Investigation on a storage LPG accident with application of mathematical models

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1) ABSTRACT

The sequences of a LPG storage accident was restored throughout application of some simulation models on the basis of the reported and filmed effects and damage.
The evolution of phenomena was studied with application of some available models or adapted engineering calculation program. The primary purpose of these applications was to check the possible use and the efficiency of the simulation models using comparisons and evidences on the dynamic of accident.
Compared with evidences and surveys, the result of the performed simulations show an appreciable efficiency in describing some phenomena, even if there are some approximation in some cases. The uncertainty of the information about some input or the lack of data make difficult the choice of the appropriate model to correct describe the events, nevertheless the models represent an useful approach for conducting hazard assessment and to investigate on accidental events.

2) ACCIDENT DESCRIPTION

The chronological sequence of the most important events related to the accident, is here below summarized.
Few minutes before 7 a.m.,the unloading of a tank truck started. Shortly afterwards, the unloading operator, to increase the flow rate, intervened on the control valve.
For reasons not yet clarified, a leakage took place around the valves of the tank truck with formation of a propane jet, part of which in vapor state owing to isenthalpic flash, inside thevalves box, part as undercooled liquid propane, forming a pool on the asphalt of the ground. The surrounding area was interested by a thick low cloud of vaporized propane; the evacuation of the people started and the National Fire Brigade was called for intervention. Some minutes after the arrival of the N.F.B., at 7.40 a.m., a primer caused a flash fire and, in consequence of that, several damages to different utilities. Practically in the meantime,an explosion took place in a building some ten meters far; the explosion distroyed part of the building.
A fire broked out from the pool of liquid propane under the back side of the truck and the flames wound the back side of the truck. The increase of internal pressure and the mechanical stress due to the high temperature, caused a wide rupture of the tank wall with gas release, very similar to a fire-ball followed by the combustion of the released gas like a flare.
The initial flash-fire also caused, very probably, damages to the loading arm of a nearby tank truck (capacity about 15 m^3) but containing LPG no more than 10% of its volume..
At 8.40 a.m, the wall of the second tank, heated by the jet fire, broke out and a BLEVE, followed by a fire ball ,took place; the BLEVE destroyed the second tank truck.

Later, some gully-holes of the underground sewer in the area, due to the pressure of the spilt propane, burst open.
Fire Brigade succeded in putting the situation under control, limiting the fire area and leaving the gas flowing from the first tank to burn till exhaustion.
The fire was completly put out at 5 p.m.

3) Adopted criteria for the reconstruction and the study of the events.

Conditions and aspects ,important for the present study, will be examined according to the chronological sequence of the events.

A) Initial flowing.

The initial overflowing can be considered as a two-phase flow in a half-enclosed environement.
The starting point of the initial jet was located into the box valves, in the back side of the tank.
A subdivided spout created presence of liquid propane in the valves box, undercooled gas due to lamination with isenthalpic flash and spilling of liquid propane from the valves box to the ground asphalt.
For simulation purposes of models, the above described scenario can be considered as an atipic scenario, as the modelling common options are referred either to free two-phase jet or to a single phase flow.

B) Gas dispersion in the atmosphere.

The site atmospheric conditions, with reference to the starting moment of the events, were obtained from the data of two different meteorological stations , located few kilometers far from the area of the accident.

	FIRST STATION	SECOND STATION
wind velocity	0.5 m/s	0.5 m/s
temperature	5 C°	6 C°
wind direction	100 °	250°
relative humidity	80%	85%

The low wind velocity, referred to a standard altitude of 10 m., and, therefore lower if referred to ground level, excludes the possibility of recourse to gaussian models, requiring a wind velocity not lower than 2 m/s, with absolut limit 1 m/s.
With reference to the sky overcasting ratio (from 4/8 to 7/8) and to wind velocity, according to Pasquill scheme, a stability class B can be considered.
With reference to the standard deviation of the wind direction (NRC) and considering that no variation in the wind direction takes place at 0.2 m/s velocity at the altitude of two meters, a stability class F could be assumed.

C) Flash fire, fire.
The reconstruction of this phase was not closely examined, due to several difficulties in defining the initial steps of the flash fire.

D) First tank burst.

Few minutes after the flash fire a burst happened with consequent gash in the wall of the tank.

The causes of this event have been analyzed considering that the back side of the truck was involved in a mixed fire: pool fire and jet fire with pulsating flame lapping on the surface of the tank. Normally the models consider a steady combustion with an average heat emission divided among conduction, convenction and radiation.

Considering the common ripartition used in simulations, assuming that 30% of the developed heat is propagated by radiation, we can consider that 70% of the combustion heating of LPG was developped.

As in a second time verified, just 1/3 of the total surface of the tank was heavily interested by overheating for the flame action. In the second place the irregular shape of the gash with dimensions 40 by 60 cm, located in the connection area between cylinder and the hemyspheric bottom.The size of the gash is important for the analysis of the gas release that , according to the above said description, can't be classified as a classic fire ball,as related to BLEVE,normally generated by a very large gash or by the collapse of the vessel.

E) Consequences of the fire and Bleve on the second tank.

A consequence of the flash fire and of the following fire was the damages to the connection device of the second tank. The initial spilling of LPG from the damaged connection device, and the consequent fire due to the near flames brought to a total fire around the second tank , with a final phenomenon that can be classiefied as a BLEVE.

F) Control of the fire an comments.

The controlled combustion of the first tank lasted 8 hours.To avoid the interruption of the combustion, water was spread on the wall of the tank to heat the liquid propane.

On the basis of the combustion time and the vaporization rate of propane inside the tank,the quantity of gas present after the burst and vapour release, has beeen calculated.

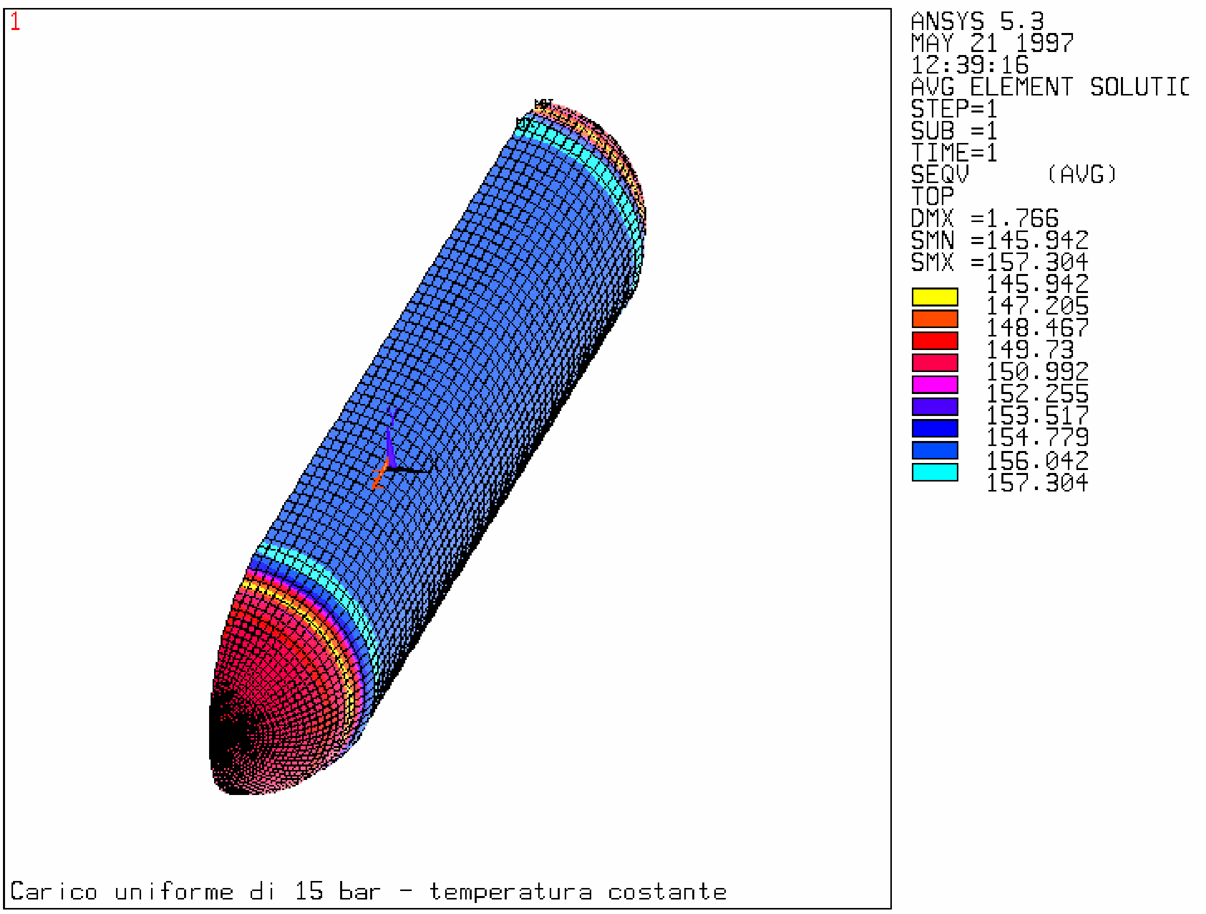
4) Events reconstruction and recourse to simulation models .

The termomechanical analysis of the collapse of the tank has been carried out according to the calculation code ANSYS 5.3.

Due to the tickness of the vessel wall (about 1 cm) rather high compared to diameter,the theory of the pressure vessels with high thickness wall has been used.

The model of the structure is explained in fig.1

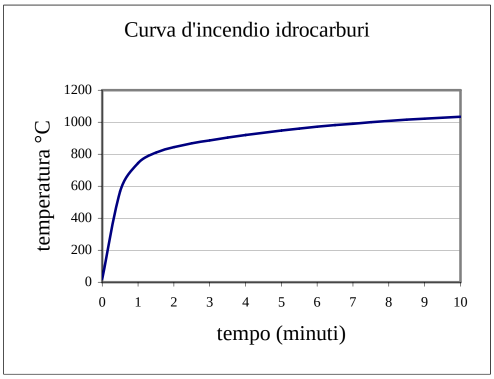
fig. 1



The fire around the back side of the tank has been simulated with thermic flow variables and considering that the whole gas coming out of the tank was involved in the combustion. This is partially true, for the presence of unburnt fraction.

In fig. 2 the the application of the UNI ENV 1991-2-2 to the described case has been reported.

fig. 2



The stress and strain situation in the connection area cylinder -sphere of the tank has been simplified and reported in fig. 3 .

fig. 3

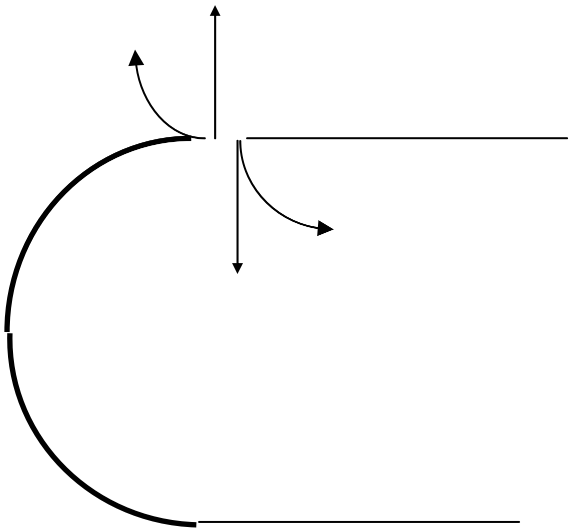
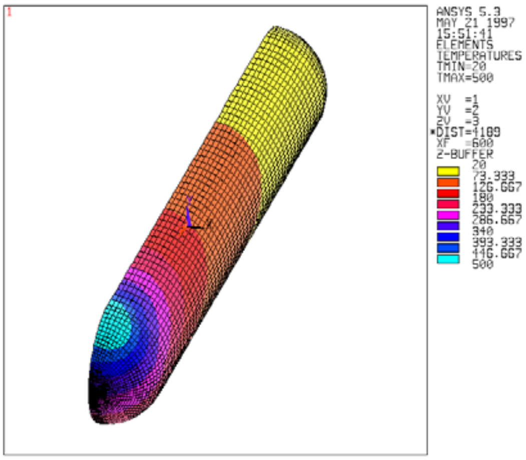


fig. 4



In spite of the adopted semplified hypoteses ,the above said considerations take into account the most important aspects related to the weakening and the collapse of the vessel. The application of the program allowed the determination of the stress on the structure, relevant to thermic and mechanical actions and the location of the collapse point. (see fig. 4).

The obtained results are in accordance with the reports of the people attendig to the accident.

Analysis and reconstruction of the events by simulation models.

The models utilized are:

ARCHIE(Automated Resource for Chemical Hazard Incident Evaluation- Federal Emergency Management Agency, U,S. DOT, U.S. EPA)

DEGADIS 2.1 (DEnse GAs DISpersion- U.S. Coast Guard, G.R.I. & A.P.I.-US EPA)

HGSYSTEM 3.0 developped by Shell an distributed by A.P.I.(ed. 4636-1995)

SIGEM -SIMMA developped by TEMA S.p.A.and used by the Italian National Fire Brigade

STAR 3 (Safety Techniques for assesment of Risk) developed by ARTES and including several simulation models typical for risk analysis.

The reference points for the study of the different phenomena ,obtained by testifying of attending people, can be summarized :

- initial LPG release ,before fire, with duration time 40-50 minutes
- primer source caused a flash fire and several damages due to increased pressure
- the flash fire caused a fire around the back side of the tank ,due to the formation of pool and jet fire
- fire caused the breach of the shell of the tank with formation of an intermediate phenomenon between fire ball and jet fire
- the flash fire and subsequent fire on the first tank caused damages to connection arm of a near second tank truck with spilling of LPG and fire.
-after some ten minutes a Bleve with fire ball happened as a consequence of the collapse of the second tank.

The flow rate has been determined by considering the presence of a deep tube 1 meter long and an orifice with equivalent diameter 25 mm ; LPG temperature 278 K, equilibrium pressure 5,4 bar(a).The results are indicated in the following table:

Model	Flow rate (kg/s)	Flow condition
ARCHIE	11,6 (peak)	two-phase
Sigem-Simma	0,46	gas
STAR	2,25	two -phase

Flow, not in steady condition for to the presence of ice in the orifice, last about 50 minutes and 1/3 of of the content has been emptied. The only consistent result is the one referred to a flow rate of 2.25 kg/s. Tacking into account the above said time (50 minutes) a total amount of 6,75 tons of LPG flew outside, that is 1/3 of the initial content, as testified by some people present on the site.
The quantity of LPG evaporated during the flash can be obtained by adding the amount of LPG evaporated inside the tube and the amount of LPG evaporated during the isenthalpic flash, that is about 23% of the total flow.
To evaluate the concentration in the air several models have been utilized ,outlining that the atmospheric conditions are of limited acceptability for most models. The atmospheric conditions are: stability class F and wind velocity 0,51 m/s.The results are reported inthe following table:

Model	vapour flow rate	LFL	50% LFL	inflammable
ARCHIE	peak 11,6 kg/s	140 m	203 m	1800 kg
Degadis	2,25 kg/s	160 m	205 m	1030 kg
HGSystem	2,25 kg/s	33 m	55 m	n.c
Sigem.Simma	0,46 kg/s(gas)	n.r	n.r	n.r
STAR	1,046 kg/s	24 m	35 m	46 kg
“	2,25 kg/s	38 m	55 m	157 kg

n.c not calculated n.r not reached

Regarding the ARCHIE model it is clear that the vapours flow rate adopted for dispersion is lower than the peak value indicated in the results, but this datum is not supplied.
Degadis model result, that is in accordance with the Archie model, is affected by the limit related to wind velocity (minimum 1 m/s).
Similar limit (1.5 m/s) is requested by HGSystem, however the final result is considerably different in comparison with the ARCHIE model.
SigemSimma model have not a calculation routine for dispersion of heavy vapours and areosols and the evaluation of the flow rate is referred just to gas phase.
The STAR model, that considers the presence of obstacles or buildings in the propagation of the gas, offers an indication of gas accumulated in the area in front of the building, without in substance modifying the distances of the flammability limits.
Disregarding the simulation of the initial flash fire,the radiation phenomenon caused by the burning gas related to the first tank and the cases of fire ball and bleve related to the second tank , will be analized.
The phenomenon related to the first tank in concomitance with the burst or structure collapse can be regarded as “transient jet release” that occurs when the substance into the vessel is not overheated. From different relations the requested time for vessel collapse is a function of the geometry and characteristics of the flame wrapping the vessel; according to the model for turbolent flames on the top of the vessel a time of 7 minutes can be estimated; for pool flames a time of 15 minutes can be considered.
On the basis of the survey the opening of the first tank is equivalent to a hole with equivalent diameter 50 cm; according to this indication the following criteria have been adopted to evaluate the phenomenon effects:
1) simulation of a jet fire with flow rate equal to the initial flow rate, with pressure 17 bar and temperature 323 K°.
2) evaluation of the jet fire duration by analysis of the amount of the released gas for the time ncessary to obtain an atmospheric pressure inside the tank.
3) evaluation of the quantity of radiated energy.

The initial flow rate has been calculated by two models , with very similar results (503 kg/s by SigemSimma; 523 kg/s by STAR).
The duration of the release has been calculated according to STAR model(about 3 seconds) and evaluating the amount to be released to obtain (starting from the initial pressure 17 bars) the atmospheric pressure in the tank. Considering the quantity of stored LPG (about 13 m^3), and the volume of the tank (52 m^3) filled by 80%, the volume occupied by the gas , before the burst, was 28 m^3 with a pressure of 17 bar, equivalent to 456 m^3 of gas , that is 12700 kg. With a flow rate equal to 520 kg/ sec, 24 seconds are necessary to decrease the internal pressure to about the atmospheric value.The indications supplied by jet fire models have been considered to take into account the limited duration of the phenomenon by transforming theradiation to energy as indicated in the following table

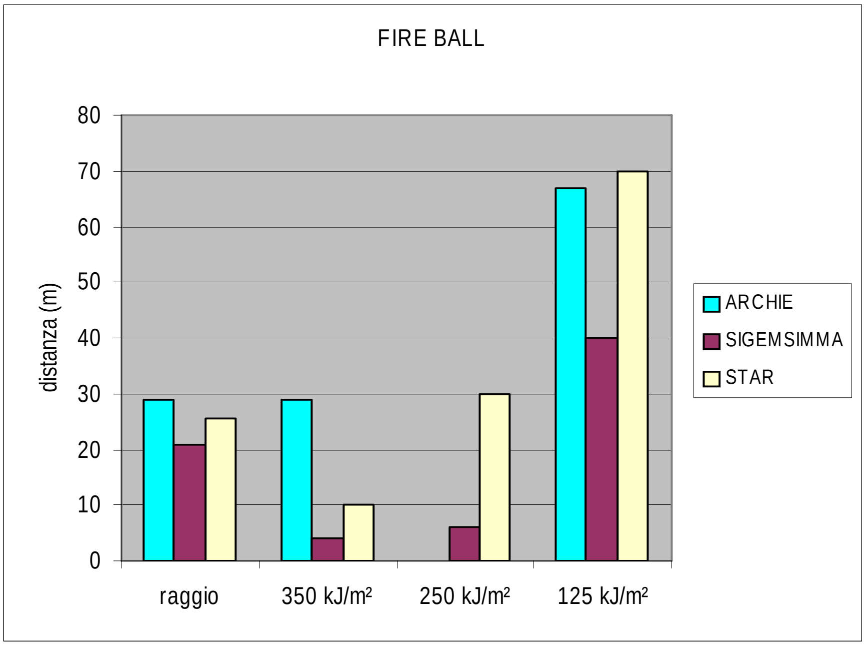
Model	350 kJ / m^2	250 kJ /m^2	125 kJ / m^2
ARCHIE	49 m	-	106 m
SigemSimma	n.r	n.r	n.r
STAR	n.r	n.r	110 m

The results seem to have a very high caution, because people present around the site at less than 100 m were no injured. It must outlined that the evaluation of the phenomenon

is affected by semplifications, mainly for no considering the decrease of the flow rate and gas desity in accordance to the pressure decrease.
The phenomenon regarding the second tank is quite near to BLEVE theory, with total collapse of the tank and pieces and metal splinters at a distance of 500 m from the origin.By application of the simulation models and considering the collapse conditions similar to the conditions of the first tank(17 bar; 323 K), the following results have been obtained:

In this case the results are more homogeneus, but also in this case , with a good level of caution. The compared results of the models are reported in fig. 5.

fig. 5



It must be considered that for small quantities the models supply very prudent forecasts and often not in accordance with the practical results; for phenomena of great magnitudo the results are more accurate and similar.
Regarding to the projected pieces, two of them , with considerable size ,were found at a distance of 500 m; the first was a part of the tank shell and the relevant dimensions were 1,2 m by 1,2 m and thickness 10mm, the second was a part of a pipe, probably part of the deep tube.
The simulation of the phenomenon of the pieces projection is affected by great uncertainity related to the shape of the pieces and to the leaving angle. With exception for STAR model, based on NASA studies and pubblications, it is no possible to consider in a correct manner shape and size of the pieces, for this reason the results obtained by using models different from STAR look quite rough.The result coming from Sigem.Simma is referred to a range 314-1800 m; the results coming from the adoption of STAR model, considering leaving angle 35 ° are : 670 m for the first piece and 520 m for the second.

Conclusions

With reference to the hystorically registered accidents, the accident described in this study, related to a particular sequences of a great number of events and circumstances, can't be considered as a single case. It can be outlined a general difficulty in the description of the phenomena by simulation models. With reference to the content of this study ,it is clear that the answer supplied by the models adopted for risk analysis appears prudent and, however, useful for forecasts but the above said answer appears no appropriate for complicated cases as the one in subject and in particular for the simulation of the diffusion of heavy gases in presence of obstacles; in this case the use of 3D models is suggested, particularly in case of absence of wind.

References:

[1] Pasquill'stability categories – Tabella 15.14 ed al. Lees 2nd ed. 1996 – 15/89-94

[2] Nuclear Regulatory Commission – Loss prevention in the process industries – Lees 1996 – Tab. 15.23

[3] BLEVE Research – A.M. Birk – Queen's University of Kingston – Ontario – Canada – 1997 (http://conn.me.queensu.ca/birk)

[4] "Le esplosioni BLEVE: rischi e misure preventive" – Antincendio Agosto 1987

[5] API RP521 Guide for pressure relieving and depressuring system - 1997

[6] Hazard from propane BLEVE: an update and proposal for emergency responders – A.M. Birk – Journal of Loss Prevention in the Process Industries – Vol 9 n°2 1996

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