FEM ANALYSIS OF THERMAL PROPERTIES OF AN OPTICAL GAS CELL FOR RO-VIBRATIONAL SPECTROSCOPIC GAS THERMOMETRY (RVSGT)

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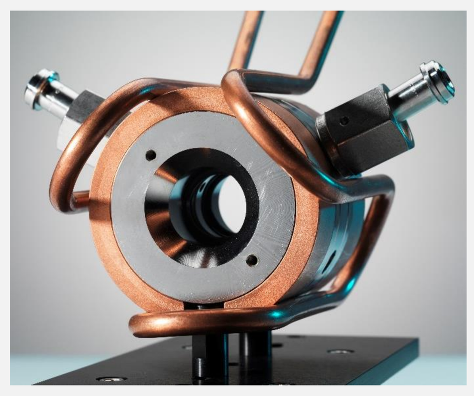
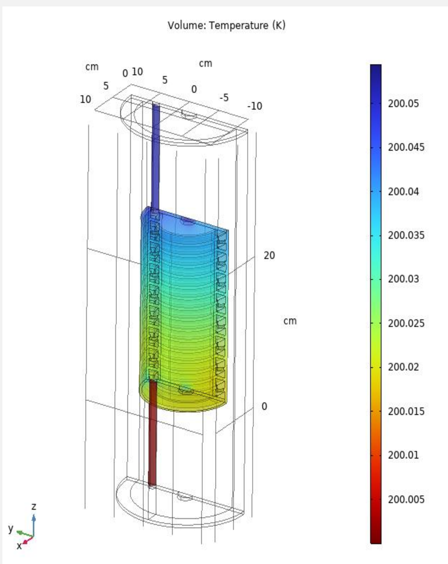
Introduction

OPTICAL GAS CELLS are used in gas analysers to determine the **amount fraction of target molecules** in a gas sample [1], **gas temperature** [2], and **isotope ratio** [3], etc. Despite the successful thermal design of laser-based Doppler thermometry [4], ro-vibrational spectroscopic gas thermometry [5] require improvement in gas cell design [6].



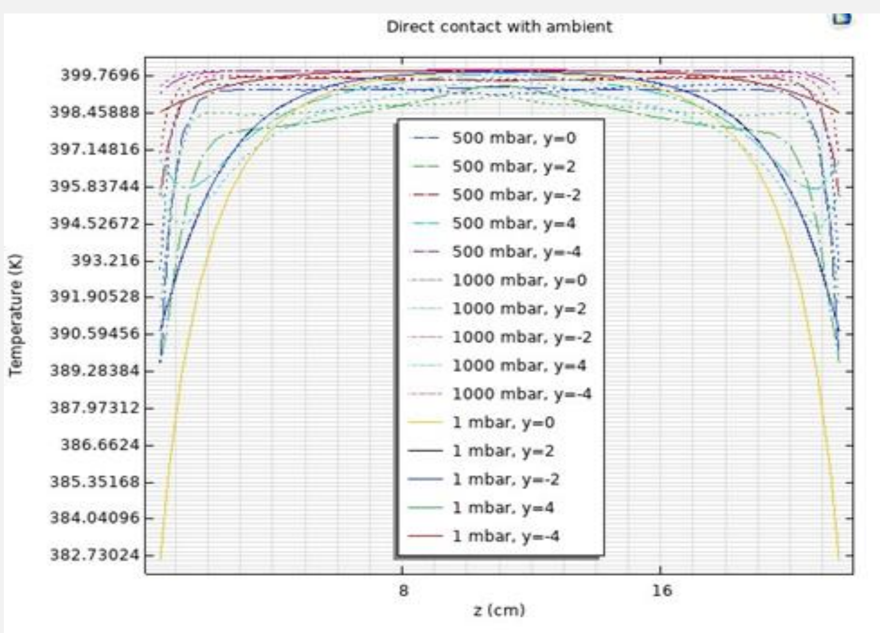


The aim of this study was to address the challenges towards an optical cell which provides an **uncertainty of 10 mK,** targeting:

- **Temperature non-uniformity** within the gas cells due to design of the optical windows, gas cell's heat treatment, the effect of pressure and flow regime inside the heat exchanger.
- **Uncertainties because of the indirect measurement** of the gas temperature.

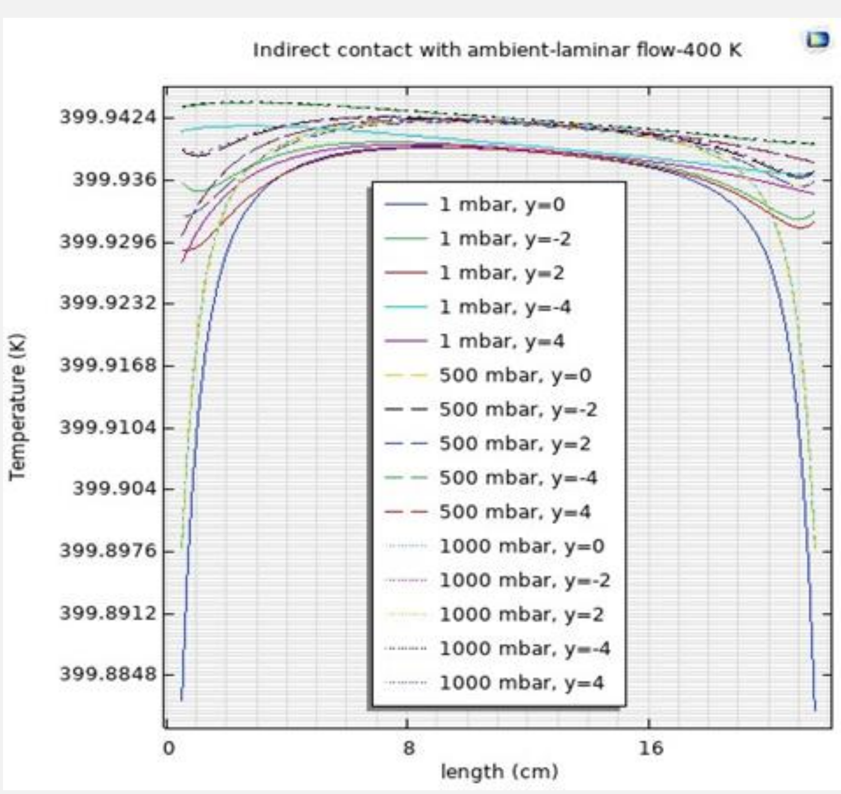
Results : Temperature gradient INSIDE the gas cell

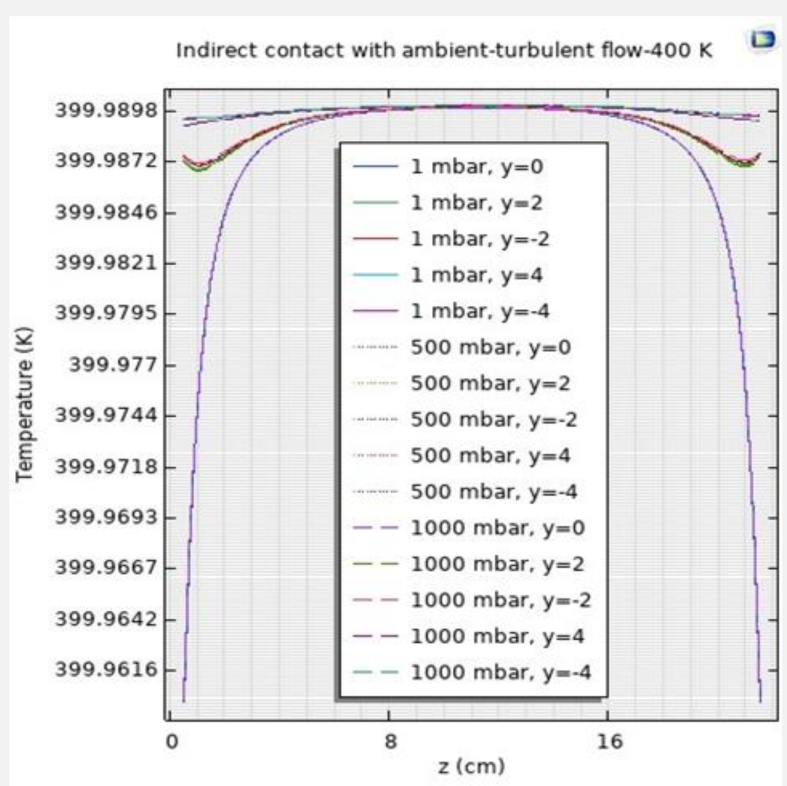
Scenario 1: optical windows are in direct contact with the ambient air.



- A temperature difference of 17 K between the area near the optical windows and the center of the gas cell along the central path (y=0) .
- Higher temperatures at higher pressures.

Scenario 2: optical windows are in direct contact with ambient air. Fluid inlet temperature 400 K.

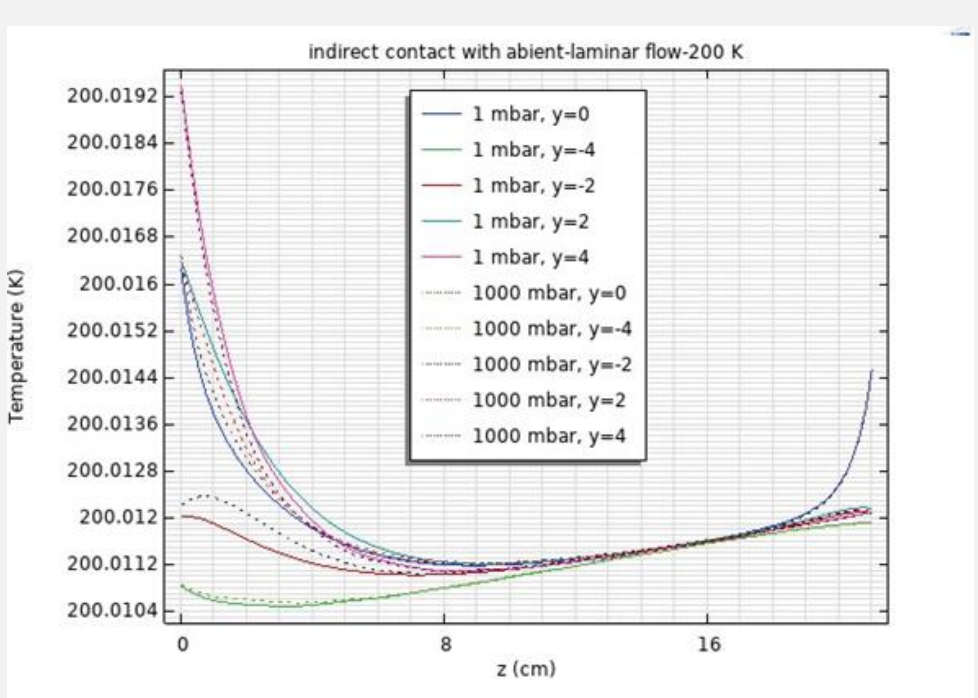


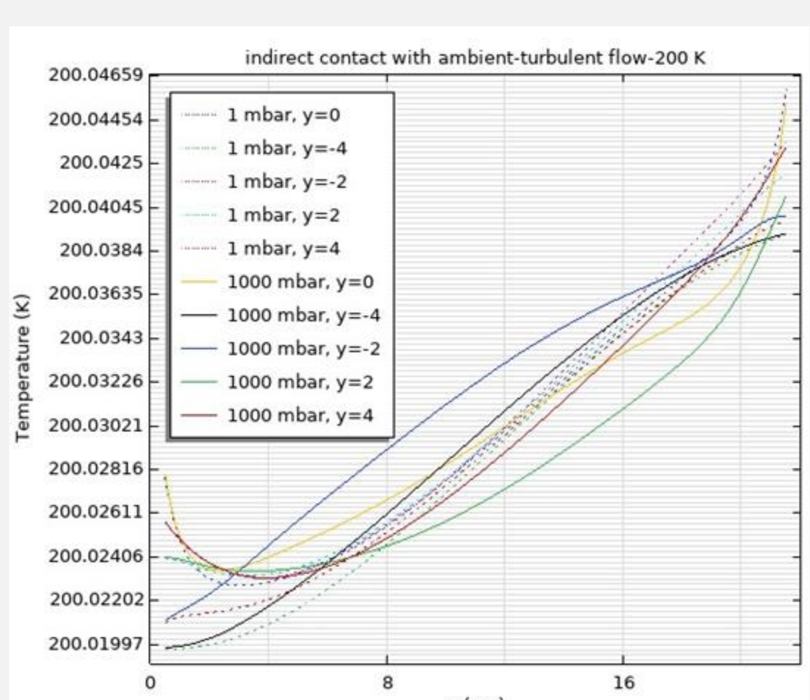


On the central line within the gas cell (y=0)

- A larger temperature gradient (30 mK) for laminar flow at 400 K and 1 mbar compared to that for turbulent flow.
- Less efficient thermal interaction compared to turbulent flow results in Lower temperature. The maximum dissimilarity is 70 mK.
- The system is more affected by gas pressure at laminar flow, causing larger non-uniformity at larger pressure.

Scenario 3: optical windows are in direct contact with the ambient air. Fluid inlet temperature 200 K.



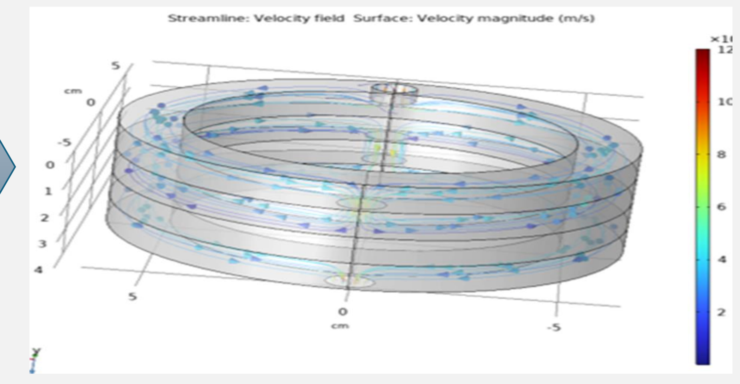


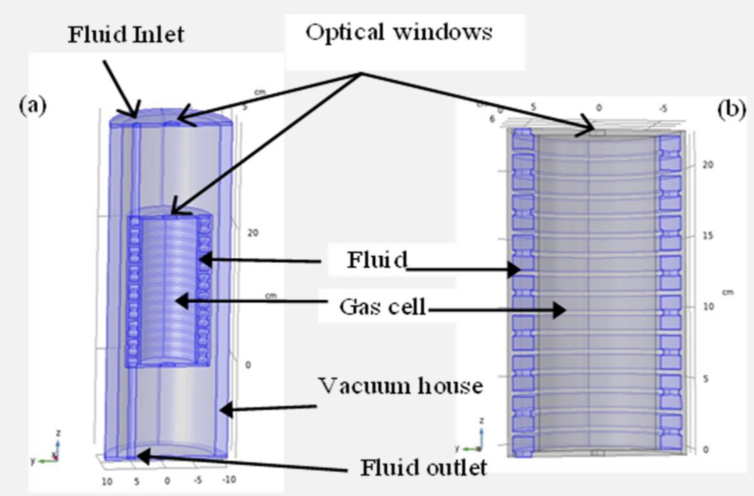
- The temperature difference between the two end of the gas cell is more pronounced compared to 400 K.
- Temperature profile escalates from the window near the heat exchanger fluid inlet towards the other side of the gas cell
- This is attributed to the viscous dissipation resulting from turbulent flow coupled with the higher dynamic viscosity of silicon oil at this temperature.

Methodology

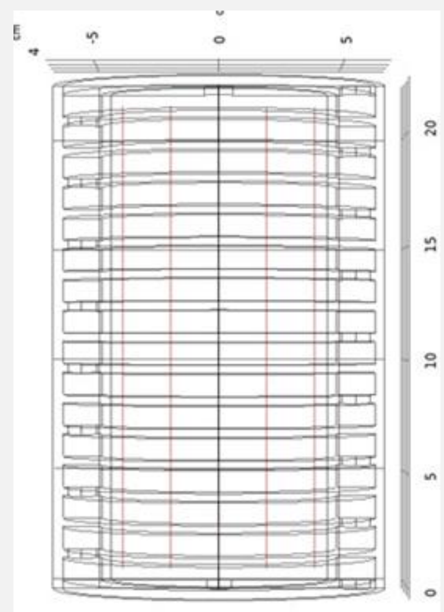
COMSOL® Multiphysics simulation software are used for our simulation analysis.

- The **heat exchanger system** containing silicon oil surrounds the gas cell.
- It adopts **labyrinth form** to facilitate heat transfer to both sides of the gas cell body simultaneously .



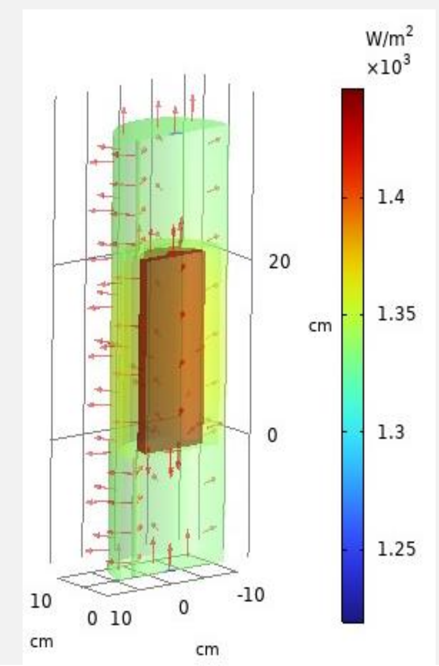


- **Optical cell** with vacuum housing. Optical windows at both sides of the gas cell are not in direct contact with the ambient condition. Heat transfer occurs by thermal radiation.
- **Optical windows** on the vacuum house are in direct contact with the ambient conditions.



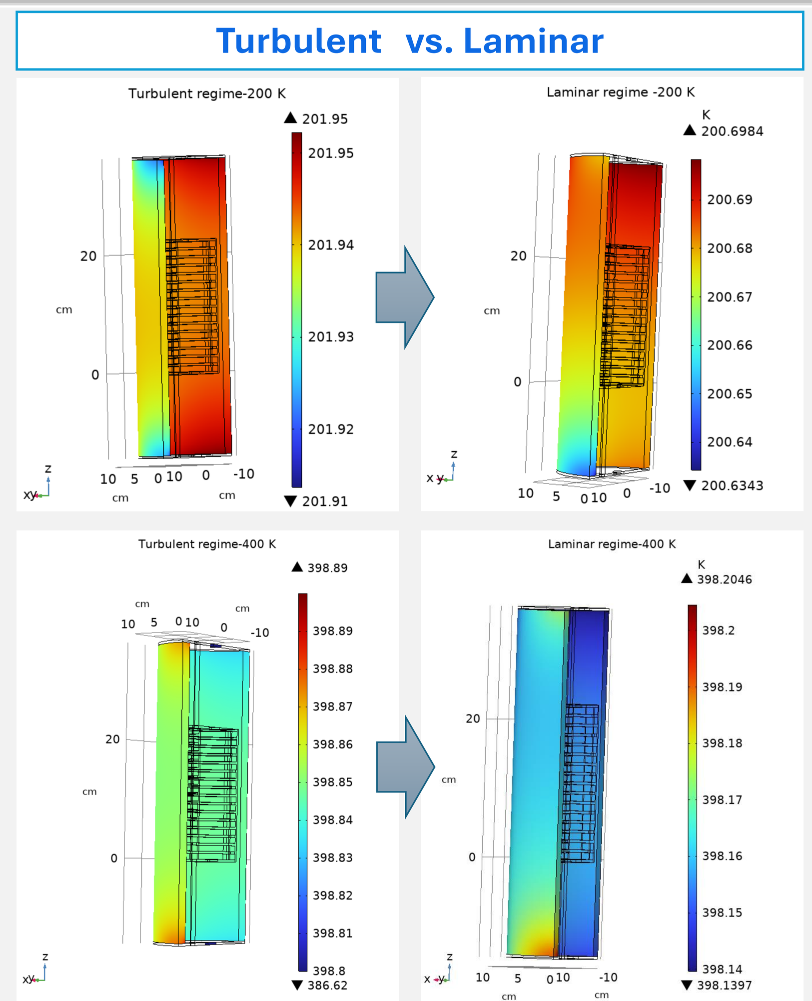
Paths for **temperature monitoring** extend from the top to the end of the gas cell and are distributed along the diameter in the y-axis direction, corresponding to gravity.

Illustration of **thermal radiation** from the gas cell to the vacuum house and optical windows



Results: Temperature OUTSIDE the gas cell

Turbulent vs. Laminar



- The **contact thermometers** are usually installed outside the gas cell, at the first body which surrounds it.
- **Non-uniform temperature** on the outer body.
- Temperature range is different from the gas.
- In the modelled system, over 1 K lower temperature than the gas cell for both flow regimes at 400 K.
- 0.35K to 0.6K difference in temperature range from the gas cell for turbulent and laminar flow at 200 K.

Conclusion

- We investigated the **parameters which affect the temperature variation** inside the gas cell. The effect of these parameters can be reduced with a careful design of the optical cells.
- The **most significant temperature inconsistency** occurs because of the areas on the gas cell body with direct contact with the ambient conditions e.g. **the optical windows**.
- The **effect of gas pressure** on the temperature variation is less than 1 mbar, but it grows in case of direct contact with the ambient conditions.
- The **heat exchanger fluid regime** can affect the temperature disparity at very low temperature. It was in the order of 20 mK at 200 K.
- The **indirect temperature measurement** outside the gas cell can decrease the accuracy of the gas temperature evaluation.

References

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