Consideration of sub-cooled LN2 circulation system for HTS power machines

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A sub-cooled LN2 circulation system for HTS power machines was considered. The circulation system consists of a heat exchanger and a circulation pump. The heat-exchanger is connected a neon turbo-Brayton cycle refrigerator whose cooling power is 2 kW at 65 K. Sub-cooled LN2 is delivered into the heat exchanger by the pump and cooled down from 70 K to 66 K. After the heat exchanger, sub-cooled LN2 goes to HTS power machines and its temperature is increased up to 70 K. Sub-cooled LN2 of 66 K is adequate fluid for cooling HTS power machines, because its dielectric strength is higher than saturated LN2 and it makes larger critical current than 77 K. However a possibility of LN2 solidification in the heat exchanger is a considerable issue. The refrigerator produces cold neon gas of 60 K and its temperature is lower than nitrogen freezing temperature, 63 K. Therefore process simulations for three types of the heat exchanger, namely pleat-fin type, tube-in-tube type and fin-tube-coil type, were done. As results, it is possible that sub-cooled LN2 is not solidified in the heat exchanger and the design of the circulation system, especially heat-exchanger type, affects COP (coefficient of performance) of the turbo-Brayton cycle refrigerator. Detail of the circulation system is introduced in this presentation. This research was supported by New Energy and Industrial Technology Development Organization.

Installation and performance test of cooling system for HTS cable in Icheon substation

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HTS cable system has many advantages such as high transmission efficiency, high capacity, and low loss. On the other hands, the reliability and economical efficiency of the HTS cable system are not verified, therefore, there are not many precedent studies for applying HTS cables on the commercial power grid all over the world. Korea Electric Power Corporation (KEPCO) has started a project of operating and manufacturing technology for applying 22.9kV, 50MVA, 500m class HTS cable to the commercial power grid in 2008. LS cable Ltd. has joined this project for designing and manufacturing HTS power cable including cooling system. We verify the reliability and economical efficiency of the system throughout this real power grid connection project. In this paper, we introduce the design of the cooling system for the 500m class HTS cable and summarize results of performance test.

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Thermodynamic design of 10 kW Brayton cryocooler for HTS cable

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A thermodynamic design of Brayton cryocooler is presented as part of the ongoing governmental project in Korea to develop 1~3 km HTS cable at 22.9 kV 50 MVA. The refrigeration requirement is 10 kW for continuously cooling the liquid nitrogen flow from 72 K to 65 K in the cable system. Two key design parameters are the operating pressure and mass flow rate of refrigerant. In addition, detailed specifications of plate-fin heat exchangers are incorporated to quantitatively examine the effect of heat exchanger size on thermodynamic efficiency. Helium, neon, and their mixture with different compositions are investigated as refrigerant. An analytical model is developed on simplified cycles, and then full details of thermodynamic design are carried out with Aspen HYSYS, aiming at a prototype to be constructed immediately in the HTS cable project.

This study was carried out as the Power Generation & Electricity Delivery by supporting of the Korea Institute of Energy Technology Evaluation and Planning (KETEP) and by funding of the Ministry of Knowledge Economy, Korea. (No.2009T100200205)

Neon turbo-Brayton cycle refrigerator for HTS power machines

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We developed a prototype turbo-Brayton refrigerator whose working fluid is neon gas. The refrigerator is designed for HTS power transformer and its cooling power is more than 2 kW at 65 K. The refrigerator has a turbo-expander and a turbo-compressor, which adopt magnetic bearings. These rotational machines have no rubbing parts and no oil-components. It makes a maintenance-free machine of the refrigerator. The refrigerator is very compact because our new developed turbo-compressor is volumetrically smaller than a displacement type compressor. Another feature of the refrigerator is a wide range operation capability for various heat-loads. Cooling power is controlled by the input-power of the turbo-compressor instead of a conventional electric heater power. The rotational speed of the compressor motor is adjusted by an inverter. This system makes more energy-saved and higher efficient. We show design details, specification and cooling test results of the new refrigerator in our presentation.

Operation mode studies of the ITER cryodistribution system

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In order to achieve and maintain the proper cryogenic conditions for fusion experiments, the ITER Cryogenic System has to cope with various operation modes as per the requirements of the superconducting magnets and 4 K cryopumps (CP's). The refrigerators, source of the cooling power, should operate as far as possible in a quasi-steady-state manner for efficiency and reliability reasons, and to optimize their cooling capacity. The cryogen-related transients generated or required by the magnets and CP's should therefore be managed and smoothened inside the primary helium loops of the cryodistribution (CD) cold boxes which distribute and recover the cooling flows.

In this proceeding we will propose the internal-component layouts of the ITER CD cold boxes and demonstrate how they should fulfill the necessary functions for all identified operation modes. The various methods foreseen for the smoothing of the cryogenic loads and optimization of the cooling power requirements will also be introduced.

TIMO-2 – A cryogenic test bed for the ITER cryosorption pumps

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KIT has been carrying out research and development in the field of vacuum cryopumps for nuclear fusion devices over the last decade. Together with the development activities also experience in the operation of the needed cryogenic systems necessary for such type of large scale cryopumps could be collected. Due to the specific requirements of a large DT fusion device, such as ITER, the cryogenic distribution is based on gaseous helium at the needed temperature levels rather than liquid nitrogen or liquid helium. KIT has set up a large scale research facility, called TIMO-2, fully equipped with supercritical helium supply at large flow rates to be able to perform cryogenic tests of components under ITER-relevant conditions. During first test campaigns at TIMO-2 with a large scale model cryopump the ITER cryosorption vacuum pumping concept was successfully validated. After major refurbishments and upgrades, the TIMO-2 facility is now ready for the acceptance tests of the ITER Pre Production Cryopump (PPC).

This paper describes the modified test facility TIMO-2 with the needed infrastructure for the planned PPC tests. For the tests with the ITER PPC a process gas supply including a metering system to simulate plasma exhaust gas flow as well as the cryogenic supply with forced flow gaseous helium at different temperature levels are indispensable. Particular attention of this paper will be given to the available supply at different temperature levels as for example 4.5 K and 80 K for nominal operation and 4.3 K, 20 K, 100 K, 300 K and 475 K for various cryopump operation procedures. The new 100 K helium supply facility which became available recently will be described in detail. It is based on heat exchange via a bath of pressurized liquid nitrogen.

CEC Submission category: CEC-02 (Large-Scale Systems, Facilities, and Testing)

THERMO-HYDRAULIC ANALYSIS OF COOL-DOWN FOR ITER TOROIDAL FIELD COILS FROM 80 K TO 6 K

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ITER is the next-step large-scale experiment for magnetically confined fusion, whose cryogenic system should be cooled down in parallel. The cool-down of TF coils can be divided into 3 phases, gradual cool-down to 80 K, fast cool-down from to 6 K, and filling coils with 4.5 K supercritical helium. The gradual cool-down from 300 K to 80 K stage was completed. Thermo-hydraulic analysis of the cool-down from 80 K to 5 K for TF coils has been carried out recently. This TF coils cool-down stage should be analyze by considering the influence of the refrigerators. To carry out the simulation, a time-dependent thermo-hydraulic simulation cool-down from 80 K to 6 K stage has been performed by using a new FORTRAN code. The code for analyze coils is based on a 1D helium flow and 3D solid heat conduction model. The model for describing the thermal and gas dynamic process of the equipments in refrigerators is also developed. The results indicate that cool-down from 80 K to 6 K stage can be finished in 10 days.

Thermal Mechanical Analysis on the ACB-CP Valve Box of ITER Cryogenic System

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ACB-CP is an auxiliary cold box used to distribute and control the cryogenic fluids to cool the cryopumps in ITER cryogenic system. A 3-D structure design was performed as a preliminary design. In order to validate the structure design, the thermal mechanical analysis on the piping must be followed. A 3-D finite element model of ACB-CP was built. The steady state thermal analysis and thermal mechanical coupling analysis of the internal piping were performed. The thermal stress distributions and the maximal thermal stress values were obtained. The stress intensity of internal piping was analyzed. The results laid the reliable foundation for the design and improvement of ACB-CP.

Conceptual Design of ACB-CP for ITER Cryogenic System

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ACB-CP (auxiliary cold box for cooling cryopumps) is used to supply the cryopumps system with necessary cryogen in ITER (International Thermonuclear Experimental Reactor) cryogenic distribution system. The conceptual design of ACB-CP contains thermo-hydraulic analysis, 3D structure design and thermo-mechanical analysis. Through the thermo-hydraulic analysis we can decide the main specifications of process valves, pressure safety valves, pipes, heat exchangers, electrical heater, circulating pump and cold compressor. During the 3D structure design process, vacuum requirement, adiabatic requirement, assembly constraints and maintenance requirement have been considered to arrange the pipes, valves and other components. The thermo-mechanical analysis has been performed to crosscheck if the 3D design meets the thermo-mechanical requirements for the ACB-CP.

Cryogenic facilities for the LMJ targets

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As part of the French Inertial Confinement Fusion (ICF) program, CEA has developped Cryogenic Target Assemblies (CTAs) for the Laser MegaJoule (LMJ). The central element of these targets is an organic microshell which is filled with a high pressure deuterium-tritium (D_2 or DT) gas at room temperature and then are cooled down to 20 K to solidify the gas mixture. The next operations are the conformation and the optical characterization of the solid layer inside the microshell.

These filling, cooling and characterization operations are performed in gloveboxes (nuclear technology) with cryostats which are mainly cooled with liquid helium. After many years of operating in gloveboxes with D_2 gas and liquid helium, this conception of cryostat had shown limits and difficulties which are presented here.

These cryostats are shortly give up as well as the use of liquid helium. Today the recent evolutions of cryogenic machines permit to be directed towards new conceptions of cryostat and in particular the use of pulse tube. We show here the advantages and embarrassment of this new technology.

Helium subcooling system for EAST PF coils

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The poloidal field (PF) coil of EAST superconducting tokamak was a large NBTi superconducting coil. The PF magnet system of EAST consists of three pairs of central solenoid coils and four pairs of big outer rings. PF coils are cooled with a supercritical helium stream from the J-T valve in the helium refrigerator. In order to improve the cryogenic stability of the PF coils, an upgrade of the cooling system was carried out and then it has been possible to supply the coils with subcooled helium at 3.5K, 3bar. A designed mass flow of the supplied subcooled helium is 110g s^{-1}. The subcooled helium is generated at heat exchanger in a saturated helium bath. A series of two centrifugal cold compressors with gas foil bearing is utilized to lower the helium pressure in the bath. The supplied helium temperature is regulated by rotational speed of the cold compressors and power of a heater in the bath. The mass flow of the supplied helium is also controlled manually by a supply valve. In the present study, the design of the cooling system has been investigated and a stable operating method has also developed.

The new cryogenic system for the SCH and the 45 T hybrid at the NHMFL

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The SCH magnet is under development at the NHMFL and will be a vertical bore, 36 T magnet which will be installed at the NHMFL. The SCH Magnet combines a set of resistive Florida-Bitter coils with a superconducting outsert constructed of Nb3Sn cable-in-conduit conductor (CICC). The resistive insert and superconducting outsert are electrically connected in series and energized by one power supply. The superconducting magnet will be forced flow cooled with supercritical helium at 4.5 K. The 45 T hybrid magnet system, also combines superconducting and resistive magnet technologies to produce 45 T steady field (although at a lower homogeneity than the SCH). It has been operating successfully as a user facility for the past ten years. The superconducting magnet is bath cooled at 1.8 K. A new cryogenic system with a refrigeration capacity of 750 W @4.5K will be built at the NHMFL. The cryogenic system will supply the helium refrigeration requirements of the Series-Connected Hybrid (SCH) magnet, and the 45 T hybrid magnet replacing the piston expander refrigerator which has been in place for more than 15 years. The cooling of the superconducting magnets, the design of the cryogenic system including the helium refrigerator and distribution system are discussed in this paper.

Key words: Cryogenic System, Series-Connected Hybrid, 45 T hybrid, Superconducting magnet

Cryogenic system for the future accelerator complex NICA at JINR

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Joint Institute for Nuclear Research (JINR) initiated the creation of a new and unique heavy ion collider facility NICA, which is planned for commissioning in 2016. Cryogenic system for the NICA facility will be based on the existing liquid helium plant which was constructed for the Nuclotron. Main goals of existing system modernization are: total capacity increasing from 4000 to 8000 W at 4.5 K; replacing of worn-out and outdated machinery; new storage and transport systems for liquid helium and nitrogen; reliability and efficiency increasing; full automation. Doubling of the refrigerator capacity will be achieved with an additional 1000 l/hour helium liquefier and several evenly distributed “satellite” refrigerators which operate with consumption of liquid helium from the central liquefier. In this case the refrigerators, which consist only of heat exchangers and liquid helium separators, are highly reliable and require no maintenance, because the least reliable elements are concentrated in the central liquefier. Status of the existing Nuclotron cryogenic supply, plans of the nearest development of cryogenic system for future accelerator complex NICA are given in the presented paper.

Cryogenic adsorber design in a helium refrigeration system

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The cryogenic adsorber was specially designed to eliminate impurities in gaseous helium such as O_2, and N_2 which was normally difficult to remove, based on the reversible cryo-trapping of impurities on an activated carbon bed. The coconut shell activated carbon was adopted because of its developed micropore structure and compares the surface area. This activated carbon adsorption was mostly determined by the micropore structure, and the adsorption rate of impurities was inversely as the square of the particle sizes. The active carbon absorber's maximum permission speed of flow was 0.25m/s. When the gaseous helium pressure increased, the adsorption diffusion rate was reduced, because the turbulent flow would be formed. According to the numerical simulation of the N_2 adsorption dynamics progress, the appropriate void tower link speed and the saturated adsorption capacity were determined. Then the diameter and height of the adsorber were designed. The length the mass transfer should be take account into the adsorber height design. The pressure decrease and the regeneration conditions of the adsorber were also calculated. The important factors to influence the adsorber pressure decrease were the void tower speed, the adsorbed layer height, the active carbon particle shape and size.

Dynamic analysis of a SHe closed loop with the 4C code

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The Cryogenic Circuit Conductor and Coil (4C) code has been recently developed for the simulation of thermal-hydraulic transients in the ITER magnets and cryogenic circuit [1]. The code validation was started against different types of transients ranging from (fast) safety discharge [2] to (slow) cool-down [3], but it did not include, so far, the cryogenic circuit module.
The Helios SHe cooling loop, developed at CEA Grenoble, France, is going to test different options for the smoothing of the heat load from the magnet system to the cryoplant, during ITER operation.
The main components of the Helios loop are: a cold circulator; heat exchangers to a saturated helium bath equipped with a resistive heater; pipes simulating the cooling channels of the ITER TF magnet casing and equipped with resistive heaters; control and bypass valves.
In this paper, we will show how the cryogenic circuit module of the 4C code can be used to model the Helios loop and present results for the evolution of pressures and temperatures driven by different heaters, mimicking the load from the ITER TF coil structures to the cryoplant during a 1800 s plasma pulse. Among the possible heat load smoothing options, we shall then analyze with the model that based on the use of a by-pass valve.

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Cryogenic and Warm High Pressure Valves for New Processes of L/GH2

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Latest hydrogen technologies in distribution infrastructures are characterized by high pressures up to 700barg whereas temperatures in the facilities vary from 21K up to ambient temperature. For these demands a range of valves were developed. Such valves are graded for pressures of 420barg, 640barg and 1000barg and were designed for sizes DN6 up to DN25 with integrated pressure balanced design feature. Depending on the application the actuation is carried out manually or pneumatically and the valve will operate as control or as shut-off valve. Due to explosion risk critical parts are double sealed and equipped with a verifiable back up sealing. Instead of a metallic bellows as a spindle seal, which could not bear such pressures without getting too inflexible, advanced spring force actuated sealing devices are used. Highly qualified design and manufacturing aspects assures a comparable level of tightness with that alternative seals. Supporting parts in the valve are made from high-strength stainless steel grade those are exactly dimensioned to the pressure load and allowing a minimal heat load. Focus in that development has been further on in materials and design of fluid contacted valve components to achieve reasonable life time durability.

Pre-series of Refuel Coupling for Liquid Hydrogen Tank Trailers

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For fuelling and refuelling of tank trailers with liquid hydrogen today an open constructed Johnston type coupling is used however that requires a long time for preparation and postprocessing procedures. In a joint development project with IWATANI, KANSAI Electric Power and WEKA therefore a first prototype of an automatically coupling has been developed and tested in laboratory already. Based on results of these tests the design concept has been substancially optimized reducing weight significantly and improving the handling performance. To realize such advancement a sophisticated design of the sealing system to ambience was developed and the actuation of the coupling ergonomically and intuitively designed. So the coupling can be operated easily by one person and coupled and uncoupled even with GH2 inside. Additional design elements were integrated in the coupling avoiding faulty operation and damages on the system. A further prototype has been manufactured and several performance and practical handling tests are in progress to give valuable inputs and approaches for the continuation in field tests with pre-series types.

Experimental investigation of mobile small-scale LNG prototype of 10000 Nm^3/d

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The future commercial exploitation of remote, small and less accessible gas fields might require the development of new technologies. More compact and efficient liquefied Natural Gas (LNG) technologies are a possible solution for the exploitation of such gas reserves. In recent years, the interest in introduction of LNG utilization technologies based on small-scale LNG production has been rising steeply. In this paper, a 10000 Nm^3/d mobile LNG equipment prototype has been designed, constructed and tested. It has two cascade refrigeration systems. The high-temperature refrigeration system will cool the resource gas to 5 ^oC, and the low-temperature refrigeration system will continue to cool the resource gas to liquefied point with Mixed Refrigerant Cycle (MRC). The kernel compressor is conventional oil-lubricated air-conditioning compressor with the highest pressure 2.0 MPa. The main heat exchanger is plate-fin heat exchanger with four passages. A serial of experiments have been done on the prototype at different resource gas pressures and environmental temperatures. It is less than one hour from the start of the equipment to the existence of LNG. The maximum of LNG capacity is 12500 Nm^3/d as the pressure of resource methane gas is 1.3 MPa, and the energy consumption of liquefying 1 Nm^3 methane is 0.612 kWh.

Fractional Consumption of Liquid Hydrogen and Liquid Oxygen During the Space Shuttle Program

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The space shuttle uses the propellants, liquid hydrogen (LH_2) and liquid oxygen (LO_2), to meet part of the propulsion requirements from ground to orbit. The Kennedy Space Center (KSC) procured over 25 million kilograms of LH_2 and over 250 million kilograms of LO_2 during the 30-year Space Shuttle Program. Because of the cryogenic nature of the propellants, approximately 55% of the total purchased LH_2 and 30% of the total purchased LO_2 were used in the Space Shuttle Main Engines (SSME). The balance of the propellants were vaporized during operations to accomplish various purposes. This paper dissects the total consumption of LH_2 and LO_2 and attributes a fraction to each of the various processing and launch operations that occurred during the entire Space Shuttle Program at the KSC.

Liquid natural gas regasification combined with adsorbed natural gas filling system.

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Adsorbed natural gas (ANG) has attracted recently much attention, as promising alternative to compressed natural gas (CNG) for energy storage and transportation purposes. Having a similar energy density, the ANG can be stored under much lower pressures compared to CNG. The ANG storage systems require efficient adsorbents, usually activated carbons. The adsorption isotherms of methane on activated carbon depend strongly on the temperature. The adsorbent bed temperature should be maintained at the lowest possible level. This paper describes the ANG vessels filling system with the adsorbent bed cooled down by the LNG undergoing the regasification process. It allows a low pressure during the natural gas adsorption, which is then elevated when the bed reaches the environment temperature. The system makes efficient use of the LNG physical exergy and is competitive to other technologies of recovering of the energy spent on the gas liquefaction. A thermodynamic analysis of the combined LNG regasification and ANG filling processes is presented and possible technical solutions are discussed. The proposed system enables the natural gas distribution in remote areas, without the gas pipe network developed.

Combined Brayton-JT cycles with pure refrigerants for natural gas liquefaction

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Natural gas liquefaction cycles with pure refrigerants are investigated as a governmental effort in Korea towards new processes to meet the recent requirements on high efficiency, large capacity, and simple equipment. Based upon a thermodynamic optimization theory recently published by the present authors, it is proposed to replace the methane-JT cycle in the conventional cascade process with nitrogen-Brayton cycle. A variety of combined systems with N2-Brayton, ethane-JT and propane-JT cycles are simulated with Aspen HYSYS and quantitatively compared in terms of thermodynamic efficiency, flow rate of refrigerants, and estimated size of heat exchangers. An optimal cycle configuration is suggested with full details of thermodynamic design for process development. The suggested cycle is expected to be more efficient and simpler than the existing cascade process, while still taking advantage of easy and robust operation with pure refrigerants.

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Optimization of the working fluid for a sorption-based Joule-Thomson cooler

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A Joule-Thomson (JT) cold stage can be driven by a sorption compressor that operates vibration-free, has a potentially long life time, and causes no electromagnetic interference. It, therefore, is appealing to a wide variety of applications, such as cooling of low-noise amplifiers, superconducting electronics, and optical detectors. The operating temperature needed depends on the device to be cooled and extends into the cryogenic range well below 80 K. This paper presents the optimization of the working fluid for sorption-based JT coolers depending on the cold and warm-end temperatures. For specific operating temperatures, the working fluid is optimized on basis of the overall efficiency, which is defined as the heat absorbed at the cold tip (i.e. the cooling energy) per unit of heat supplied to the sorption compressor. Also, the cooling energy is considered per unit of adsorbent mass. Furthermore, a figure of merit is introduced which represents the cooling power for a certain amount of adsorbent, as an additional criterion for selecting the best working fluid. In this study, both Saran and Maxsorb are considered as the adsorbents.

Characterization of Sorption compressor for Mixed Refrigerant J-T Cryocooler

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Abstract

The requirement of a cryocooler with minimum vibrations for space borne system and highly sophisticated electronic devices for ground applications, has led to the development of Sorption compressor type J-T cryocooler. The adsorption capacity of any adsorbent material increases with an increase in pressure and decreases with an increase in temperature. In a Sorption compressor, adsorbed gases are desorbed in a confined volume by raising temperature of the sorption bed, which results in increase in pressure of gas. A uniform temperature across the sorption bed ensures maximum discharge from the compressor amounting to higher flow rates and longer cycle time on account of reduced residual loading. In addition, it is also very important to determine the adsorption capacity of any material with respect to the gas or gases to be adsorbed as this varies with source of the adsorbent. The present work reports the characterization of a fully operational two-cell sorption compressor developed. The sorption Compressor is characterized for discharge pressure variation with cycle time; this is essentially a function of a) The amount of adsorbent b) the adsorption capacity for respective gas or gases c) desorption temperature and its uniformity d) system dead volume. The present paper analyses these aspects theoretically and the results are compared with the experimental data obtained for individual gases as well as for gas mixtures. The effect of gas distribution on temperature uniformity across the bed and of heater power on high pressure generated is also studied. The paper also discusses the pressure profile obtained for a given amount of adsorbent for different gas or gas mixture. The work, based on the results obtained so far, is further extended for a four cell sorption compressor.

Effects of environmental temperature on performance of Joule-Thomson refrigerator

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Miniature Joule-Thomson refrigerators have been widely used for rapid cooling of infrared detectors, probes of cryosurgery, thermal cameras, missile homing head and guidance system, due to their special features of simple configuration, compact structure and rapid cool-down characteristics. Typical performance factors of the Joule-Thomson refrigerator are cool-down time, temperature of the cold end, running time and gas consumption. The above performance factor depend on the operating conditions such as the pressure of the gas, the thermal environment and etc.. In this study, experimental study of a miniature Joule-Thomson refrigerator with the gas pressure up to 12 MPa were performed to investigate effects of the thermal environment (-40 ~ 50 DegC). In experiments, in order to collect the information of cool-down time, gas consumption and etc., the temperature of the cold end, mass flow rate and pressure of the argon gas are simultaneously measured. The Joule-Thomson refrigerator in the cold thermal environment has rapid cool-down characteristics. Effects of the environment temperature on performances of the refrigerator are discussed.

Application of Cryocoolers to a Vintage Dilution Refrigerator

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A dilution refrigerator is required for 50mK detector operation of CDMS(Cryogenic Dark Matter Search). An Oxford Instruments Kelvinox 400 has served this role for ten years but required daily transfers of liquid nitrogen and liquid helium. Complicating the cryogen supply is the location 800 meters below ground in an RF shielded, class 10000 clean room at Soudan, MN.

Nitrogen and helium re-liquefiers using cryocoolers were installed outside the clean room and continuously condense room temperature gas and return the liquids to the dilution refrigerator through a transfer line. This paper will describe the design, installation, controls and performance of liquefaction systems.

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Cryogen-free dilution refrigerator with separate 1K cooling circuit.

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He-3,4 dilution refrigeration is indispensable for low temperature science and engineering as it is the only method that provides temperatures between 0.3K and 0.005K for unlimited working periods. Cryogen-free dilution refrigerators (DR) have become very popular in recent years and are about to replace traditional cryostats with liquid helium precooling. A wide variety of DRs has become commercially available. The dilution circuit is always precooled by a two-stage pulse tube cryocooler; therefore, refrigeration capacities are available to the experimentalist at the temperatures of the two stages of the pulse tube cooler, and furthermore at three temperatures of the dilution circuit (~ 0.7K - still, 0.1K - heat exchanger, ~ 0.01K - mixing chamber). However, there are quite a few applications (e.g. quantum information processing or astro-physics) where the cooling power of the still near ~1K is not sufficient to cool amplifiers and electric lines. In our work we present a dilution refrigerator where a He-4 cooling circuit has been added to the dilution circuit. This He-4 circuit provides up to 100mW of refrigeration capacity in addition to the cooling capacity of ~ 10mW of the still. The dilution circuit and the 1K-circuit can be operated separately and independently of each other. Constructional and experimental details of this cryogen-free DR are presented in our paper.

Experimental investigation of active magnetic regenerator operating between 77 K and 20 K

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An active magnetic regenerator (AMR) operating between 77 K and 20 K is fabricated and tested. The main components of the AMR system are magnetic refrigerant, superconducting magnet and heat transfer medium. Due to the wide temperature span, four magnetic refrigerants that have different transition temperatures are selected. They are $GdNi_2$, $Dy_{0.85}Er_{0.15}Al_2$, $Dy_{0.5}Er_{0.5}Al_2$, and $Gd_{0.1}Dy_{0.9}Ni_2$. The two stage AMR with two different magnetic refrigerants are layered in each stage. $GdNi_2$ and $Dy_{0.85}Er_{0.15}Al_2$ are layered in the first stage AMR that operates between 77 K and 45 K, and $Dy_{0.5}Er_{0.5}Al_2$ and $Gd_{0.1}Dy_{0.9}Ni_2$ are in the second stage one that operates between 44 K and 20 K. The superconducting magnets that can produce over 3 T magnetic field are utilized as magnetic field sources and they are cooled in liquid helium bath. The magnetic field variation is achieved by the AC operation of the magnets. The gaseous helium is the heat transfer medium and it is circulated by the helium compressor. The heat transfer medium is pre-cooled in the liquid nitrogen bath and is supplied to the first stage AMR with its temperature around 77 K. The layering volume fraction in each AMR is determined with the numerical simulation and the performance of the fabricated AMR according to the various layering fraction is experimentally investigated. The overall performance of the two stage AMR system that operates with almost 60 K of temperature span is also investigated.

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Hybrid numeric model for regenerators based on thermoacoustic theory

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The regenerators play important roles in thermal systems based on oscillating flow, which include the Stirling engines, Stirling type cryocoolers and traveling-wave thermoacoustic engines, etc. There have been several famous computational codes for regenerators or the complete systems, such as REGEN and Sage. For the most recent ten years, the thermoacoustic theory has been extensively used in the simulation of these systems and DELTAEC is one of the most famous. Since 2003, the author has also developed a modular program based on the theory to simulate the engines and cryocoolers, which have been validated through practical experiments. One of the special features of the program is that a hybrid model based on Jia Hua Xiao's theory and Swift's theory is used for the regenerator. The article mainly compares the results from the model with the results of REGEN to see their conformity. For the given five case studies, including engines and coolers, high frequency systems and low frequency systems, both programs show surprisingly good agreement with each other.

Exergy-based figure of merit for regenerative and recuperative heat exchangers with application to multistage cryocoolers

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One of the major losses in cryogenic refrigerators operating on oscillating regenerative cycles or steady state recuperative cycles is due to regenerative or recuperative heat exchangers in the cycles, respectively. Accurate numerical modeling of these losses requires extensive numerical simulation of coupled mass, energy, and momentum conservation equations. In this study, a unified model based on exergy flow is developed to define the Figure of Merit (FOM) for heat exchangers with application to multistage cryogenic refrigerators. It is shown that the conventional definition of exergetic efficiency used for heat exchangers is not convenient for their performance evaluation in their application to multistage cryocoolers. It is shown that a rational definition of exergy input to the heat exchanger component is necessary for proper definition to the FOM. The result of the first order model of the regenerator is compared to the results of computational fluid dynamics using REGEN 3.2. The effect of intermediate cooling on the FOM of recuperative heat exchangers is presented. The exergy destruction in the heat exchangers due to heat transfer and fluid flow are presented and discussed.

Thermodynamic Properties Status of Deuterium and Tritium

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Deuterium and tritium are increasingly seeing use in cryogenics as a fuel for nuclear fusion energy machines. The current Equation of State (EOS) for deuterium was based on work completed before the mid 1980's and tritium does not have an EOS in the literature. In order to assess the need for new property correlations and experimental measurements, this paper presents a review and comparison of the available thermodynamic property measurements and models for deuterium and tritium. The comparisons extend a wide range of temperatures and pressures from the onset of solidification to the highest temperature and pressure measurements available. Based on the comparisons, recommendations for new experimental measurements and thermophysical property correlations will be made.

Thermal conductivity of helium-3 between 3 mK and 300 K

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The thermal conductivity property of helium-3 is investigated within the temperature range of 0.003 - 300 K, and at pressures to 20 MPa. An empirical equation, in a form of Chebyshev polynomials, is proposed for cryogenic engineering applications in the entire concerned range. Because of lacking sufficient experimental data above 20 K, a quantum version of the principle of corresponding states is used to predict the reference data of the thermal conductivity helium-3, by incorporating the reduced properties of argon, neon, hydrogen, and helium-4. The calculated data by the equation are in good agreement with the historical measurements. At extremely low-but-finite temperatures, the equation could be smoothly switched to the theoretical limit ($1/\lambda T \sim a+bT$) predicted by the quantum theory by applying Fermi-Dirac statistics to fluid helium-3. At higher temperatures up to 1000 K but with low densities, the predictions by the equation well join the precise thermal conductivity curve of dilute ^{3}He gas proposed by Hurly and Moldover from NIST. On this basis, the thermal conductivity behaviors of helium-3 and helium-4 are compared.

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Apparatus for accurate density measurements of fluids over wide ranges of temperature, pressure, and density based on a compact single-sinker densimeter

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A new apparatus used to obtain accurate (p-ρ-T) measurements of fluids over wide ranges of temperature, pressure, and density (90 to 290 K; 0 to 3 MPa; 5 to 1700 $kg \cdot m^{-3}$) is described in detail. This apparatus is designed based on a compact single-sinker densimeter and includes the refrigeration system, the thermostat system, the temperature and pressure measuring system. The total uncertainty in density is less than 0.1%+0.001 $kg \cdot m^{-3}$. It is primarily due to the calibration of the sinker. The uncertainty in temperature is 0.005 K and that in pressure is 300 Pa and 600 Pa for the 1.5MPa and 3MPa full scales respectively. This apparatus is specially designed for the density measurements of pure or mixed liquid refrigerants and standard fluids for the calibration of other type densimeters. The densities of high-purity nitrogen and isobutane were measured to test and verify the reliability of the apparatus. The experimental results were campared with the literature data and the data calculated from the equation of state. Good agreements are obtained.

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Performance of an ortho-para concentration measurement cryostat for hydrogen

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In this paper the results of the performance tests of an ortho-para analyzer for hydrogen are presented. The measurement is based on the easy and reliable gauging of the adiabatic heat of conversion between the hydrogen allotropes. A hydrogen gas flow is brought to a defined temperature here by the means of a liquid nitrogen bath at 77 K. Subsequently it is led through a catalyst bed inside an adiabatic cell. The ortho-para ratio can be derived from a precise temperature measurement before and after the catalytic induced conversion. Vice versa, with a known para content of the hydrogen feed, the activity of a given catalyst sample can be determined. The discussion of the results of the performance tests includes a chapter for the essential proper preparation of the necessary ortho-para catalyst material for the adiabatic conversion and the use of a suitable database of the thermodynamic properties of orthohydrogen and parahydrogen. A slight drawback of this method is the relatively large amount of hydrogen gas compared to other ortho-para concentration measurements.

Design of a Solid Hydrogen Target Cryostat for Positron Moderation Studies

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Despite the widespread use of positron technology the efficiency of positron source utilization, the ratio of usable positrons to positrons produced from a nuclear source, is less than 1 %. The low efficiency is due to positron destruction during moderation; emitted positrons must be filtered through a moderator material to restrict the re-emitted positrons to a useable and defined energy range. The quantum mechanical nature of solidified hydrogen holds the potential to increase the moderator efficiency an order of magnitude over solid neon–the current leader in moderator efficiency; however the characteristics of solid hydrogen as a positron moderator have never been investigated. This paper discusses the preliminary design of an experimental cryostat to create solid hydrogen targets for positron beam studies. The design is constrained by the sublimation pressure of the solid hydrogen target exceeding the vacuum pressure of the positron accelerator, and the ability to control hydrogen crystal growth and quality. Thermal control calculations of the test section and heat exchangers will be presented.