Experimental investigation of a carbon-based direct absorption parabolic trough solar collector

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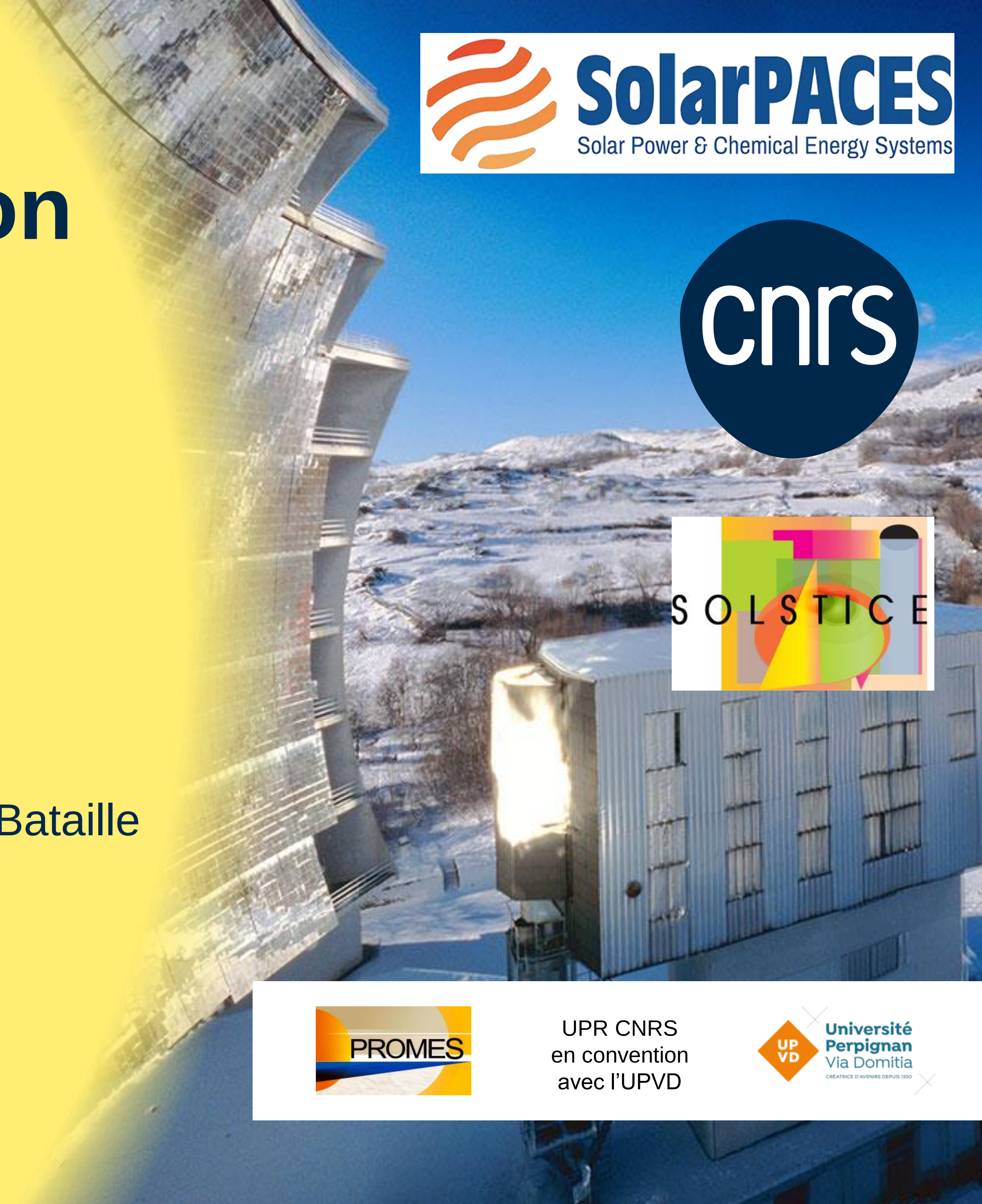

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SolarPACES – Rome (Italy) – October 8-11 2024

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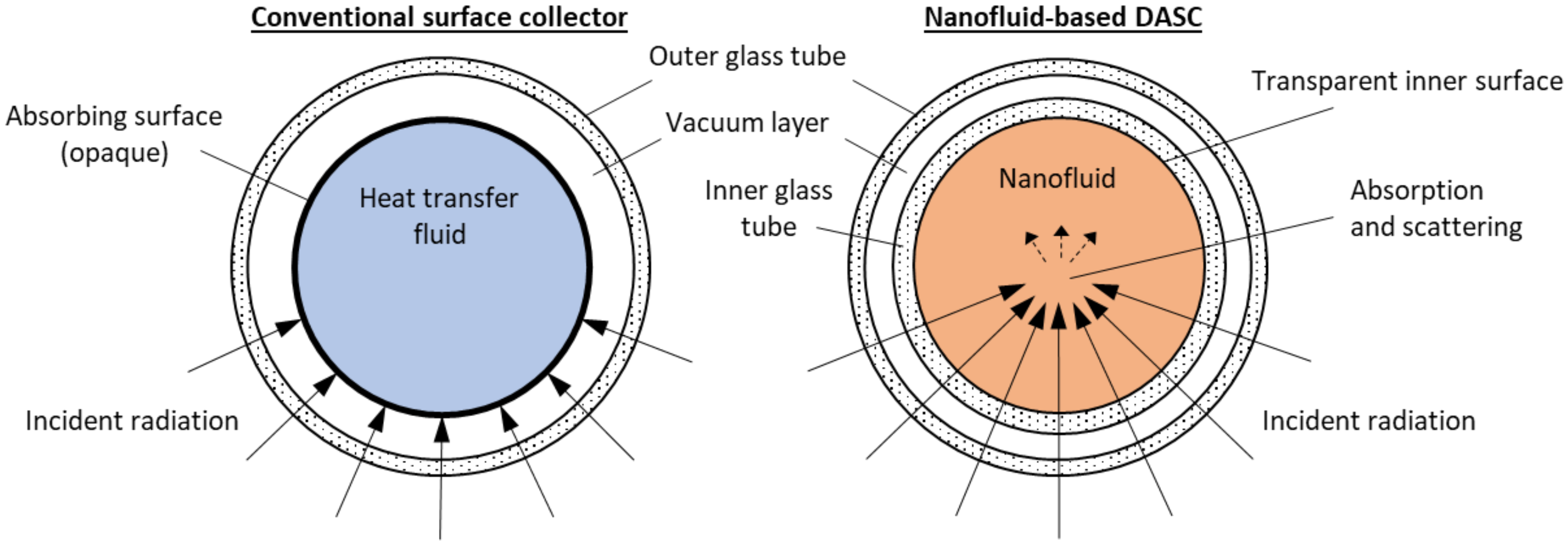
Nanofluid-based direct absorption solar collector (NDASC)



Surface absorbing receiver

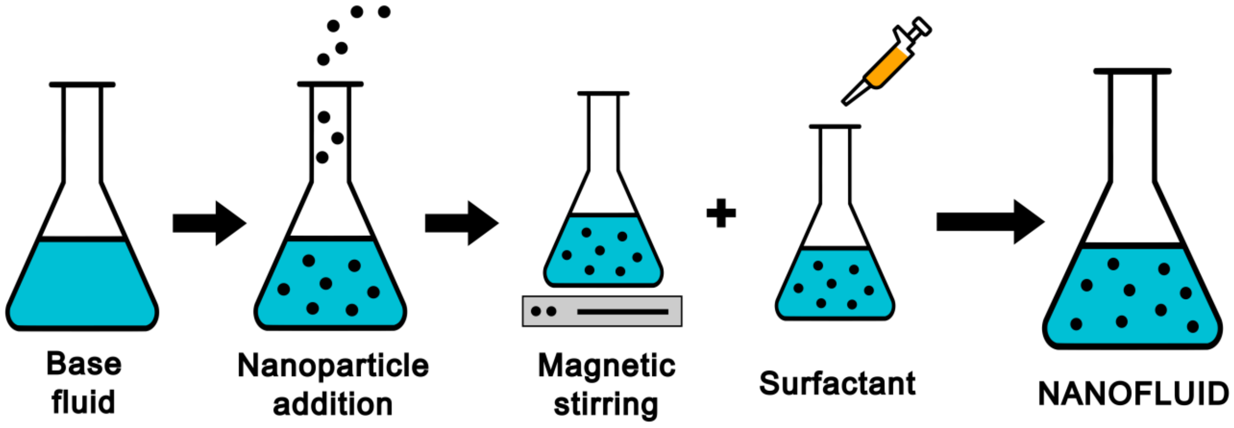
- Selective absorption surface with glass envelope.
- Heat transfer fluid to recuperate the heat at the surface.

Volumetric absorption receiver – Nanofluid absorber

- Double-glass receiver with selective absorption nanofluid.
- Absorbing medium: heat transfer fluid + nanoparticles (nanofluid).

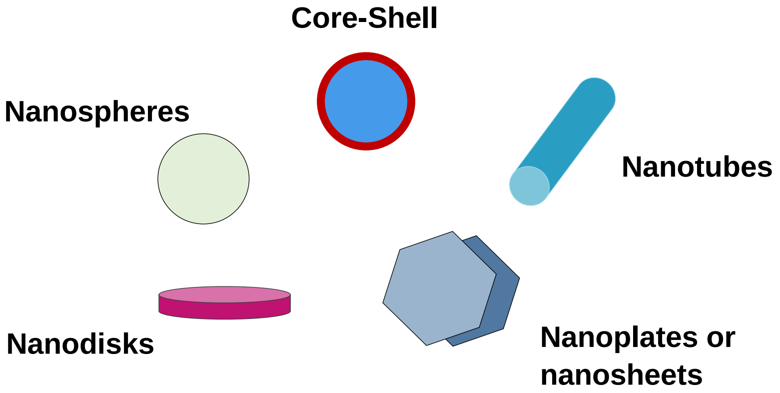
Sainz Mañas, M., Bataille, F., Caliot, C., Vossier, A., & Flamant, G. (2022). Energy, 260, 124916.

What is a nanofluid ?



- **Avantages**: - Heat transfer enhancement (thermal conductivity).
  - High optical absorption properties.

- **Applications**: - Barrier & Anticorrosion.
  - Thermal Management.
  - Mechanical Reinforcement.
  - Electrical conductivity.



What advantages nanofluids bring?

NDASC

- **2009** – First study of a NDASC [1].

Trends

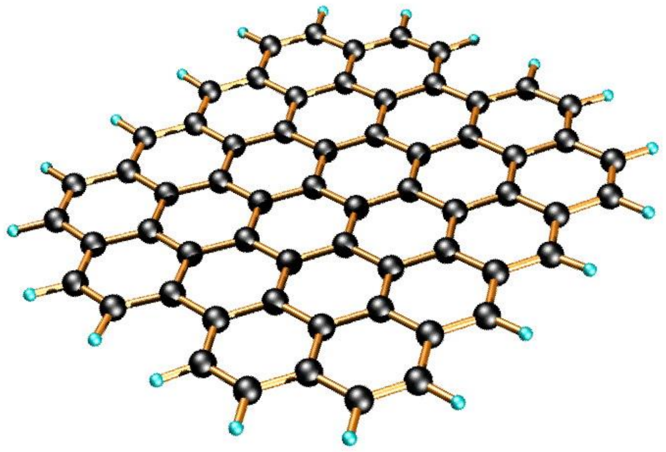
- Nanoparticles: **metals** and **carbon-based**.
- Particle concentration: **0,001% - 0,1%** volume fraction.

Main features

- Not restricted to turbulent flows.
- Double glass tube (no metal-glass connections)
- High versatility for hybridization (e.g. PV cell).

Limitations: - Nanofluid stability.
- Production costs.
- Environmental impact and toxicity.
- Erosion and corrosion of components.

GRAPHENE

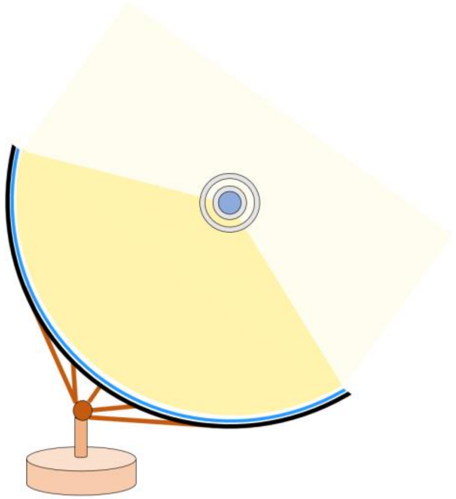


- 2D material – High surface-volume ratio.
- Wide range of application areas.
- Excellent physical properties.

[1] TYAGI, Himanshu, et al. Predicted efficiency of a low-temperature nanofluid-based direct absorption solar collector. ASME Journal of Solar Energy Engineering 2009.

Objective of the study

NDASC



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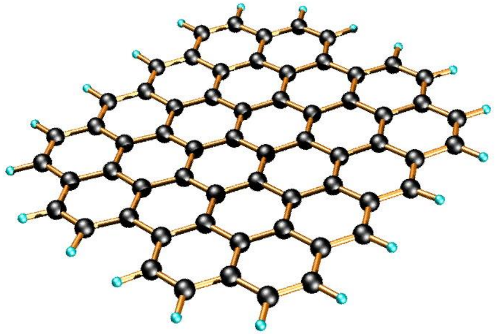
GRAPHENE



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Gaps in the literature

- Parabolic trough NDASC experimental studies.
- 2D particles optical properties in absorbing media.
- Stability of nanofluids with temperature.

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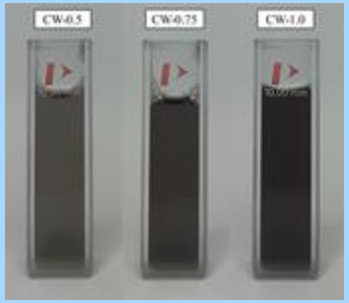
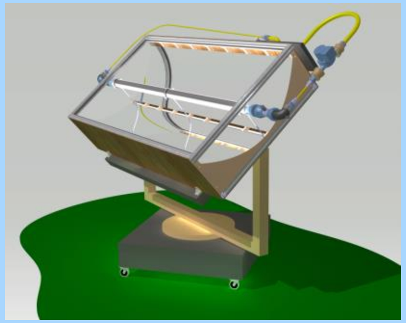
Breakdown of the study

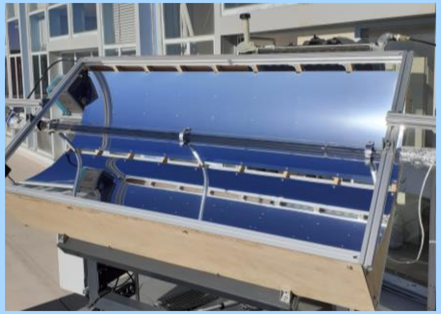


Optical characterization

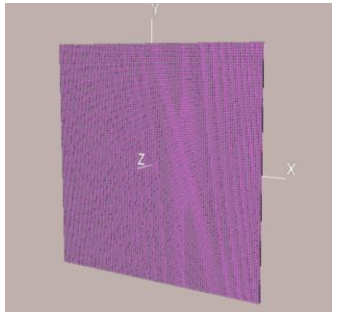
Stability of particles



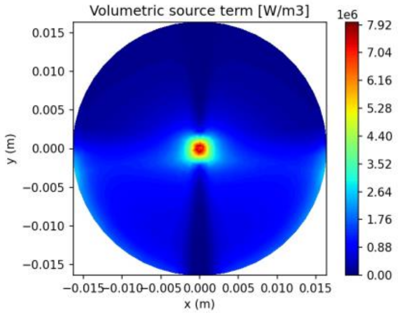
Pilot design



Experimental pilot



Radiative Heat Transfer
Nanoparticles + Fluid



Ray tracing model

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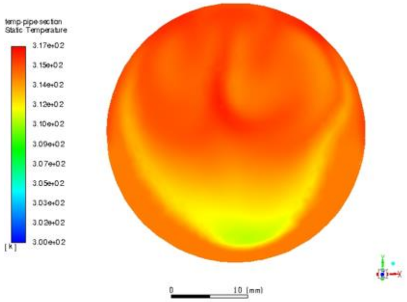


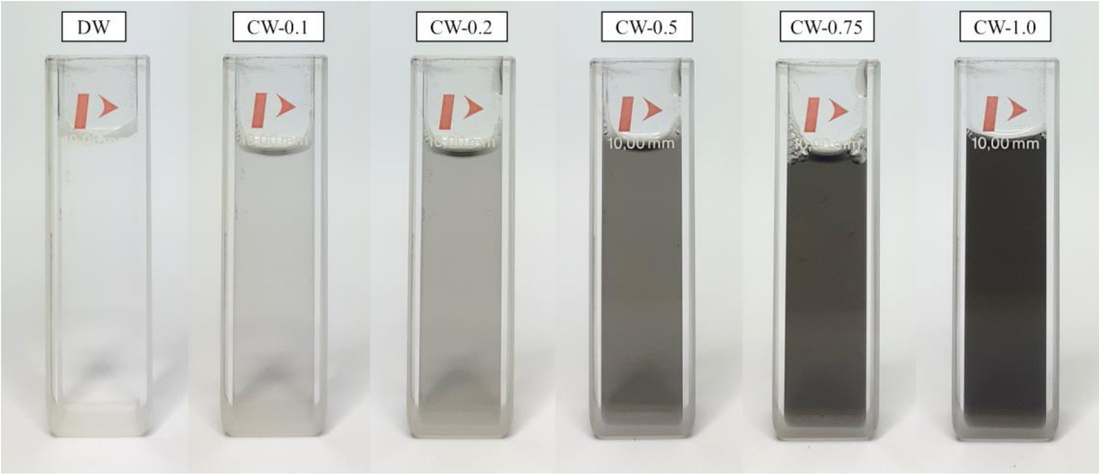
Computational Fluid Dynamics

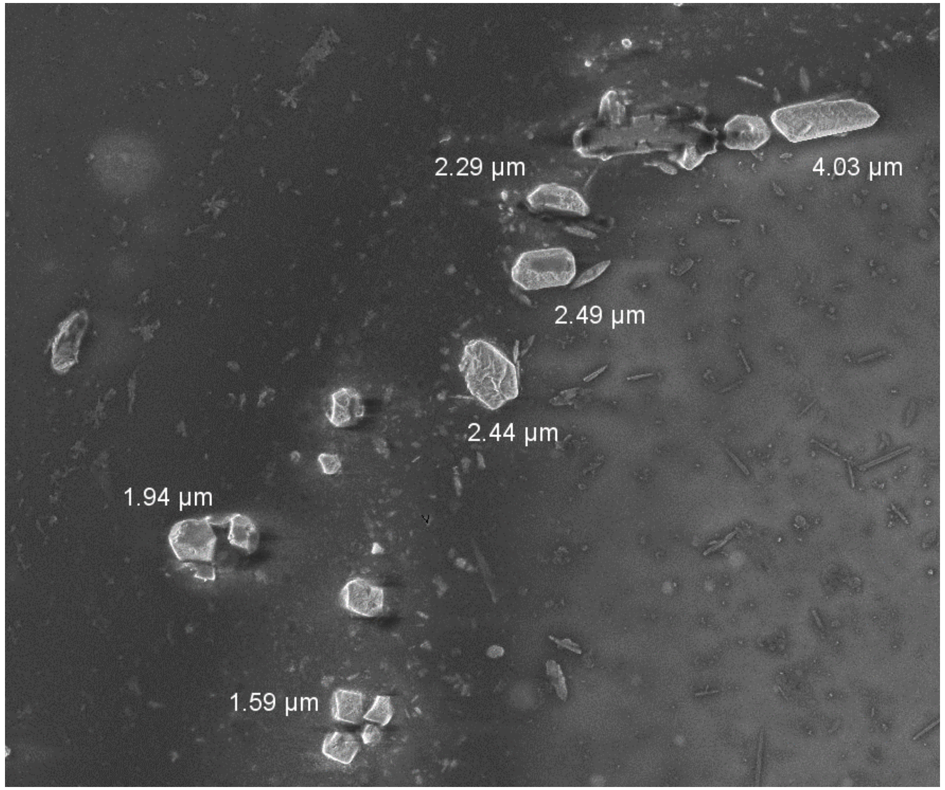
Parametric study

Carbon-based nanofluid

Graphene aqueous dispersion

- Initial concentration: 1 g/L
- Lateral size: [0,1 - 6] µm
- Thickness: [1 - 3] nm





Objectives

- Determine the optical properties of dispersed carbon nanoparticles.
- Evaluate the stability of the nanofluid with temperature.

Optical properties

0.1 to 1.0 g/L dilutions

Spectrophotometer Lambda 950 Perkin Elmer – 10mm light path

DIRECTIONAL TRANSMITTANCE ($\tau_{d\tau}$)

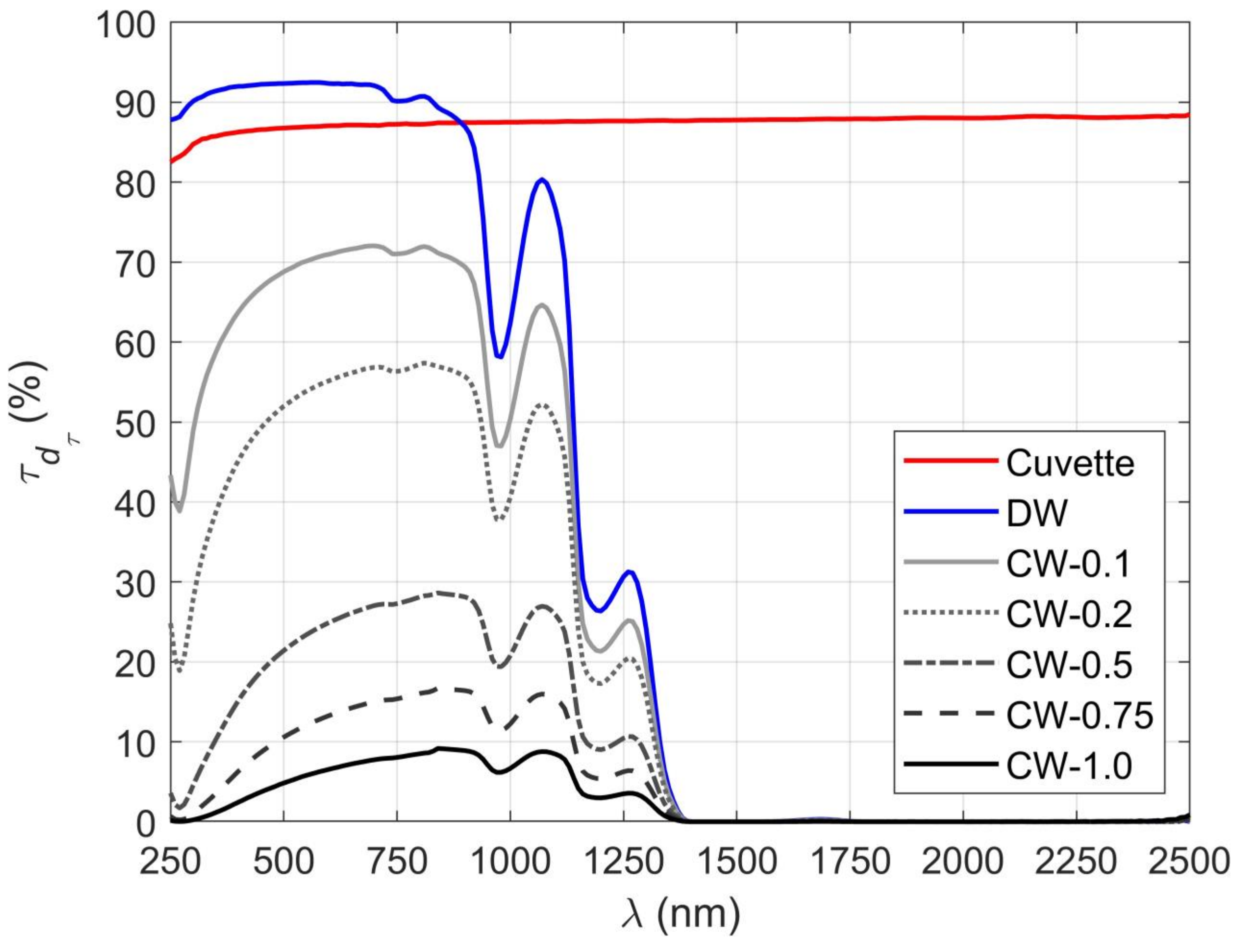
- Impact of the cuvette multiple reflections in measurements.
- **269nm peak** intrinsic to graphene's atomic structure.
- Over **1200nm**, water dominates extinction.
- High extinction with low volume fractions.

REFLECTANCE

- High impact of the cuvette interfaces in the measurements.
- Reflectance on samples attributed to the cuvette contribution

SCATTERING

- Low in directions different than the incident beam.
- Mainly forward scattering – less than 10% in all cases



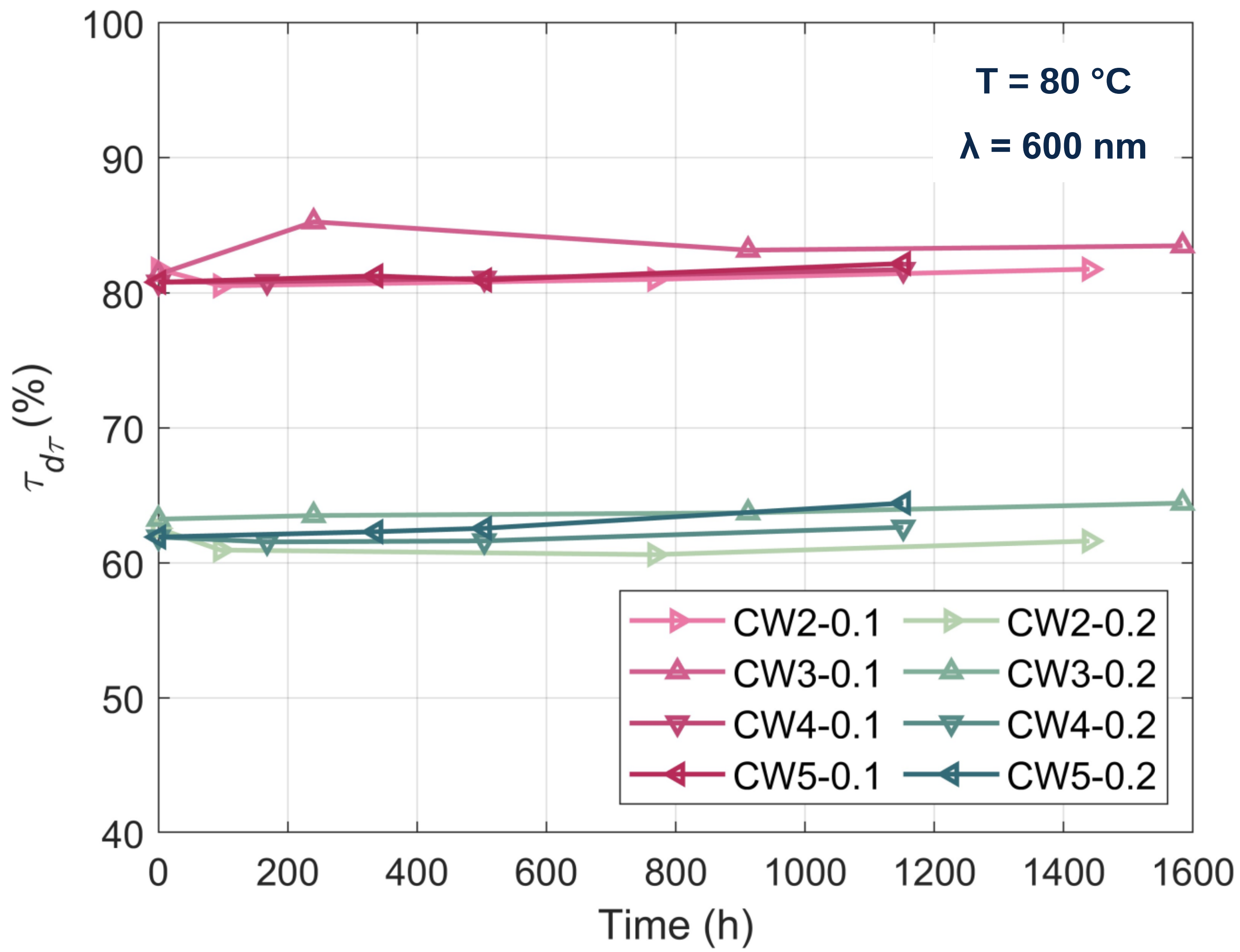
Particles' stability

0.1 and 0.2 g/L dilutions

Samples heated up to 80ºC

TRANSMISSION WITH TIME

- Long-term stability at ambient temp. and 80ºC.
- Similar tendencies for other wavelengths.
- **Suited for NDASC application**.



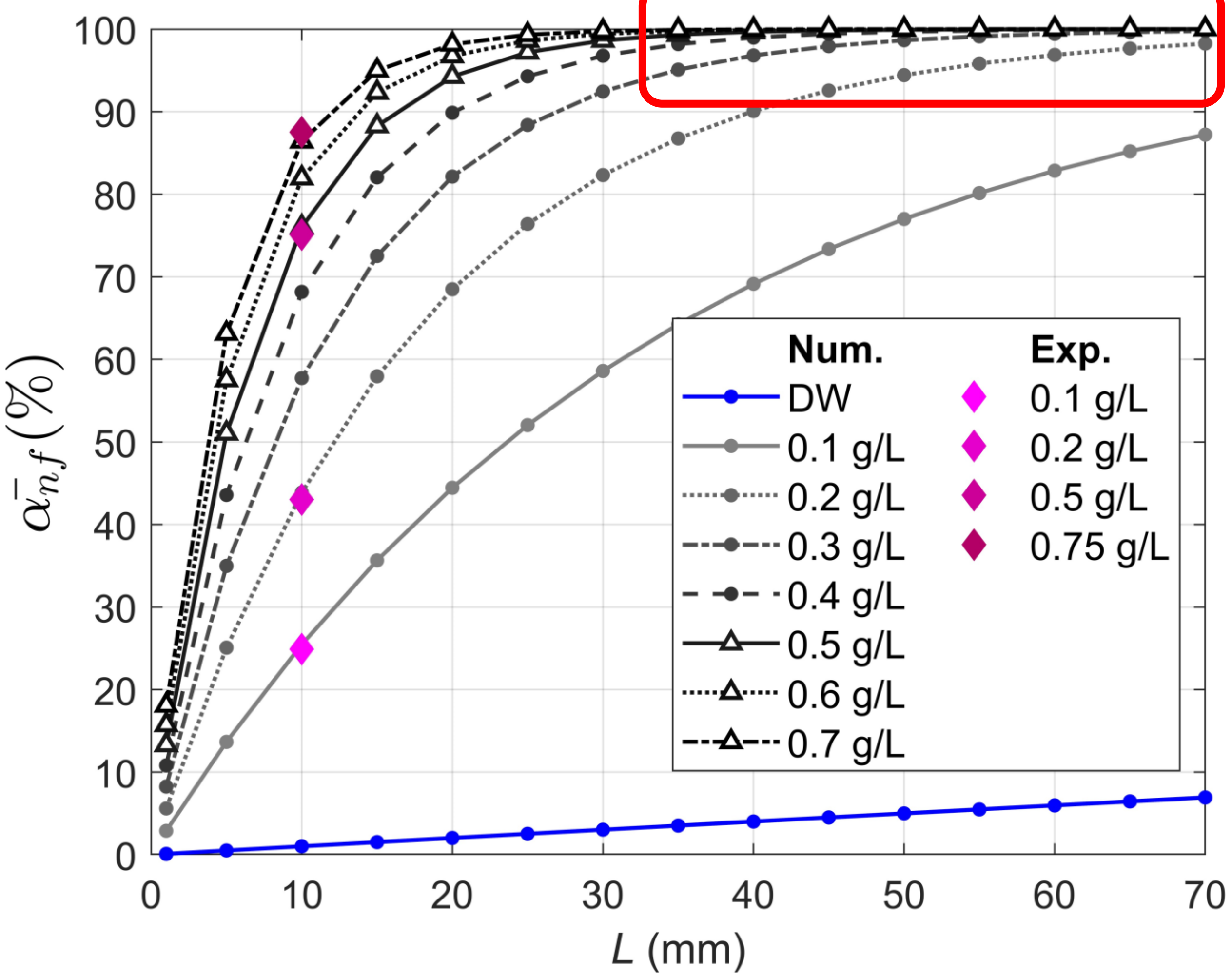
Carbon dispersion absorption potential

AM1.5 spectrum weighted average

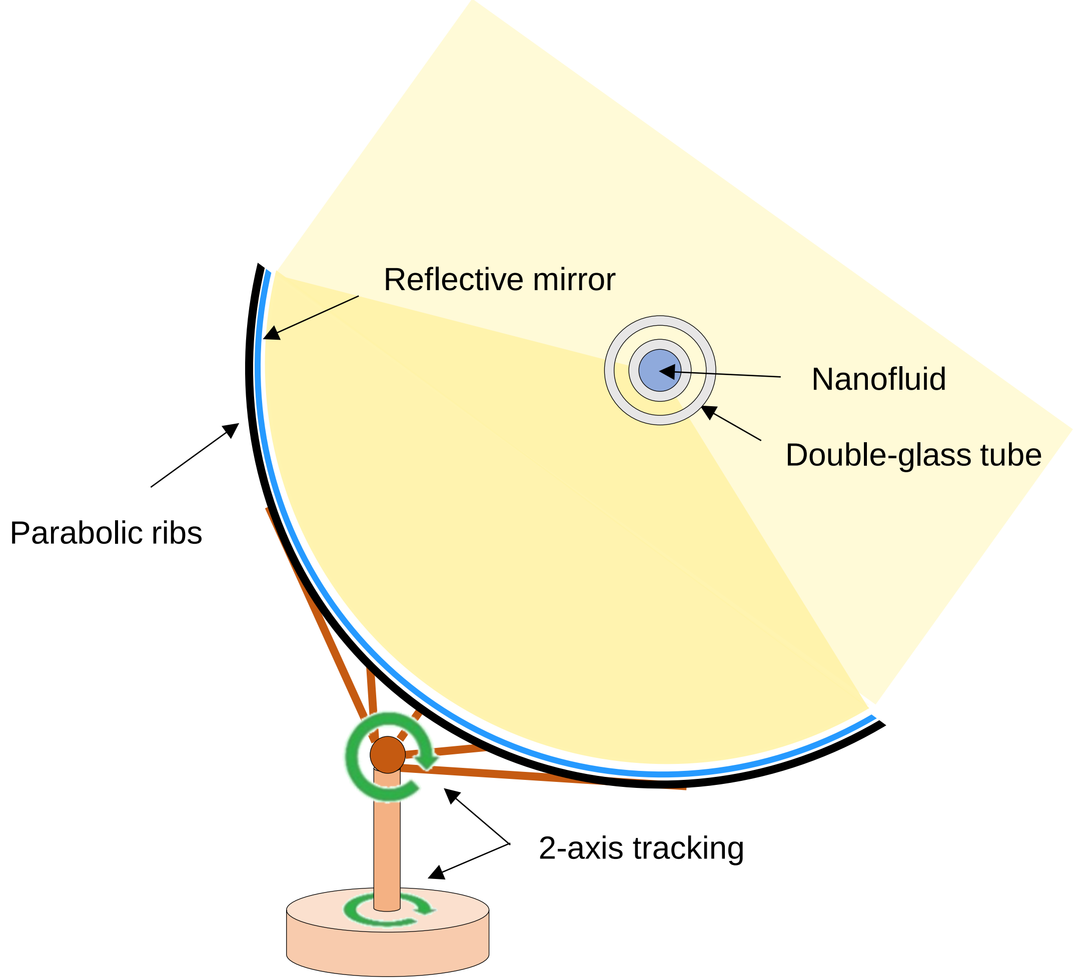
Scattering neglected ➔ **100% = T + A**

- For C = 0,1 g/l ➔ A ≥ 90% if L > 70 mm
- For **C = 0,2 g/l** ➔ **A ≥ 95%** if L ≥ 50 mm

EXPERIMENTS UNDER SOLAR CONCENTRATION



Pilot parabolic trough collector



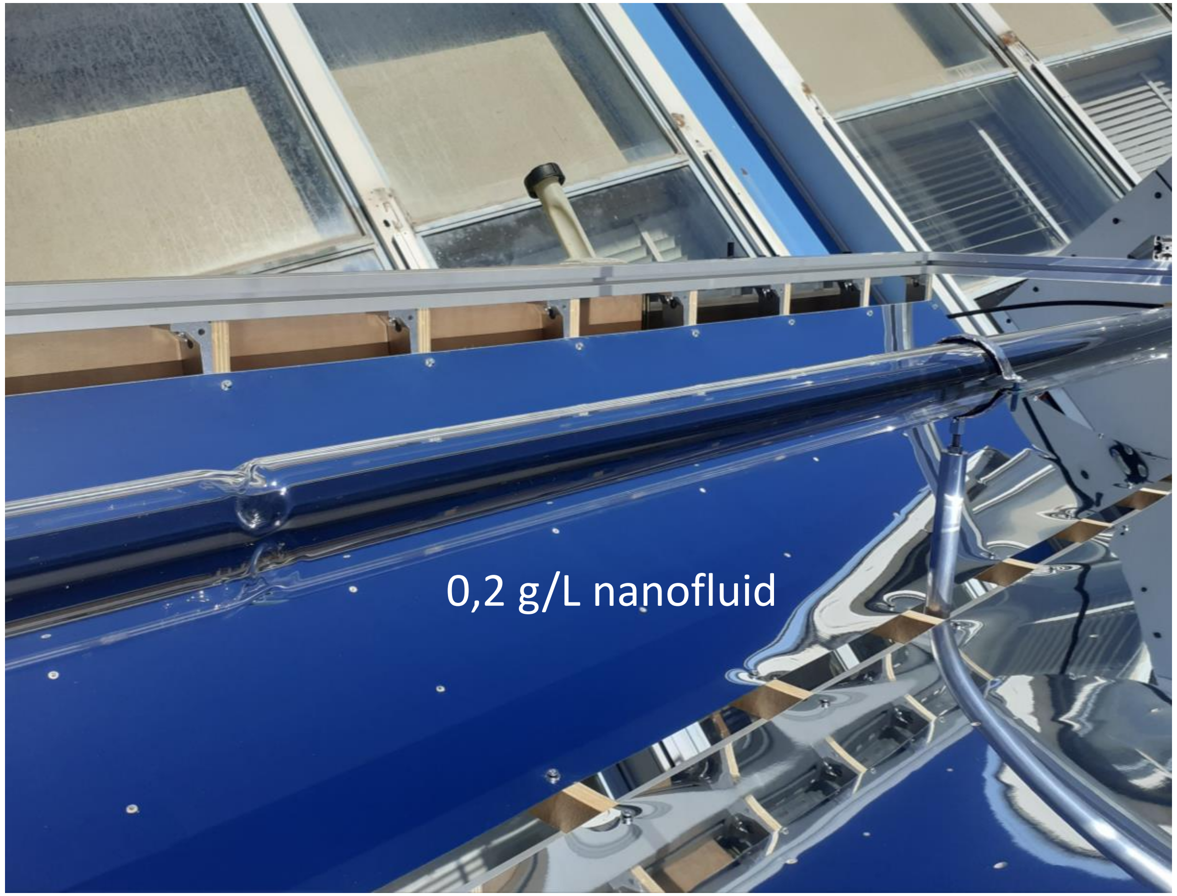
Small PT-NDASC experimental pilot

- Double-glass receiver with vacuum chamber.
- Dimensions: 28.6 concentration ratio
  - **33,6 mm inner diameter**
  - **2 m long**
- **Laminar flow**
- **0,2 g/L nanofluid → 88% absorption**
- First approach: **low temperatures** (1 atm)

PT-DASC

- Evaluate the nanofluid behavior under solar radiation
- Evaluate the performance of the collector.

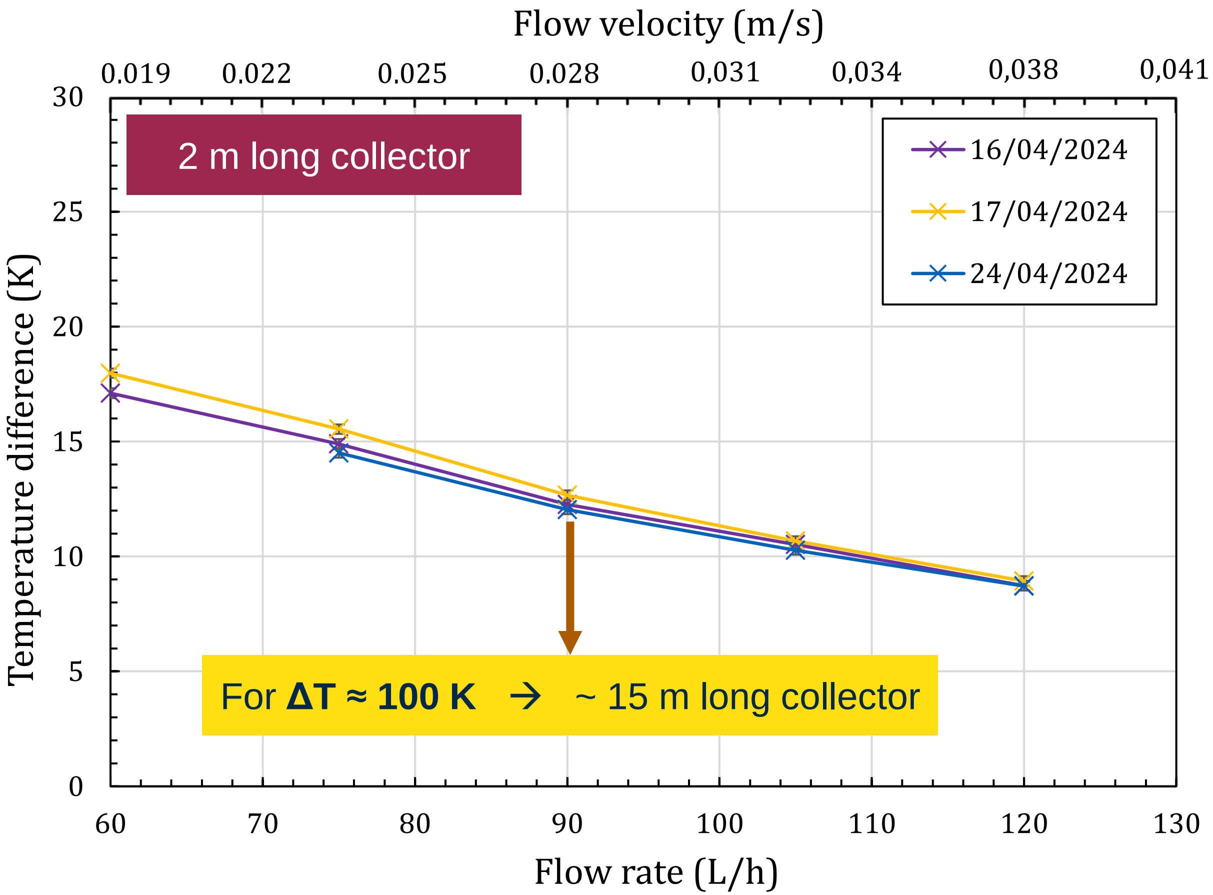
Pilot parabolic trough collector

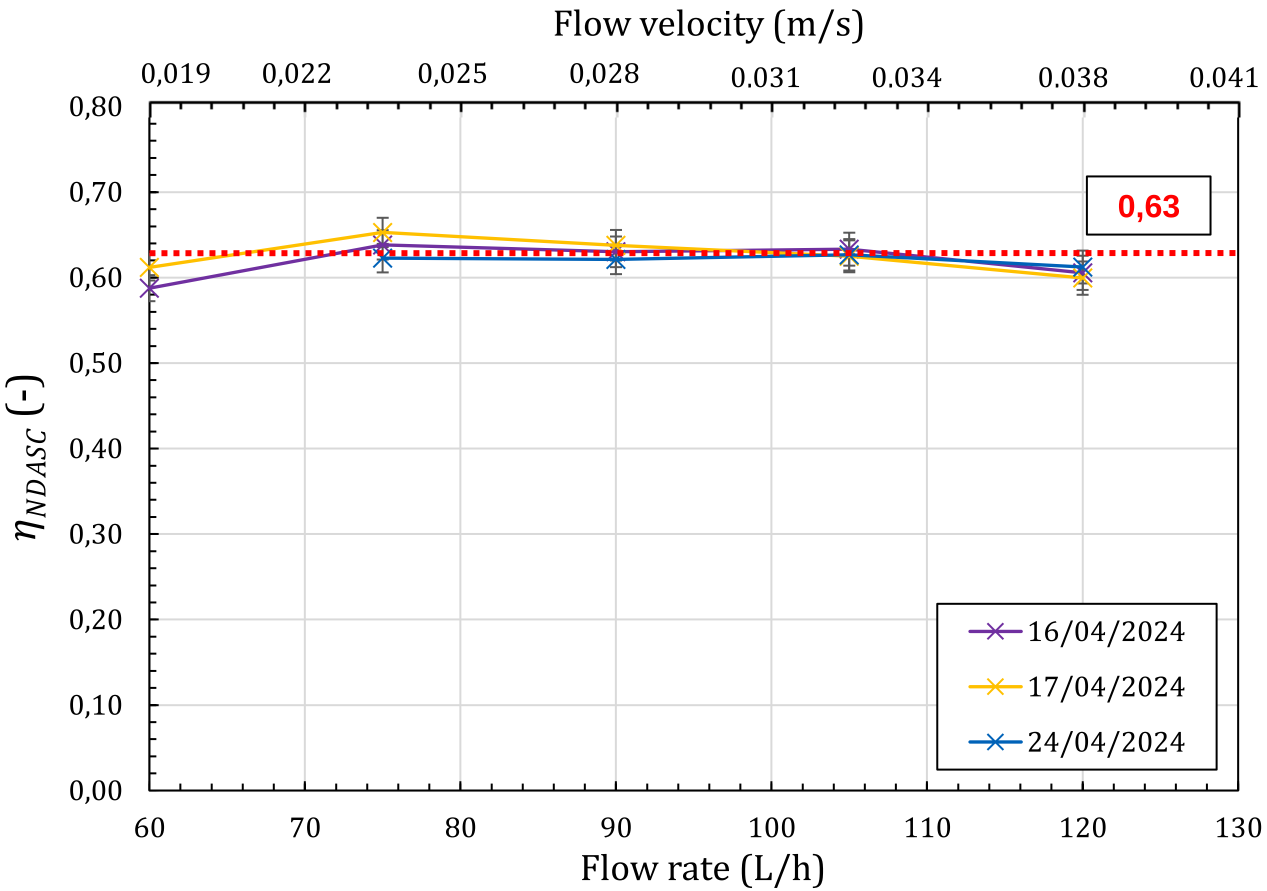


First results – Low working temperatures

$$\eta_{NDASC} = \frac{\dot{m}.Cp.(T_{out} - T_{in})}{A.G}$$

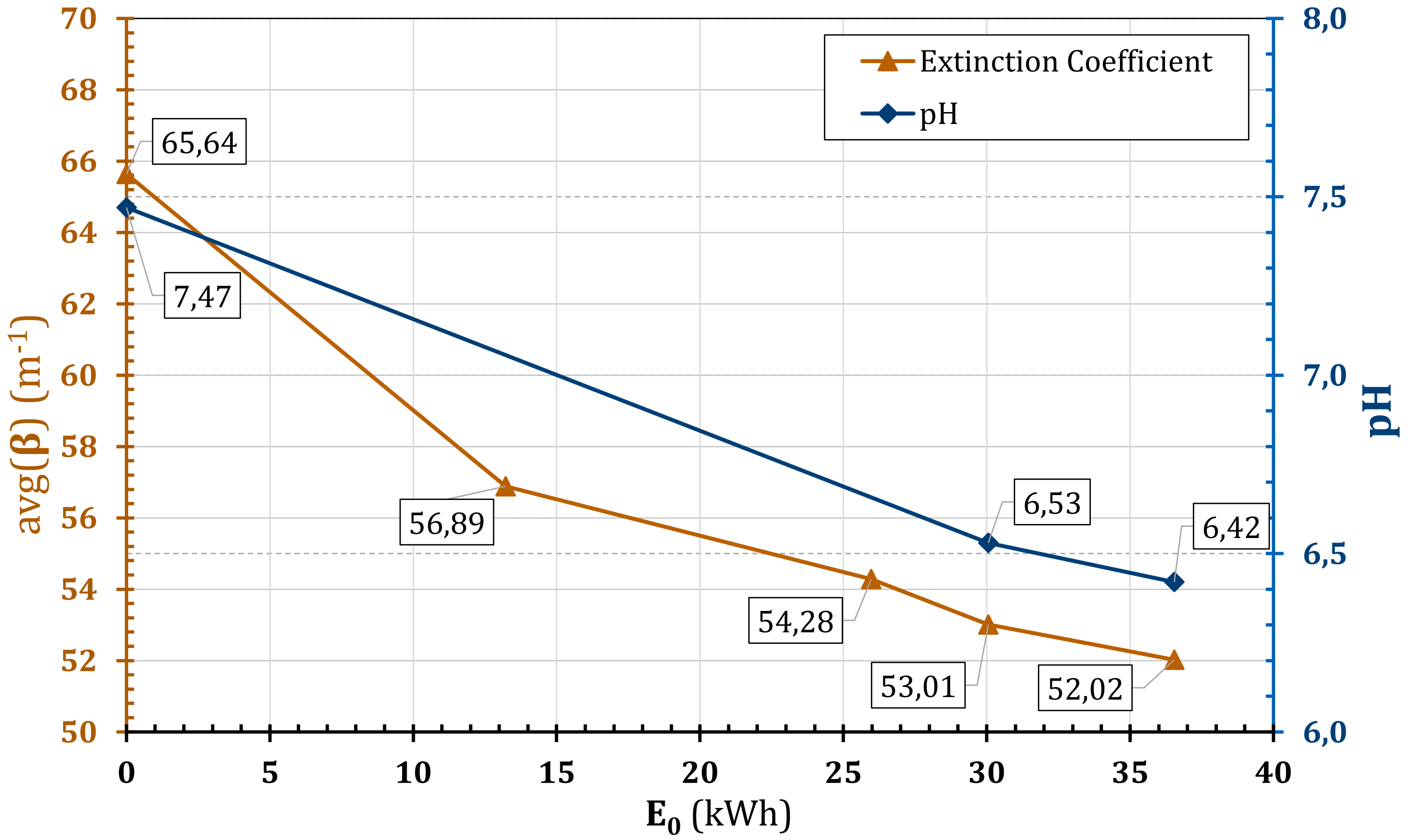
$T_{in} \in (15 - 20)\ °C$





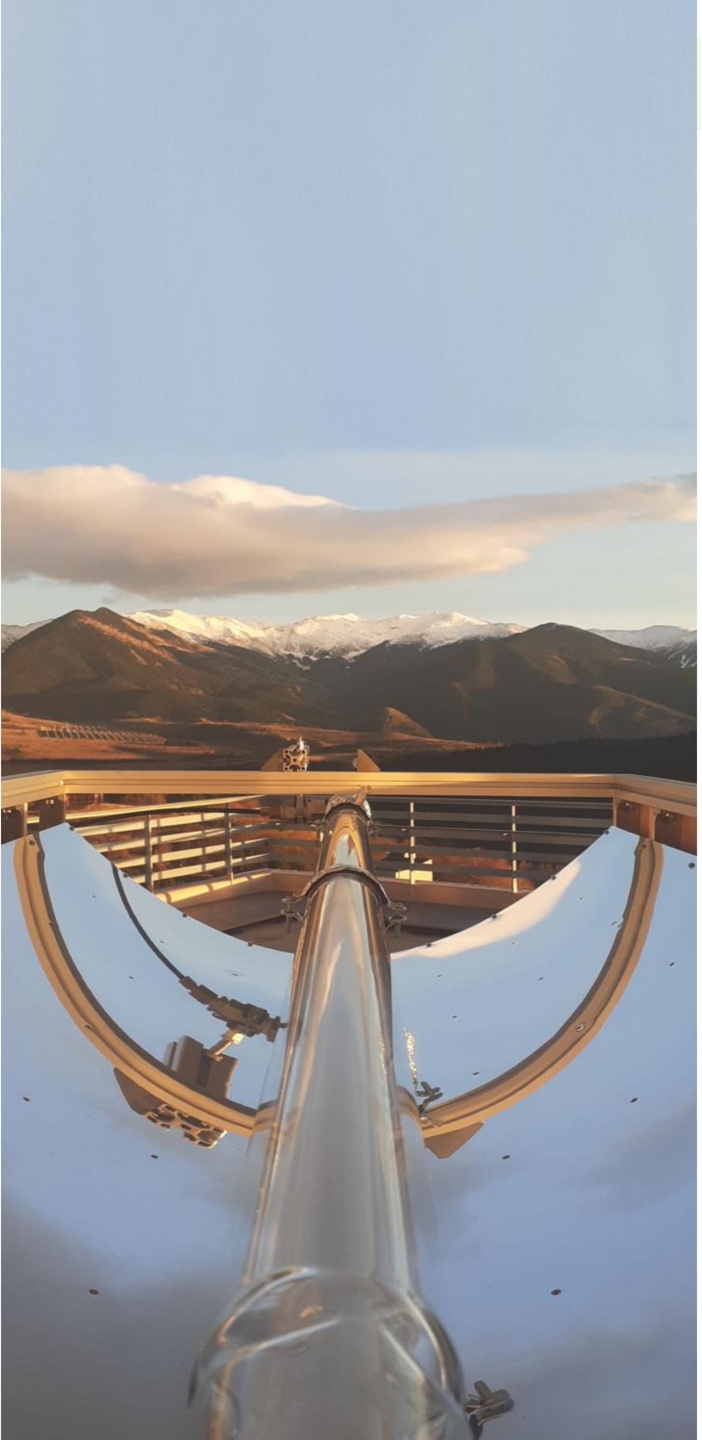
Effect of time on the nanofluid optical properties

$$E_0 = DNI \times A_{collector} \times time_{under-concentration}$$



- Extinction coefficient decreases
- pH decreases

Effects under study



Conclusion

- Graphene nanofluids potential for NDASC applications.
- Carbon Waters high optical absorption and long-term stability.
- PT-DASC experimental pilot conceive at the laboratory.
- Temperature increase of 10-18 °C for 2 m long collector.
- Drop of the extinction coefficient after experiments.

Perspectives

- Experiments with higher particle concentrations (0.3 g/L).
- High pressure & high temperatures experiments (above 100 °C).
- Evaluate the pH control for long-term stability.

THANK YOU FOR YOUR TIME

This work was supported by the French “Investments for the future” ("Investissements d'Avenir") program managed by the National Agency for Research (ANR) under contract ANR-10-LABX-22-01 (labex SOLSTICE).

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