protecting Firefighters from the Flashovers – Backdraughts and Fire gas explosion hazards. These techniques entailed utilising a water-spray nozzle to apply a fine water 'mist' into the overhead fire gases using a series of brief 'spurts' (by resorting to a 'pulsing' technique at the nozzle). The objective was to avoid contact with hot surfaces, walls and ceilings and to place small amounts of water droplets directly into the fire gases where any cooling effect was maximised. The application avoided the massive expansions of steam and other problems associated with 'indirect' water-fog attack and created a safe and comfortable environment for Firefighters to advance into prior to attacking the main source of fire. The Swedish concept (also termed 'offensive firefighting') was based on recognition of a fire's development process and great emphasis was placed upon observation of specific warning signs that might lead to an ignition of the fire gases, ie Flashover & Backdraught. The benefits of Offensive water-fog applications are equally seen in both pre-flashover situations and post flashover fires.

The 'tactical solutions' and training implications associated with applying water to control environmental conditions within a fire compartment/structure go way beyond branch techniques. These training concepts create a greater awareness of fire growth and development; fire behaviour patterns; and behaviour of flammable fire gas layers. This style of approach is being adopted world-wide as Firefighter **safety** is the prime concern.

It is also worthy of note that Sweden has reduced personnel injuries from flashover since the introduction of live fire behaviour training involving the use of flashover fire simulators over 18 years ago.

SECTION II – FUNDAMENTALS OF FIRE DEVELOPMENT

2.1 COMBUSTION

Fire is basically a chemical reaction in which fuel combines with oxygen.

This reaction **(combustion)** requires energy **(heat)** to enable it to work, thus emitting heat and light.

The following factors are required for combustion to occur: -

HEAT	-	Energy
FUEL	-	May be in one of three states, Solid, Liquid or Gas. For flaming combustion to occur, a solid or liquid must be converted into its vapour state
OXYGEN	**-**	Fuel mixes with air and reacts with oxygen

This process is commonly referred to as the **"TRIANGLE OF COMBUSTION"**

Providing these 3 factors are present **and in the correct proportions** combustion will occur.

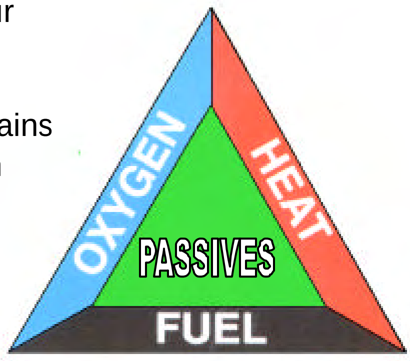
Example: -
For a candle to burn, an impulse of energy is required to start the process (i.e. a match). The lighted match melts the wax, which is drawn up the wick by capillary action, turning into a flammable vapour ("heat from match"). The vapour is ignited by the match, which then forms a flame. The flame now produces heat and light, which melts more wax and the cycle, continues.

2.2 PASSIVE AGENTS

As mentioned previously there are three sides to the triangle of fire, which requires that fuel, heat and oxygen must be present for combustion to occur. However there is a further factor that will affect the triangle. This factor can be termed as **"Passive Agents".**

These passive agents or "passives" as they are commonly referred to, are present in any combustion process and take no part in the chemical reaction of combustion. But the fact that they will absorb or steal the energy (heat) will have an effect on the fire's behaviour.
Examples of Passive Agents are: -

Non Flammable gases	-	Carbon dioxide, water vapour
Soot	-	Carbon particles
Weather	-	Temperature and humidity
Nitrogen	-	A constituent of air that remains inert throughout combustion



2.3 TYPES OF FLAME

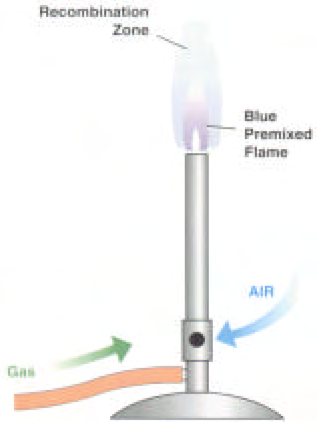
The appearance of the flame produced by a burning substance can give information to a Firefighter about the efficiency of the combustion process. In this note we will divide the appearance of the flame into two types - **Diffused & Premixed.**

2.3.1 Diffused Flames

As you are aware the type of flame given off from a Bunsen burner when the aperture is closed is a slow, bright, lazy flame. The oxygen vital for combustion is drawn from the area surrounding the flame. We have all seen this type of flame hundreds of times, a candle for example. Now consider the fact that a candle is only 25% efficient bearing this in mind, picture an average lounge fire with a settee burning producing diffused flames, we now know this relatively inefficient combustion is releasing large amounts of unburnt fuel (fire gases) into the room

2.3.2 Premixed Flames

If we return to the Bunsen burner described previously and open the aperture slightly this allows oxygen and fuel to mix before ignition greatly improving combustion efficiency, demonstrated by the colour, temperature and speed of the flame. The amount of unburnt fuel (fire gases) is dramatically reduced.



Premixed Flames

- Gases are mixed prior to ignition
- Therefore they burn cleaner
- Hotter flame which can be seen by:
- Flame colour (bluer)
- More noisy because
- Higher velocity of the deflagration
- More stable flame but harder to discern edges due to blurred flame
- More efficient burning

Diffused Flames

- Is not mixed prior to ignition
- Therefore is an unclean burn
- A cooler flame which can be seen by:
- Flame Colour (orange / red)
- Less noisy because
- Lower velocity of the deflagration
- Defined outline to the flame
- Less efficient burning

MAJORITY OF FIRES THAT YOU WILL BE FIGHTING OPERATIONALLY WILL BE PRODUCING DIFFUSED FLAMES!!!

2.4 FIRE GASES

The products of combustion (smoke) are referred to as **Fire Gases** and consist of: -

NON FLAMMABLE GASES	-	Mainly carbon dioxide and water vapour.
FLAMMABLE GASES	-	Due to pyrolysis and incomplete Combustion, includes Carbon Monoxide.
AIR	-	Entrained in by rising temperature.
SOOT	-	Carbon particles.

2.5 PYROLYSIS

Decomposition of a substance by heat.

All substances will, if heat is applied, decompose from a Solid **or** a Liquid to a Vapour state. This is due to the effect of the heat being applied to the molecules, which will absorb the heat and start to become progressively more unstable as it decomposes through the states of matter.

Therefore if a substance, whether it be a solid or liquid is heated, gases will be given off. At the right temperature and mixture these gases are flammable.
The contents and structure (paint, timber, plastics, textiles, etc.) of a compartment will produce flammable gases due to pyrolysis, when they are heated. The amount of pyrolysis taking place will increase as the temperature increases.

PYROLYSIS can start to be produced at about 80^{O}C. At 150 - 200 ^{O}C pyrolysis will occur in wood.

2.6 LIMITS OF FLAMMABILITY

A flammable gas will only burn in air if its composition lies between certain limits. If too little or too much fuel is present, combustion will not take place; the mixture is then said to be either **too lean** or **too rich**.

These limits are referred to as the **Lower Explosive Limit (LEL)** and the **Upper Explosive Limit (UEL).** The following definitions are taken from the "Manual of Firemanship book 1 - Elements of Combustion".

2.6.1 The Lower Explosive Limit Is Defined As:

The lowest concentration of fuel that will just support a self-propagating flame.

2.6.2 The Upper Explosive Limit Is Defined As:

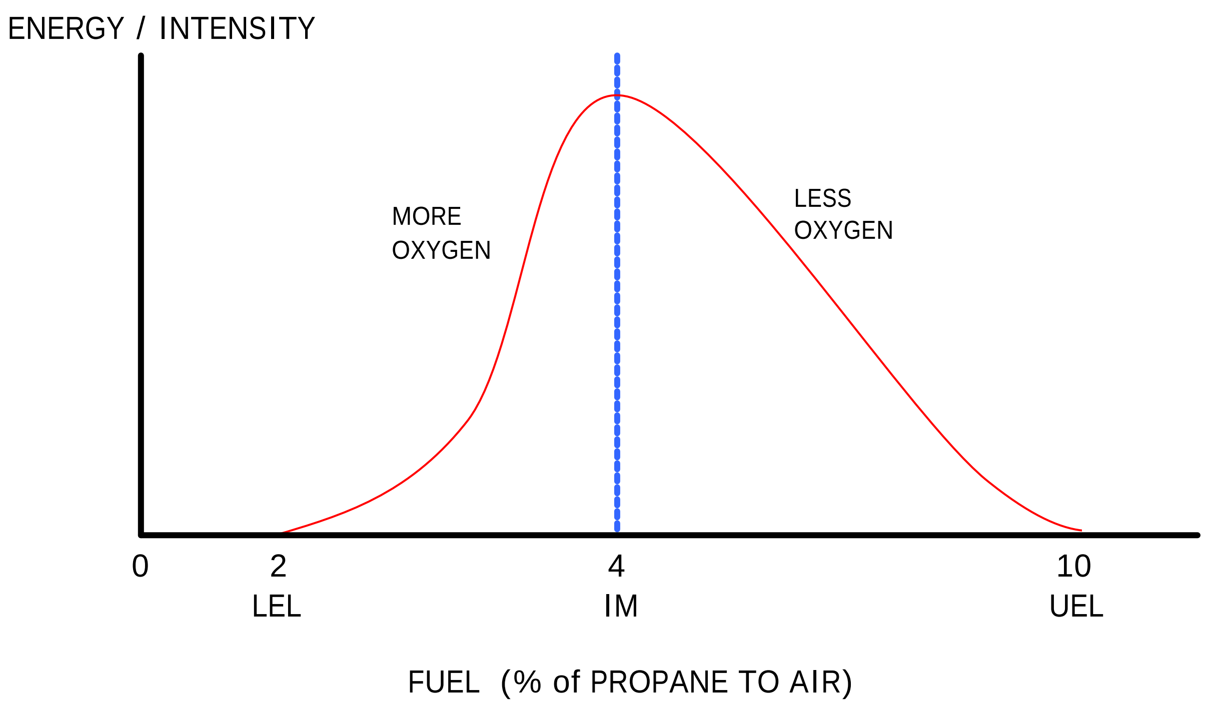
The highest concentration of fuel that will just support a self-propagating flame.

Between these limits, which are given as percentages, is the flammable range of the gas.

2.6.3 Ideal Mixture (IM)

For every gas there is a particular concentration where the amount of gas is exactly right in relation to the amount of oxygen in the air for combustion to occur. This is known as the ideal mixture (IM) and is found between the Lower and Upper Explosive limits.
If Combustion occurs at the ideal (most efficient) mixture, it will have the maximum force.
The ideal mixture (IM) will burn quicker and with the most intensity (energy & force).
However at the lower and upper explosive limits the gas is not as efficient and therefore not as flammable, (less energy & force).

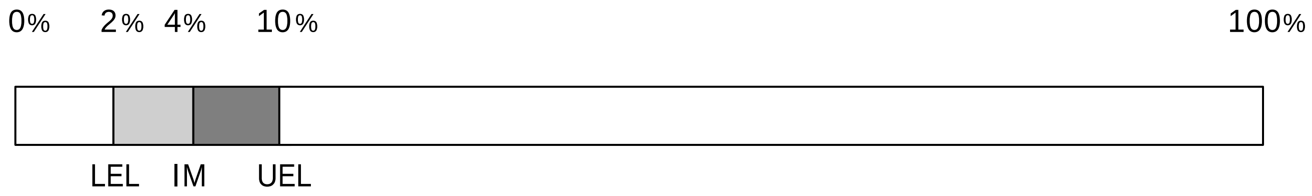
So using Propane as an example, we can add the intensity of the flammable range to a graph, which would show the following: -



Different gases have different ideal mixtures, different flammable ranges and will ignite with different levels of intensity and temperatures, e.g.

On a scale from 0 – 100% the flammable range for any gas can be marked.

Propane



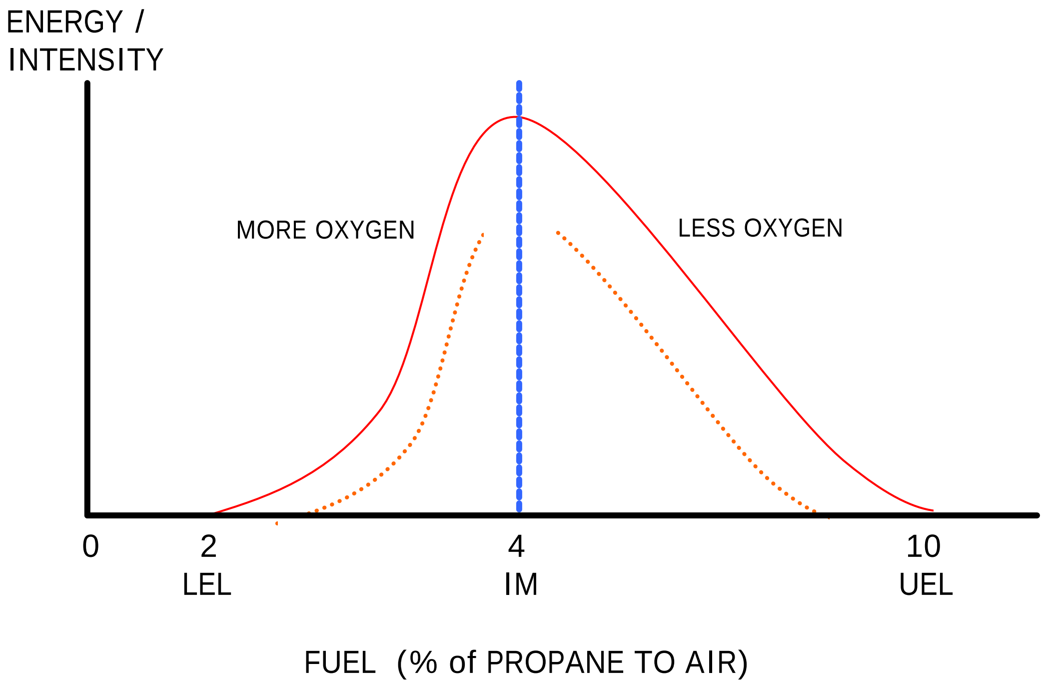
Carbon Monoxide

Hydrogen

Acetylene

All the above examples of a particular gas show their flammable ranges without the effect of passives i.e a “clean burn”/ “reaction”.

As prevoiusly mentioned, passives will effect the combustion process. If we now look at the graph showing the flammable range for Propane, you can see that with the introduction of passives, the reaction and flammability range of the gas decrease, thus the energy/intensity will also be less, therefore the combustion process is said to be an “unclean burn”.



——— = Clean burn example. No passives present.

------- = Unclean burn example. Passives present.

2.7 SUMMARY

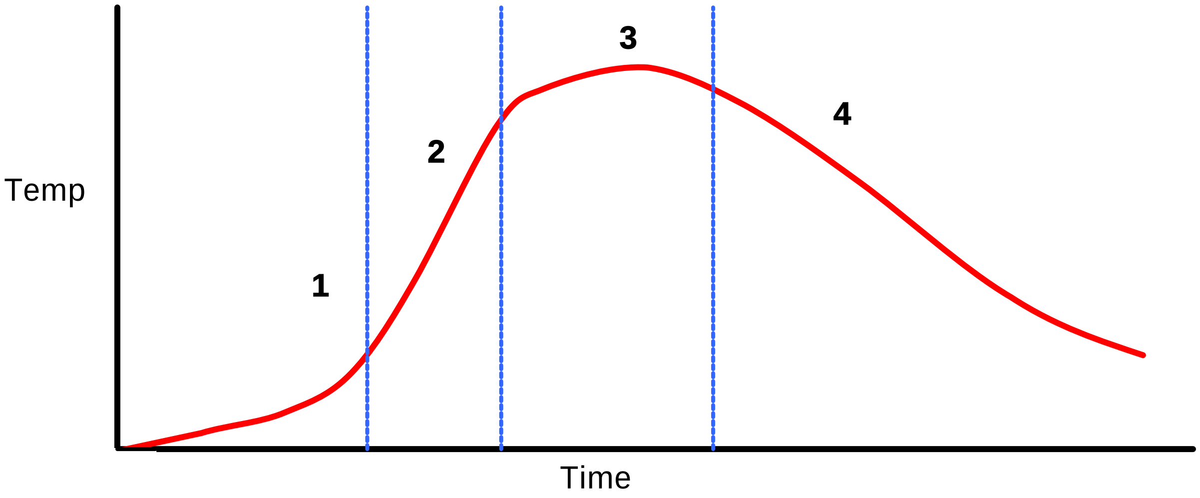
If a compartment contains a flammable gas, with air, plus an ignition source, it will only ignite providing the gas/gases are within their flammable range/ranges (i.e. between the LEL and the UEL).

A simple comparison can be made with a car's engine. Consider if you will a carburettor that is providing insufficient fuel to the engine, i.e. the mixture of gases is too lean. At the opposite end of the scale too much fuel being fed into the carburettor will cause the engine to flood. Therefore the mixture of gases would be too rich. If the carburettor is functioning correctly an ideal mixture will be achieved and the intensity of the reaction will be at its maximum.

This is often why in winter months when the engine is cold it is often difficult to start, this can be due to the cold weather acting as a passive, absorbing the reaction (energy) of the fuel with the spark plugs. Thus if the engine is warm or preheated by the sun, the reaction is often quicker when starting the engine.

SECTION III - FIRE DEVELOPMENT

3.1 FIRE PROGRESSION



The progression of a fire within a compartment can be divided into four phases using the above graph.

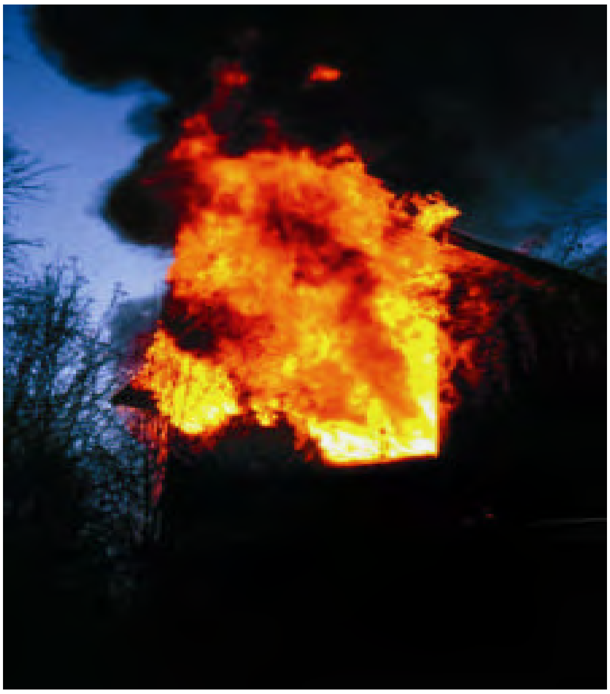
3.1.1 1st phase can be referred to as "Early Stage"

This is where the fire is initially developing at a relatively slow rate but the rate of development increases with time. Without this stage the fire could not develop to the 2nd phase.

3.1.2 2nd phase is the "Flashover Stage"

This is a transitionary phase, which leads to the 3rd phase.

3.1.3 3rd phase is a "Fully Developed Fire"



Which depending on the fuel within the compartment lead to the 4th phase.

3.1.4 4th phase is the "Decay Stage"

This is where the fire will gradually die back as the fuel is consumed

3.2 FIRE DEVELOPMENT

3.2.1 Insufficient Fuel

If the initial fire has insufficient fuel then it will die out and not reach the next stage.

3.2.2 Airtight Compartment

If the compartment is airtight, the fire will die out when all the oxygen has been used up, and the passives will disrupt any firegrowth.

3.2.3 Smouldering Fire

If the initial fire is a smouldering fire, it will have insufficient energy to ignite and flashover. It will eventually move to a too rich mixture. If the smouldering fire develops or is stirred up by Firefighters, it will then be able to provide an ignition source when the mixture in the compartment is in its flammable range.

3.3 FLASHOVER

ISO Definition:
(International Standards Organisation – ISO 1990)

"THE RAPID TRANSISTION TO A STATE OF TOTAL SURFACE INVOLVEMENT IN A FIRE OF COMBUSTIBLE MATERIALS WITHIN AN ENCLOSURE"

British definition:
(Fire Service Manual Volume 2 – Fire service Operations)

"IN A COMPARTMENT FIRE THERE CAN COME A STAGE WHERE THE TOTAL THERMAL RADIATION FROM THE FIRE PLUME, HOT GASES AND HOT COMPARTMENT BOUNDARIES CAUSES THE GENERATION OF FLAMMABLE PRODUCTS OF PYROLYSIS FROM ALL EXPOSED COMBUSTIBLE SURFACES WITHIN THE COMPARTMENT. GIVEN A SOURCE OF IGNITION, THIS WILL RESULT IN THE **SUDDEN AND SUSTAINED TRANSITION** OF A GROWING FIRE TO A FULLY DEVELOPED FIRE."

These definitions basically mean that as a fire in a compartment grows, fire gases from the fire collect under the ceiling. The temperature in the compartment will rise due to the radiated heat from the fire, $^{2}/_{3}$ rds of this radiated heat will be retained and directed downwards from the neutral plane, increasing the production of gases by pyrolysis. There will then come a stage when all the gases produced by pyrolysis will ignite.

Flashover is said to have occurred, when the total heat being produced from within the compartment, furthest away from the point of origin, is Yielding 25 kilowatts per metre squared (25 kw/m^2).

3.3.1 Flashover at Incidents

Once a flashover has occurred either ventilation (oxygen supply) or the remaining fuel (contents and structure) will control it. If either of these is exhausted or not available the fire will die out.

Once there is an opening to the compartment, it develops into a fire controlled by fuel and ventilation. A fire will remain at this stage if the opening is about the size of a doorway. If the opening is increased to the size of a complete wall or shop front, then it is possible to move to a fire controlled by fuel only.

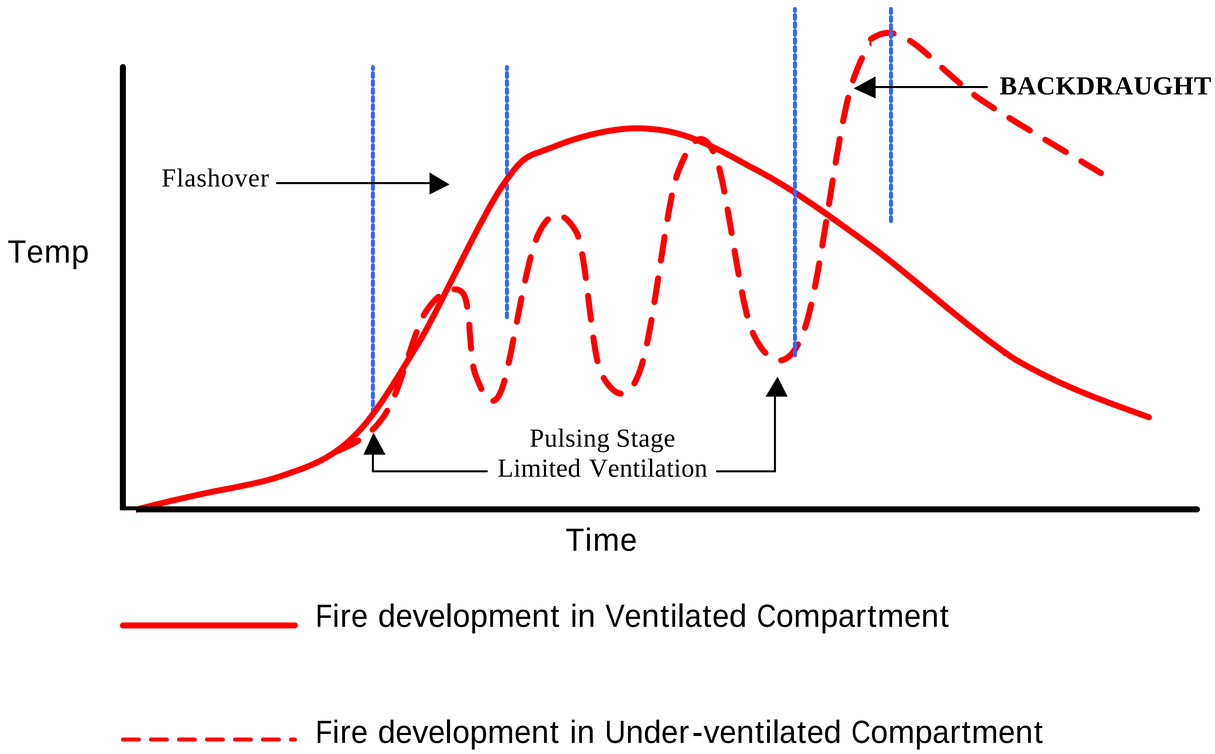
In large compartments the initial fire will not always develop into a flashover. This is due to fire gases being cooled as they rise up to the higher ceiling levels, thus moving away from the fire. The structure (steel, concrete) acts as a passive, cooling them when they reach the ceiling. This cooling will take the fire gases out of their flammable range, thus preventing them from igniting.

3.4 BACKDRAUGHT

Definition:
(Fire Service Manual Volume 2 – Fire service Operations)

"LIMITED VENTILATION CAN LEAD TO A FIRE IN A COMPARTMENT PRODUCING FIRE GASES CONTAINING SIGNIFICANT PROPORTIONS OF PARTIAL COMBUSTION PRODUCTS AND UNBURNT PYROLYSIS PRODUCTS. IF THESE ACCUMULATE THEN THE ADMISSION OF AIR WHEN AN OPENING IS MADE TO THE COMPARTMENT CAN LEAD TO A SUDDEN DEFLAGRATION. THIS DEFLAGRATION MOVING THROUGH THE COMPARTMENT AND OUT OF THE OPENING IS KNOWN AS A BACKDRAUGHT."

As the fire develops, with an adequate supply of air, the combustion process will continue to develop and grow so long as there is fuel available. But should the air supply to the compartment become restricted, the oxygen within the compartment will be consumed quicker than it can be replaced. This will cause a progressive lowering of the concentration of oxygen in the fire gases inside the compartment. This will initially cause an increase in the temperature of the compartment. As the oxygen reduces, this will then cause the radiated heat from the fire plume to reduce and the flames will start to die down. However this will not result in the reduction of flammable gases being produced and distributed throughout the compartment until the temperature has decreased. Should an opening be made to the compartment, this will allow a fresher supply of air to enter and mix with the fire gases, thus forming an explosive mixture.



3.5 FIRE GAS EXPLOSION

Whilst it is clear that flashovers and backdraught are two separate events there are further situations where ignitions of the fire gases within a compartment can occur. These additional 'events' may not necessarily conform to any of the above definitions but will present a similar outcome in terms of rapid-fire propagation. It is important for the Firefighter to have a basic understanding of all events that may lead to such ignitions under varying conditions within a fire involved structure.

a) The formation of variable-sized flammable fire gases may occur within the confines of a building. These may exist in the fire compartment itself, or in adjacent compartments, entrance hallways and corridors. They may also travel some distance from the fire source into structural voids or roof spaces. The **addition of air and/or a heat source is not a requirement for ignition** of these gases, which have already formed into an ideal pre-mixed state, simply awaiting an ignition source. Should an ignition source present itself, then the resulting deflagration will be likened to that of a backdraught but in real terms a smoke explosion or fire-gas Explosion.

b) A further ignition of heated fire gases may occur where they mix with air as they exit the compartment. This can occur at a window or doorway and the resulting fire may burn back into the compartment through the gas layers, similar to a flashback within a Bunsen burner.

Although it can be hard to differentiate between a fire gas explosion and a backdraught, there are 3 main reasons why fires gas explosions are different:

Conduction

Heat can be conducted from the fire compartment to other compartments. This can cause other materials to breakdown and produce pyrolysis within other compartments, which are not affected by the fire itself.

Leakage

There can be a leakage of fire gases from the compartment that is on fire through various voids, cavities and ducting to other compartments, which can over a period of time build up in greater quantities.

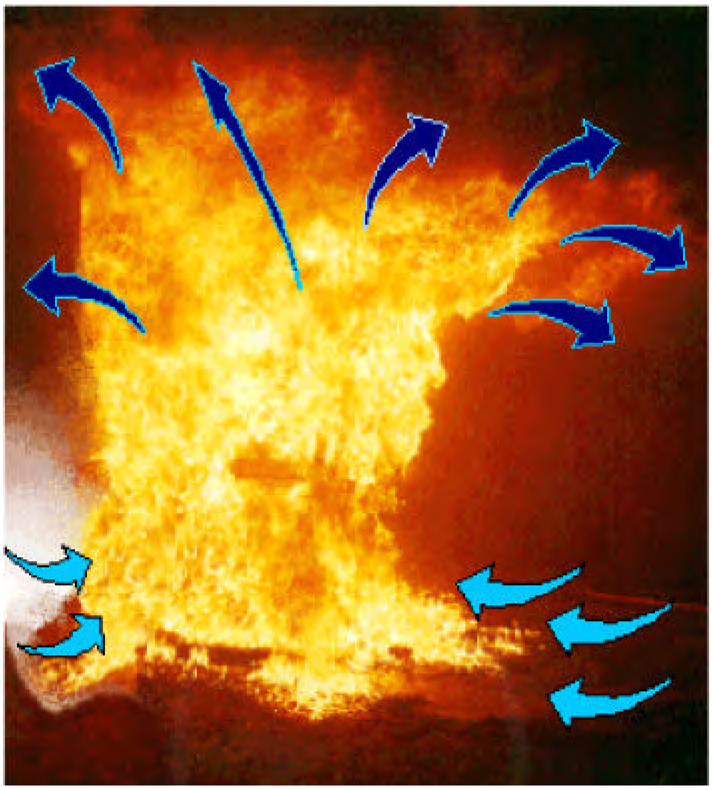
Construction

The construction of the premise will influence the possibility of a fire gas explosion, not only due the leakage as above, but also from smouldering combustion caused by the radiated heat from the fire. This smouldering combustion could be concealed within, for example, a sandwich panel if this is not detected, fire gases will be allowed to generate unchecked.

It must also be remembered that it is rare for a fire gas explosion to occur in the compartment where the fire initially starts.

SECTION IV - FIRE EXTINGUISHMENT

When a fire develops inside a compartment two separate layers will appear.



The upper layer will contain the products of the fire (fire gases) and the lower layer will contain the remaining air in the room. Separating these two layers is the neutral plane.

As the fire develops the pressure in the upper layer, called "The over-pressure, will be increasing due to the temperature rising and the production of gases from combustion and pyrolysis.

In the lower layer the pressure will be decreasing. This is called "The under-pressure". As the remaining air in the compartment is being used up, air will start to be drawn to the fire from outside of the compartment. This will cause an "Air tract" which will increase as the intensity of the fire increases.

4.1 EXTINGUISHING WITH WATER

Water is an ideal extinguishing medium as it is readily available and when applied to a fire it attacks all sides of the triangle of fire i.e.

Reduces FUEL The rapid expansion of water to steam dilutes the flammable gases. Reduces further production of flammable gases by Pyrolysis, because of the reduction in heat. The expansion of water to steam drives out some of the existing fire gases.

Reduces HEAT Absorbs heat when turning water into steam.

Reduces OXYGEN The steam limits the amount of oxygen reaching the fire by smothering.

When water turns to steam it expands in volume by 1:1700 @ 100°C. If the temperature is raised to 450°C the steam will double in expansion i.e. 1:3500.

80% of the fires energy will be absorbed by the transformation of the water from a liquid to a gas state.

So for example, if you applied a litre of water to a fire producing a temperature of 450 °C, it would take 80% of that heat to produce 3500 litres of steam.

4.2 EXTINGUISHING METHODS

Extinguishing methods can be grouped under three main headings:

1. Indirect;
2. Direct; and
3. Gas Cooling

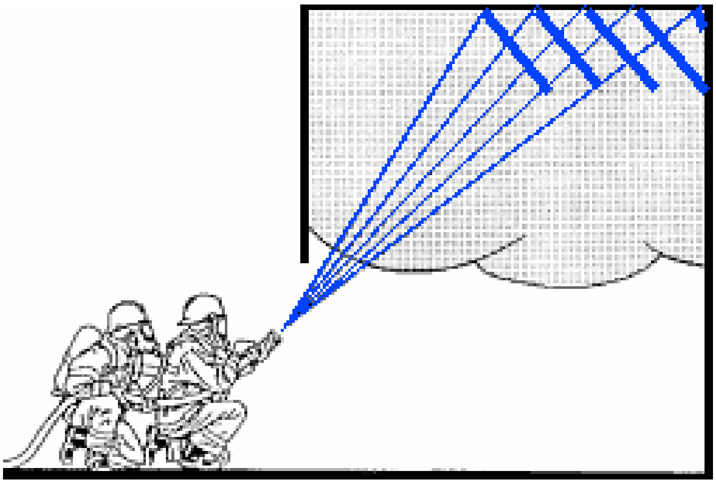
4.2.1 Indirect (Defensive)

Purpose

A fire can be extinguished by directing the water up into the compartment to produce steam and create an over-pressure which will keep out the air and smother the fire.
This method should only be used from out side when there are no casualties inside the compartment.

Branch Settings

Medium spray aimed above and around the fire. Branch must be moved around to ensure maximum coverage.



Effect

Cools and dilutes the fire gases. Cools structure of compartment. Large quantifies of steam produced has a smothering effect on the fire. Lowers neutral plane, reducing vision and worsening conditions for Firefighters and Casualties.
Should only applied from out side of the compartment due to the quantities of steam produced

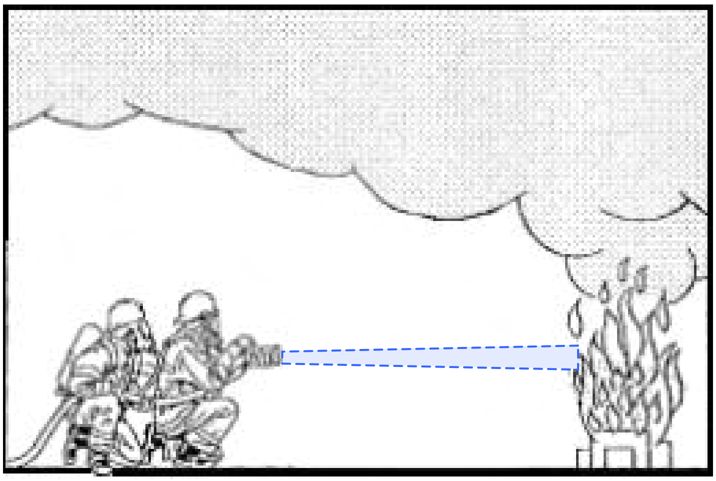
4.2.2 Direct

Purpose

Must be applied in the early stages of the fire or when the fire is out.
Used directly on the seat of the fire.

Branch Settings

Jet/narrow spray aimed directly at the fire.



Effect

Extinguish fire. Possible water damage. Entrains air into compartment, intensifying the fire if not correctly used. Worsens conditions for Firefighters and Casualties.

4.3 GAS COOLING (OFFENSIVE)

The use of Gas cooling (also termed three-dimensional (3D), water-fog or 'offensive' techniques) during gaseous-phase suppression of structural fires is a recent and innovative approach.
It should be made clear that such applications are used - not (solely) to extinguish fires - but mainly t**o make 'safe' the approach route to the fire and reduce the likelihood of Flashovers - Backdraught and Fire Gas Explosions** etc.

These techniques are not designed to replace the 'direct' style of fire attack utilising the water in a manner as previously described but moreover, to complement existing forms of fire attack in an effort to increase the safety and effectiveness of firefighting teams.

The 'Gas cooling' approach, when used as a Firefighting tool, places the water-fog directly into the heated fire gases, using short rapid bursts to place the least amount of water into the over-pressure. This water will then evaporate in the gases, leaving an 'extinguishing tract' but should not make contact with the heated surfaces such as walls and ceiling, thus producing steam. This cooling effect will cause **the fire gases to contract greater than the water can expand**, and in doing so the fire gases will shrink and move away from the Firefighters operating the branch. This, in effect, causes a negative pressure within the fire compartment and Firefighters are not burned by expansion of steam, thus also increasing the survivability rate for casualties.

This effect is achieved by resorting to specific branches and by selecting the ideal angles and pattern diameters at the branch that will produce a **droplet size not exceeding 0.3mm in diameter.**

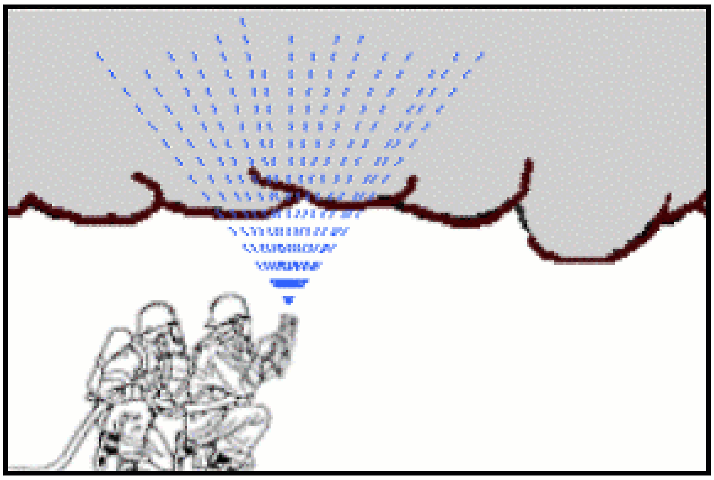
There are basically two different '**pulsing techniques'**:

1. Short Pulse;
2. Long Pulse.

A third technique, which is also used with Gas cooling, but is not a pulsing technique. This is an adaptation of the direct method, but is used with more control and direction. This technique is termed;

3. Painting.

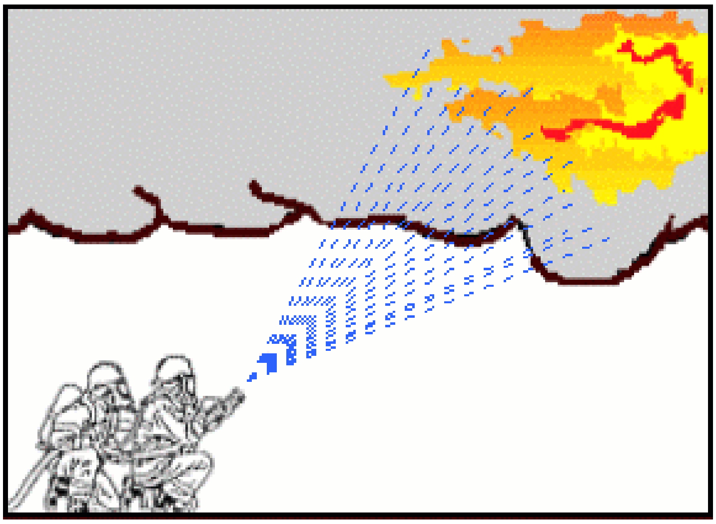
4.3.1 Short Pulse



Branch Settings
Medium/wide spray.
Using very short pulses.
Aimed directly above the Firefighters into the over-pressure.

Effect
To cool and dilute the flammable gases thereby preventing the fire gases from reaching their auto ignition temperature.

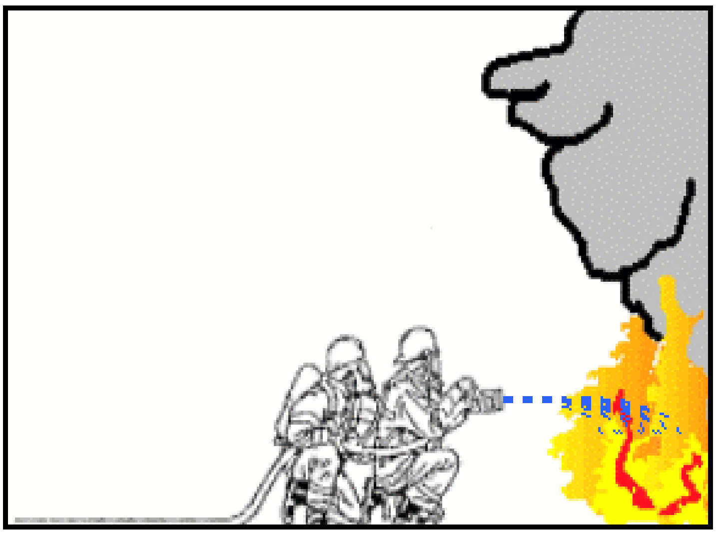
4.3.2 Long Pulse



Branch Settings
Medium spray.
Using longer pulses, depending on penetration required.
Aimed directly into the over-pressure at the ignited fire gases.

Effect
To cool and dilute the flaming combustion, thus allowing Firefighters to penetrate deeper into the compartment

4.3.3 Painting



Branch Settings
Small trickles of water.
Using the least amount of water as possible, depending on penetration required.
Aimed directly onto all combustible substances and materials.

Effect
To cool all combustible materials and substances, thus preventing decomposition that causes fire gases to be produced (pyrolysis).

4.4 EFFECTIVE USE OF WATER

To extinguish a fire, Breathing Apparatus wearers must maintain a fine balance between small quantities of water to keep steam produced to a minimum but use sufficient water to extinguish the fire.

Too much water produces large quantifies of steam, pushing down the neutral plane and deteriorating the conditions for Firefighters by reducing vision, increasing exposure to steam and rising temperatures.

To cool and dilute the maximum amount of gases with the minimum amount of water, remembering that the droplet size from the branch must be kept as small as possible, thereby increasing the amount of surface area of water available for cooling.

If the small droplets are applied in short pulsations, it will provide rapid cooling and dilution of the surrounding hot fire gases. Producing the minimum amount of steam, thereby ensuring conditions inside the compartment are as workable and safe as possible, not only for the Firefighters but casualties as well.

In addition to the quantity of water used, the place the water is directed is also important. If the water is all over the floor it is not being effective, therefore the water should be directed into the gas layer where it can be of most benefit.

4.5 SUMMARY

Although two of the methods for firefighting have been described as indirect and gas cooling, practically Firefighters will use a combination of the two methods. They may decide to use a medium spray with very short pulsations or a narrower with spray with longer pulsations.

Factors dictating the Flow Rate of the branch:-

- THE COMPARTMENT SIZE.
- THE CONTENTS OF THE COMPARTMENT.
- DO CASUALTIES NEED RESCUING.
- THE EXTENT OF THE FIRE.
- TYPE AND SIZE OF HOSE

REMEMBER FIRE IS AN EXOTHERMIC REACTION SO WHEN IGNITION TEMPERATURE AND BURNING TEMPERATURE ARE EQUAL THEN THE FIRE IS EXTINGUISHED

SECTION V – FLASHOVER AND BACKDRAUGHT AT INCIDENTS

Before entering any compartment, Firefighters need to decide if it is safe to enter. If and when the Firefighters enter a compartment, the following will aid them in recognising that a flashover or Backdraught conditions are present.

5.1 SIGNS AND SYMPTOMS OF FLASHOVER

- **VENTILATED FIRE**
- **PAINFUL RADIANT HEAT**
- **CREWS FORCED LOW BY HIGH TEMPERATURES**
- **HOT SURFACES**
- **FLAMES AT CEILING LEVEL**
- **LOWERING OF NEUTRAL PLANE**
- **INCREASED RATE OF PYROLYSIS.**
- **INCREASED TURBULENCE OF THE NEUTRAL PLANE***

*****An increase in the speed and/or turbulence of the gases indicates that the situation is moving rapidly towards Flashover. A Billowing Effect from the gases might be seen.

5.2 SIGNS AND SYMPTOMS OF BACKDRAUGHT

Firefighters need to recognise conditions where a backdraught might be present. The most important factor to determine this is the **HISTORY OF THE FIRE**. Examples of this might include: How long had the fire been burning; or what sorts of materials were involved.

Other Signs and symptoms are:

- **FIRE WITH LIMITED or NO VENTILATION**
- **THICK BLACK, YELLOW and/or COLD SMOKE**
- **BLUE FLAMES**
- **HOT DOORS AND WINDOWS**
- **SOOT BLACKENED WINDOWS**
- **LACK OF A VISIBLE FLAME**
- **AIR BEING DRAWN IN (WHISTLING NOISE)**
- **SMOKE PULSATING through small Gaps in openings**

5.3 GENERAL PRINCIPLES AT INCIDENTS

When Firefighters are inside a compartment they should always consider the following three options:-

Maintain position	Protect their position using gas cooling.
Move forward	Attack fire gases using gas cooling with short or long pulsations.
Withdraw	If conditions deteriorate withdraw protecting themselves using gas Cooling, and consider an attack from the doorway or use a larger diameter hose.

Firefighters should try to use the minimum amount of water as effectively as possible, ensuring the neutral plane is kept as high as possible, whilst cooling and diluting the maximum amount of fire gases in the over-pressure.

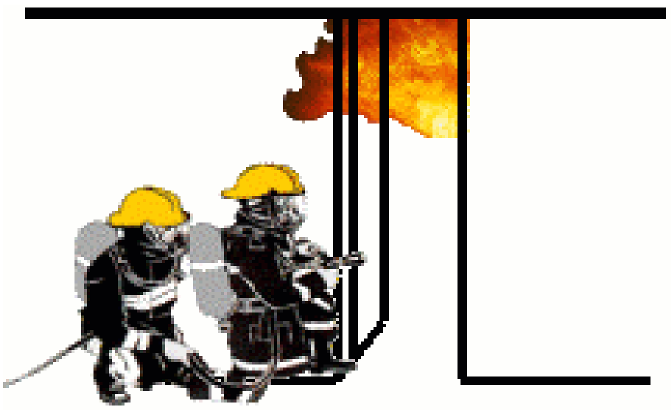
If the gas cooling method is applied correctly then the fire gases will be diluted and cooled sufficiently to take them out of their flammable range.

Using the Painting technique to "PAINT" hot surfaces with water will cool surfaces and prevents further production of flammable fire gases caused by pyrolysis.

5.3.1 Door Procedures

Use the protection of doors and walls, keeping low at all times.

Remember the walls will be stronger than the doors and will give more protection prior to entry, therefore where possible use the wall as protection rather than the door.



Opening & Entry Procedure.

- Before Firefighters gain entry to the compartment they should ensure that a good assessment has been carried out of the conditions outside, looking for the signs and symptoms of flashover and backdraught.
- Assess which way the door opens and ensure that Firefighters are to the safest side should a sudden deflagration occur, then the force of the door opening would not injure them.
- Using the branch on a narrow spray setting, spray a small amount of water up into the gap between the door opening and the door trim. If in an adjoining compartment, hallway or corridor this action may prevent the heated fire gases igniting as they exit to fresher air.

Opening & Entry Procedure Continued.

- Upon opening the door, ensuring that they have control of the door at all times, Firefighters should have a quick glance into the compartment observing, the condition, layout of the room and any casualties within the vicinity. If Firefighters are unable to enter, then either a short or long pulse dependant on the situation that presents itself should be directed into the compartment, closing the door as soon as possible after this has been completed.

- This action can be repeated as many times as required until entry into the compartment can be made.

- Upon entering the compartment, Firefighters should ensure that they move out of the doors threshold observing the fire gases at all times. A temperature check should be made utilising a 'short pulse' directed above their heads to test the temperature of the fire gases.

- This should be followed immediately by discharging further pulses into the over-pressure using 'short' and 'long pulses' as required by the conditions.

- Each pulse should be directed into a different position within the over-pressure, thus gaining the maximum cooling effect on the fire gases using the least amount of water, but avoiding a 'sweeping action'.

- The branch operator must strike a fine balance between placing an adequate amount of water-fog into the over-pressure but avoid over-drenching. This can only be achieved by reading each situation as it evolves.

- These procedures should be repeated thus allowing the Firefighters to advance deeper into the compartment.

- If a clear layer of visibility exists below the neutral plane near floor level, this can be maintained by pulsing the hot fire gases at the same time as avoiding water contact with for example, hot surfaces which would produce steam.

- This clear layer can then be utilised for the location of both the fire and any casualties that might be within the compartment.

- By maintaining the 'thermal balance' in this way, and cooling and diluting the fire gases in the over-pressure, the compartment will become noticeable cooler and the likelihood of any fire gas ignitions is considerable reduced.

Some European Firefighters, especially those in Sweden, prefer to partially close the compartment door behind them as they enter – they call this 'anti-ventilation'. The basis for such an action is to maintain 'air control', restricting the amount of air feeding the fire.
The Firefighting crew will constantly evaluate conditions with the compartment and take into account any effect the size of the opening has on the fire's development. This opening can be enlarged or reduced at any stage of the firefighting operation to influence conditions such as -

1. The height of the smoke layer interface;
2. The amounts of heat radiating down from the ceiling;
3. The intensity of the fire;
4. The direction of the fire plume at ceiling level;
5. The temperature within the compartment.

5.3.2 Temperature Check

Firefighters must carry out a temperature check upon entering the compartment.

A short pulsation is aimed directly above the Firefighters head into the over-pressure, looking and listening for any signs of water falling back onto them, this will indicate weather the immediate area above them is cool enough to advance further into the compartment.

5.3.3 Moving Between Compartments

When Firefighters enter a building they must ensure the fire in the compartment they are moving towards will not ignite the fire gases that have leaked into the compartment they are moving from (escape route).

This can be achieved by either:-

1. Cooling and diluting (taking fire gases out of their auto ignition range)
2. Venting the fire gases to outside.

5.3.4 Fire Gas Observations

When inside a compartment Firefighters must keep a constant check on their surroundings, particularly the fire gases at Ceiling level:-

The team leader will check above and in front.
The other team member will check above and behind.
Constant communication between the team is essential to ensure safe and progressive movement throughout the compartment.

5.3.5 Considerations At An Incident

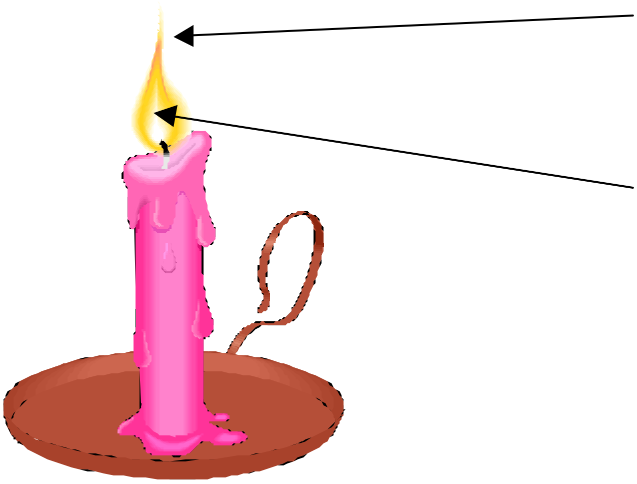
1. Observe building for size, construction, and possible contents.
2. Look for possible signs and symptoms of Flashover OR backdraught.
3. Check branch settings.
4. Consider larger diameter hose if required.
5. Layout a charged 45mm hose and hand controlled branch as backup.
6. Use correct door entry procedures as described previously.
7. Upon entering the compartment carry out "Temperature check".
8. Secure position using gas cooling, advance when safe, using appropriate gas cooling techniques.
9. Observe fire gases at ceiling level, in front, above, and behind at all times.
10. Ensure constant communication with all members of the team.
11. Continue advancing through compartment using the principles laid down in points 8 to 10.
12. Paint water onto the base of the fire using the direct method. Cool all surfaces to prevent further gases being given off. If conditions deteriorate then the Firefighters should withdraw, observing the fire as they retreat and protecting themselves by gas cooling.
13. When rescuing casualties the gas cooling method is used to keep the neutral plane as high as possible, thereby increasing their changes of survival from fire gas and steam burns. This method is purely used to protect Firefighters to enable them to advance and locate casualties and withdraw. Firefighters can then re-enter to attack the fire gases and extinguish the fire.
14. When more than one compartment is involved, procedures outlined above can be used as Firefighters move through each compartment. They must ensure a compartment is safe before entering the next compartment, using the principles laid down in points 2 to 10.

SECTION VI – LECTURE ROOM EXPERIMENTS

This section has been added to this aide memoire to assist Instructors who have successfully completed a Fire Behaviour Instructors Course.

The following examples are there to aid the instructor in the delivery of theoretical input of fire behaviour to students.

6.1 CANDLE AND MESH



Applying the mesh to the top of the flame.
Result = Lots of soot is produced because the flame is colder, will be redder in colour

Applying the mesh just above the wick.
Result = small amount of soot produced because the flame is hotter, will be whiter in colour

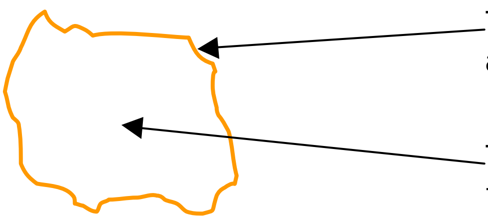
Getting the students to use the mesh while it is still cold and applying it to the areas as shown will enable the instructor to show what effect a passive (the mesh) will have on the flame.

When the mesh has been warmed up, apply the mesh to the flame so that soot (flammable gas) is produced. Now use an ignition source to ignite the soot thus proving that the gases given off are flammable

There should be a clear distinguishable gap between the candle flame and the flame being produced above the mesh

6.1.1 Above The Candle

If we use the simple diagram below to represent looking at the flame from above with the mesh applied to the flame the student will be able to see a hole in the middle of the flame.

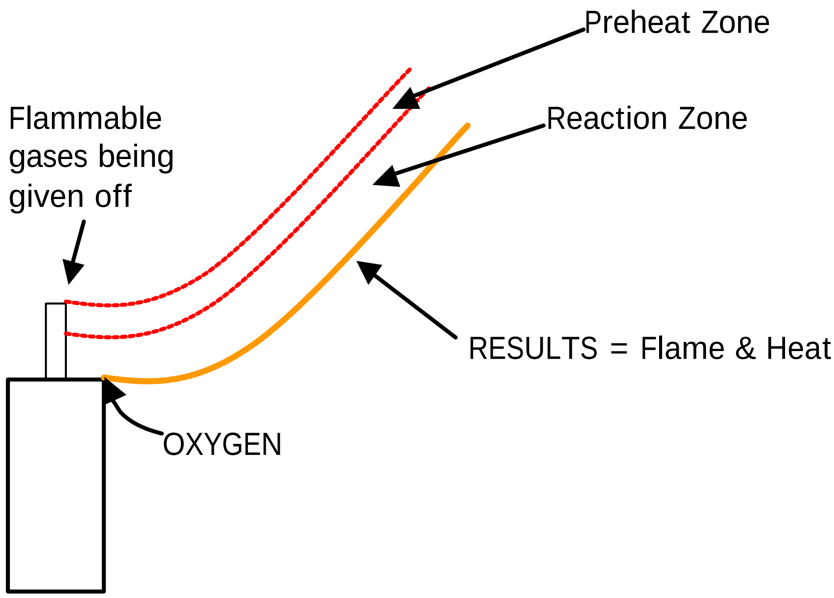


The outside edge of the flame when the mesh is applied from above.

The middle of the flame has a clear hole where the combustible gases being produced by the wax are not reacting.

This will show the student that the wick of the candle is not burning, but being used as the apparatus to draw up the gases being produced by the melting wax. These flammable gases will be preheated as they expand and mix with air in the reaction zone to produce flame and heat.

The candle will burn at about 700 – 800^{o}C. But the more passives present, the lower the temperature of the flame.



6.2 PEN KNIFE AND FLAME

Using a cold penknife and a candle can show the effect of passives on the flame.

Try to split the candle flame in half. The student will notice that the flame is not only deflected away from the knife, but also decreases in size. As the flame heats up the knife (diminishing the passives), the flame is drawn back towards the knife and increases in height along with change in colour.

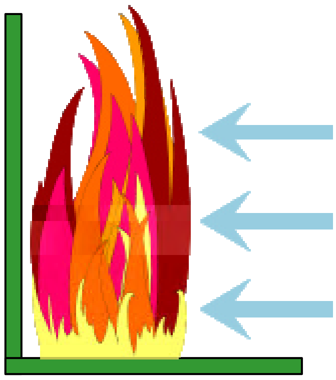
6.3. EFFECTS OF WALLS AND CEILINGS ON A FLAME

If the fire is in certain postion within a compartment it will behave in diffent ways depending on what passives are present, but basically the following can be said:

6.3.1 In The Centre of A Compartment

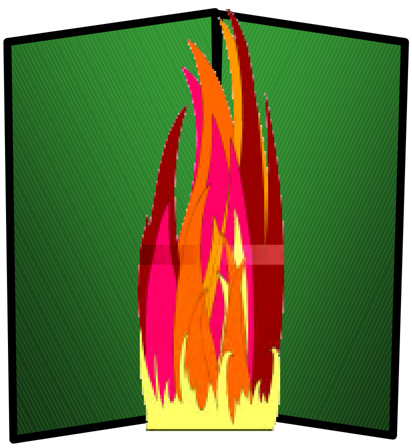
Air is being entrained from all side of the compartment.

6.3.2 Against A Side Wall of A Compartment



Air is being entrained from only 50% of the compartment.

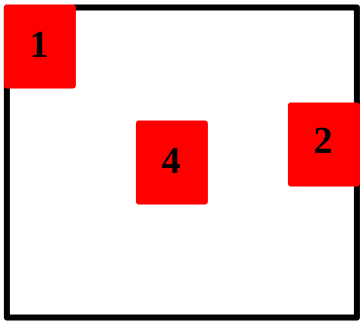
6.3.3 In A Corner of A Compartment



Air is being entrained from only 25% of the compartment.

6.4 FLASHOVER RULE OF THUMB

Taking the postion of the fire into account can give you a very basic rule of thumb about how quick flashover will be achieved



In the corner of a room, the flame height is the tallest and the velocity is faster due to less oxygen available

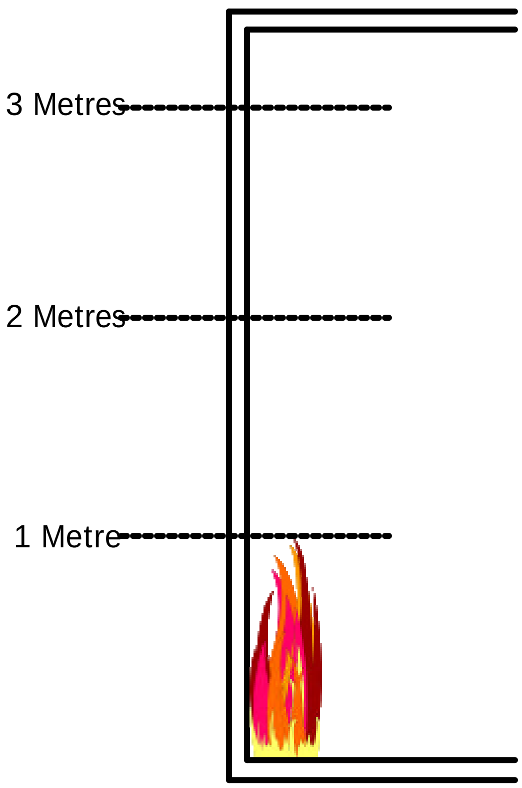
Therefore

If flashover were to occur in 4 minutes in the corner of a Compartment.
It will take 8 minutes to occur if the fire was on a side wall and 16 minutes to occur if the fire was in the centre of a compartment

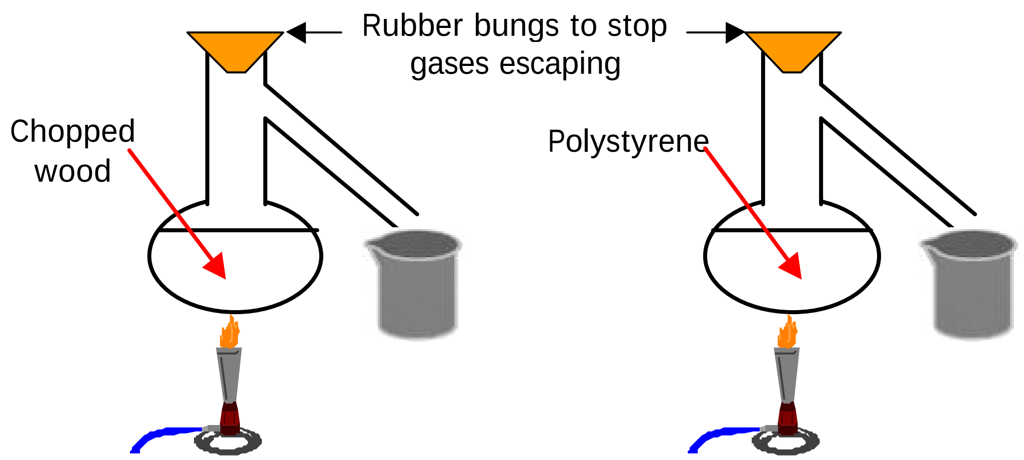
6.5 FLAME HEIGHT RULE OF THUMB

If a fire is in a corner of a compartment then the height of that flame will double in size for every minute that it is burning.

Example.
After 1 minute the flame will approximately reach 1 metre in height.
After 2 minutes the flame will approximately reach 2 metres in height
This will continue until the flame reaches the ceiling of the compartment



6.6 SMOKE DOES BURN



Using Bunsen burners heat the chopped wood and the Polystyrene, wait until the substances start to decompose and give off flammable gases. This will take a little while due to the passives present within each substance.

Once this occurs, using an ignition source ignite the gases coming out of the tube and take away the Bunsen burners. This will show to the student that the smoke being produced is flammable and that even when the heat is taken away, pyrolysis is still being produced.

After that, apply the heat once more and now collect the flammable gases the beakers. Using an ignition source ignite the gases in the beaker, showing them a small Fire gas explosion

The Wood will break down and decompose in the following order:

1. Water (usually between 30 – 50 % content)
2. ALCOHOL (Methanol)
3. Turpentine
4. CELLULOSE
5. TAR

All these substances will act as passives and will therefore inhibit the combustion process until they are burned off.

In this experiment, you are proving to the student that the gases produced, will burn and will continue to burn, even when the flame is taken away. This is due to the residual heat left within the tubes causing pyrolysis to continue.

It also shows to the student that they cannot rely on how combustible the substance is or what is actually burning from just from the colour of the gases being produced.

SECTION VII – FIRE BEHAVIOUR POEMS

7.1 FLASHOVER BACKDRAUGHT AND FIRE GAS EXPLOSION POEMS

Finally, we would like to add 3 poems that we written by Leading Firefighter P0 ODLIN 292, from Lincoln Fire service. Po successfully attended a Fire Behaviour Instructors course in April 2001 and although the poems were not intended for inclusion in this note, we're sure that you'll not only find them of interest, but also they sum up quite well, the phenomena that is Fire Behaviour.

7.1.1 Flashover Poem

FLASHOVER

BLISTERING PAINT AND DOORS, HOT TO TOUCH.
BEING IN THERE, I WON'T LIKE MUCH.

BUT I HAVE GUIDES, MY EYES AND EARS.
USE THEM WELL AND I'LL HAVE NO FEARS.

IT WILL BE HOT AND I'LL FEEL THE HEAT.
AND I MAY END UP AS LOW AS MY FEET.
THE NEUTRAL PLANE SHE WILL COME DOWN.
BRINGING TONGUES OF FLAME, SMOKE GOLDEN BROWN.
PYROLYSATION WILL INCREASE, IT WILL GET HOT.
BUT I KNOW THE SIGNS, THERE'S NOT SUCH A LOT.

INTO THE GAS LAYER, SPRAY PULSES LONG AND SHORT.
CAUSE IN A FLASHOVER I DON'T WANT TO BE CAUGHT.
WITH A LITTLE SPRAY I WILL TAME THIS BEAST.
AS I DON'T WANT TO END IN A BOX DECEASED.

JUST USE MY SKILLS AND THINK WITH MY HEAD.
AND THE FIRE IS THE ONE THAT WILL END UP DEAD!!

7.1.2 Backdraught Poem

BACKDRAUGHT

AS WE ROLL UP, THERE ARE SIGNS WE CAN SEE.
WE MUST ALL LEARN TO RECOGNISE, BOTH YOU AND ME.
WINDOWS MAY BE COVERED WITH AN OILY BLACK
AND SMOKE WILL PULSATE FROM THE SMALLEST CRACK.

FIRES THAT ARE ENCLOSED, YOU MUST TREAT WITH CARE.
THE CHANCE OF A BACKDRAUGHT, IT HAS TO BE FAIR.
WHEN THE SMOKE IS DENSE WITH NO FLAMES IN SIGHT.
THEN IT'S POSSIBLE THAT CONDITIONS ARE RIGHT.

HOT DOORS AND THEIR HANDLES ARE ANOTHER GOOD CHECK.
COVER YOUR FLESH FROM YOUR FEET TO YOUR NECK.
IF BEFORE YOU ENTER, ALL THESE THINGS YOU OBSERVE
YOU WILL ENTER THE COMPARTMENT AND HOLD YOUR NERVE.

IS IT SAFE TO GO IN, YOU MUST HAVE NO DOUBT.
CAUSE WHEN AIR GOES IN, A FIREBALL CAN COME OUT.
BLUE FLAMES MAY APPEAR, BLACK YELLOW OR WHITE SMOKE.
THE COLOURS ARE PRETTY, BUT THEY ARE NO JOKE.

IF SMOKE GETS DRAWN BACK AND THE ROOM BECOMES CLEAR.
THEN TAKE IT FROM ME YOUR END IS NEAR.
IF IT WHISTLES AND ROARS AND YOU'RE STILL AROUND.
I'LL COME TO YOUR FUNERAL AS YOU GO IN THE GROUND.

THE SIGNS ARE THERE FOR US ALL TO READ.
THE LOSS OF A COLLEAGUE WE DO NOT NEED.
IF PEOPLE AREN'T TRAPPED IN THESE SITUATIONS, WE HATE,
THEN LET'S STAND BACK TO SQUIRT AND VENTILATE

7.1.3 Fire Gas Explosion Poem

FIRE GAS EXPLOSION

THE WORST ONE OF ALL, IS THE EXPLODING GAS.
IT WILL FRY YOUR BRAINS AND BLOW OF YOUR ASS.
THE CHANCES OF IT HAPPENING MAY BE RARE.
BUT WE MUST WATCH OUT AND ALWAYS TAKE CARE.

CONTENTS WILL PYROLYSE IN THE ROOM ABOVE.
GASES MIXING WITH AIR, THAT THEY JUST LOVE.
THEY CREATE A GAS THAT'S MIXED JUST RIGHT.
IF IT EXPLODES, IT'S A DEVASTATING SIGHT.

WINDOWS WILL BREAK AND WALLS WILL CRACK.
AND BITS OF YOU WILL BE PUT IN A SACK.
THE CONDITIONS ARE PRESENT, WITH MANY A FIRE
AND IF IT SHOULD BANG THE OUTLOOK IS DIRE.

SO LET'S ALL TAKE CARE AND STOP AND THINK
OF THE MANY FACTORS THAT MAKE UP THE LINK.
LET'S NOT CHARGE IN LIKE A BULL AT A GATE.
BUT STOP AND THINK BEFORE IT'S TO LATE.

THESE WORDS MAY BE HARSH, BUT THE FACTS ARE TRUE.
THEY'RE ONLY SPELT OUT TO HELP ME AND YOU.

SO LET'S ALL KEEP LOOKING AND SPOT THESE SIGNS
AND WE WILL MATURE LIKE ~ GOOD VINTAGE WINE.