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*A yearly journal devoted to
Cryogenics, Superconductivity and Low Temperature Physics*



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EDITORIAL

We are pleased to announce the publication of Volume 25 (2025) of the *Indian Journal of Cryogenics (IJC)*, which also marks the successful clearance of the pending backlog. It is a matter of great pride that the journal celebrates its 50th year since its inception in 1975. The backlog arose primarily due to the disruptions caused by the COVID-19 pandemic and the subsequent transition period of the ICC office, which operated without adequate support staff. Despite these challenges and delays, we did not compromise on the quality of the manuscripts accepted for publication. Each paper underwent rigorous peer review by two independent reviewers, and we continue to adhere strictly to this process to uphold the academic standards of IJC.

Since its establishment in 1975, the journal has greatly benefited from the dedicated efforts of our esteemed reviewers, who generously contribute their time and expertise despite demanding professional commitments. We express our sincere gratitude to all of them. We particularly encourage submissions that highlight in-house development of components in the fields of cryogenics and superconductivity, especially those based on innovative concepts. This volume includes several contributions aligned with this vision.

The papers published in this volume cover a broad spectrum of topics, including cryogenics for quantum computing and medical, cryocooler, space cryogenics, heat transfer, High Temperature Superconductors (HTS) for power application and plasma.

We extend our sincere appreciation to the members of the IJC Editorial Advisory Board for their continued guidance and support. A revision of the Editorial Board has been planned prior to the publication of the next volume (Volume 51). For Volume 50, we were supported by two Guest Editors from the Inter-University Accelerator Centre, New Delhi, who assisted in expediting the publication process. We also convey our special thanks to Dr. R. G. Sharma, President (ICC), for his encouragement and support in bringing out this volume.

Finally, we thank all contributors for choosing IJC as a platform to publish their research and development work and express our gratitude to the journal's readership for their continued support. The Editorial Board also gratefully acknowledges the support of the Science and Engineering Research Board (DST) for its assistance in the publication of IJC.

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Design and Analysis of Continuous Heat Exchanger for Dilution Refrigerators

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We present the tentative design and numerical analysis of a compact footprint (diameter < 5 cm and length < 10 cm) continuous tube-in-tube heat exchanger (TTHx) operating at sub-K temperatures for dilution refrigerators with a base temperature of 10 mK and cooling power of 10 μ W or higher at 20 mK. A 70/30 Cu-Ni alloy is used for inner and outer tube construction and then wound spirally. We include the effect of Kapitza resistance, viscous heating due to impedance, and axial and radial conduction. We find that the axial conductivity of both outgoing dilute and incoming concentrated streams has a significant effect on the temperature profile along the length of the TTHx. Radial conduction uniformly distributes the boundary heat flux from Kapitza resistance and leads to a uniform temperature in the entire cross-section of dilute and concentrated streams. Our analysis shows that by keeping the inlet stream thermalized with the Still, i.e., the temperature of 700 mK, and flow rate below 200 μ mol/sec, the no-load outlet temperature of the concentrated stream can be kept below 100 mK at the exit of TTHx, which is necessary to reach the no-load temperature of 30 mK or below using copper or silver sintered heat exchanger and 10 mK in the mixing chamber. Moreover, by performing explicit calculations with or without viscous heating, we find viscous effects to be negligible in the operating temperature range of TTHx.

Key words: Dilution refrigerator, Continuous heat exchanger, Cryogenic heat exchanger, Sub-kelvin

Prospects for improving the technology readiness level of cryogenic carbon capture

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Carbon capture, utilization, sequestration, storage and transport (CCUSST) has been adopted to mitigate climate change caused by global warming. Cryogenic carbon capture (CCC) has been shown to give high CO₂ recovery rate, without any additives, and moreover, it can achieve both capture and sequestration of CO₂. CCC has been found to be the most economical in handling feed gas with high CO₂ concentration (>80%). However, there is a general reservation regarding the cost of adapting CCC since the process involves refrigeration for CO₂ separation. To overcome this reluctance towards adaptation of CCC, we need to benchmark this method against the popular and mature non-CCC techniques. In this work, we have reviewed different CC techniques with their technology readiness level (TRL) to assess the factors that impedes their commercial acceptance. We have analyzed the challenges of implementing CCC in light of the cost of capture, technological challenges, and policies.

Key words: Carbon capture, utilization, sequestration, storage and transport, Cryogenic carbon capture, Technology readiness level, Sustainable development, Emission control

SQUID-Based Magnetocardiography (MCG): a noninvasive tool to study cardiac activity

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Superconducting Quantum Interference Devices (SQUID) are known for their unmatched sensitivity in measuring extremely weak magnetic fields. The technique of measuring the weak magnetic fields (50-100 pico Tesla) generated by the electrical activity of the heart is magnetocardiography (MCG). This completely noninvasive and non-contact technique is known to offer diagnostic information that complements the conventional ECG. This paper highlights the capabilities of the first Magnetocardiography (MCG) facility established in the country at the Materials Science Group, Indira Gandhi Centre for Atomic Research (IGCAR), Kalpakkam. The utility of MCG in clinical cardiology is demonstrated through case studies conducted in collaboration with hospitals, focusing on subjects with cardiac anomalies. Furthermore, the study investigates the operational feasibility of the MCG setup in unshielded environments, specifically targeting hospital-based applications. Additionally, the potential for deploying cost-effective, home-built SQUID electronics is assessed by utilizing readily available electronic components, emphasizing their viability for broader clinical adoption.

Key words: SQUID sensor, Biomagnetism, Magnetocardiography (MCG)

Design, Development and Testing of an HTS Pole Coil for 1 kW Superconducting Synchronous Generator

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This work presents the comprehensive design, development, and testing of an HTS pole coil for 1 kW, 3 phase, 4 pole, and 120 V partially superconducting synchronous generator employing high-temperature superconducting (HTS) coils in the rotor. The generator is designed to operate in liquid nitrogen. Electromagnetic analysis was carried out to validate the design parameters. An HTS pole coil was fabricated and tested up to its critical current.

The development of pole coil demonstrates stable superconducting performance and effective magnetic field generation. The developed prototype demonstrates and establishes the feasibility of integrating HTS pole coil in compact HTS electrical machines for future strategic applications.

Key words: HTS, Pole Coil, COMSOL, Critical Current

Superfluid Helium Cryoplant “SHP20”: Development and Initial Experiments

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The SHP20, a 2 K superfluid helium cryoplant, was developed to test various cryogenic components of superconducting radiofrequency (SCRF)-based linear accelerators. Critical components of the 2 K coldbox include a 4.5 K saturated liquid helium (LHe) bath, a 2 K saturated LHe bath, a plate-fin type Joule-Thomson (JT) heat exchanger (HEX), bellow-sealed cryogenic control valves, and a liquid nitrogen (LN2)-cooled thermal shield. The developed SHP20 is integrated with the indigenous helium liquefier “LHP50”, and its cryogenic performance was tested during round-the-clock operation. Sub-atmospheric helium is compressed using a vacuum pump. The multiple switching operations between the 4.5 K standby mode and the 2 K mode were tested. The measured static heat load to the 2 K LHe bath is approximately 0.5 W. The current article briefly describes the development of the SHP20 coldbox and its components, and presents the initial test results.

Key words: Cryoplant, SHP20, JT HEX

Mixed Refrigerant Joule-Thomson (MRJT) cryocooler for medical applications

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Mixed Refrigerant Joule-Thomson (MRJT) cryocooler have shown great potential for cooling temperature above 80 K after the introduction of refrigerant mixtures in JT cryocoolers. These make them suitable for various medical cooling applications, where biological samples are to be stored below -80 °C. MRJT cryocoolers use conventional refrigeration and air conditioning components and have no moving parts at the cold end making them simple compared to other cryocoolers. At temperature above 150 K, MRJT cryocoolers are a great alternative to Stirling and Pulse Tube cryocooler due to their simplicity and cost effectiveness. In the present work, keeping in mind the medical industry, MRJT cryocooler for -100 °C and -130 °C applications are developed. The working fluid is a refrigerant mixture consisting of common hydrocarbons in an optimized proportion. Based on the studies, it is found that a no load temperatures of -110 °C and -133 °C are obtained using two different refrigerant mixtures, Mix 1 and Mix 2. In addition to this, cooling effect of 50 W is obtained at -100 °C and -130 °C using refrigerants Mix 1 and Mix 2 respectively. Furthermore, by increasing the charging pressure of Mix 1, no load temperature reduced to -120 °C while 50 W of cooling effect was obtained at -107 °C.

Key words: Precooled MRJT cryocoolers, Two-stage cryocoolers. LV phase separators

Theoretical and Experimental Investigation of Stirling type Pulse Tube Cryocooler with a Cold Phase Shifter

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In multistage pulse tube cryocooler (PTC) double-inlet valve offers an effective phase shift. However, it may generate a DC flow leading to an unsteady cooling performance. To overcome this, a gas coupled two-stage Stirling-type pulse tube cryocooler with an inertance tube has been designed and developed. The hot end heat exchanger, the inertance tube and the reservoir for the second stage, is precooled by the cold end of a separate single stage PTC. The effect of the inertance tube length, the pulse tube volume, the reservoir volume and the hot end temperature on the performance of the second stage of the two-stage PTC is investigated using Sage software and validated experimentally. A lowest temperature of 31.5 K is obtained with an input electric power of 200 W at 68 Hz. The experimental results are compared with theoretical results obtained by the Sage and are found in good approximations.

Key words: Pulse Tube Cryocooler, Cold Phase Shifter, Inertance Tube, Multi stage

Development of HTS Current Lead for Cryo-Cooler Based Superconducting Magnet

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High Temperature Superconductor (HTS) based current lead is an essential requirement to minimize the conduction heat load to the cryo-cooler cooled superconducting magnet. A HTS current lead consist of normal conducting part, made of ETP copper transferring current from 300 K to 45 K and the other part made of high temperature superconductor for current transfer from 45K to 4.2 K has been developed and tested. This current lead can carry maximum 300 A of current with minimum heat transfer to 4.2 K stage. This paper present the design of current leads, main fabrication steps and test results.

Key words: HTS, Current lead, Cryo-cooler, Superconducting Magnet

Separation and Storage of Carbon Dioxide from Various Mixtures by Using a Cryogenic Approach

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In this study, a thermodynamic analysis using computer programming was conducted to investigate the separation process and the quantity and quality of CO₂ produced by the cryogenic approach. Correlations are developed based on heat transfer fundamentals to predict performance parameters and desired quantities. The effects of temperature, pressure, and the amount of cryogenic fluid required for CO₂ separation, particularly in a CO₂-containing mixture, are investigated. For analysis, pure CO₂, 20%CO₂– 80%CH₄, 30%CO₂–70%CH₄, 40%CO₂–60%CH₄, and 50%CO₂–50%CH₄ combinations are considered. The mass of liquid nitrogen (as a cryogenic fluid) is considered to be in the range of 1 kg to 100 Kg. It is observed that the mass of solid CO₂ can be produced by direct sublimation by rejecting heat to liquid nitrogen for both pure and mixed. A specific amount of liquid nitrogen is required to sublimate the CO₂. As the percentage of CO₂ decreases in the mixture, the fluid nitrogen requirement increases for complete sublimation. In the case of liquid CO₂, the gas is first compressed above the triple point pressure of CO₂; then, using liquid nitrogen, the sensible and latent heat are removed for liquefaction. It is observed that the compression pressure should be in the lower range for complete liquefaction of CO₂ for a particular amount of liquid nitrogen. Increasing the compression pressure will result in low CO₂ liquefaction and increase compression power and outlet compression temperature. It is predicted that the pressure range should be 6 to 20 bars for complete conversion, and low power is required for all considered mixtures. The study also supports the effectiveness of heat exchangers and the efficiency of a compressor in reducing CO₂ emissions.

Key words: Cryogenic, CO₂, liquid nitrogen

Development and Validation of an Indirect Heating Type Superconducting Level Sensors for Liquid Helium Storage System

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For a cryogen, the liquid level is one of the crucial parameters among pressure, temperature etc. Therefore, measurement of liquid level is one of the fundamental interests related to cryogenic systems' operation. A minimum cryogen level should be maintained in the container before filling it with a new batch of cryogen and preventing the thermal quench of superconducting equipment like superconducting magnets. The level of the liquid inside the container is generally expressed as a percentage of the total volume. An indirect heating type level sensor was designed and developed to determine the liquid level inside a helium dewar in this work. The NbTi superconducting wire was used to measure the liquid level, and Manganin wire was used to heat the portion of the wire so that the portion of the sensing element above the liquid level is maintained in the normal state. The measurement of the resistance and the voltage drop across the wire is correlated with the actual liquid level. This paper presents the development of indirect heating type superconducting level sensors for liquid helium storage dewars and a suitable readout circuit with the digital display of the liquid level.

Key words: Cryogen, liquid helium, super conducting, level sensor, experiments

Parametric study on the two-phase heat transfer in a microchannel using CFD

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The study investigates flow boiling in a microchannel using computational fluid dynamics (CFD) to analyze the growth of vapor bubbles and the associated heat transfer during phase change. The simulations are conducted using liquid nitrogen as the working fluid within the open-source CFD package OpenFOAM. The volume of fluid (VOF) method with an interface capturing approach is employed, and the Tanasawa evaporation model is used to calculate mass flow and energy transfer at the phase interface. A microchannel with a circular cross-section, segmented into an initial adiabatic section, a heated section, and a terminal adiabatic section, is the focus of this analysis. Previous studies have examined the effects of various parameters on heat transfer in cases involving a single bubble. In this work, multiple bubbles are simulated to more accurately represent actual flow boiling phenomena. Parameters such as wall heat flux, inlet flow rate or Reynolds number, and bubble generation frequency are studied.

Key words: Cryogenic flow, Microchannel Heat Transfer, CFD Simulation, OpenFOAM

Transient heat transfer analysis of low-temperature packed-bed for Cryogenic Energy Storage system

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The roundtrip-efficiency of a typical Cryogenic Energy Storage system can be increased from the existing 50-55% to as high as 85% and higher by using appropriate storage of heat of compression and low-temperature refrigeration. There are few options for storing low-temperature refrigeration at around 80 K and higher. One of them is to store this refrigeration using pebbles of granite or similar materials in a packed-bed. Similar systems have been studied earlier; however, few studies have investigated the heat transfer inside the bed for optimisation. In this work, we have attempted to develop an appropriate model to capture the heat transfer in that porous medium. The model has been adapted from the literature, modified to include variations in thermo-physical properties at such low temperatures, and converted from a one-dimensional model to a polar coordinate system to capture radial heat transfer along the bed. The model was validated using experimental data.

Key words: Energy storage, Finite difference model, Packed-bed, Porous media, Cryogenic heat transfer

Experimental Investigation on the Influence of Mutual Capacitance and Channel Width on the Performance of a Cryogenic Two-Phase Flow Meter

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Accurate measurement of cryogenic fluid mass flow rate is significant for numerous applications, including particle accelerators, tokamaks, other superconducting devices and cryogenic systems. Therefore, a cryogenic two-phase flow meter has been developed in order to overcome the challenges associated with precise and reliable measurement of flow. Capacitance level gauge sensors have been incorporated in the flow meter channel to measure the liquid height at various channel locations, and thereby measuring the mass flow rate of liquid phase. The geometric configurations of the channels and fluid characteristics, on the other hand, are critical in assuring reliable measurement. To enable real-time data acquisition and to enhance its suitability in various applications, the effect of channel width and mutual capacitance on the two-phase flow measurements needs to be analyzed. Therefore, this study focuses on the influence of mutual capacitance in the liquid height measurement and thereby analyzing the methods to improve the accuracy in flow measurements. Also, the effect of channel width on the slope development and the flow measurement has been investigated at various incoming flow conditions. It has been found that the slope developed along the channel length increases with decrease in channel width. For lower mass flow rate, a channel width of 1mm is found to predict the mass flow rate of the liquid phase with an accuracy of $\pm 3\%$. Meanwhile, for higher mass flow rate, it has been found that channel with 1.5mm width is capable enough to predict the flow rate within an error limit of $\pm 5\%$.

Key words: Cryogenic flow meter, Two-phase flow, Capacitance level gauge, flow measurement, Cryogenic instrumentation

Persistent Mode Operation of 1.5 Tesla MRI Magnet for Human Extremities

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The Electromagnetic Applications & Instrumentation division has developed 1.5 Tesla conduction cooled superconducting magnet for Magnetic Resonance Imaging (MRI) applications. The warm bore size of the magnet is 300 mm which is cooled by low vibration two stage pulse tube cryocooler. The central magnetic field and the stray magnetic field measurements are carried out. A persistent current switch made of Nb-Ti filaments in Cu-Ni high resistivity stabilizer material is installed in the magnet. The magnet is energized with the help of four-quadrant power supply and after reaching 178 Amp is put into persistent mode. The spatial field uniformity is measured with Nuclear Magnetic Resonance (NMR) probes in a Diameter of Spherical Volume (DSV) of 160 mm. The spatial magnetic uniformity is measured to be 56 ppm. The temporal field stability has also been measured by measuring the drift in the magnetic field for 48 hours. The centering of NMR probe array is also carried out to minimize the errors. The temporal field stability is measured to be 0.05ppm/hour. In this paper persistent mode operation of the superconducting magnet is discussed in detail along with magnetic measurements using NMR sensors.

Key words: Magnetic Resonance Imaging (MRI), spatial magnetic uniformity, temporal stability, Nuclear Magnetic Resonance (NMR)

Development of Control and Data Acquisition Circuit for Electrical Capacitance Tomography

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Accurate measurement and visualization of fluid distribution in cryogenic transfer lines are critical for optimizing performance and safety. Electrical capacitance tomography (ECT) is attractive for such diagnostics because it can infer liquid–vapour distribution from permittivity changes without optical access. This paper reports the first-stage development of a control and data-acquisition (DAQ) front-end for an 8-electrode ECT sensor intended for liquid-nitrogen (LN_2) two-phase flow studies. Mutual capacitances are acquired sequentially ($n(n-1)/2$ pairs) using a low-parasitic relay matrix and a high-resolution capacitance-to-digital converter (TI FDC1004Q) with CAPDAC offset compensation and active shield drive. Guard electrodes on the flexible-PCB sensor and shielded lead routing are used to suppress cable parasitics and electromagnetic interference, enabling stable measurement of sub-picofarad capacitances in a dynamic, noisy environment. The microcontroller performs I²C control, timing/averaging, and data framing, while a LabVIEW interface executes electrode-pair sequencing, live display, and logging. Calibration/normalization and a permittivity-to-void-fraction estimation approach for LN_2 flows are outlined; detailed reconstruction and cryogenic flow images are reported separately..

Key words: Electrical Capacitance Tomography, Low-level Capacitance Measurement, Capacitance Multiplexer, Cryogenic Two-Phase Flow, Data Acquisition

Development and testing of novel hybrid CICC joint

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The electrical joints are very important parts for any kind of superconducting magnet like solenoid magnet, hybrid magnet and superconducting bus-bar etc. Joints preparation is very crucial for superconducting magnets because of the local heating from resistive losses can drive the superconductor into unstable condition of the magnet and as a result the superconducting magnet get premature quench. In this paper a joint has been developed in shake-hand type. The joint has been made by using the two different type of cable in conduit conductor (CICC) i.e. Nb_3Sn and $NbTi$ CICC. The $15 \times 15 \text{ mm}^2$ Nb_3Sn and $14.8 \times 14.8 \text{ mm}^2$ $NbTi$ CICC of length $\sim 200 \text{ mm}$ have been used for preparing superconducting joint. The joint length is approximately 110 mm and enclosed with copper jacket. Lead-Tin (Pb 60% & Tin 40%) solder material having melting point 188°C , is used for the preparation of the joint. The four probe method was used for the joint resistance measurement. The measured joint resistance is $\sim 2 \text{ n}\Omega$. The main aim of this type of joint fabrication is the testing of Nb_3Sn based CICC solenoid magnets. In this paper we have discussed the joint fabrication procedure, & its electrical characterization with different wattage of heating pulse near liquid helium (LHe) temperature.

Key words: CICC, Hybrid joints, Heat treatment, resistance, LHe and superconducting

Numerical and experimental investigation of bowing in large diameter liquid oxygen feed lines

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The Indian Space Research Organisation (ISRO) is developing a semi-cryogenic engine with a thrust of 2000 kN. Due to the engine's high thrust, the required Liquid Oxygen (LOX) flow rates are substantial, necessitating the use of 290 mm diameter pipelines to convey LOX from the test facility to the engine. During the initial chill-down phase, the large diameter of the pipeline can lead to significant temperature gradients across the circumference, potentially resulting in thermal bowing, which poses concerns such as, pipeline bending and increased loads on the supports. To address this, detailed non-linear finite element simulations were conducted to predict the structural behavior of the feed lines. An acceptable thermal gradient was identified, ensuring that the stresses caused by thermal bowing remained within safe limits. Novel techniques were implemented to maintain these gradients during the chilling process. During the first chill-down test of the system, multiple temperature and displacement measurements were employed. All necessary conditions for engine start were met in the very first attempt, and thermal bowing remained well within acceptable limits. This paper presents both the numerical simulations and experimental results.

Key words: Thermal Bowing, Finite element analysis, Liquid oxygen feed lines, hot test

