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NATURALHY

"Preparing for the Hydrogen Economy by Using
the Existing Natural Gas System as a Catalyst"
Project Contract No.: SES6/CT/2004/502661

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Vapour Cloud Explosions involving Natural Gas/ Hydrogen Mixtures

Figure 1: The VCE Test Rig

The Safety Work Package of the Naturalhy project is comparing the current hazards and risks presented to the public by the existing gas infrastructure conveying natural gas with the hazards and risks presented by the same infrastructure assuming that a natural gas/hydrogen mixture is conveyed. One particular hazard that needs to be assessed is the consequences of a gas/air mixture accumulating and then igniting giving rise to an explosion. It is well known that hydrogen is more reactive than natural gas and 100% hydrogen mixed with air can produce explosions of a greater severity than natural gas/air mixtures in the same circumstances. So the question arises, how does the severity of explosions change as hydrogen is added to the natural gas?

Firstly, we need to understand what is meant by an explosion and how explosions cause harm. When flammable gas mixtures burn, a large increase in volume occurs, principally due to the high temperature of the combustion products formed. If this process occurs within a confined (or semi-confined) region, such as a building or enclosure, the presence of the confining walls prevents free expansion of the combustion products and results in the generation of pressure. This is the key mechanism for the generation of pressure in confined explosions.

It has also been observed that gas explosions can generate pressure without the presence of confining walls. These are referred to as Vapour Cloud Explosions (VCEs). In this case, the flame front travels through the unconfined gas cloud. If the flame is travelling quickly, the gas/air mixture ahead of the flame is unable to move away quickly enough to allow free expansion of the combustion products formed by the flame. Hence a pressure wave is formed ahead of the flame front. The presence of obstacles (called congestion)

▶▶ PAGE 2

TABLE OF CONTENTS

EDITORIAL

With this seventh Newsletter on the NATURALHY project we would like to update you on the progress of our project, which investigates the potential of the existing natural gas system for the delivery of hydrogen.

The main objective of the project is to identify and if possible remove the potential barriers inhibiting the development of hydrogen as an energy carrier, using the existing natural gas system as a catalyst for change.

As a first logical step in the transition towards the hydrogen economy, the project focuses on using the existing natural gas grid for the delivery of hydrogen/natural gas mixtures from the perspective of the "greening of gas" but also perhaps to deliver 'pure' hydrogen where necessary.

The addition of hydrogen to natural gas affects the chemical and physical properties of the gas and will have an impact on the safety aspects related to the transmission, distribution and en use of the gas.

The main article of this issue is dedicated to the progress obtained in the Safety workpackage related to Vapour Cloud Explosions (VCE) with Natural Gas / Hydrogen mixtures up till 50 % Hydrogen.

The results show clearly the importance of congestion in creating turbulence which enhances the severity of the VCE's.

The second article in this issue focuses on a statistics software tool developed for the prediction of the Probability Of Failure (POF) of a pipeline based upon the behaviour of defects and the type of inspection technique selected.

If you have any questions or would like to discuss certain aspects of the NATURALHY-approach with us, than please react through our website www.naturalhy.net.

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(continued from page 1)

within the flow field of the gas cloud produces turbulence which enhances the burning velocity, accelerates the production of combustion products and increases the flame speed. The faster the flame travels, the higher the pressure generated ahead of it. If very high flame speeds are produced, a Transition from Deflagration to Detonation (DDT) can occur. In simple terms, a detonation involves a very high pressure shock wave that auto-ignites the gas/air mixture. The combustion of this mixture then provides the energy to sustain the shock wave. As a result, a detonation is self-sustaining as long as the concentration of the gas is within certain limits. In a detonation, the flame front and shock wave are coupled and travel at a speed of approximately 2000 m s-1. Very high overpressures (in excess of 20 bar) result, and hence measures must be taken to avoid the possibility of DDT.

In the context of the gas industry, the possibility of a detonation occurring on a gas processing installation is a serious concern as the hazard boundary of such an event could extend beyond the boundary of the site and hence present a hazard to the surrounding population. Previous studies involving various hydrocarbons have shown a key difference in the behaviour of natural gas (methane) compared to higher hydrocarbons such as propane or ethylene (ethene) [1]. Whilst obstacle congestion can cause flame acceleration (and hence pressure generation) with all the fuels, in the case of methane, this acceleration is not sustained and the flame speed plateaus or declines. By contrast, with the more reactive higher hydrocarbons, continued flame acceleration can be produced within large congested regions and, in some cases, result in a DDT, generating very high damaging overpressures.

These previous studies showed that a DDT would not occur with natural gas (methane) within the kind of piperack geometries found on gas processing installations and this is essential information in determining the risk presented by the site to the surrounding population.

By contrast, hydrogen is well known for its susceptibility to detonate and work by Shell provided to this project [2] has shown that 100% hydrogen mixed with air, can result in DDT during a VCE within a compact congested region. Detonation was not observed with methane: hydrogen ratios up to 25:75. However, the path length (and hence time for flame acceleration) through the congested region was relatively short during these experiments.

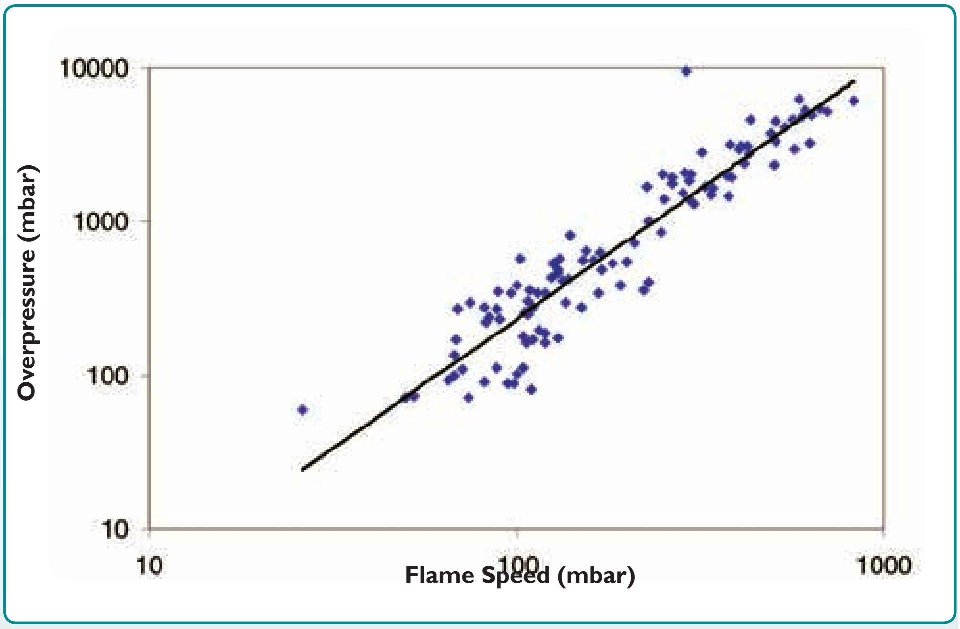

Figure 2: Overpressure Flame Speed Relationship

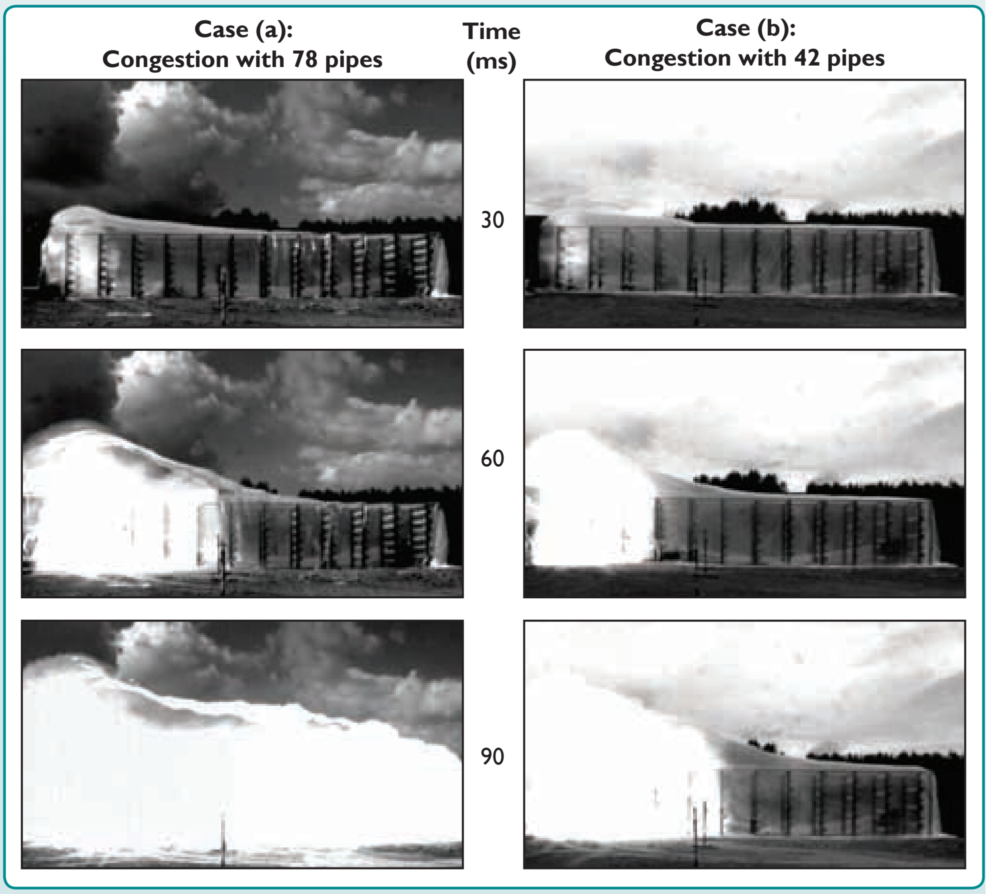

Figure 3: Explosions at different times after the flame enters the congestion for (a) 78-pipe congestion arrangement and (b) 42-pipe congestion

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The key question for the Naturalhy project is; how much hydrogen can be added to natural gas, before the risk of DDT within a long congested region, such as a piperack, becomes significant? To answer this question, a series of large scale VCE experiments have been conducted within a test rig simulating a long congested region (piperack). The test rig is shown in Figure 1; the congested region was 18 m long and 3 m by 3m in cross-section. The chamber at the beginning of the congestion allowed an explosion flame to be generated which entered the congested region at a given speed. A large polythene sheet was used to cover the congested region in order to retain the gas/air mixture during the filling process, so that the correct mixture could be formed, before the mixture was ignited at a location within the chamber.

During the experiments, the flame speed and overpressure generated was measured as the flame progressed through the congestion. A range of natural gas/hydrogen mixtures was studied (containing up to 50% volume hydrogen) and the initial flame speed entering the congestion was varied as was the number of pipes forming the congestion.

As expected a close relationship between flame speed and the resulting overpressure was observed (Figure 2) and during some experiments very high, damaging overpressures were produced. (Most buildings would collapse at overpressures of less than 350 mbar and structures on a process/storage site at around 700 mbar).

Figure 3 shows the flame progressing through the congested region from images captured by high speed video. Both experiments involved the same gas/air mixture. In case (a) 78 pipes were used to form the congested region, whereas in case (b), just under half the pipes were removed to provide a reduced congestion arrangement of 42 pipes. In both cases, the flame entered the congestion at much the same speed. The images show the location of the flame 30 ms, 60 ms and 90 ms after the flame entered the congested region. As can be seen, after 30 ms the locations of the flame were similar, but after 60 ms, the flame in case (a) (78-pipe congestion) had travelled half way along the congested region compared to about one third of the distance in the reduced (42-pipe) congestion of case (b). After 90 ms, the flame in the case (a) had reached the end of the test rig, but in case (b) had only reached halfway. Indeed, within the 78-pipe congestion arrangement, the flame accelerated continuously through the congested region and produced very high damaging overpressures. By contrast, in the reduced congestion, after a period of initial flame acceleration, the flame speed and overpressures declined. The results clearly show the importance of congestion in creating turbulence which enhances the severity of VCEs.

The results of all the tests have now been analysed and a report will be published soon. Overall, important information has been gathered on the influence of the controlling parameters that can lead to high overpressures or even the risk of DDT, such as the amount of hydrogen in the mixture, the initial flame speed entering the congestion and the degree of congestion as illustrated above. ❖

References

1. Harris, R. J. and Wickens M. J., Understanding Vapour Cloud Explosions – An Experimental Study, Institution of Gas Engineers 55th Autumn Meeting, Communication 1408, UK, 1989.
2. Shirvill, L. C. and Royle, M., Vapour Cloud Explosions from the Ignition of Methane/Hydrogen/Air mixtures in a Congested Region, 2nd Intenrational Conference on Hydrogen Safety, San Sebastian, Spain, September 2007.

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Predicting The Probability Of Failure of A Pipeline

An important aspect of the Naturalhy project is the assessment of the impact of the addition of hydrogen on the integrity of a pipeline. Pipelines are subject to many threats such as corrosion, crack-like defects, third party damage, etc. and each of these has a certain risk associated with it, which operators develop management strategies to counter. In the Integrity work package a methodology has been developed to calculate the impact of hydrogen on the probability of failure of the pipeline.

The main focus of the work to date has been on crack-like defects, as hydrogen has been demonstrated to change the behaviour of this type of defect and consequently may affect the safety of a pipeline or make it more expensive to operate. The reason why crack-like defects are potentially more vulnerable to the addition of hydrogen is that hydrogen can change the material behaviour and the crack growth rate for very low cycle fatigue situations like those found in transmission pipelines. The exact change in the material behaviour is being investigated in the Durability work package through an experimental programme and this data will be used by the integrity assessment tools. Corrosion or third party interference may be impacted if hydrogen is shown to affect the mechanical properties of the material or if crack-like defects are associated with these other types of defects so, for this reason, the tool will also consider these defects.

A tool has been developed based on a stochastic approach to assess the failure probability of the gas pipeline due to the existence of crack-like defects, corrosion defects and third party defects, including

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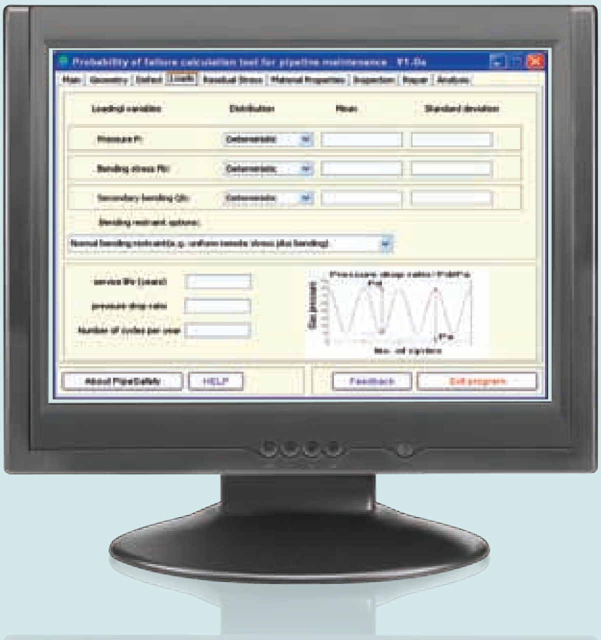

Figure 1: View of input screen for the PipeSafety software tool developed to predict the probability of failure

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the operational aspects of the pipeline, such as inspection and repair procedures. With various parameters such as defect sizes, material properties, gas pressure etc. modelled as uncertainties, a reliability analysis based on a failure assessment diagram is performed through Stratified Monte Carlo (SMC) simulation (see figure 1). The performance of inspection (i.e. detection probability, sizing error, etc) and repair procedures (i.e. repair criteria) are also included in the simulation to enable realistic pipeline maintenance scenarios to be simulated.

In the data preparation process, the accuracy of the probabilistic definition of the uncertainties is crucial as the results are very sensitive to certain variables such as the defect depth, defect length and defect growth rate. The failure probabilities of each defect and the whole pipeline system can be obtained during simulation. Different inspection and repair criteria are available in the SMC simulation (see figure 2) whereby an optimal maintenance strategy can be obtained by comparing different combinations of inspection and repair procedures. This analysis both provides data on the number of repairs which are necessary and indicates when they have to be performed, so there is a clear link to more economics type models.

Currently the tool is being used to provide data on the probability of failure for integrity management purposes. Data from the tool is also being evaluated for use in assessing the safety of pipelines and incorporation in the Decision Support Tool (DST). In order to provide results, which can be used for the safety model and the DST the failure mode will be determined and results of different levels (high and detailed) of severity will be provided. ❖

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CMI/BEASY Ltd, www.beasy.com

Figure 2:
The pipeline management strategy also affect the probability of failure.
Here the user can choose the repair policy on the pipeline

Definition of repair process:

● Repair option 1: The cracks will be repaired if it is deeper than ☐ mm

○ Repair option 2: The crack is repaired if it will reach the critical value after ☐ year(s)

* Option 2 is only available when the crack length is assumed to be constant during fatigue calculation

UPCOMING EVENTS

June 15-19, 2008 the 17th **W**orld **H**ydrogen **E**nergy **C**onference (WHEC) 2008,
Brisbane Convention and Exhibition Centre, Queensland Australia

September 8-10, 2008 International Hydrogen Conference,
Jackson Lake Lodge, Grand Teton National Park, Wyoming, USA

October 9, 2008 the 3rd NATURALHY Workshop, Paris
(hosted within IGRC 2008)

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