HSE
Health and Safety Executive

THE HEAT WITHIN

THE EFFECT OF FIRE IN PRESSURISED TUNNELS

Notes for trainers

INTRODUCTION

These notes are intended to provide you, as the trainer showing the DVD, with additional information on fire in pressurised tunnels, as well as points for discussion with the audience. They complement information provided in *A guide to the Work in Compressed Air Regulations 1996* L96 ISBN 0 7176 1120 5 (available from HSE Books at www.hsebooks.co.uk)

Before giving training, we recommend that you should be familiar with the above guidance, the content of the DVD and these notes. The discussion points in the notes have been combined onto a single sheet at the end for convenience.

The Work in Compressed Air Regulations 1996 require, under regulation 15, that:

> *"The compressed air contractor shall ensure that adequate information, instruction and training has been given to any person who works in compressed air so that he is aware of the risks arising from such work and the precautions which should be observed."*

This training and information needs to be comprehensive and cover all health and safety issues associated with compressed air working. Paragraphs 230-234 in the HSE document *A guide to the Work in Compressed Air Regulations* (L96) give advice on training and list the basic topics which should be covered in any training programme. As the trainer, you should tailor your programme to the specific requirements of your site.

Paragraph 233 (b and c) specifically mentions the need to provide training on risks to safety from fire and emergency procedures, including fire extinguishers and self-rescuers. This video does not cover all these issues in detail but it is intended to be used as part of a wider training programme which covers the requirements of regulation 15.

The video can be used to demonstrate the effect of compressed air and any raised oxygen concentration on fires involving various materials commonly found in tunnelling. Emphasis is placed on preventing the fire starting in the first place, the overwhelming need for maintaining good standards of housekeeping and the importance of wearing the correct personal protective equipment (PPE). It can also be used to show the effects of fire in non-pressurised tunnels.

OPENING SEQUENCE - FIRES

The fires shown are real incidents filmed by fire brigades in Kent and West Yorkshire. Part of the sequence is of the Channel Tunnel fire which, although not a compressed air fire, graphically demonstrates the conditions which can occur during a tunnel fire. You may wish to draw the attention of those watching the video to the ferocity of the blaze and the cramped and difficult conditions within which the firefighters had to work. They should be reminded that the Channel Tunnel is large in comparison to most tunnels.

In the open-air sequence you may wish to emphasis that, in a building fire, the flames and smoke are able to rise away from the fire source leaving the area relatively close to the fire free from smoke, allowing an area for the firefighters to work from and somewhere for people in the building to escape to. A proportionately smaller fire in a tunnel will generate considerable volumes of smoke which will rapidly fill the much smaller and confined space.

Schematic of tunnel fire

This shows the effect of confining a fire in a tunnel. In comparison with a fire in the open air, you could point out how the smoke and heat rise to the soffit and are then deflected along the length of the tunnel.

The more fuel which is available, the larger the fire will be and the greater the quantity of smoke produced. The fire can only travel along the length of the tunnel as it has nowhere else to go, so it can travel very quickly. The direction of smoke travel can only be controlled by the most sophisticated ventilation systems.

The rate at which the smoke and heat travel along the tunnel will depend on the fire size and the ventilation arrangements. Close to the fire, smoke velocities will be greater but even at some distance from the fire a speed of 4 mph (brisk walking speed) is not uncommon.

Self-rescuer

This is mentioned now because it is essential that this equipment is carried by all people underground. You should remind the audience that if a fire starts, their first action should be to put on the self-rescuer so that they have a source of breathable air.

NOTE: See page 10 'Safety equipment' relating to the effectiveness of self-rescuers in compressed air.

In a fire, the air will rapidly become unbreathable due to the generation of large volumes of thick, hot, toxic smoke (in compressed air, the reduction in the oxygen concentration due to the fire is of secondary concern).

You should know of the limitations in terms of pressure and duration of currently available self-rescuers for use in compressed air. Your Contract Medical Adviser can provide more information on this if required. HSE is currently carrying out research aimed at providing a modified self-rescuer for use in compressed air at all pressures. Oxygen rebreathing sets are toxic at pressures in excess of 1 bar g and should not be used.

Training in the use of the self-rescuer should be included in the course for working in compressed air but is not covered in detail here.

Discussion point

What are your arrangements for ensuring that all workers are trained to use the self-rescuer and have had enough practice?

Fire brigade assistance

It is unlikely that the fire brigade will provide assistance within the compressed air section of your tunnel. All escape and rescue provisions are, therefore, the responsibility of the contractor.

Fire brigades are limited on how far they can go into any (including non-pressurised) tunnel because their breathing apparatus only lasts for a limited time. Because of this, the training for work in compressed air tunnels should take account of the arrangements made between the contractor and the emergency services for the specific site.

Preventing fires starting

You should strongly emphasise the importance of preventing fires starting in the first place, rather than putting them out after they have stated, because they are so unpredictable. You should remind the audience that this is even more critical in compressed air tunnels because materials burn more easily and more fiercely, emergency access is restricted, and rescue and escape from the fire is difficult with the accompanying need for decompression. The bulkhead doors are a particular restriction to access and egress as well as the difficulties from the presence of heat and smoke.

Later in the video the 'fire triangle' (i.e. the three conditions needed for a fire to start) is discussed in some detail (see page 6).

THE EFFECTS OF COMPRESSED AIR ON THE WAY MATERIALS BURN

The next sections use video footage of testing work carried out in a tunnel at the HSE Laboratory in Buxton to demonstrate the effect of compressed air on the way that materials burn.

HSE test facility at Buxton

The tunnel was originally built to investigate coal dust explosions in mines. There is a sequence in the video to show such an explosion – this is only to grab attention and has *nothing to do with work in compressed air*. The existing tunnel was modified for the experiments by the addition of bulkheads and bulkhead doors, instrumentation, and atmosphere pressurisation equipment.

In the paper referred to in the notes (see reference 2) you will find details of the full range of fuels and tunnel pressures used and more details of the test procedures and results.

The range of fuels used in the tests was more extensive than those in the video and included materials such as electric cabling, conveyor belting and liquid fuels such as hydraulic fluids. You may wish to tell the audience that hydraulic oil produced so much smoke that tests on it had to be abandoned. The materials chosen for the video can be found in most tunnels. You should be aware that there may be additional fuel sources in the tunnel. The illustrative fires shown in the video are only intended to provide a representative sample of the types of fuels which may be found in the tunnel environment.

The Fire Triangle

The video outlines the principle of the ‘Fire Triangle’ and describes the three conditions essential for a fire to start. The three conditions are:

- an ignition source;
- fuel;
- oxygen.

If any one of these three elements is removed then the fire will not start. If fuel or oxygen is removed it will go out.

You should re-emphasise the importance in any tunnel of preventing the fire from starting in the first place rather than having to control a fire once it has already started.

This is achieved by controlling:

- potential ignition sources; and
- the amount of potential fuels present, which determines the fire size.

Typical potential ignition sources are:

- smoking materials;
- welding or cutting equipment;
- electrical systems.

Typical potential fuels are:

- timber;
- straw;
- flammable liquids;
- compressed fuel gases;
- plastic or paper packaging materials;
- vehicle fuel oil;

- hydraulic oil;
- methane.

Note that some materials may be referred to as 'fire retardant' or 'fire resistant'. These improve safety by being more difficult to ignite and/or burning more slowly. However, remember that they can still catch fire.

Discussion point

What potential ignition sources and fuels are there in your tunnel?

Risk of fire can be increased by poor planning, poor maintenance, failure to carry out repairs and poor housekeeping.

Discussion point

What are your procedures for controlling fire risks which may be increased by poor planning, poor maintenance, failure to carry out repairs and poor housekeeping?

FIRE TEST SEQUENCE

The first test sequence shows two materials typically found in tunnels. These are

- rubbish – this very often accumulates as a result of poor housekeeping;
- straw – used to stem water inflows in hand-driven tunnels.

The straw shown burning here is in loose form but tests were also carried out on bales. The results of the tests showed that the loose straw burned 10 times faster than a bale and was much easier to ignite.

The tests were carried out at atmospheric pressure and at 2 bar g.

2 bar g is shown on the screen. On the screen, pressures are shown in ‘bar gauge’. Tunnellers will be more familiar with this pressure as 2 bar – either term can be used.

The quarter screen views show the two materials burning under different atmospheric pressures. The time clock shows the real time duration of the test fires. This illustrates how quickly the fires in compressed air burn compared to the same materials at atmospheric pressure.

The rubbish clearly takes longer to burn than the straw, but this is a function of the material itself. Comparison should not be made between materials but rather between the same materials at the difference air pressures. That is, compare frames vertically rather than horizontally.

Schematic demonstrating the effect of compressing air on oxygen content

It is clear from the first fire sequences that compressed air allows fires to burn more fiercely and more rapidly. This schematic is intended to explain why this should be.

In the discussion on the fire triangle it was shown that oxygen was one of the three essential conditions for a fire to start and to continue to burn. For the majority of fires, it is air which is about 21% oxygen that provides this.

In a given volume of air at atmospheric pressure, oxygen makes up 21% of its volume. If the same volume of air at atmospheric pressure is added to the same space that was occupied by the first volume of air the pressure of the air will double. This is what happens when air is compressed.

The oxygen still occupies 21% of the volume but the pressure has increased. There are more oxygen molecules in the same space in the compressed air, which causes fires to grow faster than they would at normal pressure.

Heat produced and speed of burning

The tests showed that for fires burning in compressed air the rate of burning is higher and the heat output is higher.
The example given is for loose straw.

At atmospheric pressure the heat output was 200 kW.
At 2 bar g the heat output was measured at 1000 kW – equivalent to 1000 electric fires **and five times greater than at atmospheric pressure.**

To try to convey an impression of this, try to imagine how near somebody could approach 1000 x 1 kW domestic electric radiant bar fires.

The illustration demonstrates that, once a fire takes hold, the possibility of being able to get close enough to successfully fight it is remote just because of the heat output. Don't forget that there will be other factors which will add to the problems of fighting fires such as smoke, difficulty of access and problems caused by the wearing of safety equipment such as self-rescuers and rescue breathing apparatus (BA) sets.

Housekeeping

This test sequence also highlights the message that good housekeeping is an essential part of fire prevention. It illustrates typical rubbish found in tunnel construction. Please emphasise the key message which is to make sure that rubbish is not allowed to accumulate.

Discussion point

What are your procedures for controlling the accumulation of rubbish?

SECOND TEST SEQUENCE

Generally, this sequence of tests demonstrates the importance of wearing the correct type of overalls. They show the effect of fires at atmospheric pressure and in compressed air on two types of overalls commonly found in use on construction sites.

The standard polycotton type are blue in this test but could be different colours. The orange overalls in this test have been treated with a fire-retardant chemical. They are commonly known as Proban treated overalls. Proban is a trade name and there are others available on the market.

It is important that the specific materials and their characteristics when exposed to fire are checked with the manufacturer.

The tests clearly show the benefits of wearing overalls treated with a fire-retardant material.

In the tunnel environment, orange-coloured overalls which also have reflective strips are a great advantage in improving visibility.

Discussion point

What are your arrangements for providing protective clothing?

Safety equipment

This sequence of tests is interspersed with reinforcement of the message regarding the general importance of wearing the correct safety equipment. This should be an essential feature of the training programme for work on the site. The trainer should also consider the addition of other equipment required as a result of the risk assessment carried out for the site and which will be specific to the site operations.
The specific safety equipment mentioned is:

- overalls;
- safety boots;
- hearing protection;
- cap lamp and battery;
- self-rescuer;
- hard hat.

Self-rescuers are specifically mentioned here though instruction in their use should be a separate part of the training programme. This video is not intended to cover the specific training for the use of the self-rescuer.

Discussion point

What are your procedures for providing and maintaining self-rescuers?

You should be prepared to discuss the problem that the self-rescuer may not last as long when used in compressed air. You may also wish to mention the problem that oxygen self-rescuers cannot be used above 1 bar. The characteristics of the chosen self-rescuer must be checked with the manufacturer and related to the specific pressures which will be used in the tunnel. The emergency and rescue arrangements need to take account of any modification to the effectiveness of the equipment when in use on the particular site.

Discussion point

What is the effective duration of the self-rescuer in the tunnel in question – if evacuation times exceed this, what are the other arrangements for safe evacuation?

THIRD TEST SEQUENCE

This sequence of tests demonstrates the effect of increasing the overall oxygen content of the air, i.e. enriching the oxygen concentration of the air, at two increased levels of air pressure.

The air pressures used are 0.6 bar g and 1.8 bar g. You will recognise 0.6 bar is a typical stage pressure for decompression under the Blackpool Tables. 1.8 bar is a pressure commonly used in treating decompression illness.

The oxygen concentrations used for the tests are 21% (the concentration in normal air) and 25% (a typical oxygen-enriched atmosphere which could occur in a medical lock if atmospheric monitoring and proper ventilation of the lock was not carried out, or locally in a tunnel in the event of oxygen leaks from equipment).

The tests are carried out on a mannequin and provide a comparison between fire development in compressed air atmospheres and compressed oxygen-enriched atmospheres. They illustrate the effect of increasing air pressure by comparing the differences between the fires at 21% oxygen. They also illustrate the effects of increasing oxygen concentration by comparing the fires at constant pressure (either 0.6 bar g or 1.8 bar g).

Notes relating to the use of oxygen

Where oxygen is used in medical locks and standards of cleanliness has to be higher than normal. 'Oxygen cleanliness' standards apply to minimise the risk of fire starting.

Increased oxygen concentration can result from leaks from cutting or welding equipment. Where oxygen breathing apparatus is being used, some leakage from around the face mask can be expected as no mask is a perfect fit for everyone.

NOTE: In the video, a man breathing oxygen from a portable cylinder is shown entering a chamber. The portable cylinder is only used to give oxygen as a first-aid treatment – once inside the chamber the proper closed-circuit oxygen-breathing system built into the chamber must be used. Also, they would not be wearing site clothing on entry into the 'oxygen clean' area.

Discussion point

What are the medical lock procedures to ensure that the chance of an incident is minimised?

Results of the tests

The tests show that at all air pressures the addition of oxygen to the atmosphere will result in the following:

- fires burn more fiercely;

- fires burn more quickly;
- fires produce more heat;
- fires produce more smoke.

All theses make fires more difficult to fight and make escape and rescue more difficult.

Emphasis on prevention

The importance of preventing fires starting should be re-emphasised.

You should remind those watching the video of regulation 14(2) of the Work in Compressed Air Regulations. This regulation makes it an offence for any person to smoke or have materials for smoking when in compressed air.

The training should clearly outline the company policy for infringement of this rule.

Commonly this offence results in immediate dismissal but could also lead to prosecution.

The arrangements for the control of contraband need to be related to the site rules.

SUMMARY

The Summary section is essentially self-contained but highlights the key learning points of the video.

Fires in compressed air:

- start more easily – demonstrated in other tests carried out at Buxton but not illustrated here;
- burn faster;
- produce more heat;
- spread faster;
- are more difficult to put out – again demonstrated in other tests at Buxton.

The confined heat and smoke:

- cut off escape routes;
- make firefighting difficult;
- lead to deaths or serious injury.

Increased oxygen content (oxygen enrichment) makes fires:

- burn even more rapidly;
- give out even more heat and smoke.

The essential safety rules

Safety rules must be site-specific. You should use this video to complement site-specific training. As the trainer, you should be aware of differences between what is shown in this video and the situation on your specific site. You may have to modify the learning material as appropriate.

Safety rules should be developed which emphasise the prevention of fire as well as giving procedures for escape and rescue. Close monitoring of the safety management system is essential.

Rules should include:

- no contraband;
- good housekeeping;
- employ safe working practices - such as a control system for tunnel entry;
- procedures for dealing with fire and where to find emergency equipment;
- use the correct PPE at all times;
- carry a self-rescuer.

References

1 *A guide to the Work in Compressed Air Regulations* 1996 L96 HSE Books1996 ISBN 0 7176 1120 5

2 *Fire tests in a compressed air tunnel at up to 3 bar pressure* Lamont, Buckland, Bettis, Jagger and Hambleton. Published Proc. Of World Tunnel Congress '98 on Tunnels and Metropolises Sao Paulo/Brazil/25-30 April 1998
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Discussion points

1 What are your arrangements for ensuring that all workers are trained to use the self-rescuer and have had enough practice?

2 What potential ignition sources and fuels are there in your tunnel?

3 What are your procedures for controlling fire risks which may be increased by poor planning, poor maintenance, failure to carry out repairs and poor housekeeping?

4 What are your procedures for controlling the accumulation of rubbish?

5 What are your arrangements for providing protective clothing?

6 What are your procedures for providing and maintaining self-rescuers?

7 What is the effective duration of the self-rescuer in the tunnel in question - if

evacuation times exceed this, what are the other arrangements for safe evacuation?

8 What are the medical lock procedures to ensure that the chance of an incident is minimised?