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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 49 (2024) of *The Indian Journal of Cryogenics (IJC)*. This issue comprises 19 papers across various categories. In accordance with the journal's policy, each manuscript was accepted for publication based on favourable reports from at least two referees from our review panel. In cases of conflicting opinions, the final decision was taken by the Editorial Board. We strictly adhere to this review process to uphold the academic standards of IJC. We sincerely regret the delay in releasing this volume, which was primarily due to the lack of dedicated secretarial support for coordinating communication with reviewers and authors.

Since its inception in 1975, the journal has benefited immensely from the commitment of our distinguished reviewers, who generously devote their valuable time despite demanding schedules to ensure the quality and timely publication of each issue. We express our heartfelt gratitude to all of them. We particularly encourage submissions highlighting in-house development of components in the fields of cryogenics and superconductivity, especially those based on innovative concepts, and this volume reflects contributions in that direction.

We are also exploring collaboration with reputed publishers such as Elsevier and Springer to bring out an open-access version of the journal for wider dissemination. This will require adherence to the publishers' standards and guidelines. Authors are therefore encouraged to ensure the highest quality of research, as well as clarity in language and presentation, to meet these standards and avoid rejection.

The papers in this volume span a broad range of topics, including cryo-electronics, space cryogenics, heat exchanger & regenerator, energy storage & carbon capture, High Temperature Superconductor (HTS), material at low temperature.

We extend our sincere appreciation to the members of the IJC Editorial Advisory Board for their continued guidance and support. For Volumes 49 and 50, we were assisted by two Guest Editors from Inter University Accelerator Centre, New Delhi to help expedite 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 the platform for disseminating their research and express our gratitude to the journal's readership for their continued support. The Editorial Board also gratefully acknowledges the support of Science and Engineering Research Board (DST) for its assistance in the publication of IJC.

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Theoretical study on pre-cooling of a cold mass using a 4 K Pulse-Tube cryocooler

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The 4 K pulse tube cryocooler is a key part of a Dry Dilution Refrigerator, designed to reach temperatures of around 40 K and 4 K on the 1st and 2nd stage flanges, respectively. At VECC, a system is being developed to explore helium condensation under different pressures in a high-impedance line, with the goal of achieving low temperatures close to 1 K. Before the system can operate, the temperature of the test cold mass needs to drop below 20 K in a reasonable amount of time. Since the main system has high flow impedance, a separate pre-cooling loop has been introduced. This closed-loop system, thermally anchored to the cryocooler's two stages, helps cooldown the cold mass to below 20 K. This paper describes the design and analysis for fabricating a pre-cooling system using a PT cryocooler.

Key words: Pre-cooling, Dry Dilution, Heat Exchanger, Cryocooler, 1 K system

Design Optimization and study of Fluid Dynamics for the Porous, Multi-Layered Baffled Porous and Hybrid Regenerators for Cryogenic Applications

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Regenerators play a crucial role in cryocoolers by efficiently transferring heat between a working fluid and the matrix material, thereby enhancing cooling efficiency. The paper describes the modelling, design optimization, and fluid dynamics of various types of porous structured regenerators, such as SS, multi-layered baffle, and hybrid regenerators, in an attempt to fabricate them using an additive manufacturing process. The regenerator's physical dimensions are optimized to ensure retrofit compatibility with existing cryogenic systems at Tata Institute of Fundamental Research (TIFR) Mumbai, facilitating seamless integration and performance enhancement of an appropriate regenerator. The selection of a body-centred cubic (BCC) lattice structure, through FEA analysis, aims to optimize the regenerator design based on factors such as porosity and surface area concerning fluid volume interaction. Integrating baffles (multi-layered porous structure) into the structured porous regenerator aims to extend fluid-matrix interaction, thereby improving heat transfer efficiency and overall performance. Developing a hybrid regenerator utilizing lead at the cold end and stainless steel at the hot end aims to achieve lower operational temperatures, enhancing cooling capabilities for extreme cryogenic applications. CFD analysis using ANSYS 24.1 software enables comprehensive evaluation of temperature, pressure, and velocity variations along the regenerator length, providing insights into fluid dynamics and performance optimization. The results are cross-verified in REGEN 3.3 software, which ensures robustness and accuracy in predicting regenerator behaviour and performance under varying operational conditions.

Key words: Regenerator, Porosity, Hybrid Regenerators, Simulation

Quality factor enhancement of detection electronics of Penning trap at cryogenic temperature

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At VECC, a cloud of trapped electrons is stored in a Penning trap, and the weak image current induced by these electrons on the trap electrodes is detected using resonant detection methods. It was observed that the loaded quality factor of the detection unit increased to approximately 5000 by adjusting the gate bias of a low-noise amplifier in the cryogenic environment (4 K). The entire detection electronics performed satisfactorily under an extreme magnetic field up to 5 Tesla.

Key words: Liquid helium, Resonant detection, Cryogenic electronics, Helical resonator

Process analysis and sizing of heat exchangers for an LN₂ cooled external helium purifier

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Horizontal Testing Stand (HTS) and Vertical Test Stand (VTS) facilities are operational at RRCAT, Indore for testing of the Super Conducting Radio Frequency (SCRF) cavity at 2 K temperature. An external helium purifier is required to ensure the continuous and efficient operation of these testing facilities for longer durations. This system purifies the impure helium from these testing facilities and supplies it to the cryogenic liquid helium (LHe) plant for liquefaction. The purifier consists of helium dryer, three heat exchangers and Liquid Nitrogen (LN₂) cooled charcoal adsorber. Impure helium is initially cooled to LN₂ temperature using series of heat exchangers, and then it passes through a charcoal adsorber for further purification. This complete heat exchanger assembly is housed inside the vacuum vessel. The present work describes the design of these heat exchangers, system analysis for different process conditions, and parametric study to identify the relative importance of each heat exchanger of a helium purifier. A computer program has been developed for the parametric study and for sizing of heat exchangers considering the fluid properties variations.

Key words: Helium purifier, Coil fin tube heat exchanger

An alternate approach to modeling of cryogenic heat exchangers

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Heat exchangers used in mixed refrigerant cryogenic systems ($\Delta T_{\text{glide}} > 150$ K) require special attention while modeling, as the conventional simulation methods fail to account for property variations along the heat exchanger and secondary effects. High-effectiveness multiple tubes in tube heat exchangers are extensively used in Mixed Refrigerant Joule Thomson cryocoolers operating with Nitrogen-Hydrocarbon mixtures for very low-temperature applications (Typically 90 K) such as electronics cooling in large telescopes and Vacuum traps in electronics manufacturing.

An alternate 1D-heat exchanger Modeling technique using enthalpy-based equations for hot fluid and cold fluid, considering the property variation, axial conduction, heat leak, and two-phase pressure drop, has been presented in this work using the Finite difference method, and the results have been validated against the published data in the literature. Also, the total charge present in the heat exchanger has been estimated using different void fraction models present in the literature, and a comparison of the same has been presented in this work.

Key words: Heat exchanger, 1D-Modeling, Liquid-holdup, Void-fraction, Mixed Refrigerants

Integration of LNG regasification and Cryogenic Energy Storage systems towards addressing cold-loss during regasification, intermittent renewable energy and CCU

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Cryogenic Energy Storage (CES) systems are showing promising results as an alternative to pumped hydro, compressed air, etc. The advantages of such systems include being independent of location, having high lifetime, sustainable working fluid, being naturally available, abundant storage materials, and comparable efficiency. On the other hand, natural gas is one of the cleanest energy sources. Natural gas is transported as liquid and regasified at the terminals for distribution. During regasification, considerable refrigeration is lost due to the gasification processes, such as heating by seawater, etc. Thermal energy storage (TES) can recover lost refrigeration and later be used in CES systems. This paper attempts to integrate an LNG regasification plant with a typical CES system powered by renewable energy sources. It proposes heat integration to improve its overall efficiency by including oxy-combustion of natural gas. Optimum operating conditions for the oxy-combustion plant with nitrogen as a working fluid were obtained.

Key words: Energy storage, Oxy-Combustion, Cryogenic Energy Storage (CES), Thermal Energy Storage (TES), Liquefied Natural Gas (LNG)

Investigation of Flow Features in a Vertical Cryogenic Feedline During Non-Flow Conditions

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In the present work, experiments and computational fluid dynamics (CFD) simulations are performed to investigate the flow behaviour in a cryogenic feedline under stagnant conditions using liquid nitrogen as the test fluid. The effect of heat-in-leak into liquid nitrogen, and feedline aspect ratio on the flow pattern are brought out. The various aspect ratios are achieved by varying the pipe diameter from 17 mm to 100 mm for a constant length of 2 m. In the experimental study, the pressure and temperature of the fluid is measured and the flow pattern in the feedline is visualized. It is found that for the conditions studied, the flow in a bottom-closed feedline ends up in the boiling regime and geysering does not occur. Further, studies show that for larger feedline diameter, the boiling is suppressed due to the free-convective currents formed in the feedline.

Key words: Two-Phase Flow, Cryogenic Fuel, VOF, Rocket Feedline, Geysering

Design Failure Mode and Effect Analysis of Liquid Nitrogen Based Refrigerated Standalone Transportable Container

**Devendra Sinnarkar, Ankit Tiwari, S. C. Patidar,
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Liquid nitrogen (LN₂) based refrigerated transportable standalone system named “SHIVAY” has been developed at RRCAT for transportation and storage of perishable fruits and vegetables (F&V) at required temperature. Reliable and safe operation of refrigerated system is crucial for preserving quality of stored F&V in container during transportation. Design Failure Mode and Effect Analysis (DFMEA) of SHIVAY to diagnose, evaluate and alleviate probable design failures is discussed in this paper. The analysis perceives breakdown of components, identifies probable failure modes, assess the effect on performance/safety and evaluates the risk involved. The DFMEA provides Risk Priority Numbers (RPN) for various possibilities of failure. High RPN number events have been identified like solenoid valve malfunction, leak in heat exchanger etc. and proper measures have been incorporated to improve reliability. DFMEA provided a detailed assessment for the possible design improvements to ensure operational safety and performance of system.

Key words: Design Failure Mode and Effect Analysis, Liquid Nitrogen Refrigeration, Cryogenic Containers, Temperature Control.

Dynamic analysis of AC loss in HTS SMES integrated with DFIG during voltage disturbances using field-circuit interaction method

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Improved fault ride-through (FRT) capability in doubly fed induction generator (DFIG) wind turbines during voltage disturbances is achieved by integrating superconducting magnetic energy storage (SMES). During power stability operations, SMES experiences dynamic currents that lead to AC losses, affecting the critical state of the high-temperature superconducting (HTS) coil. This article proposes a field-circuit interaction method to analyse dynamic AC losses for an SMES integrated with DFIG under voltage disturbances. In this system, a class D chopper-based SMES is connected to the DC link of the DFIG system and implemented using MATLAB, with an HTS coil model coupled through COMSOL Livelink. The performance of the SMES and AC loss of the superconducting coil is calculated during power stability operations of the DFIG. Additionally, an experimental study is conducted for the class D chopper, and its operation is studied.

Key words: Fault ride through (FRT), Doubly fed induction generator (DFIG), Superconducting magnetic energy storage (SMES), AC loss.

A preliminary study to determine the charging cut-off temperature in a packed bed cryogenic energy storage system

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The charging process in a packed bed cryogenic energy storage system is said to be complete when the temperature of the carrier gas at the bed outlet reaches a cut-off temperature. This temperature cannot be arbitrarily chosen since it dictates the thermodynamic performance behavior during the transient operation which in turn governs the cost of storage. In this paper, we consider the second law performance of packed bed system under various inlet mass flow rates and packing diameter during charging to gain insights into the selection of cut-off temperature. The results indicate that the charging exergy efficiency first increases and then decreases as the bed is charged. The time gap between the peak exergy efficiency and charge completion increased with increase in particle diameter and decrease in mass flow rate. The optimal cut-off temperature may be selected by representing the efficiency and energy stored in the bed in terms of cost.

Key words: Cryogenic energy storage, PCM, LNG, packed bed, Thermal energy storage

ANN-based prediction of solid-vapor equilibria for N₂-CO₂ system relevant to cryogenic carbon capture

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Cryogenic carbon capture (CCC) has been recognized as an efficient method to mitigate carbon dioxide emission to the atmosphere. The capture efficiency is dictated by the phase equilibria and interphase mass transfer rate. This paper focus on the desublimation-based CCC from a N₂-CO₂ mixture that is taken as a representative flue gas. The phase equilibria are conventionally predicted using equations of state (EoS), for which the computational time is generally large depending on the complexity of the EoS. Artificial neural network (ANN)-based models are often used to speed up the phase equilibrium predictions. Therefore, we have developed an ANN-based multilayer perceptron (MLP) model, to predict the solid-vapor equilibria (SVE) associated with the CCC by desublimation from a N₂-CO₂ mixture that is taken as a representative flue gas. We found that our ANN model not only reduced the computational time significantly but also gave more accurate SVE predictions than EoS.

Key words: Solid vapor equilibrium, Cryogenic carbon capture, Multilayer perceptron, Sustainable development, Emission control

Simulation study of mechanical performance parameters of REBCO-based HTS Cables

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Nuclear fusion has the potential to become a viable energy source in the future, given the high depletion rate of conventional energy sources and increasing energy demands. fusion require wires and cables that can carry high currents with minimal loss to generate high magnetic field. High-temperature superconductors (HTS) are considered cost-effective compared to low-temperature superconductors (LTS), but developing HTS-based wires and cables poses significant challenges.

The second-generation HTS of the rare-earth barium copper oxide (REBCO) family shows promise conductor due to its high current density and low hysteresis losses. However, its brittleness requires transformation into tapes before being converted into cables and wires. Determining the critical limits for various superconductor types, geometries, and sizes under mechanical forces is essential. However, experimental investigations are costly and challenging due to the brittle nature, high current density, and cryogenic operating temperatures of HTS tapes and cables. Simulation studies using FEM software offer a viable alternative. Therefore, a simulation-based investigation on the degradation of REBCO tapes under different mechanical loads (tensile, bending, torsion, and winding) for varying geometric parameters (thickness of Hastelloy & copper, tape width, central core diameter) have been performed. The findings will aid manufacturers and researchers in developing better HTS REBCO tapes and cables that can withstand various loads and fatigue.

Key words: High temperature superconductor, REBCO tapes, CORC cable, Bending, Twisting. Winding, Superconductivity

Thermal performance evaluation of microwave remote sensing satellite's tile antenna in radiation mode using a gaseous Nitrogen based thermal vacuum system

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The microwave remote sensing satellite's tile antennas are crucial for operational success. This study evaluates the thermal and RF behaviour of 1 m × 1 m honeycomb quartz tiles bonded with cyanate ester adhesive, tested in a gaseous Nitrogen-based thermal vacuum system at SAC-ISRO. Unlike conventional setups, the system achieved a temperature gradient of ≤ 2 K across the antenna surface, surpassing the standard requirement of ≤ 10 K. Strategic placement optimized radiation heat transfer, while precise shroud control ensured uniform thermal exposure during cycling between 253 K and 358 K. Radio Frequency (RF) measurements confirmed stable dual-polarization performance, with return losses consistently below 10 dB. Measurement uncertainties (± 0.1 K for temperature sensors, ± 0.05 dB for RF data) validated the robustness of results. The findings establish an integrated thermal-RF validation methodology, confirming antenna readiness for operational missions and contributing to reliable, cost-effective satellite systems.

Key words: Space, Radiation, Antenna, Microwave

Performance Analysis of Compact Joule-Thomson Cryocooler Using Aspen-HYSYS Optimization Tool

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The Joule-Thomson (JT) cryocooler is a critical technology for achieving cryogenic temperatures in compact and reliable systems. The JT cryocooler cools via gas expansion through a throttle valve, enabling cooling without moving parts. This study focuses on the design, cooling capacity, and temperature stability of a compact JT cryocooler. The working fluid, Helium⁴, is compressed, precooled via recuperators and two-stage coolers to 20.95K, and expanded through a JT valve, achieving 25 mW cooling at 4.5K at the cold tip. Optimization using Aspen-HYSYS evaluates the effects of parameters such as mass flow rate, pressure ratio, and cooling stage temperatures on the performance of the JT cryocooler. The study identifies an optimal pressure ratio of 14 and a coefficient of performance of 0.0054. These findings provide valuable insights into the miniaturization of JT cryocoolers and the development of hybrid JT-Stirling systems for improved performance.

Key words: Joule-Thomson cryocooler, Space-based instrumentation, Compact cryocooler design, Helium⁴.

Experimental investigation of pressure drop across regenerator at cryogenic temperature

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The pulse tube cryocoolers use stainless steel wire meshes (SS 400) as regenerative heat exchangers. A regenerator should have minimum pressure drop, high heat transfer area, high heat capacity, etc. The data available on the pressure drop when subjected to cryogenic temperatures and temperature gradient is limited. The regenerator in the actual cryocooler has a high-temperature gradient. Previously an experimental setup was made to study the pressure drop in the SS 400 wire mesh used in a pulse tube cryocooler (PTC) at room temperature. The obtained data was used to calculate the hydrodynamic parameters required for the ANSYS simulations. The experimental and simulation results were compared and showed good agreement with experimental values. The present work involves the testing of the regenerator for pressure drop when subjected to a high temperature gradient. The setup consists of a regenerator whose one end is cooled to the cryogenic temperature to create a large temperature gradient representing the actual case encountered in a cryocooler with the use of external cryocooler cold temperature. The experimental setup is used to study the effect of pressure drop at different power inputs, different charge pressures, and temperatures across the heat exchanger length. Also, the study is extended to different lengths of regenerators.

Key words: Pulse tube, Cryocooler, Pressure drop, Regenerator, Wire mesh

Inverse Approach for RRR Measurement in Thin-Film Nb-Coated SRF Cavities Using Planar Inductor Eddy Current Sensors

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Superconducting Radio Frequency (SRF) cavities are crucial components in particle accelerators and are typically constructed from bulk niobium (Nb) due to their excellent superconducting properties. However, bulk Nb is prone to localized defects, which can degrade performance. Thin-film (TF) Nb coatings on copper (Cu) substrates have emerged as a promising alternative, offering reduced material costs and potentially improved performance. The Residual Resistivity Ratio (RRR), a key indicator of material purity, plays a vital role in determining the thermal and superconducting properties of Nb. Traditional methods for measuring RRR, such as the 4-probe DC method, are not suitable for thin films due to the risk of damaging the coating, necessitating the development of non-destructive techniques. This study explores the use of planar inductor eddy current sensors to measure the RRR of thin-film Nb coatings through a non-contact method. Finite Element Analysis (FEA) using Ansoft Maxwell was conducted to simulate the impedance variations of the coil in the presence of Nb-coated Cu targets at both room and cryogenic temperatures. The resistance change (ΔR) of the coil was analyzed across frequencies, and a distinct minimum (F_{min}) was identified. A relationship was identified between F_{min} , conductivity, and RRR, allowing the determination of the conductivity of TF Nb and, consequently, its RRR. The results showed that increasing the conductivity of the TF Nb shifts F_{min} to lower frequencies, while the thickness of the Nb coating has no effect on the minimum ΔR .

Key words: Superconducting RF cavity, Residual Resistivity ratio, Eddy current, Planar inductor

Study the effect of Isenthalpic Joule-Thomson valve and Isentropic wet expander on Refrigeration Capacity of Helium Plant

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Refrigeration capacity of large scale helium liquefaction plant depends on inlet process parameters, efficiencies and arrangement of cold components within the cold box. Refrigeration capacity of helium liquefaction plant is estimated by placing Joule Thomson valve in final stages of cycle and then replacing it with wet expander engine. Refrigeration capacity has been estimated for different efficiencies of wet expander as a function of inlet pressures and inlet temperatures of wet expander and JT valve. It is observed that refrigeration capacity of JT valve is higher when it is operated below ~5 bar and ~6 K whereas refrigeration capacity of wet expander engine is higher when it is operated at higher inlet pressures range of 5 to 18 bar. When the inlet temperature in both, is below ~6 K, then maximum refrigeration capacity can be achieved. Reduction in refrigeration capacity is observed for both, for inlet temperature of >6 K.

Key words: Refrigeration capacity, isenthalpic Joule Thomson valve, isentropic wet expansion engine

Thermal Design of Heat Exchangers of a Dual Mode LOX-LIN Plant at BARC

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An air separation plant with a liquid oxygen (LOX) and liquid nitrogen (LIN) generation capacity of 50 l/hr and 75 l/hr, respectively, is being developed at the Bhabha Atomic Research Centre (BARC), Mumbai. The plant will be capable of working in either LOX or LIN generation modes as needed. The targeted minimum purity values for LOX and LIN are 96% and 99% by volume, respectively. A modified Claude cycle-based liquefaction process is designed to cater to the simultaneous demands of liquid and gas products. For the feasibility of this process, along with the turboexpander and rectification column, high-effectiveness heat exchangers (HEX) are required. Three-stream HEXs are required for the mixed (liquid + gas) mode of operation. Plate fin heat exchangers (PFHEs) are selected for the dual-mode LOX/LIN plant being developed. The thermal design of the multi-stream plate fin heat exchanger is based on bypass fin efficiency and a layer-by-layer analysis method. Sizes required for the different modes are evaluated for the PFHEs, followed by the selection of optimum sizes to suit all the operating modes. The sizing calculations for the required PFHEs are detailed in the current article.

Key words: Liquid oxygen, Liquid nitrogen, Air separation, Plate-fin heat exchangers

Fatigue strength properties of titanium (grade 2) at cryogenic temperatures

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Knowledge of fatigue strength properties of materials is very crucial in the design of a mechanical system failing which the entire system can fail prematurely. Reliable data of strength properties of many engineering materials are not available at cryogenic temperatures. Available room temperature data cannot be extrapolated down to cryogenic temperature zone since many of the mechanical properties change abruptly. In this experimental study, a rotating beam fatigue testing machine suitable for both room and cryogenic temperatures has been designed and developed to determine fatigue strength properties of materials which are frequently used in cryogenic engineering applications. Tests are conducted within an insulated cryogenic chamber. Desired cryogenic temperatures down to 77K are maintained by circulation of pressurized liquid nitrogen with the help a solenoid valve and a PID controller. Fatigue strength properties of titanium (grade 2) are determined both at room and cryogenic temperatures and analyzed.

Key words: Liquid nitrogen, Fatigue strength, stress cycles, S-N curve and Cryogenic chamber

