Problem No. 12

COLD BALLOON

Ábel Beregi, Team Hungary

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The problem

As air escapes from an inflated rubber balloon, its surface becomes cooler to the touch.
Investigate the parameters that affect this cooling. What is the temperature of various parts of the balloon as a function of relevant parameters?

Outline

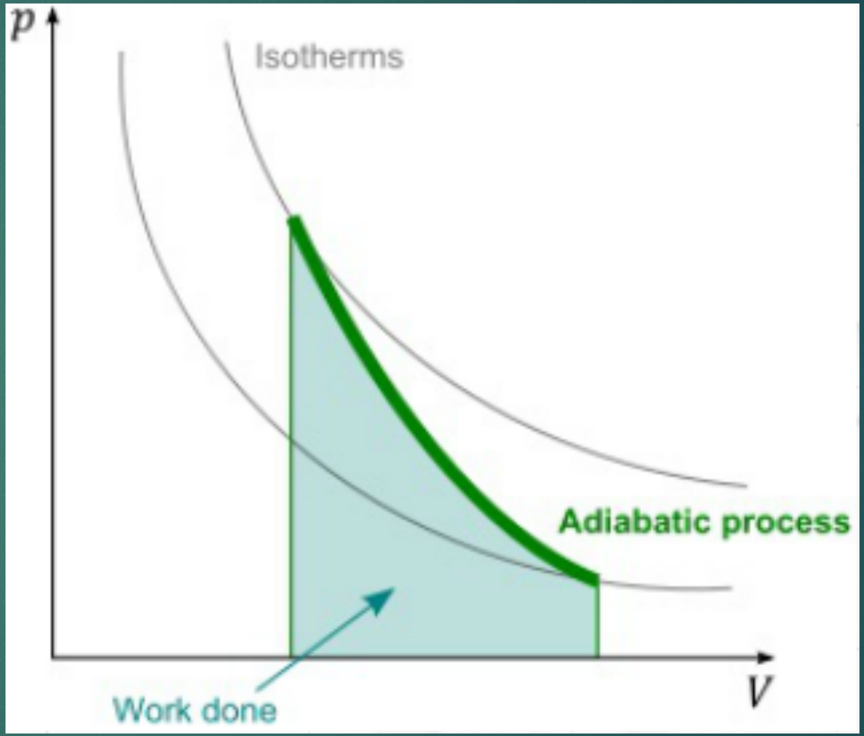
- Setup
- Theoretical investigation
  - Part one: Adiabatic cooling of air
  - Part two: Cooling of the rubber, because change of entropy
- Experiment results
  - Thermal images
  - Heat distribution
  - Isotherms on the surface of the baloon
- Summary
- Sources

Setup

- Surface temperature ➔ IR Camera
- Inside temperature ➔ Thermistor
- Pressure ➔ Pressure sensor

Adiabatic cooling of air

- Pressure is decreasing
- Volume is increasing
- There is no time for heat transfer

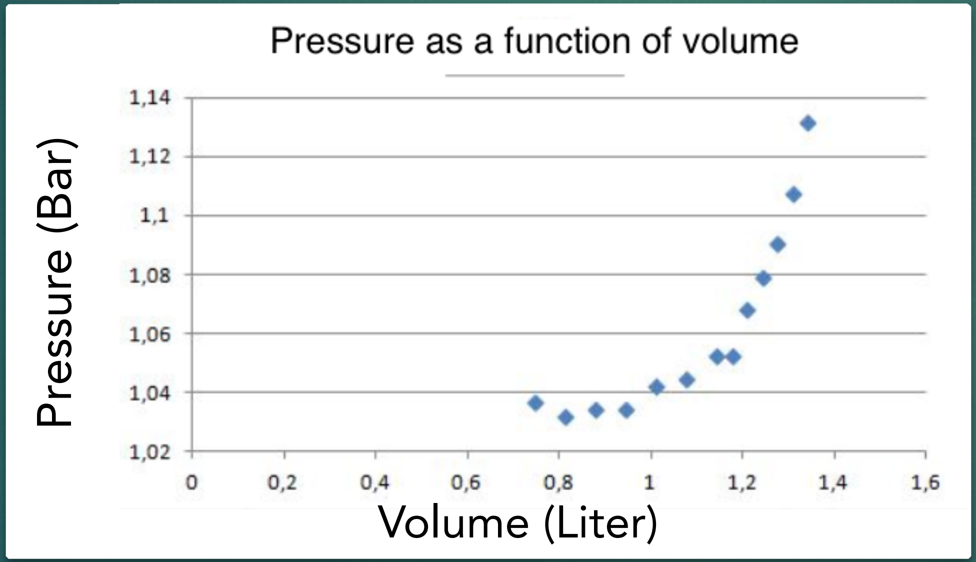


Theorem part one: adiabatic cooling of air

$$\Delta U = W_{1;2} = \frac{p_1 V_1}{\kappa - 1}\left[1 - \left(\frac{p_2}{p_1}\right)^{\frac{\kappa-1}{\kappa}}\right]$$

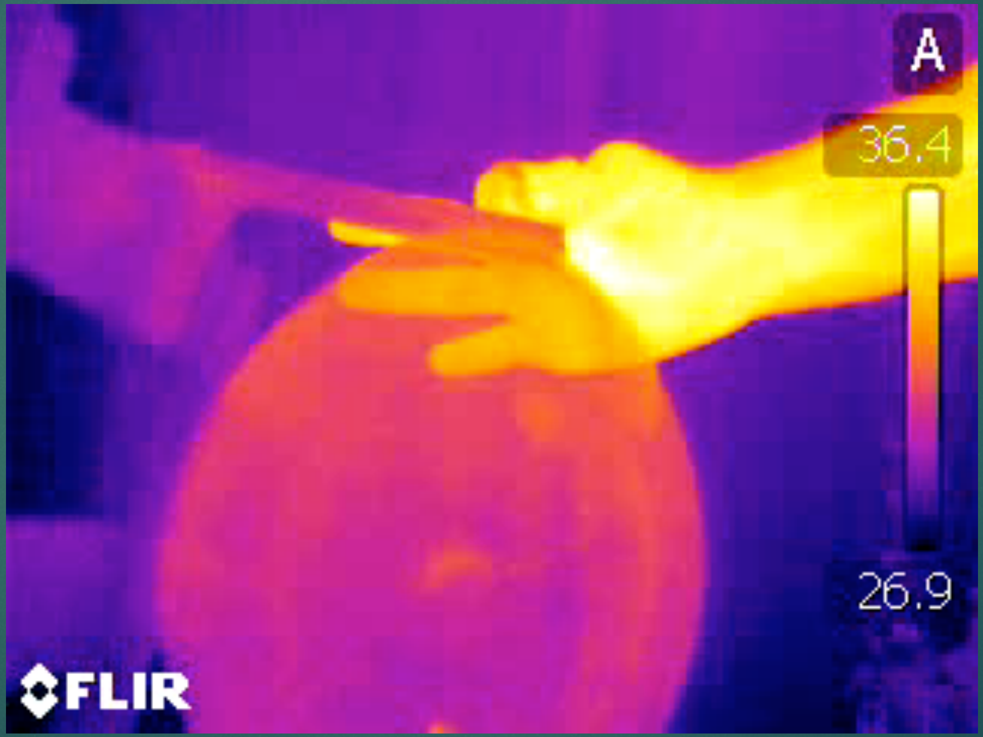
$$\Delta T_{theory} \approx 4°C$$

$$\Delta T_{measured} \approx 1°C$$



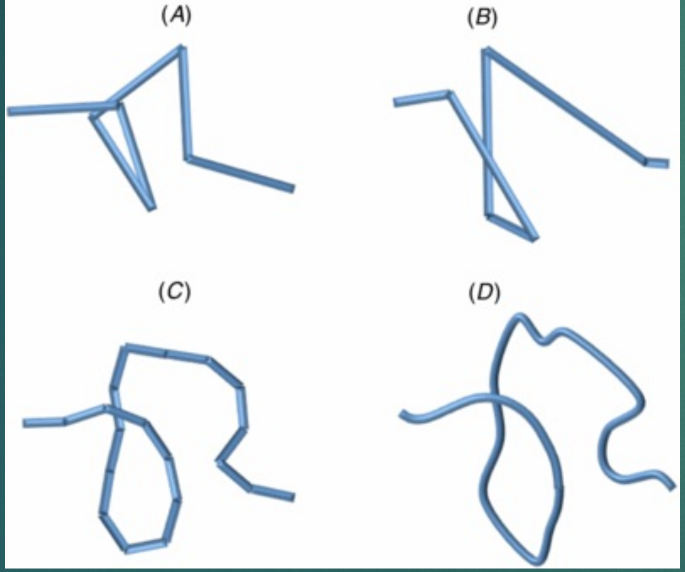
Reasons for the difference

- The process is approximately adiabatic
- The rubber heats up the air



Theorem part 2: change of entropy

Using the freely-jointed chain model



$$S = S_{athermal} + S_{thermal}$$

$$S_{thermal} = S_{thermal}(T)$$

Slow (isothermal) stretching

(1) $$dS_{thermal} = 0$$

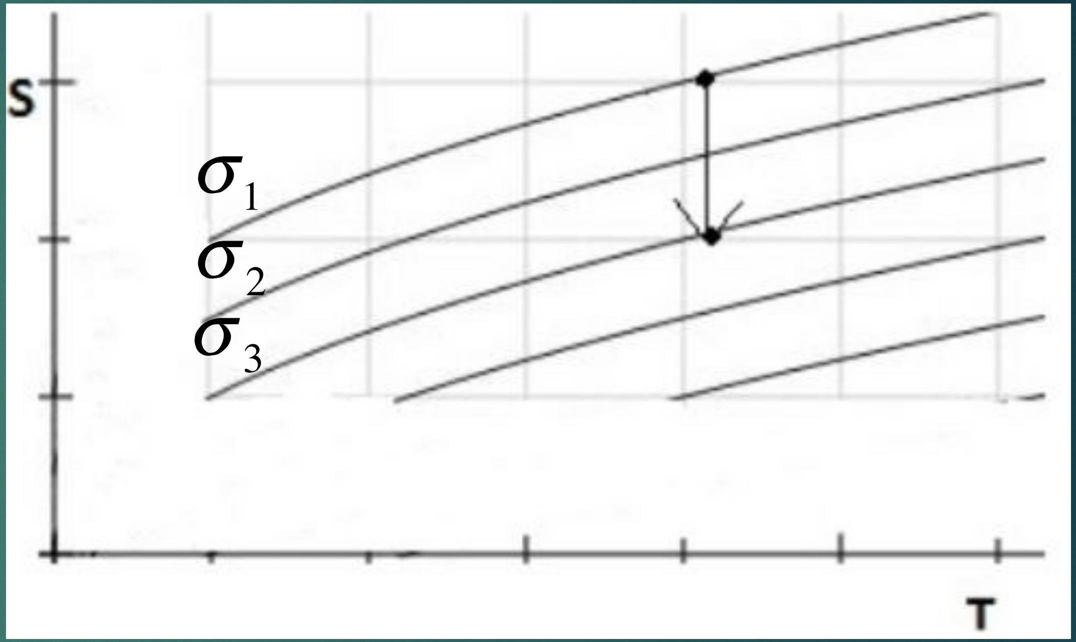
(2) $$dS = TdS_{athermal}$$

(3) $$TdS_{athermal} = \cancel{dU} - \delta W$$

(4) $$TdS_{athermal} + \delta W = 0$$

(5) $$T\Delta S = -\int_{L_0}^{L} F\,dl$$

(6) $$F = -T\left(\frac{\partial S}{\partial L}\right)_{T,V}$$



$$F = F(T)$$

$$\sigma_1 < \sigma_2 < \sigma_3$$

Fast (adiabatic) stretching

(1) $\delta Q = 0$

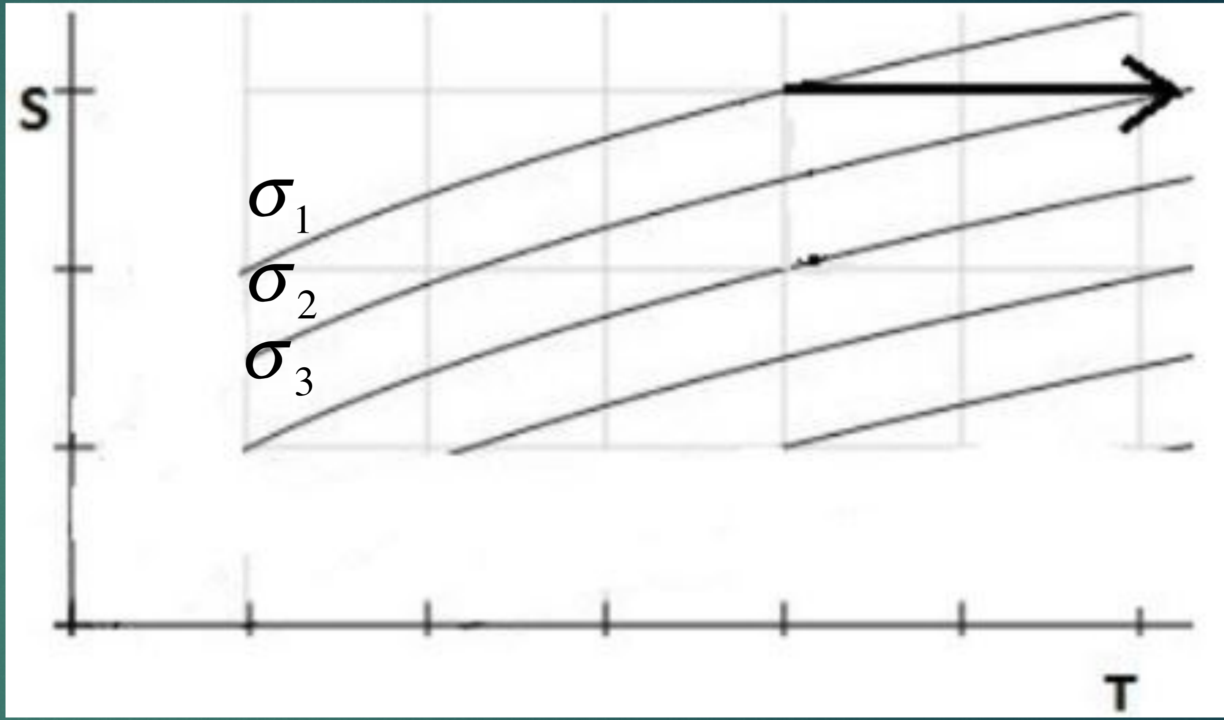
(2) $\delta Q = TdS$

(3) $dS_{thermal} = -dS_{athermal}$

(4) $\sum dS = 0$

(5) $TdS = dU - \delta W$

(6) $dU = \delta W$



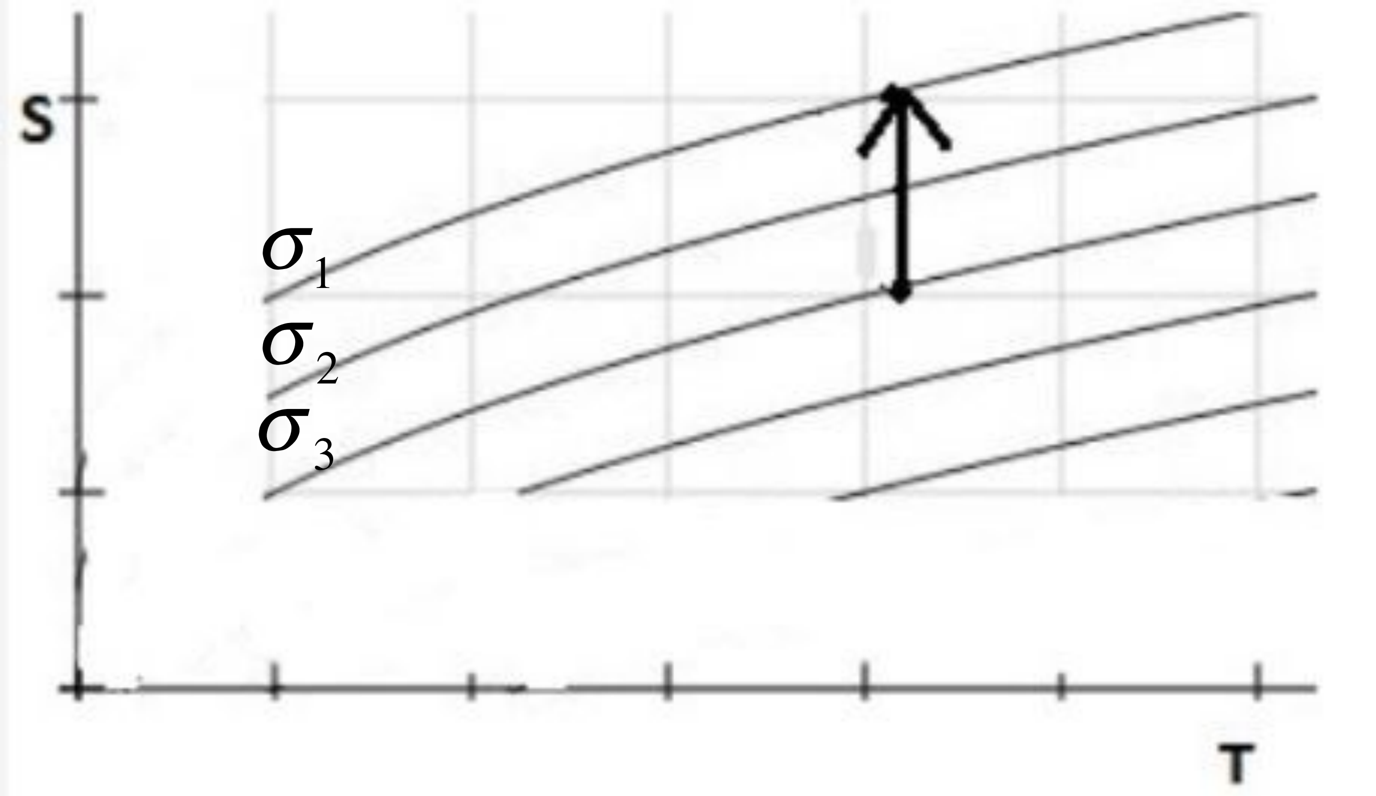
$\delta W > 0 \quad dU > 0 \quad dT > 0$

$\Delta T = \frac{1}{C_p} W$ [3]

*

Slow (isothermal) deflation

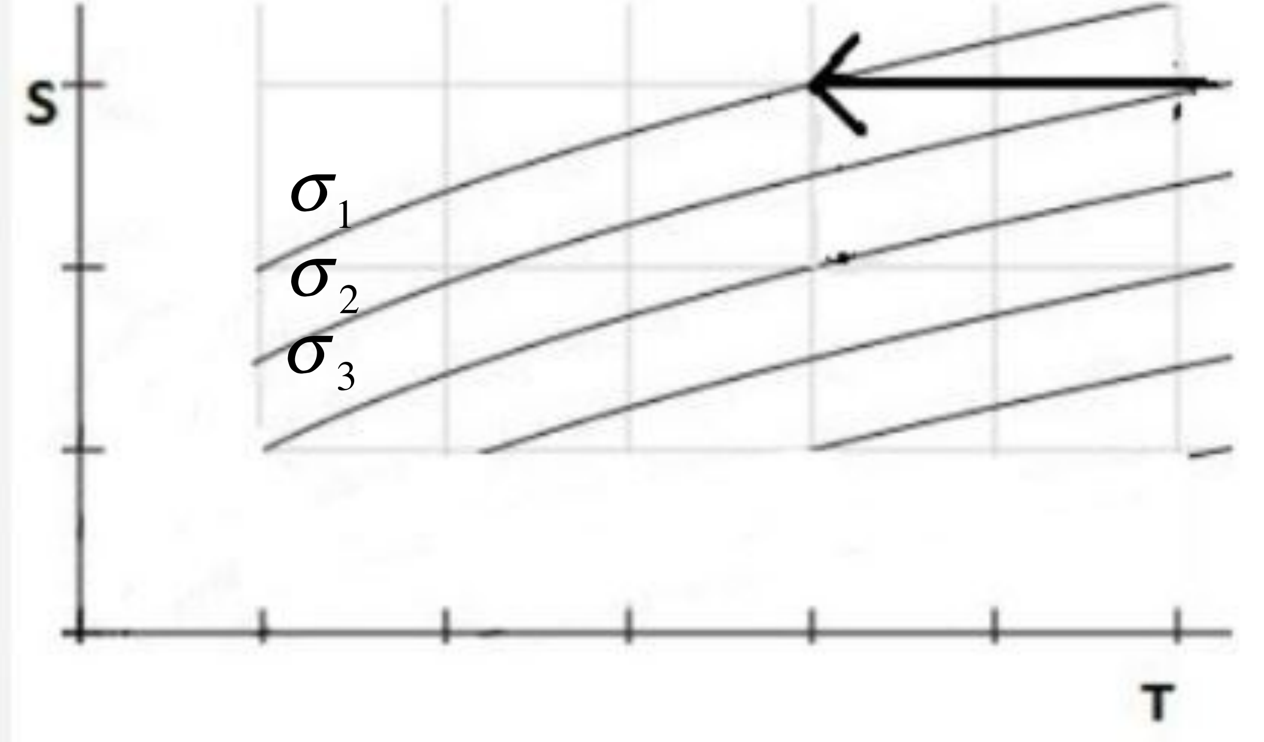
$$TdS = dU - \delta W$$



Main point: fast (adiabatic) deflation

$$TdS = dU - \delta W$$

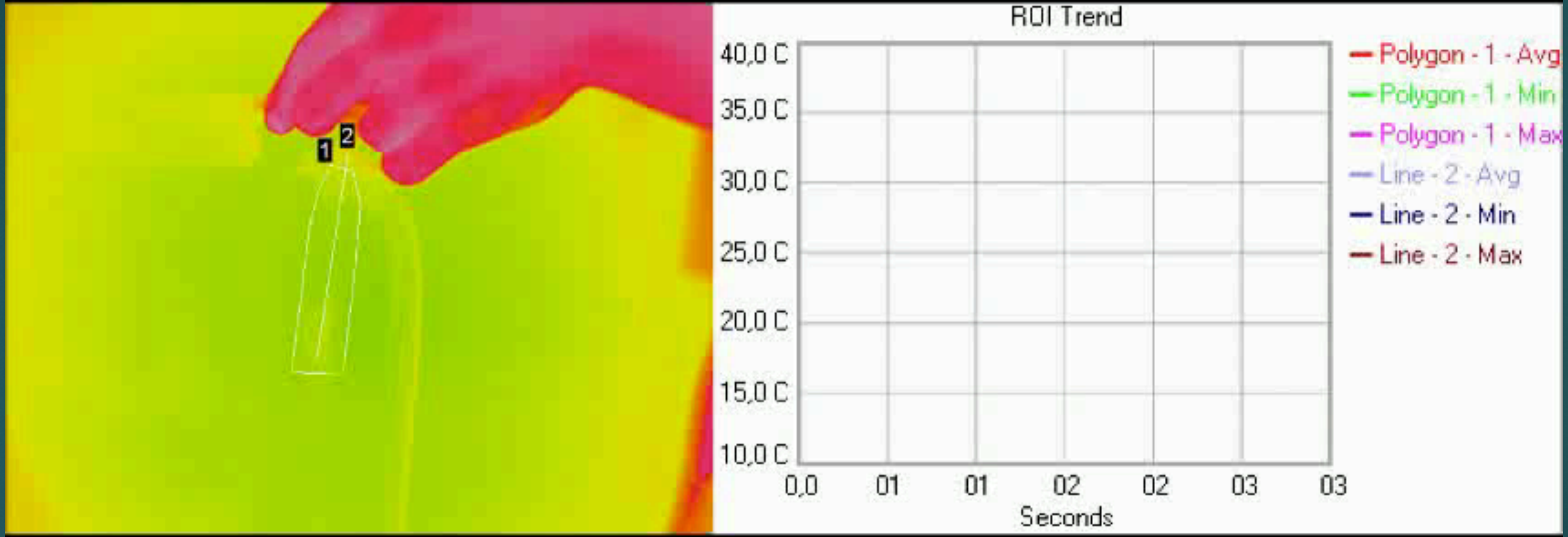
$$\Delta T = \frac{1}{C_p} W$$



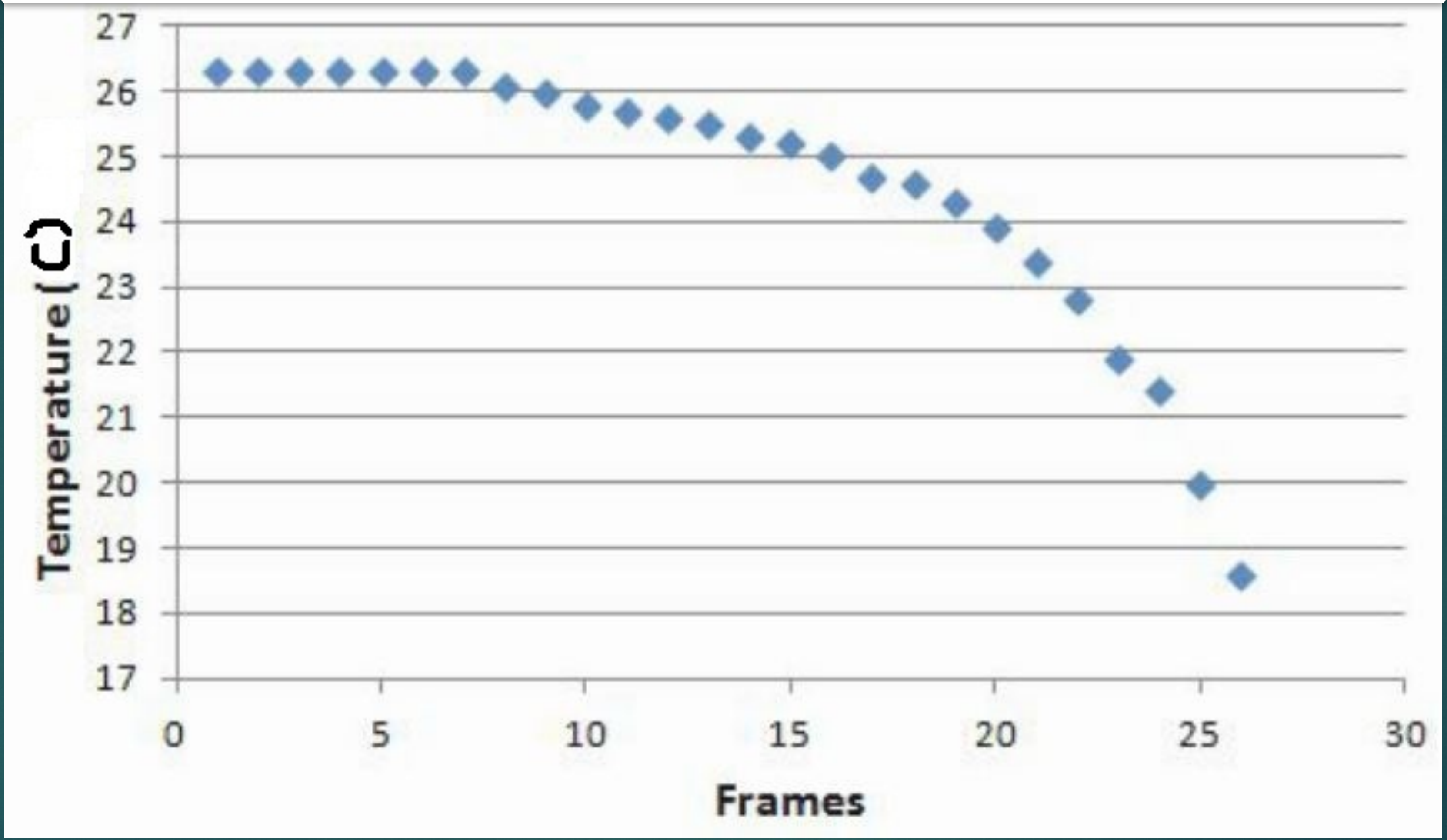
Experiments

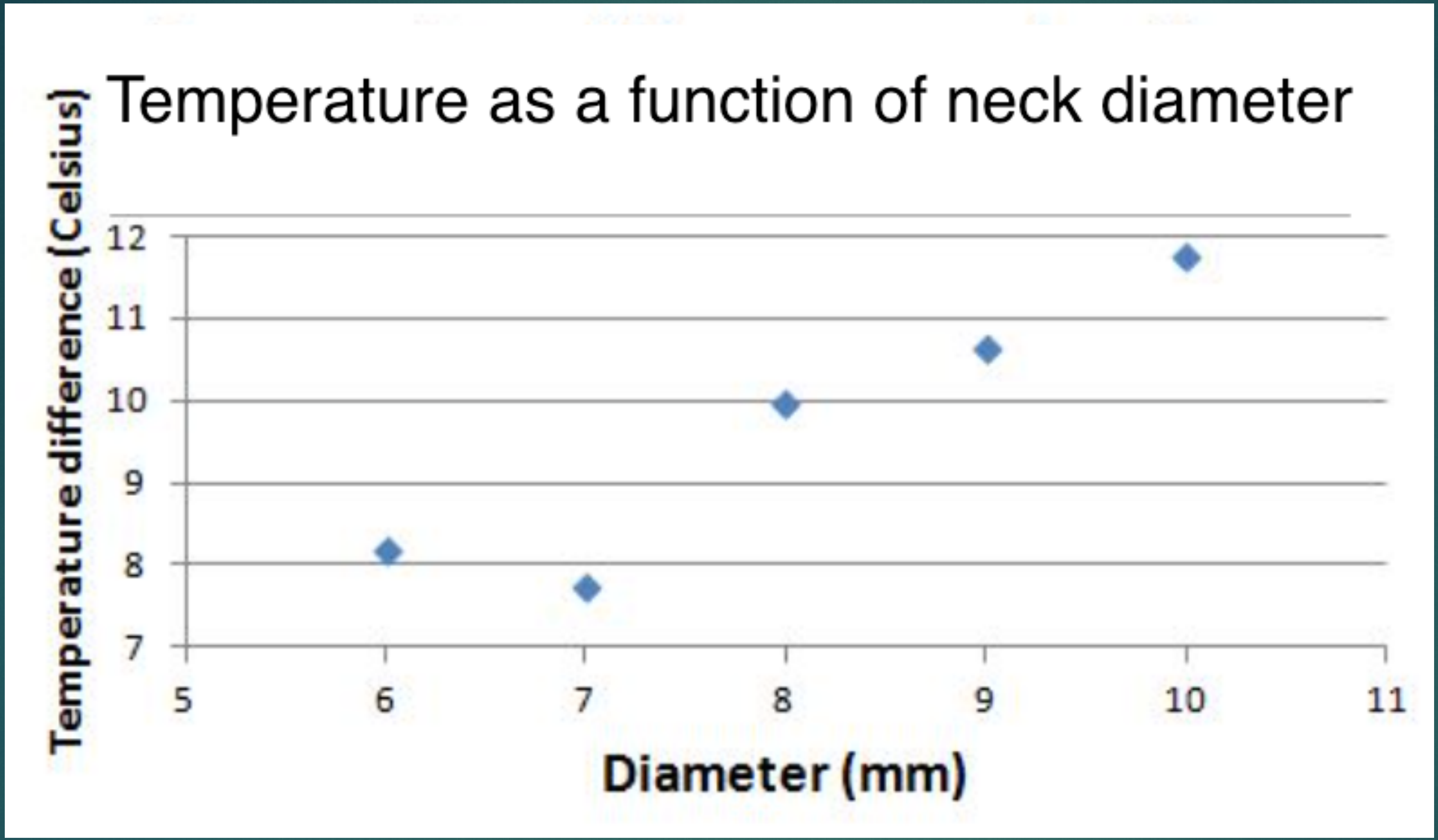
Let`s see the results of the theoretical investigation in our experiments

Thermal image



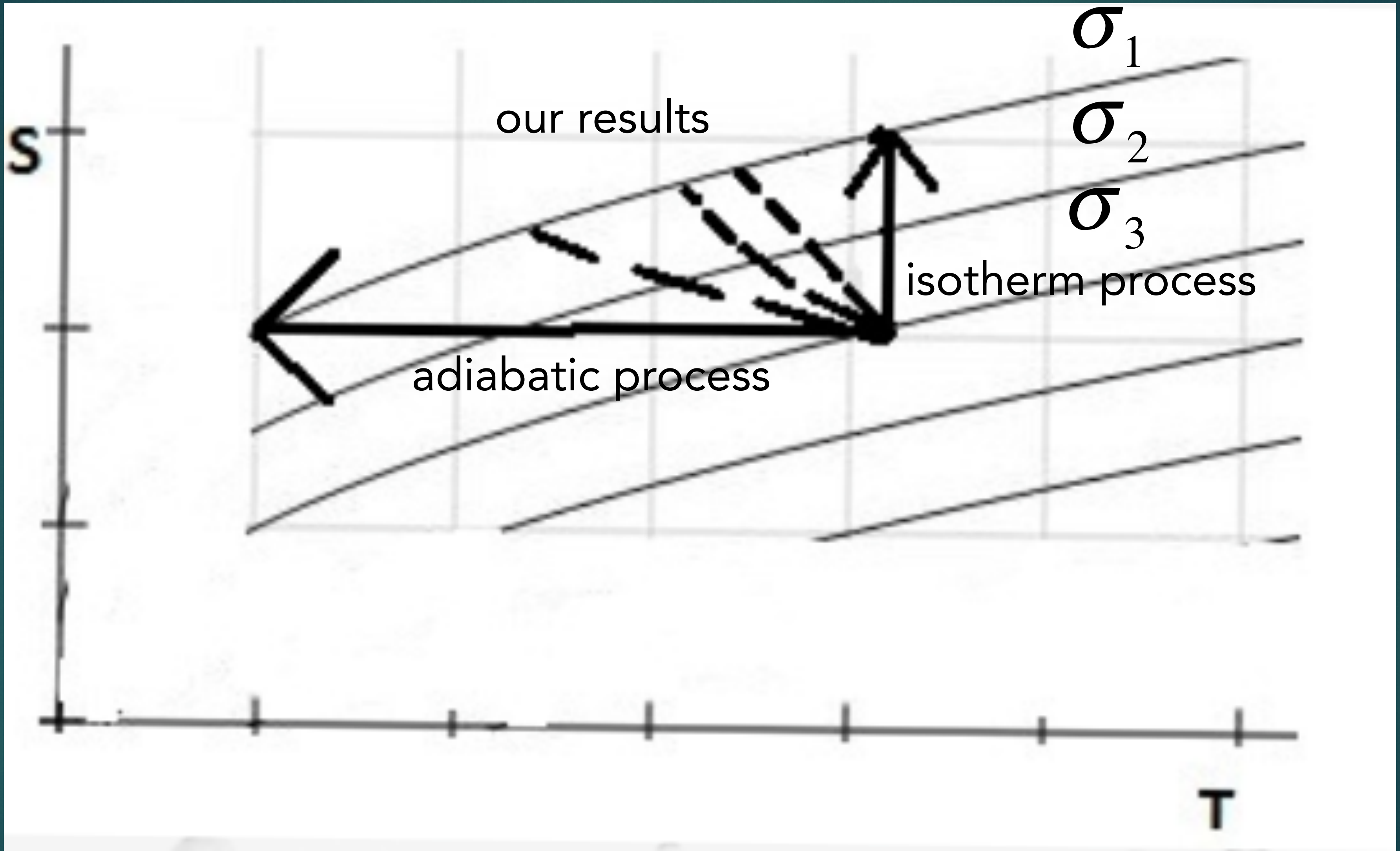
Temperature as a function of time





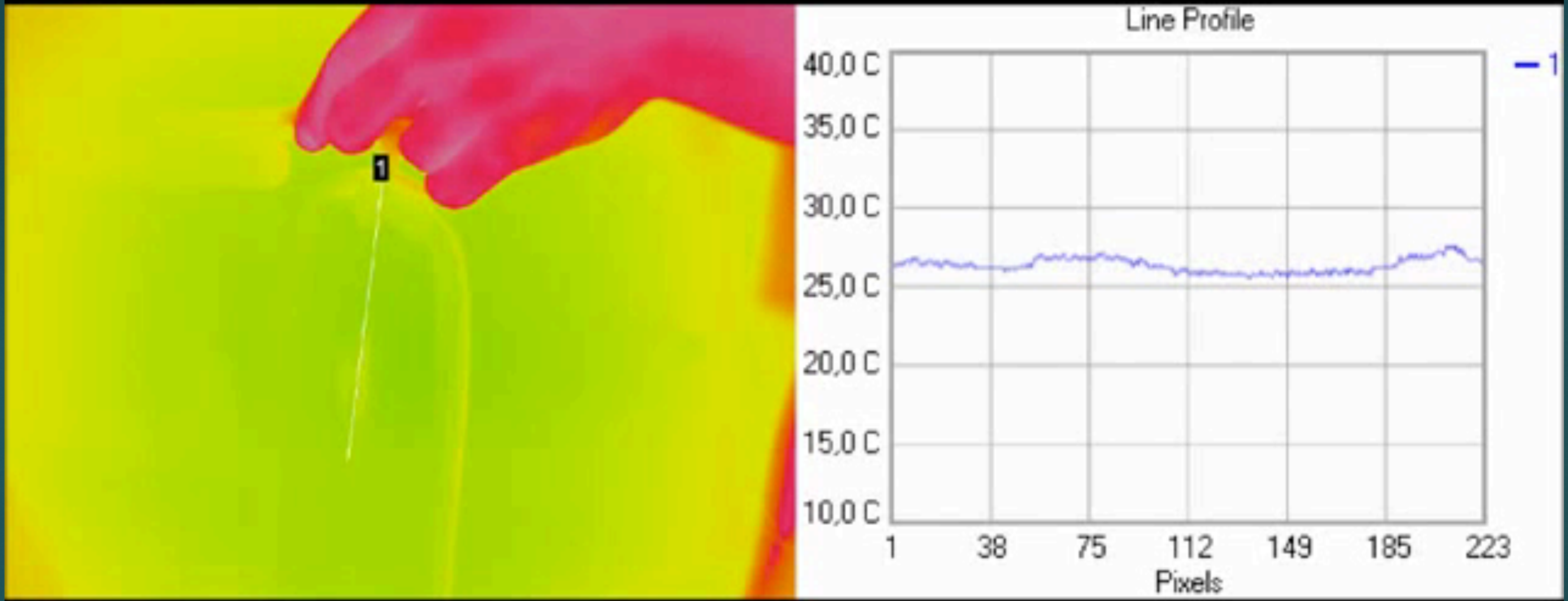
The theoretical maximum of cooling is 15 degrees of Celsius *

*Juhasz A., Tasnadi P: Erdekes anyagok anyagi erdekessegek, Akademiai kiado, Budapest 1992

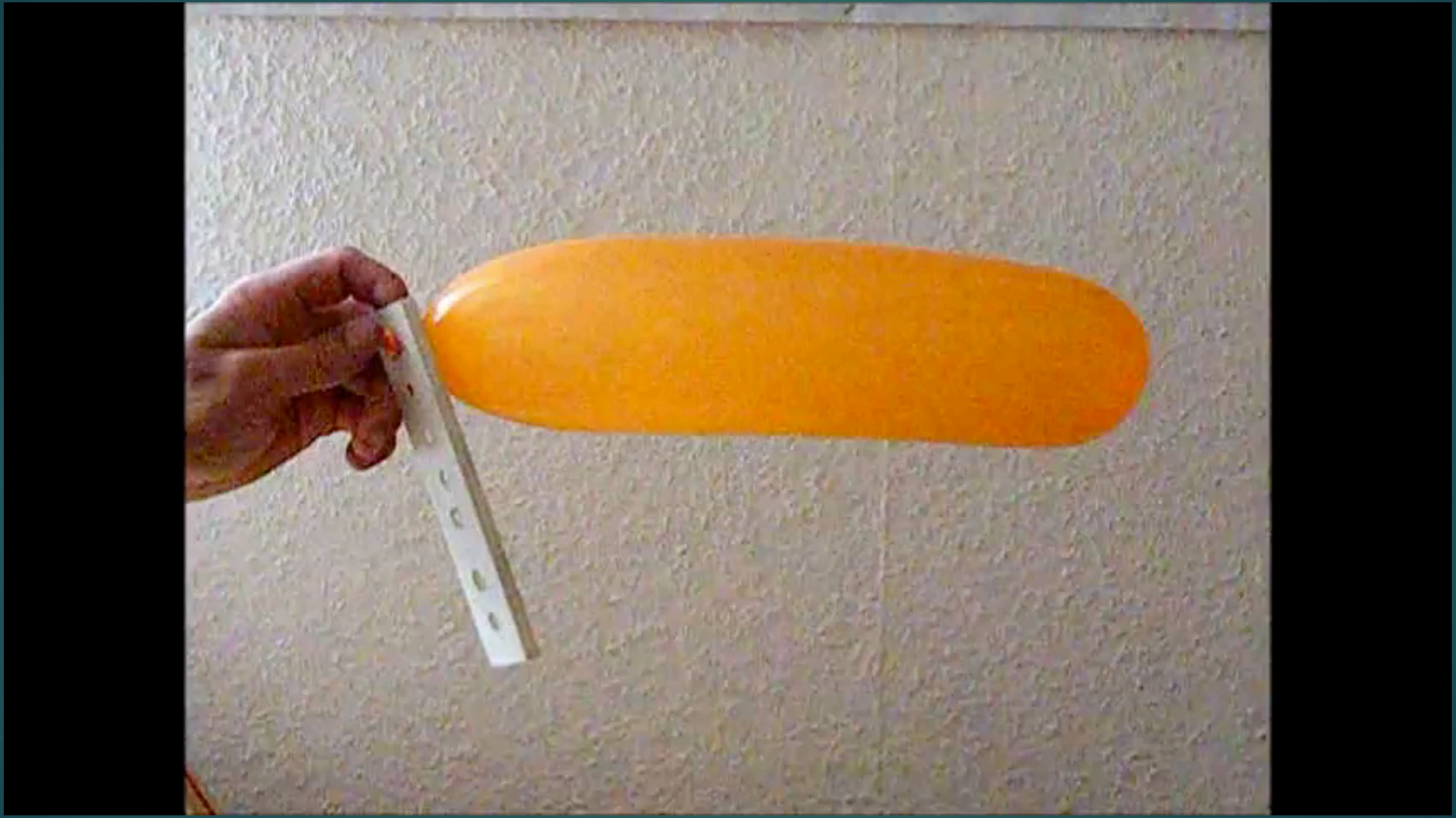


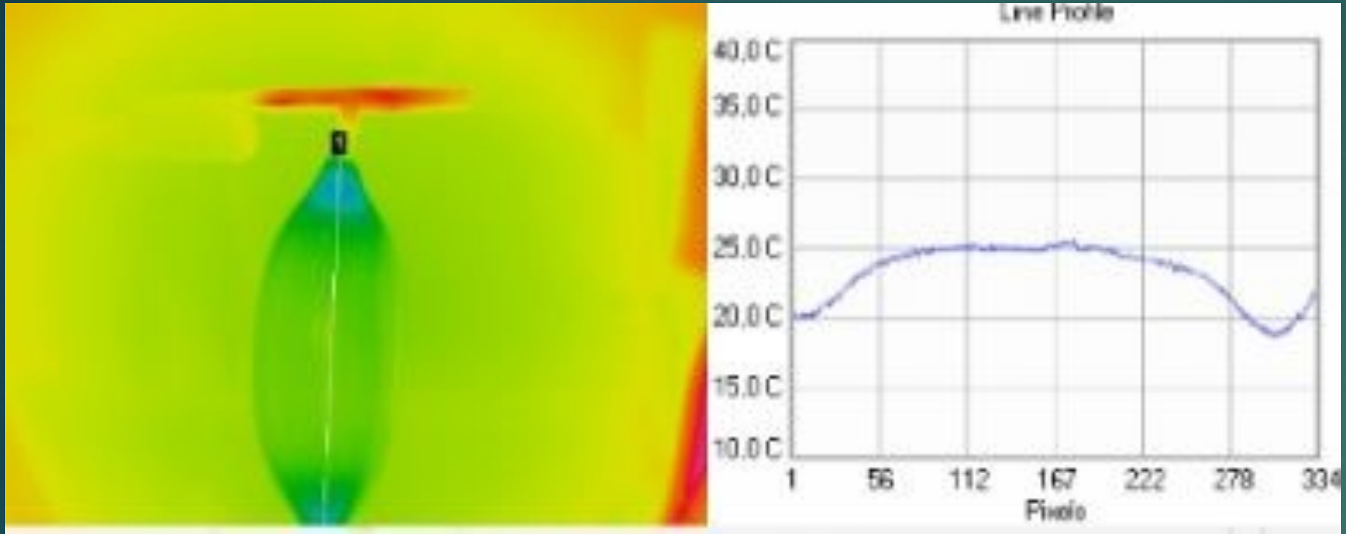
S
T
our results
σ_1
σ_2
σ_3
isotherm process
adiabatic process

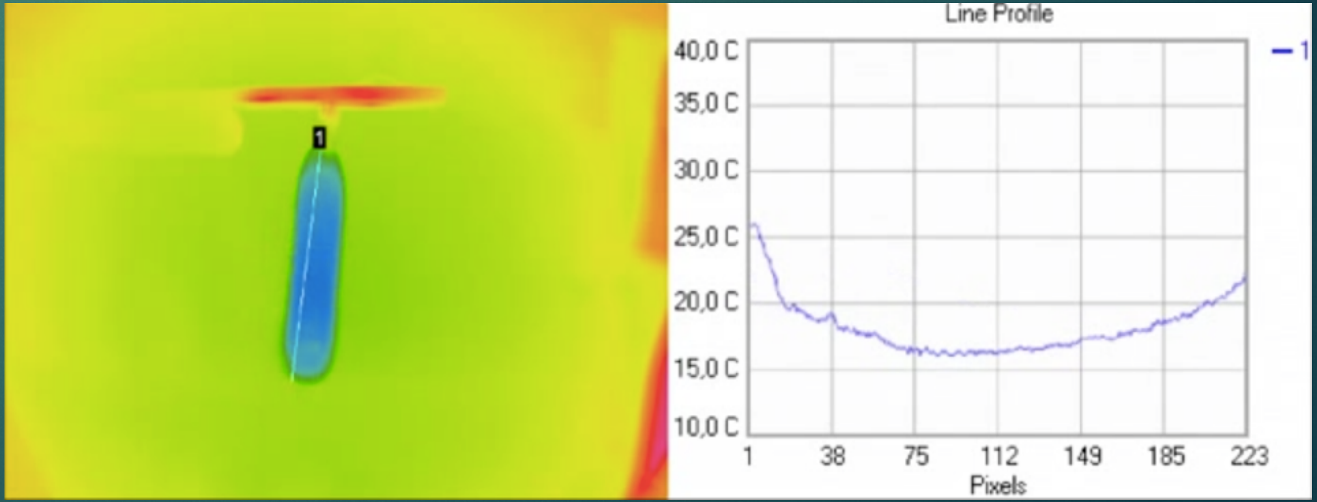
Heat distribution



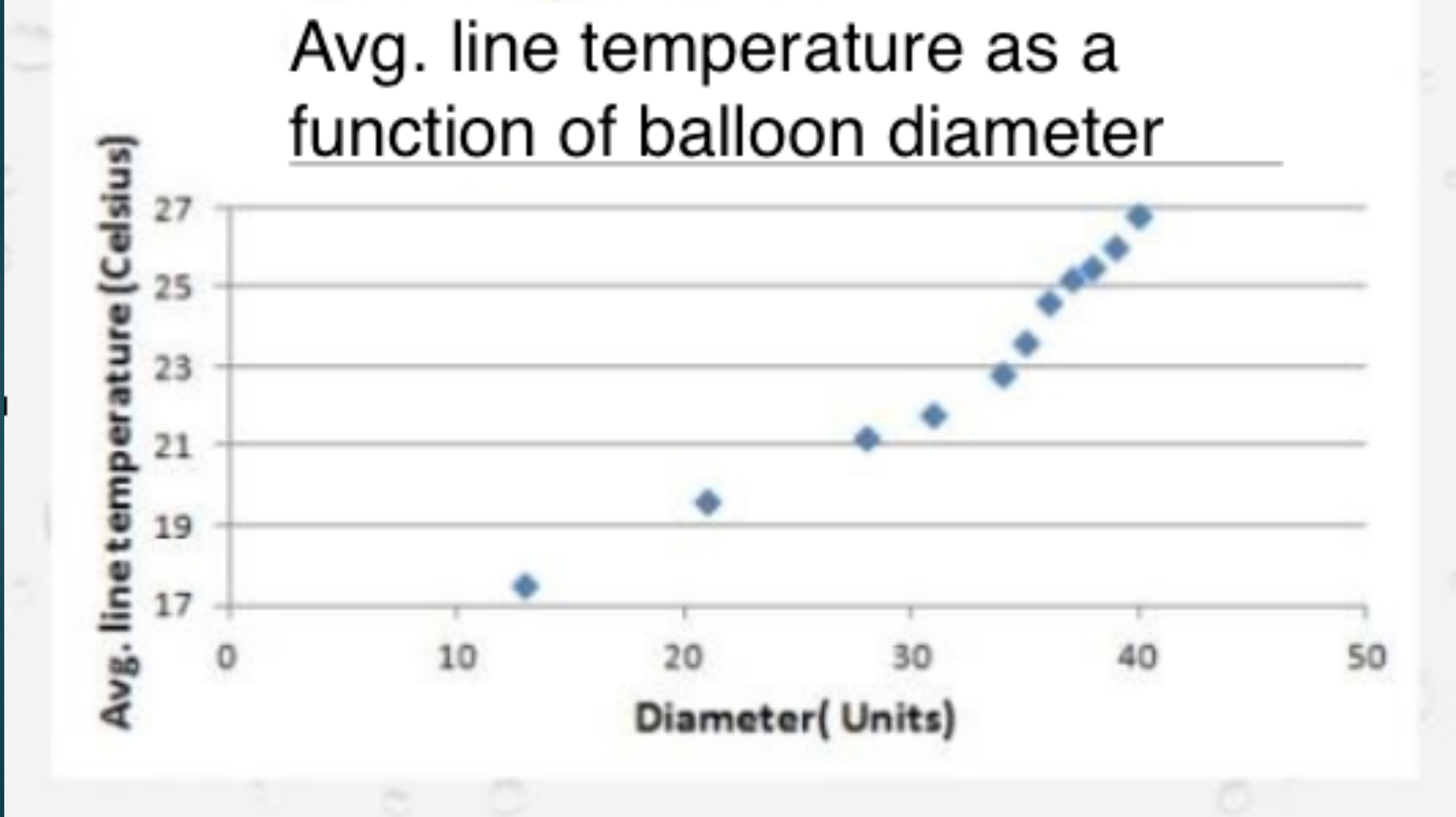
Heat distribution

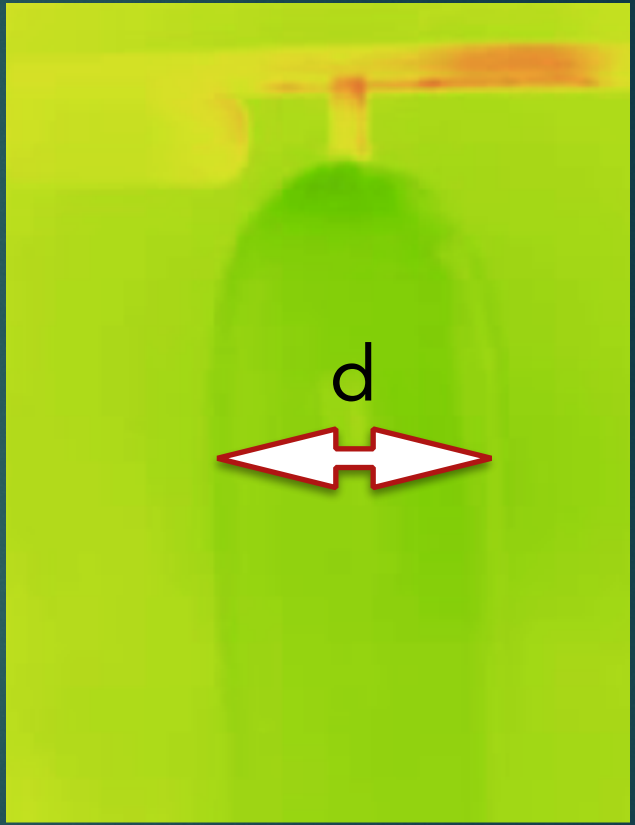



Line Profile
40,0 C
35,0 C
30,0 C
25,0 C
20,0 C
15,0 C
10,0 C
1
56
112
167
222
278
334
Pixels

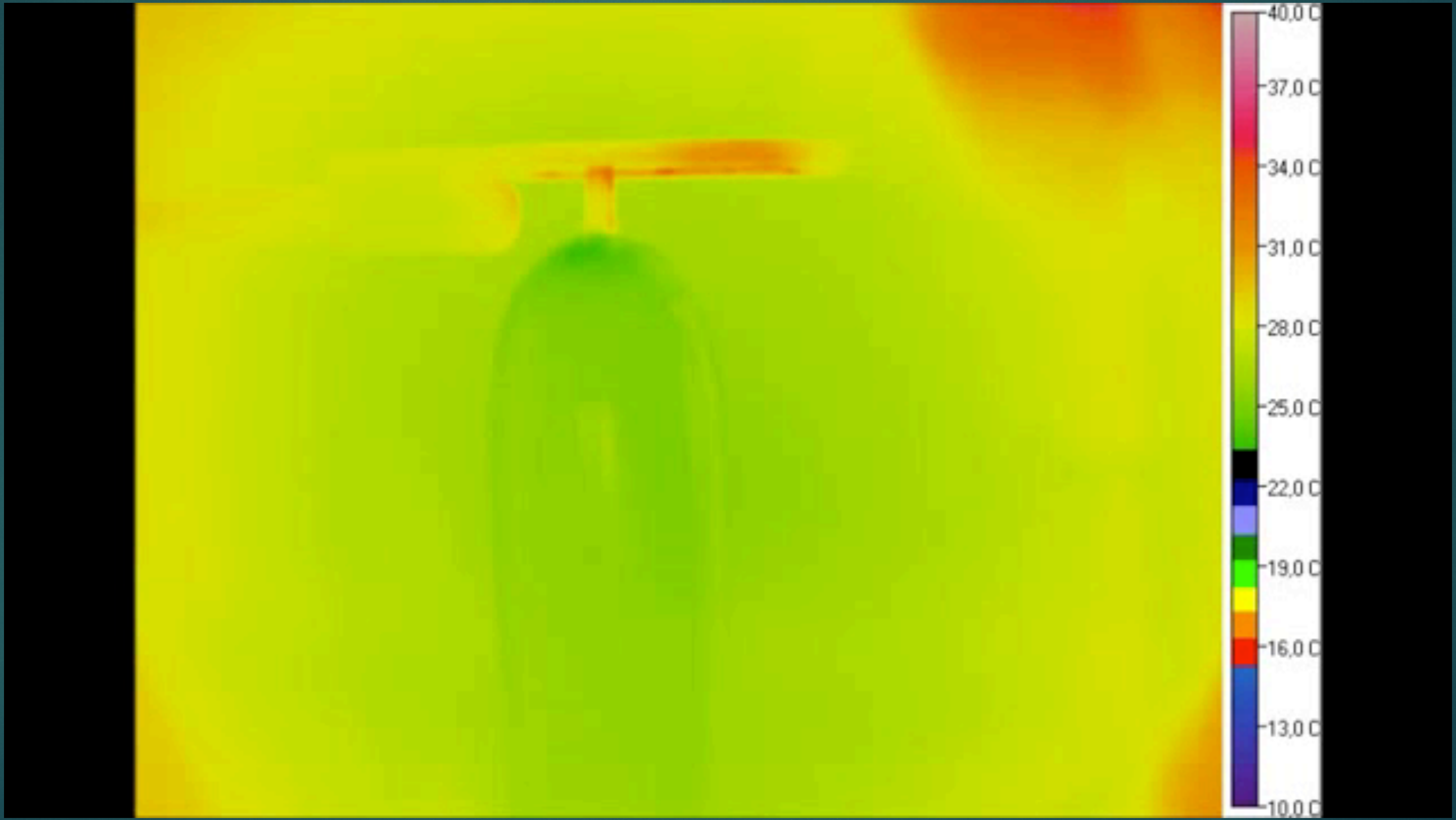

Line Profile
1
40,0 C
35,0 C
30,0 C
25,0 C
20,0 C
15,0 C
10,0 C
1
38
75
112
149
185
223
Pixels

Average line temperature as a function of balloon diameter

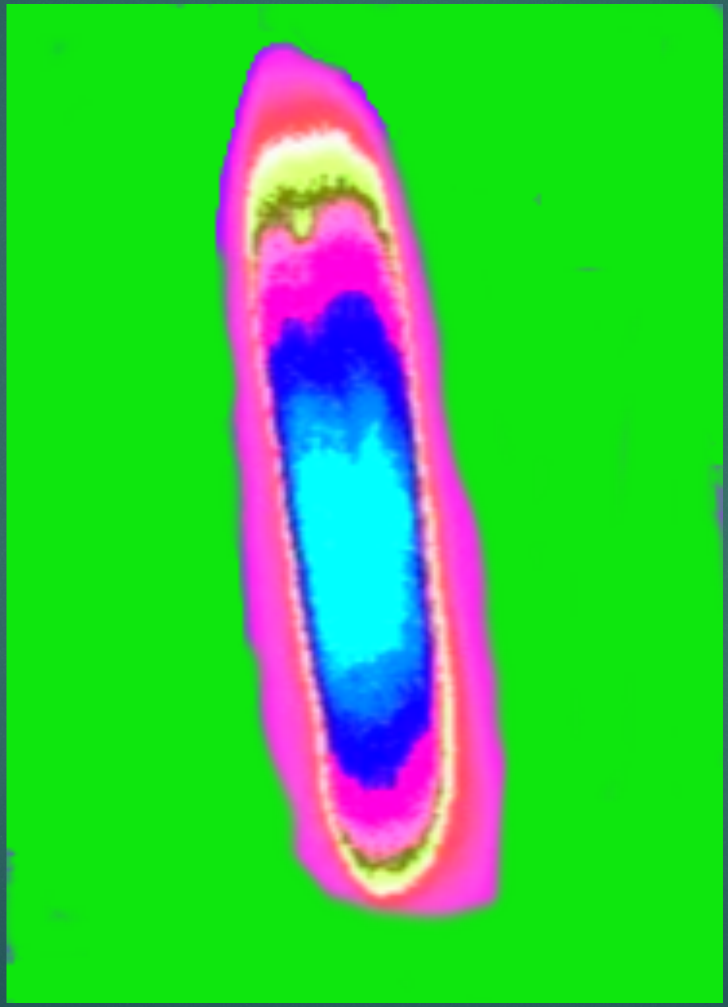




Isotherms



Isotherms



Conclusions

➡ Rubber has a really interesting material behavior
➡ The cooling has to be investigated not just in space but in time too
➡ Unnecessary to use a big balloon
➡ The cooling was mostly because of change of entropy

Sources

1. Kathryn R. Williams: The Thermodynamic Properties of Elastomers: Equation of State and Molecular Structure
Nash, L. K. J. Chem. Educ., 1979, 56 , 363.

2. Juhasz Andras, Tasnadi Peter: Erdekes anyagok anyagi erdekessegek, Akademiai Kiado, Budapest 1992

3. http://inside.mines.edu/~dwu/classes/CH351/labs/elastomer/Wet%20Lab%204/Wetlab4.pdf

Thank you for your attention!