# Modelling LNG vaporisation rate following release

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# LNG Ship

# Facts & Projections

- Natural gas is one of the fastest growing sectors of energy market; by some accounts entering '*golden age*';
- demand for natural gas by 2035 is expected to be 50% higher than today.

- currently approximately quarter of natural gas is transported as LNG;
- Some forecasts indicate that the world trade in LNG is to double by 2035;

# New Developments

- Nature of LNG trading is rapidly changing
- The clash between the two structural models of the international LNG industry – the traditional, risk-averse, contract dependent model and the free market trading model
- Floating LNG developments are gathering speed driven by the need to exploit stranded offshore gas fields

# LNG Risks

- increase in the amount of LNG transported & the complexity of trading will invariable increase a risk of accidental spillage;
- renewed pressure on improved quantification of risk associated with LNG transport and loading operations;
- Although the track record of LNG industry is very good the regulators remain unconvinced;

# What happens when LNG is accidentally spilled on water or soil?

- spreading;
- rapid vaporisation;
- formation of the dense vapour cloud; possibility of pool fire;
- dispersion of the vapour cloud; asphyxiating and highly flammable;
- possibility of  flash fire, fireball or destructive explosion

In accidental cryogen spills one of the crucial factors that determines the formation and the future behaviour of the hazardous vapour cloud is the rate of vaporisation of LNG.

# Rate of Vaporization

# Rate of vaporization

$$\frac{dM}{dt} = -\frac{\pi R^2 q}{L}$$

$$q = h\left(T_w - T_B\right)$$

$$\frac{dR}{dt} = 1.64\left[\frac{g\left(\rho_w - \rho\right)}{\pi \rho_w \rho}\right]^{1/2} \frac{\sqrt{M}}{R}$$

# Assumptions

- methane spill
- the water surface temperature remains constant throughout the spill duration;
  - the boiling occurs in the film boiling regime;
  - heat transfer coefficient remains constant throughout the spill duration;

$$t_{\max.} = 1.0562\left[\frac{\pi\rho_w\rho_{C1}L_{C1}^2M_0}{g(\rho_w-\rho_{C1})h^2(T_w-T_{C1})^2}\right]^{1/4}$$

# Rate of Vaporization

# Heat Transfer

$$\frac{\partial T_i}{\partial t} = \kappa_i \frac{\partial^2 T_i}{\partial z^2}$$

$0 \le z < \varepsilon$

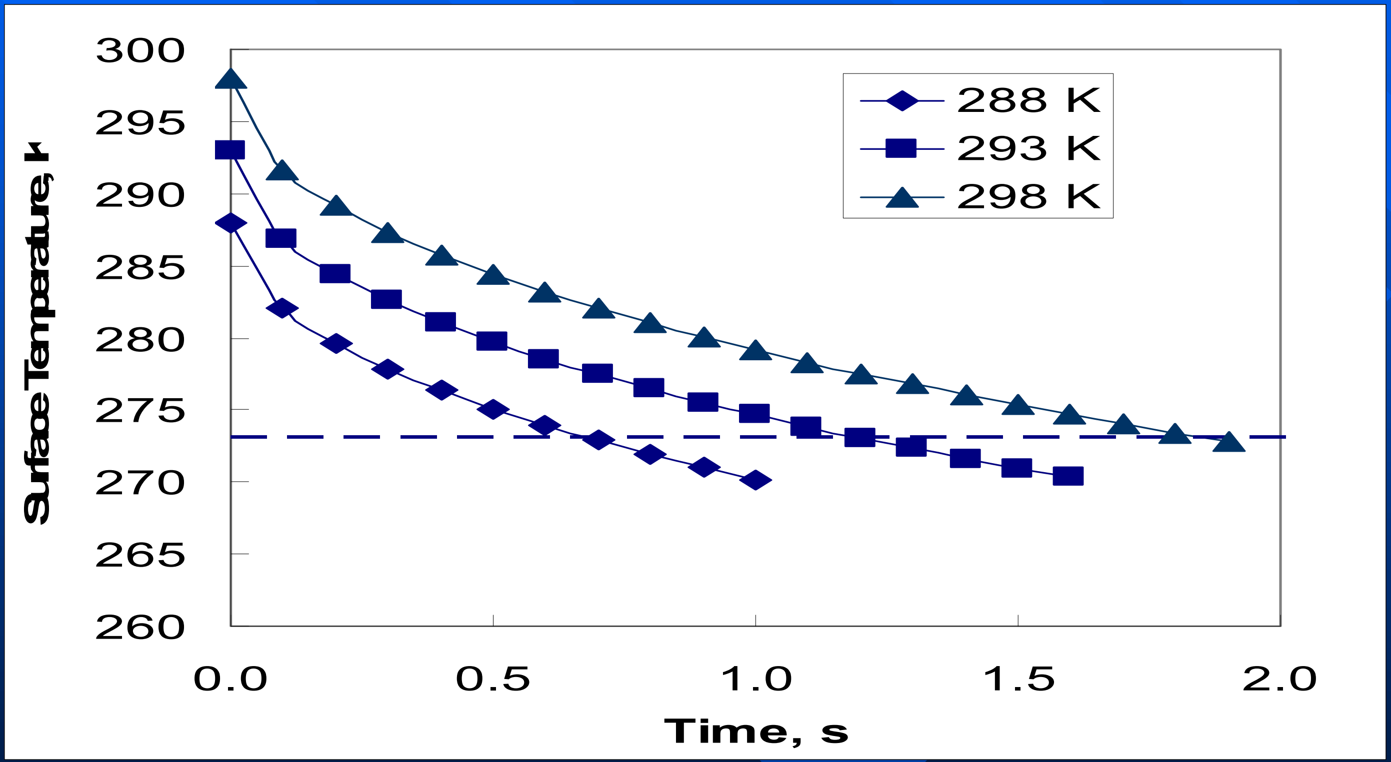
$$\frac{\partial T_w}{\partial t} = \kappa_w \frac{\partial^2 T_w}{\partial z^2}$$

$z > \varepsilon$

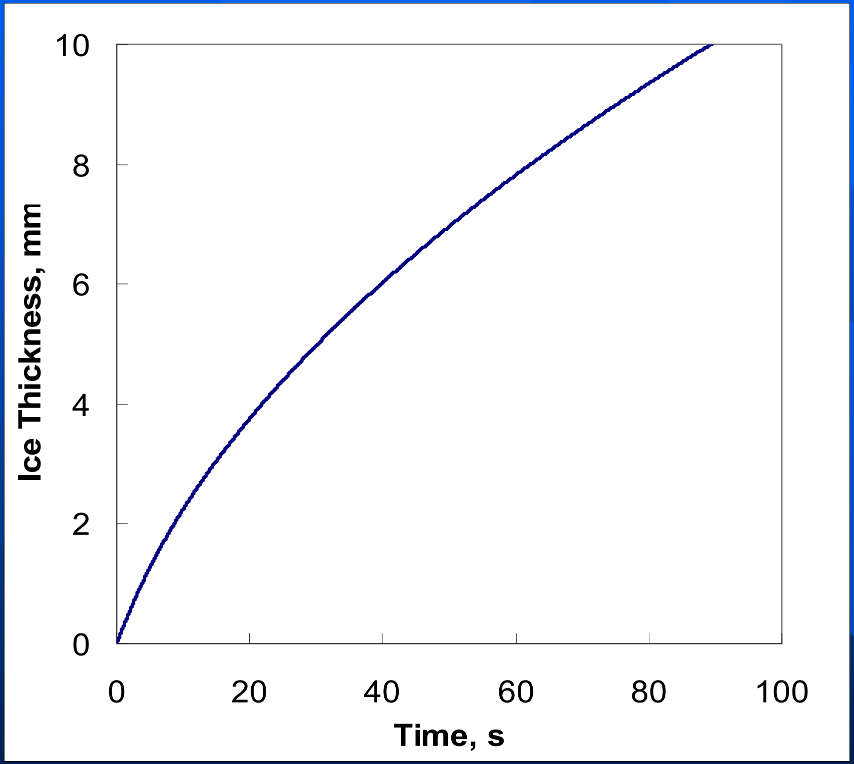
$$\rho_w L_w \frac{\partial \varepsilon}{\partial t} = \lambda_i \left. \frac{\partial T_i}{\partial z} \right|_{z=\varepsilon} - \lambda_w \left. \frac{\partial T_w}{\partial z} \right|_{z=\varepsilon}$$

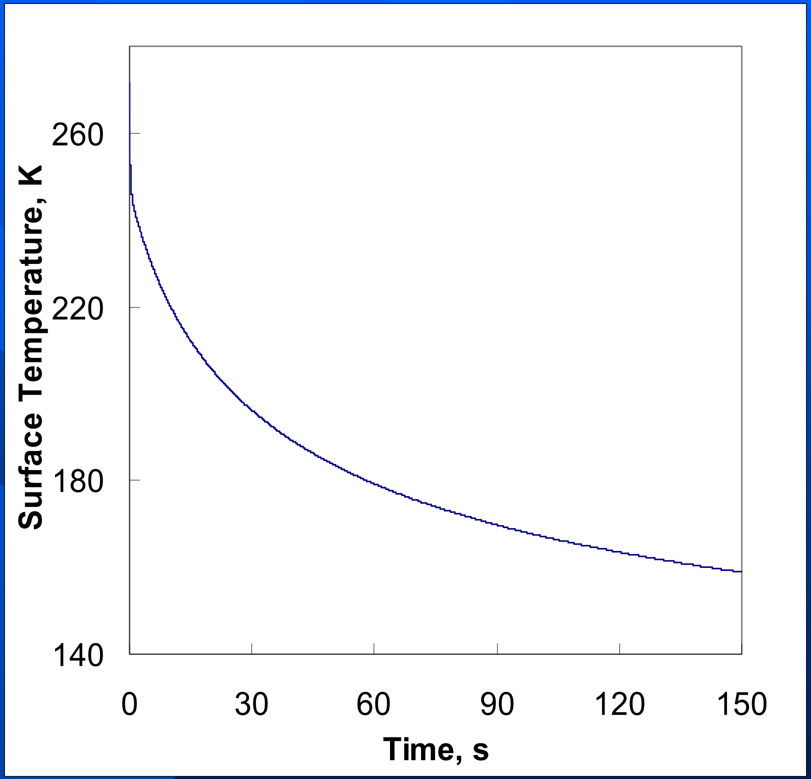
$z = \varepsilon$

# How quickly does ice form?

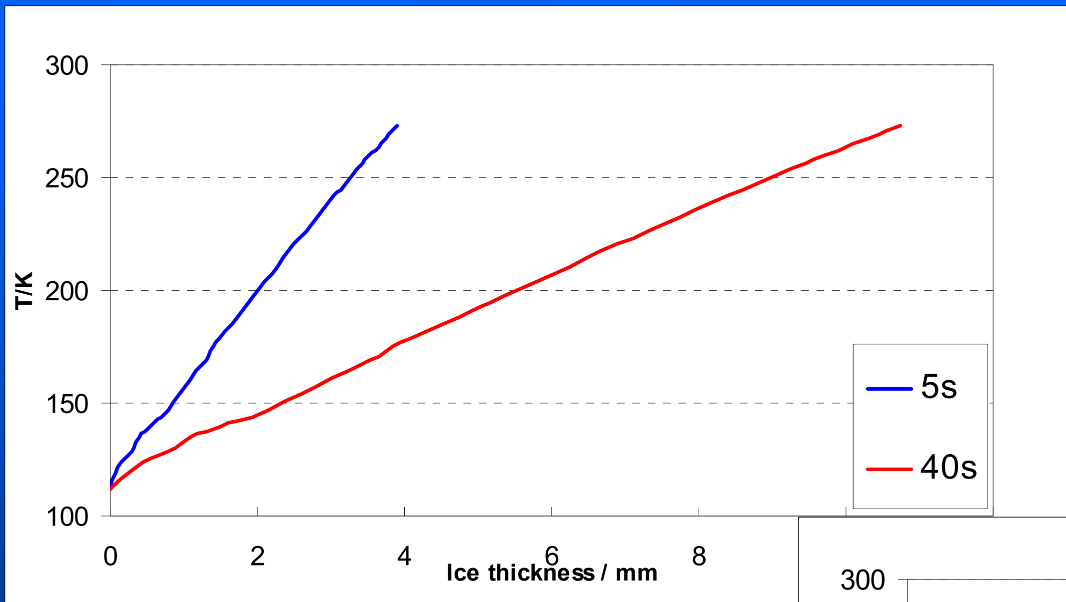


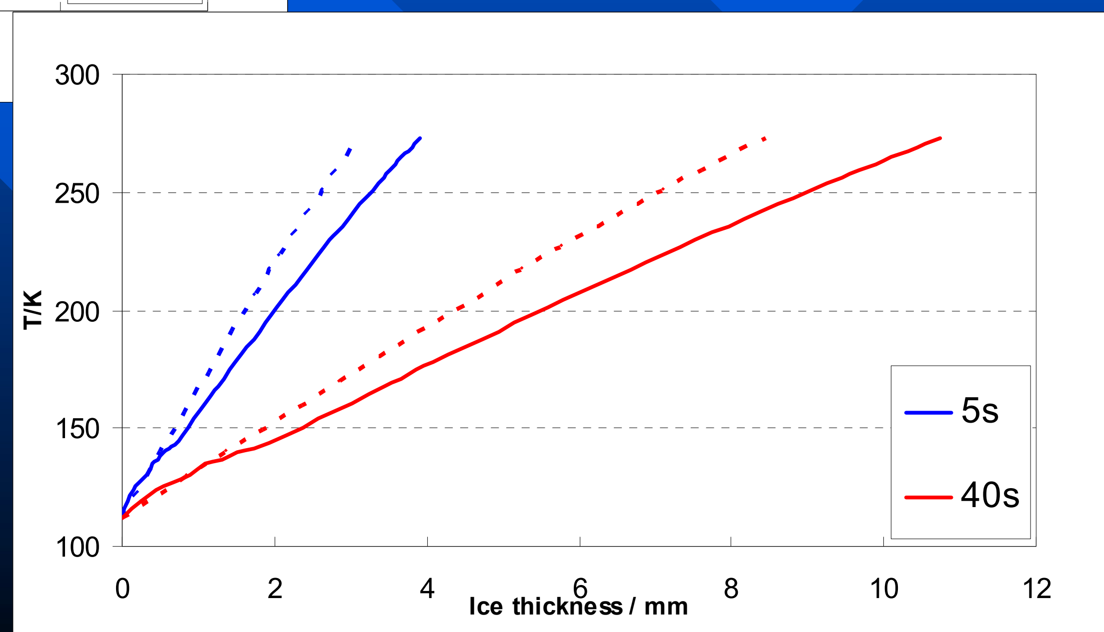
# Rate of ice formation & Surface temperature



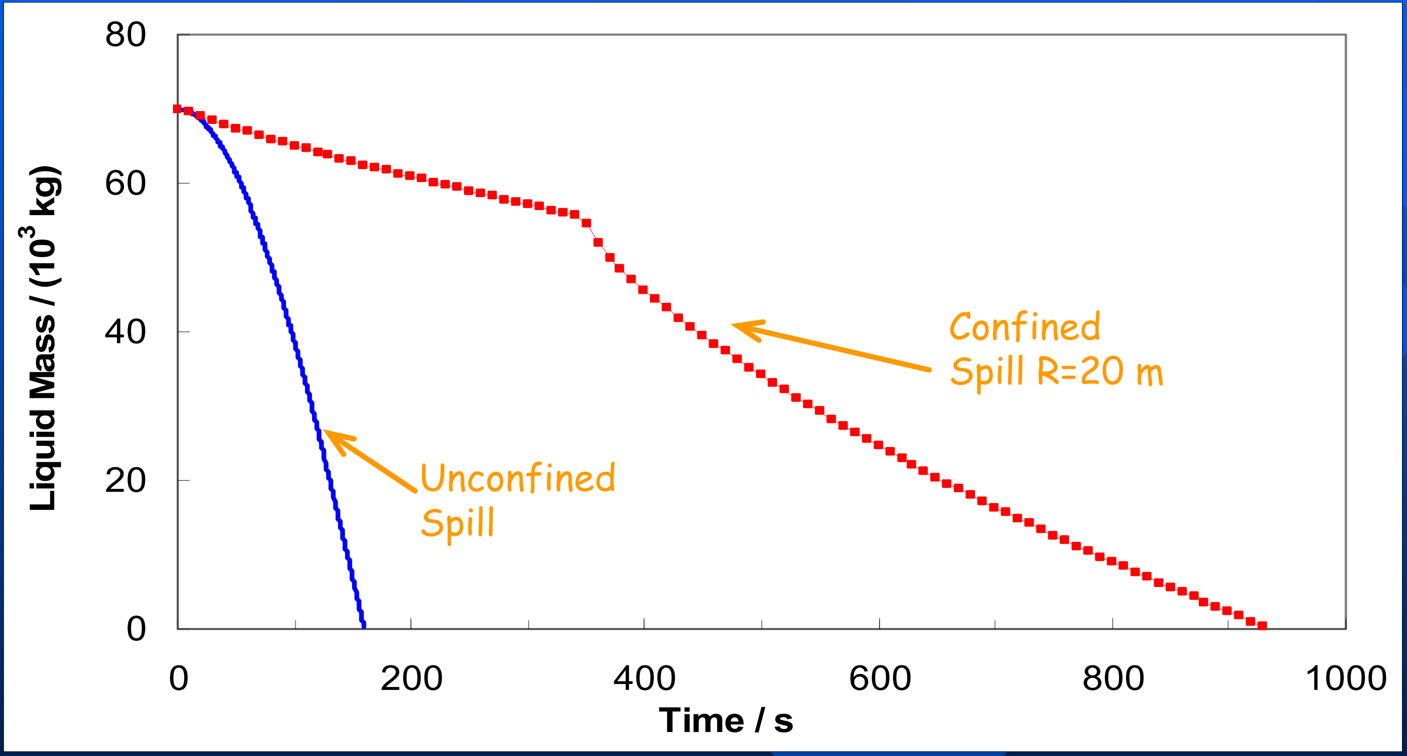



# Ice thickness

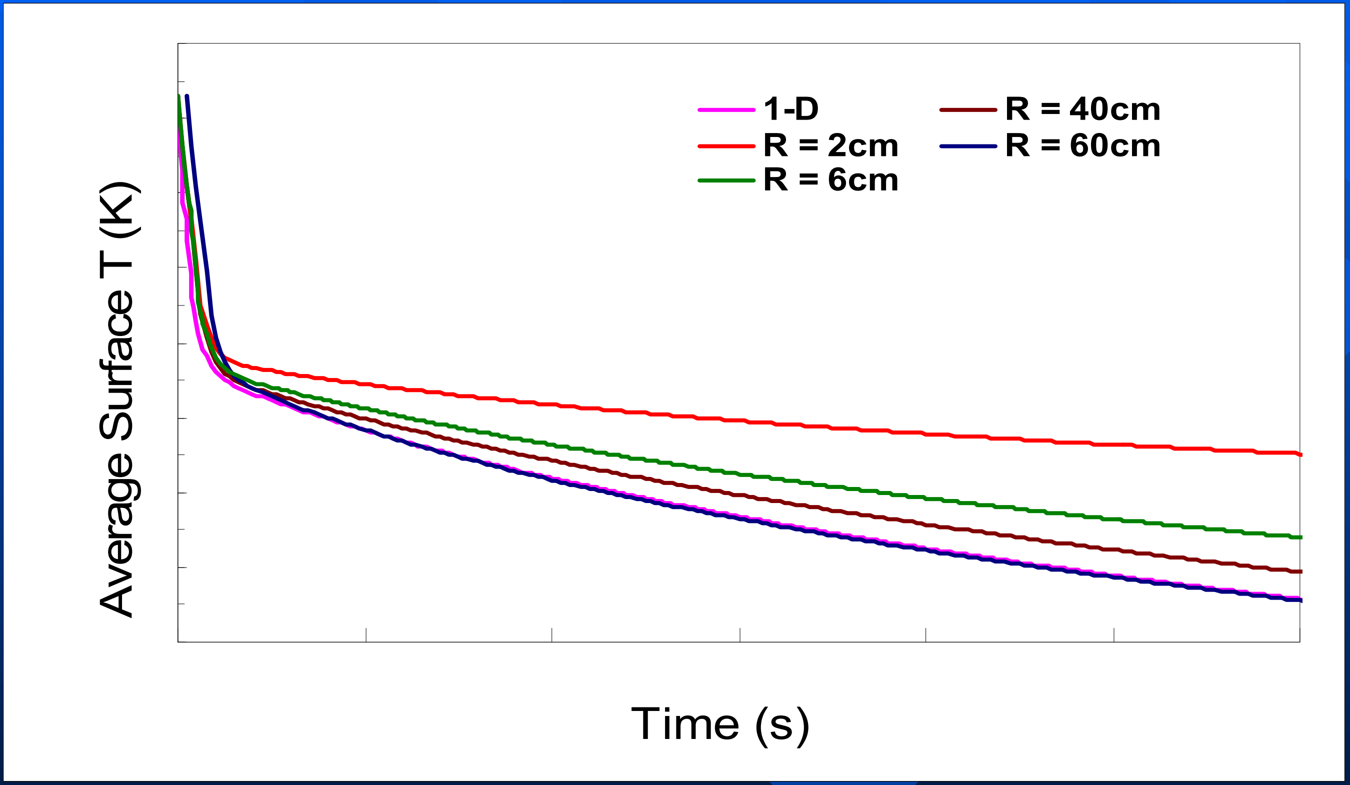


# Rate of Vaporization



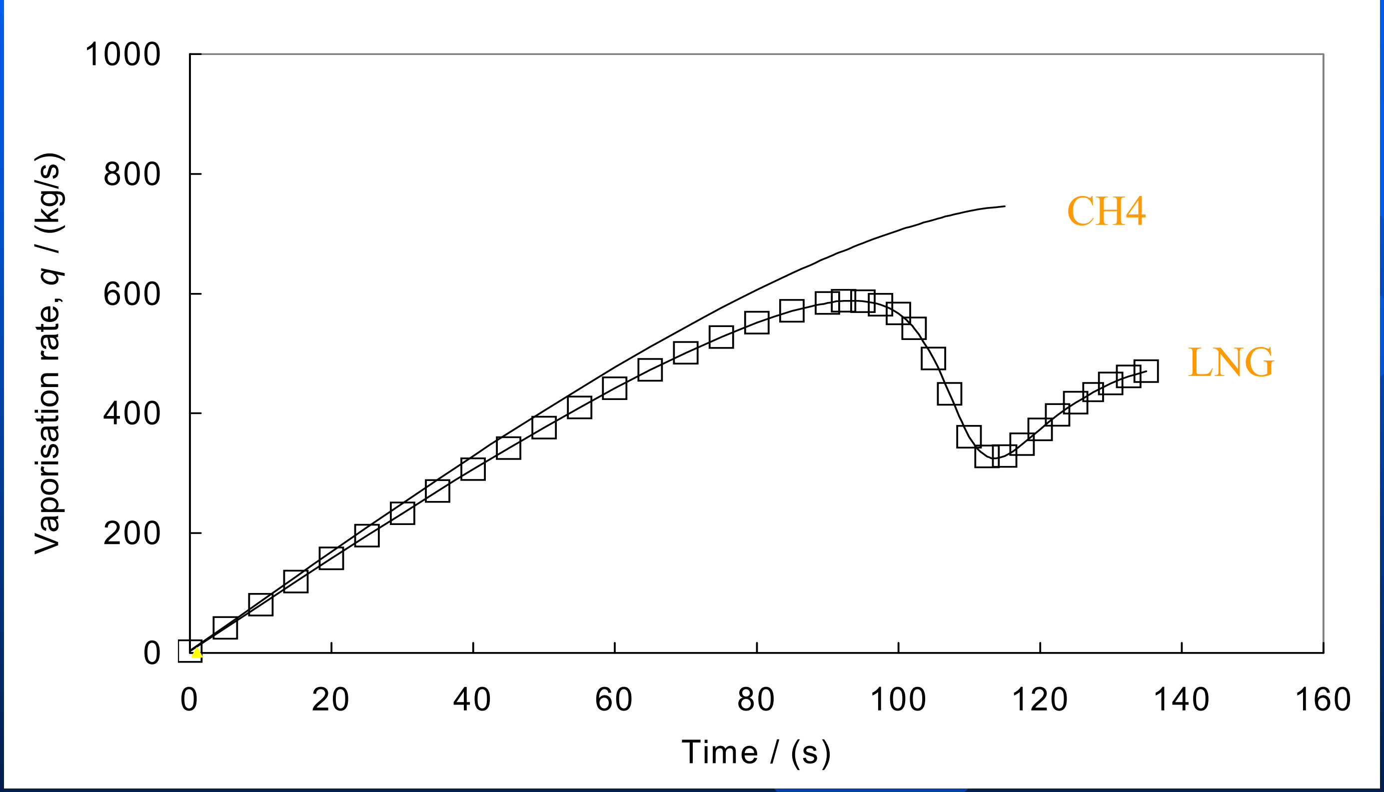
# Size of enclosure



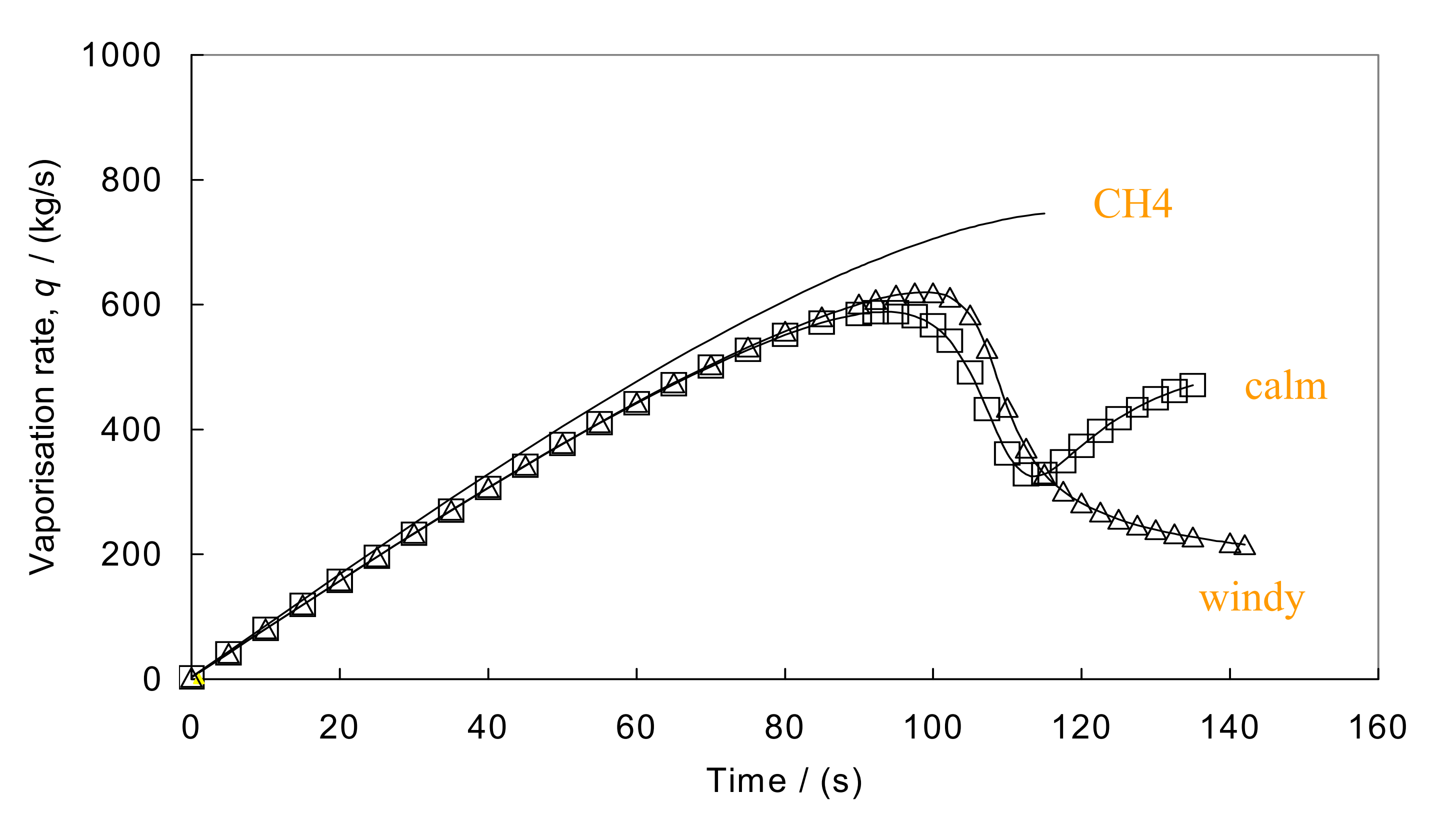
# Compositional influence

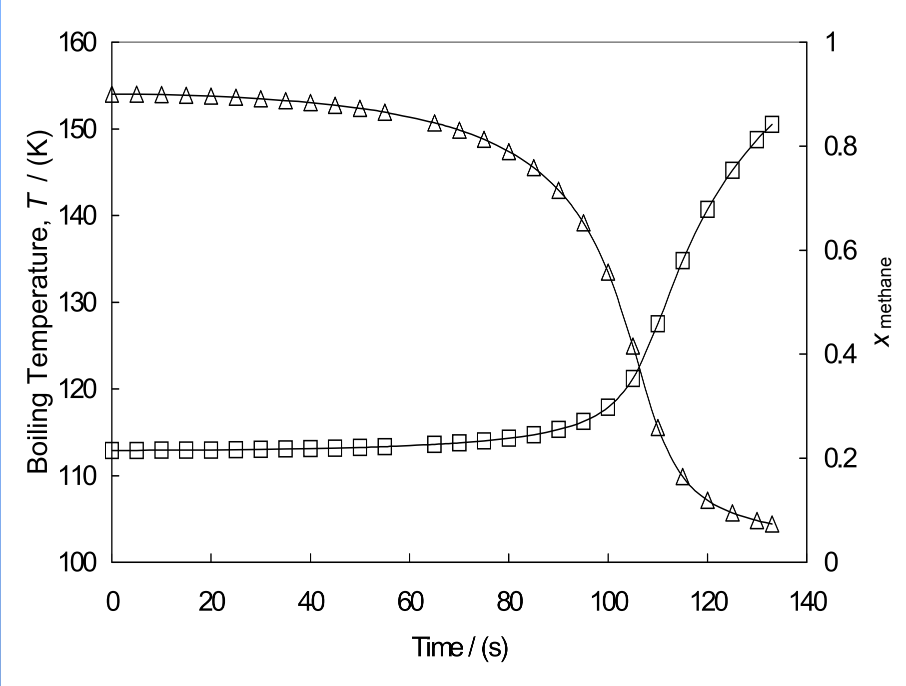
- Treat LNG as $C_1$-$C_2$ mixture
- Preferential evaporation of methane
- Phase equilibria calculations have to be performed
- Latent heat will no longer be constant, but will vary as a function of composition
- LNG boiling temperature will increase as vaporization progresses.

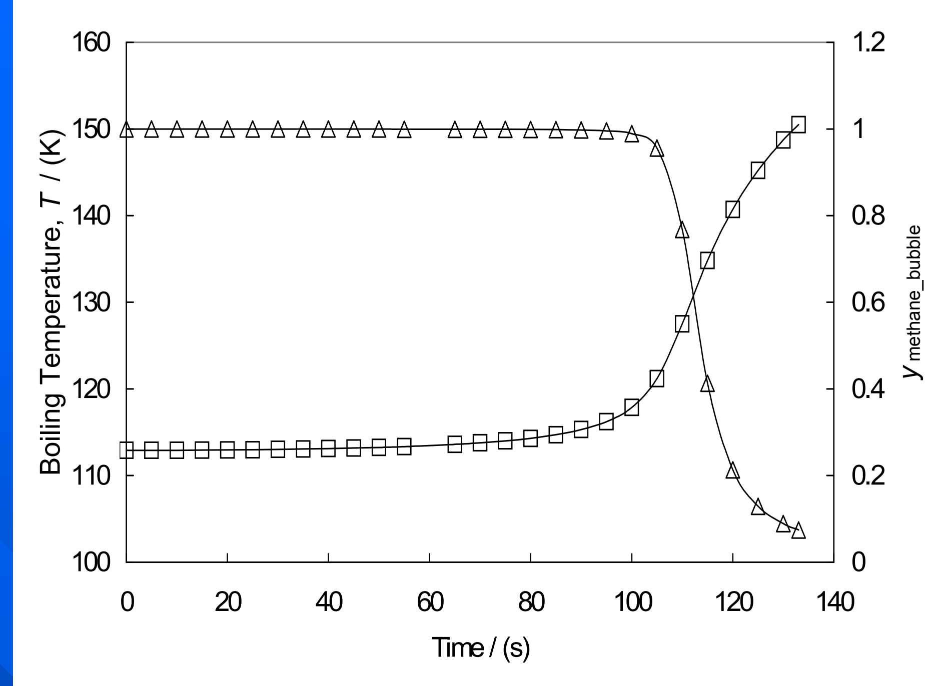
# Rate of Vaporization

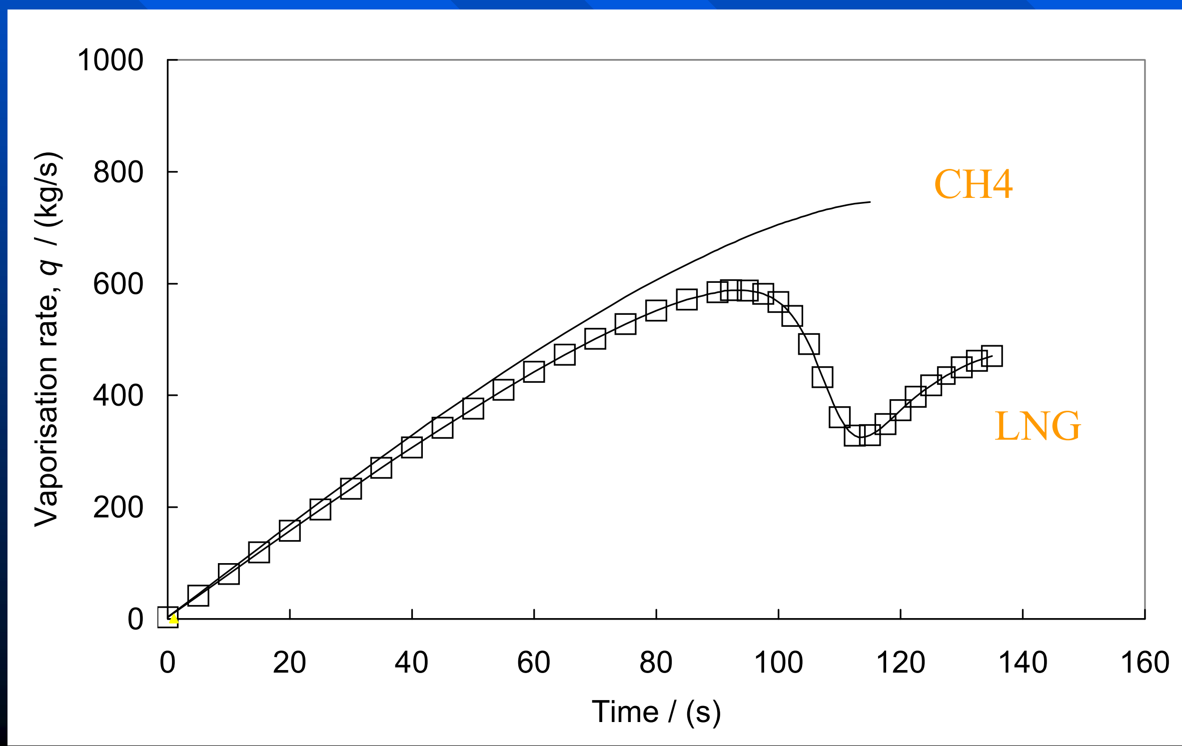


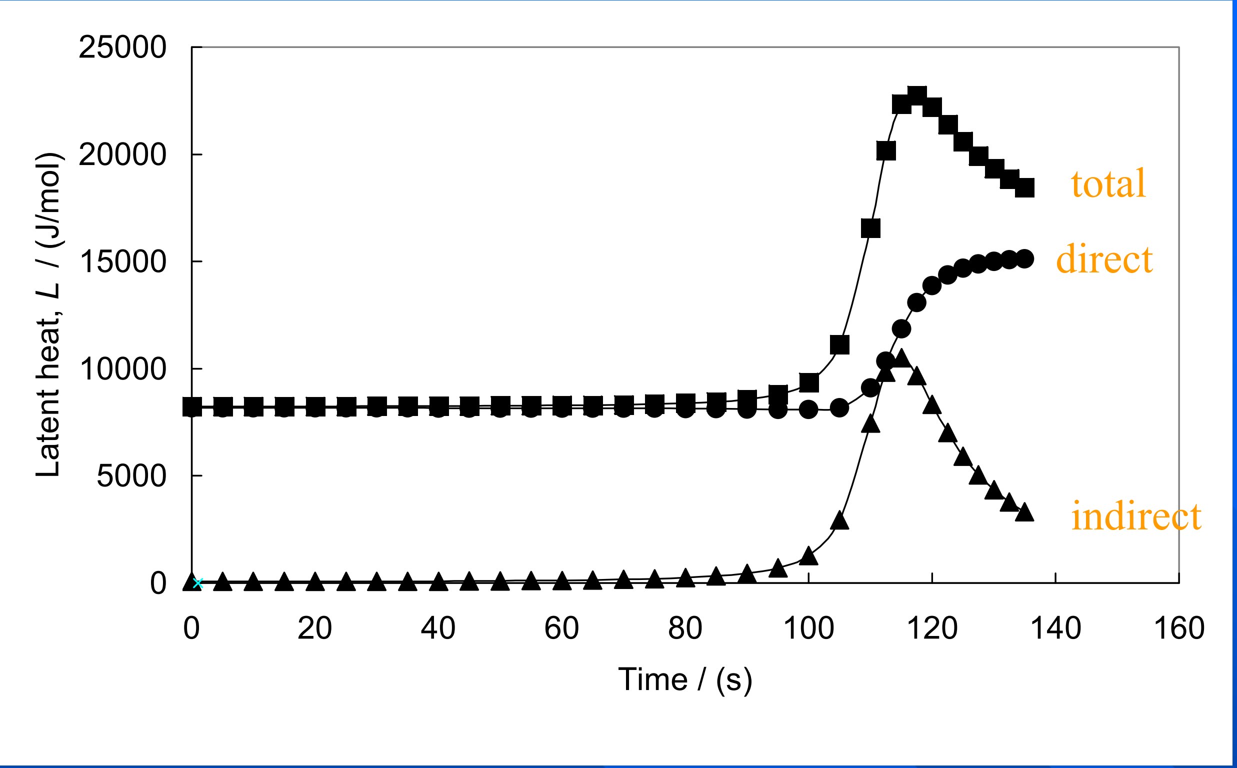
# Rate of Vaporization

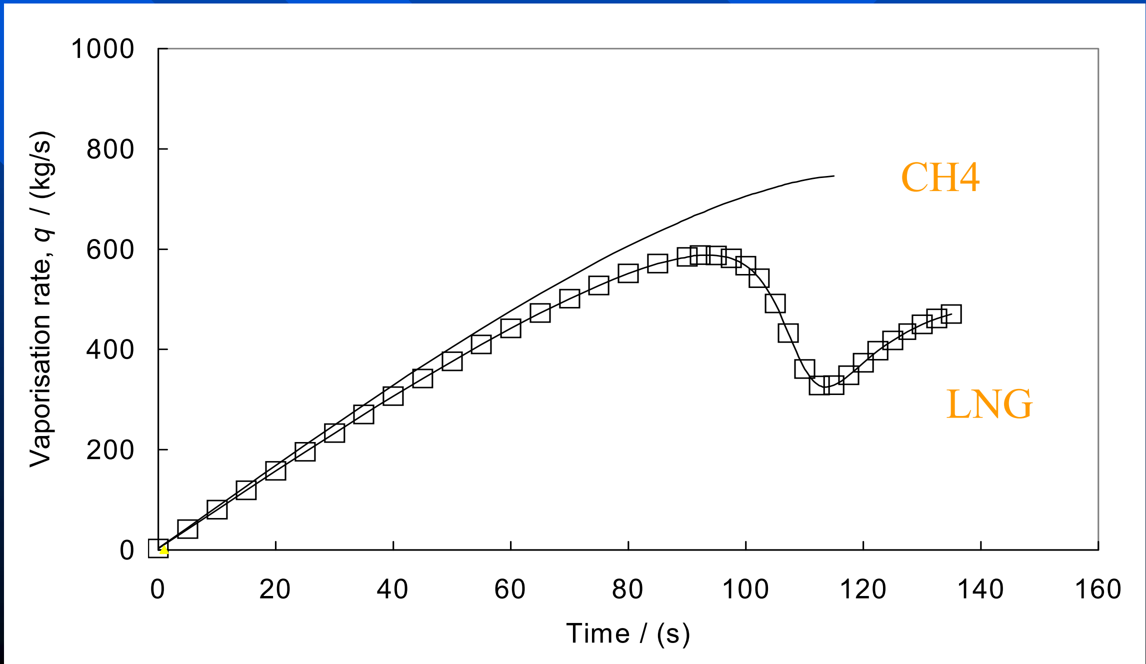



Boiling Temperature, T / (K)
160
150
140
130
120
110
100
x methane
1
0.8
0.6
0.4
0.2
0
0
20
40
60
80
100
120
140
Time / (s)


Boiling Temperature, T / (K)
160
150
140
130
120
110
100
y methane_bubble
1.2
1
0.8
0.6
0.4
0.2
0
0
20
40
60
80
100
120
140
Time / (s)


Vaporisation rate, q / (kg/s)
1000
800
600
400
200
0
CH4
LNG
0
20
40
60
80
100
120
140
160
Time / (s)


25000
20000
15000
10000
5000
0
Latent heat, $L$ / (J/mol)
0
20
40
60
80
100
120
140
160
Time / (s)
total
direct
indirect


1000
800
600
400
200
0
Vaporisation rate, $q$ / (kg/s)
0
20
40
60
80
100
120
140
160
Time / (s)
CH4
LNG

# Conclusions

- the rate of vaporization of LNG on water is a strong function of the surface temperature of water.
- the formation of an ice layer will have a profound effect upon the vaporization rate leading to much longer evaporation times.
- this can have important consequences on assessing risk associated with LNG spill.
- when predicting real life scenarios based on scaled up laboratory data, the extent of ice formation needs to be taken into account and modelled accordingly.
- treating LNG as pure methane will result in overestimation of the vaporisation rates in the latter stages of the spill and wrong dynamics;

# Key Research Issues

- Modelling transitional boiling, especially the heat transfer coefficient; Both theory & experiments needed
- Scale-up of lab experiments & making use of experimental data in large spills;
- Influence of surface roughness on heat transfer (larger surface area, break-up of the pool; )
- Modelling effective heat transfer through water