IGNITION AND FLOW STOPPING CONSIDERATIONS FOR THE TRANSMISSION OF HYDROGEN IN THE EXISTING NATURAL GAS NETWORK

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ABSTRACT

This work formed part of the H21 programme, whose objective is to reach the point whereby it is feasible to convert the existing natural gas (NG) distribution network to 100% hydrogen (H2) and provide a contribution to decarbonising the UK's heat and power sectors with the focus on decarbonised fuel at point of use.

Hydrogen has an ATEX Gas Group of IIC compared to IIA for natural gas, which means further precautions are necessary to prevent the ignition of hydrogen during network operations. Both electrostatic and friction ignition risks were considered. Network operations considered include electrostatic precautions for polyethylene (PE) pipe, and cutting and drilling of metallic pipes.

As a result of the updated basis of safety from ignition considerations, existing flow stopping methods were reviewed to see if they were compatible. Commonly used flow stopping methods were tested under laboratory conditions with hydrogen following the methodologies specified in the Gas Industry Standards (GIS). A new basis of safety for flow stopping has been proposed that looks at the flow past the secondary stop, as double isolations are recommended for use with hydrogen.

1.0 INTRODUCTION

This paper documents some of the work that was done to address knowledge gaps that were identified through a review of the UK Gas Distribution Network (GDN) procedures. The objective of the H21 programme is to reach the point whereby it is feasible to convert the existing natural gas (NG) distribution network to 100% hydrogen (H_2) and provide a contribution to decarbonising the UK's heat and power sectors with the focus on decarbonised fuel at point of use. The scope of work is limited to the low pressure (LP), medium pressure (MP) and intermediate pressure (IP) networks (i.e. up to and including 7 barg).

1.1 Gas Groups and Regulations

BS EN ISO 80079-20-1:2019 [1] classifies industrial methane as Group IIA provided it contains less than 25 vol% hydrogen (vol% is equivalent to mol% for an ideal gas); it also states that methane blended with any other IIA gases is IIA, which would be the case for natural gas. Hydrogen is classified as Group IIC in the same standard. The current Group IIA equipment for use with natural gas will need to be replaced with equipment that is Group IIC rated for use with hydrogen.

The possibility was that blends above 16% hydrogen in methane could be Gas Group IIB based upon minimum ignition current ratio (MIC) data [2]. However, BS EN ISO 80079-20-1:2019 [1] did not change its classification as maximum experimental safe gap (MESG) data is preferred for determining IIA/IIB for border cases where the two methods disagree.

ATEX equipment is required where the Dangerous Substances and Explosive Atmospheres Regulations (DSEAR) (2002) apply and flammable atmospheres could occur [3]. It is a legal requirement in the UK to use correctly certified ATEX equipment in areas where potentially explosive atmospheres are classified, even when it appears to be clear that the equipment will not pose an ignition risk. It is a requirement that equipment is demonstrated to be safe and certified by a Notified Body rather than assumed to be. ATEX applies to both electrical and mechanical sources of ignition, and pneumatic equipment is in scope.

Simple tools such as hand tools are exempt from ATEX certification [4], but they must still be subject to an assessment of whether they are suitable for use in an explosive atmosphere. BS EN 1127-1:2019 [5] Annex A divides these tools into single and multiple spark; multiple spark tools are not allowed in explosive atmospheres, however single spark tools can be used in Zones 1 & 2 with natural gas but only Zone 2 with hydrogen. Definitions of zones from BS EN 60079-10-1:2015 [6] are required to apply this to the GDN's operations (see Table 1). The definition of negligible extent (NE) of a flammable volume too small to cause significant injury or damage is also useful.

Table 1 summarises the zone classifications for the GDNs' operations; these were determined for comparison of operations to standards which quote zones as the GDN does not explicitly quote zones for their operations. It assumes that hand powered tools are of limited speed and power and as such can only generate single sparks, powered equipment would generate multiple sparks and as such the operations would not be allowed in flammable atmospheres. This analysis assumes metallic pipe for spark generation as PE pipe will melt at 200°C. Zone 0s (where a flammable atmosphere is present continuously or will frequently occur) are rare on the gas network. Inside the pipes would not be a Zone 0 as they do not contain air, so do not contain a flammable mixture.

Table 1: Applying the concept of zones to the GDN's operations.

	Zone 1	Zone 2
Definition	A flammable atmosphere created occasionally during normal operations	A flammable atmosphere that should not occur during normal operations but is foreseeable
GDN example	Cutting or drilling into a pipe containing gas* Work in the area of a leak, the size of the zone depends on the size of the leak	Work on the outside of a pipe where no breaking of containment is planned Inside a line purged to air held on a single isolation
Natural Gas	Steel tools allowed*	Steel tools allowed
Hydrogen	Steel tools not allowed	Steel tools allowed
*This is assuming hand powered tools where the potential to create multiple sparks is not considered credible.		

The exposure of operators to Zone 1 areas should be kept to a minimum; this becomes more important in the case of hydrogen compared to natural gas due to the increased likelihood of ignition of hydrogen (from both the reduced minimum ignition energy (MIE) and the larger flammable range). As an example, for the GDNs' operations this applies to the cutting of gas pipe. Risk assessments on cutting operations will need to consider the size of the hydrogen gas cloud that the operator could be exposed to, based upon the pressure and size of the pipe, whether the flow has been stopped, etc.

Other Zone 1 areas exist, such as venting drills and excavating leaks, and risk assessments will be needed for these operations. In some of these the GDNs will have to balance competing factors such as protection of workers working on a leak compared with the potential consequences of allowing the leak to last longer while the flow in the pipe is stopped.

2.0 ELECTROSTATICS

Electrostatic discharges from conductors (such as people or small metal tools) are large enough that they can ignite both hydrogen and natural gas (due to their large capacitances). However charging would only need to occur for 30% of the time, or less, of the time to achieve a voltage that can ignite hydrogen compared to natural gas. For personnel, this risk control can be achieved via appropriate antistatic/electrostatic discharge (ESD) footwear and clothing.

Handling of PE has been reported to produced voltages up to 9 kV and cleaning of dirt and dust off a pipe prior to joining can create voltages of 14 kV [7]; this voltage was reduced to below 500 V by application of a wet towel but the voltage doubled to 1000 V on removal of the towel. It was shown a wet rag discharged charge at the outer surface but not the inner after charging via swarf carried in the pipework [8].

Damp rag earthing is typically employed as a safety precaution when cutting into PE pipes following isolation. This is where a dampened rag is placed over the pipework being worked on in order to dissipate any static charge build-up that may be on the pipe. Network procedures state the damp cloths should be in contact with the ground on both sides of the pipe on both sides of the cut to be made to prevent a static spark.

The focus of this experimental work was to quantify the magnitude of discharge from the surface of electrostatically charged PE pipework in order to assess the potential for electrostatic based ignition of mains gas when pipework is breached during network operations such as cutting or drilling. This work also looked at the quantity of charge built up during cutting of PE pipe. The study aimed to investigate a worst-case scenario during these activities, i.e. a low humidity environment, clean pipe surfaces, pipework isolated from ground and pipework being electrostatically charged.

The testing scheme aimed to investigate the efficacy of the damp rag earthing technique for a number of potential scenarios:

- Correct earthing procedure i.e. rag makes good contact with the ground;
- Incorrect earthing procedure i.e. rag has no contact with ground; and
- Efficacy of earthing procedure at distance i.e. how effectively earthed the pipe surface is at various distances from the rag.

This is only applicable to PE pipes as metallic pipes are conductors and are earthed through contact with the ground.

Experimental Results

The pipework was tribocharged and transferred charge measurements made, as described in BS EN 60079-32-2:2015 [6] and BS EN ISO 80079-36:2016 [1]. The general principle of this method is to induce a charge onto a target by forcefully rubbing the surface with a suitable material i.e. a material that has a tendency to develop a positive or negative charge. The charged surface is then discharged by bringing a measuring electrode close to it and the magnitude of this discharge noted. This process is carried out 10 times in total. Figure 1 shows the typical test setup for the damp rag earthing investigation. The pipework itself was insulated from earth; an earthed metal sheet was placed on the stand to allow for earthing as desired.

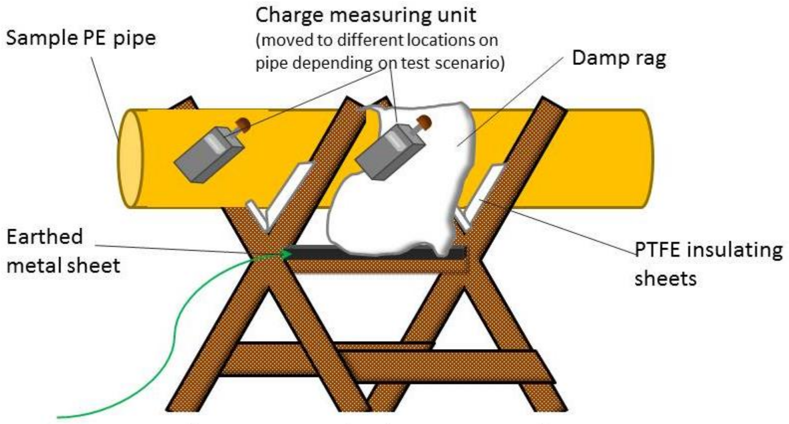

Figure 1: Typical damp rag earthing test setup. The pipework sample was isolated from ground using PTFE insulating sheets.

Tribocharging of the PE pipes of all diameters resulted in discharges above the level which is allowed by BS PD CLC/TR 60079-32-1:2018 [9] for use with both natural gas and hydrogen (see Table 2). BS PD CLC/TR 60079-32-1:2018 [9] puts a limit of on the possible charge transfer for Zones 1 and 2 of 10 nC for hydrogen and 60 nC for natural gas. The values are high enough to give a reasonable chance of ignition for all pipe diameters for hydrogen (assuming the pipe is in Zone 1 or 2). The maximum discharges for 63 and 250 mm pipes are similar to the lowest discharge values that have been observed to ignite methane (around 100 nC) [10] and the discharge is 168 nC for a 630 mm pipe.

Application of a damp rag that contacts earth removed the charge from the area and no discharges occurred to the probe; no discharge could be measured from the rag itself or from under it (see Table 2). The closest distance from a damp rag that a discharge greater than 10 nC occurred was 100 mm; this occurred from the 63 mm pipe. The suppression of incendive discharges was more effective for larger pipes, with measurements needing to be taken at further distances from the damp rag for discharges above 10 nC to occur. Often no discharge occurred from the pipe at all. These measurements were taken with the damp rags still in place.

Even when the damp rag was not earthed it often removed or reduced the size of the discharges. The discharges that did occur were not audible and the measurement on the charge meter increased slowly suggesting that multiple small discharges occurred that may not be energetic enough to ignite hydrogen.

Table 2: The discharges observed before and after damp rag earthing. The average is over ten measurements for each pipe diameter.

		63mm Pipe (nC)	250mm Pipe (nC)	630mm Pipe with the outer (removable) layer stripped (nC)	630mm Pipe (nC)
Typical charge obtained before earthing	Avg	-67	-55	-145	-138
	Max	-107	-106	-164	-168
Test 1: Ideal earthing of wet rag	Avg	0	0	0	0
	Max	0	0	0	0
Test 2: No earthing of wet rag	Avg	-20	-39	-20	-4
	Max	-43	-106	-69	-12

3.0 FRICTION IGNITION

A literature review [11] [12] of the information on ignition by friction and hot surfaces that was available at the time concluded that while methane (labelled as a Group I gas in that work) was more difficult to ignite than Group IIA gases such as propane. Both were relatively difficult to ignite except in the case of sparks from light metal alloys which can combust in air. Gases from Group IIB (such as ethylene) and Group IIC (such as hydrogen) were easier to ignite; this is shown in Figure 2. The experimental data reviewed [11] [12] was for methane, not for firedamp or natural gas. Recent work has supported the conclusions of [11] and [12].

Experimental data [13] [14] can be used to show that the minimum ignition energy (MIE) of hydrogen, ethylene, propane and methane correlates with ease of friction ignition. When considering the 20% (by mol) hydrogen-methane, the MIE is similar to that of propane so its potential to be ignited by friction should be considered to be similar to that of other IIA gases. There is no practical difference for friction ignition if blends between 16 and 25% hydrogen were Group IIB [2], as different precautions are only required when a Group IIC gas is or could be present (BS EN 1127-1:2019) [5]. BS EN ISO 80079-36:2016 [1] puts a 1 m/s limiting value for friction ignition, however hydrogen ignited at 0.7 m/s for a 0.7 kW circular saw with a 3000 N load cutting steel [15].

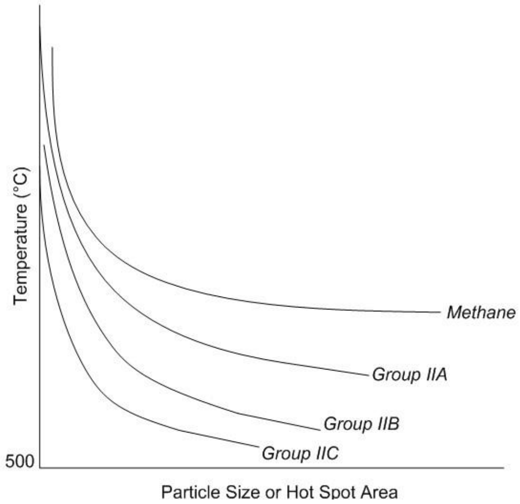

Figure 2: A representative graph to show how the ignition temperatures vary with particle or hot spot size.

Non-Sparking Tools

From the review of the use of non-sparking tools [12]; the evidence for their use is not clear due to competing findings, however it is stated that use of non-sparking tool "*may appreciably reduce the risks with more easily ignited gases*". H21 Phase 1 ignition experiments had ignitions of hydrogen for impacts of shovels on cables, steel and stone (flint) [16]. The GDN procedure currently states that "spark reducing" tools may be used and states that they will not entirely eliminate risks, that the ground must be wetted before using a pick where there is a leak, and wet rags wrapped around a pipe before breaking out with a hammer (the procedure also states the pipe should have been thoroughly purged). Hydrogen is one of the most easily ignited gases, so the use of non-sparking tools where possible would be a sensible precaution, but they may not entirely eliminate the risks of ignition. As discussed above, BS EN 1127-1:2019 [5] prohibits the use of steel tools that could generate a single spark in atmospheres that are expected to contain flammable concentrations of hydrogen (Zone 1).

The current steel hand tools (such as shovels, sockets and stillsons) are suitable for use in a hydrogen or natural gas Zone 2, so can be used alongside a live pipe, but not when there is work on a known leak or a break in containment planned for hydrogen. It would be simpler to manage if all tools were non-sparking rather than there being different tools for different jobs.

Cutting and Drilling of Pavements

This analysis considers cutting and drilling of stone, which includes barholing and rock drilling. For these to pose an ignition risk with hydrogen through the friction/impact on the rock, temperatures in excess of the autoignition temperature (AIT) of 560°C would need to be generated. Layer or particle ignition temperatures are in excess of the AIT, and tend towards the AIT for larger areas/particles (see Figure 2). This review could not find temperatures reached while drilling rock, the closest equivalent data was diamond cutting of glass where temperatures of 135°C were found [17]. Glass has similar chemical and structural compositions to rock; both are usually composed of silicates. It is judged that is unlikely the ground or drill bits reaches such temperatures as it would have been noticed by operatives as it would be glowing red and pose a burns risk.

The impact on the rock of barholing and rock drilling is unlikely to have significantly different risks for hydrogen and natural gas as the loads and cutting speeds, or impact speeds will be significantly lower than those to achieve ignition in [13] and [14]. There are, however, differences in risk posed by the equipment's inner workings.

Barholing is performed using simple hand operated equipment (i.e. no powered moving parts) and as such the equipment is not going to be ATEX rated. A single spark could be generated inside the barholing equipment where the two pieces of metal impact on each other. It should be ensured that there are no hydrogen gas concentrations above 20% LEL at the level above the ground where the two pieces of metal impact on each other.

Drilling is performed by pneumatic drills which could be a source of ignition through sparks or hot spots generated within the equipment (i.e. powered moving parts in the motor). There are three options for the continued use of rock drilling:

- Have the motor outside of any flammable regions (concentration less than 20% LEL) through the use of flexible drill shafts, etc.
- The motors should be Group IIC (or Group IIB + H_2) ATEX rated equipment if there is a chance that they could encounter a hydrogen atmosphere within the flammable range.
- Perform a Mechanical Equipment Ignition Risk Assessment (MEIRA) as per BS EN ISO 80079-36:2016 [1] to demonstrate the suitability of the equipment.

If non-ATEX equipment is used for cutting, it should be ensured that the works are at a safe distance from the leak where a flammable atmosphere cannot occur; this is the same for hydrogen and natural gas.

Cutting and Drilling of Live Mains

A possible update to the process is shown in Figure 3.

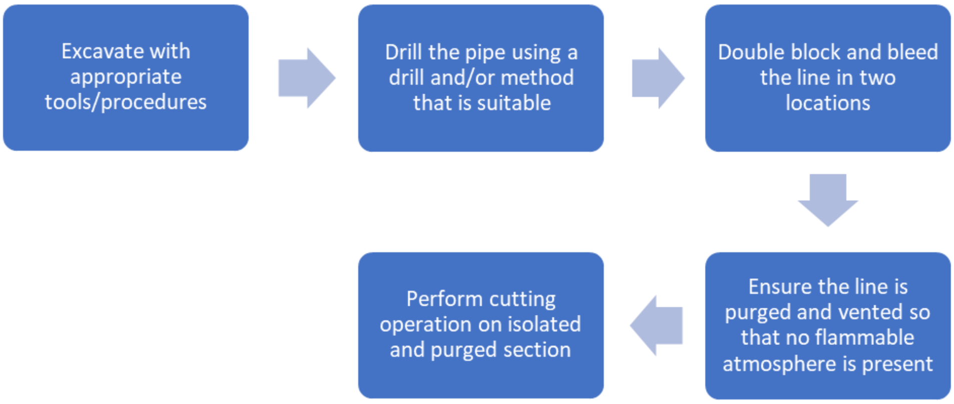

Figure 3: A possible change to the cutting and drilling procedures for metallic pipe.

Proven isolations such as double block and bleed are required to use multi sparking tools, if only a single isolation is used then a Zone 2 exists and only single sparking tools can be used. This analysis does not apply to the cutting and drilling of PE as a mechanical spark will not be generated and high temperatures cannot be achieved due to the low melting point of the PE (however, the motors would need to take the precautions above). Precautions against static discharges however will need to be taken in account for PE pipe. HSG 253 also recommends double block and bleed isolations.

Cutting operations cannot be considered of negligible extent as any flammable atmosphere is not contained and the operative would be exposed to the consequences of any ignition. Options for cutting hydrogen containing metallic pipes are purging the line or on dead mains the use of non-sparking blades. Currently pipes containing natural gas are vented but not purged before cutting.

A risk assessment would be required looking at the quantity of hydrogen released (for both metallic and PE pipe), taking into account factors such as the size and pressure of the line, whether the line has been stopped and whether it has been depressurised. BS EN IEC 60079-10-1:2021 [6] defines negligible extent (NE) as a volume that is not considered hazardous enough to require specific risk reduction measures. It states: *"An example of zone NE is a natural gas cloud with an average concentration that is 50 % by volume of the LFL and that is less than 0.1 m^3."* This corresponds with the definition of Vz used in previous versions of the standard and forms part of HSE's Quadvent Hazardous Area Classification tool [18]. As the LFL of hydrogen is 4%, a volume of 0.002 m^3 (at ambient pressure) or less is needed for NE to be concluded.

Temperatures achieved during drilling have been reviewed. PE pipe will melt at temperatures below 200°C which is well below any temperatures capable of causing ignition. Drilling steel can achieve temperatures in the region of 500-550°C with very high drill tip cutting speeds (100 m/min) [19] but only 200-250°C at more typical cutting speeds (25 m/min) [20]. Temperatures achieved drilling in cast iron are around 15% lower than in steel [21]. Other forms of iron could be considered to behave similarly.

Regardless, cutting or drilling of live hydrogen mains in metallic pipe is prohibited by BS EN 1127-1:2019 due to potentially creating a single spark using steel tools. However, if the flammable atmosphere inside the drill body was considered to be of negligible extent (NE) such that no significant injury or damage occurred, then the use of such equipment could be allowed.

Under pressure mains drilling

Under pressure mains drilling is performed using specialist equipment that attaches to the pipe and any gas released is nominally trapped within the body of the drill. Flammable atmospheres may occur in the drill body for natural gas at mains pressures in the range 46 to 200 mbarg, or between 41 mbarg to 3 barg for hydrogen. The pressure that could be generated in the drill body in the event of ignition have been calculated using GasEq; this assumed that there was no venting of pressure and no heat losses to the drill body or pipe, so are a worst-case pressure. The calculated pressures are shown in Figure 4, a zero has been entered where no ignition is possible because the concentration is outside of the flammable range. There are Zone 1 areas inside the body of the drill and where the vent is released, and a Zone 2 around the drill in case a release from the seal onto the main.

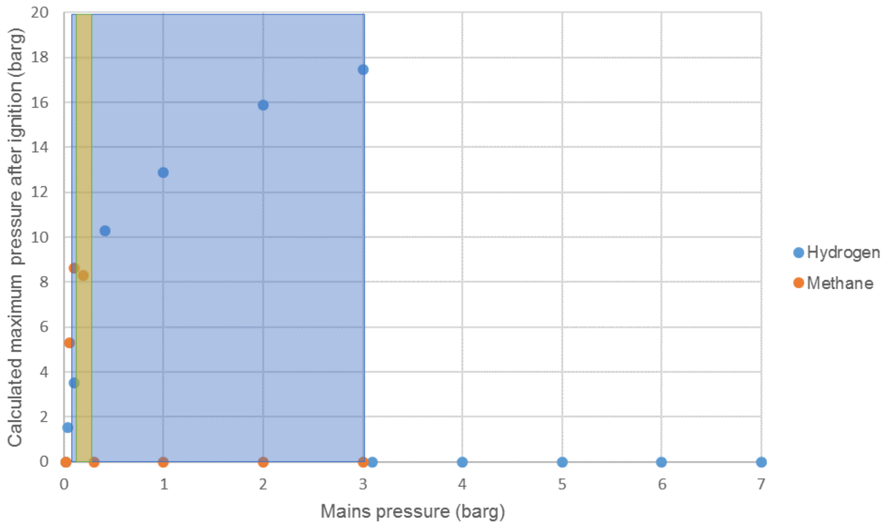

Figure 4: The pressures that could be achieved in a drill body as the result of an ignition during drilling of live mains. The flammable regions for methane and hydrogen have been marked in orange and blue flammable regions respectively.

To achieve NE, while drilling hydrogen filled metallic mains with a pressure that could achieve a flammable concentration in the drill body (41 mbarg to 3 barg), there are three potential options:

- Use a hand or mechanical vacuum pump to remove the air from the drill body:
  - This would reduce the oxygen content and so reduce the likelihood of ignition or prevent combustion if enough air was removed.
  - The lower starting pressure will reduce the over pressure generated by an explosion in the drill body.
- Inert the drill body with an inert gas by pressure swing purging
  - If there are two vent ports on the drill body then flow purging would be possible.
- Use a drill that has a maximum allowable working pressure (MAWP) above the overpressure that could be achieved if ignition occurred:
  - 41 mbarg ≤ pipe pressure ≤ 2 bar – a drill with a MAWP above 16 barg must be used.
  - 2 barg < pipe pressure ≤ 3 barg – a drill with a MAWP above 17.5 barg must be used.

The hierarchy of control should be considered, and prevention measures such as a vacuuming or inerting should be applied if reasonably practicable ahead of mitigation measures such as the drill withstanding the explosion.

Outside of the drill body a Zone 2 will exist due to the possibility of a leak from the drill body or due to a failure of the seal(s) onto the pipe. This cannot be considered as NE due to the potential for large leaks. If the drilling is done using a hand driven drill, then it will be classed as simple equipment and as such will not need to be ATEX rated, but this is only practical for smaller pipes. For powered/pneumatic drills, the options are the same as for drilling of stone (above).

Live Leak Repair and Service Isolations

The generalised method for live leak repairs involves drilling a 9 mm hole into the pipework which does not fully breach the main. A nipple with a rubber gasket is inserted into the hole. A 3 mm hole is drilled through the gasket and into the bell on the led yarn joint or gasket on the flange. An anaerobic sealant is then injected. Service isolation uses a similar method. Locking pliers grip onto the service to be isolated and contains a rubber gasket through which a 5 mm hole is drilled into the service. An aerobic sealant is then injected.

If the rubber gasket works as intended, then the quantity of hydrogen released will be small and can be considered a zone of negligible extent due to the small hole size and low pressure (up to 2 barg) in the pipe. It will need to be demonstrated that the rubber gaskets are effective at preventing the release of hydrogen.

However, if the gasket fails or the initial hole for the nipple is drilled all the way through, then a large release could occur. This release will be considerably larger for hydrogen compared to natural gas, and the hydrogen cloud will be easier to ignite. The size of the release and distance to ½ LFL is given in Table 3. While the leak rate will increase with pressure, the distance to ½ LFL varies little with pressure in the low pressure (LP) network (< 75 mbarg) but will increase in the medium pressure (MP) network (pressures between 75 mbarg and 2 barg). Vz needs to be less 0.1 m^3 for the release to be considered negligible, and none of the releases from the holes considered match this criterion. This increase in hazard places more emphasis on ensuring the initial hole drilled for live leak repairs does not breach the main, and that risks are reduced to ALARP.

The drills used for these operations need to be specified such that they are not a source of ignition. A Zone 2 will exist for the drilling of the initial hole or beyond the rubber gasket for the scenario of the larger release; the same options for the drills above apply to the drill used for these operations. The drill tip speed must be kept below 0.7 m/s to prevent ignition of hydrogen, this has been converted in revolutions per minute (RPM) in Table 3. All drills used should be limited so they cannot be a source of ignition of hydrogen through their tip speed.

Table 3: The leak rate for hydrogen from holes of various sizes in a main or service and distance to ½ LFL. The RPM to achieve a tip speed of 0.7 m/s is also calculated.

Drill size (mm)	RPM to achieve 0.7 m/s	Leak rate of hydrogen through hole at 22 mbar (g/s)	Vz (m^3)	Distance to ½ LFL (m)
3	4456	0.13	0.7	2.6
5	2673	0.37	3.4	4.3
9	1485	1.21	19.9	7.8
10	1336	1.50	27.3	8.6

4.0 FLOW STOPPING

Basis of Safety of the Operation

The basis of safety for the use of flow stops with hydrogen should change from that for natural gas. The basis of safety should now include preventing an ignitable atmosphere in the region to be cut rather than solely re-pressurisation of the section and/or excessive losses from the network. This is due to the increased ignition sensitivity of hydrogen compared to natural gas; some existing tools and procedures that are suitable for natural gas are no longer suitable for use with hydrogen.

Current GIS criteria for effectiveness of flow stopping look at the leak rates of one stop at their maximum usage pressure. A new criterion for judging the effectiveness of flow stopping for use with hydrogen was developed based upon the differential pressure across the secondary stop being low enough to avoid a flow forming an ignitable concentration in the section to be cut within given times.

The pressure dependence of the flow stopping technique needs to be determined to calculate the pressure at which the prescribed maximum flow occur. This calculated value from laboratory testing needs to be greater than 0.2 mbarg so that the prescribed maximum flow will not occur in practice. Operatives using flow stopping methods could measure the pressure generated on the intermediate vent, and this should be less than 0.2 mbarg to demonstrate effectiveness. A number of flow stopping methods within scope of the trials were tested against this criterion.

Stopping Method Effectiveness

The GISs for the different flow stopping techniques have a method specified for testing the leakage past the flow stop. There are slight variations in the methodologies, but the biggest variation is whether the flow measurement is up or downstream of the bag. The first phase of testing in this work reproduced the test set-up from GIS/E4 [22] as far as possible with minor modifications to allow a nitrogen purge before the introduction of hydrogen and measurement of pressure after the flow stop. This set up had the advantage of not measuring leaks from the equipment at the high-pressure (upstream) side of the bag stop.

The experimental set-up was modified for the second phase of testing (see Figure 5a); the flow meter was installed before the bag stop so that the pressure drop across it did not interfere with the flow past the stop, and an end of line flame arrestor was installed so that the back pressure from a vent that represented one used in operations could be measured.. Figure 5b shows the squeeze off of a 400 mm PE SDR 21 pipe.

The pipe was purged with nitrogen to ensure an oxygen free environment, then with hydrogen. The flow stopping technique was deployed with hydrogen at ambient pressure, then the gas flow started. The pressure was gradually increased up to the maximum for the technique in a series of steps. The pressures measured were for flowing conditions using pressure transducers, and the flow was measured using a Bronkhorst Mass-view. Steady state measurements were taken after any initial flows had subsided. After the measurements, the pipe was depressurised and purged with nitrogen before the flow stopping equipment was removed.

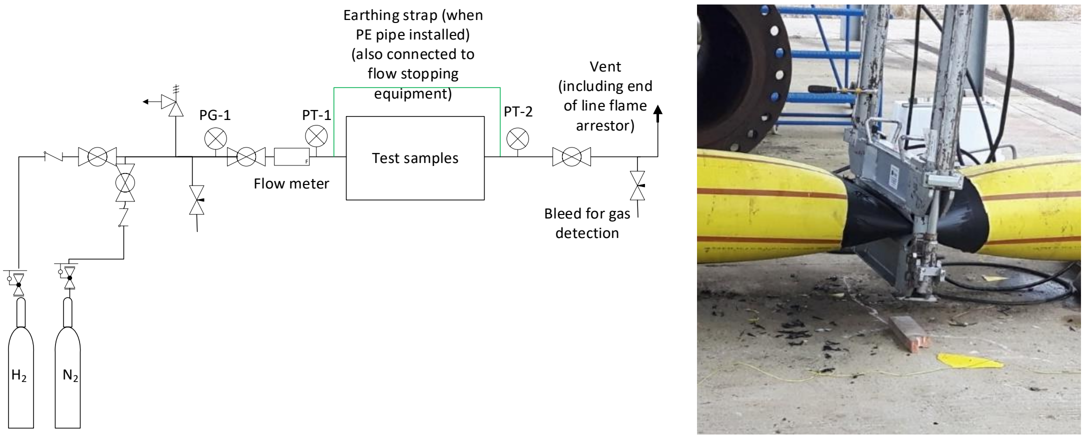

Figure 5: (a, left) the P&ID from the second phase of testing, (b, right) the squeeze off of a 400 mm PE SDR 21 pipe.

It was recommended following a review of the procedures and relevant guidance that only double isolations are used with hydrogen (the two stops are referred to as primary and secondary). The important factor in determining safety is the flow past the secondary stop, and whether it builds to an ignitable concentration. The following method can be used to calculate the maximum allowable flows past the secondary stop:

1. The theoretical upper limit of the time required to make a cut has been estimated.
2. The flow rate to just achieve an ignitable mixture (5.5 vol% hydrogen) in the pipework volume to be cut can be calculated (permissible volume flow past the secondary stop).
3. The flows can be measured experimentally for a single stop for a range of pressures.
4. The flow rates from 3 can be used to calculate the differential pressure needed across the secondary stop to achieve the maximum flows calculated in 2.

Figure 6 summarises the results of these calculations. The higher the calculated pressure, the better the flow stop is performing. The criteria of 0.2 mbarg developed in this work has been shown. Those which fail the criteria are highlighted in red. The graph has been blown up to ease viewing.

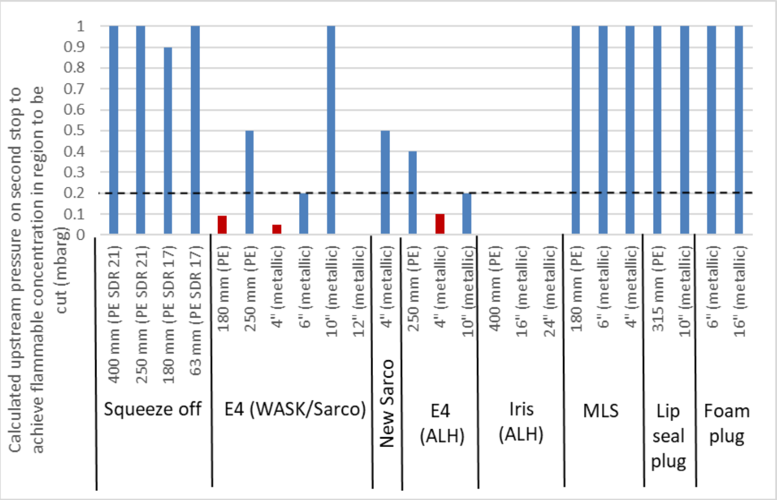

Figure 6: The calculated upstream pressures required on a secondary stop to create a hazard beyond it.

Based on the limited testing performed, some existing flow stopping methods performed well against this new criterion of allowable pressure on a secondary stop, but others will require some development work for continued use.

Testing showed that squeeze-off, MLS, lip seal plugs and foam plugs performed well and met the new criteria. For MLS, lip-seal plugs and foam plugs, so little flow occurred that it was not measurable, and hence no pressure build up was measured after the flow stop. Squeeze-offs were also found to be effective, and in the case of SDR 21 pipes, the flow past was too low to measure.

E4 bags appear to need some development, such as optimising bag inflation pressures, to make them suitable for use with hydrogen. New bag technologies could be developed, or the shape and design of bags changed to promote laminar rather turbulent leaks (such as longer bags). Promoting laminar leakage leads to better performance at low pressures, and the leak rate past the flow stop will fall away significantly faster with pressure. This could be done by increasing the contact length and/or decreasing the diameters of the leakage paths gas passes through. E20/IRIS proved difficult to get a seal with hydrogen.

The results of this testing programme were obtained for particular samples of pipe under given ambient conditions. Multiple repeats of the flow stopping techniques were not performed, and in most cases multiple different pipe samples of the same size and material were not used. The test results are therefore indicative in nature and serve as a guide as to which stopping methods appear to be effective or not.

5.0 CONCLUSIONS

The commonly used technique of earthing PE pipe using a wet towel has been shown to be effective for use with hydrogen. Application of a damp rag that contacts earth removed the charge from the area and no discharges occurred; no discharge could be measured from the rag itself or from under it. The closest distance from a damp rag that a discharge greater than 10 nC (the allowed limit on the charge for hydrogen) occurred was 100 mm. The suppression of incendive discharges was more effective for larger pipes, with measurements needing to be taken at further distances from the damp rag for discharges above 10 nC to occur. Often no discharge occurred from the pipe at all. Even when the damp rag was not earthed it often removed or reduced the size of the discharges measured.

The potential for friction ignition was reviewed; it was concluded that no significant changes were need for 20% hydrogen blended into natural gas, but that changes are required to procedures and tools when using hydrogen. Non-sparking tools are recommended as a sensible precaution, but are unlikely to completely remove the risk of ignition. Barholing should not be done where there is 20% LEL at the level where the metal on metal impact occurs. Limits should placed on motors (including pneumatic) to prevent them being an ignition source. Under pressure drills have been shown to suitable for continued use provided certain conditions are met. Drills speeds should be limited to 0.7 m/s when not encapsulated.

The basis of safety for the use of flow stops with hydrogen should change from that for natural gas. The basis of safety should now include preventing an ignitable atmosphere in the region to be cut rather than solely re-pressurisation of the section and/or excessive losses from the network. This is due to the increased ignition sensitivity of hydrogen compared to natural gas; some existing tools and procedures that are suitable for natural gas are no longer suitable for use with hydrogen.

A new criterion for judging the effectiveness of flow stopping for use with hydrogen was developed based upon the differential pressure across the secondary stop. This need to be low enough to avoid a flow forming an ignitable concentration in the section to be cut within the time required to make the cut. Based on the limited testing performed, some existing flow stopping methods performed well against this new criterion, but others will require some development work for continued use.

6.0 ACKNOWLEDGEMENTS AND DISCLAIMER

This project was funded by Ofgem and led by Northern Gas Networks as part of the H21 Network Innovation Competition project. The contents, including any opinions and/or conclusions expressed, are those of the authors alone and do not necessarily reflect HSE policy.

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