Analysis of risks of pressure vessels

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Abstract. In spite of having advanced technologies and the increasingly strict regulations, serious accidents involving pressure vessels and piping can still occur. This has led us to conduct a study on the risks and the root causes of accidents related to these devices. This article is based on a literature review of the last 10 years in addition to the analysis of the accident reports of Quebec and American for the last 16 years. The main risks highlighted are the explosion of tanks, by rupture of enclosure, and leak of the confined fluid products. The consequences of these accidents depend on the type of product contained and the dimensions of the vessel. The main cause of these accidents is not related to technical failure but corresponds to the non-compliance, failure or absence of the work procedures. Moreover, the accidents occur mainly in small and medium-sized enterprises, whether in the US of America or in Quebec. In order to prevent possible risks and occupational accidents, the impact of the corporate structure and social responsibility on the implementation of effectiveness of Occupational Health & Safety Management Systems should be parameters to be taken into account in the next studies on the health and safety risk assessments of pressure vessels.

Keywords. pressure vessels, risk assessment, accident, health and safety, root cause

1. Introduction

A pressure vessel indicates an equipment intended for the production, the manufacturing, storage or the implementation, of vapour or a gas compressed, liquefied or dissolved, under a pressure higher than the atmospheric pressure. They exist in all shapes (spherical, cylindrical, conical, elliptic etc.) and sizes. Pressure vessels are commonly used in the industrial sectors and in particular in the petrochemical and gas and nuclear industries, but also daily use (gas bottles, pressure-cooker, air compressor, etc…)(Majid et al., 2015). These pressurized equipment present a high risk in case of failure.For the purpose of reinforcing security, limiting or controlling the risks of pressure vessels and avoiding the reoccurrence of major accidents, the laws and regulations related to pressure vessels evolves and are reinforced with new standards. However, in spite of the advancement of science and technologies and the implementation of the strict regulations, accidents related to the pressure vessels still happen. The objective of this work is to determine the documented risks associated to pressure vessels and piping equipment as well as the common causes of accidents in order to determine why these accidents still occur.

2. Methodology

The current state of scientific knowledge and techniques was carried out by reading of the grey literature as well as documents found in bibliographical databases and references quoted by authors. The search was made in databases such as:Compendex, Scopus, Web of science and Google Scholar. The websites of some official and governmental institutions were also scrutinised in order to obtain additional information: IRSST, INRS and Transportation Safety Board of Canada. The bibliographical research was concentrated on documents from 2006 to 2016.

Moreover, the reports of accidents related to pressure vessels, during the last 16 years (period from 2000 to 2016), were studied and analyzed. The different analyzed accidents occurred in North American (Canada and the United States). The reports of these accidents come from the following databases: CNESST and NIOSH. The search was made using the following English keywords, and their French equivalent in: “pressure vessels” or “pressurised tank” or “oil tanker” or “tank truck” or “steam generator” “gas bottle or gas cartridge” or “boiler” or “compressor” or “gas currier” or “pressurized water reactor” or “heat exchanger” or “autoclave” associated with (and) “risk” or “risk analysis” and “accident” or “material damage” or “failure” or “defect” or “bursting” or “explosion” and “workplace health and security” or “occupational health and safety” or “ergonomics” or “human factors engineering”. The documents with unavailable English or French translations were excluded.

3. Results

3.1 State of the scientific knowledge

In spite of all these different applications, the two major identified risks related to the use of pressure vessels, independently of their types, are:

- Explosion by rupture of the vessel shell or the auxiliary components (valves, openings, fittings, pressure reducer, etc…), and
- Leak of confined fluid product.

3.1.1 Explosion by rupture of the enclosure

With regard to the risk of rupture of a pressure vessel, several authors (INERIS, 2013) have established that the two possible causes are

- An increase of the internal fluid pressure beyond the burst pressure of the vessel; or
- A decrease of the resistance of the vessel material due to the operating conditions which in turns causes a decrease in the burst pressure.

Nevertheless, technical problems are not the only factors leading to the susceptibility rupture of pressure vessels. Human and organisational factors are also other parameters to consider. (Majid et al., 2015)

During their study of the Transport of Dangerous Material (TMD) De Marcellis-Warin et al. (2006); (2008) identified the principal risks related to the transport and the storage of dangerous material; explosion, fire and emission of toxic products are to name a few. The study reveals that human error is identified as the principal causal factor in this kind of accident (65% of the accidents in Canada and 83% of those in the United States over the period 1988-2004) (De Marcellis-Warin et al., 2006). Explosion due the rupture of the shell concerns pressure vessel equipment of the type gas bottles, compressors, evaporators used in many industrial applications, research, medical and household appliances, etc…) (Boissinot et al., 2002). In this case, one fears hazard from the projection of fragments and impacts as well as incidents related to pipe whipping energy. According to the phase (liquid, gas or vapour) and to the product contained in the pressure device, the consequences can vary from jet of steam or superheated water to intoxication or explosion.

The rupture generally takes place at the fragile parts of the pressure vessels: seals, welds (Barbosa et al., 2006), pipe fittings, valves, pressure reducer, etc…

3.1.2 Leak

As mentioned previously, fragile components of the pressure vessel and piping are prone to leakage. They're more sensitive to wear, fatigue but also to human error. As for the material of the enclosure of the vessel, the environment has a great impact on the fragile parts of the vessel (Barbosa et al., 2006).

The leak of these pressure vessel components can sometimes be classified as fugitive emissions, i.e. "a release of pollutants to the atmosphere after an escape from the equipment after an attempt to collect them using a hood, a gasket joint or any other means which should have ensured their capture and retention." (Bouscaren, 1999). The misuse or incorrect installation of a gasket can generate a leak of the confined fluid of the pressure vessel (Bouzid, 2014). The consequences of such leaks can be the cause of creation of a slick of flammable products or poisons, the creation of flammable or toxic gas or vapour clouds which can lead to a fire or an explosion or an asphyxiation or poisoning of workers (Zhongqiang, 2014).

In the current context, terrorism spreads and gains in extent, the intentional deterioration of an industrial installation under pressure resulting in important escape of hazardous substances cannot thus be ignored (Bubbico, Di Cave et Mazzarotta, 2009).

3.2 Analysis of the accident reports

A total of 35 reports were analyzed, 17 found in CNESST and 18 found in NIOSH databases. The accidents related to the transport of dangerous materials were not analyzed here because they were already the subject of a particular study by De Marcellis-Warin et al. (2006); (2008).

These reports involve accidents related to all sectors of activity and all types of pressure vessels. In Quebec, in the 12 accidents out of the 17 referred to, there is only one explosion resulting from the characteristics of the product contained in the vessel according to the concerned industry (petrochemical or gas). In the United States however, nearly all accidents are due to an explosion by rupture or bursting of the shell of the pressure vessel following an overpressure due to a component failure or human error.

Part of the results obtained from these reports is presented in table 1.

3.3 Ishikawa diagram

All causes of accidents, implying a pressure vessel, determined from the literature review and the analysis of the reports of accidents were highlighted in the Ishikawa diagram (Figure 1). This shows that the technical problems are not the only causes of accidents involving pressure vessels.

Table 1. *Extract of results from the analysis of accident reports implying pressure vessel.*

Year / Place	Line of business	Type of pressure vessel	Risk
2002 Saint-Étienne-des Grès	Recycling	Gas bottles	Explosion of flammable gas and fire
2003 Lévis	Business (transport)	Gas cylinder	Sudden gas release
2005 Drummondville	Industrial delivery of propane	Flexible pipe connecting tanks	Deflagration and fire because of gas emission
2007 Beauceville	Production et recycling of rubber products	Actuator	Gasket fracture
2008 Canton Casa-Bérardi	Mining	Compressed air pipe	Fracture by mechanical shock
2010 Granby	Business (oil delivery)	Road tanker Storage tank	Explosion of flammable vapours during products transferFire
2012 Valcourt	R&D Production of transport equipment	Under pressure fuel pipe (gasket)	Leak Fire and explosion
2014 Piedmont	Business (sale and delivery of oil products)	Road tanker Storage tank	Explosion and fire during products transfer
2014 Saint-Théophile	Transport	Diesel tank	Explosion
2006 Montréal	Mechanics of heavy vehicles	Pneumatic brake system	Explosion Projection of tank fragments
2004 Montréal	Business	Bitumen storage tank	Explosion
2004 Salaberry-de-Valleyfield	Chemicals transfer	Road tanker	Explosion Fire
2004 Hérouxville	Workshop	Oil furnace	BLEVE explosion
2000 Blainville	Automobile test	Natural gas tank	Explosion
2012 Delson	Production of refrigeration equipment	Pipe	Projection of mechanical connection
2001 Pointe-Claire	Production of spices and sweet herbs	Autoclave Gas cylinder	Explosion
2007 Vallée-Jonction	Business (Sale and metal recovery)	Propane heater	Explosion

4. Discussion

Following the review of the scientific and gray literature found in different databases, it is to be noted that the main sectors represented are the petrochemical, gas and others such as nuclear and transport of dangerous products. The scientific concerns are about technical failures but do not address the occupational safety and health management aspects, the maintenance or the training of workers as potential causes of the accidents. Only a few authors (Majid et al. (2015); Zhongqiang (2014) ;De Marcellis-Warin et al. (2006)) address vaguely the socio-organizational causes of the pressure vessel accidents and recommend regular maintenance or a strengthening of the workplace health and safety culture in companies in order to prevent the occurrence of the risks of rupture and leakage.
However, the reality of these facts is that the cause “technical problems” such as a defect or a dysfunction of a measuring device, a substantial component or the material of the vessel, corresponds to only 56% (NIOSH) and 41% (CNESST) of the causes of the accidents studied against 71% (CNESST) and 56% (NISOH) due to the absence, deficiency or non-compliance of the procedures related to the activity.

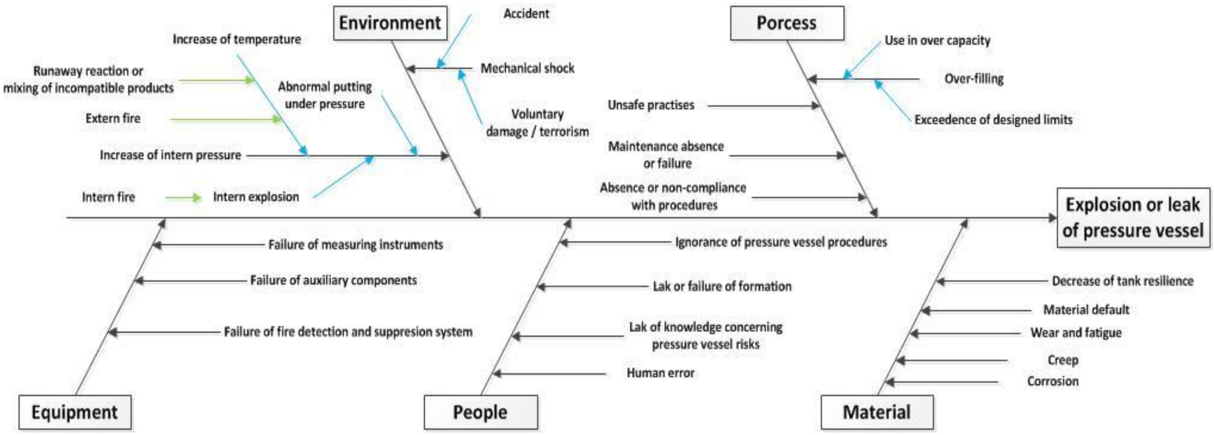

Figure 1. *Ishikawa diagram of causes of accidents implying pressure vessel*

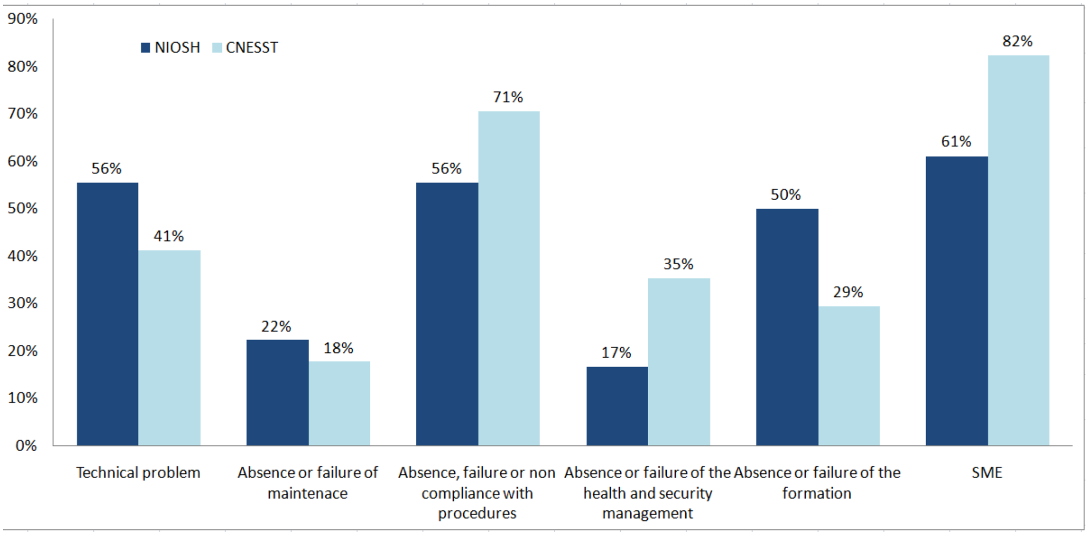

Figure 2. *Comparative graph of causes of accidents implying pressure vessel in CNESST and NIOSH database*

Thus the question is whether the technical problems encountered in the case of the accidents studied are not due to misuse of pressure vessels and their related components, to the non-compliance with the work procedures and the lack of knowledge of the workers about the function, risks and dangers associated to pressure vessels.

Also, note that 61% (NIOSH) and 82 % (CNESST) of accidents occurred in SME. In general , SMEs have a record of accidents and deaths more unfavourable than large companies because of limited perception of the OHS(Lescure, Nadeau et Morency, 2015). This comes from their role as subcontractor, working relationships based on proximity and a lack of resource investments in OHS. SMEs are under a lot of pressure whether concerning their business model or management of OHS. SMEs should perhaps consider developing their own model of Occupational Health & Safety Management System. Lescure, Nadeau et Morency (2015) suggest some actions to improve the OHS management in SMEs; for example, use an intermediary such as the accountant of the SME or an external organization to transmit information and OHS trainings to workers.

Following this study the keys to improvements for Quebec are the respect and control of procedures, control and knowledge of hazardous materials and the management of OHS in SMEs. However, in the United States improvements should be aimed towards the utilization and reliability of pressurized equipment used.

5. Conclusion

Following this study, the principal risks related to the pressure vessels are identified as follows: the explosion due to the rupture of the enclosure of the vessel or one of its component and the leakage of the confine fluid product. The consequence can then be an explosion, domino effect due to fragments, fire, creation of a slick of products or gas cloud or toxic or flammable vapours and the projection of fragments. In case of accidents of this type, there may be serious consequences for workers, surrounding communities and the environment. The study of the scientific literature review and various reports of referenced accidents enabled us to determine the various causes of these types of accidents.

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