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Comparing Consequences of Different Liquid Tank Explosions Triggered by Lava Inundations

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Natural disasters can cause several accidents affecting the integrity of industrial facilities and lifelines, the so-called natural-technological accidents or simply Na-Techs. Amongst several volcanic hazards, lava flows appear less dangerous for human life than other phenomena and their impact on structures, traffic and communication are even also more manageable, because the slow movement of these streams allows mitigation strategies to be employed. Nevertheless, in 2002 two Italian newspapers reported about an explosion due to a boiling liquid expansion inside a civil tank (BLEVE), which was triggered by thermal radiation produced by a lava flow, during an effusive eruption of Mt. Etna. BLEVEs are amongst the most severe accidents that could occur in chemical and process industry as well as in the storage of hazardous materials; as an example the result of the previous mentioned explosion was a number of 32 injured people. This accident highlighted a lack of these scenarios reported in the local emergency plans. To allow improving the emergency management, the present work compares the potential damage scenarios associated with different liquid tanks (containing water and fuel) used in civil activities and triggered by lava inundation.

1. Introduction

Several recent events evidenced that natural disasters can trigger also technological catastrophes according to a domino dynamics (Kadri et al., 2014). These complex scenarios, also known as Na-Techs (Cruz et al., 2004), may pose remarkable risks to people and the environment (De Rademaeker et al, 2014). In Europe, there are many vulnerable installations located in areas prone to various natural hazards, thus potentially triggering Na-Techs, moreover it must be highlighted that the hazard could be significant also due to the unpreparedness to face such phenomena (Vetere Arellano et al., 2004). Several other issues are associated with Na-Tech accidents: (i) the simultaneous occurrence of a natural disaster and a technological accident determine also a concurrent response effort in a context where resources could be unavailable and (ii) the releases of hazardous-materials may occur from single or multiple leaks in one or several installations, this makes worse the overall consequences.

Recently some dedicated risk-assessment methodologies (Cozzani et al., 2014; Kadri et al. 2014; Ancione et al., 2014a; Marzo et al., 2015) and tools (Posthuma et al., 2014) were developed to investigate, assess and manage natural technological hazards. By comparing Na-Techs, only during these last years a growing attention has been paid to those caused by volcanic eruptions (Milazzo et al, 2012). Amongst many volcanic hazards, ash fallouts appear much more interesting due to their wide impact areas and the great number of potential affected vulnerable elements, whereas lava flows are considered to be less dangerous and more manageable. Approaches to the vulnerability modelling of atmospheric storage tanks and filters to volcanic ash fallouts are due to Milazzo and coworkers (Milazzo et al. 2013a; Milazzo et al. 2013b); Baxter et al. (1982) previously investigated the hazards related to the transportation of hazardous materials due to slippery road conditions from a qualitative point of view, whereas more recently Ancione et al. (2014b) studied the reduction of functionality of primary wastewater treatments (screening operations and grit removals were respectively studied by Milazzo et al. (2015) and Ancione et al. (2015a)). Even if lava flows could be more manageable, the literature shows that, in some case mitigation strategies, adopted to face thermal radiations and thus to

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prevent Na-Techs, can fail. Barnard (2004) cited an example, it is related to a liquid tank explosion occurred during an effusive eruption of Mt. Etna (Italy) in 2002. After the study of this event and the analysis of the surrounding Mt. Etna, Ancione et al. (2015b) pointed that only a few local emergency plans take into account the hazard associated with civil tanks potentially exposed to lava flows. These plans provide a damage probability for each vulnerable facility, but they do not analyse the potential consequence of the scenarios.
This work compares the consequences of the explosion of two civil tanks containing water and fuel when involved in lava inundations; it will be shown that the impact of these scenarios could damage several human targets. This observation points toward the need to improve the emergency planning in areas characterised by lava flows. The paper is structured as follows: in the first Section the proposed methodology analysing Na-Techs due to effusive eruptions is described; in the second Section a case study, located in the surrounding of Mt. Etna, is presented; then the results are given in the third Section and finally the conclusive part follows.

2. Methodology

A previous study of Ancione et al. (2015b) showed that civil tanks used to store fuels and water can give explosive scenarios, such as BLEVEs (Boiling Liquid Expanding Vapour Explosions) if they are exposed to thermal radiation. The radiation is generated by the lava during effusive eruptions, thus tanks could be heated from the stream flowing at a certain distance and, in some cases, can be completely inundated by the flow. Impact areas of the Na-Tech could include buildings and blast effects, due to their extent, could determine several injuries and fatalities. Potential targets are inhabitants, most of them are evacuated, and tourists and civil protection operators, whose number could not be exactly foreseen. These considerations point the need to include these scenarios in the emergency plans in order to be proper managed. To contribute to the improvement of the emergency planning, Ancione et al. (2015b) suggested a methodology which allows the assessment and the inclusion of Na-Tech scenarios triggered by lava flows in emergency plans. Their approach includes the following steps:

1. Identification of potential Na-Tech scenarios due to lava flows or inundations;
2. Collection of lava flow maps for the case-study;
3. Census of territorial elements (i.e. people, infrastructure, storage tanks, etc.).
4. BLEVE modelling (in case of flammable substances thermal radiation and overpressure scenarios are simulated, whereas in case non-flammable substances only overpressure);
5. Representation of damage zones on cartography by using a GIS (Geographical Information System) software;
6. Calculation of the number of people involved in the scenario by means of the GIS.

It must be pointed that, given that this study is focused on Na-Techs occurring from thermal radiation on domestic tanks, which are used to store water and fuels, toxic effects are not considered as they are not generated from the release of these substances and those produced by their combustion could be considered negligible.

2.1 BLEVE modelling

In this work, the consequences of two types of tank containing two different substances (i.e. LPG and water) were calculated. Both BLEVEs were modelled as suggested by Casal et al. (2001) and compared. In the case of LPG only the blast effects were considered because, as shown by Ancione et al. (2015b), the effects of the thermal radiation due to the fire, which depend on the flame extent and temperature (Palazzi and Fabiano, 2012), involve a portion of the territory within the damage zones identified for the blast effects. The overall heat transfer coefficient requires a complex modelling (Reverberi et al., 2013) and the effects of the projections of fragments of tanks and lava crust need of a proper approach (Lisi et al., 2015). Thus these latter effects were not considered in this preliminary work.
According to Casal et al. (2001), the energy released during the vapour expansion from the breaking pressure in the vessel up to the atmospheric pressure, is given by the model of Prugh and converted in TNT equivalent mass (W_{TNT}):

$$W_{TNT} = \left(\frac{0.021 \cdot P \cdot V^*}{\gamma - 1} \right) \cdot \left(1 - \left(\frac{P_o}{P} \right)^{(\gamma-1)/\gamma} \right) \tag{1}$$

where: P_o = atmospheric pressure (bar); P = pressure in the vessel just before the explosion (bar); V^* = volume of vapour in the vessel plus the volume (at the pressure inside the vessel) of the vapour generated in the explosion (m^3); γ = ratio of specific heats.
The term V^* can be calculated by using the following equations:

$$V^* = V + V_l \cdot f \cdot \left(\frac{\rho_l}{\rho_v} \right) \tag{2}$$

$$f = 1 - \exp(-2.63 \cdot Cp / H_v \cdot (T_c - T_b) \cdot (T_c - T_o / T_c - T_b)^{0.38}) \tag{3}$$

where: ρ_l = liquid density (kg/m^3); ρ_v = vapour density (kg/m^3); f = vaporisation fraction (flash), i.e. the fraction of liquid which vaporises in the depressurisation (dimensionless); Cp = specific heat of the liquid (kJ·K^{-1}·kg^{-1}); H_v = enthalpy of vaporisation of the substance (kJ·kg^{-1}); T_c = critical temperature of the substance (K); T_b = boiling temperature of the substance at atmospheric pressure (K); T_o = temperature of the substance in the moment of the explosion (K).

2.2 Representation of the damage and calculation of the number of people involved

A GIS (Geographical Information System) is often defined as a tool that enables capturing, processing, analysing, storing and representing georeferenced spatial information (Milazzo et al., 2014). In this work, the representation of the impact areas of each Na-Tech and the calculation of the number of involved targets were possible through the use of a GIS.

3. Case-study

The case-study is the territory surrounding Mt. Etna, located in the South of Italy (Sicily), where the city of Catania and several small urban centres and agricultural and industrial sites are located. The activity of this volcano is characterised by effusive eruptions, even if several explosive eruptions have been recently observed with volcanic ash emissions. Several municipal areas were identified as potential exposed to lava flow and a proper hazard assessment due to lava inundations was given by Del Negro (2013). Figure 1 shows the map of the probability of inundation. By overlapping the collected vulnerable elements and the areas identified within the map, each tank can be associated with a probability of inundation.

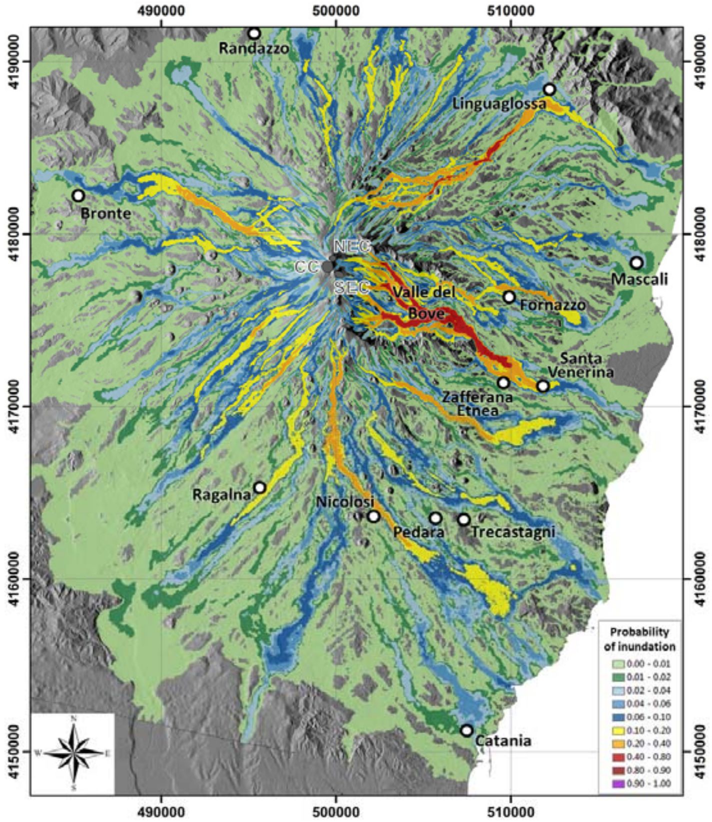

Figure 1: Probability of inundation (source Del Negro et al. 2013)

Two type of tanks were studied in this work: they have the same geometrical characteristics (diameter and length), in order to compare the consequences of the scenario, but the construction material is different due to the physical state of the substances to be stored and the different conditions inside the vessel (LPG is a pressurised liquid and water is a liquid).
Table 1 summarises the characteristics of the tanks used to simulate the blast effects. The calculations of the pressure inside the tank (due to the vaporisation of the liquid) was the first step, then the procedure of Casal et al. (2001) was applied.

Table 1. Characteristics of the tanks.

Parameter	Value	
	LPG tank	Water tank
Volume (m^3)	2.5	2.5
Diameter (m)	1.2	1.2
Height (m)	2.5	2.5
Length (m)	1.2	1.2
Temperature (K)	293	293
Pressure inside the vessel (bar)	3	1
Filled percentage of the tank (%)	80	80
Construction material	steel	(high density) polyethylene

4. Results

If the tank is heated from the lava (assuming that its location is close to the edge of the flow), the overpressure, generated by the BLEVE, could have devastating consequences for people and buildings which are located within the impact areas. Figure 2 and Figure 3 show the representation of the consequence on the cartography, respectively, for the explosion of LPG and water. Table 2 gives the dimension of the damage zones associated to the blast effects caused by both the BLEVEs.

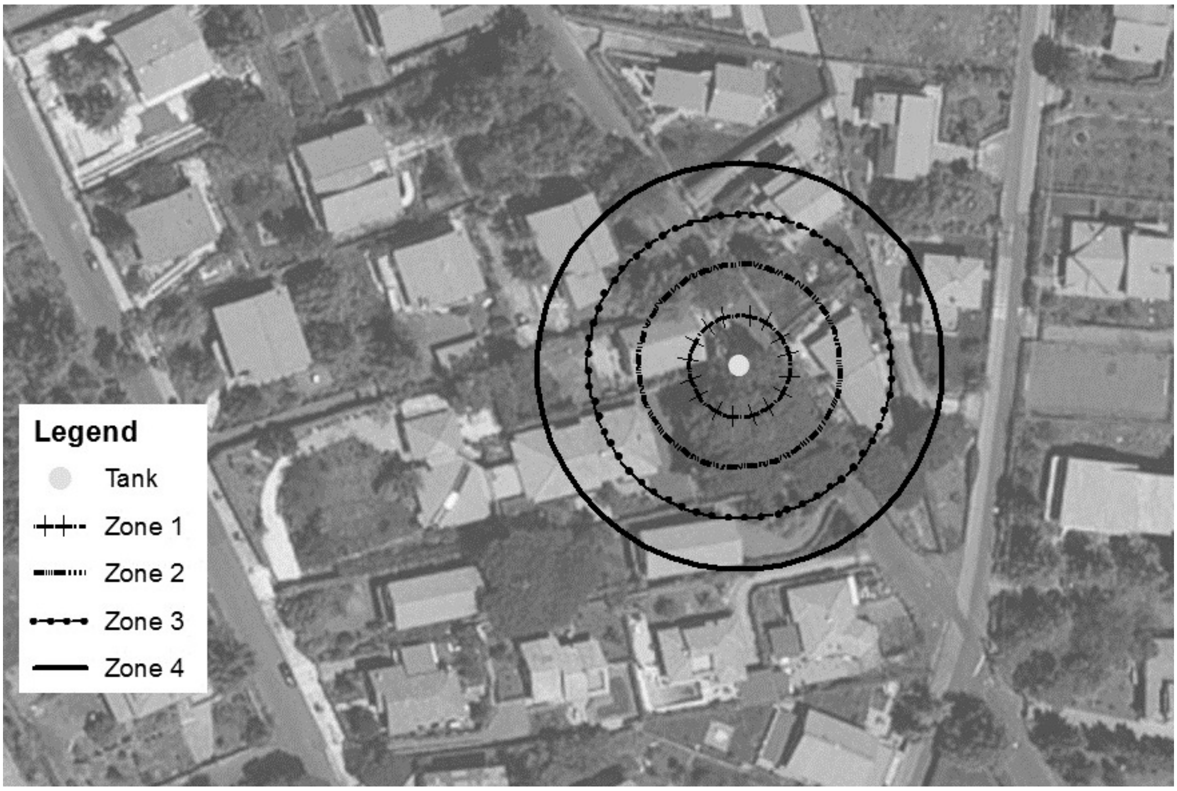

Figure 2. Damage zones for a LPG BLEVE.

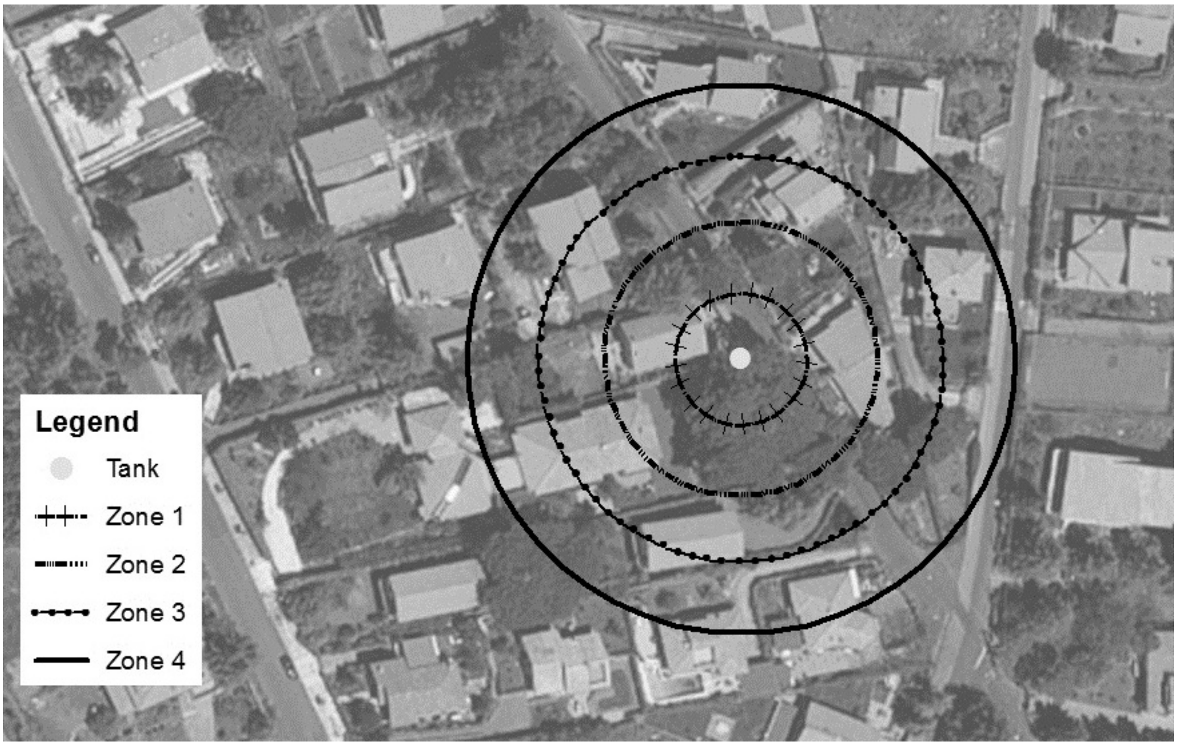

Figure 3. Damage zones for a water BLEVE.

Table 2. Damage zones and vulnerable elements

Zone	Threshold of overpressure (bar)	Distance (m)		Elements involved			
				Building		People	
		LPG*	Water	LPG	Water	LPG	Water
1	0.30	10	13	1	2	2	4
2	0.14	20	27	2	5	4	10
3	0.07	30	40	6	11	12	22
4	0.03	40	54	11	23	22	46

*Ancione et al. (2015b)

These scenarios are located within the urban centre of a small city and close to an area potential affected by lava inundation. The results of the simulation show that the zone 4 has a radius of 40 m for the LPG explosion and 54 m for the water explosion, it represents the area where 50 % of people suffer to be injured by the pressure wave. It can be seen that, as also mentioned by Casal et al. (2001) and confirmed through a different modelling given by Pinhasi et al. (2007), a BLEVE of a water tank give more severe consequence.

5. Conclusions

As shown by Ancione et al. (2015b), the review of local emergency plans for the municipalities surrounding Mt. Etna highlighted the need of improving these documents by taking into account potential Na-Tech scenarios triggered by lava flows. By comparing the consequence of the BLEVEs of LPG and water, obtained with the application of the approach of Casal et al (2001) and using a Geographic Information System, it can be seen that the impact is more severe in case of water. Given that the storage of water for civil purpose is a common practice in this territory, a proper consequence analysis for these Na-Techs is greatly recommended. Moreover the presence of operators of Civil Protection and tourists must also be considered during the occurrence of such an event, as these could be more exposed to the scenario than the local population.

Reference

Ancione G., Salzano E., Maschio G., Milazzo M.F., 2014a, A GIS-based tool for the management of industrial accidents triggered by volcanic ash fallouts, J. Risk Res., in press, doi: 10.1080/13669877.2014.961515.

Ancione G., Salzano E., Maschio G., Milazzo M.F., 2014b, Vulnerability of Wastewater Treatment Plants to Volcanic Na-Tech events, Chemical Engineering Transactions, 36, 433-438.

Ancione G., Primerano P., Salzano E., Maschio G., Milazzo M.F., 2015a, The impact of volcanic ash fallout on industrial facilities: Natural-Technological hazards in wastewater treatments (Grit removals). In The impact of volcanic ash fallout on industrial facilities: Natural-Technological hazards in wastewater treatments (Grit removals), in press. Ed. D.Graver, Nova Science Publishers, Inc.

Ancione G., Milazzo M.F., Lisi R., Maschio G., 2015b, Consequences of liquid tank explosions caused by lava flow, Chemical Engineering Transactions, 43, 2071-2076.

Barnard S.T., 2004. Results of a reconnaissance trip to Mt. Etna, Italy: The effects of the 2002 eruption of Etna on the province of Catania. Bull. New Zealand Society for Earthquake Engineering, 37, 47-61.

Baxter P.J., Bernstein R.S., Falk H., French J., Ing R., 1982, Medical aspects of volcanic disasters: An outline of the hazards and emergency response measures. Disasters, 6, 268-276.

Casal J., Arnaldos J., Montiel H., Planas-Cuchi E., Vılchez J., 2001, Modeling and Understanding BLEVEs. In: Hazardous Materials Spills Handbook, Fingas M. Ed.

Cozzani V., Antonioni G., Landucci G., Tugnoli A., Bonvicini S., Spadoni G., 2014. Quantitative assessment of domino and NaTech scenarios in complex industrial areas. J. Loss Prevent. Proc., 28, 10-22

Cruz A.M., Steinberg L.J., Arellano A.L.V., Nordvik J.P., Pisano F., 2004, State of the art in Natech risk management. European Commission Directorate General Joint Research Centre, EUR, 21292.

Del Negro C., Cappello A., Neri M., Bilotta G., Herault A., Ganci G., 2013, Lava flow hazards at Mount Etna: constraints imposed by eruptive history and numerical simulations. Scientific Reports 3, Article number: 3493.

De Rademaeker E., Suter G., Pasman H.J., Fabiano B., 2014, A review of the past, present and future of the European loss prevention and safety promotion in the process industries, Process Saf. Environ., 92(4), 280-291.

Kadri F., Birregah B., Châtelet E., 2014, The impact of natural disasters on critical infrastructures: A domino effect-based study. Journal of Homeland Security and Emergency Management, 11(2), 217-241.

Lisi R., Consolo G., Maschio G., Milazzo M.F., 2015, Estimation of the impact probability in domino effects due to the projection of fragments, Process Saf. Environ., 93, 99-110.

Marzo E., Busini V., Rota R., 2015, Definition of a short-cut methodology for assessing the vulnerability of a territory in natural-technological risk estimation, Reliab. Eng. Syst. Safe, 134, 92-97.

Milazzo M.F., Ancione G., Lister D.G., Salzano E., Basco A., Maschio G., 2012, Analysis of the effects due to fallout of ash from Mt. Etna on industrial installations. Chemical Engineering Transactions, 26: 123-128.

Milazzo M.F., Ancione G., Basco A., Lister D.G., Salzano, E. Maschio G., 2013a, Potential loading damage to industrial storage tanks due to volcanic ash fallout, Nat. Hazards, 66, 939-953.

Milazzo M.F., Ancione G., Salzano E., Maschio G., 2013b, Risks associated with volcanic ash fallout from Mt. Etna with reference to industrial filtration systems, Reliab. Eng. Syst. Safe. 120: 106-110.

Milazzo M.F., Ancione G., Salzano E., Maschio G., 2014, A GIS-tool for the vulnerability mapping of industrial facilities. Proc. European Safety and Reliability Conference ESREL 2013, "Safety, Reliability and Risk Analysis: Beyond the Horizon", 1881-1888, Amsterdam, The Netherlands.

Milazzo M.F., Ancione G., Primerano P., Salzano E., Maschio G., 2015, The Impact of Volcanic Ash Fallout on Industrial Facilities: Natural-Technological Hazards in Wastewater Treatments (Screening Processes).. In Volcanic Eruptions: Triggers, Role of Climate Change and Environmental Effects, Chapter 1, pp. 1-21. ISBN: 978-1-63463-308-6. Ed. T.Milburn. Nova Science Publishers, Inc.

Palazzi E., Fabiano B., 2012. Analytical modelling of hydrocarbon pool fires: Conservative evaluation of flame temperature and thermal power, Process Saf. Environ., 90(2), 121-128.

Pinhasi G.A., Ullmann A., Dayan A., 2007, 1D plane numerical model for boiling liquid expanding vapor explosion (BLEVE), Int. J. Heat Mass Tran., 50, 4780-4795.

Posthuma L., Wahlstrom E., Nijenhuis R., Dijkens, C., de Zwart D., van de Meent D., Hollander A., Brand E., den Hollander H.A., van Middelaar J., van Dijk S., Hall E.F., Hoffer S., 2014, The Flash Environmental Assessment Tool: Worldwide first aid for chemical accidents response, pro action, prevention and preparedness, Environ. Int., 72, 140-156.

Reverberi A.P., Fabiano B., Dovì V.G., 2013, Use of inverse modelling techniques for the estimation of heat transfer coefficients to fluids in cylindrical conduits, Int. Commun. Heat Mass, 42, 25-31.

Vetere Arellano A.L., Cruz A.M., Nordvik, J.P., Pisano, F., 2004. Analysis of Natech (Natural Hazard Triggering Technological Disasters) disaster management. Report European Commission Joint Research Centre (JRC).