Spray A Nozzle Tip Temperature Measurements

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<u>Summary of the workshop session:</u>

This session presented Spray A nozzle tip temperature measurements conducted at 6 contributing institutions: Sandia, IFPEn, CMT, Caterpillar, TUE and Argonne.

As an introduction, the fact that it is impossible to measure the fuel right at the outlet of the injector was reminded. The measurement techniques and results shown in this presentation were thus attempts to access this fuel temperature as close as possible, through the measurement of the nozzle body temperature.

The first part of the presentation described the different devices used by the contributing institutions, with an emphasis on the impact of the characteristics of the vessels on the fuel temperature:

- For continuous flow vessels (CMT, CAT) or cold flow vessels (Argonne), the vessel walls and ambient gas temperature are constant, so the injector is in steady state (no temporal evolution of its temperature).
- For preburn vessel, the ambient gas temperature is increasing during the combustion and then decreasing during the cool down process. The temperature of the injector and of the fuel is thus changing with time.

Besides, continuous flow vessels and preburn vessel require cooling systems to control the injector (in the cold flow vessel, the injector is heated). The geometry of these cooling systems and their ability to limit the heat rise may have an effect on the fuel temperature.
At last, a ceramic cover is used to protect the nozzle tip from the ambient gas hot temperatures, and thus also to limit the temperature rise of the fuel.

In the second part, the three different techniques used by the institutions to measure the nozzle tip temperature were presented.

The first one consists in putting a thermocouple on the injector's body, quite far from the nozzle tip. This type of measurement is relevant when the injector is in steady state and has been performed by CMT an Argonne.
The second one, carried out at IFPEn, is based on the Laser Induced Phosphorescence (LIP), which allows the measurement of the temperature of the surface of the nozzle tip, and its evolution during the preburn event.

The last one requires the use of a dummy injector equipped with a K-type thermocouple. This technique allows the measurement of the temperature within the sac volume, and gives access to its temporal and spatial evolution. At the moment of the workshop, only Sandia, TUE and CAT have used this dummy injector.

In the third part, of the presentation, the results were analyzed.
The temperature measured in the sac volume with the dummy injector is first compared between Sandia and TUE. This comparison shown great differences both in the amplitude of the temperature rise during the preburn, and of its evolution during the cool down event. But it is difficult to know whether these differences are due to variations in the efficiency of the ceramic shields, in the efficiency of the cooling systems or in the cool down behaviors. So no conclusion was drawn so far.
The effect of the ceramic shield has also been investigated by IFPEn (LIP) and TUE (dummy injector). The results shown similar temperature evolutions, however at different levels, for theses two institutions, in spite of the different techniques used. The temperature of the surface of the nozzle tip seems thus to be strongly correlated with the sac volume temperature. Moreover, the ceramic shield used by TUE seems to be slightly more efficient than IFPEn one's, as the temperature rise is higher at IFPEn.
At last, the use of the dummy injector also allowed assessing the temperature gradients within the injector (Sandia, TUE, CAT). This showed a slight decrease of the temperature when the distance to the sac volume increases, but no conclusion can be drawn concerning the effect of such a gradient on the injected fuel temperature.

As a conclusion, the difficulty to correlate the different temperature measurements with the real temperature of the injected fuel and its evolution was underlined.

Recommendations:

- In order to assess and control the temperature of the injected fuel, the temperature must be measured in the sac volume.
- The dummy injector technique is the best one to access the sac volume temperature because of its simplicity (the post treatment is also quite easy) and of its accuracy.
- The use of a ceramic shield is a good way to limit the temperature rise of the sac volume. The design of TUE one's seems to be the more efficient.
- When using a cooling system, people must be careful of the corrosion that can be induced by water condensation on the injector tip.

Discussion items from the workshop:

- As an answer to a question on the effect of the fuel temperature on liquid length, it was reminded that this was of first order, and thus needs to be controlled as precisely as possible.

- The modelers underlined that for the moment, there was no model able to take into account the heat transfers between the fuel and the injector's body within the nozzle hole. Thus, the temperature of the injected fuel right at the outlet of the injector can not be inferred from its temperature in the sac volume.

Nozzle tip and injector's body temperature measurements

Spray A and hydraulic characterization

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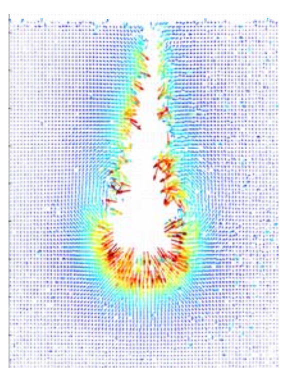
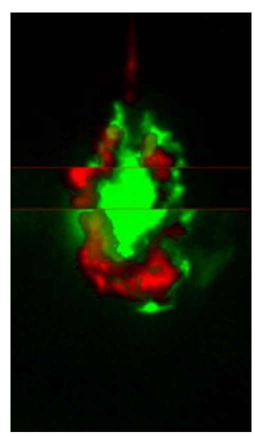
IFPEN Precombustion vessel ECN experiments

- 2009-2010
  - Spray A
- 2011
  - Multi points ambient temperature measurements: 5 thermocouples probe
  - Non reacting & reacting velocity fields: PIV
  - Soot: LII + TEM
- 2012
  - LIF formaldehyde + OH





Lyle M. Pickett, Caroline L. Genzale, Gilles Bruneaux, Louis-Marie Malbec, Laurent Hermant, Caspar Christiansen, and Jesper Schramm, Comparison of Diesel Spray Combustion in Different High-Temperature, High-Pressure Facilities, SAE Int. J. Engines December 2010 3:156-181, SAE paper 2010-01-2106.

Bruneaux, G., Maligne, D., Study of the Mixing and Combustion Processes of Consecutive Short Double Diesel Injections, *SAE Int. J. Engines* **2**(1):1151-1169, 2009. (SAE 2009-01-1352)

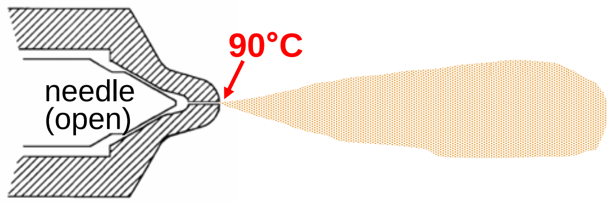
Bruneaux, G., Combustion Structure of Free and Wall Impinging Diesel Jets by Simultaneous Laser Induced Fluorescence of Formaldehyde, PAH and OH, International Journal of Engine Research, volume 9, issue 3, 2008.

Context

- Behavior of the spray and characteristics of the combustion depend on the temperature of the injected fuel.
- Fuel temperature is an input of the combustion models.

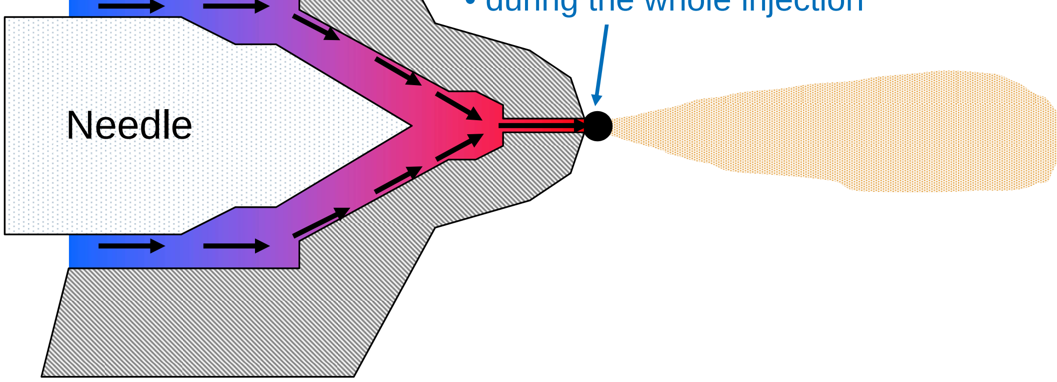
=> Need for measuring and regulating the temperature of the injected fuel.

- Target for Spray A conditions: fuel injected at 90°C.



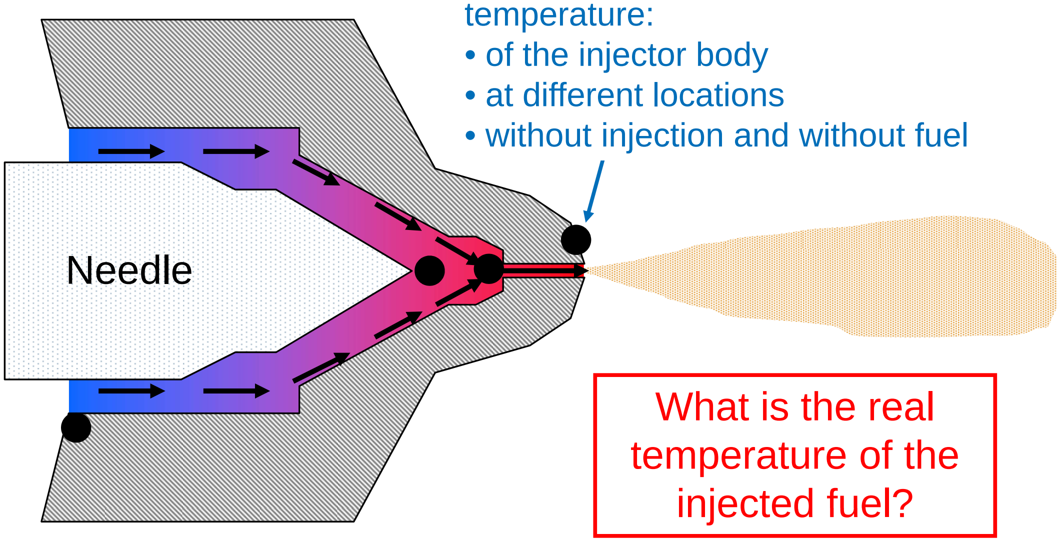
Context

Ideally, we want to measure/control the temperature:
- of the fuel
- just at the nozzle tip
- during the whole injection



Context

Practically, we can measure the temperature:
- of the injector body
- at different locations
- without injection and without fuel



What is the real temperature of the injected fuel?

Institutions and facilities

- **CMT**
- **Caterpillar**

Temperature measurements are not time dependant

- **TUE (Eindhoven)**
- **Sandia Nat. Labs**
- **IFPEn**

Temperature measurements are time dependant

- **Argonne**

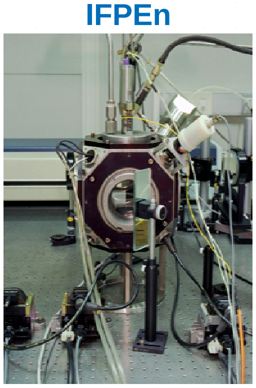
Temperature measurements are not time dependant, injector is *heated*

Continuous flow vessel

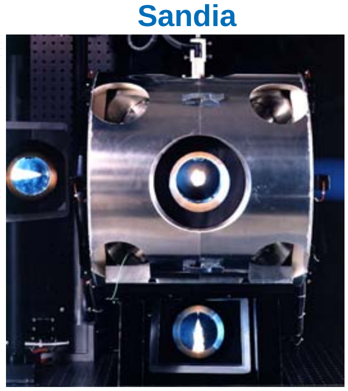
- Heated walls
  => the injector needs to be cooled
- Constant and tunable temperature of the ambient air
  => the injector's temperature is in steady state (except for the effect of the fuel flow during injection)

Precombustion vessel

IFPEn



Sandia



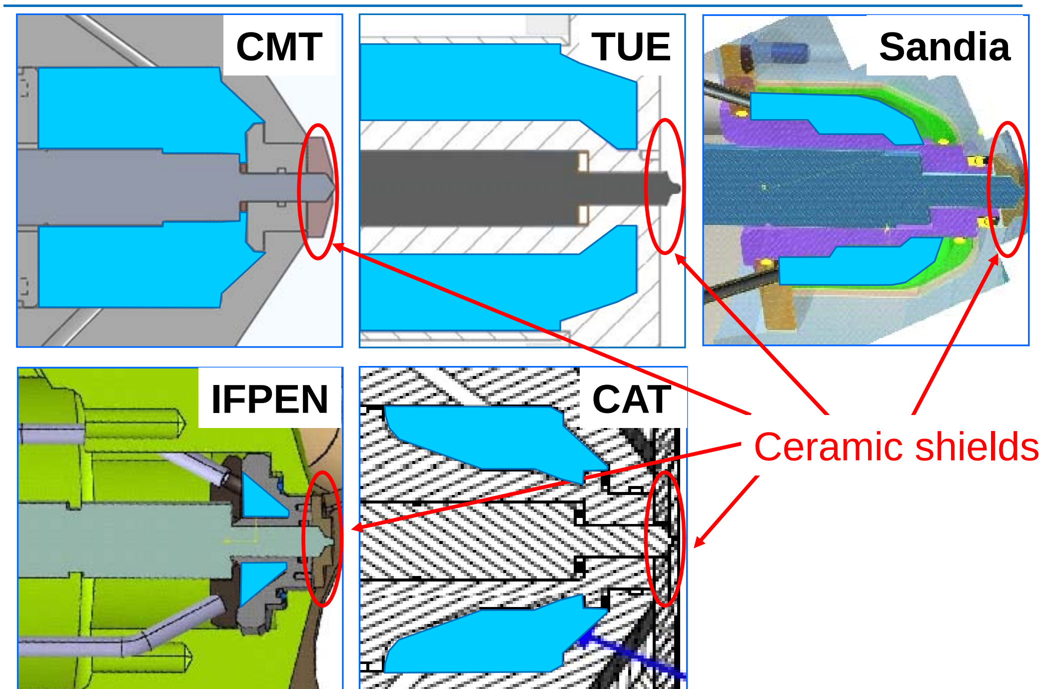
TUE

Cold flow vessel

- Cold flow
  => the injector needs to be heated

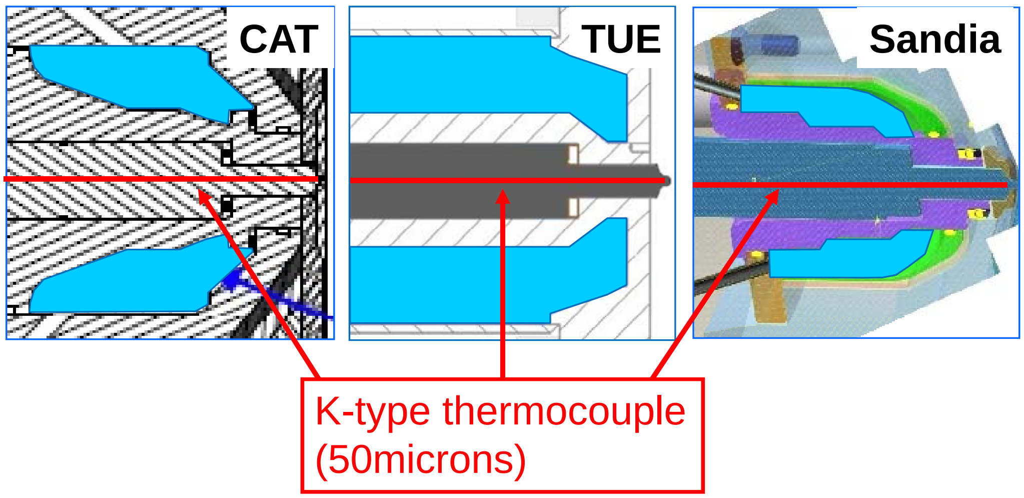
- Constant temperature of the ambient air
  => the injector's temperature is in steady state (except for the effect of the fuel flow during injection)

Institutions and facilities

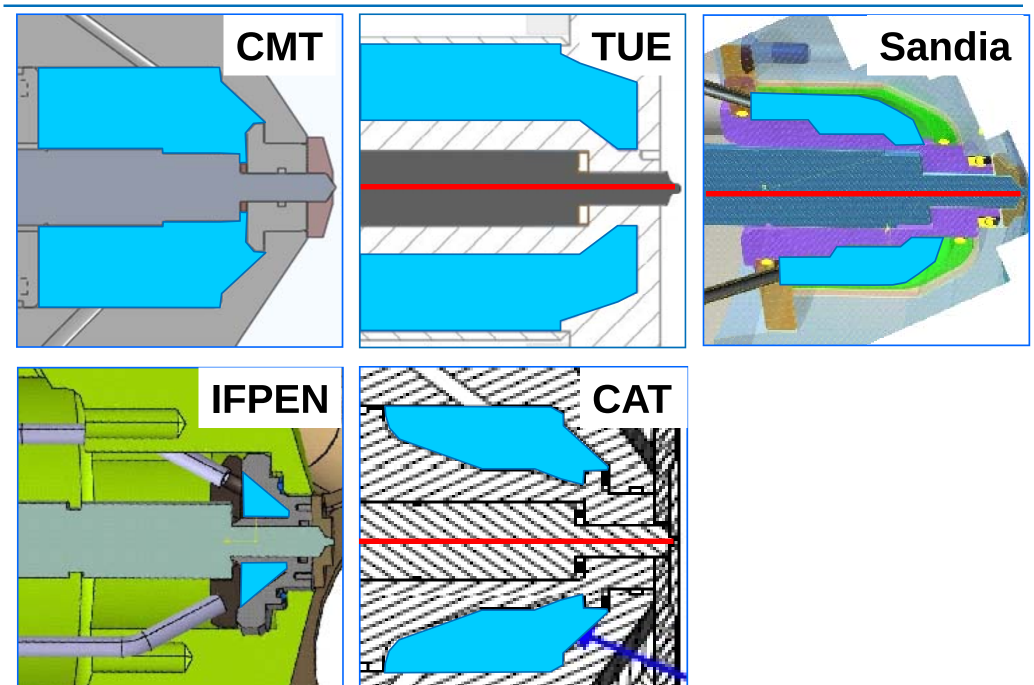


Temperature measurement methods

Thermocouple in dummy injector

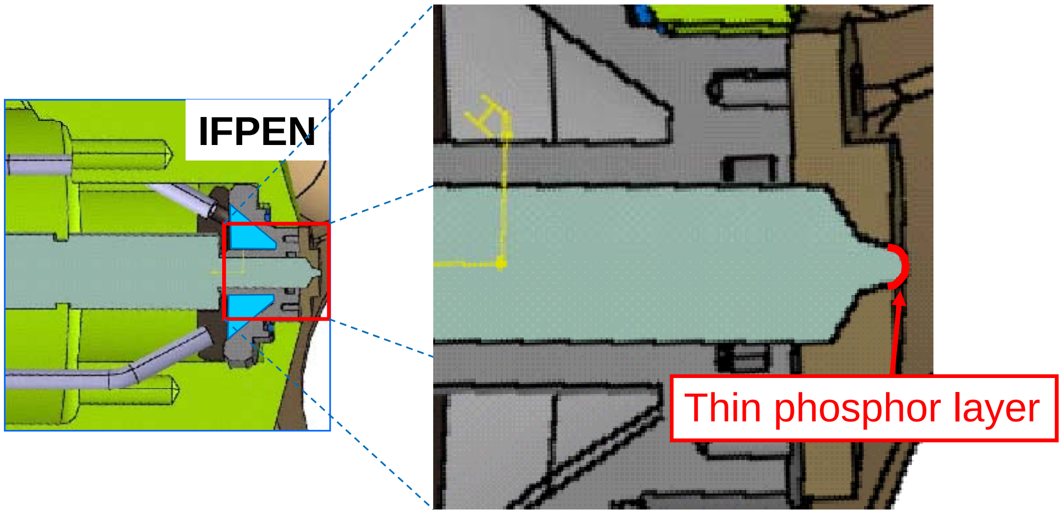


Temperature measurement methods

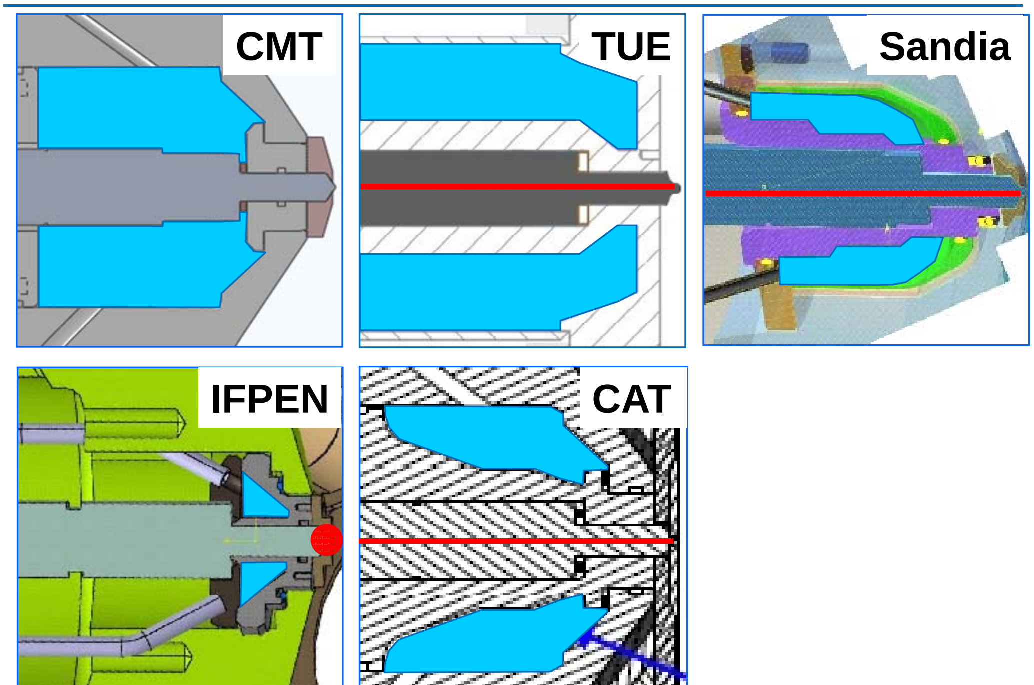


Temperature measurement methods

Laser Induced Phosphorescence (LIP)

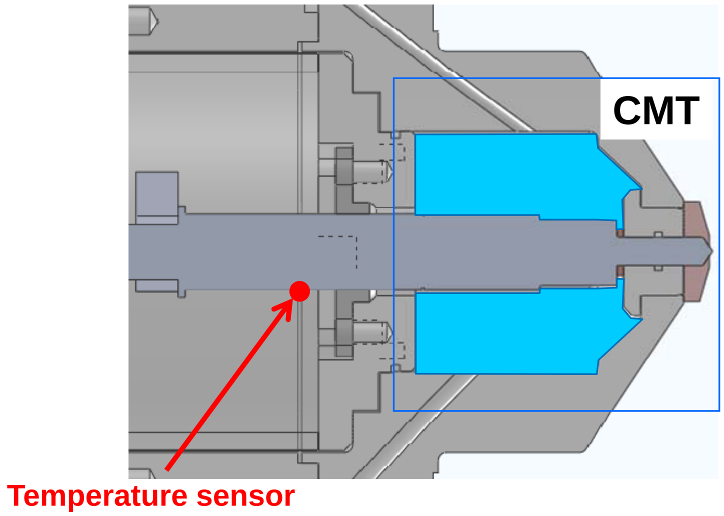


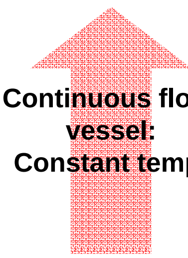
Temperature measurement methods



Temperature measurement methods

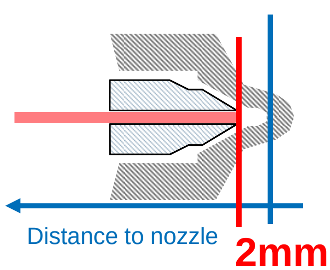
Thermocouple on real injector

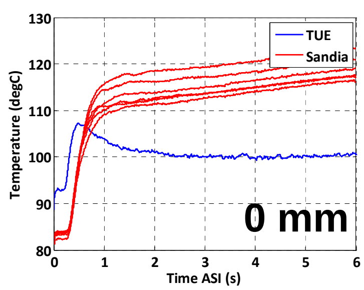


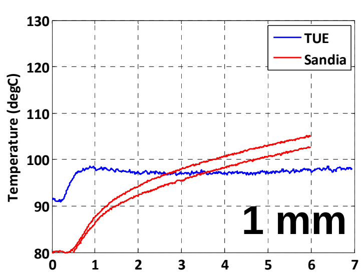


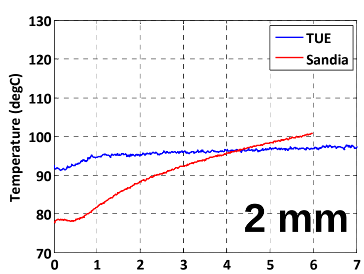
Results

Transient temperature: TC in dummy injector, precomb. vessel (TUE, Sandia)





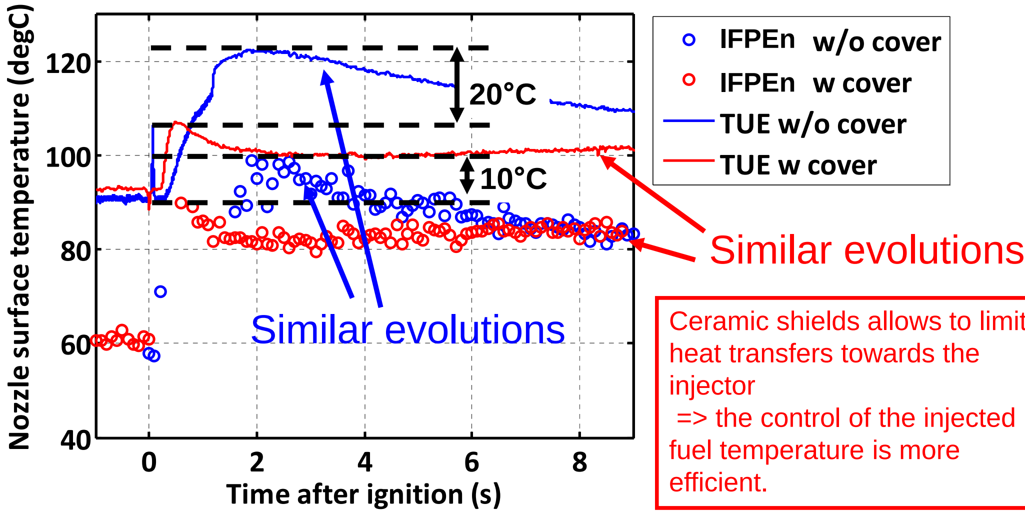




- Amplitude is higher for Sandia's vessel.
- Temporal evolution is different
  - Efficiency of the ceramic shield?
  - Efficiency of the cooling system?
  - Different cool down behaviour?
  - Effect on injected fuel temperature?

Results

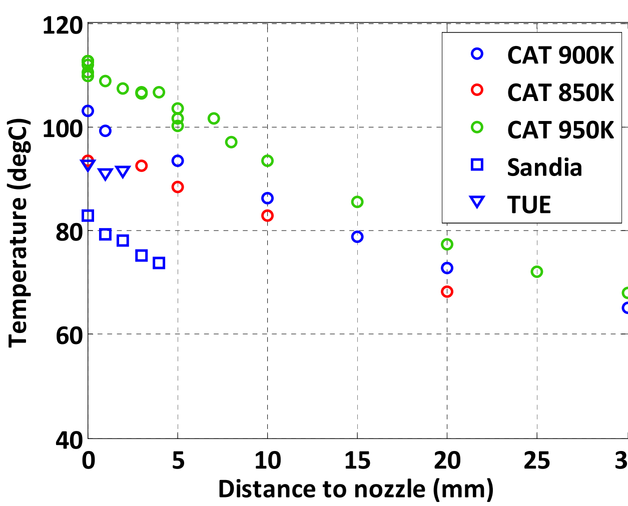
Transient temperature: cover effect



Ceramic shields allows to limit heat transfers towards the injector
=> the control of the injected fuel temperature is more efficient.

Results

Steady state tip temperature



These results give an idea of the temperature gradients within the injector.
=> Effect on injected fuel temperature?

Synthesis

- **Recommendations for the "best" experimental methods**
  - Use dummy injector to control the nozzle tip temperature at 90°C for spray A. Post-processing is quite easy.
  - Use a ceramic shield to limit heat transfers towards injector
  - Be careful with low injector temperature (corrosion)

- **Modelling**
  - The tip temperature and its evolution strongly depends on the experimental setup
  - What is the real temperature of the injected fuel? We can assume an experimental uncertainty of about 30K.