CHEMICAL ENGINEERING TRANSACTIONS
VOL. 77, 2019

A publication of
AIDIC
The Italian Association of Chemical Engineering
Online at www.cetjournal.it

Guest Editors: Genserik Reniers, Bruno Fabiano

ISBN 978-88-95608-74-7; ISSN 2283-9216

DOI: 10.3303/CET1977168

A Semi-Quantitative Risk Assessment Method in Process Plants: Confined Spaces

Salvina Muré[a*], Gianfranco Camuncoli[a], Micaela Demichela[b]

[a] ARIA Srl, Corso Mediterraneo 140, 10129 Torino, Italy
[b] Dipartimento di Scienza Applicata e Tecnologia, Politecnico di Torino, Corso Duca degli Abruzzi 24, 10129 Torino, Italy
salvina.mure@aria.srl

The purpose of the present work was to develop a methodology for the confined spaces risk assessment in the workplace. Within the technological risk function, R=PxD, in order to account for the specific features of confined spaces, the probability of occurrence P was defined in two indices: the frequency of exposure to confined spaces, F, and the contact time I (strictly related to the complexity of the intervention that must be performed). The damage M has been separated into specific parameters considering the energy, the environment and the geometry of the confined space under examination, and in detail:

- ✓ an incorrect or not correctly signalled insulation that may lead to a sudden operation of part of the system with consequent accidental leakage of fluids or substances inside the confined space and / or movement of any mechanical part, with the energy damage factor D_E;
- ✓ the atmosphere present in the confined space, which may be poorly oxygenated, corrosive, harmful, toxic or potentially explosive, with the environment damage factor D_A.

Moreover, as a specific corrective factor of damage factors, the criticality of the physical and geometrical characteristics of the confined space is evaluated, considering how it's easy for the worker to leave the confined space or to be rescued if he feels bad, with the factor of FCD_G geometry damage correction. Once the damage factors have been identified and corrected with the FCD_G factor, the specific risks of the confined space are evaluated by multiplying each damage factor by the probability of occurrence P, thus obtaining the index of:

- ✓ Risk of contact with hazardous substances or with moving mechanical parts;
- ✓ Asphyxiation risk;
- ✓ Chemical risk;
- ✓ Risk of fire and explosion.

The application of this method to the confined spaces of a real process plant allowed to validate the methodology.

1. Introduction

According to English institute for the Health and Safety Executive (HSE) *a* confined space is a place which is substantially enclosed (though not always entirely), and where serious injury can occur from hazardous substances or conditions within the space or nearby (e.g. lack of oxygen). In order to evaluate and manage the risk in confined spaces, regulations, standards and guidelines have been developed in the last years. The Italian regulation deals with in particular the qualification of companies and self-employed workers operating in suspected pollution or confined environments in the President of Republic Decree n. 177/2011. The Italian National Institute for the Insurance against Occupational accidents and Professional diseases (INAIL) highlighted in its guideline “Specific risks while entering silos, basins and septic tanks, sewerage collectors, purifiers and tanks for the storage and transport of hazardous substances – art. 66 of the Legislative decree 81/08” the dangerousness of confined spaces for the limited or restricted areas where employees enter and perform a specific task (INAIL 2012).

Paper Received: 8 February 2019; Revised: 7 April 2019; Accepted: 2 July 2019

Please cite this article as: Mure S., Camuncoli G., Demichela M., 2019, A semi-quantitative Risk assessment method in process plants: confined spaces, Chemical Engineering Transactions, 77, 1003-1008 DOI:10.3303/CET1977168

Several publications and reports treat the accidents and the risks of confined spaces (NIOSH, 1994) and (OSHA, 2015b), fire, explosion, contact with high temperature object, etc. Despite the efforts made so far, it was not defined in the standards and/or guidelines a methodological approach to be adopted in order to develop a risk assessment for confined spaces (Comberti et al., 2017). Botti, et al., 2018 describes as a structured comprehensive methodology to assess and control risks associated with working in confined spaces, based on confined space regulations and standards, but a risk assessment support is missing. In this work we propose a specific methodological approach to evaluate and manage the risk in the confined spaces considering the criticalities signalled by INAIL in the its guidelines.

2. Methodology for risk assessment in confined spaces

Article 2 s) of the Italian Legislative Decree 81/08 defines risk as the probability of reaching the potential level of damage during the use and/or exposure to a certain factor or agent.
As a consequence, the results of the risk assessments are obtained through the product of two numerical factors, that express the frequency of occurrence of an incidental event, and its related damage. Risk can therefore be expressed as follows:

$$R = P \times D \quad (1)$$

where: R = risk index; P = probability of occurrence; D = magnitude of the damage.

However, for a more effective and punctual risk esteem, a third factor should be considered: the parameter "Correction Factor" (PeP) is a number between 0 and 1 that considers the preventive and protective measures applied for the risk reduction. The formula for the risk index is modified as follows:

$$R = P \times D \times PeP \quad (2)$$

The introduction of PeP parameter allows the evaluators to contextualize the risk for the examined situation, obtaining the real level of risk to which the workers are exposed, the so-called residual risk.
As far as it concerns the Frequency of occurrence F, it derives from the combination of two indexes:

- ✓ the frequency of exposure to 'Confined spaces risk' CF;
- ✓ the duration of the contact I, that is necessary to complete the requested task (strictly depending on the complexity of the task itself).

As far as it concerns the Damage D, it is subdivided in factors that express the energy, the type of environment (Murè et al, 2017) and the spatial characteristics of the examined confined space. These factors were identified on the basis of two sources the criticalities signalled by INAIL in its guideline and the case history of the accidents that occurred in Italy in the last years.
The damage factors consider:

- ✓ problems deriving from an incorrect or inadequately signalled confinement, that can bring to the unforeseen activation of part of the plant, with consequent accidental spills inside the confined space and /or movement of mechanical part → Damage factor for Energy D_E, subdivided in two subfactors D_{E1} and D_{E2}
- ✓ atmosphere inside the confined place (scarcely oxygenated, corrosive, harmful, toxic or potentially explosive) → Damage factor for Environment D_A, subdivided in three subfactors D_{A1}, D_{A2} and D_{A3}.

In addition, a corrective coefficient for the damage factors is introduced: it expresses the level of criticality related to the physical and geometrical characteristics of the confined space, i.e. considering if the worker can easily leave the confined space and/or be easily helped in case of sudden illness → Damage factor for Geometry FCD_G.
After the identification of the damage factors and of the corrective coefficient FCD_G, it is possible to calculate the specific risks of the confined space multiplying each damage factor for the probability of occurrence P. The following indexes are obtained:

- ✓ Risk of contact with fluids or substances and/or mechanical components in movement, due to the sudden activation of the plant;
- ✓ Suffocation risk;
- ✓ Chemical risk;
- ✓ Fire and explosion risk.

These potential risks are then corrected through the application of the factor PeP. The proposed risk assessment methodology adopted cascade matrixes for the definition of the indexes for the risk function, because they can facilitate the establishment of correlations between the parameters involved.

2.1 The probability of occurrence (P)

To define the Probability of occurrence of a damage event in a confined space, the frequency and the time requested for the intervention / complexity were put in relation. The Probability index can assume a value in a range from 1 to 4:

- ✓ Very unlikely, 1: it is unlikely that the scenario takes place during the lifetime of the plant;
- ✓ Unlikely, 2: the scenario could happen during the lifetime of the plant. It happened in similar plants belonging to the Company or external. The personnel is aware of the scenario, but does not have direct experience of it.
- ✓ Likely, 3: the scenario could occur within a year. For a functioning plant, the event probably occurred during the last 5 years.
- ✓ Very likely, 4: the scenario can occur several times a year.

2.2 The magnitude of damage (D)

Values from 1 to 4 are attributed to the damage factors D_E and D_A:

- ✓ Minor, 1: Injury or episode or acute exposition with rapidly reversible inability; rapidly reversible minor injuries or physical pathologies;
- ✓ Medium, 2: Injury or episode or acute exposition with reversible inability; reversible injuries or physical and psco-physical pathologies;
- ✓ Severe, 3: Injury or episode or acute exposition with partial invalidating effects; chronical injuries or physical and psico-physical pathologies with partial invalidating effects;
- ✓ Major, 4: Injury or episode or acute exposition with lethal effects or permanent invalidating effects; chronical injuries or physical and psico-physical pathologies with invalidating effects.

The corrective factor can assume values in a range from 1 to 1,5, considering that the Damage sub-factors D_E and D_A could reach a maximum value of 4.

2.2.1 Damage factor - D_E (energy)

D_E parameter considers the sudden activation of the plant, with consequent accidental leakage of fluids and substances inside the confined space (D_{E1}) and/or movement of mechanical components (D_{E2}). In order to calculate D_{E1}, the section of the pipe/item that can cause the leakage of fluids or solid substance, and its elevation from the ground of the confined space are considered.

2.2.2 Damage factor - D_A (environment)

D_A considers the type of atmosphere inside the confined space, that could be scarcely oxygenated, corrosive, harmful, toxic or potentially explosive; it is composed by the sub-factors D_{A1}, D_{A2}, D_{A3}.
The INAIL guideline indicates the acceptable oxygen thresholds to grant health and safety of the workers: the concentration of oxygen inside the space should be equal to 20,9% volume of oxygen / total volume (v/v); when the concentration is inferior to 19,5% v/v, the atmosphere is considered ‘lacking of oxygen’; under the 16% concentration, the atmosphere is dangerous for people’s health.

2.2.3 Damage corrective factor - FCD_G

When a risk assessment is carried out, several information on the examined confined space should be analysed; the way to enter the confined space is particularly important for a correct evaluation, and for adopting the adequate prevention and protection measures.
An easy and comfortable access to the confined space is fundamental for the rescue team, in case the rescue of the worker is necessary.
Therefore, the following parameters were considered for the identification of the damage corrective factor FCD_G:

- ✓ Floor space, depth and volume of the confined space, elevation of the gateway from the ground level of the confined space → parameter ‘Confined space’;
- ✓ Dimensions of the gateway; ease of escape → parameter ‘Gateway’.

The damage corrective factor FCD_G assumes the following values: Low: 1, Medium: 1,25, High: 1,5. The corrective factor is multiplied to each damage factor and/or sub-factor to obtain the specific risk, considering that the damage factors and sub-factors can assume a maximum value of 4.

2.3 Corrective factor PeP

During the assessment, the preventive and protective measures adopted for the reduction of the risk shall be considered: Table 1 shows, as an example, the identified corrective factors. The corrective factors are used to evaluate the specific residual risks. The presence of several preventive and protective measures entails the multiplication between corrective factors (Yan et al., 2017), assuming in any case that the minimum value is 0,35.

Table 1: Corrective factors - PeP

Corrective factor	PeP
No corrective factors applicable	1
MPOP – Organizational and Procedural Preventive measure (Operational instruction for confined spaces, LOTO - Lock-out/Tag-out, SMA – Atmospheric monitoring system, work permits, rescue team)	0,85
MPOP + PPE (Personal Protective Equipment)	0,75
MPOP + LPE (Local Protective Equipment) + PPE	0,50
MPOP + DPC (Collective Protective Equipment) + PPE	0,35

2.4 Risk evaluation

The risk assessment based on the formula (2) produces a 4x4 matrix, that returns the value of residual exposure risk, as for Figure 1.

		P- Probability of occurrence			
		Very unlikely	Unlikely	Likely	Very likely
D- Magnitude of the damage		1	2	3	4
Minor	1	1	2	3	4
Medium	2	2	4	6	8
Severe	3	3	6	9	12
Major	4	4	8	12	16

Risk level	Actions
R > =12	Non-acceptable risk. Immediate actions for risk reductions. Possible suspension of the activity.
6 ≤ R < 12	Severe risk. Urgent actions for risk reductions, in order to obtain a reduction of the risk level EHS 2. Working activity can be carried out only under continuous monitoring.
2 ≤ R < 6	Acceptable risk; technical and/or procedural actions could be carried out.
R = 1	Correctly managed risk. Actions for maintaining the acquired risk level could be implemented.
--	The hazard is not present; therefore, the risk is not evaluated.

Figure 1: Risk Matrix

3. Case study

The development of the methodology presented in this paper derived also from the need of an Italian polyurethanes plant to elaborate a document for the evaluation of risks related to confined spaces. In the site there are many confined spaces in which the cleaning and maintenance activities are performed with annual periodicity. These activities can be carried out directly by employees, or even by employees of external companies. In any case, the Italian mandatory procedures request that before to begin an activity in confined spaces, a coordination meeting have been developed to verify the current risk of confined space respect the expected ones.

3.1 Confined spaces description

In the plant a dozen of confined spaces have been identified: tanks, mixers, water storage/treatment tanks, heating units, etc. Some confined spaces have been grouped considering for example the geometry of the places or the type of hazard present.

According to the methodology described above, the evaluation considers:

- ✓ Risk of contact with fluids or substances and/or mechanical components in movement, due to the sudden activation of the plant;
- ✓ Suffocation risk;
- ✓ Chemical risk;
- ✓ Fire and explosion risk.

As an example, the company has six water storage and treatment tanks (S4, S5, S6, S9, S10, S11) from rainwater, civil waste, laboratories and the entire production cycle.
The tanks S10 and S11 are used for the storage of treated water to be given to the municipal collector, possibly integrating with the biological waters coming from civil waste; while the tanks S4, S5, S6, S9 are dedicated to the water treatment plant. The S6 and S5 tanks are used to store industrial water to contain, the S9 tank to store industrial water (concentrate) and the S4 tank to store the permeate (or diluted) deriving from the reverse osmosis treatment. The water treatment tanks are grouped in a type of confined spaces, named CS_1, whose description is partially shown in Table 2 to exemplify the grouping criteria and the hazards considered.

Table 2: CS_1 water treatment tanks hazard (extract).

Unit	Substances	Hazard specific for tank	Confined Space	Hazard general
Tank 4	Permeate	..		
Tank 5	Industrial water to treat	Asphyxiation/poisoning (reaction between sewage and oxygen with development of non-respirable gases and vapors)		Poor visibility, poor ventilation (possible asphyxiation), microclimate, difficulty in access, difficulty in recovery, contact with fluids or substances for sudden activation of parts of the plant
Tank 6	Industrial water to treat	Asphyxiation/poisoning (reaction between sewage and oxygen with development of non-respirable gases and vapors). Contact with moving mechanical parts	CS_1	
Tank 9	Industrial water for disposal as non-hazardous waste	Reaction between sewage and oxygen possible formation of biogas/ methane		

3.2 Results of the analysis and decision making procedure

Table 3 shows the results of confined spaces risk assessment for the case study carried on according to the methodology above described.

Table 3: Results of the methodology application

Unit	Confined Space (CS)	Contact with fluid or substances	Contact with mechanical components in movement	Suffocation risk	Chemical risk	Fire and explosion risk
Tank 4		3,0	3,0	3,0	N.A.	N.A.
Tank 5		3,0	N.A.	3,0	3,0	3,0
Tank 6	CS_1	3,0	N.A.	3,0	3,0	3,0
Tank 9		3,0	3,0	3,0	3,0	3,0
Tank 10		3,0	N.A.	3,0	3,0	3,0
Tank 11		3,0	N.A.	3,0	3,0	3,0
Heating unit	CS_2	2,0	N.A.	3,0	N.A.	N.A.
Blender B10	CS_3	3,0	N.A.	3,0	3,0	3,0
Blenders B11	CS_4	3,0	3,0	3,0	3,0	3,0

Unit	Confined Space (CS)	Contact with fluid or substances	Contact with mechanical components in movement	Suffocation risk	Chemical risk	Fire and explosion risk
First rain water container	CS_5	3,0	N.A.	1	N.A.	N.A.
Flammable liquid storage tank	CS_6	3,0	N.A.	3,0	3,0	3,0
Fire pump inspection pit	CS_7	N.A.	N.A.	3,0	N.A.	N.A.

In the case proposed, the residual risk assessment provides as results tolerable risk conditions in all the cases evaluated.

4. Conclusion

The confined spaces risk analysis requires the knowledge of many parameters, in order to evaluate the main conditions that could be present in this “not traditional workplace”. In many cases, the risk assessment is developed by an indexes approach, where the probability of occurrence and the damage of the event are defined in the traditional way, without for example the definition of the geometry characteristics of the place.
The Italian Decree n. 177 has placed the attention about the coordination meeting and the verification of the safety procedures and equipment before to enter in confined places, without however providing technical information on how to carry out the risk assessment. The application of the methodology developed and proposed in this paper has permitted in a polyurethane plant to evaluate in specific and systematic way the risk for the maintenance and cleaning of a dozen of confined spaces, considering in the calculation of the damage of the event the geometrical characteristic of the place and the dangerousness of the substances could be present in the confined spaces. Also, the methodology developed is resulted a complete support to quantify the effectiveness of the prevention and protection measures to adopt and of which verify the available in the coordination meeting before to begin the activities of cleaning and maintenance.

References

Comberti L., Baldissone G., Demichela M., Patrucco M., Maida L., 2017, Investigation on the impact of National regulations on the occupational safety. In: European Safety and Reliability Conference, ESREL 2017, At Portoroz, Slovenia.

Ministero del lavoro e delle politiche sociali, 2011. DPR177/2011 Regolamento recante norme per la qualificazione delle imprese e dei lavoratori autonomi operanti in ambienti sospetti di inquinamento o confinanti.

INAIL (Istituto Nazionale Assicurativo Infortuni sul Lavoro), 2012, Manuale illustrato per lavori in ambienti sospetti di inquinamento o confinati ai sensi dell'articolo 3 comma 3 del Decreto del Presidente della Repubblica 177/2011.

National Institute for Occupational Safety and Health (NIOSH), 1994. Worker Deaths in Confined Spaces. A Summary of NIOSH Surveillance and Investigative Findings. Publication No. 94–103. U.S. Department of Health and Human Services, Public Health Service, Centres for Diseases Control and Prevention, National Institute for Occupational Safety and Health (NIOSH), Cincinnati, OH.

Occupational Safety and Health Administration (OSHA), 2015b. Report Accident Report Detail, Occupational Safety and Health Administration. Retrieved December 22, 2017, from https://www.osha.gov/pls/imis/accidentsearch.accident_detail?id= 201320439.

Botti L., Duraccio V., Gnoni M.G., Mora C., 2018, An integrated holistic approach to health and safety in confined spaces, Journal of Loss Prevention in the Process Industries 55 (2018) 25-35.

Ministero del lavoro e delle politiche sociali, 2008 .D.lgs 9 aprile 2008, n.81 Testo unico sulla salute e sicurezza sul lavoro.

Murè S., Comberti L., Demichela M., 2017, How harsh work environments affect the occupational accident phenomenology? Risk assessment and decision making optimisation. Safety Science 95,159–170.

Murphy D.J., Manbeck H.B., Hofstetter D.W., Puri, V.M., 2017, Online CAD/CFD-based design tool to assess ventilation strategies to reduce confined-space entry risk, Chemical Engineering Transactions, 58, 1-6.

Yan C.K., Siong P.H., Kidam K., Ali M.W., Hassim M.H., Kamaruddin M.J., Kamarden, H, 2017, Contribution of permit to work to process safety accident in the chemical process industry, Chemical Engineering Transactions, 56, 883-888