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



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EDITORIAL

It is a matter of great satisfaction that the volume 48 (2023) of our esteemed journal “the Indian Journal of Cryogenics” (IJC) is out. In all, the issue has 27 papers under different categories. As per the policy of the journal, the papers were accepted for publication on the basis of the positive review reports by at least two of our referees on journal’s panel. In the event of conflicting reports, the editorial board takes a final decision. We consistently follow this policy to maintain the standard of IJC. We regret the delay in bringing out this issue, caused by the worst pandemic of the century, COVID-19 which brought the whole world to a halt.

The journal owes its timely publication year after year much to our distinguished reviewers who, in spite of their tight schedule, spare time and burn extra oil to carry out the job. I thank all the reviewers profusely. As per the policy of the ICC and the journal we encourage our young researchers to publish papers with IJC and many of them happen to be first timers. We are constantly pursuing with UGC for the restoration of the UGC approval of our journal and its inclusion in the list of UGC approved Journals. We are also exploring with the reputed publisher like Elsevier/ Springer for an open access journal for wide publicity for which we will have to adhere to the norms of the publisher vis -a- vis the standard of the paper. Authors too will have the responsibility to ensure high quality of the research work and the grammar / language etc. to avoid rejection.

The papers have been grouped under a wide range of topics such as; cryocoolers, space cryogenics, cryogenic refrigeration, superconductivity, heat transfer, cryogenics and superconductivity for particle accelerators, tokamaks, cryogenic materials, Liquid hydrogen, MRI and liquefied natural gas (LNG).

We are planning to restart publishing “Invited Review Articles” on these topics and publish them in the successive issues of the IJC.

We would like to extend my sincere thanks to my colleagues in the IJC Editorial Advisory Board for their continued guidance. Our special thanks to Prof. Milind Atrey, President (ICC), Dr. Soumen Kar, Dr. Uttam Bhunia , and Ms. Tania, for their support in publishing this volume. We also thank veteran Dr. R G Sharma for his guidance and advice on critical decisions. Finally, I thank all the contributors for having opted to publish their research with IJC and the entire readership of the journal.

The Editorial Board would like to place on record its gratitude to SERB (DST) for its support to the publication of the IJC.

T S Datta
R Karunanithi
H B Naik
Tapas Kumar Nandi

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PLC based control system for LN₂ based reefer SHIVAY

**S. C. Patidar*, Chintan Gupta, Prashant Khare, Ankit Tiwari, Hemant Patel,
Shailesh Gilankar, Gaurav Agrawal, Devendra Sinnarkar**

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Reefer containers are used for transportation of perishable goods in temperature-controlled environment. SHIVAY (Sheetal Vahak Yantra) is Liquid Nitrogen (LN₂) based reefer container with temperature range from -40°C to 8°C. A PLC based control system has been developed for this container. The PLC is mainly used for auto-control logic implementation and sequence control of different sub-systems. In addition, a human-machine interface (HMI) is used to input system parameters, monitor the system status, system health & logging of data. This system has been installed on 20 feet container & tested for its operation on 3000 km of road trials. The system was able to maintain temperature inside the container within ±1.5°C without human interventions. Both software and hardware-based implementations of our system are described in this paper.

Key words: PLC, Control system, LN₂ reefer, SHIVAY

Practical methodology adapted in ground test facility to induce cavitation in turbopump

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It was planned to induce cavitation phenomena in turbopump during ground testing so as to finalise the inlet parameters of this turbopump. A detailed study was carried out to meet the stringent requirement of conducting cavitation test at test facility where the turbopump being regularly tested. Facility tuning trials were carried out and during third tuning trial, the pressure and temperature conditions were achieved close to the requirement. After proving the ground test facility capability, cavitation test was conducted and cavitation was precisely demonstrated. Based on the test results, the inlet parameters of the selected pump shall be finalized with margin. Thus, the resources available within ground test facilities were effectively utilized/ managed to accomplish the task of inducing cavitation in turbopump.

Key words: turbopump, cavitation, tuning trials

A 1 T HTS magnet with multi-coil-based design for extremity MRI

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Two magnet configurations of multi-coil design (i.e. 5-coil and 6-coil) for 1T extremity Magnetic resonance Imaging (E-MRI) magnet were analysed and compared numerically by using COMSOL multi-physics. Each configuration consists of 20 double pancake coils, which were wound using second generation (2G) HTS tape (SCN04200) from SuNAM and were operated at 50A, 65 K. The magnet satisfies a target field homogeneity < 50 ppm over an 80 mm Diametric Spherical Volume (DSV) by fixing the inner winding diameter as 200 mm and its length and outer winding diameter are restricted to < 350 mm and < 500 mm respectively. The key parameters such as central flux density, maximum total field, maximum radial field, stray field distribution and field homogeneity were analysed for both configurations. Comparison was carried out based on homogeneity for minimum length of HTS tape at 65 K. Configuration -1 results homogeneity of 32 ppm for a 5.35 km long tape.

Key words: HTS Magnet, multi-coil design, extremity MRI

Exergy analysis of cold recovery in a cryogenic packed bed system

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Cold recovery and storage in a packed bed is suggested during the regasification of LNG and liquefied air; the latter is found in a cryogenic energy storage system. The efficiency of cold recovery depends on the pressure, temperature, thermophysical properties of the packing material and the fluid, fluid flow rate, bed geometry and bed dimension. These factors dictate the irreversibilities accompanying the heat leakage from the surroundings, heat transfer between the flowing cryogen and the packing material and pressure drop along the flow direction. These irreversibilities lead to exergy losses in the packed bed. As a result, the exergy efficiency of the charging operation is lowered. The present work focuses on the effect of inlet temperature on the thermodynamic performance of cryogenic packed bed during charging. Losses due to irreversibilities are quantified and exergy efficiency of charging operation is evaluated. It was seen that the axial conduction within the bed resulted in temperature drop at the outlet, thereby reducing the exergy efficiency of the charging operation. The exergy efficiency of the charging operation increased with inlet temperatures.

Influence of external heat interaction of working fluid on the oscillating heat transfer behavior of cryogenic regenerator

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In this paper, an analytical and numerical investigation has been conducted to illustrate the influence of external heat interaction (i.e. heat addition/ heat removal) of the working gas with surrounding on the effectiveness of the regenerator. Governing equations for temperature distribution have been derived by utilizing the principle of energy balance to describe the regenerator heat flow phenomena subjected to external heat interaction and are converted into a dimensionless form using reasonable dimensionless parameters. The dimensionless equations are solved to illustrate the effect of external heat interaction of incoming gas on its effectiveness. It is noticed that external heat addition and removal to the working gas reduces and enhances the effectiveness of the regenerator respectively.

Key words: Cryocooler, Regenerator, External heat interaction, Effectiveness

A novel approach for thermal conductivity measurements of powdered adsorbents for cryo-adsorption vacuum pump applications

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The thermal conductivity values (k) of adsorbents are one of the major factors that decide the pumping performance of cryo-adsorption vacuum pumps. There is limited data available in the literature that characterizes the ' k ' values of adsorbents in cryogenic temperatures, due to the complexities in measurement methods. Most of the measurement techniques use the 1 D Fourier heat conduction equation, which involves measuring the temperature differences (ΔT) created with a known heat source, over a specific length of a test sample (Δx), which is thermally isolated from its surroundings. Adsorbents in the powdered form cannot be held between the heat source and sink for the process, without using binders or by sintering it into test sections, which can alter its real ' k ' value. A holder-based test method is described in the study which can test samples in their powdered form, in varying densities, and without using any additives. This method maps experimentally obtained the ' ΔT ' value for heat conduction through the adsorbent loaded sample holder, against a calibration chart for thermal conductivity ' k ', prepared from a simulated model of the setup. The COMSOL-based simulation model of the setup used to prepare the calibration chart, plots ' ΔT ' values for all possible ' k ' values in the predicted range for the material. This method can account for heat conduction in all directions, conduction of heat through the sample holder, and test the sample in its original form, even though it is powdered in varying densities.

Key words: Cryopumping, cryo-adsorption, vacuum pumps, Carbon, thermal conductivity

Development of numerical model for cryogenic pulsating heat pipe

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Pulsating Heat Pipes (PHP) are gaining popularity due to advantages over conventional heat pipes. A conventional multi-control volume model for PHP is used by accommodating the effect of the equation of states (EOS) and surface tension force. The computational results are presented for a time of 1 s using a time step of 2 μ s. Results are presented in terms of wall temperature, fluid temperature, mass exchange in vapour bubbles, and film thickness. Results show higher wall temperature, higher evaporation mass, and thicker film with the introduction of surface tension force. However, there are no variations observed in boiling mass due to surface tension. Variations in these results are also shown with changes in the equation of state. Two equations of states i.e. Ideal gas and Redlich–Kwong–Soave (RKS) are used. Higher wall temperature, higher evaporation mass, boiling mass, and thicker film were observed in the case of vapour bubbles using the RKS equation of state.

Key words: Cryogenic pulsating heat pipe, Transport equation modelling, Multi control volume model

Theoretical and experimental investigation of cryogen boil-off for a stationary storage vessel

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Cryogen evaporation rate is of prime concern in various industrial as well as research settings. Thermal response of cryogenics is quite important in their transportation (due to sloshing) and storage. A transient two-phase thermodynamic model, for a stationary liquid nitrogen cryocan, is developed for two cases, first to understand the boil-off rate (isobaric condition / vent open) and second to measure transient pressure evolution (closed condition /vent close) due to external heat in-leak. Experiments were performed for the validation of the model. A 25.5-liter cryocan of cylindrical geometry is considered with liquid nitrogen as a working fluid. Due to the high insulation of cryogenic vessels, boiling mechanism is governed by interfacial surface evaporation. In isobaric conditions of constant ullage pressure, thermal stratification in both liquid and vapour phases has been studied. Based on heat in-leak calculation and energy equation applied to the total fluid domain (considering temperature, pressure, and enthalpy of vaporization), the boil-off rate in cryogenic vessels is investigated. In closed conditions of the vent, due to the continuous evaporation process, the pressure inside the tank increases thus ullage pressure is determined experimentally from 1 bar to 2 bar due to self-pressurization.

Key words: Isobaric, Cryogen, Evaporation, Storage tank

Characterization of fiberglass reinforced resin tube for its application in a cryogenic container

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The progress in cryogenic applications is strongly dependent on advances in the development of materials. It is revealed from the available literature that most often the suitability of a large number of metals and alloys has been studied but much less work is reported about components made of resin-impregnated fiberglass composites which may have a reasonable edge over many metallic components for cryogenic and allied applications. In this regard, a fiberglass composite neck is fabricated and its suitability for application as the neck of a liquid nitrogen container is studied. The paper presents various physiochemical characterizations such as XRD, SEM of the material, and successful testing of the fiberglass composite neck in situ in a liquid nitrogen environment towards its compatibility at cryogenic temperature.

Key words: Fiberglass, Reinforced Composite, cryogenic container, Epoxy resin

Development and validation of room temperature bore cryostat for testing of HTS solenoid magnet up to 55 K

Mahesh Ghate¹, Dhaval Bhavsar¹, Hemang Agravat¹, Nayan Solanki¹, Deven Kanabar¹, Piyush Raj¹, Anees Bano¹, Umesh Pal¹, Firozkhan Pathan¹, Arun Panchal¹, Arvind Tomar¹, Nitish Kumar¹, Arun Prakash¹, Shiju George¹, Vipul Tanna^{1,2}, Upendra Prasad¹

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Magnet System Division of IPR is working on the development of high-temperature superconducting (HTS) magnets, test facilities, and associated technologies for plasma experiments. Under this initiative, the development of a cryostat with a room-temperature bore of ~50 mm for an HTS solenoid magnet capable of producing >0.2 T at 64 K has been carried out. The integrated system consists of an outer vacuum chamber, inner cryogenic chamber, HTS solenoid magnet, and top flanges with cryogenics, electrical, and instrumentation service ports, required for its operation has been validated up to 55 K by sub-cooling of LN₂. Integrated RTBC setup is demonstrated for the steady state operation of the HTS magnet up to ~ 3 Hrs. The design, development, manufacturing, assembly, integration, and validation tests of this integrated system of RTBC will be discussed in this paper.

Key words: Cryostat, Subcooling, Test Setup, HTS, HTS Magnets

Developing mixed refrigerant Joule-Thompson cryocooler in the range of 60 K

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Mixed Refrigerant Joule-Thompson (MRJT) cryocoolers, that use Linde-Hampson cycle, have been successfully demonstrated to reach temperatures above 80 K. In the present work, MRJT cryocooler to reach temperatures below 80 K is developed using a liquid-vapour (LV) phase separator. By incorporating LV separator in the system, the cryocooler essentially becomes an two-stage autocascade cycle. Development of an inhouse LV separator operating at cryogenic temperature is presented. The minimisation of the thermal mass of the separator is carried out using several iterations achieving a final mass of 490 grams from an initial mass of 1555 grams. Using the two-stage MRJT system, uncertainties associated with the LV separation process created irregular flow of refrigerant in the second stage resulting in choking the second stage. Lowest temperature of 61 K is achieved using the two-stage MRJT cryocooler and cooling effect of 4 W is obtained at 70 K.

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

Simulation study of cryogenic $^{11}\text{CO}_2$ capture system for RIB project

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A cryogenic radioactive $^{11}\text{CO}_2$ trap is under development for the Radioactive Ion Beam project in VECC. The trap uses the process of de-sublimation (frosting) and sublimation for separating radioactive $^{11}\text{CO}_2$ from the $^{11}\text{CO}_2/\text{N}_2$ mixture. The mixture will be passed through the coiled stainless-steel tube submerged in liquid N_2 . A pump maintains the pressure of the coil below 0.1013 MPa (1 atmosphere), preventing the condensation of N_2 gas, but allowing trapping of gases like $^{11}\text{CO}_2$, NO_2 , etc. Completing the entire separation process well within the half-life of the ^{11}C is a challenge in the design of the trap. This paper presents the overall scheme of the trap as well as its numerical modeling of frosting of $^{11}\text{CO}_2$ inside the tube. Parametric study is performed to study of the effect of channel diameter, flow rate, and $^{11}\text{CO}_2$ concentration on the frosting.

Key words: Cryogenic, Cryogenic Trap, Radioactive, Numerical Model

Design of liquid nitrogen cooled 80 K thermal shield and flexibility analysis of internal piping for cryogenic distribution box of horizontal test stand

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Horizontal Test Stand (HTS) cryostat at RRCAT is capable of housing two high beta 650 MHz dressed Superconducting Radio Frequency (SCRF) cavities at nominal 2 K in a single cool down and can absorb the 50 W dissipative power by cavity. Test stand plays an important role for developing and testing superconducting pulsed proton accelerator project at RRCAT. Achieving and maintaining a stable cryogenic temperature at 2 K in HTS on regular and reliable basis is a challenging task and requires broad range of cryogenic expertise, large scale system level understanding and many in-house technological and process developments. Detailed design of distribution box for efficient distribution of cryogen is very important for reliable operation of HTS. Liquid nitrogen cooled 80 K shield is one of the important components of distribution box to arrest the ambient heat in leak and reduce the heat load. Present paper describes the flexibility analysis, design of 80 K nitrogen shielding, cool-down study, different tube tracing arrangements for efficient cooling of the shield and effect of thermal parameters.

Key words: Distribution box, LN2 thermal shield

Development of new supervisory control and data acquisition system for 1.3 kW helium refrigerator cum liquefier at 4.5 K

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The 1.3 kW Helium Refrigerator cum Liquefier (Helium plant) at 4.5 K is the major cryogenics system of SST-1. The superconducting magnet systems of SST-1 are cooled by Helium plant. The Helium plant consists of compressor station, oil removal system (ORS), on-line purifier and cold box. Each subsystem has dedicated Programmable Logic Controller (PLC) for their operation. A Supervisory Control and Data Acquisition (SCADA) application was developed in Citect SCADA software in 2002. The Citect SCADA software is obsoleted now and no technical support is available from principal. Therefore, a new SCADA application is developed in Wonderware InTouch 2017 R2 software and deployed for Helium plant for uniform SCADA system for SST-1 Cryogenics subsystems. This has provided many new features and satisfactory experience over old SCADA system. This paper discusses the various technical issues arise during development, integration experience with Helium plant, new additional features and future development plans.

Key words: Helium Refrigerator cum Liquefier, SCADA, PLC

Alarm annunciation system development for SST-1 cryogenics

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Gaurang Mahesuria, Dasrath Sonara, Vipul Tanna**

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At IPR, we have wide spread of cryogenics system facilitating to SST-1 Tokamak Machine. The cryogenics related sub-systems include 1.3 kW helium refrigerator/liquefier plant, liquid nitrogen (LN2) distribution system, integrated flow distribution and control system (IFDCS), current feeder system (CFS) and 80K booster system. These cryogenics sub-systems have their own control system consist of Programmable logic controller (PLC) and Supervisory Control and Data Acquisition (SCADA). It is essential to have centralized alarm annunciation system for immediate attention of operator in case of abnormal process parameters behaviour and emergency situation exists in any cryogenics sub-systems. Alarm annunciation application designed and developed in Wonderware SCADA. Control area network established among all cryogenics sub-system's control nodes. OPClink gateway and FSGateway are configured for establishing communication between Alarm annunciation application and SCADA applications running on different cryogenics sub-systems control nodes. The main critical process parameters of all sub-systems are addressed and defined in Alarm annunciation SCADA application. This application runs at back end and alerts the operator by audible sound and blinking graphics in case of abnormal events. The alarm annunciation application performed satisfactory in recent SST-1 plasma experiment campaign. The features of developed applications are presented in this paper.

Key words: Gateway, MODBUS, SCADA, PLC

Design studies on turboexpanders for dual mode LOX-LIN plant

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Recognizing the technological and market void for a dual mode, i.e., liquid oxygen (LOX) or liquid nitrogen (LIN) mode of small to medium capacity air separation plant, a dual mode turboexpander-based air separation plant is proposed to be developed by BARC. The work described in this article begins with the preliminary design of turboexpanders for different modes of operation of the plant. The off-design characteristics of these conceptualized turbines are then used to size a single turbine to fit most of the modes of operation with varying levels of compromised performance in different modes. The article further describes the profile design of the selected turbine impeller using the Enhanced Midstream Method (EMDM). The turboexpander design and performance play a key role in the performance, operation and feasibility of the dual-mode plant.

Key words: Turbomachinery, Air separation, Liquid Oxygen, Liquid Nitrogen, medical oxygen

Parametric analysis of inertance type pulse tube cryocooler using computational fluid dynamics

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The inertance type pulse tube cryocooler has accumulated applications in various fields such as aerospace, bio-tech and military by achieving temperatures below 100 K. The computational fluid dynamics approach chosen for the present work deals with the complex, confined and cyclic fluid flows encountered in the cryocooler. The analysis of the cryocooler for the zero-refrigeration load condition is carried out using the Ansys Fluent® software. A parametric study of the cryocooler is conducted by varying the pulse tube radius and reservoir volume, where an increase in cooling performance is observed. Porous medium of regenerator was also varied which emanated a fluctuating cooling performance for the range of porosity.

Key words: Inertance Type Pulse Tube Cryocooler, Computational Fluid Dynamics, Heat Transfer

