Safety review

The hazards of confined space operations

Tony Fishwick

Introduction

Previous articles in this series of safety reviews have focussed on the hazards associated with potentially dangerous chemicals, and others on the same theme will follow. However, some operations present situations that are at least equally hazardous, and working in confined spaces is a particularly good example. Dangerous situations and occurrences arise extremely frequently in these circumstances, have led to many serious accidents, and continue to do so. This article looks at different types of confined spaces and the dangers inherent in them, legal requirements, methods of avoiding or minimising risks, and arrangements for dealing with emergencies. Case studies are presented to illustrate some of the potential hazards and how they were dealt with.

Types of confined space

A confined space can be defined as *'any space of an enclosed nature where there is a risk of death or serious injury from hazardous substances or other dangerous conditions e.g. lack of oxygen*.'[1] Some are easy to define, like storage tanks, silos, sewers, large pipelines, flare stacks and other enclosures with limited openings and access. Others are less obvious, such as open-topped chambers and pits, ducting, floating roofs, ship's cargo holds and congested areas with restricted air circulation. There are many other examples, as accident statistics and types verify. They exist in all areas of industry, commerce and academia, not just the process sector. Other examples are in the agricultural industry, where grain silos, slurry pits, and glass houses into which carbon dioxide is introduced to promote plant growth are just some of the items that fall into this category. The Health and Safety Executive (Great Britain) publishes advice on how to manage these safely[2]. Civil engineering, with dangers inherent in trenches, pits and culverts and the shipping industry, where confined spaces can exist in the holds and boiler rooms of vessels, are other sectors that present these hazards. The case studies describe accidents that occurred in several of these areas, with varying causes and consequences.

The dangers from confined spaces

The main hazards associated with confined space working can be summarised as follows:

- lack of oxygen – this can be caused by release of toxic gases from sludges, purging with nitrogen and reactions between oxygen and other materials resulting in oxygen depletion;
- presence of poisonous gases – these can accumulate in sewers, manholes and pits, leak from refuse tips, occur due to fires and explosions, or arise from residues and sludges;
- use of machinery – this may also require protection against dust, electric shock or fumes from welding;
- items falling from above or trench walls collapsing;
- restricted escape routes, for example through a manhole;
- liquids or solids that suddenly fill the space, or release gases into it, when disturbed (free-flowing solids such as grain, or finely divided powders, can have the same effect; these usually arise because of inadequate isolation);
- fire or explosion;
- residues inside vessels which might give off toxic fumes;
- hot conditions leading to a dangerous increase in body temperature;
- poor lighting and visibility;
- electricity, including static;
- presence of dangerous conditions and substances such as radioactivity, pyrophoric materials and bacteriological hazards;
- attempting to rescue a person without first taking proper precautions which is also a matter for emergency arrangements as discussed below;
- inadequate isolation of the confined space before work begins which, in many ways, over-arches all of the above.

Adequate isolation means:

- physical breaks in all pipework leading to, or from, any vessel or other space that is to be entered including those that are not actually 'vessels' at all for example, trenches and pits;
- if that is not possible, then at the very least, insertion of a blank spectacle plate into all pipelines;
- isolation from all sources of electricity, pressure, vacuum, excessive heat, or severe cold and moving machinery.

It is also important to recognise that persons outside a confined space can sometimes be at risk from conditions inside the space. One of the case studies exemplifies this.

The size of the problem – confined space accident statistics

Between 2003 and 2011 there were 29 fatalities due to confined space working reported to the Great Britain Health and Safety Executive (HSE). During the same period of time, eight fatalities occurred in Australia. In the USA, US Bureau of Statistics data shows that 350 workers died as a result of trench walls collapsing on them between 2000 and 2009 and, in some

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years, a further 50 fatalities occurred due to other confined space causes. Data from OSHA tells a similar story for the USA – 63 confined space worker fatalities in 2010 and a further 22 in the first half of 2011[3]. These figures show that confined space working presents significant hazards across international borders though there is a need to allow for the effects of different systems for reporting and classification. There is evidence that many of these accidents have similar causes, indicating that recurrence is a determining factor.

Although details of confined space accidents in Great Britain are not easy to find, some reliable sources estimate that actual figures are even higher than those given above. For example, the Institution of Electrical Engineering has stated a view that the true figure for fatalities might be as high as 15 per year[4]. This, if true, would indicate some degree of under-reporting or misclassification.

US Bureau of statistics also show that about 60% of confined space fatalities occur to people trying to rescue colleagues already trapped inside the space.

Recent HSE statistics[5], although not presenting confined space accidents as a specific category, lend further support to the belief that the problem is a continuing one, since it is reasonable to conclude that some, perhaps most, of the accidents summarised in Table 1 fall into this category.

Accident type	2011/12		2012/13	
	Fatal	Non-Fatal but Major	Fatal	Non-Fatal but Major
Trapped by something collapsing or overturning	14	88	6	105
Asphyxiation or drowning	8	6	3	7

Table 1: Extract from HSE Statistics for Workplace Injuries

Legal requirements

In Great Britain, the legal requirements for working in confined spaces are contained in the Confined Spaces Regulations 1997, Statutory Instrument No 1713[6] and associated Code of Practice[7]. Guidance on how to comply with this legislation is provided in HSE's document at Reference 1. Underpinning this are the Management of Health and Safety at Work Regulations 1999 which require the carrying out of a *suitable and sufficient assessment of the risks for all work activities to decide what measures are necessary for safety*. If this assessment identifies risks of serious injury from confined space working, the Confined Spaces Regulations then set out the following key duties:

- avoiding entry into the confined space if possible;
- if entry is unavoidable, a safe system of work must be followed;
- adequate emergency arrangements must be put in place.

Avoiding entry to the confined space

Consideration should be given to possible alternative ways of doing the work for example, by the use of remote equipment. It may be possible to use vibrators, rotating flails or purges to clear blockages. Inspection or sampling can often be done from outside the space. Remote cameras can sometimes be used for internal inspections of vessels.

If entry cannot be avoided – safe systems of work

The risk assessment will help to identify precautions needed to reduce the risks of injury. These will need to be put in place and everyone involved in the job trained and instructed as to how they can carry it out safely. Key points for consideration would include:

- detailed planning for, and adequate supervision of, the job;
- suitability and competence of the people doing the job – have they got sufficient experience and been adequately trained, are they claustrophobic and are they comfortable wearing respiratory protection? Are they healthy – even if they just have a heavy cold they might be more sensitive to heat stress than usual? Account must certainly be taken of more serious, or permanent, conditions such as angina or asthma;
- mechanical and electrical isolation;
- shoring up of trench walls to prevent them from collapsing inwards;
- draining, flushing, cleaning, purging and ventilation of the space;
- size of the entrance to the space and how people could be got out in an emergency; defined access and escape routes (normally minimum of two);
- adequate cleaning of the space before entry;
- testing of the air inside the space for toxic or flammable vapours and oxygen concentration all against relevant standards; making the atmosphere safe to breathe if at all possible; provision and use of adequate ventilation and respiratory protection if the air is not fit to breathe;
- emergency arrangements, including training, practice drills and provision of rescue harnesses;
- communications between people inside the space and those outside it; use of two-way radio systems; positioning of a standby person outside the space;
- a tally (or other) system for checking people in and out of the confined space;
- permit to work aimed at ensuring that all the elements of a safe system of work are in place and complied with and raised and approved by designated persons. An excellent description of the requirements of a confined space permit is included in Reference 8.

Emergency arrangements

Even with the best systems in place, things can still sometimes go wrong, and people can then be exposed to serious and immediate danger. It is because of this that effective arrangements for raising the alarm and dealing with the emergency are essential. The exact nature of these emergency arrangements will depend on the type of confined space, the job being carried out and the potential risks identified. However, some key features are common to all types of work and these would include:

- Effective communications so that the emergency procedures can be put into effect at any time. The different

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demands presented by shift and weekend working, or work during holiday periods, need to be accounted for.

- Provision of rescue and resuscitation equipment and adequate training in its use. One of the case studies that follow illustrates a potential pitfall in this respect.
- Ensuring that rescuers are fully capable and trained and fit for the work. They should be able to use any rescue equipment, for example, breathing apparatus, lifelines and fire-fighting equipment. They should be trained in first aid.
- As far as is practicable, emergency procedures should be regularly rehearsed and practised. It will not be possible to foresee all potential accidents, but there will be generic features that are common to many jobs.
- Involvement of local emergency services so that they have sufficient familiarity with the plant before an emergency occurs.
- *A golden rule* – if a person has collapsed inside a confined space *never* enter the space to help or rescue them without first putting on respiratory protection. The dangers of ignoring this rule are graphically and tragically demonstrated by one of the case studies. Rigorous training and adequate rehearsal of emergency arrangements are the key to preventing people attempting this highly dangerous procedure though it is always done with the best of intentions. The *golden rule* is necessary because, if a person is collapsed inside a confined space, then going in without respiratory protection to help them will almost certainly result in the helper suffering the same fate.

Case studies

Accidents involving confined spaces are, sad to say, many and varied. A selection is presented to demonstrate the different ways in which these have happened.

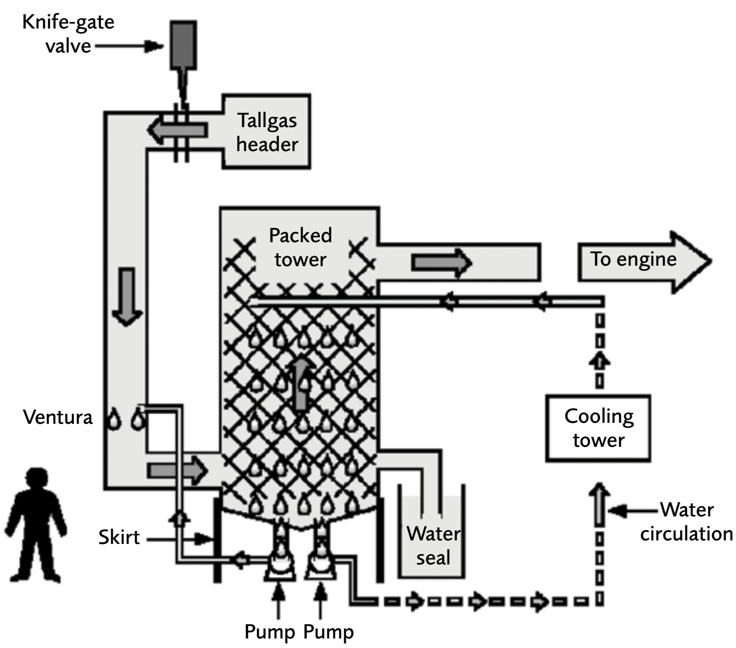

Figure 1: Waste gas tower, water seal vent valve closed

Inadequate isolation and failure to recognise a confined space

An electrician and a student were working underneath a waste gas tower (Figure 1[9]). They were on their hands and knees inside the skirt under the tower. The skirt was designed to prevent any impact from passing traffic, such as fork lift trucks, with the valves, pipework and pumps under the tower. It had four arched access openings in it. The electrician became motionless and unresponsive. Fortunately, the student remained conscious and was able to get out of the skirt and pull the electrician clear. Both of them recovered. The fumes contained a mixture of carbon monoxide, dihydrogen sulphide and hydrogen cyanide and these were present inside the skirt due to a combination of inadequate isolation, poor venting and failure to recognise that, despite the openings, the skirt was a confined space. Air circulation was poor and was exacerbated by the fact that the tower was located in a congested area of the plant. The fumes were present inside the skirt because purging and venting of the tower was not carried out properly. The water seal vent was not open to allow toxic gases to be purged.

Careless use of rescue equipment

An operator was cleaning inside a reaction vessel. The vessel had been emptied, purged and correctly isolated. The operator was wearing the correct protective clothing including breathing apparatus. He had a fully functional two-way radio system to keep him in contact with the standby man stationed above the open manhole of the vessel and was wearing a harness connected to a mechanical winch designed to get him out of the vessel. It seemed that everything was in place and nothing could go wrong. He called the standby man on the radio to say that he wished to come out of the vessel in order to visit the toilet. The winch was set in motion to raise him out of the vessel. As he was being lifted, one of his arms became entangled with a cross-member beam inside the vessel and was broken in two places before the standby man could stop the winch. Mechanical winches that 'brake' when they encounter any obstruction are available commercially. They can then be reversed until the obstruction is freed. The risk assessment had been inadequate.

An accident in the civil engineering sector showing the dangers of an ill-advised rescue attempt

Four workers had the job of spray painting the walls and ceiling of a box culvert under a road carriageway (Fig 2a and b[10]). Three of them were killed as a result of acute toluene poisoning. They set up a blower at one end of cell 1, then workers 1 and 2 spray-painted for almost one hour before leaving because they could no longer stand the smell. They were replaced by workers 3 and 4. On hearing cries for help from them, workers 1 and 2 re-entered the cell but worker 1 felt nauseous, so he again left the cell but then passed out. The foreman arrived and found the three workers collapsed inside cell 1. Emergency services removed them but they were all dead.

The cell of the culvert, a small space with access restricted by soil, was not recognised as a confined space, so a risk

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Figure 2a: Restricted access to cell 1 under carriageway

assessment was not carried out. Respiratory protection was only provided for the worker actually spraying and it was the wrong type, being for particulates not for aerosol solvents. Most tragically of all, workers 1 and 2 went back into a toxic atmosphere without any respiratory protection and worker 2 died as a result. Some estimates place the percentage of fatalities resulting from ill-advised rescue attempts at as high as 60% of all confined space fatalities.

Fatalities due to a fire in a tunnel

Five workers died in an accident at a hydroelectric plant. They were part of a group of 11 painters working in a tunnel and using a cleaning product that contained flammable solvent. The solvent ignited, presumably due to a spark, and the flames spread to open buckets of the solvent and other flammable material. The five workers were trapped behind the fire and died from smoke inhalation. The possibility of fire had not been anticipated. Flammable material should not have been left in open buckets, especially in a confined space.

Fatality due to total disregard of confined space entry procedures

A supervisor entered an underground motor fuel storage tank that was to be cleaned out. The tank had been embargoed for entry due to a change of plan and this had been made clear and the tank cordoned off (Fig 3[8]). He lowered a bucket and shovel into the tank to enable him to remove sand that had been put in as part of the previous plan to abandon the tank. He plugged his nose and ears with toilet paper and put one end of a rubber hose into his mouth to act as a snorkel. The other end was fixed near to the tank manhole. He lowered himself into the tank and was immediately affected by the fumes inside. He tried to breathe through the hose and climb up the rope to get out of the tank. The standby man tried to pull him out but he was too heavy so the fire and rescue services were called. By the time they arrived, the supervisor was dead.

This tragic accident was a result of blatant disregard of procedures and specific safety instructions possibly motivated by a misguided attempt to attempt to impress the project management. The accident is described more fully in

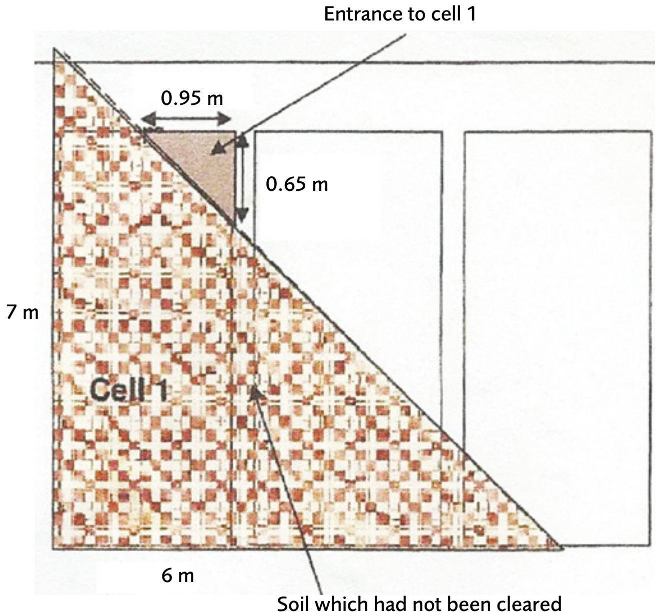

Figure 2b: Dimensions of access to Cell 1

References 8 and 11.

Static electricity causes a confined space fatal accident

A tank that had contained methyl tertiary butyl ether was being cleaned using a rotating high pressure water nozzle through the top manhole. An explosive atmosphere had been inadvertently created inside the tank when a vacuum truck sucked some vapour out of the tank and air was drawn in. The fine water mist generated by the pressure cleaner set up a static discharge and this ignited the explosive atmosphere in the tank. The explosion blew an operator off the roof of the tank and killed him[8]. He was outside the confined space, but he still perished.

A fatal accident in an office

A worker was re-laying plastic floor tiles inside a small cupboard in an office corridor. He was using a solvent-based, quick-setting adhesive. The fumes overcame him and he fell forwards into the adhesive, where his face became stuck. He died from inhaling the fumes[8]. This was an accident that could

Figure 3: Underground tank with entry forbidden

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have happened in almost any place of work or, indeed, the home. When working in small spaces with any substance that might give off noxious fumes, respiratory protection must be worn if practicable. If not, then adequate ventilation must be ensured. Proprietary adhesives and solvents, available at any DIY shop, always display warnings about this.

A flash fire in a tanker in a shipyard

Repairs were being carried out on a tanker in a shipyard when, without warning, a huge fireball was emitted from a manhole on deck. A man, engulfed in flames, was ejected from the manhole. He was doused in water but died in hospital from serious burns. Below deck, six other workers died, four from burns and two by asphyxiation. The workforce had just returned from lunch to resume cutting away rusted parts of a tank and welding in new steel plates. A flammable atmosphere, thought to have been created by a leak from acetylene cylinders, was ignited and led to a flash fire. When workers leave a confined space for a period of time, for example a meal break, gas tests should be carried out before they re-enter the space, to check that conditions are still safe[8].

Avoiding or minimising the risks from confined spaces

In principle, the means of avoiding accidents in and around confined spaces are very similar to those associated with any other type of accident. Thorough planning and preparation, adequate isolation, use of appropriate personal protective clothing, an effective risk assessment and emergency plan are key factors, as is not attempting rescue unless properly equipped. All this is common knowledge, but confined space accidents continue to occur and, more importantly, *recur.* Why should this be so? The late, highly respected, safety practitioner Trevor Kletz, identified the loss of 'corporate memory' as a significant reason and there is a lot of evidence to support this[12]. The lessons learned from accidents are not always properly recorded and passed on. Experience and skills are lost when people retire or staff cuts are made. Greater use of contractors can increase hazards if they are not properly trained. Overloading supervisors, who are the vital interface between management and the workforce, can result in ineffective control and leadership. Understaffing often results in people taking dangerous short cuts. A good 'accident avoidance' plan, would be to collate all these, and other, factors as they apply to confined spaces, into a comprehensive package to be used for training and information.

Getting the message across effectively is the next step forward. Proper training is essential, and thought needs to be given to the best techniques, as these will vary from situation to situation and place to place. However, there are a few tools that can be helpful across the board. These include:

Tool box talks (TBT)

A TBT is an informal way of informing the workforce and getting their views in an interactive manner on topics related to safety. A TBT on confined spaces (of which IChemE has an available example) would typically include case studies, lessons learned, prevention of recurrence, types of confined space and how to make them safe. Heavy emphasis would be placed on the extreme dangers of entering confined spaces without respiratory protection in order to rescue colleagues. The group should be encouraged to map out a way forward to be applied to their own specific circumstances.

Mental imaging

Participants should be asked to imagine the worst possible outcome from a particular set of circumstances, then what they would do to avoid it. Visual aids depicting real outcomes from previous accidents can be used to support the discussion. The technique yields best results when used as part of a step-by-step package incorporating interactive stages such as examining the reasons for unsafe behaviour, encouraging suggestions for safer behaviour and others. When used in this way quantified reductions in accident rates over a period of time can usually be observed[13].

Emergency planning

As already stated, different situations will require different responses to any emergency but there will be some common themes including risk assessment, fire fighting skills, isolation from noxious substances and sources of pressure or electricity, rescue techniques and use of effective PPE.

Whatever means are chosen, there must be a single, common objective – be a 'what if' person and avoid the accident, not an 'if only' person after it has happened.

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Dear Editor

As a member of the Loss Prevention Panel, may I offer a few words on two confined space incidents?

The first incident occurred at ICI's Wilton site between about 1978 and 1980 when I was the plant manager (aged ~30) on T7 Oxidation. This was a plant which made crude terepthalic acid (an intermediate in the production of polyester) from the oxidation of paraxylene in a catalyzed acetic acid medium. The vessel in question carried out a crude separation of the catalyst to recover the solvent and had a slow moving (~ 15rpm) anchor agitator which scraped the walls of the vessel. The plant was 'high maintenance' i.e. it shut down regularly and during one of these shutdowns we decided to carry out repair work inside the vessel (I can't remember what, but it involved 15-20 people working inside the vessel at the same time). All the usual isolations were carried out and vessel entry permit issued (by myself) under reg 7. The requirement for electrical isolation was that there should be two barriers. At the agitator motor we had a choice of either removing the coupling or disconnecting and wrapping the cables, we chose the latter. The second level of isolation was to lock off the MCC (motor control centre). On the day of the incident, the first day of the entry, it was raining very hard and the cable managed to connect between the junction box and earth (the handrail) and the motor kicked. We had isolated the wrong MCC. No one was injured.

As the plant manager it was my job, under reg 7, to inspect the isolations and issue the entry permit. All the rules were followed but:

Lesson: You see what you expect to see.

Another incident occurred around 1986 in New Zealand. I was the technical manager at the time so on the fringe of the entry.

An entry was required on a very long steam drum which had a small oval manway at each end. Time was short and it was decided that the vessel had cooled sufficiently to permit an entry. The entry was performed and the work carried out, but when things heat up they swell – which the human body does also. The man inside found himself unable to get out of the manway and he was beginning to show signs of claustrophobia. The solution required him to strip naked, be greased all over with margarine from the mess room, have his hands tied together and be pulled through the manway. He came out like a cork from a bottle!

Lesson: All things expand with increasing temperature and margarine is better than butter!!

Colin Feltoe FIChemE

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