BAM
Bundesanstalt für
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BAM Research Report

Acetylene cylinders in a fire, phase 3: Executive Summary

R&D Project Vh 2514

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British Compressed Gas Association (BCGA)
and partners

1 Introduction

1.1 Problem

Fire services, gas companies, and public bodies concerned with fire and explosion safety in the UK are looking for a generally recognized, acceptably safe and easy procedure to handle acetylene cylinders which were involved in a fire. The UK Fire service protocol for dealing with acetylene cylinders in fires is generally to create a 200 m hazard zone. There is considerable uncertainty, however, after how much time and on the basis of which observations the zone can be collapsed totally or at least partly, if at all. Keeping such a zone upright for 24 hours has occasionally given rise to huge road and other infrastructure disruptions.

The BCGA (British Compressed Gas Association) approached BAM to get some scientific support for the improvement of this unsatisfactory situation. It did so jointly with

HSE	Health and Safety Executive
DfT	Department for Transport
TFL	Transport For London
CFOA	Chief Fire Officers Association.

1.2 Particular problems associated with acetylene

Acetylene (C_2H_2) is flammable which means that it can react with oxygen. This reaction generates much heat at high temperatures, which is the reason why acetylene is so popular for cutting and welding.

The acetylene molecule, however, can also decompose by breaking up into one hydrogen molecule and two carbon atoms. This reaction delivers much less energy than combustion but would be strong enough to destroy a cylinder if acetylene would be stored just like any other flammable gas under a pressure of 200 bar or more.

For this reason the maximum working pressure of an acetylene cylinder is much lower (19 bar), and the cylinder is filled with a porous material which is a very effective obstacle for energy and fluid flow. The porous material is the most important safety feature of an acetylene cylinder.

It has been found that the gas content can be enhanced by a factor of about 10 when the cylinder is filled additionally with solvent (e. g. acetone) and the gas dissolved in the liquid. Acetone is a very powerful solvent for acetylene. It was used as solvent in all tests described here.

The acetylene cylinder is thus a complex system comprising a number of components interacting with each other.

1.3 BAM work plan

On the basis of a long experience with acetylene and acetylene cylinders and their equipment [2] BAM was asked by BCGA and partners to give advice on a new procedure for the fire service men to follow in case they find an acetylene cylinder in or near to a fire.

The agreement with BAM was to split up the work on this problem in three different phases: (1) laboratory experiments, (2) numerical modelling and (3) large scale experiments.

In phase 1 laboratory experiments were done, phase 2 meant the preparation of the numerical modelling of the phenomena in the laboratory and in the field tests. The results of both phases have been reported earlier [1].

In phase 3 tests on real acetylene cylinders were made, accompanied by numerical simulations on the basis of the preparation done in phase 2. The results of the experiments [3] and of the simulations [4] in phase 3 have been reported in detail before. This is the summary of our results and conclusions.

2 Work done in phase 3

2.1 Preparation

The objective of these tests was to find out what happens inside an acetylene cylinder under heating in a fire and why it happens. In order to measure the temperatures inside the porous material twelve cylinders (six each with a geometrical volume of 10 and 50 l) were equipped with six temperature sensors within the porous material at different heights and at different distances from the shell plus one on top. Details are given in chapter 5 of [3]. This has to our knowledge been done for the first time and offered valuable new insights into the phenomena.

2.2 Tests

Most of the tests consisted of heating the cylinder under different conditions and observing its reaction. What was done in detail was:

- Heating cylinders with porous material only inside
- Heating cylinders with porous material and solvent, but no gas inside
- Heating cylinders with porous material, solvent, and gas in a fire until burst
- As above, but attempting to save the cylinders from burst by cooling with water
- Miscellaneous tests

Details on the test environment are given in chapter 7 of [3].

2.3 Simulations

The simulations were made by means of COMSOL Multiphysics®, version 3.5a, which uses the Finite Elements Method (FEM) to solve differential equations for various physics and engineering applications. Details about this tool are given in chapter 2 of [4].

There was a close interaction between experiments and simulations. Experimental results were used as new input for the simulations, and some experiments were made in particular to provide data for them.

The first objective of the simulations was to apply the numerical model set up in phase 2 to the experiments of phase 3 and to check whether the results were reproduced. This was to test whether the result worked reasonably. Then a few cases were simulated which could not be investigated in the experimental part, for example the case of a cylinder which is not engulfed by a fire but is heated by a fire of a certain extension in a certain distance.

3 Results

This is a condensed summary of the results found in the experiments and numerical simulation of phase 3.

- First of all it was confirmed both in the experiments and in the simulations that the porous material in an acetylene cylinder is indeed a very powerful and reliable means to suppress the uncontrolled propagation of an unwanted reaction. Even if high temperatures are applied to the cylinder shell it may take hours until the effect is felt even a few cm inside the cylinder. This was found both in the experiments and in the simulations. This statement still holds when a solvent is present.
- But this is true only as long as the porous material is intact. Voids from damage (cracks after drops, bubbles after bad filling) or the unavoidable gas space on top may be the starting point for decompositions. As a matter of fact decompositions were observed rather regularly in the gas space during the fire tests. But due to the very small amount of gas involved the energy released was not enough to create a pressure rise which was able to do serious damage to the cylinder. No correlation between the occurrence of such a decomposition and rupture of the cylinder was found. The decompositions which really did destroy the cylinders by causing an excessive pressure occurred somewhere else in the porous material.
- A purely mechanical impact (dropping or toppling of the cylinder) is not able to trigger a decomposition in its interior. This is state of knowledge and was not the subject of the tests described here. The energy must be provided as heat.
- Since the heat which may start a decomposition comes from the outside through the shell the reaction is also likely to start close to the shell. It is not realistic to assume that a decomposition may happen near the cylinder axis and remain undetected for hours.

- If a cylinder with porous material and acetone is heated, the vapour pressure of the acetone in combination with decreasing strength of the cylinder shell due to the enhanced temperature is enough to make the cylinder burst if enough heat is applied. The cylinders used for these tests were found to be deformed after the experiment; the fact that they did not burst is probably only due to a problem with the power supply for the electrical heater caused by this very deformation. It should be taken into account that there was no acetylene at all present in these test samples while in a real acetylene cylinder there is always also dissolved acetylene; even an "empty" cylinder still contains saturation acetylene corresponding to the atmospheric pressure.
- Pure acetone has a critical temperature of 235 °C and a critical pressure of 47 bar. These are conditions which will easily be reached in the case of a cylinder engulfed in a fire. The behaviour of a supercritical fluid is very difficult to describe numerically, even more in the vicinity of the critical point. So this is a natural limit for a reliable simulation. It appears, however, that a cylinder which has a pressure of 40 bar or more is very likely to burst anyway.
- In the tests during which the cylinder was fully engulfed in a fire it failed usually between 5 and 12 minutes after the start of the fire. The experimental observations and the numerical simulations agree very well about this. Such a short time makes it more or less impossible for a fire service to save such a cylinder. A much better chance to save a cylinder exists when it is only near a fire.
- Some of the cylinder failures were due to a decomposition, in other cases no trace of such a reaction could be found in the temperature recordings. This confirms the statement made above that a decomposition is not necessary at all to destroy a cylinder; the enhanced pressure and the reduced shell strength due to the enhanced temperature are enough. It was found that the holes through which the thermocouples were fed into the porous material did not have an influence on the rupture behaviour of the cylinders.
- A cylinder which bursts may either disintegrate into different pieces, or it may rip open while the shell remains in one piece. In the first case the fragments may travel more than 100 m (85 m was the maximum during these tests, but higher values were observed on other occasions). The number of fragments was never higher than three, apart from the neck ring and the valve which are separate parts anyway. A "shrapnel" effect is impossible due to the way an approved cylinder is made and in particular under fire conditions because the high temperature makes a brittle failure impossible.
- Failure of a cylinder will in most cases generate a fireball which has typically a diameter of 20 m or more. This is not necessarily so, however. Sometimes the acetylene has already been consumed by internal decomposition so that nothing or very little is left. In case of a small rip a darting flame a few m long may come out of the rip which will last for a few minutes until the acetylene is consumed. Acetone vapour may burn for hours but not with a big flame since there is no pressure any more in the cylinder.
- In the tests during which it was tried to save the cylinder the attempt was successful in some cases and not in others. This obviously depends on whether the cooling starts early enough. It appears that there is a good chance to save

the cylinder if the pressure inside has not yet exceeded the mark of 40 bar. This statement should be considered as a purely empirical one.

- If the cooling of the cylinder was successful so that pressure and temperature dropped again the cylinder was again and remained safe. There is no conceivable mechanism by which a decomposition could start again unless there is more energy provided from outside.
- The cooling time necessary to bring a cylinder back to safe conditions was always less than half an hour. This agrees with the numerical results.
- Comparison between the experimental results and the simulations shows that the numerical model of a cylinder is indeed able to reproduce the effects of a fire with a satisfactory degree of reliability. So there is a tool which is able to make statements on situations which could not be tested experimentally, like different cases of side wind, heating by radiation, partial cooling, cooling with water of different temperatures, etc.
- A cylinder which is not engulfed in a fire but is heated by radiation receives much less energy. It should be much easier so save such a cylinder by cooling. A burst is to be expected only if the fire is really very big and very close to the cylinder. This follows both from the numerical simulation and from observation in cases when a fire was difficult to start and engulfed the cylinder only after a while. This case is difficult to predict because the behaviour of the system reacts very sensitively to small perturbations.
- Every fire is different, and small causes may have important effects. Side wind, for example, may change the heating process of a cylinder in a very significant way. It is important to stay on the safe side always.
- The temperature of the cooling water does not have a great effect on the attempts to save the cylinder as long as the water on the shell remains liquid, i. e. has a temperature of no more than 100 °C. No decomposition is to be expected at temperatures that low.
- Partial cooling may have an effect on the cylinder similar to total cooling because of the good heat conductivity of the cylinder shell. This assumption has not yet been confirmed with experiments but follows from the numerical simulations.

4 Conclusions

It is generally known that acetylene is dangerous. The gas is flammable and can also react exothermically on its own without the presence of oxygen (decomposition). But with due care and expertise acetylene can be handled just as any other of the numerous dangerous substances we come across in our daily life, and in particular during the work of a fire service man. This statement holds both for normal use and for accident situations. There is no reason for extreme measures.

There exists a proposal for a revision of the UK Fire Service protocol for acetylene cylinder fires to be included in a new HazMat guidance. The proposal basically says that the suspicious acetylene cylinder should be cooled for one hour with copious amounts of water from a safe distance. If no burst occurred until then the extension of the hazard zone would be reduced. The cylinder would be observed for another hour to check whether there are any signs of heat development inside. Simple ways to do this are visual inspection (progressing discoloration) or the wetting test. IR cameras may be used as well if they are available.

From our point of view and on the basis of our results we can say that this procedure appears to be reasonable and will not lead to any significant lessening of fire fighter safety as compared to the existing UK guidance. When the fire is extinguished and the cylinder is still in a good condition after one hour of cooling, there is a good chance that there either was no decomposition inside or that it has been quenched, because otherwise it probably would have burst already after this time.

The second (monitoring) hour of the proposed scheme should mainly be seen as precautionary measure. It is very unlikely that any adverse signs of re-heating of a cylinder will be seen in the monitoring phase. Neither do we expect that any dangerous situation could develop within the 15 minute gaps between suggested checking (by Thermal Imaging, IR or "wetting test"). If there is any uncertainty about this the firemen on site should be free to shorten or to extend the intervals between the checks.

The results presented in the current report are to be applied to <u>single</u> acetylene cylinders involved in fire. If the fire brigade has to deal with bundles of acetylene cylinders the situation is different because a dangerous cylinder may be shielded by others. Cooling and observing it may be more difficult. The situation of a bundle has not been considered here.

5 References

[1] Research Report “Handling of acetylene cylinders in / after a fire”, BAM R&D Project Vh 2514, submitted on March 12, 2009 (report on phase 1 of the work and of the part of phase 2 done during that time)

[2] [L. Kurth et al.:] *Abschlussbericht zum Forschungsvorhaben 13 RG 9001 „Explosionsgefahren beim Umgang mit Acetylenflaschen und –bündeln nach der Einleitung eines Acetylenzerfalls*, BAM report dated March 30, 1995

[3] Research Report “Acetylene cylinders in a fire, phase 3: Experiments, observations, and conclusions”, BAM R&D Project Vh 2514, submitted in November 2010 (report on the experiments in phase 3)

[4] Research Report “Acetylene cylinders in a fire, phase 3: Numerical model definition, results and conclusions”, BAM R&D Project Vh 2514 (report on the numerical simulations in phase 3)