REAL-TIME MULTI-SENSOR IOT SYSTEM FOR POST-HARVEST FISH QUALITY MONITORING IN PCM-ASSISTED COLD-CHAIN LOGISTICS: *APPLICATION TO CAPTURE AND CULTURE FISHERIES*

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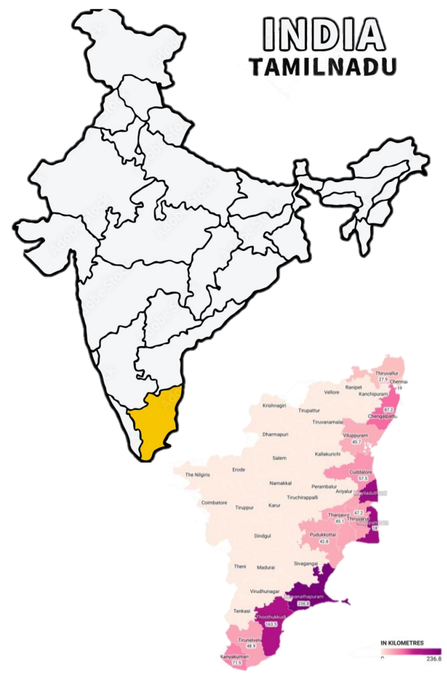
87.1% Lower energy vs vapour compression

90.9% PCM discharge efficiency

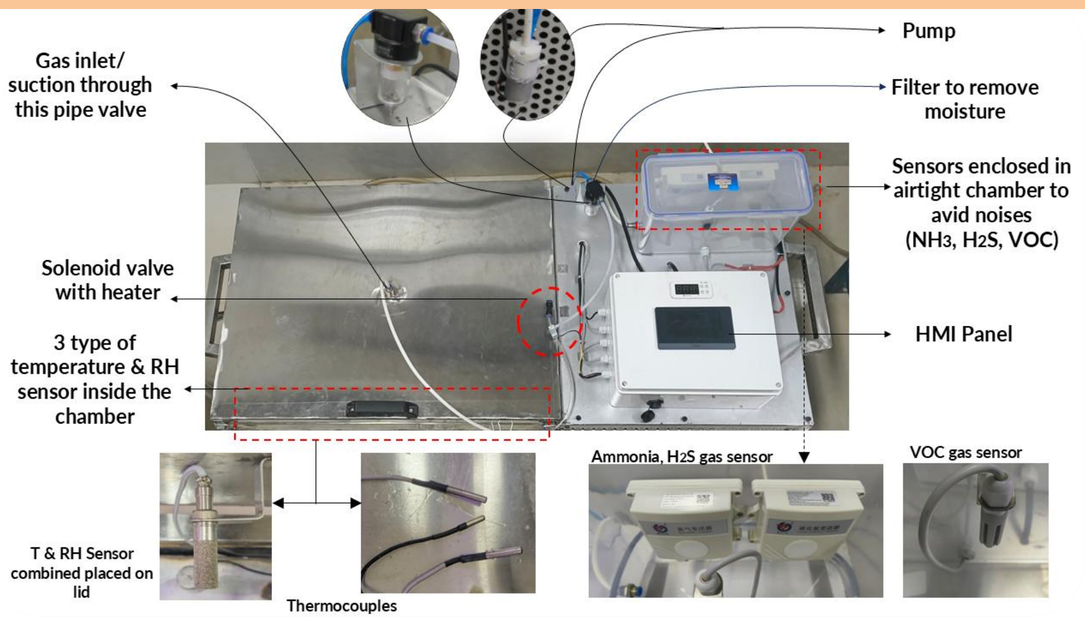
32.28 h Safe cold storage below 4 °C

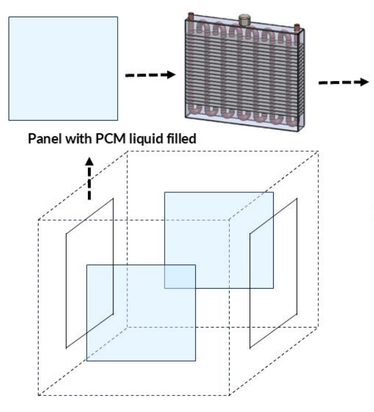
Why this study?

- Post-harvest losses in Indian fisheries reach **20-40%** of catch value. A life cycle assessment of insulated transport in the Nagapattinam district revealed that 60% of landed fish is transported by vehicles with no real-time quality monitoring, contributing 2.13 kg CO_2e per km of GHG emissions.
- Conventional spoilage indicators (TVB-N, TMA) require **4-6 h lab analysis**, far too slow for cold-chain decisions.
- This study presents the **HFPCM-STM,** a fin-enhanced PCM-integrated chamber with embedded IoT sensors designed to deliver real-time spoilage classification without laboratory equipment.

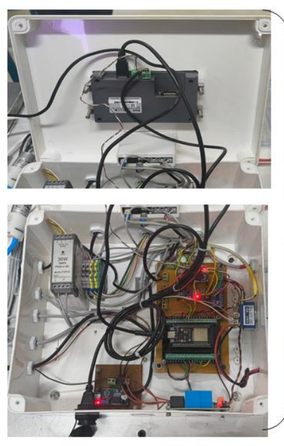


HFPCM –STM SYSTEM FABRICATION & SENSOR SPECIFICATIONS

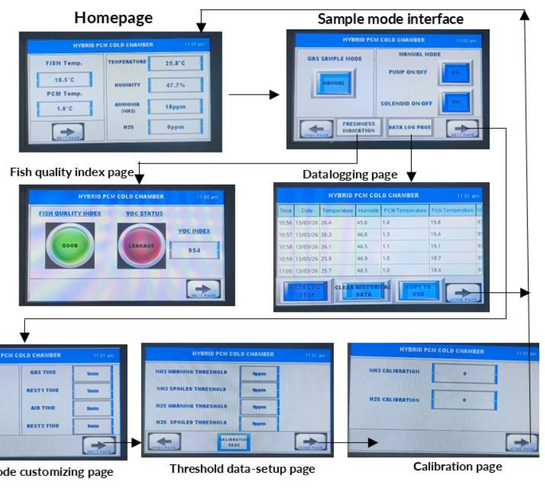




Sensor wiring setup / connectivity



Output in HMI screen



Spoilage Classification Index (SCI)

$SCI = 0.6 \times VOCnorm + 0.3 \times Tnorm + 0.1 \times NH_3norm$

Pathway	Sensor	Range
Early -lipid oxidation & amino acid metabolites	VOC · Sensirion SGP40 (MOS)	0–500 index
Mid - proteolysis by Pseudomonas spp.	NH_3 · Electrochemical RS-485	0–100 ppm
Late - anaerobic sulphur reduction	H_2S · Electrochemical RS-485	0–100 ppm
Environment	T/RH · SHT40 + DS18B20 ×2	±0.2 °C / ±1.8% RH



SCI < 0.3



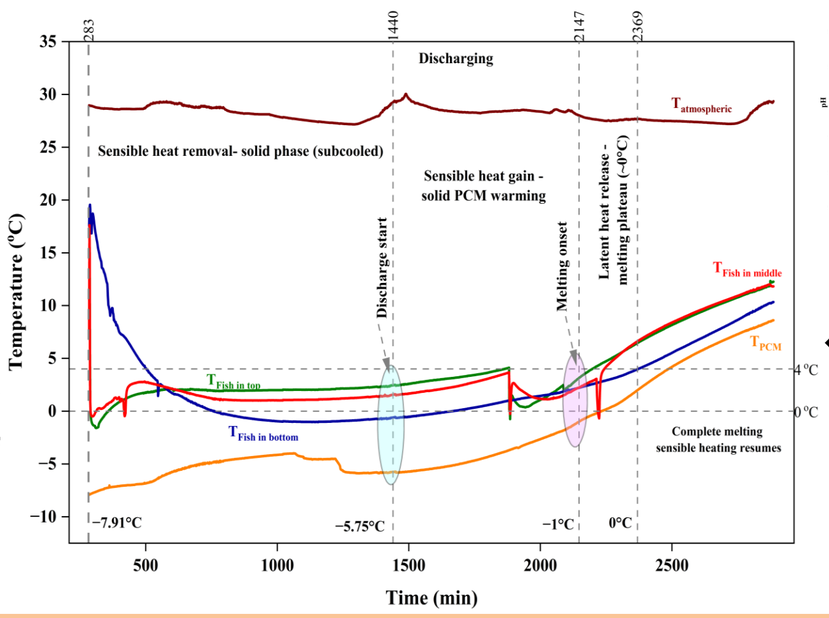
SCI = 0.3 – 0.6



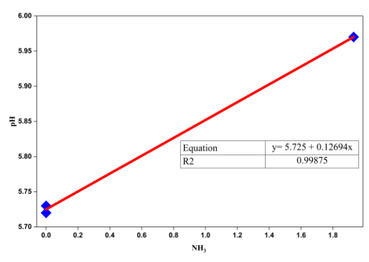
SCI > 0.6

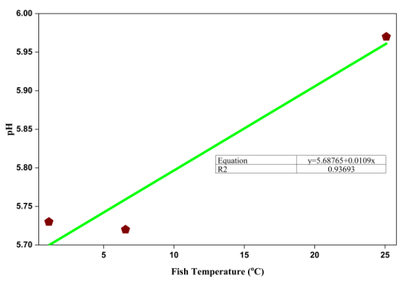
THERMAL PERFORMANCE VALIDATION

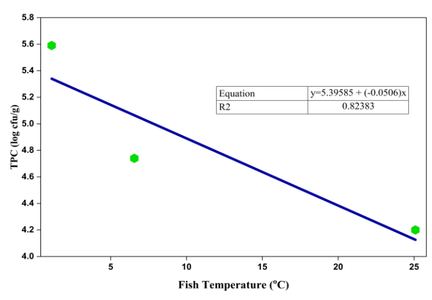
Fish core temperature pulled from 25.1 °C to below 4 °C within 4.83 h. PCM plateau maintained at -4.74 °C for 25.47 h. Safe storage (< 4 °C) sustained for 32.28 h confirmed by discharge efficiency of 90.9%.



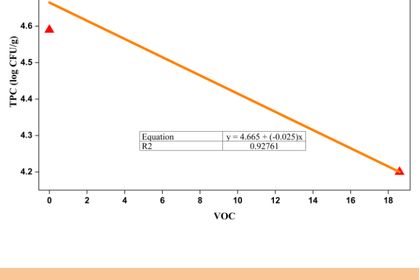
SENSOR PERFORMANCE VALIDATION





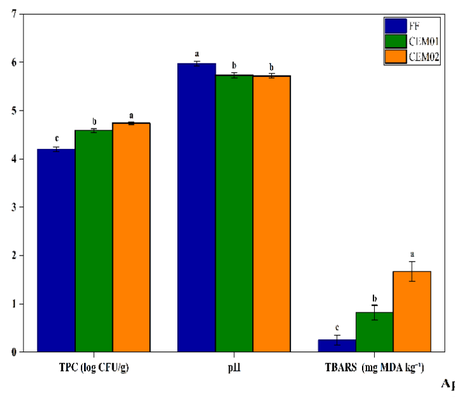


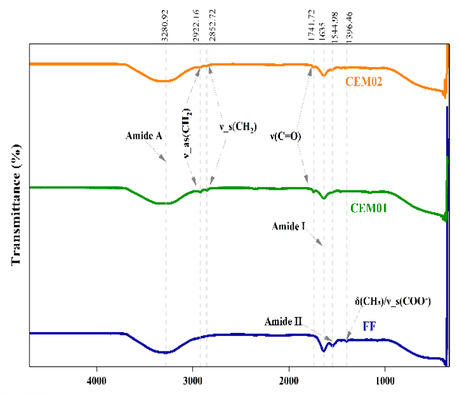
❖ **Pearson correlation between IoT sensor outputs and laboratory quality parameters at 0, 24 and 48 h. Fish temperature vs pH: r = +0.968, R^2 = 0.937. VOC index vs TPC: r = −0.963, R^2 = 0.928. All TPC values remained 2.3 log units below ICMSF rejection limit (7.0 log CFU/g).**



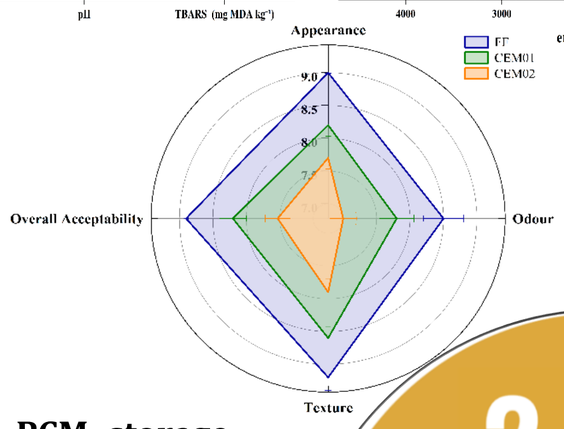
LABORATORY VALIDATION







TPC increased from 4.20 to 4.74 log CFU/g over 48 h well below the ICMSF limit of 7.0. TBARS rose from 0.25 to 1.67 mg MDA/kg below the 5.0 mg/kg rejection threshold. Sensory acceptability maintained above 7.5 throughout PCM storage.



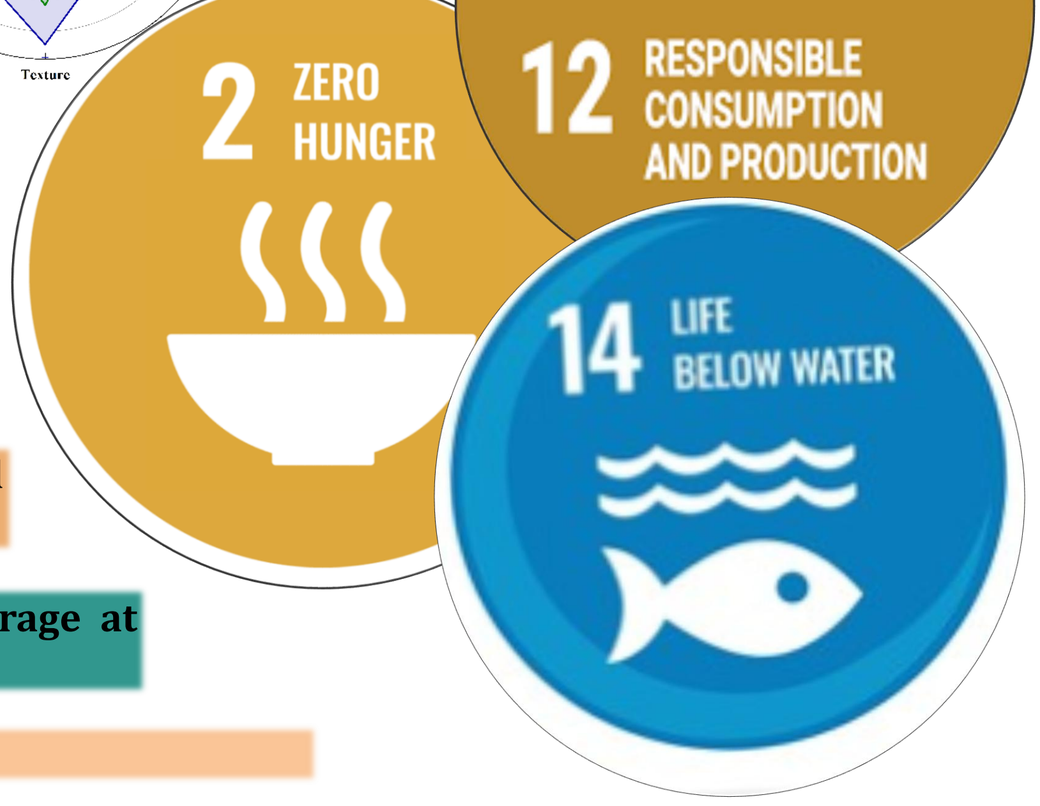
❖ **Visual freshness of *Rastrelliger kanagurta:* Fresh (FF, 0 h), 24 h PCM storage (CEM01), 48 h PCM storage (CEM02). No visible spoilage signs at 48 h under HFPCM-STM cold storage.**

❖ Amide I (1635 cm^{-1}) stable at 24 & 48 h, protein structure preserved. Minor lipid carbonyl shift (1741 cm^{-1}, ΔT = 2.94%) at 48 h only below sensory rejection threshold.

❖ **A first-of-its-kind analytically designed, 77.3% lower GHG emissions** vs diesel reefer transport PCM passive cooling eliminates continuous refrigerant use.

❖ **IoT-integrated PCM cold-chain system delivering 32.28 h safe fish storage at 90.9% discharge efficiency, validated against TPC, FTIR.**

❖ **Scalable for coastal fisheries logistics across tropical emerging economies.**



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