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Study of Immersion in a Pool of Water as an Alternative to Concrete-Spraying or Mounding of LPG Tanks

Fabian Tambour*[a], Patrick Sellier[b], Sylvain Brohez[c], Christian Delvosalle[c]

[a]Polyris SPRL : Rue René Descartes 2, 7000 Mons, BELGIUM
[b]L'Oréal Libramont S.A. : Route de Saint-Hubert 1, 6800 Recogne, BELGIUM
[c]Faculté Polytechnique (UMONS), Major Risk Research Centre: Rue de l'Epargne 56, 7000 Mons, BELGIUM
fabian.tambour@polyris.be

Belgium has a densely populated territory and counts numerous plants covered by the Seveso II Directive. Regional authorities in Wallonia (Belgium) tend to impose additional safety barriers in order to reduce or prevent the external risk, and the BLEVE phenomenon in particular. This paper presents an innovative solution which was studied on the Belgian Seveso plant of L'Oreal to prevent the BLEVE phenomenon by the immersion of LPG tanks in a pool of water.
This solution is compared with the main classical solutions which are the mounding of the tanks or concrete-spraying on them, in order to prevent or delay the heating due to an external fire. The proposed immersion in a pool is here complemented with a gas detection and aspiration system, which allows to conduct, in case of a leak, the released gas to a safe area.
The comparison of the three solutions firstly focuses qualitatively on the causes of accident, based on the ARAMIS Project generic fault trees. Apart from the BLEVE, which prevention is the main goal, the other consequences of an accidental release (jet fire, explosive cloud dispersion and vapor cloud explosion (VCE)) are then quantified for different weather conditions, for each of the three safety barriers providing an overview of the residual risks.
Qualitatively, the proposed tank immersion shows a reduced number of accidental causes in comparison with the two others solutions. Moreover, for jet fires and VCEs, both the gas detection and the canalization system makes it safer than both concrete-spraying and mounding. The immersion of the tanks also should prove to be more flexible from the practical point of view than mounding (e.g. external inspection of the tanks, replacement of a tank).
However, specific aspects of the innovative immersion solution require a particular attention, such as water treatment and ice formation. Propositions are then made on how to deal with these aspects.

1. Introduction

The Seveso Directive (1996) and its amendment (2003) stress the need to maintain appropriate distances between establishments covered by the Directive and residential areas, areas of public use and areas of particular natural sensitivity or interest. In Belgium, land use planning as well as the evaluation of the part of the safety reports related to external risk fall within the competence of regional authorities.
Belgium has a densely populated territory and counts numerous plants covered by the Seveso II Directive. Therefore it is difficult, in some cases, to keep the balance between economic development and the presence of nearby populated area. As a result, regional authorities in Wallonia (French speaking part of Belgium) tend to impose additional safety barriers in order to reduce or prevent the external risk when delivering or renewing the operating licenses of Seveso plants. More specifically, the authorities require on an almost systematic base to set the storages of products that could lead to a BLEVE in underground or mounded tanks, in order to supress the occurrence of this hazardous phenomenon.
This paper presents an innovative solution which was studied on the Belgian Seveso plant of L'Oreal to prevent the BLEVE phenomenon by the immersion of LPG tanks in a pool of water. This solution is still at the project stage. This solution is compared with the main classical solutions to prevent or delay the

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BLEVE resulting from an external heating source, which are the mounding of the tanks or concrete-spraying on them.
The comparison of the three solutions (mounding, concrete-spraying and immersion) firstly focuses qualitatively on the causes of accident, based on generic fault trees from the ARAMIS Project (Delvosalle et al, 2004).
The influence on the effect distances of each of the three safety barriers are then compared for the remaining possible consequences of an accidental release (jet fire, explosive cloud dispersion and vapor cloud explosion (VCE)), providing an global overview of the residual risks.

2. Definition of the proposed pool immersion

2.1 Definition of the storage

L'Oréal Libramont uses a range of LPG substances, which are presently stored in pressure tanks. For the need of the study, the Isobutane (65 %) - propane (35 %) mixture was selected as the most hazardous material. Its saturated vapor pressure at 20 °C is 4.3 barg.
The studied tank capacity is 57 m³, the main liquid pipe diameter is 80 mm and is fitted with an excess-flow valve designed to shut-off at 8.8 kg/s.

2.2 Definition of the pool immersion

In the proposed innovative solution, the tanks are immerged in a pool of water below ground level and the water layer above the tanks is at least 1 m. The pool is equipped with a retractable and opaque cover. The first use of this cover is to prevent the sunlight from reaching the water in order to reduce the micro-organisms proliferation, but still providing an easy access to the pool, for the tank inspections. The second use of this cover is to ensure tightness, allowing to evacuate a potential gas release from the tank to a safer place thanks to a 800 mm diameter underground pipe. The release would therefore be conducted in the middle of a grass area, without any ignition source within an 80 m radius.
A 1 m deep layer of air is kept between the top level of the water and the cover in order to place a gas detection system and the 800 mm diameter pipe. This pipe is fitted with an aspiration system that would be activated in case of a gas detection.

3. Qualitative comparison

3.1 Comparison criteria

In order to qualitatively evaluate the advantages and disadvantages of the 3 solutions, the generic fault trees from the ARAMIS Project (Delvosalle et al, 2004) were used, as well as the main causes of release detailed in the generic frequencies database from Handbook (Flemish Government, 2009). The causes of particular interest are detailed in the next points.

3.2 External heating

Concrete spraying on a tank only delays the heating in case of a fire engulfment, while mounding and immersion completely prevent the BLEVE phenomenon.

3.3 Corrosion

Mounding as well as concrete layer do not allow the visual external inspection of the tank and measuring of the metal thickness, and so require periodic internal inspections. A cathodic protection is required in the case of mounding.
Immersion in a pool of water allows external inspection. On the other hand, some water treatments can be corrosive and this aspect needs to be studied carefully.

3.4 Internal inspection

Internal inspections might not be mandatory in the case of immersion of the tanks (in discussion), as thickness measures and visual inspections can be realized from outside the tank. Many hazards related to internal inspections would therefore be avoided: hazard related to the opening of the tank, to the presence of residual gas, to the asphyxiation of operators due to inert gas realizing the internal inspection, to the presence of residual air (and oxygen) when filling the tank after the inspection.

3.5 Impact

A concrete layer doesn't significantly improve the resistance to a missile impact (domino effect) or to a vehicle collision. Mounding is a much better protection for these two aspects but presents the risk of an impact when excavating the soil, in case of works on the tank, on its instrumentation or on nearby equipment.

Immersion in a pool below ground level therefore seems to be the better protection against missiles, vehicle or excavation impacts.

3.6 Freezing

Freezing isn't a problem for aerial or mounded tanks, but is an aspect to consider in the case of immersion. The formation of ice could damage the pool and the pipes at the water/air interface.

3.7 Leak detection

A leak on a mounded tank or its connections is difficult to detect, and there is a risk of a gas accumulation before detection of the released substance. The precise location of the leak is even harder to achieve.
With a concrete-sprayed tank, a leak would result in a release in a plume in the atmosphere. The leak can be quickly detected by gas sensors, but an effective system requires placing a dense net of these sensors in order to cover the different wind directions.
In the pool solution, the gas coming from a leak underwater would efficiently and rapidly be detected by the sensors located, in the air layer between the water surface and the cover. Moreover, the leak could then be precisely located by the generation of bubbles in the water.

3.8 Practical aspects

From a practical point of view, it was suggested that the access to instruments and valves for maintenance is very complicated in the case of mounding, easier in the case of a concrete-sprayed tank but mainly for the pipes and not the tank itself, and finally very easy in the immersion case.
It was also stressed that the addition of a tank (i.e. production increase) in the same area is complicated and risky in case of a mounded tank, easy with a concrete-sprayed tank and rather simple for immersion if the pool was initially designed for one or more additional tanks.

3.9 Discussion

The pool immersion shows interesting advantages in protection against heating and impacts, in allowing external inspections, quick and effective gas detection, and a better flexibility for further addition of tanks.

4. Comparison of accidents consequences

4.1 Hypotheses and software

PHAST 6.7 was used to evaluate the effects distances for jet fire and vapor cloud explosion. "UDM 2" dispersion model was use, in association with the "Modified CCPS" discharge model (these are the defaults models in version 6.7). Ignition of the flammable cloud was conservatively being considered possible until half of the lower flammability limit was reached (LFL fraction set to 0.5). The explosion center was set as "Cloud Centroid".

4.2 Reference scenario

The comparison was made using a reference scenario which consists of a full rupture of the 80 mm liquid pipe, but with only 120 % of the excess-flow valve shut-off flowrate. This value was chosen because the probability of failure of the excess flow valve is then as low as 0.06, according to the Handbook (Flemish Government, 2009). The resulting flowrate is 10.6 kg/s. Storage temperature was set at 15 °C.

4.3 Meteorological conditions

Seven representative local weather conditions were defined in PHAST for the full study. These weather conditions are extracted from the STATIRMA database (IRM, 2002) and relate to local conditions. In this paper, the results are shown for two of these conditions, which are detailed in Table 1.

Table 1: Weather conditions data

	Weather 1	Weather 2
Wind speed (m/s)	6.5	1.5
Pasquill stability	D	E
Atmospheric temperature (°C)	6.2	9.8
Surface temperature (°C)	6.1	7.8
Relative humidity	0.946	0.907
Surface roughness length (mm)	1,400	1,500

4.4 Specific Assumptions

For a concrete-sprayed tank, the release was considered at 1 m height and the direction set to horizontal, without impingement.

For a mounded tank, the release height was set to ground level (0 m) and the jet was considered impinging down on the ground. In PHAST, this option implies that a rainout of the liquid fraction of the release immediately occurs.

Finally, for the proposed pool immersion, the release would take place inside the water, which is not an option in PHAST 6.7. A bibliographical research was made to define more precisely the underwater release characteristics (i.e. part of the release which would vaporize, which would form a pool at the water surface, formation of ice…). Unfortunately, the papers found about liquefied petroleum gas (LPG) underwater release were not relevant for the present reflection or they didn't actually allow to define more precisely the release characteristics. The research was therefore extended to liquefied natural gas (LNG) underwater release. Mannan et al (2011) and Bowdoin et al (2010) showed that, for a cryogenic LNG release, the vapor fraction when reaching the water surface is 100 %, the vapor temperature at that time is very close to ambient temperature, and that no LNG pool forms at the water surface. According to Bowdoin et al (2010), the initial velocity of the release is quickly reduced in water, to reach the much slower rise speed of the LNG bubbles.

Although the hazardous material in the present study (mixture of isobutane and propane) is not cryogenic LNG, it was assumed that the release would vaporize completely in water and that no LPG pool is therefore formed. The assumption is supported by the fact that, when a leak occurs on a LPG storage, the initial expansion to atmosphere generates liquid at boiling temperature but in lower proportion than for a cryogenic stored liquid, as a part of the material is vaporized (the liquid fraction for the studied isobutane/propane mixture at 15 °C is 0.76). Moreover, heat of vaporization at boiling temperature of the mixture (391 kJ/kg according to PHAST) is significantly lower than for methane (513 kJ/kg according to PHAST at boiling temperature). As both the liquid fraction to vaporize and the heat of vaporization of the studied mixture are lower than the ones for a LNG cryogenic release, it is assumed that the release entirely vaporizes before reaching water surface.

In the proposed pool immersion, the pool has a cover and the release is therefore evacuated through a remote place by a 800 mm diameter underground pipe. To take account of this additional system, the release in Phast was modeled as vertical at ground level, entirely gaseous, and with the lower discharge velocity allowed by PHAST (5 m/s). An aspiration system might complement the described pool immersion, so consequences were calculated for two cases: firstly, gas release in a remote place without any aspiration, and secondly, gas release in a remote place with the addition of 10000 Nm³/h of air.

4.5 Thresholds

The thresholds used in Walloon Region for external safety are defined in the Vade-mecum (Ministère de la Région Wallonne, 2005). In this paper, the results are only shown in this paper for a selection of the defined thresholds. Thermal flux of 6.4 kW/m² and overpressure of 50 mbar are considered for human related effects. Two thresholds are also considered for domino effects: 44 kW/m² (of a protected pressurized vessel) and 160 mbar.

4.6 Results

Effects distances for both weather conditions presented in this paper are detailed in Table 2 and Table 3.

Table 2: Effects distances (m) for weather 1 (6.5 m/s D-class)

	Jet fire 6.4 kW/m²	Jet fire 44 kW/m²	Dispersion ½ LFL	VCE 50 mbar	VCE 160 mbar
Concrete-sprayed	64	41	62	77	51
Mounded	35	18	52	83	51
Pool immersion without aspiration	54	24	32	57	34
Immersion + 10,000 Nm³/h air aspiration	52	23	22	43	25

Table 3: Effects distances (m) for weather 2 (1.5 m/s E-class)

	Jet fire 6.4 kW/m²	Jet fire 44 kW/m²	Dispersion ½ LFL	VCE 50 mbar	VCE 160 mbar
Concrete-sprayed	73	53	95	141	90
Mounded	36	22	64	137	79
Pool immersion without aspiration	42	6	72	135	81
Immersion + 10,000 Nm³/h air aspiration	41	4	24	69	37

4.7 Discussion

Concrete-sprayed tank shows the largest effect distances for every situation. The pool immersion solutions show the shortest overpressure effect distances for 50 mbar (this threshold results in the largest distances) for both weather conditions.
The addition of 10,000 Nm³/h of air aspiration in the pool immersion would greatly reduce the distances to reach the ½ LFL, and therefore the effects distances for 50 and 160 mbar overpressures, especially for low wind speed and stable weather condition (weather 2), which leads to the largest distances.
It should be emphasized that the immersion solutions also allow to release the gas in a safer remote place, significantly increasing the distance to the first ignition source and to the potential target for a domino effect (in the present case, the LPG trailers in the unloading zone), as shown in Table 4.

Table 4: Noteworthy distances (m) for the tank farm and the remote release zone

	Tank farm	Remote release zone
Nearby railroad	95	110
Nearest potential ignition source	<10	80
Nearest potential domino target	<10	80

As a summary, the choice of the pool immersion, combined with a 10000 Nm³/h air aspiration system would reduce the effect distances to the point that: the nearby railroad would not be reached by the 50 mbar threshold in case of a VCE, the nearest domino target would not be reached neither by the 160 mbar nor by 44 kW/m² thresholds and the vapor could would dilute under the ½ LFL before reaching the first potential ignition source.

5. Specific points of attention for pool immersion

5.1 Introduction

Specific aspects of the innovative pool immersion solution require a particular attention, such as water treatment, buoyancy forces and ice formation.

5.2 Water treatment

In a previous work (Harzée, 2008), different solutions were compared for the water treatment. The objective is here to prevent micro-organisms proliferation in the water, but also to avoid a corrosive environment for the immerged tanks.
The study selected a non-oxidizing biocide, efficient for a wide range of micro-organisms, without corrosive properties. This biocide would be complemented by the retractable an opaque cover on top of the pool, preventing light to reach the water.

5.3 Buoyancy forces

(Harzée, 2008) calculated the tank supports to handle the maximum buoyancy forces (if the tanks were to be completely empty).

5.4 Ice formation

Due to the negative temperatures reached in winter, it is relevant to consider that ice formation could occur in the pool. However, in the proposed solution of pool immersion, the level of water in the pool remains below ground level, which greatly reduces thermal exchanges with the atmosphere, the main exchange surfaces being in contact with the ground, which temperature is more stable and above zero. Moreover, the cover would also reduce thermal exchange with the atmosphere. The layer of ice would therefore be limited at some dozens of centimeters.
This ice layer would imply mechanical tensions (increase of volume) but also tightness of the pool.
Mechanical tensions have to be managed by compressible materials arranged around the organs going through the water/air interface, like relief valve exhausts, in order to absorb the increase of volume. Tanks would be located too deep (more than 50 cm under water level) to be concerned. The amount of compressible material should be designed to ensure that integrity of the concrete pool.
A uniform layer of ice could also prevent the possible gas resulting from a leak to be continuously conducted in the remote release zone. An accumulation of gas could potentially lead then to an overpressure that could threaten the integrity of the pool cover. A 800 mm section should therefore always be kept free of ice by the mean of a low temperature circular heating resistance (EX-proof).

6. Conclusions

An innovative tank immersion solution in a pool of water was proposed for the Belgian plant of L'Oréal Libramont, and compared with the more classical concrete-spraying or mounding of LPG storage tanks. The first goal of these measures is to reduce or prevent the possibility of a BLEVE.
The three solutions were compared qualitatively on one hand, and the consequences for the main remaining hazardous phenomenon (jet fire and vapor cloud explosion) were modelled on the other hand.
The proposed pool immersion allows for the possibility of direct external inspection of the tanks, easier maintenance of the instrumentation and efficient gas detection. In comparison with concrete-spraying, pool immersion achieves better impact protection and BLEVE prevention. In comparison with mounding, the excavation risks are greatly reduced and pool immersion also allows for more flexibility in a later addition of tanks, if the pool is initially designed to have enough room for one or more additional tanks.
Finally, both the external risk (towards a nearby important railroad) and domino risk (towards the unloading LPG tankers) are managed in the case of the proposed pool immersion associated with a retractable cover, an underground piping to evacuate the hazardous release in a remote area and an aspiration system (thanks to an important reduction of the consequences of the remaining hazardous phenomenon and a safer localisation of the release area).
Beside these advantages, immersion of tanks in a pool also requires to pay a particular attention in the aspects of water treatment, supports design to take account of the buoyancy forces and ice formation in winter. Solutions to these aspects have been proposed.

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