

Effects of Enveloping Pool Fires on LNG tank Containment Systems

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Germanischer Lloyd

Content



“other authors”:

Prof. Jerry Havens, Prof. James Venart;
Fire Performance of LNG Carriers
Insulated with Polystyrene Foam;
Journal of Hazardous Materials;
electronically published February 2008,
HAZMAT-7824, 7 pages

- Introduction to the topic
- Results
 - LNG: Nucleate boiling → Film boiling ?
 - FEA and CFD analysis for heating up of the weather cover
 - Heating up cover / insulation
 - Temperature distribution
 - Relation of CFD results to pool fire burning duration according to SANDIA report
- Deterioration of the insulation
- Conclusion

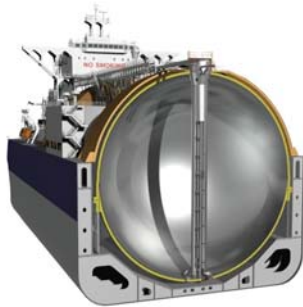
Introduction to the topic

- Increased trade of LNG over the past decade has led to discussion of possible major fire hazards associated with both marine accidents and intentional acts. This is becoming a part of public awareness.
- A major area of concern has been the ignition of a LNG pool around a Moss LNGC
- The spill is assumed to be caused by failure of one tank. The fire effects to the other Moss tanks were regarded to lead to overpressure and tank failure.
- The evaluation of consequences of a moss containment system under fire exposure is presented:
 - One tank is breached and spills the LNG onto the water which results in a large pool fire
 - The calculations have been done under the assumption that the hull is completely engulfed by the fire.
 - Only breach sizes larger than 3 m² will lead to pool diameter above 300 m (SANDIA report).
 - The ship length overall of a moss LNG carrier is approximately 300 m
 - The assumptions of an engulfing fire is regarded to be most severe but (very) hypothetical.

Introduction to the topic

- There are considerable uncertainties about the realistic behaviour and consequently about the emissive power of an LNG pool fire:
 - Experiments have measured maximum local heat fluxes of 300 kW m⁻² at the outer surface. Inside the fire ball the combustion is incomplete which will result in lower heat fluxes.
 - Basis for API-520 and IGC-Code Chapter 8 is a constant average heat flux of 108 kW m⁻², which is reduced by factors considering the protection of the tank and the incomplete fire engulfment.
- Therefore the following investigations to evaluate the heat transfer into the spherical tank system consider the interval of 88 kW m⁻² up to 300 kW m⁻².
- The fire itself has not been modelled. Instead radiation heat transfer from the fire to the weather cover and ships hull was assumed.

Introduction to the topic



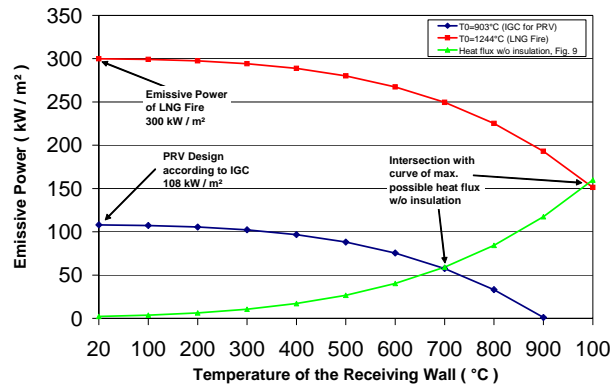
- Moss type spherical tank design, with polystyrene insulation.
- Steel weather cover welded to the main deck.
- Tank is covered by a polystyrene insulation of 0.29 m, melting temperature: 473 K - 573 K.
- Regarding the heat fluxes into the spherical tank the 1 m air gap between weather cover and insulation is of particular importance:
 - heat conduction,
 - convective heat transport,
 - heat radiation.

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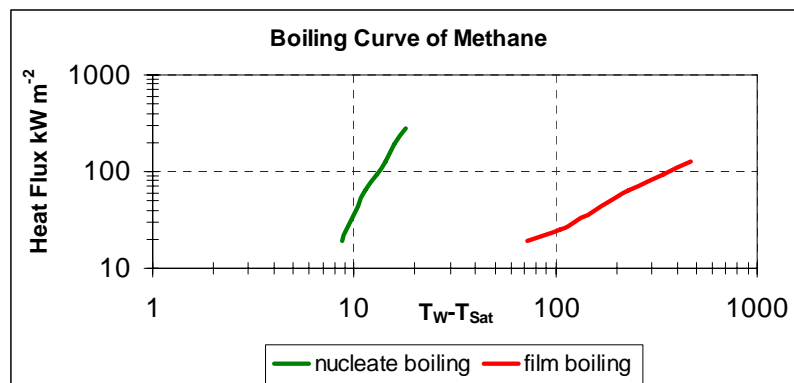
Inner Tank Failure by Film Boiling



$$\dot{q} = \sigma(T_0^4 - T_1^4)$$

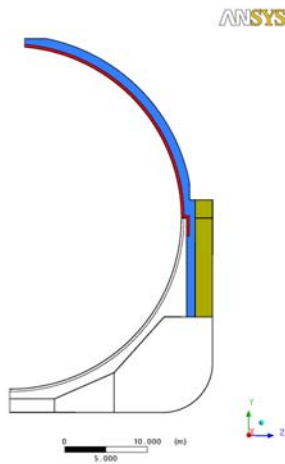
- The heat flux into the containment system (case: insulation has been removed) is approximately half the initial heat flux from the fire.

Film Boiling



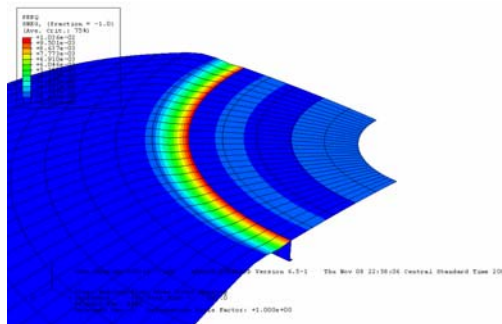
- No risk of damaging the inner tank due to film boiling, because the direct heat flux to this component is below 300 kW m⁻².
- Available oxygen will only support insulation combustion of 21 m³ (uniform burning → 5 mm)

CFD-calculations



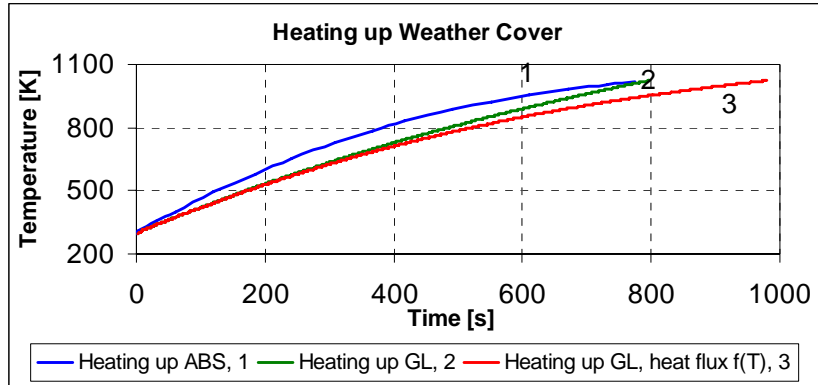
- Transient Analysis via CFX 11,
- All three phenomena of the heat transport are simulated.
 - Radiation, Convection, Conduction
- Model has been tested regarding quality aspects to assure the significance of the calculations, e.g.:
 - three mesh sizes
 - different model / convergence criteria
 - turbulence model

Weather Cover: FEA



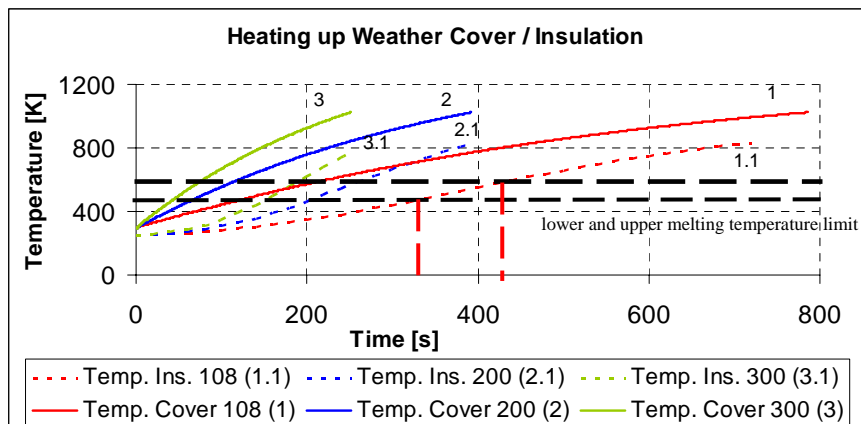
- ABS did separate Finite Element analysis (FEA) for buckling of the weather cover.
- First sign of local deformation is predicted at the connection of the upper cover sheet to the top platform and 1023 K because of an abrupt drop in the Young's modulus which occurs at this temperature.

Weather Cover: FEA / CFD comparison



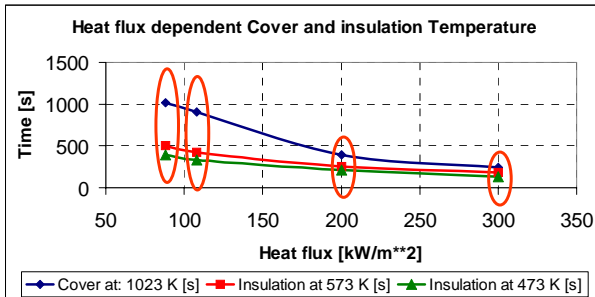
- Validation of temperature increase by two independent calculations with two different software tools.
- Curve 3: T^4 behaviour. $\dot{q} = \sigma(T_0^4 - T_1^4)$
- CFD model for the weather cover used by GL was calibrated with very good correlation against the buckling analysis carried out by ABS.

Heating up weather Cover / Insulation



- A complete heating up of the cover is simulated until buckling of this component occurs.
- The gradient of the curves depend on the initial heat flux.

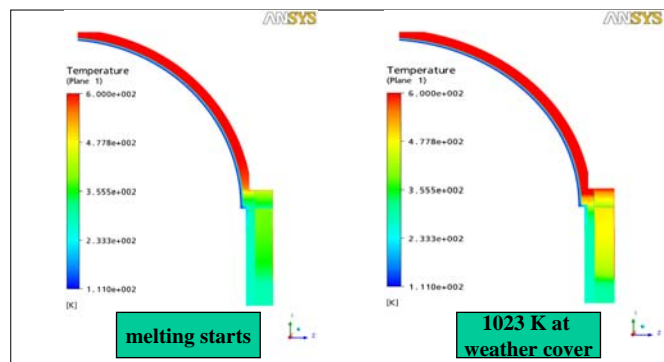
Heating up weather Cover / Insulation



Heat Flux	473 K	573 K	1023 K
300	134 s	185 s	245 s
200	210 s	255 s	391 s
108	335 s	420 s	910 s
88	390 s	500 s	1015 s

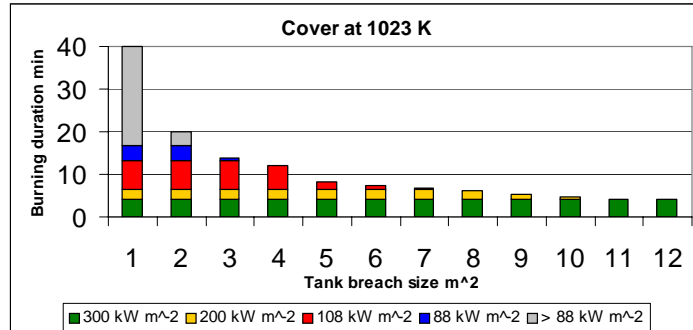
- Graphs shows - dependent on the heat flux - the trend for achieving the melting temperature of the polystyrene insulation and buckling temperature of the weather cover.

Temperature distribution during incident



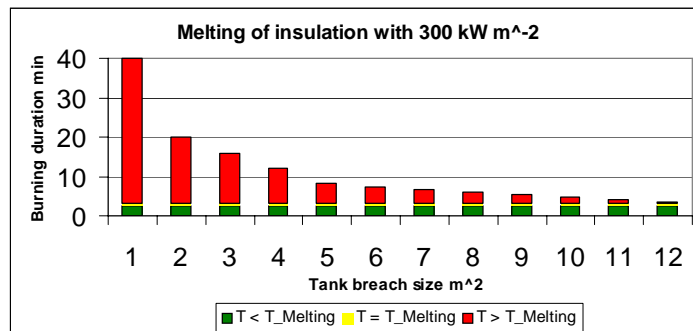
- The skirt area does not reach high temperatures with regard to structural integrity → Failure of the support can be excluded.
- Due to the rotational symmetry of the sphere the two-dimensional calculations are sufficient.

Heating up the weather cover to 1023 K (GL): Relation to pool fire duration (SANDIA)



- Heating up of the weather cover.
- The height of the bars indicates the duration of the fire.
- The colour specifies the required time to heat up the weather cover to the temperature when buckling starts. The green colour represents the heat flux of 300 kW m⁻², the other colours indicate the additional time for lower heat fluxes.

Start to melt the insulation: Relation to pool fire duration (SANDIA)



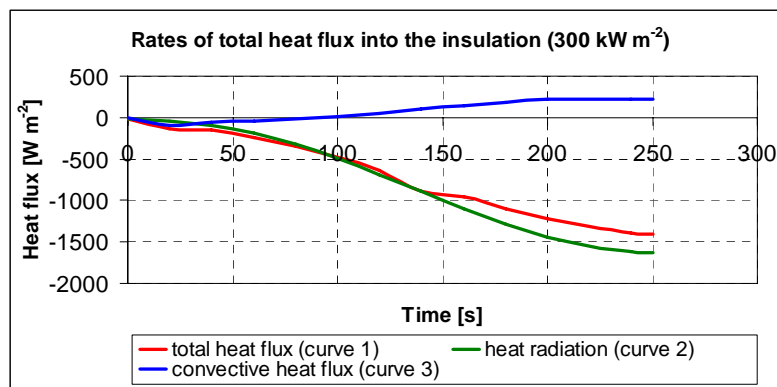
- Green bar indicates the time required to reach the minimum assumed melting temperature. The yellow bar describes the temperature interval of melting and the red bar displays the period which remain for deterioration.
- Hole sizes with a red bar will create a fire which will affect the insulation system.

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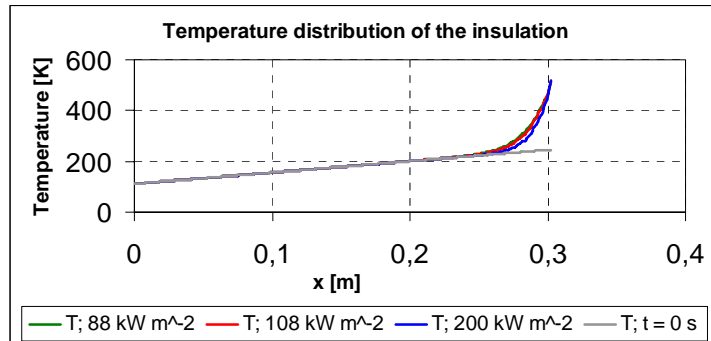
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Rates of the heat flux into the insulation



- Radiation is the dominant effect of the total heat flux.
- Compared to the heat load on the weather cover due to the engulfing fire the heat flux into the insulation is small.

Temperature distribution inside insulation



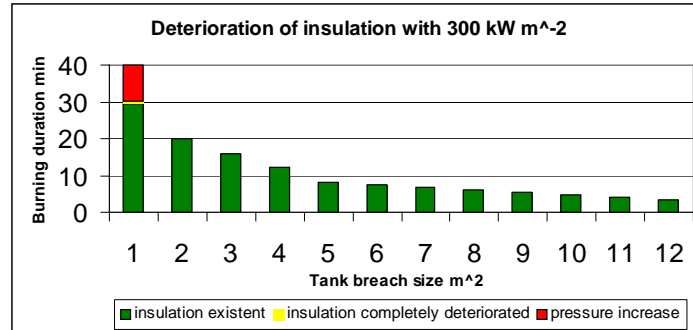
Time for heating up and melting must be added

- Independent of the initial heat flux only 4 cm of the insulation thickness are affected by an engulfing fire → heat transfer into the insulation is slow.
- Insulation must be heated up to melting temperature.

Deterioration of the insulation

- At the beginning of insulation melting only the surface has reached the melting temperature (after 2 min with 300 kW m⁻²):
 - In addition to energy for melting heat for the temperature increase to the melting temperature is required.
 - For polystyrene the heating up to the interval of melting requires the two- to threefold of the energy, which is necessary for melting.
 - The melting rate results from the quotient of the heat flux and the product of density and latent heat of fusion
- Case 300 kW m⁻²: a melting rate of 3 cm min⁻¹ is calculated which result in 9 min for melting.
- Another 18 min are needed to heat up the insulation (300 kW m⁻²).
→ The complete deterioration of the insulation will last 29 min as a minimum.

Relation to pool fire duration (SANDIA)



- Green bar indicates the time required to destroy the insulation completely.
- The red bar displays the period which remain to increase the pressure inside the containment system.
- Hole sizes with a red bar will create a fire which will affect the pressure inside the containment system.

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Conclusions

- An engulfing fire as assumed is not able to destroy the complete polystyrene insulation of a Moss Tank.
- With 300 kW m⁻² initial heat flux:
 - only spills from holes below 2 m² burn long enough to destroy the insulation thickness. But the tank will not be engulfed by the fire in these cases.
 - the minimum time period to destroy the insulation will be 29 minutes after the fire is started (not 10 min as assumed by other authors).
- With the more realistic sizing heat flux of the PRVs (108 kW m⁻²):
 - for large engulfing fires with breach sizes of 5 m² or greater the fire duration is too short to heat up the weather cover to the buckling temperature (1023 K).
 - only for leak sizes smaller than 3 m² the heat flux is able to heat up the weather cover above 1023 K.
 - even with a small hole size of 1 m² the fire does not burn long enough to completely destroy the insulation system.
- There is no increase in heat flow into the cargo tank until virtually all the insulation is destroyed.
- Dangerous tank wall overheating of a LNG filled Moss Tank can be excluded even if the insulation is destroyed completely

Thank you for your attention!

