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Internship at the WPI
Fire protection engineering department
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Internship report

Summary

Characteristics of a flame spreading on a corrugated cardboard

Lot of fire take place in warehouse and create lot of damage that is why it is important to understand how fire spread to ensure the security of material and people. This study aims at showing the evolution of the characteristics as, the flame height, the pyrolysis length, the standoff distance and the incident flux, of a flame spreading on half box of cardboard. All these parameters are crucial to characterize safety equipment.

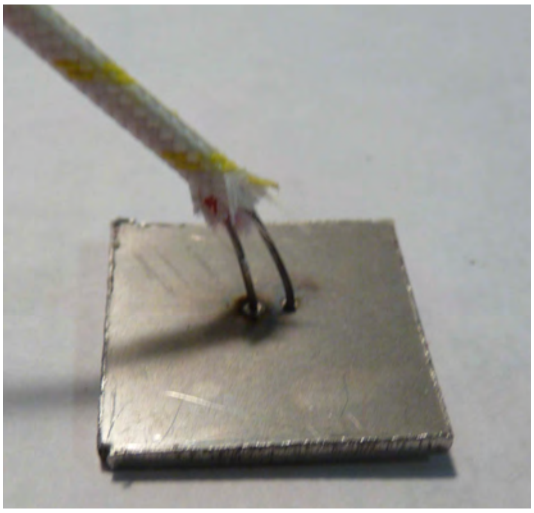
Two kinds of cardboard will be study: one with vertical corrugations and the other one with horizontal.

This presentation will explain, the experimental and ignition set up, and how the boxes were instrumented. A description of the design and making of thin-skin calorimeter, which with we measure the flux, will be also done. At least, results will be established. Correlations between flame height and pyrolysis length, as well as correlations between heat release rate and flame height, will allow to match the result and see the repeatability of the test.

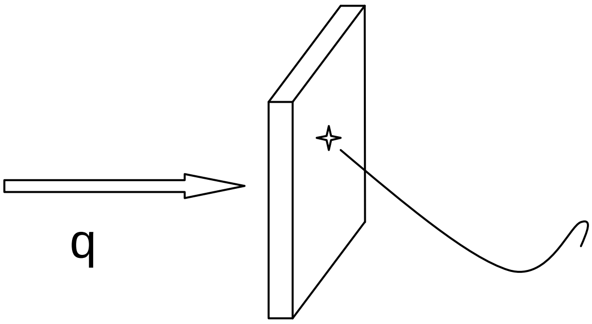
Thin skin calorimeters

1. Theory

A thin skin calorimeter is a thin metal plate where a thermocouple is welded. It is used to measure a heat transfer rate, convective, radiative or both. A one-dimensional heat flux flow analysis is used for calculating the heat transfer rate, from the temperature measurements.



The calculus of the flux is based on the assumption of one dimensional heat flow arriving on the exposed face of the thin skin calorimeter



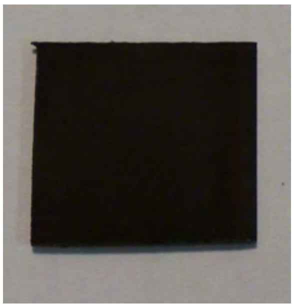
$$q = \rho C_p \delta \frac{dT}{d\tau}$$

- Know: properties of the metal
  - Density ρ [kg/m^3]
  - Specific heat C_p [J/kg.K]
  - Thickness δ [m]
- Measure: Rate of rise temperature of the back unexposed surface of the calorimeter $\frac{dT}{d\tau}$, thanks to the thermouple
- So we can get the flux q

2. How to build them

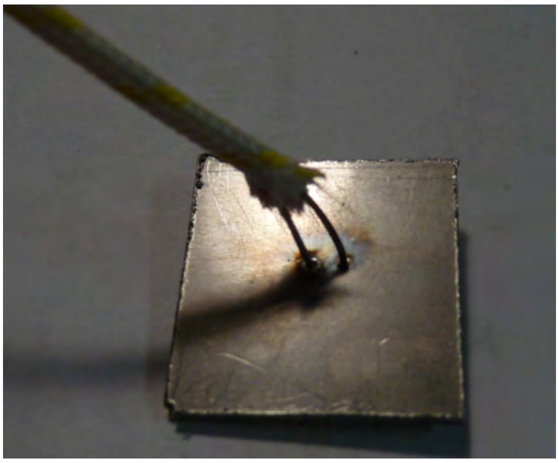
➢ **Metal plate**:

- Material with a low thermal conductivity to minimize lateral heat conductive effects
- Thin metal
- Any size and any shape
- Face exposed painted in black to minimize the reflected flux



➢ **Thermocouples**:

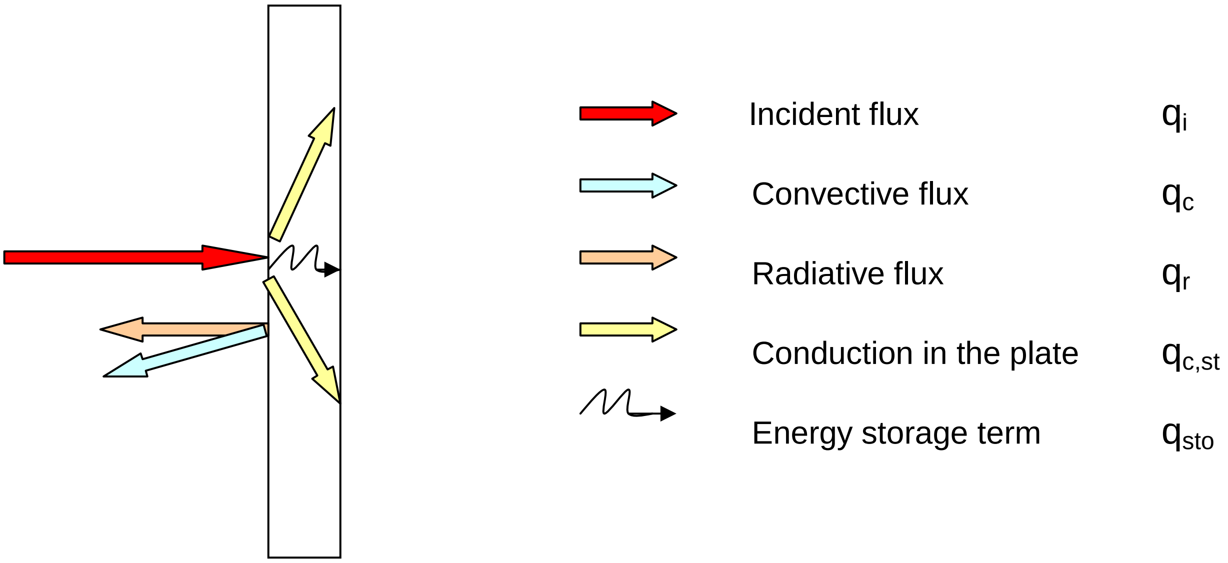
- attached to the metal by welding
- thermocouple wires are individually welded to the unexposed surface. They are pulled apart of 1.6mm. This specific kind of thermocouple joint, provide superior transient response.
- wire diameter should be small compare to the thickness of the calorimeter to minimize heat conduction



3. Heat transfer analysis

The thermal balance done above for the calculation of the flux doesn't take care about the losses. We are going to see what are the effects of these and where they come from.

Thermic balance on a stainless steel plate



$$\boxed{q_i = q_c + q_r + q_{sto} - q_{c,st}}$$

q_c : Convection

The heated plate will transfer heat to the cooler surrounding air by convection heat transfert

$$qc = h\,(Ts - T\infty)$$

h convection heat transfert coefficient
Ts surface temperature of the stainless steel plate
$T\infty$ ambient temperature

q_r : Radiation

The heated steel plate will radiate energy to the environment

$$qr = \sigma\varepsilon(Ts4-T\infty4)$$

σ Stefan Boltzmann constant
ε emissivity

$q_{c,st}$: conduction in the plate

Conduction heat transfert within the plate.

$$q_{c,st} = -k\ DTs/dt$$

q_{sto} : storage term

Storage term see above

$$q_{sto} = \rho\delta Cp\ DT/dt$$

If we choose a metal with a low thermal conductivity we can ignore the losses by conduction within the plate

The equation become:

$$\boxed{q = h\,(Ts - T\infty) + \sigma\varepsilon(Ts^4 - T\infty^4) + \rho\delta Cp\ DT/dt}$$

4. Test and calibration

In order to build the best thin-skin calorimeter, I have decided to build four different one and analyse the data from each of them. As well as, we will thereafter able to choose the good one.

- **Experimental procedure**:

a. **To build the thin-skin calorimeter**

Choice of the metal:

One constraint for the choice of the metal is the low conductivity. A good compromise is stainless steel, with a thermal conductivity of about 16W/mK.

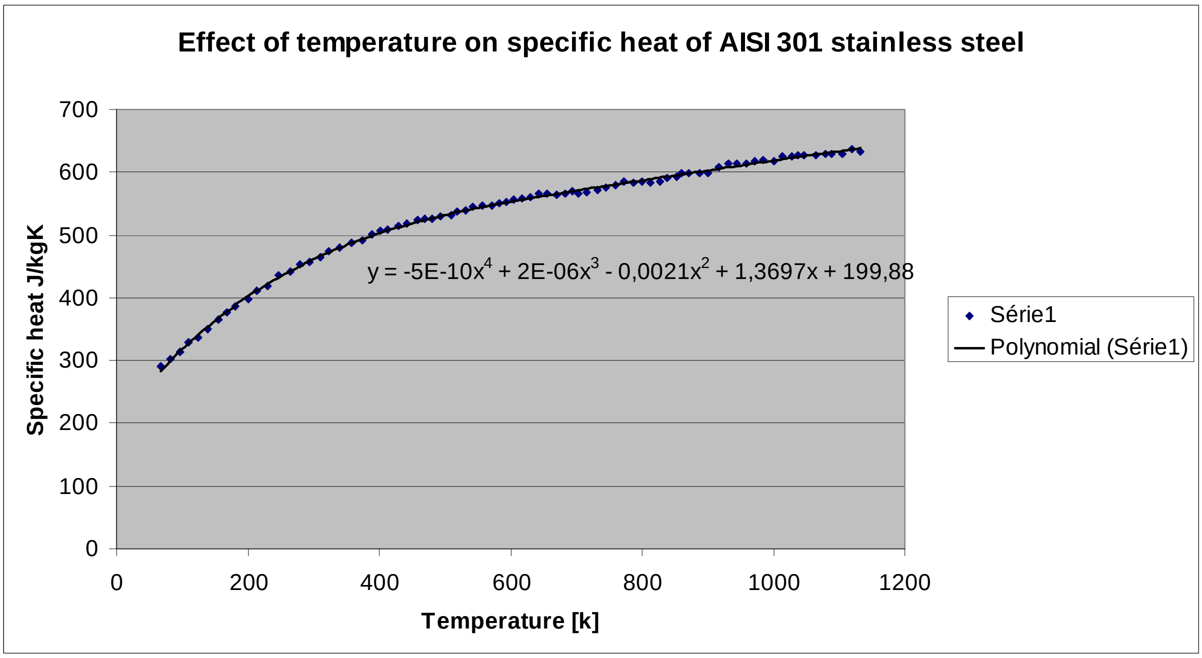
So we have found in the laboratory a plate of stainless steel 301, of about 1.25mm thick, which is very good.

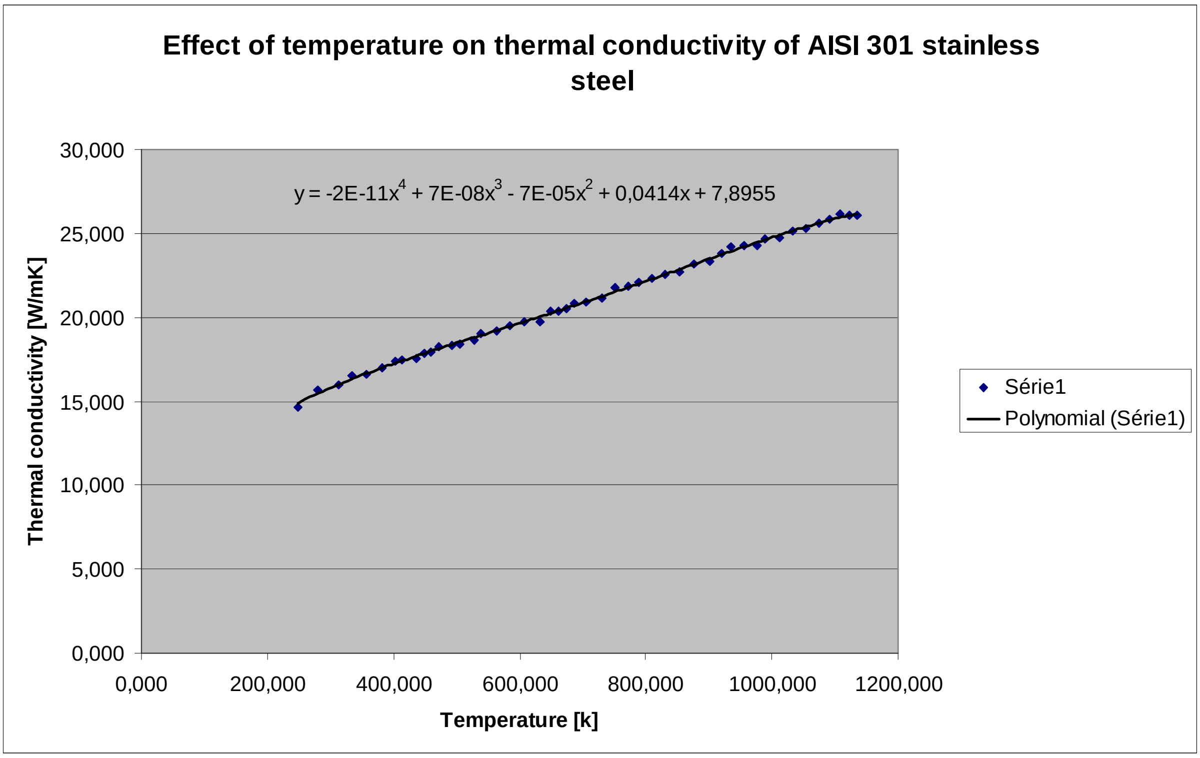
- Properties of the AISI stainless steel 301

Density: ρ=8030 kg/m3

Specific heat: Cp (J/kgK) is a function of temperature $Cp=-5E-10T^4+2E-6T^3-0.0021T^2+1.397T+199.88$

Thermal conductivity: k (W/mK) $k=-2E-11T^4+7E-8T^3-7E-5T^2+0.0414T+7.8955$

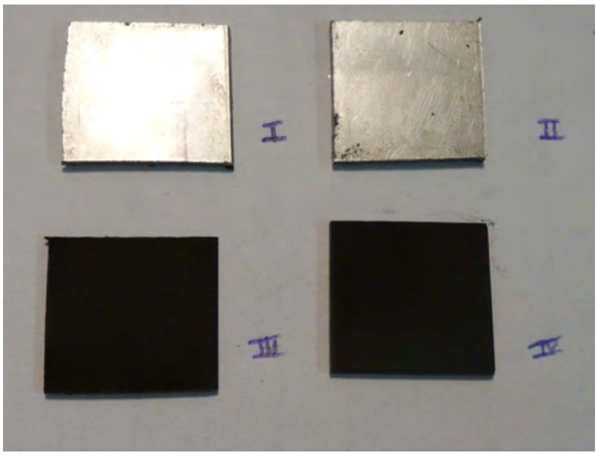


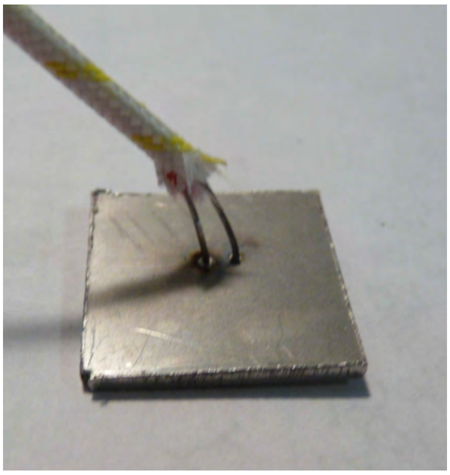


- <u>The different thin skin</u>.

The metal and his thickness being fixed, to ameliorate the thin skin the only way is to play this the thermocouple.
We have two kinds of thermocouple wires. The “big” one with a diameter of and a thicker one with a diameter of
I built four different thin skin calorimeters. They are square of 2mm side.

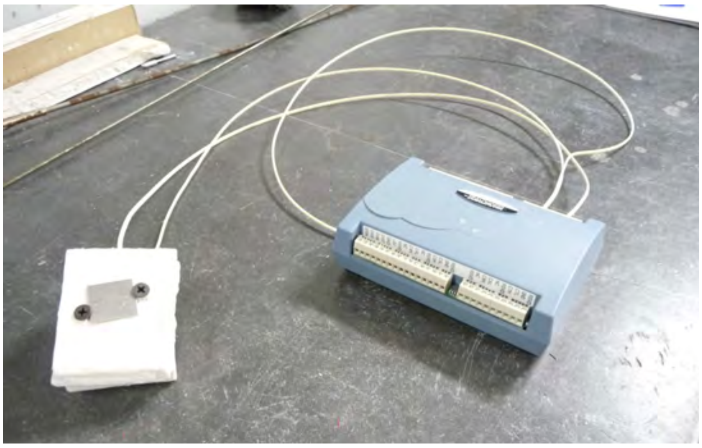
	Thin Skin I	Thin skin II	Thin Skin III	Thin Skin IV
Thickness (mm)	1.21	1.27	1.24	1.32
Length (mm)	21.28	21.03	20.06	19.10
Width (mm)	20.19	19.28	19.40	19.09
Aspect	Shinny	Black	shinny	Black
Thermocouple	Big one	Big one	Little one	Little one





Thus with all this thin skin, we can compare he effect of the size of the thermocouple wires and the aspect of the exposed face (shinny or black). Moreover we could also see the effect of the losses.

b. **Date acquisition**



We record the data given by the thermocouple thanks to the software TRACERDAQ
The output of the acquisition board is connected to the computer by usb.

c. **test**

We want to know if our six thin-skin calorimeter measure well the incident flux and which is the best. In this aim, we put the thin-skin under the cone, which emits a flux. We can know it thank to a gauge Schimt-boetler which is very well calibrate. Thus we will compare the flux measure by the thin skin to this of the gauge.
Each thermocouple is tested twice. And we test them for a flux of 50kW/m2

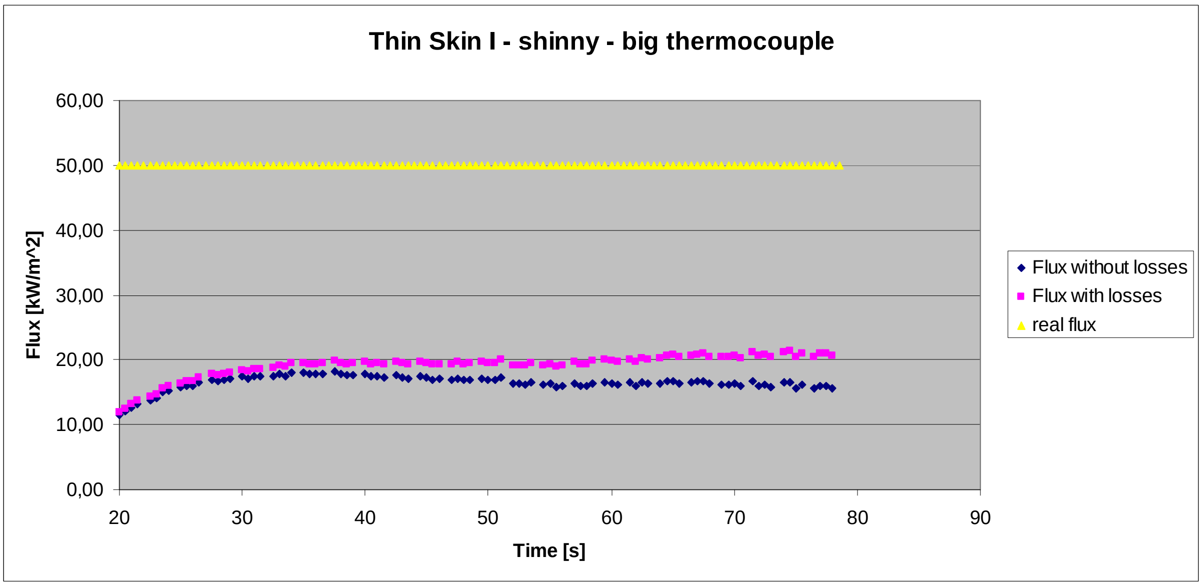
d. **Results**

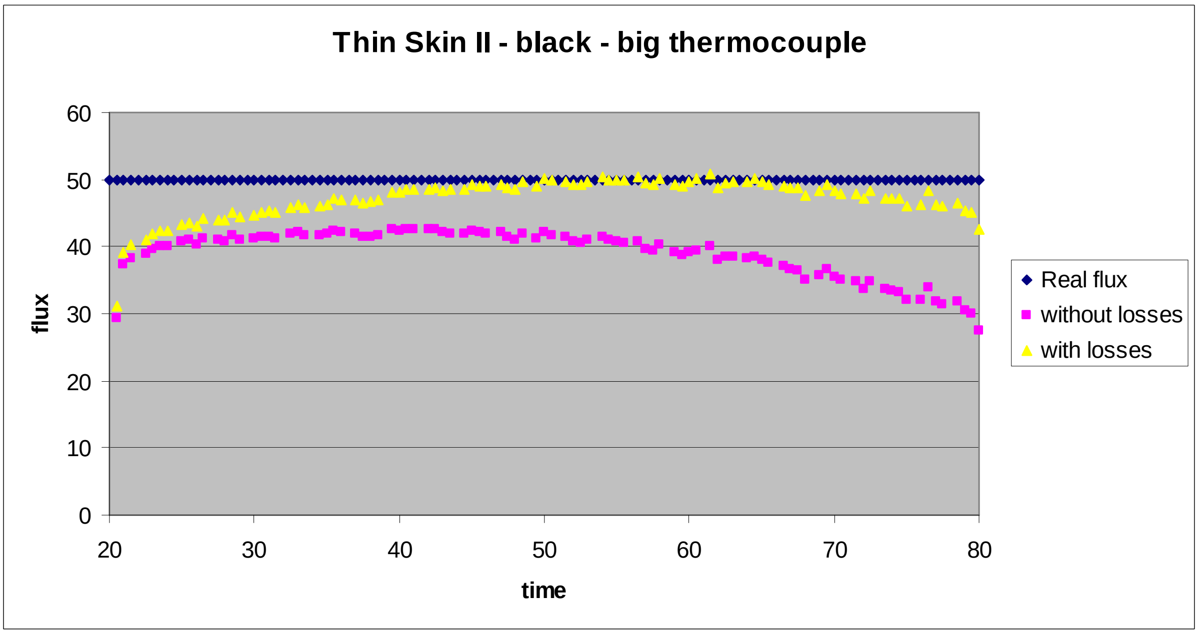
- Gauge

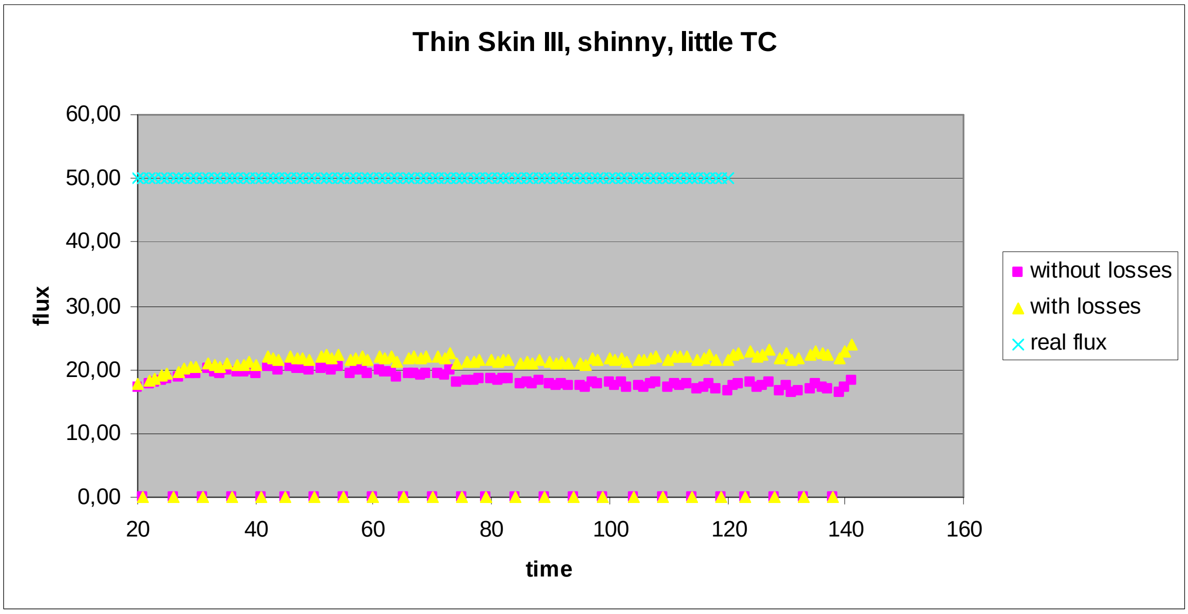
The gauge is exposed to the cone during about 20 seconds. The gauge gives a flux of 50kW.m^{-2}

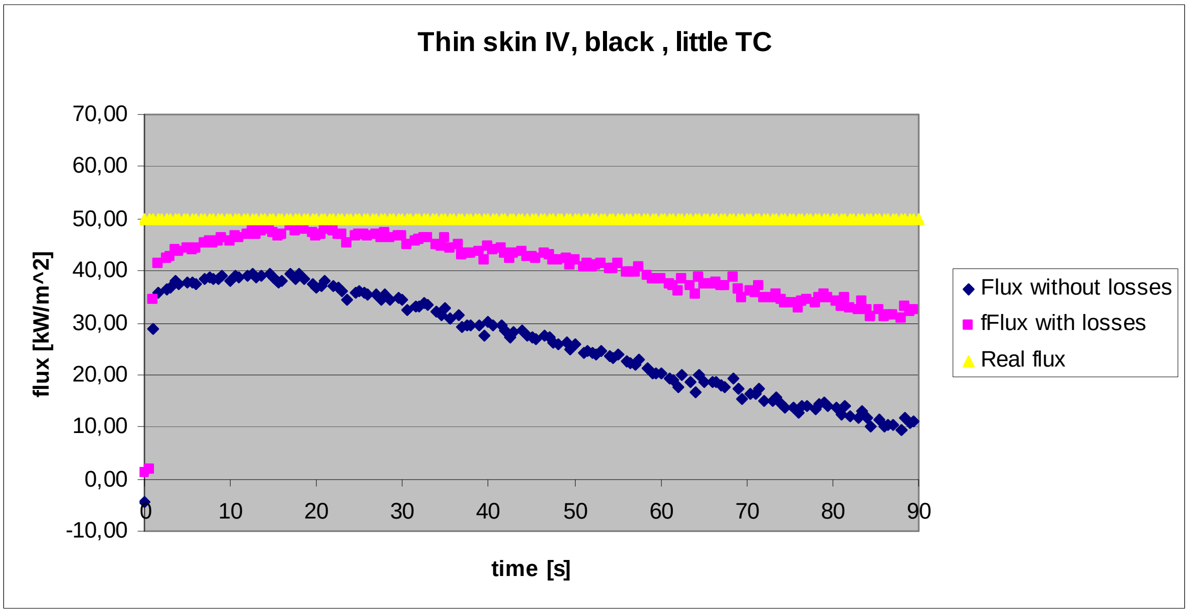
- Result from the thin-skin calorimeter

Each thin-skin is tested twice. Results from the first test:









5. Conclusion

Thin-skin calorimeter chosen:

Metal: AISI Stainless steel 301

ρ=8030 kg/m3
Cp=-5E-10T^4+2E-6T^3-0.0021T^2+1.397T+199.88 [J/kg.K]
k =-2E-11T^4+7E-8T^3-7E-5T^2+0.0414T+7.8955 [W/mK]

Square of 2*2cm
Thick about 1.25mm
Face exposed painted in black

Thermouco