Design optimization and Calibration of a void fraction measurement capacitance sensor for LN2 flow

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Abstract ID C2Po1A-06[20]

INTRODUCTION

- Transfer of cryogenic fluids from the storage Dewar to the end applications is a daily occurrence in laboratories / industries.
- Vacuum or Super-insulated transfer lines are efficiently used for the above applications.
- Most of the time two-phase flow occurs during the transfer process.
- It is very important to measure void fraction (liquid hold up).

MOTIVATION

- Many techniques are available to measure the void fraction.
- Implementation of these techniques to cryogenic fluid flow is sometimes difficult and expensive.
- An attempt has been made to develop simple capacitance sensors for measuring the void fraction for LN2 flow.

SELECTION OF TUBE MATERIAL FOR CAPACITANCE SENSOR

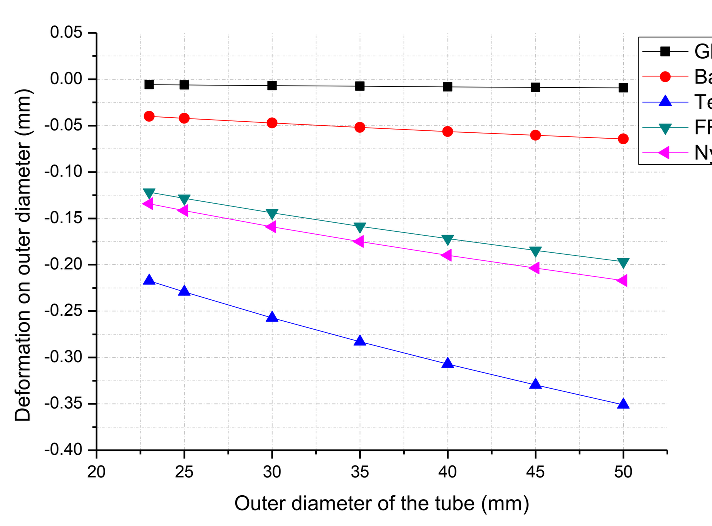

Fig. 1. Deformation on outer diameter.

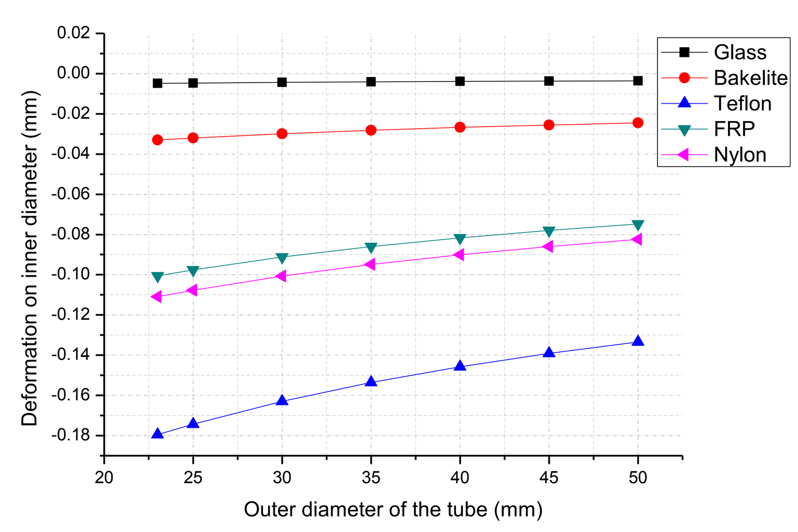

Fig. 2. Deformation on inner diameter.

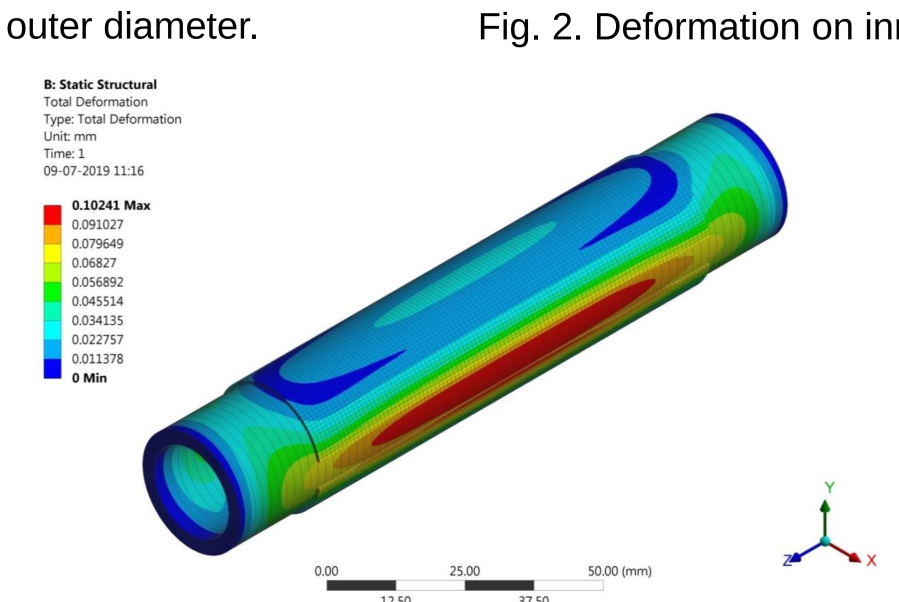

Fig. 3. Total deformation on 19 mm ID and 25 mm OD Bakelite tube.

- Glass tube deformation is minimum among other insulating tube materials. Handling and making end connections for glass tubes is quite difficult.
- Deformation of Bakelite material is next to glass and is considered for the capacitance sensor development.

MEASUREMENT OF DIELECTRIC CONSTANT OF BAKELITE

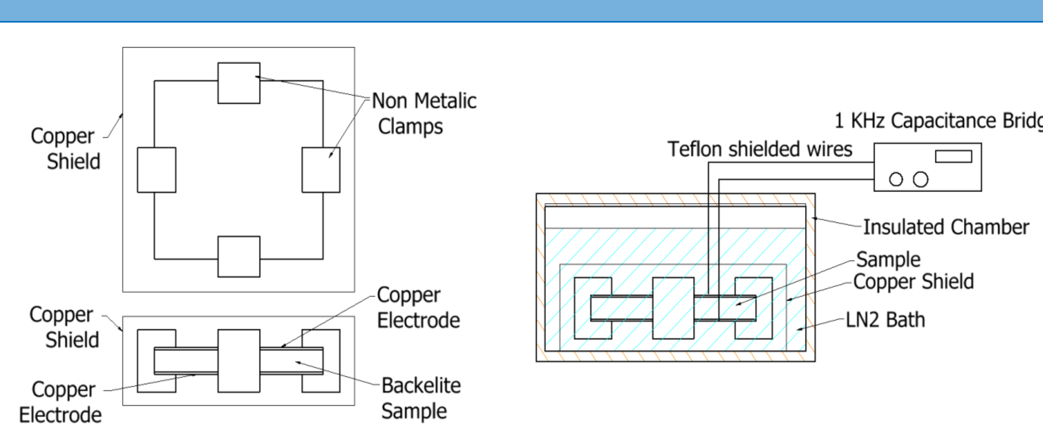

Fig. 4. (a) Sample Chamber. (b) Experimental setup.

- It is very important to measure the dielectric constant of tube material for capacitance simulation.
- The capacitance C, is defined as,

$$C = (\varepsilon_0 \times \varepsilon_r)\,(A/d) \qquad \text{.... (1)}$$

Where ε_0 = permittivity of free space = 8.84×10^{-12} F/m, ε_r = relative permittivity, A = Area of electrode in m^2 and d = distance between the electrodes in m.

Equation 1 can be written as, $C_0 = (\varepsilon_0 \times \varepsilon_r)_0\,(A/d)$ ... (2)

$$(A/d) = C_0 / (\varepsilon_0 \times \varepsilon_r)_0 \qquad \text{... (3)}$$

$$C_b = (\varepsilon_0 \times \varepsilon_r)_b\,(A/d) \qquad \text{... (4)}$$

Substitute equation 3 in equation 4 , we get $C_b = (\varepsilon_0 \times \varepsilon_r)_b\,(C_0 / (\varepsilon_0 \times \varepsilon_r)_0)$

- C_0 and C_b can found by simple experimental setup shown in Fig 4.
- Measured dielectric constant of Bakelite is 2.06 at 77 K.

DESIGN OF CAPACITANCE SENSOR

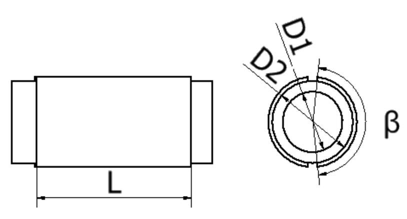

Fig. 5. Cross sectional view of a concave capacitance sensor.

Sl. No	Capacitor	D1 in mm	D2 in mm	L in mm
1	C1	19	26.2	50
2	C2	19	31.6	50
3	C3	19	38.0	50

Table 1: Capacitance sensor dimensional parameters at β = 160°

Sl. No	Capacitor	C_{max} pF	C_{min} pF	ΔC pF Experimental	ΔC pF Simulation
1	C1	5.1	4.84	0.26	0.23
2	C2	6.26	5.93	0.33	0.31
3	C3	4.17	3.99	0.18	0.16

Table 2. C_{max}, C_{min} and ΔC for developed sensors

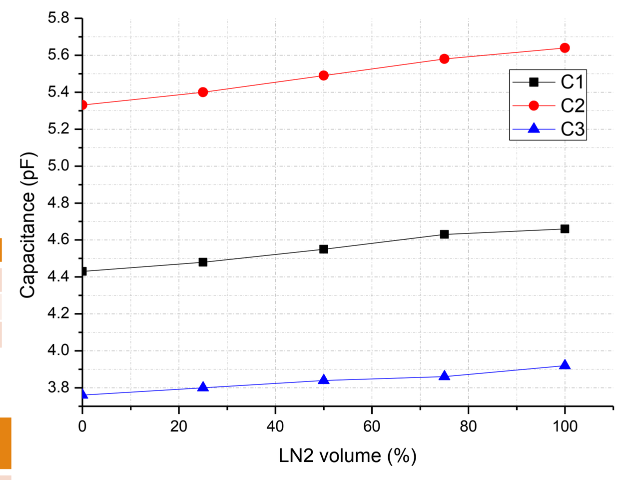

Fig. 6. Simulation results for C1, C2 and C3.

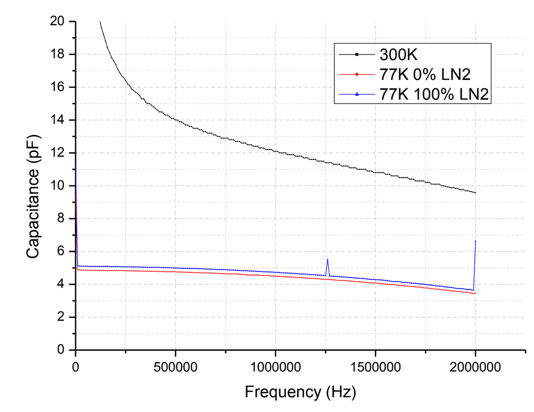

Fig. 7. Capacitance vs. Frequency for C1.

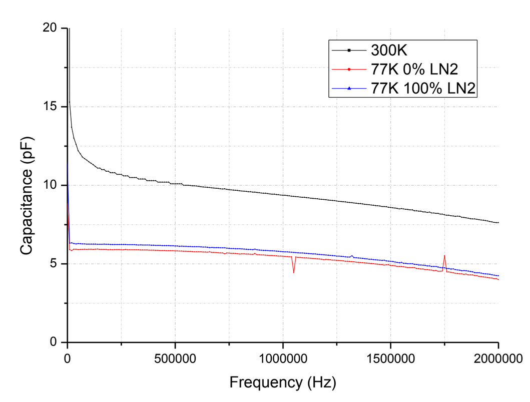

Fig. 8. Capacitance vs. Frequency for C2.

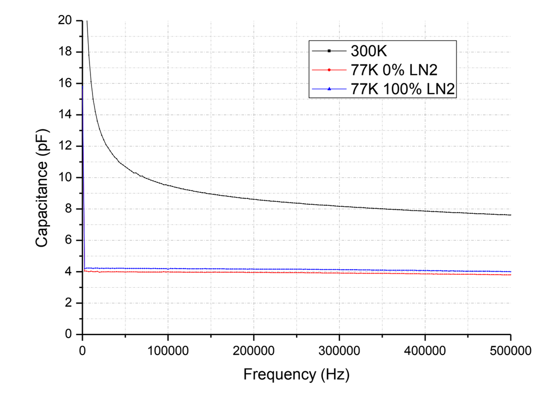

Fig. 9. Capacitance vs. Frequency for C3.

EXPT. SETUP FOR SENSOR CALIBRATION

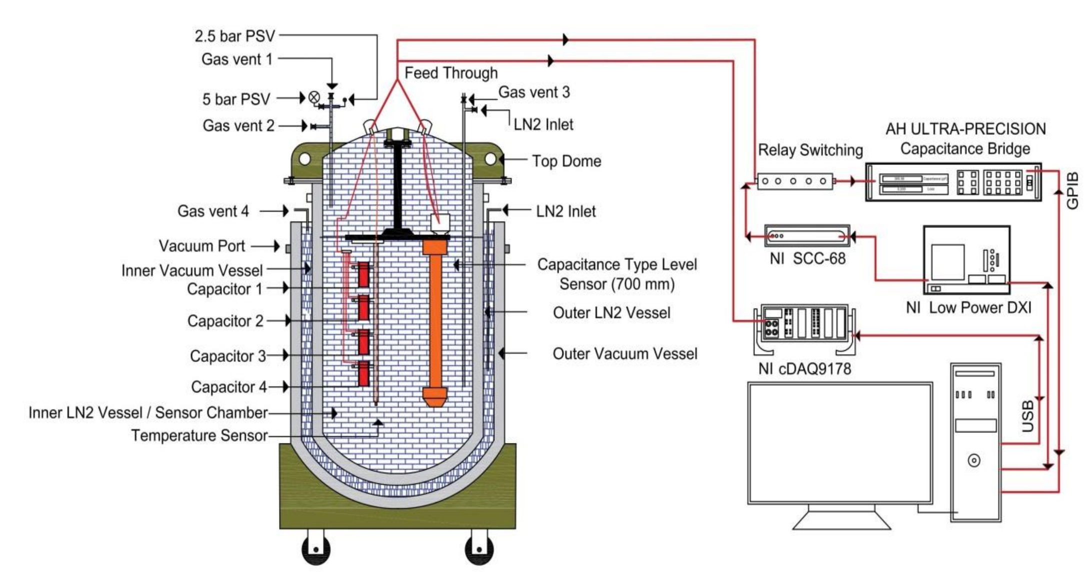

Fig.10. Schematic of Expt. Setup for calibration of Capacitance sensors.

CALIBRATION CURVE

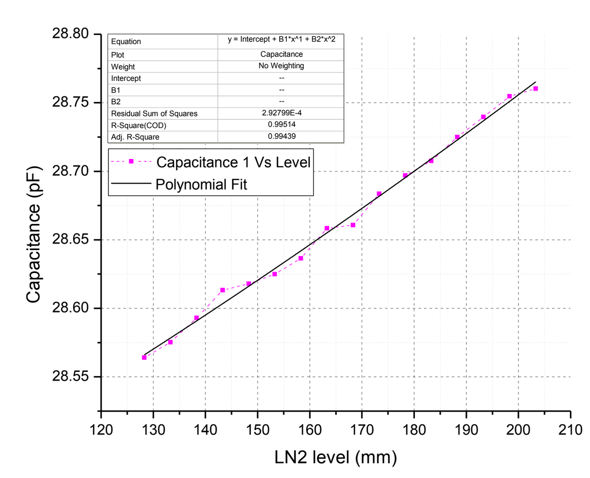

Fig .11. Calibration curve for C1.

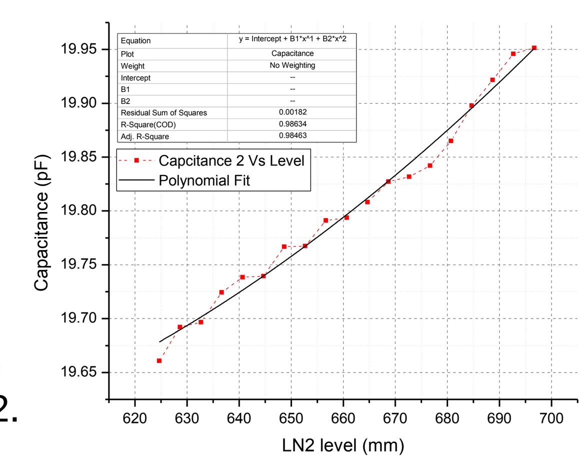

Fig. 12. Calibration curve for C2.

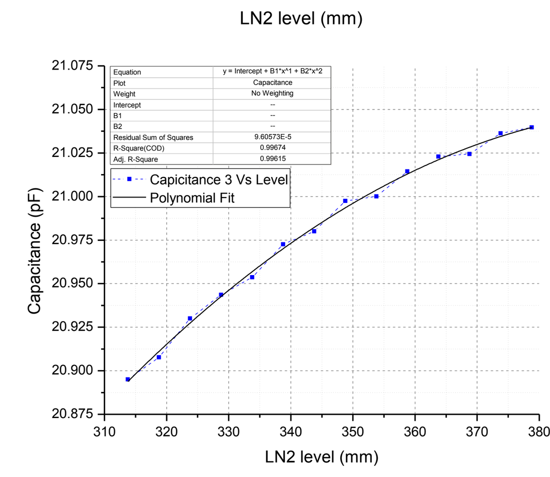

Fig.13. Calibration curve for C3.

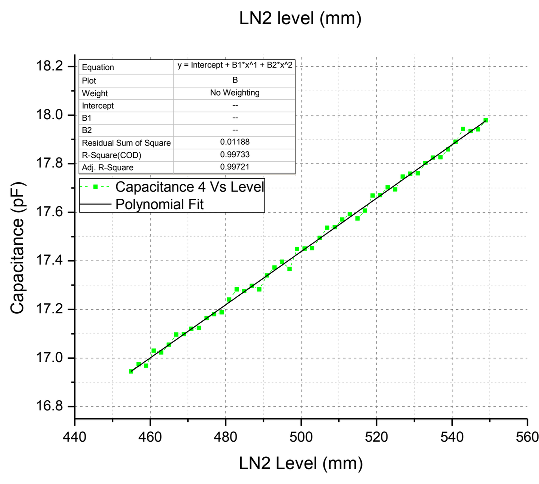

Fig. 14. Calibration curve for C4 (FRP tube).

CONCLUSIONS

- An attempt has been made to develop simple capacitance sensors for measuring the void fraction for LN2 flow.
- Thermo-structural analysis has been done for different insulating materials.
- Bakelite has been selected as the insulating materials.
- Experimental setups have been developed to measure the dielectric constant and the capacitance of the developed sensors at 77 K.
- Capacitance simulation has been done with the developed sensors by ANSYS Maxwell software and the results are in good agreement with the experimental results.
- The developed capacitance sensors are calibrated with standard sensor.
- These simple sensors will be very useful for void-fraction measurement of LN2 flow.

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ACKNOWLEDGEMENT

This work was carried at Centre for Cryogenic Technology, Indian Institute of Science, Bangalore with financial support of Board of Research in Nuclear Sciences (BRNS), India.