Modeling of a vertical circulation loop in two-phase helium

Bertrand Baudouy[1]

[1] *CEA Saclay, IRFU/SACM, 91191 Gif-sur-Yvette, France*

An efficient cooling method for superconducting coils of large magnets working at an operating around 4.2 K is a two-phase circulation loop where the flow is naturally driven by the weight difference between the two branches of the loop due to vaporization. The main advantage of this cooling technique is that it eliminates the use of pressurization system such as pumps which require a costly maintenance and operation at low temperatures. To study the thermohydraulics properties of such cooling method, a single tube experimental test apparatus has been built and several experimental studies have been achieved on heat transfer, pressure drop and general thermohydraulics behavior. To build on these experimental studies, a predictive numerical model has been developed. In this paper we present the thermohydraulics modeling of such a flow configuration with and the comparison with experimental results.

Wall Shape Optimization for a Thermosyphon Loop featuring Corrugated Pipes

P. I. Rosen Esquivel[1,*], J.H.M. Ten Thije Boonkkamp[1], J.A.M. Dam[1,2], and R.M.M. Mattheij[1]

[1]*CASA, Department of Mathematics and Computer Science, Eindhoven University of Technology, P.O. Box 513, 5600 MB Eindhoven, The Netherlands.*
[2]*Stork FDO Inoteq B.V., P.O. Box 379, 1000 AJ Amsterdam, The Netherlands.*

In the present paper we address the problem of optimal wall-shape design of a thermosyphon loop. The model takes the buoyancy forces driving the flow into account via the Boussinesq approximation. We focus our study on finding the optimal geometrical configuration for the thermosyphon loop. To this extend we determine de dependency of the friction factor and the heat transfer rate, on the geometrical characteristics of the loop. The geometry considered is a set of axially symmetric corrugated pipes described by a set of parameters; namely the pipe inner radius, the period of the corrugation, the amplitude of the corrugation, and the ratio between the expansion and contraction regions of the pipe.

The governing equations are solved using the Finite Element Method, and since the computations of Jacobians is unfeasible, the optimization procedure is carried out with a derivative-free method. This technique allows us to find an optimal set of values for the design parameters, either maximizing the heat transfer rate, or minimizing the friction factor. The results show that by adequately choosing the design parameters, the performance of the thermosyphon loop can be significantly improved.

This work is part of a project in collaboration with Stork FDO Inoteq and it is funded by Ballast Nedam IPM.
* CEC Program Chairperson

Experimental investigation of the free convective heat transfer along inclined connection pipes in high-pressure cryogenic storage tanks

R. Langebach[1], Ch. Haberstroh[1]

[1]*Technische Universitaet Dresden, Bitzer-Stiftungsprofessur fuer Kaelte-, Kryo- und Kompressorentechnik, 01062 Dresden*

The minimization of heat intake is one of the main challenges during the design process of cryogenic storage tanks. Previous investigations, mostly based on numerical schemes, have shown that connection pipes can increase the heat intake to those devices significantly. Under certain geometric conditions a free convective flow field builds up which is able to enhance the heat transfer from the warm end to the cold end of the pipe in a dramatic way. Due to the non-linear dependency to the pressure in the pipe this effect is mainly an issue for high-pressure cryogenic storage tanks. In order to investigate the transferred heat experimentally, a test cryostat was designed and manufactured. The cryostat is pivot-mounted and can be positioned in any inclination angle. Inside the outer vessel a thermally isolated test pipe with a maximum length of 1 m and a maximum fluid pressure of 200 bar can be placed. The paper gives a closer look to the main issues of the cryostat design and the measurement principle. First measurement results are presented and discussed in comparison to previous numerical calculations. The main outcome is that correlations and heat transfer numbers gained from numerical calculations can be validated and compared with those experimental results.

Flow boiling heat transfer characteristic of hexafluoroethane in a horizontal tube

S. WANG [1, 2], M.Q. Gong [1],*, G.F. Chen [1, 2], Z.H. Sun [1], J.F. Wu[1], **

[1] *Key Laboratory of Cryogenics, Technical Institute of Physics and Chemistry, Chinese Academy of Sciences, P.O. Box 2711, Beijing, 100190 China.*

[2] *Graduate University of the Chinese Academy of Sciences, Beijing, 100049 China.*

Hexafluoroethane (R116) is one component of the binary mixture refrigerant of R508, which is currently used in the low-temperature stage of two-stage cascade refrigeration systems for refrigeration applications around 180 to 200 K. R116 is also used in the auto-cascade mixed-refrigerant Joule-Thomson refrigerators to reach cryogenic temperature.

To improve the performance of mixed-refrigerants containing hexafluoroethane as a component, accurate knowledge of boiling heat transfer coefficients is essential. In this work, saturated flow boiling heat transfer characteristics in a smooth horizontal tube of hexafluoroethane were measured at various pressures ranging from 0.15 to 0.60 MPa, which is rarely available in the open published articles. The experiments were carried out at various heat fluxes ranging from 20 to 74 kW m^{-2}, and mass fluxes from 350 to 800 kg m^{-2} s^{-1}. The influences of different experimental parameters on the flow boiling heat transfer coefficient (HTC) were discussed. The uncertainties of the experiment were also analyzed in detail.

* Corresponding author. Tel./fax: +86-10-82543728.

** Corresponding author. Tel./fax: +86-10-62627843.

E-mail addresses: gongmq@mail.ipc.ac.cn (M.Q. Gong), jfwu@mail.ipc.ac.cn (J.F. Wu).

Forced convection heat transfer of subcooled liquid hydrogen in a horizontal tube.

H. Tatsumoto[1], Y. Shirai[2], M. Shiotsu[2], K. Hata[3], Y. Naruo[4], H. Kobayashi[4], Y. Inatani[4], K. Kinoshita[5].

[1]*J-PARC Center, Japan Atomic Energy Agency, Ibaraki, 319-1195 Japan.*
[2]*Dept. of Energy Science and Technology, Kyoto University, Kyoto, 606-8501 Japan.*
[3]*Institute of Advanced Energy, Kyoto University, Kyoto, 606-8501 Japan*
[4]*Institute of Space and Astronautical Science, Kanagawa, 229-8510 Japan*
[5]*Energy Use R&D Center, The Kansai Electric Power Co.Inc., Amagasaki, 661-0974 Japan.*

Liquid hydrogen has various applications such as a coolant for HTS superconducting magnets, a cold neutron moderator material for a spallation neutron source, a fuel for a rocket engine, and a clean energy source. It is important for the cooling design to understand forced flow heat transfer in liquid hydrogen. However, the heat transfer data in forced flow of liquid hydrogen are very few, as far as the authors know. In this work, heat transfers from inner side of a heated horizontal tube to liquid hydrogen were measured for wide ranges of flow rate, pressure and liquid temperature. Inner diameter of the pipe was 6 mm and the length was 100 mm. The heat transfer coefficients before the inception of boiling for each flow velocity agreed with the Dittus-Boelter equation. Effect of flow velocity and liquid subcooling on the DNB heat flux in liquid hydrogen was clarified. Furthermore, the tube attitude dependence was also clarified, compared with the previous data for a vertical tube.

Modified-Collins Cryocooler for Zero-Boiloff Storage of Cryogenic Fuels in Space

C.L. Hannon[1], B. Krass[1], J.R. Hogan[2], and J.G. Brisson[2]

[1]*Advanced Mechanical Technology, Inc., 176 Waltham Street, Watertown, MA 02472 U.S.A.*
[2]*Massachusetts Institute of Technology, 77 Massachusetts Avenue, Cambridge, MA 02139 U.S.A.*

Future lunar and planetary explorations will require the storage of cryogenic propellants, particularly liquid oxygen (LOX) and liquid hydrogen (LH2), in low earth orbit (LEO) for periods of time ranging from days to months, and possibly longer. Without careful thermal management, significant quantities of stored liquid cryogens can be lost due to boil-off. Boil-off can be minimized by a variety of passive means including insulation, sun shades and passive radiational cooling. However, it has been shown that active cooling using space cryocoolers has the potential to result in Zero Boil-Off (ZBO) and the launch-mass savings using active cooling exceeds that of passive cooling of LOX for mission durations in LEO of less than 1 week, and for LH2 after about 2 months in LEO. Large-scale DC-flow cryogenic refrigeration systems operate at a fraction of the specific power levels required by small-scale AC-flow cryocoolers. The efficiency advantage of DC-flow cryogenic cycles motivates the current development of a cryocooler based on a modification of the Collins Cycle. The modified Collins cycle design employs piston type expanders that support high operating pressure ratios, electromagnetic valves that enable "floating pistons", and recuperative heat transfer. This paper will describe the design of and the results of testing a prototype Modified-Collins cryocooler for ZBO storage of cryogenic fuels in space.

Modeling and Testing of Cryo-Adsorbent Hydrogen Storage Tanks with Improved Thermal Isolation

Alexander W. Raymond[1] and Joseph W. Reiter[1]

[1]*Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109 U.S.A.*

One material storage concept for hydrogen-fueled vehicles is adsorption of hydrogen on activated carbon at cryogenic temperatures (nominally 77 K). In idle tanks, parasitic heat transferred from the environment induces desorption to the tank void volume, thus increasing the hydrogen gas pressure. Over long periods, the pressure can become such that hydrogen must be vented to prevent rupture. To minimize the amount of fuel lost to venting, multi-layer vacuum insulation and thermally isolating structures made of low-conductance G-10 CR composite have been proposed in the literature for cryo-compressed hydrogen storage. A model is developed to predict the amount of conduction through structural supports and hydrogen lines, the amount of radiation through multi-layer insulation, and the amount of rarified gas convection in the vacuum jacket of a tank sized for adsorption storage. The model reveals that conduction through the G-10 CR structure accounts for approximately half of the parasitic heat transfer. To reduce this value, an improved method of structural support is proposed, which utilizes Kevlar cable to suspend the pressure vessel in the vacuum jacket. The G-10 CR and Kevlar structures are sized to support comparable inertial loadings; the overall parasitic heat transfer is found to be up to 46 percent less for the Kevlar design. A lumped-parameter tank simulation is used to show that the lower heat transfer rate significantly extends the time before venting commences and conserves up to 1 kg of hydrogen in a 5.6 kg tank over a 20 day idle period. The results of thermal testing of sub-scale G-10 CR and Kevlar-supported tanks are presented. These experiments are used to validate the improved dormancy of the Kevlar design predicted by simulation.

Design, Fabrication and Testing of a Liquid Hydrogen Fuel Tank for a Long Endurance Aircraft

G. L. Mills[1], B.W. Buchholtz[1], A. D. Olsen[2]

[1]*Ball Aerospace & Technologies Corp.,1600 Commerce Street, Boulder, CO 80301, U.S.A.*
[2]*The Boeing Company, 5301 Bolsa Avenue, Huntington Beach, CA 92647, U.S.A.*

Liquid hydrogen has distinct advantages as an aircraft fuel. These include a specific heat of combustion 2.8 times greater than gasoline or jet fuel and zero carbon emissions. It also can be utilized by fuel cells, turbine engines and internal combustion engines. The large heat of combustion is particularly important in the design of long endurance aircraft with liquid hydrogen enabling cruise endurance of several days. However, the mass advantage of the liquid hydrogen fuel will result in a mass advantage for the fuel system only if the liquid hydrogen tank and insulation mass is a small fraction of the hydrogen mass. The challenge is producing a tank that meets the mass requirement while insulating the cryogenic liquid hydrogen well enough to prevent excessive heat leak and boil off. In this paper, we report on the design, fabrication and testing of a liquid hydrogen fuel tank for a high altitude, long endurance (HALE) demonstration aircraft. High level design options on tank geometry, tank wall material and insulation systems are discussed. The final design is an aluminum sphere insulated with spray-on foam insulation (SOFI). Several steps and organizations were involved in the tank fabrication and test. The tank was cold shocked, helium leak checked and proof pressure tested. The overall thermal performance was verified with a boil-off test using liquid hydrogen.

Development of 20 kW class high temperature superconducting induction/synchronous machine for automobile application

T. Nakamura[1], Y. Itoh[2], M. Yoshikawa[2], T. Terazawa[2], Y. Ohashi[3], N. Okumura[3], D. Sekiguchi[1], S. Misawa[1], H. Kitano[1], Y. Kawanishi[1], M. Fukui[1], T. Matsuo[1], M. Miyamoto[1], N. Amemiya[1], K. Osamura[4], J. Ogawa[5], S. Fukui[5], and T. Oka[6]

[1]*Graduate School of Engineering, Kyoto University, Kyoto 615-8510, Japan*

[2]*IMRA MATERIAL R&D Co., Ltd., Kariya 448-0032, Japan*

[3] *AISIN SEIKI Co., Ltd., Kariya 448-8650, Japan*

[4]*Research Institute for Applied Sciences, Kyoto 606-8202, Japan*

[5] *Graduate School of Science & Technology, Niigata University, Niigata 950-2181, Japan*

[6] *Faculty of Engineering, Niigata University, Niigata 950-2181, Japan*

This paper reports on the current status of 20 kW class High Temperature Superconducting Induction/Synchronous Machine (HTS-ISM) development for the next generation automobile applications. Basic structure of the HTS-ISM is the same as that of the squirrel-cage induction machine, and DI-BSCCO tape conductors are utilized for the fabrication of rotor and stator windings. Geometrical shape of the DI-BSCCO racetrack double-pancake coils is carefully designed and fabricated for the stator windings, by considering the limitation of allowable bending radius from the point of view of the superconducting property. Iron core is also selected through the precise measurements of the electromagnetic behavior and the mechanical property in liquid nitrogen, from some candidates. And then, magnetic structure of the HTS-ISM is designed based on the FEM analysis. Small scale cryostat is specially designed for the improvement of thermal performance. We successfully carry out the rotation test at the rated speed of 1800 rpm. Fabrication and test details will be presented.

This work was supported by New Energy and Industrial Technology Development Organization (NEDO) in Japan.

Design of a high power cryogenic permanent magnet wind generator

Mehran Mirzaei[1], Mojtaba Ghodsi[2], Mohammad taghi Khodakarami[3]

[1] *Energy Conversion, Darmstadt University of Technology, P.O. Box 64283, Darmstadt, Germany*
[2] *Mechanical Department, Tarbiat Modares University, Tehran, Iran*
[3] *Mechanical Department, K. N. Toosi University of Technology, Tehran, Iran*

Using wind generators are increasing to produce electricity as a renewable and clean energy source. Permanent magnet wind generators are suitable options for direct drive wind turbines. Cryogenic permanent magnet generator reduces the mass and volume of the system which is very important for 5-10 MW wind turbines. The cryogenic systems help to reduce copper losses and increase the power density of generators. In this paper, electromagnetic design of a cryogenic permanent magnet generator and thermal analysis are presented to evaluate the generator behavior at very low temperatures. Finally, a designed cryogenic permanent magnet generator will be compared with one conventional direct drive permanent magnet generator to evaluate the mass reduction and efficiency of generators for 10 MW wind turbines. Finite element and analytical methods are used for calculations.

A New power source for steel industry: Design a liquid nitrogen power generator

L. K. Naik[1,†], B. Mallick[2,]*, and S. K. Sahu[1,2,**]

[1]Department of Electrical and Electronics Engineering, Spintronic Technology and Advance Research, Taraboi-752050, Bhubaneswar, India.[‡]
[2]Institute of Physics, Bhubaneswar 751005, India.

Liquid nitrogen warms up at room temperature (25°C) because of its low liquefaction temperature of -196°C. In this stage, it undergoes first a phase change (from liquid to gas), which results in an expansion of (0.807g/cc / 0.004622g/cc) 174.6 times the original volume of liquid. The resulting nitrogen gas is than warmed by room temperature (25°C) expanding an extra (0.00462g/cc / 0.00125g/cc) 3.7 times. Hence, the net expansion for liquid nitrogen is 645.3 (i.e., 174.6 × 3.7) times the original volume when heated to room temperature. This means that 1 liter of liquid nitrogen will occupy 645.3 liters as a gas once it has all vaporized. Due to this dramatic expansion, when liquid nitrogen is placed in a Heat Exchange Pressurizes Tank (HEPT) and allowed to vaporize, the pressure in the container will rise very quickly. Due to the non-ideal gas behavior of N_2 at such extreme pressures, the theoretical pressure of the container would be over 30000 PSI. So a specially built HEPT consists of manual-compressor and a gas regulator with an adjustable nuzzle can deliver high-pressurized gas jet, which is capable to rotate a turbine with very high speed, hence produces electricity. In the full paper, the engineering and technical details of the HEPT discussed. This portable LN_2 based electric power generator can provide vital information to built an alternative electric power plant for steel industry using the waste LN_2 produce during processing of steel.

Author would like to thank the Director and Staff of “Mech-Tech Engineering”, Bhubaneswar, India for their help during fabrication of HEPT.
* Corresponding author: bmallick@iopb.res.in (BM, Scientist, IOP Bhubaneswar)
** Co-author: ssahu@iopb.res.in (SKS, Scientist, IOP Bhubaneswar and Secretary, STAR, Bhubaneswar)
† Presenting author: kumarlohita@yahoo.com (LKN, Scholar, STAR, Bhubaneswar)

Theory of cascade refrigeration

H. H. Quack

Bitzer-Stiftungsprofessur fuer Kaelte-, Kryo und Kompressorentechnik,
TU Dresden, D-01062 Dresden, Germany

The possible difference between the warm and the cold temperature of a refrigeration cycle are often limited by the properties of the refrigerant or losses associated with the transport of the refrigerant from the warm to the cold temperature and back. Therefore one is often forced to use several refrigeration cycles “above” each other, each cycle spanning a certain temperature difference. This approach is called cascade refrigeration.

Cascade refrigeration has played an important role in the history of cryogenics, e.g. in the first liquefaction of air. And it is still important today, e.g. when natural gas is liquefied or in magnetic refrigeration.

For a general theory of cascade refrigeration it is helpful to define first a general one-stage non-reversible refrigeration step and to visualize it within the temperature-entropy (T-S) diagram. Then one can combine several one-stage cycles to a cascade. It turns out that there exist two types of cascades: “Full” cascades, where all entropy gains of lower temperature cycles are transferred to the next higher temperature cycle, and “partial” cascades, where each single cycle goes up to ambient temperature, where a part of the entropy gain is removed, and only the rest of the entropy gain is transferred to the next higher temperature cycle.

It turns out, that “partial” cascades are generally more efficient than “full” cascades. This result is important for the prediction of the practical limits of magnetic refrigeration systems.

Options for Cryogenic Load Cooling with Forced Flow Helium Circulation

P. Knudsen[1], V. Ganni[1], R. Than[2]

[1]*Thomas Jefferson National Accelerator Facility, 12000 Jefferson Ave., Newport News, VA 23606 U.S.A.*
[2]*Brookhaven National Laboratory, Upton, NY 11973 U.S.A.*

Cryogenic pumps designed to circulate super-critical helium are commonly deemed necessary in many super-conducting magnet and other cooling applications. Acknowledging that these pumps are often located at the coldest temperature levels, their use introduces risks associated with the reliability of additional rotating machinery and requires the refrigeration system to handle the additional loads. However, as it has been successfully demonstrated, this objective can be accomplished directly by the refrigeration system, without using these pumps, using less system input power and with improved reliability to the overall cryogenic system operations. In this paper we examine some trade-offs between using these pumps vs. using the refrigeration system directly and examples of processes that used this concept successfully and eliminated using such pumps.

Program ID: C2OrC-03, 2011 Cryogenic Engineering Conference and International Cryogenic Materials Conference © 2011

Process Options for Nominal 2-K Helium Refrigeration System Designs

P. Knudsen, V. Ganni

Thomas Jefferson National Accelerator Facility, 12000 Jefferson Ave., Newport News, VA 23606 U.S.A.

Nominal 2-K helium refrigeration systems are frequently used for superconducting radio frequency and magnet string technologies used in accelerators. This paper examines the trade-offs and approximate performance of four basic types of processes used for the refrigeration of these technologies; direct vacuum pumping on a helium bath, direct vacuum pumping using full or partial refrigeration recovery, cold compression, and hybrid compression (i.e., a blend of cold and warm sub-atmospheric compression).

Control-oriented modeling and multivariable control of a cryogenic refrigerator

Pawel Majecki[1], Fanny Clavel[1], Patrick Bonnay[1], and Mazen Alamir[2]

[1]*Service de Basses Températures, CEA/DSM/INAC, 17 rue de martyrs, 38054 Grenoble Cedex 9, France*
[2]*GIPSA-lab, Control Systems Department, BP 46, Domaine Universitaire, 38400 St Martin d'Heres, France*

In this paper, we present the results of model-based multivariable control of a cryogenic refrigerator subject to high pulsed thermal loads, such as those occuring in tokamak thermonuclear reactors. The development of a control-oriented "grey-box" model of the coldbox is described first, which is obtained from a combination of first-principles analysis and identification methods, and combined with the model of the compressor station, available from the previous work. The objective was to derive a complete nonlinear dynamic model of the refrigerator, which would be physically sound and accurate enough to be used as a simulator, reproducing the dominant system behaviour as faithfully as possible, and yet simple enough to be used for control design purposes. Such a model was developed in the Matlab/Simulink environment and validated against experimental data for the case of one Brayton cycle. The model can be readily used to extract models linearized around specified operating points. The multivariable controller is described in the second part of the paper, and is based on a linear model of the refrigerator, corresponding to the nominal operating conditions. Two control algorithms were compared in simulation: a linear-quadratic (LQ) regulator (simple to implement), and a predictive controller (taking into account process constraints). Computational limitations led to more emphasis to be put on the real-time implementation of the LQ scheme, and good results are reported. Overall, the tests performed on the experimental refrigeration facility, located at the Institute of Low Temperatures, CEA, Grenoble demonstrate that advanced control can be successfully implemented on a refrigerator of a relatively small size (400 watt at 4.5K).

Linde's Dynamic Gas Bearing Turbine Technology in Hydrogen Plants

Klaus Ohlig[1], Stefan Bischoff[2]

[1] *CEO, Linde Kryotechnik AG, Daettlikonerstrasse 5, 8422 Pfungen, Switzerland*

[2] *Project Manager Turbine Technology, Linde Kryotechnik AG, Daettlikonerstrasse 5, 8422 Pfungen, Switzerland*

Linde Kryotechnik AG is the leading company in the field of engineering and fabricating plants for cryogenic helium and hydrogen applications based on turboexpander technology. Dynamic gas bearing turbines – although applied for helium refrigerators and liquefiers for decades – experienced limitations for hydrogen applications due to restrictions in axial bearing capacity. With its new design concept for gas bearing turbines in 2004, Linde significantly improved axial bearing capacity enabling the transfer of this technology to hydrogen liquefiers. Prior to marketing the technology, Linde conducted extensive tests in its R&D facilities in Switzerland. Industrial scale demonstration was subsequently conducted at Linde Gas' hydrogen liquefier in Leuna, Germany, where the first of in total three expansion steps could optionally be realized via this innovative turbine type. Since its installation, this turbine has now gathered more than 8,000 successful operating hours and has outperformed its oil bearing brother both in terms of performance, maintainability as well as reliability. Linde's dynamic gas bearing turbines have since become the state-of-the-art technology. A first hydrogen liquefier solely equipped with dynamic gas bearing turbines is presently in execution and will start-up mid 2012.

More than 40 years experience for Air Liquide in the field of cryogenic turbomachines

Franck Delcayre[1], Luc Drevard[1], Fabien Durand[1], Gérard Marot[1]

[1]*Air Liquide DTA, 2 rue de Clémencière, BP 15, 38360 Sassenage, France*

Air Liquide has developed for more than 40 year cryogenic turbo-expanders mainly for hydrogen and helium liquefiers and refrigerators.

More recently, in the 80's and 90's, following the demand of cooling power at 1.8 K for cryogenic applications, Air Liquide has also developed cold compressors. Now, machines with isentropic efficiencies better than 80% are available on the market. And Air Liquide has in total now more than 500 references of cryogenic turbo-expanders and cold compressors. The last developments in this field will be presented.

Design and development of the Astro-H 3-stage ADR

Peter J Shirron[1], Mark O Kimball[1], Bryan James[1], Donald Wegel[1], Raul Martinez[2], Dick Faulkner[3], Marcelino Sansebastian[3]

[1]*Cryogenics and Fluids Group, NASA/Goddard Space Flight Center, Greenbelt, MD 20771*
[2]*Ball Aerospace & Technologies Corp., 7404 Executive Place, Suite 100, Lanham, Md 20706*
[3]*SGT, Inc., 7701 Greenbelt Road, Suite 400, Greenbelt, Maryland 20770*

The Japanese Astro-H mission will include the Soft X-ray Spectrometer (SXS) instrument provided by NASA/GSFC. The SXS will perform imaging spectroscopy in the soft x-ray band using a 6x6 array of silicon microcalorimeters operated at 50 mK. The detectors will be cooled by a 3-stage adiabatic demagnetization refrigerator (ADR). The configuration allows the ADR to operate with both a 1.3 K superfluid helium bath and a 4.5 K cryocooler as its heat sink. Initially, when liquid helium is present, the two coldest stages of the ADR will operate in a single-shot mode to cool the detectors from 1.3 K. The 3rd stage may be used to transfer heat from the liquid to the cryocooler to extend its lifetime. When the liquid is depleted, the two warmest stages will operate in a continuous mode to establish a 1.3 K base temperature, from which the cold stage will operate in a single-shot mode to cool the detectors. This paper will describe the design and operating modes of the ADR, as well as details of individual components.

Localization of the liquid-vapor phase interface in the still of a closed cycle ^3He-^4He dilution refrigerator for space applications

Angela Volpe, Gunaranjan Chaudhry, and Gerard Vermeulen[†]

Néel Institute, CNRS-UJF, BP 166, 38042 Grenoble CEDEX 9, France

We present our work on the localization of the liquid-vapor phase interface in the still of a closed cycle dilution refrigerator (CCDR) for space applications. A prototype of the CCDR without a vapor-liquid phase separator (VLPS) has been reported previously[†]. A peculiarity of the CCDR is that the ^3He as well as the ^4He are being circulated. The ^3He circulation is driven by pumping the gas phase in the still which contains more than 90 % of ^3He and the ^4He circulation is driven by a fountain pump which pumps only superfluid ^4He from the liquid phase in the still through a superleak. The principle of operation of the VLPS consisting of a porous material is similar to that of phase separators used in superfluid ^4He cryostats in space, where the thermomechanical (or fountain) pressure difference is exploited to keep the liquid inside the cryostat. We discuss the still design which assures that there is always a continuous liquid flow path inside the porous material of the VLPS between the entrance of the superleak, the liquid-vapor phase interface and the ^3He-^4He exit of the heat exchanger into the still, even in zero gravity conditions. We also present our experimental results on the still with the VLPS obtained on Earth.

† F. Martin, G. Vermeulen, P. Camus, and A. Benoit, Cryogenics, 50 (2010) 623-627.

Low-thermal conductivity suspensions used in the isolation of the salt pills aboard the Astro-H Adiabatic Demagnetization Refrigerator

Mark O. Kimball, Peter J. Shirron, Donald C. Wegel, Bryan L. James, Nicholas M. Galassi, Richard L. Faulkner, and Marcelino San Sebastian

NASA Goddard Space Flight Center, Greenbelt MD 20771 USA

An adiabatic demagnetization refrigerator (ADR) utilizes the magnetocholoric effect in a paramagnetic salt to produce sub-Kelvin temperatures. It is a solid-state device that has no moving parts and does not rely upon a density gradient in a working fluid. This makes it ideal for cooling space-based instruments. Typically the salt is enclosed in a cylindrical pill that is suspended within the bore of a magnet. The suspension between the salt pill and magnet must be robust enough to survive a launch yet have a thermal conductance that minimizes heat from the magnet that is mechanically, and thermally, anchored to a stage at a higher temperature. Here we detail such a design that uses Kevlar™ as the supporting media in a system that limits motion of the salt pill axial as well as laterally with respect to the magnet bore.

Development of the cold end of a gravity-insensitive closed-cycle dilution refrigerator

Gunaranjan Chaudhry[1], Angela Volpe[1], Philippe Camus[1], Sebastian Triqueneaux[2] and Gerard Vermeulen[1]

[1]Institut Neel, CNRS-UJF, 25 rue des Martyrs, BP166, 38042 Grenoble CEDEX 9, France
[2]Air Liquide DTA, 2 chemin de Clemenciere, BP15, 38360 Sassenage, France

This work describes the experimental results and analytical modelling of the cold end of a closed-cycle gravity-insensitive dilution refrigerator adapted from the open-cycle dilution refrigerator used for the Planck mission. The refrigerator is designed to provide 1 µW of cooling at a temperature of 50 mK. The cold end of the refrigerator comprises a counterflow heat exchanger (which pre-cools the ^{3}He and ^{4}He components down from a temperature of about 1 K to below 100 mK), the mixing chamber and the load heat exchanger (at about 50 mK). We discuss various counterflow heat exchanger designs that were considered and present experimental results for the different configurations. The best configuration shows a cooling power of 1 µW of 51 mK. We present analytical models for the heat exchangers and the mixing chamber and compare them with experimental data. Based on the analytical models, we suggest a preliminary cold end design.

Nitrogen Activated-Carbon Sorption Compressor

N. Tzabar* and G. Grossman

Faculty of Mechanical Engineering, Technion – Israel Institute of Technology, Haifa 32000, Israel

Sorption cryocooling is the most mature technology for cooling from a normal Room-Temperature (RT) down to temperatures below 100K in the absence of moving parts. Therefore, high reliability and no vibrations are attainable, in comparison with other cryocoolers. Nitrogen is usually used as the working fluid for cooling to temperatures between 80 and 100 K and activated carbons are the best adsorbent for this purpose. In this paper we present the development of a sorption compressor for nitrogen with a commercial Chemviron pelleted activated carbon. The development consists of sorption measurements that we performed for characterizing the adsorption of nitrogen on the selected adsorbent and the compressor experimental results are compared with simulation predictions.

* Corresponding author; Ph.D. candidate, Faculty of Mechanical Engineering, Technion – Israel Institute of Technology
Present affiliation: Cryogenics Group, Rafael Ltd., Israel.
Address: P.O.B 2250(39), Haifa 31021, Israel. Fax: 972-4-9906100. email: nirtz@rafael.co.il

Heat switches providing low-activation power and quick-switching time for use in Adiabatic Demagnetization Refrigerators

Mark O. Kimball and Peter J. Shirron

Goddard Space Flight Center, Greenbelt MD 20771, USA

An adiabatic demagnetization refrigerator (ADR) is a solid-state cooler capable of achieving sub-Kelvin temperatures. It neither requires moving parts nor a density gradient in a working fluid making it ideal for use in space-based instruments. The flow of energy through the cooler is controlled by heat switches that allow heat transfer when on and isolate portions of the cooler when off. One type of switch uses helium gas as the switching medium. In the off state the gas is adsorbed in a getter thus breaking the thermal path through the switch. To activate the switch, the getter is heated to release helium into the switch body allowing it to complete the thermal path. A getter that has a small heat capacity and low thermal conductance to the body of the switch requires low-activation power. The cooler benefits from this in two ways: shorter recycle times and higher efficiency. We describe such a design here.