Economic Commission for Europe

Inland Transport Committee

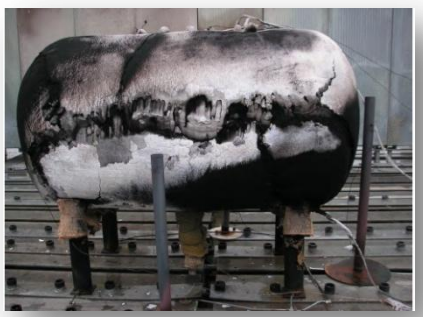
Working Party on the Transport of Dangerous Goods

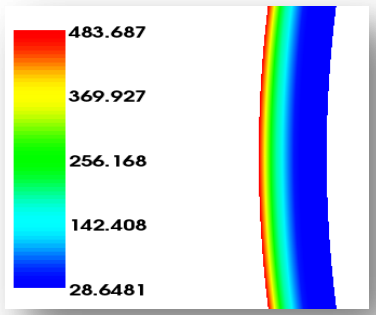
Joint Meeting of the RID Committee of Experts and the Working Party on the Transport of Dangerous Goods **23 September 2015**
Geneva, 15–25 September 2015
Item 11 of the provisional agenda
Any other business

The model of thermal response of Liquefied Petroleum Gas Tanks subjected to accidental heat input

Transmitted by the Government of France

The Model of thermal response of Liquefied Petroleum Gas Tanks subjected to accidental heat input





Adrien WILLOT - Mathieu REIMERINGER

INERIS
Structural Resistance Unit - Accidental Risk Division

ONU Meeting 23-09-2015

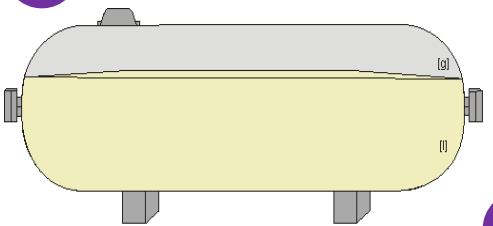
INERIS
maîtriser le risque
pour un développement durable

Summary

Context - Introduction

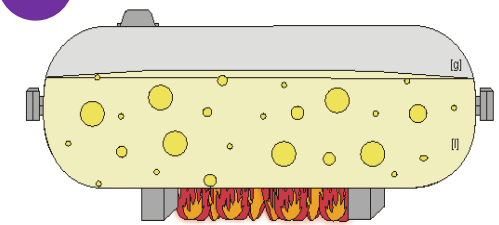
Introduction to the « BLEVE Scenario »

1



The tank is filled

2

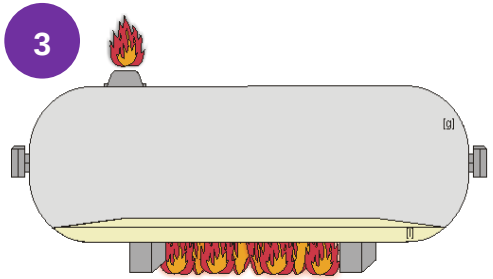


Tank is located in fire

=> Boiled liquid

Video (Video.mpg)

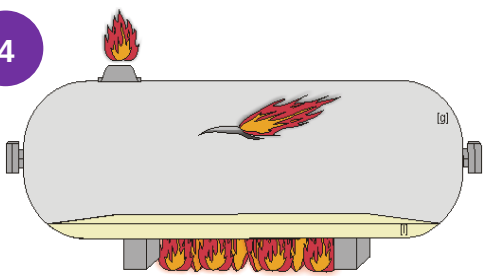
3



Pressure increases

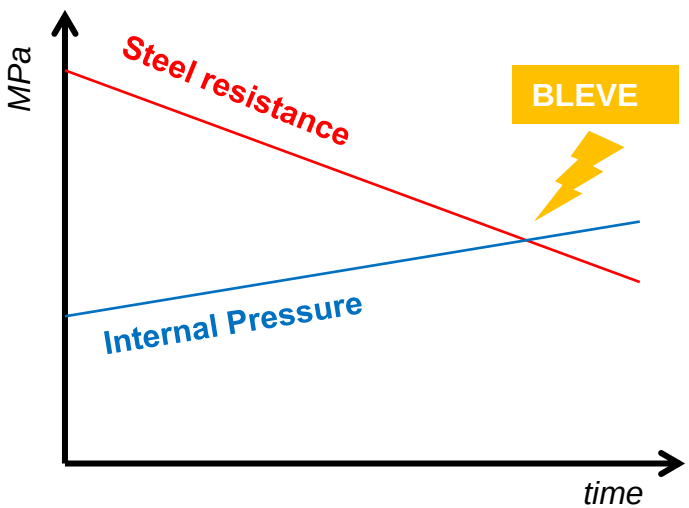
=>Safety valve opens
=>Liquid level drops

4



Pressure continues to rise

=>Tank loses its strength
=>Tank wall cracks



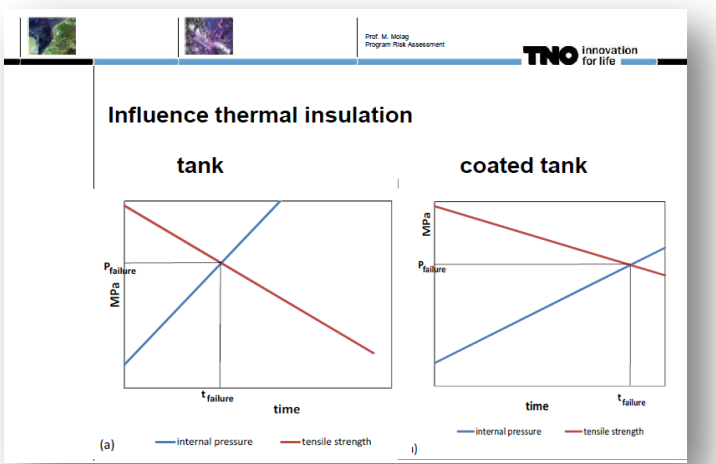
Context

Working group on the reduction of the risk of a BLEVE during transport of dangerous goods

- **Concept to be verified** : equipment of tanks with safety valves and/or full fire protection coatings
- 2013-2014 : **Tests carried out by BAM** to study the response of low capacity LPG tanks under thermal loads (capacity : 2,75 m3)
- TNO : qualitative validation => extension to larger tanks

Main conclusion : Thermal coatings and safety valves or their combination may delay or avoid a BLEVE

BAM tests : Abstract Test Results BAM-VH 3228



TNO Report : Heat Resistant coatings and PRV Investigation of uncertainties

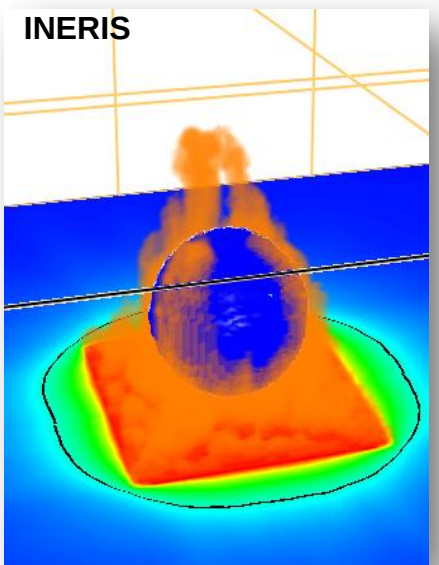
*Capacity real scale LPG tanks ~ 30000-60000 m3

Context

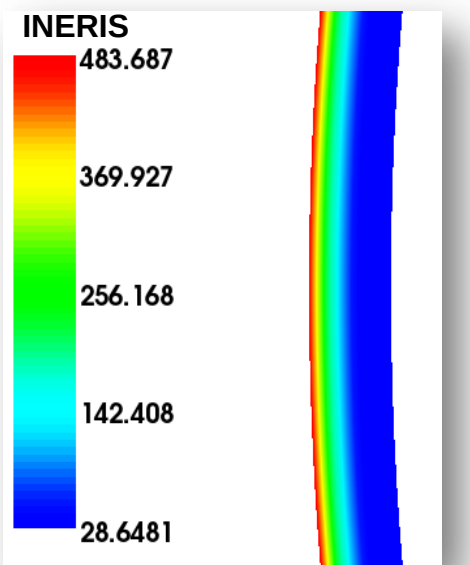
2015 : French competent authority requests INERIS to use its predictive tool to study the behaviour of different configuration tanks :

- Tanks with fire **protection coating**
- Tanks with **safety valve**
- Tanks with fire **protection coating** and **safety valve**

Main Objective : To assess the vulnerability of LPG tanks under thermal loads whatever the tank geometry (safety valve size, tank capacity,…)



Thermal loads modelling (software : FDS 6)



Structural resistance analysis (software : CODE ASTER)

Model example

Methodological approach used for models (INERIS model,…)

Input

- ❖ Geometry definition (coating, safety valves)
- ❖ Lading characteristics (Level filling, Products)
- ❖ External thermal loads characteristics

MECHANICAL MODEL ⟳ **THERMAL MODEL**

Failure Criterion : Loss of containment

1 **Standard approach** : elastic model only

2 **Complex approach** : irreversibles : plastic deformation is allowed

Model Results

- ✓ Stress maps
- ✓ Local stress intensity in fragility zones (safety valves,...)
- ✓ Temperature Distribution in the tank shell
- ✓ Temperature distribution in the lading
- ✓ Pression evolution
- ✓ Level filling evolution

✓Effective protection ← **No collapse**

Collapse →

- ✓Effectiveness of the measure depending on time to failure (to be defined by authorities)
- ✓Non effective protection

An existing INERIS tool based on this approach was used. BAM tests were helpful for calibration of model parameters (thermal exchanges coefficients, evaporation model,…)

Current Model

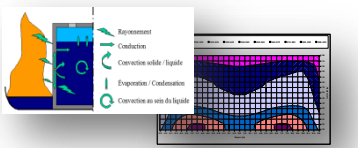
Several models have been developed in the last 30 years

Analytical Models

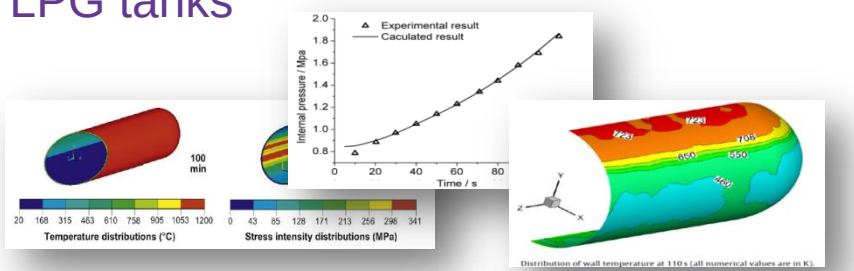
- The Model of Thermal Response of liquefied Petroleum Gas Tanks partially exposed to Jet fire – Xing, Jiang, Zhao – *Chinese Journal of Chemistry Engineering – 2004*
- Thermal response Analysis of LPG tanks exposed to fire – Aydemir, Magapu, Sousa, Venart – *Journal of hazardous materials - 1988*

Numerical models

- Modélisation du phénomène de pressurisation du contenu d'un bac à toit fixe pris dans un incendie – F. Fouillien – *INERIS – 2008*



- Fredric research Project – *2006-2007* – The behaviour of protected pipes subjected to thermal loads
- Modelling the performance of coated LPG tanks engulfed in fires – Landucci, Molag, Cozzani – *Journal of hazardous Materials – 2009*
- Effect of fire engulfment on thermal response of LPG tanks



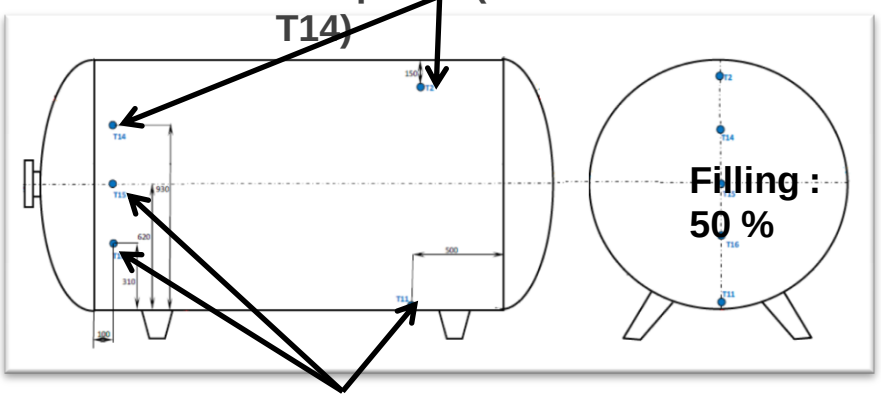
BAM Tests

Low capacity tanks : Investigation Tests

- 2,75 m3 LPG tanks (propane)
- Temperature measurements on the tank shell and in the lading
- Internal pressure measurements

Test Matrix defined :

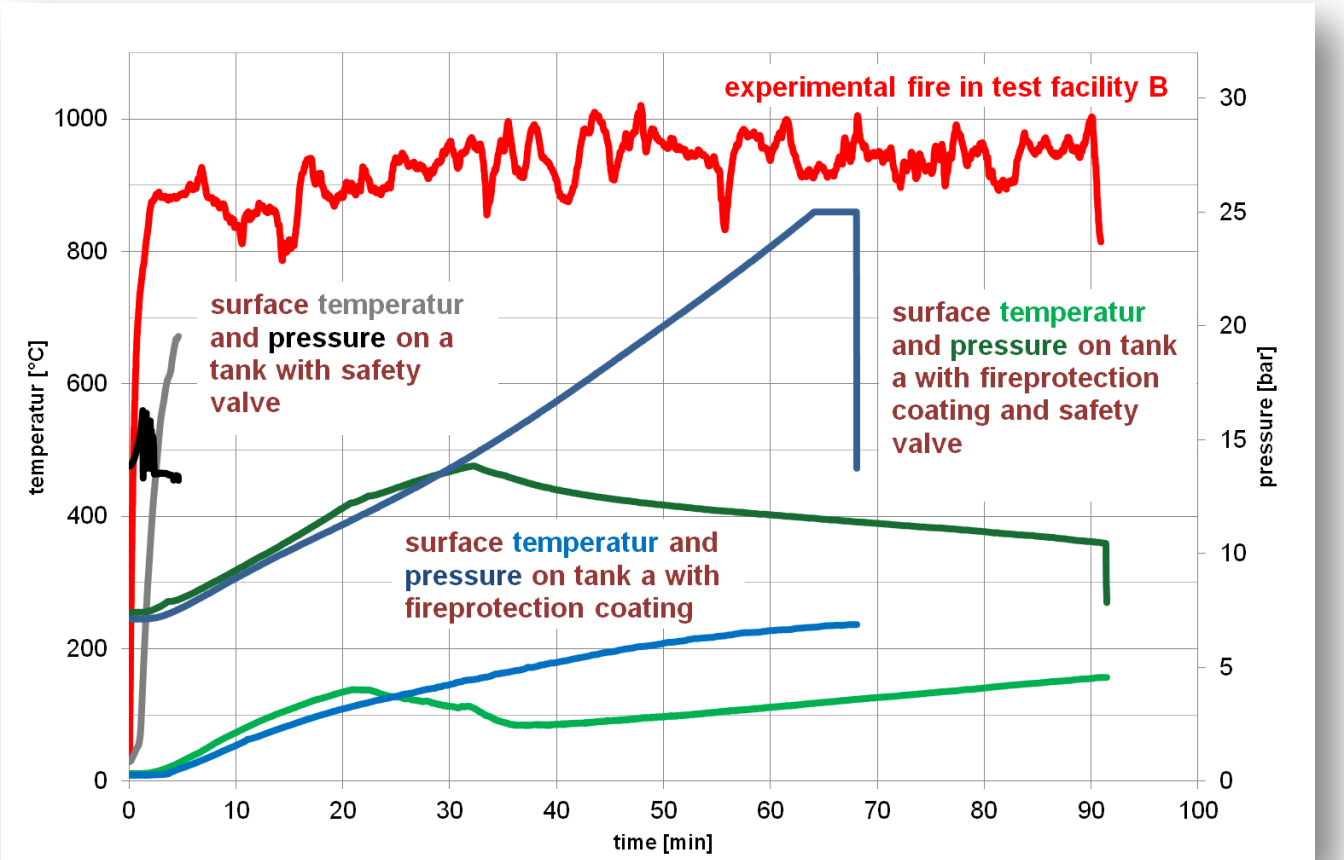
- Variation of coating thickness/degree
- Tests with & without safety valves (various types)



BAM Tests

Low Capacity tanks : Results

- Coating is efficient
- Appropriate safety Valves can be very helpful but must be thermally protected

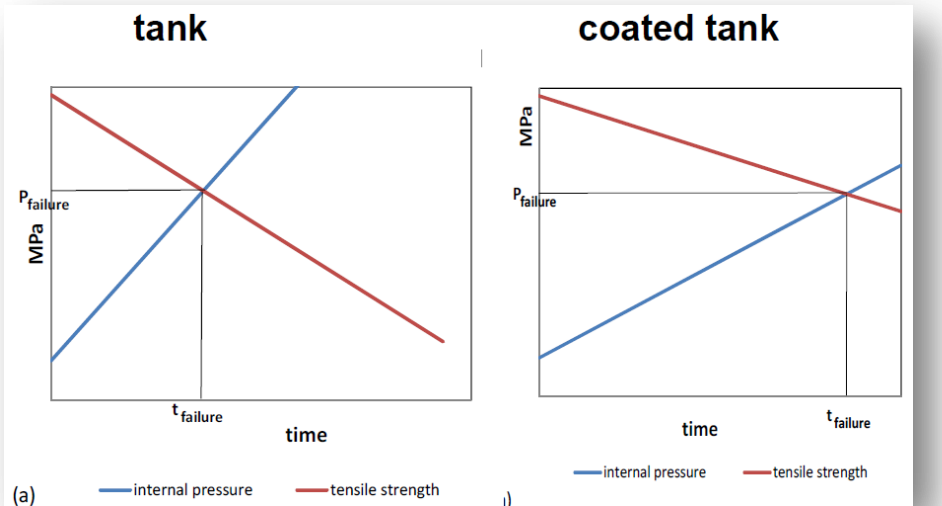


Modelling can be used to assess coating and safety valves design

TNO investigations

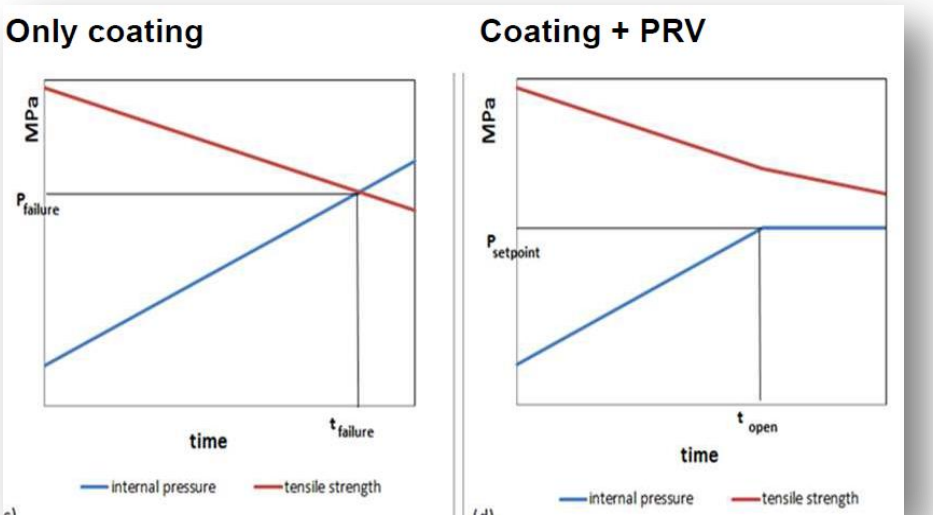
TNO report describes the effectiveness of thermal coatings and safety valves to delay or avoid the BLEVE

Case N°1



Coating thermal protection will delay the BLEVE. Tank steel temperature increase more slowly

Case N°2



Safety valves will delay the BLEVE and may avoid it. The tank pressure is regulated.

1 Context

2 Examples of models to study the LPG thermal response

3 BAM tests – TNO investigations

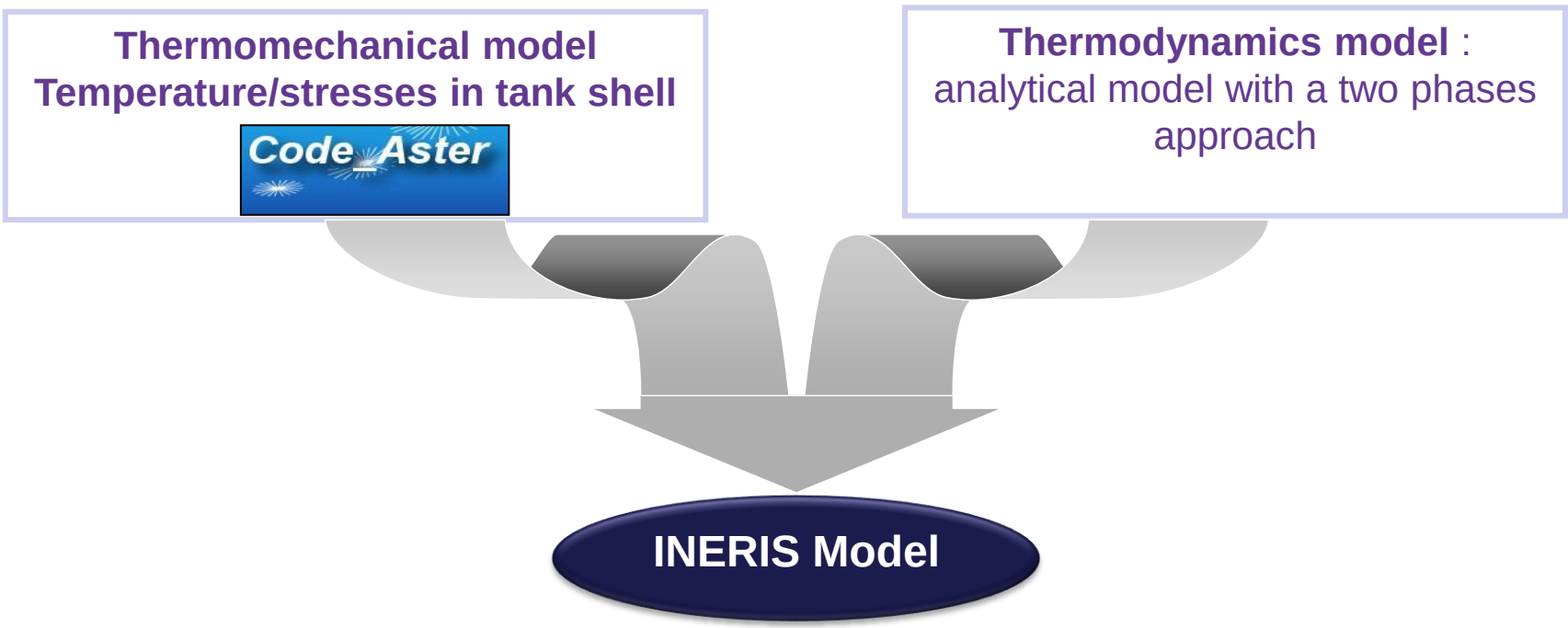
4 INERIS Model and comparison with tests

5 Conclusion

INERIS Model

Models characteristics

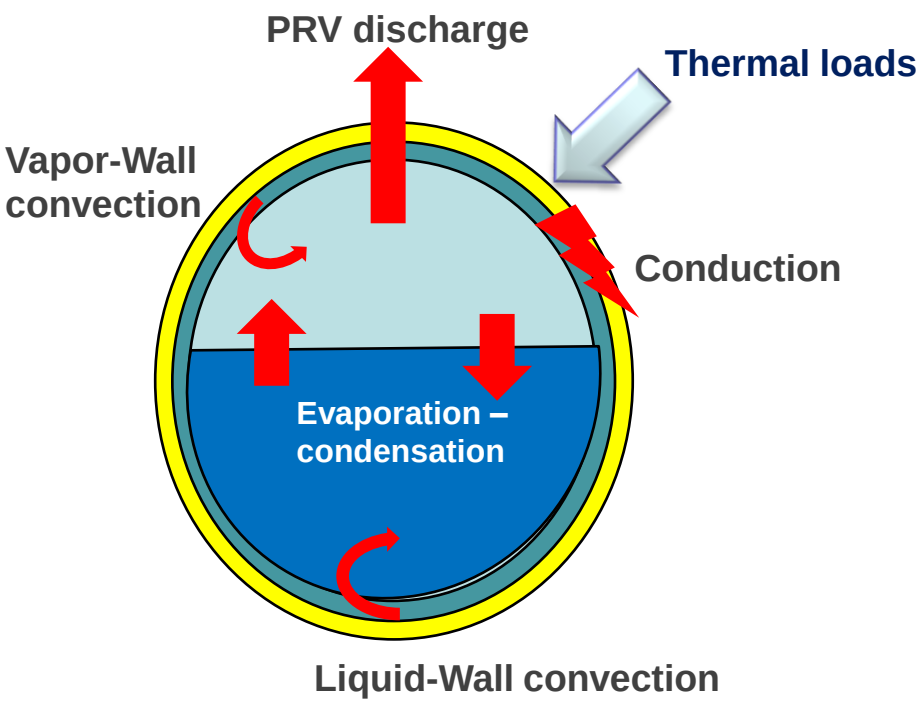
- Finite elements* model for the tank shell (insulation+ steel wall)
- Analytical approach with a 2 phases model. This quick model provides relevants results for low capacity tanks but can't be used for large vessels.



*** Finite Elements method** : In mathematics, the finite element method (FEM) is a numerical technique for finding approximate solutions to boundary value problems for partial differential equations

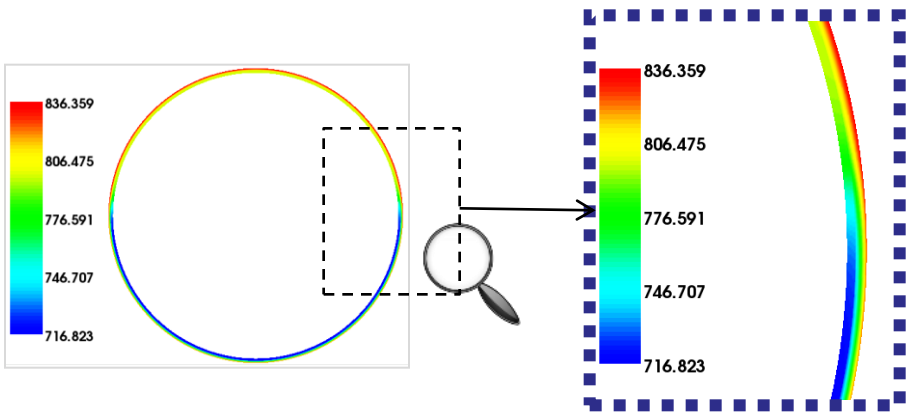
INERIS Model

Thermal transfert in a GPL tank



Numerical model with robustness very helpful to simulate :

- complex geometry (safety valve, pipes connexion)
- various Mesh precisions (3D-2D models)

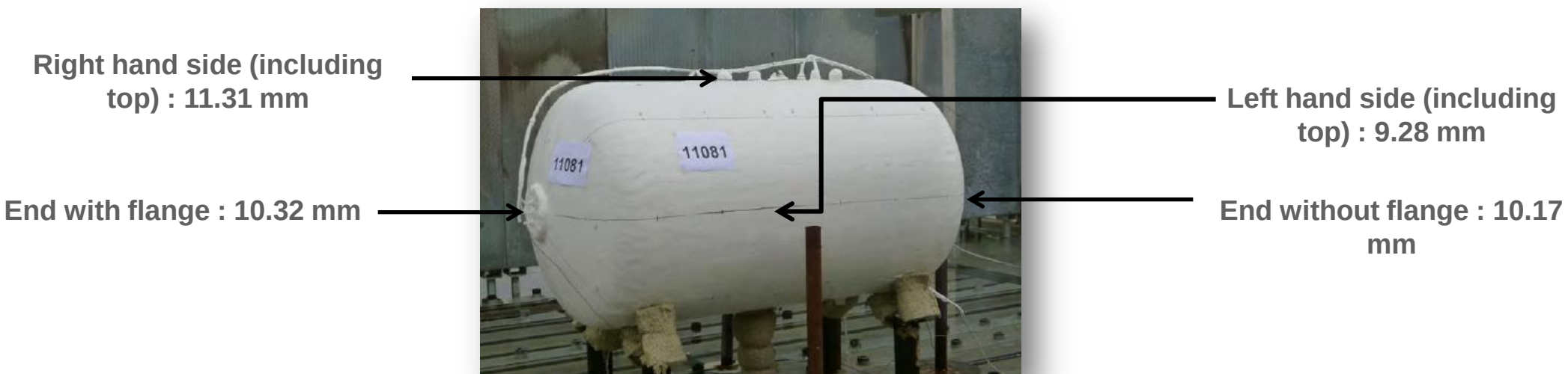


- results : stress maps / T°C maps.

Comparison tests – model results

Tank characteristics (BAM test)

Tank volume	2750 l
Degree of filling	50 % (1375 l liquide propan)
Material	Fine grain steel StE36
Wall thickness	Sheating : 6.5 mm
	Ends : 6.5 mm
Working pressure / Test pressure	16.7 bar / 22 bar
Coating	Two component epoxy resin coating (density 1000 kg/m3) About 10 mm
Thermal loads	75 kW/m² - full fire engulfment

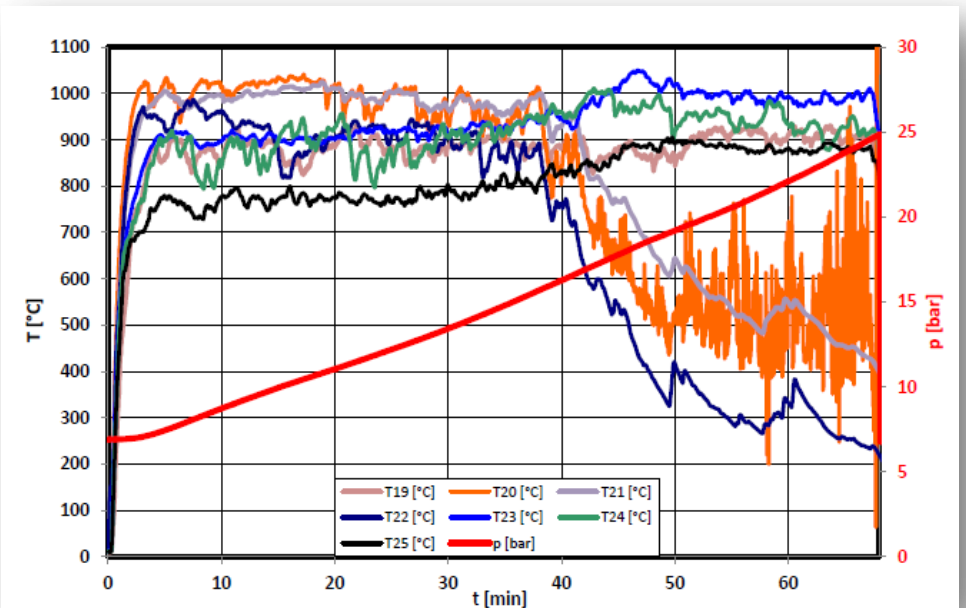


Comparison tests – model results

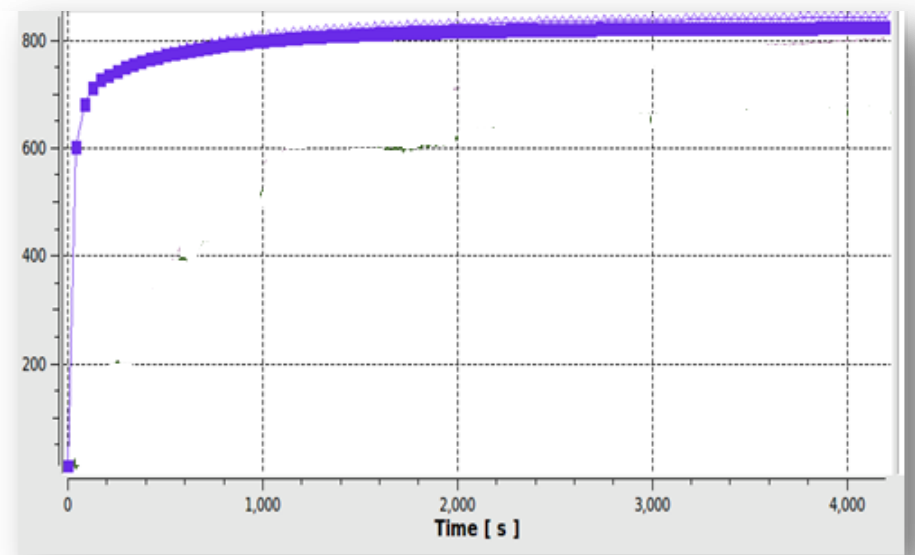
Progression of fire temperature

TEST → MODEL

Fire temperature measured during the test



Fire temperature calculated with the model

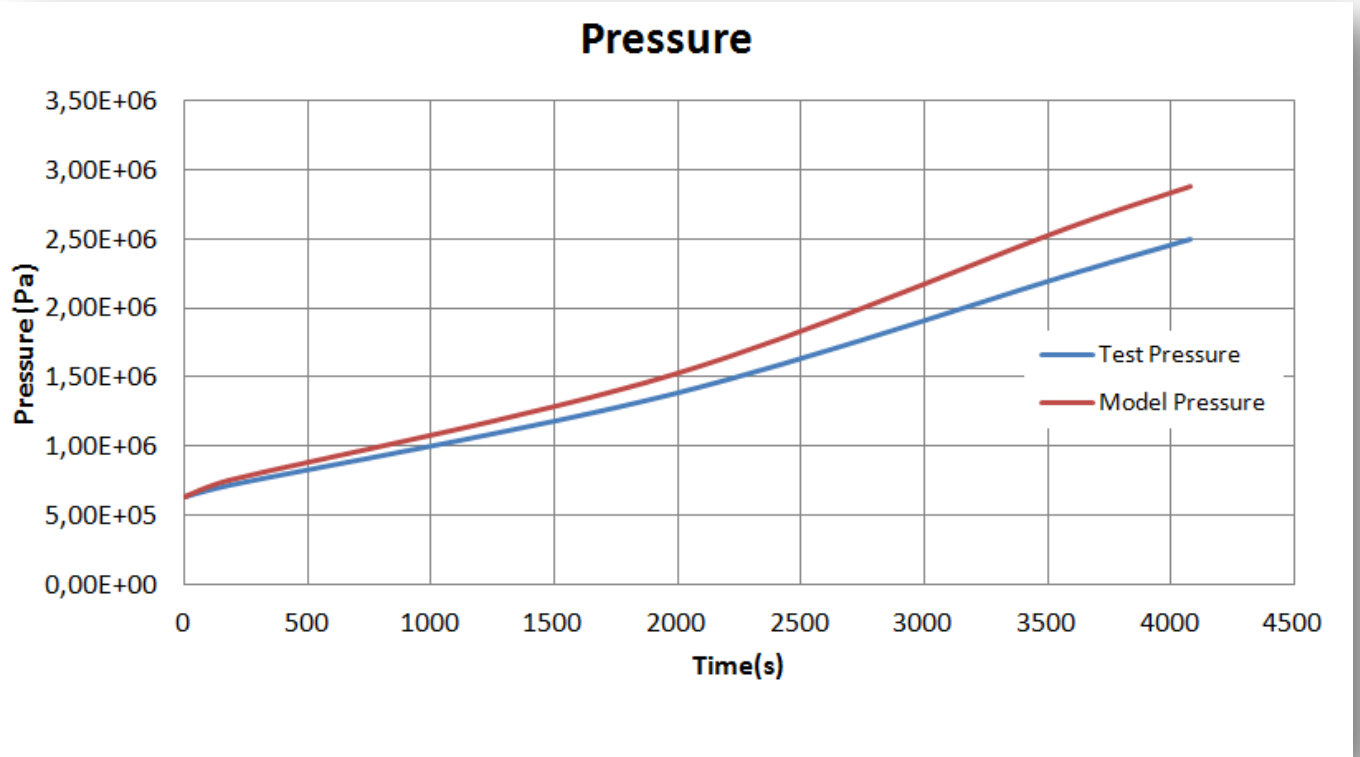


Comparison tests – model results

Sequence of tank internal pressure

- Models results are in accordance with tests measures
- Differences => information losses about insulation thermal properties

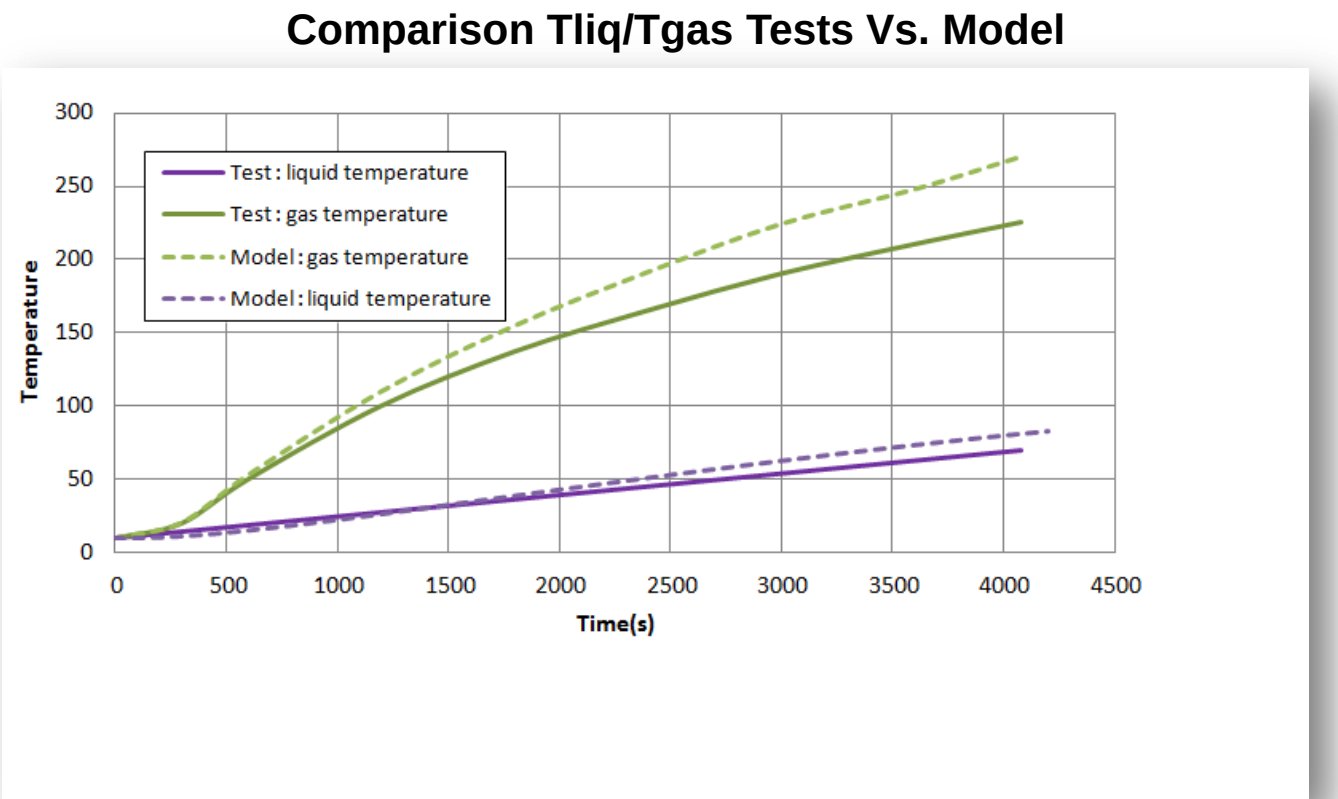
Pressure measured during the test / with the model



Comparison tests – model results

Sequence of tank internal temperature (gas & liquid phases)

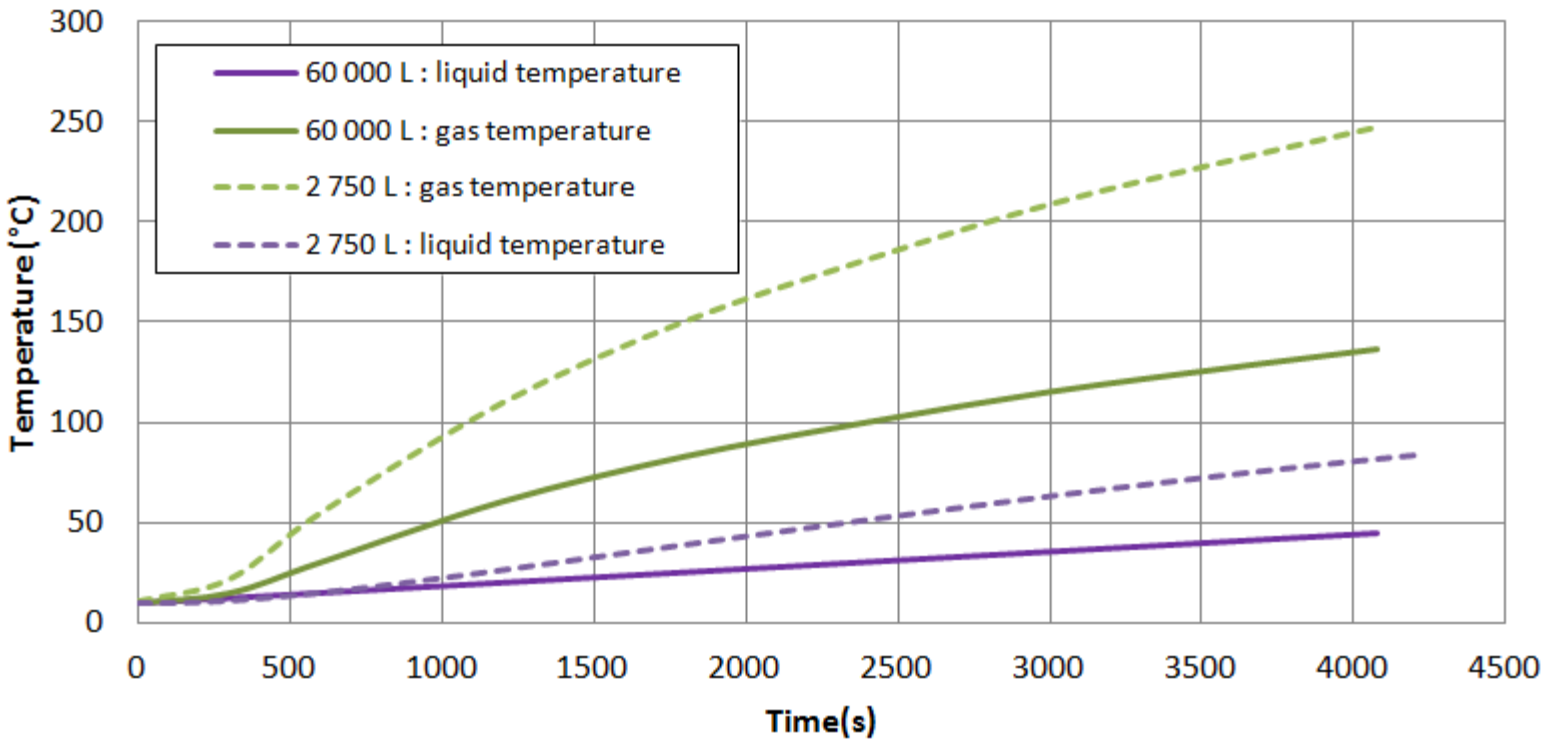
- Models results are in accordance with tests measures for liquid and gas



Example : a real scale LPG tank

Tanks characteristics

- Volume : 30 000 L
- Steel Thickness : 11 mm
- Propane – Filling Level : 50 %
- Coating : similar to BAM tests



These results confirm that temperature levels are higer for low capacity tank than for real scale tanks

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Conclusion

Comparison BAM tests – numerical model complete

- Coating thermal properties must be specified to finalize the model validation

The model may now be used to study several configurations in terms of tank volume, safety valve size, coating thickness

Model results show the effectiveness of safety valves and thermal coatings on large scale tanks.

- Compared with BAM tests, larger tanks have slower wall temperature increase : Time life performance is increased.
- Calculations will be led on tanks equiped with normalized safety valves. As a result, the efficiency of this measure will be assessed.
- The mechanical response of safety valves under high temperature conditions must be studied.