Heat transfer analysis of SH2IFT bonfire tests on liquid hydrogen tanks

Workshop No. 4

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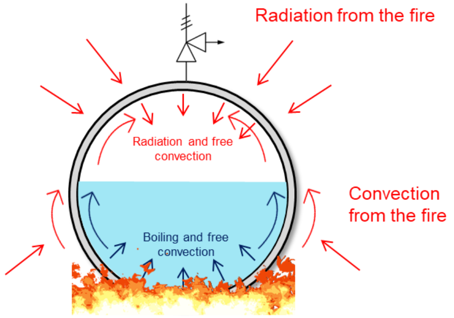
Liquid hydrogen tanks exposed to fire

What happens?

Inner perspective

What happens inside?

- ❑ Self-pressurization
- ❑ Temperature stratification
- ❑ Degradation of the insulation

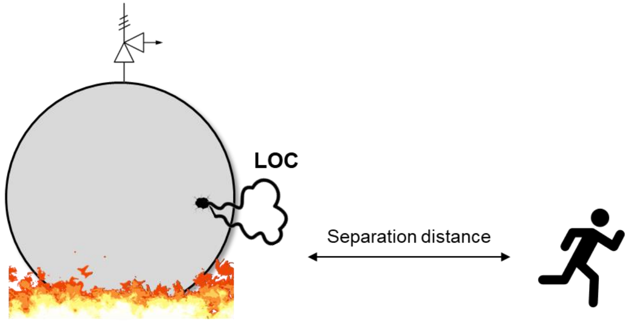


Video recorded during the SH2IFT project carried out at the Federal Institute for Materials Research and Testing (BAM), Berlin

Outer perspective

What happens outside?

- ❑ Loss of Containment (LOC)
- ❑ Tank failure
- ❑ Fires and explosions



Modelling of fire scenarios

Challenges and limitations

The tank behaviour during the fire engulfment and the hazardous consequences of such a scenario can be predicted by means of **mathematical models**.

Lumped models

Computational fluid dynamic models

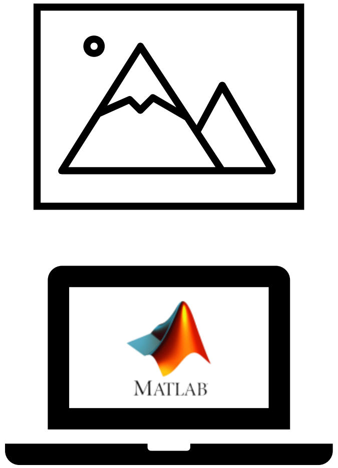
Simplifications are required to simulate the scenario

Boundary condition
=
Static full engulfment

Digital Image Processing

How does it work?

DIP: transforming a digital image, processing it by means of an algorithm and performing specific operations to extract information



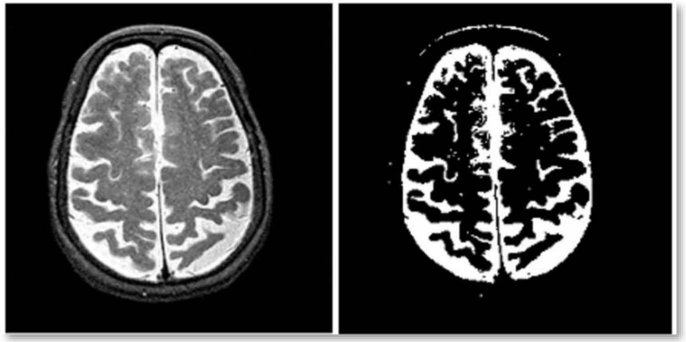
Digital Image Processing

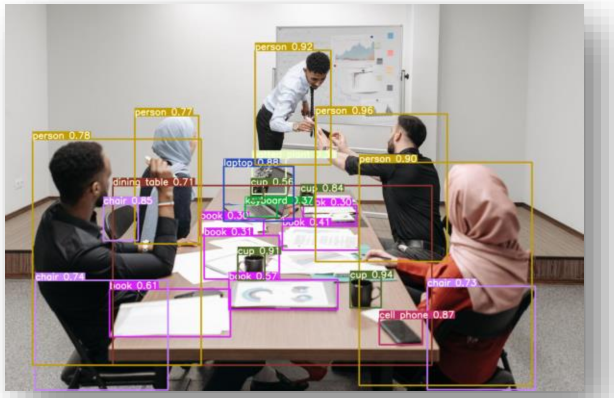
How does it work?

DIP: transforming a digital image, processing it by means of an algorithm and performing specific operations to extract information

$$f = \begin{bmatrix} f(0,M) & \cdots & f(1,N) \\ \vdots & \ddots & \vdots \\ f(M,0) & \cdots & f(M,N) \end{bmatrix}$$

- Image enhancement
- Image Restoration
- Color Image Processing
- Wavelets and Multiresolution Processing
- Compression
- Morphological processing
- Segmentation
- Representation and Description
- Object recognition





Goal and methodology

Flame coverage and thermal power calculation

Q1: Which is the **flame coverage** of the tank during the fire engulfment?

Q2: Which is the **thermal power** received by the tank?

Step 1 – **Image acquisition:** *From image to numerical matrix*

Step 2 – **Rerence image:** *Isolation of the tank surface from the image*

Step 3 – **Tank segmentation:** *Creation of the tank mask*

Step 4 – **Flame segmentation:** *Creation of the flame mask*

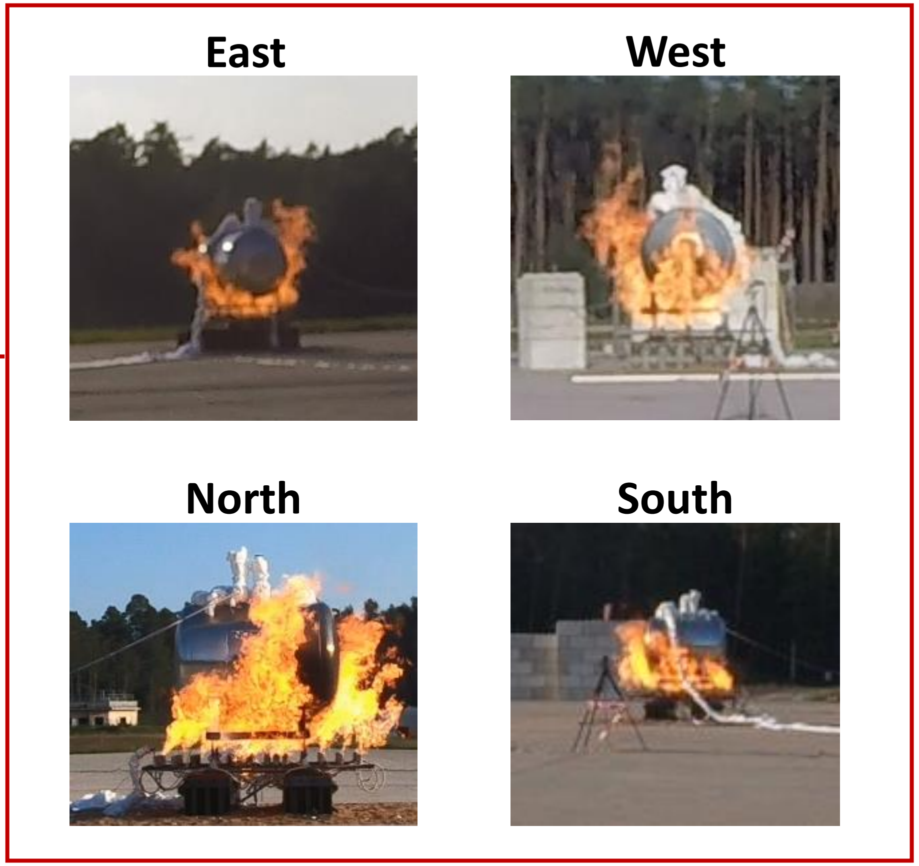
Step 5 – **Calculation:** *Flame coverage and thermal power*

Case study

Fire tests of the SH2IFT project

The DIP was applied to the frames extracted from the recordings of the **three fire tests**.

Images taken during the SH2IFT project carried out at the Federal Institute for Materials Research and Testing (BAM), Berlin



BLEVE02	BLEVE03	BLEVE01
Multi-layer insulation	Perlite	Perlite
1 h 9 m	4 h	1 h 31 m

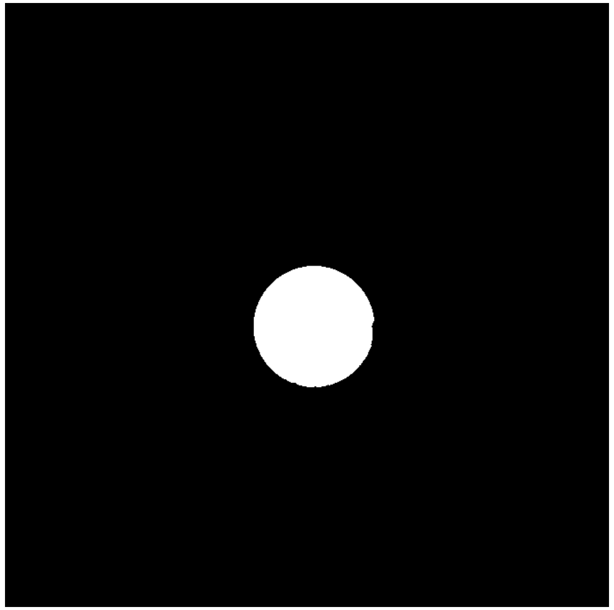
Results

Flame coverage and thermal power

Starting from an image taken **before the fire exposure**, the result are the reference image and the tank mask.

Reference image

Tank mask



Results

Flame coverage and thermal power

Starting from an image taken **after the fire exposure**, the result is the flame mask.

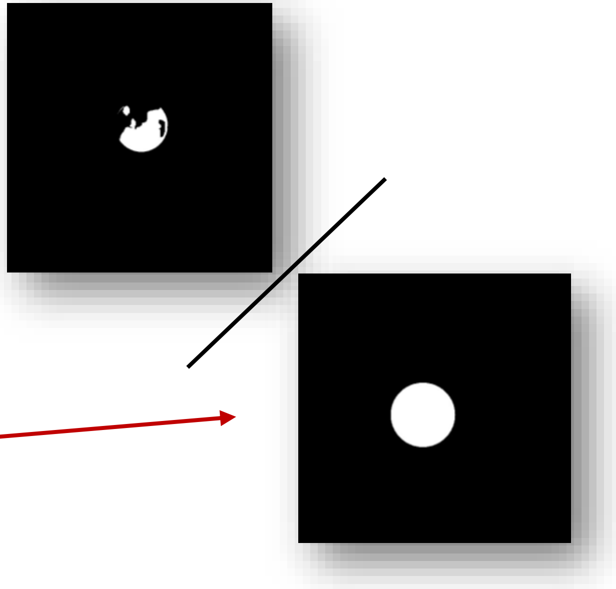
Results

Flame coverage and thermal power

Q1: Which is the **flame coverage** of the tank during the fire engulfment?

- ❑ ***At a fixed time and for a specific view (i)***

$$Flame\ coverage_i\ (t) = \frac{Number\ of\ pixels\ in\ the\ flame\ mask_i\ (t)}{Numer\ of\ pixels\ in\ the\ tank\ mask_i}$$

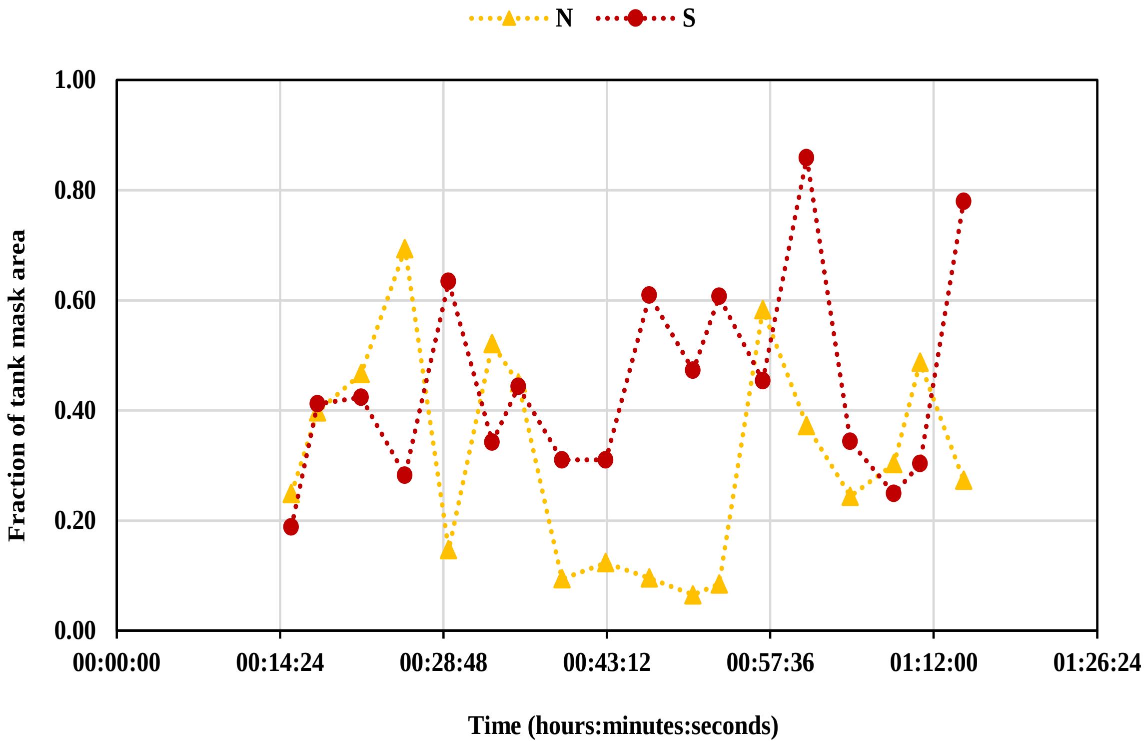


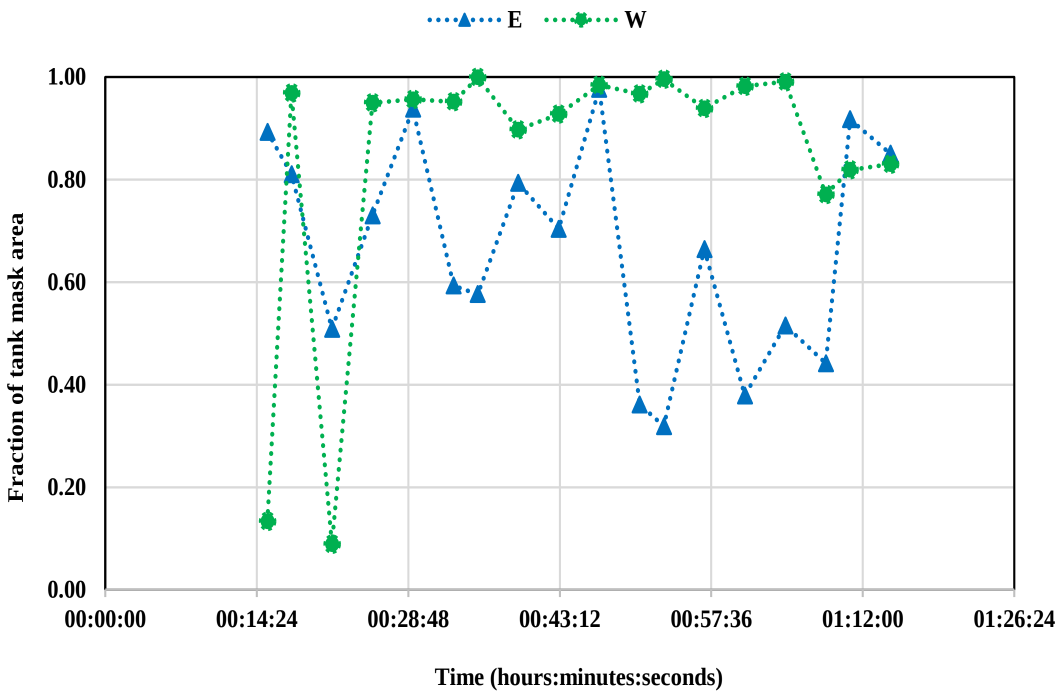
Results

Flame coverage and thermal power

Q1: Which is the **flame coverage** of the tank during the fire engulfment?

❑ ***At a fixed time and for a specific view (i)***





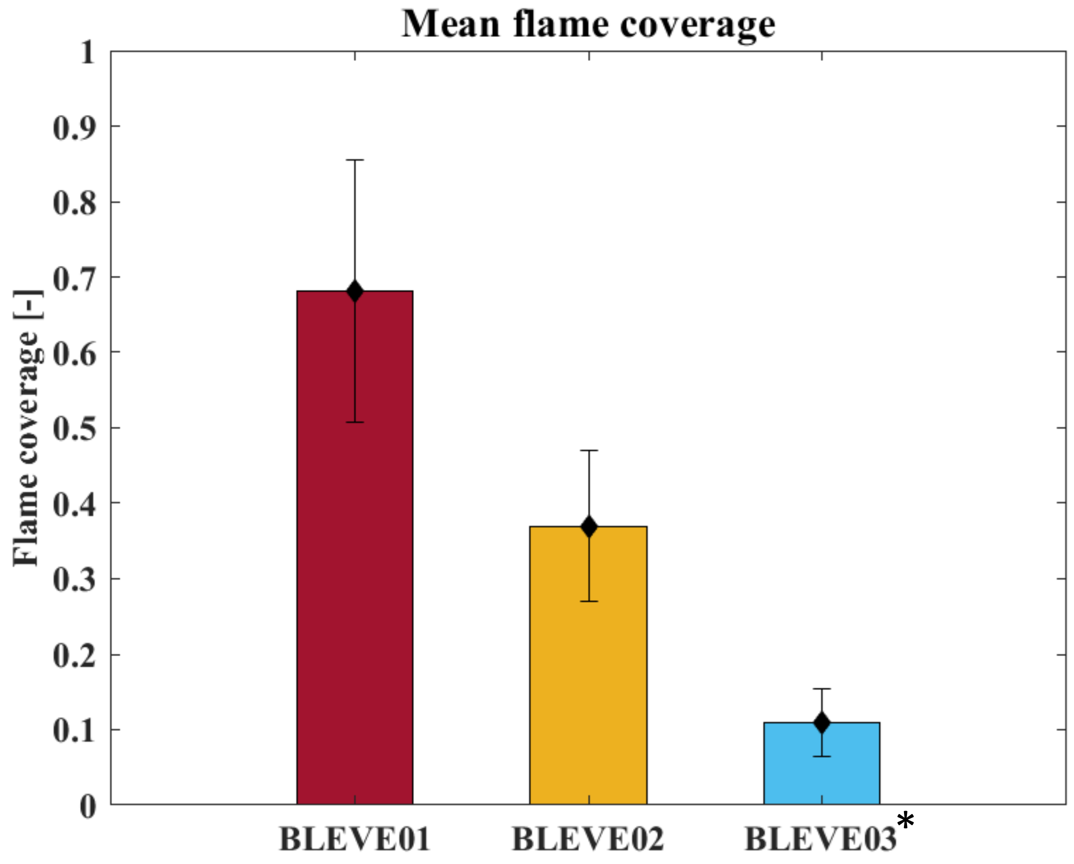
Results

Flame coverage and thermal power

Q1: Which is the **flame coverage** of the tank during the fire engulfment?

- ❑ ***During the test and for the entire tank***

$$Mean\ flame\ coverage\ (\%) = \sum_{0}^{end} \sum_{i}^{4} \frac{A_i}{A_{TOT}} \times Flame\ coverage_i(t)$$



*recordings were available for only half of the test

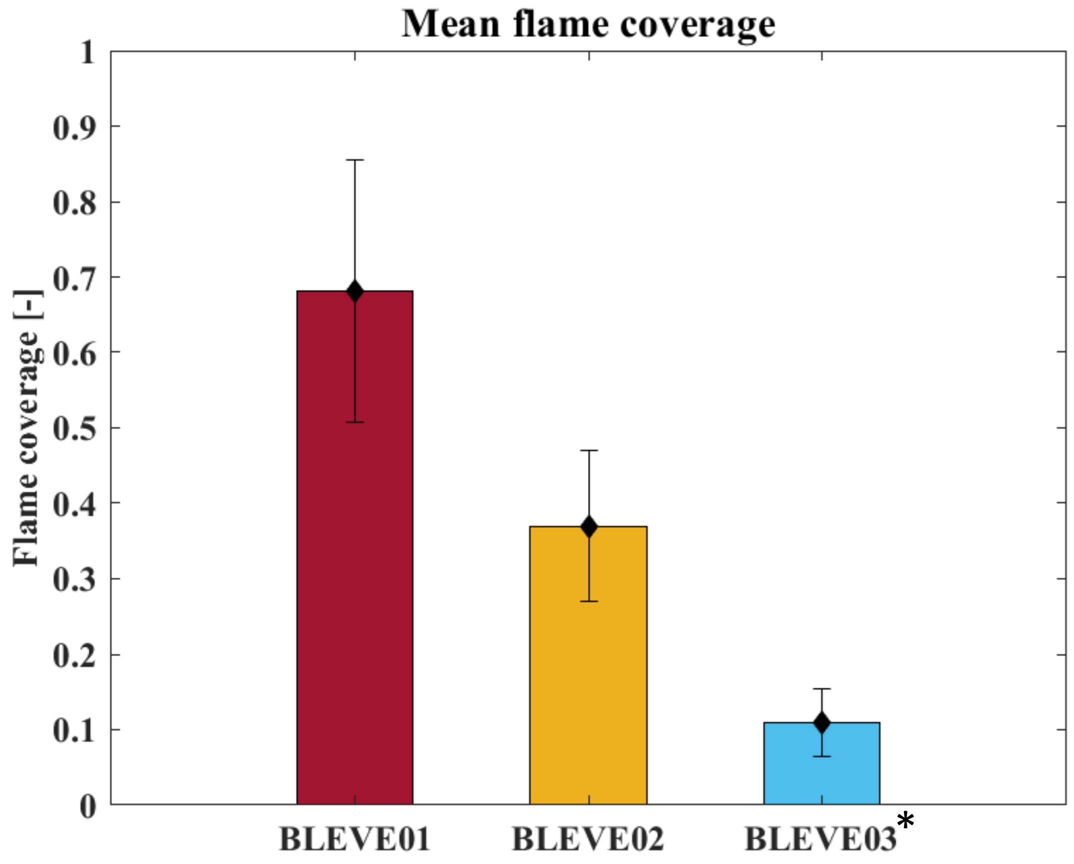
Results

Flame coverage and thermal power

Q1: Which is the **flame coverage** of the tank during the fire engulfment?

Flame coverage for a static full engulfment = 1

The assumption of a static full engulfment is **overconservative and does not represent the real case** scenario because it neglects fundamental aspects, such as the **wind influence** on the flame distribution around the tank



*recordings were available for only half of the test

Results

Flame coverage and thermal power

Q2: Which is the **thermal power** received by the tank?

- ***Considering a propane fire with a heat load of 100-150 kW/m², at a fixed time interval***

$$Thermal\ power\ (kW) = Heat\ load\ \times Tank\ outer\ surface \times \sum_{i}^{4} Flame\ coverage_i \times \frac{A_i}{A_{TOT}}$$

Minimum thermal power received from the tank:

Maximum thermal power received from the tank:

BLEVE02

264.9 kW

791 kW

Conclusions

Discussion and future development

The application of the digital image processing technique allows to obtain the **real flame coverage** of the storage tank during the fire attack, including capturing the effects of the wind on the flame distribution

The results demonstrate that the assumption of static full engulfment is **overconservative** with respect to the real scenario

The results obtained can be used to define accurate **boundary conditions** in mathematical models

The method can be combined with data from **thermocamera** to better characterize the flame features

Thank you for your attention

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