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HEAT PIPE TECHNOLOGY

UNIVERSITY OF NEW MEXICO
ALBUQUERQUE, NEW MEXICO

1973

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HEAT PIPE TECHNOLOGY

A BIBLIOGRAPHY WITH ABSTRACTS

ANNUAL SUPPLEMENT

1974

ASSEMBLED BY

THE HEAT PIPE INFORMATION OFFICE

of

THE TECHNOLOGY APPLICATION CENTER
INSTITUTE FOR SOCIAL RESEARCH & DEVELOPMENT
THE UNIVERSITY OF NEW MEXICO
ALBUQUERUQE, NEW MEXICO 87131

PREFACE

This annual supplement to Heat Pipe Technology continues the work begun with the publication of the "Cumulative Volume" in March of 1971. Contained in this supplement are abstracts of documents and patents identified and added to the Heat Pipe Information Office collection during 1974. Also included is a review of the year's highlights in heat pipe development prepared by the technical editor, Dr. K.T. Feldman, Jr.

It is intended that a supplement such as this will be published at the end of each calendar year. In addition, a quarterly update service is available to those who need to keep current on new applications and developments between supplements.

This volume is in large part based on the efforts of Eugene Burch, Director of the Heat Pipe Information Office and Ding C. Lu, Staff Engineer, who devoted a vast amount of time and energy in its preparation. Our gratitude goes to Dr. Feldman of the College of Mechanical Engineering for his interest, encouragement and support. A number of individuals contributed foreign material to this collection, and in partiuclar, the continued cooperation of Dr. C.A. Busse of EURATOM is gratefully accepted and appreciated.

This publication was further made possible by the Technology Utilization Program of NASA, from which the Technology Application Center derives a major portion of its support and by the close cooperation of the College of Engineering of the University of New Mexico.

William A. Shinnick
Director
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DEPARTMENT OF MECHANICAL ENGINEERING

1975

INTRODUCTION

This annual supplement of Heat Pipe Technology for 1974 includes 149 references with abstracts and 47 patents. Although this number of publications is down from the 229 references and 94 patents of 1973, it is greater than any previous year. In addition to compiling and publishing this annual bibliography, the Heat Pipe Information Office maintains a library of nearly all of these references which are available for public use.

The emphasis of heat pipe work reported during 1974 shifted toward more practical applications. Included in the heat pipe work reported were articles on heat exchangers for heat recovery, electrical and electronic equipment cooling, temperature control of spacecraft, cryosurgery, cryogenic IR cooling, nuclear reactor heat transfer, solar collectors, laser mirror cooling, laser vapor cavities, cooling of permafrost, snow melting, thermal diodes, variable conductance, artery gas venting, EHD, gravity assisted pipes, and many other topics.

Although a considerable effort has been made to insure that the bibliography is complete, readers are encouraged to report omissions to the Heat Pipe Information Office.

K. T. Feldman, Jr.
Technical Editor

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CONTENTS

A. GENERAL INFORMATION, REVIEWS, SURVEYS

74001 APPLICATION OF HEAT PIPES AND THEIR THERMAL TRANSPORT CAPABILITY

H.M. Rosenbaum, J.B. Goodacre. Marconi Review, Vol. 36, 2nd Quarter, 1973, p. 93-121, 11 refs. Avail: TAC

The heat pipe is a two phase heat transfer device which can have an effective thermal conductivity several hundred times that of a good metallic conductor yet does not require the gravitational forces of a thermosyphon or the complexity of a pumped fluid system. Such devices can be designed to operate in temperature bands ranging from near absolute zero to approaching 2,000°C. This article describes the basic principles of operation, outlines a number of potential applications and presents the theoretical basis for performance or design calculations.

74002 HEAT PIPES

C.L. Tien, Editor (University of California, Berkeley, California). AIAA Selected Reprint Series, Vol. 16, 1973, 123 pages. Avail: TAC

Incompressible laminar vapor flow in cylindrical heat pipes, liquid transport properties of some heat-pipe wicking materials, and structures of very high thermal conductance are among the topics covered in papers concerned with heat pipes. Other topics covered include heat pipe startup dynamics, theoretical studies of heat pipes operating at low vapor pressures, and feedback controlled variable conductance heat pipes.

74003 HEAT PIPE - A NEW TUNE ON AN OLD PIPE

Ron Kemp, Jermyn Manufacturers, Kent, England. Electron Power, Vol. 19, No. 14, August 9, 1973, p. 325-326. Avail: TAC

A technique for transferring heat, discovered during the Second World War, has recently been revived and incorporated in devices called heat pipes. A typical pipe has an inherent thermal conductance over 100 times better than that of a solid metal, and there are potential applications in a wide range of industries.

74004 HEAT PIPE TECHNOLOGY: A BIBLIOGRAPHY WITH ABSTRACTS CUMULATIVE VOLUME
Technology Application Center, University of New Mexico, Albuquerque, New Mexico. NASA-CR-135953, TAC-Bibl-1. 31 March 1971, 239 pages, refs. Avail: TAC

74005 HEAT PIPE TECHNOLOGY - A BIBLIOGRAPHY WITH ABSTRACTS ANNUAL SUPPLEMENT 1971
Technology Application Center, University of New Mexico, Albuquerque, New Mexico. NASA-CR-135951, TAC-Bibl-1 (71/2). 1971, 102 pages, refs. Avail: TAC

74006 HEAT PIPE TECHNOLOGY, QUARTERLY UPDATE 1 JANUARY-31 MARCH 1972
Technology Application Center, University of New Mexico, Albuquerque, New Mexico. NASA-CR-135956, TAC-Bibl-1 (72/1). 31 March 1972, 26 pages, refs. Avail: TAC

74007 HEAT PIPE TECHNOLOGY: A BIBLIOGRAPHY WITH ABSTRACTS, QUARTERLY UPDATE 1 APRIL-30 JUNE 1972
Technology Application Center, University of New Mexico, Albuquerque, New Mexico. NASA-CR-135955, TAC-Bibl-1 (72/2). 30 June 1972, 35 pages, refs. Avail: TAC

74008 HEAT PIPE TECHNOLOGY: A BIBLIOGRAPHY WITH ABSTRACTS, QUARTERLY UPDATE 1 JULY-30 SEPTEMBER 1972
Technology Application Center, University of New Mexico, Albuquerque, New Mexico. NASA-CR-135952, TAC-Bibl-1 (72/3). 30 September 1972, 42 pages, refs. Avail: TAC

The subjects discussed in above five bibliographic series are: (1) general information, (2) heat pipe applications, (3) heat pipe theory, (4) design and fabrication, (5) testing and operation, (6) subject and author index, and (7) heat pipe related patents.

74043 HEAT PIPE TECHNOLOGY. A BIBLIOGRAPHY WITH ABSTRACTS. CUMULATIVE VOLUME Through 31 December 1972
Technology Application Center, University of New Mexico, Albuquerque, New Mexico. TAC/HP-72100. December 31, 1972. 459 pages.

The bibliography includes the following: (A) General Information, Reviews, Surveys; (B) Heat Pipe Applications; (C) Heat Pipe Theory; (D) Design and Fabrication; (E) Testing and Operation; (F) Subject and Author Index; (G) Heat Pipe Related Patents

74076 HEAT PIPE TECHNOLOGY. A BIBLIOGRAPHY WITH ABSTRACTS
Technology Application Center. University of New Mexico, Albuquerque, New Mexico. Annual Supplement, 1973. TAC-HP-73-11, 236 pages. Avail: TAC

The number of heat pipe publications during 1973 was double that in 1972. Emphasis shifted so that more work on applications and less on fundamentals was reported. Heat pipe applications described in articles published during the year include: heat exchangers for heating and air conditioning, electronics cooling, temperature control of spacecraft, heat transfer in thermionic and thermoelectric power generators, heat transfer in nuclear reactors, measurement of thermophysical properties, solar collectors, cooling engines, electrohydrodynamic phenomena, and vapor laser ovens.

74039 HEAT PIPES. ELEGANT CONCEPT IN SEARCH OF AN APPLICATION
Cedric Beatson (England). Engineer, Vol. 237, No. 6140, 1973, p. 38-39, 41. Avail: TAC

A review is given on principles, structures, applications, etc. of heat pipes.

74040 HEAT PIPE
P.D. Dunn (University of Reading, England) and D.A. Reay. Physics Technology, Vol. 4, No. 3, 1973, p. 187-201. 17 refs. Avail: TAC

The heat pipe is a device having a high thermal conductance which utilizes the transport of a vapor and rejection of latent heat to achieve efficient thermal energy transport. The theory of heat pipes is well developed. Their use in applications involving temperatures in the cryogenic regime, and with development units running as high as 2000°C, shows that they can function over a large part of the temperature spectrum. Applications in spacecraft, electronics and die casting are but few of the uses for these devices.

74041 THE HEAT PIPE - A NEW TUNE ON AN OLD PIPE
Ron Kemp (Jermyn Manufacturing, Seven Oaks, Kent, England). Electronics & Power, Vol. 19, p. 325-326, August 9, 1973. Avail: TAC

This report presents the principles and operations of heat pipes, and describes some of the application fields such as cooling of electronic equipments, warmups of carburetors, removal of heat from motors and generators, solar energy converters and waste-heat heat exchangers.

74042 HEAT PIPES
L.L. Vasiliev and S.V. Konev, Heat Transfer - USSR, January-February 1974, 102 pages. In English (refer to the original Russian edition 73002). Avail: TAC

This text includes a preface to the English edition, an introduction and three chapters. The first chapter introduces theoretical fundamentals of heat pipe operation, the second chapter discusses study of heat and mass transfer processes in heat pipes, and the last chapter presents experimental investigation of heat pipes and their application in various industrial branches. 115 references are also listed.

74075 HEAT PIPE SYMPOSIUM/WORKSHOP AT THE UNIVERSITY OF MARYLAND

D.K. Anand (Editor, Mechanical Engineering, University of Maryland, College Park, Maryland). NSF Grant GK-38697. November 5-6, 1973. Avail: TAC

This symposium/workshop was called to review the state-of-the-art of all aspects of heat pipe technology as well as to identify and recommend new areas of research and development.

In all twenty-four participants attended the meeting. Nine speakers gave summaries of the work being pursued in the United States. One speaker from West Germany presented work being done in Europe.

The first day, split into two sessions, was devoted to presentations dealing with fundamental consideration, wicking materials, manufactuirng methods, low temperature operation, gravity-assist heat pipes for high temperature applications, solar and space applications. The second day dealth with controllable heat pipes and work in Europe followed by a general discussion.

Included in this report are summaries of the presentations made at the meeting. Recommended areas of research that should have priority were identified and have been separately listed. A list of the participants appears at the end of this report.

74117 HEAT PIPE WORK IN EUROPE
M. Groll, Report 5-175. March 1974, Avail: TAC

The intention of this report is to give a rather comprehensive survey of heat pipe work in Europe. To a large extent the contents of this report is based on papers presented at the 1st International Heat Pipe Conference 1973 in Stuttgart. The following countries are included: Belgium, Czechoslovakia, Federal Republic of Germany, France, Great Britain, Italy, The Netherlands, USSR, and Yugoslavia.

74118 HEAT PIPE RESEARCH AND DEVELOPMENT AT THE NUCLEAR ENERGY INSTITUTE, UNIVERSITY OF STUTTGART (WAERMEROHRFORSCHUNG UNDENTWICKLUNG AM INSTITUT FUER KERNENERGETIK DER UNIVERSITAT STUTTGART)
M. Groll (University of Stuttgart, West Germany). Klim Kaelte Ing. Vol. 2, No. 7, July 1974, p. 281-284, 10 refs. In German, Avail: TAC

Heat pipes are relatively novel heat transfer devices finding a steady growing application. Their physical principles and characteristic performance data described. Heat pipe research and development at Institut fur Kernenergetik, Universitat Stuttgart is presented in brief. Thereby, some heat applications are discussed.

74119 CONTROLLED HEAT PIPES
L.L. Vasiliev. Heat Transfer - Soviet Research, Vol. 6, No. 3, May-June 1974 p. 37-41, Avail: TAC

This article discusses in general the presently available kinds of controlled heat pipes and presents several equations which are beneficial to the understanding of the operation of such pipes. The article implies that the development of these devices is still in the early stage and that much more work needs be done in this field.

74120 PHYSICAL SCIENCES: THERMODYNAMICS, CRYOGENICS, AND VACUUM TECHNOLOGY
National Aeronautics and Space Administration, NASA SP-5973(01). 23 pages, Avail: TAC

A compilation of thermodynamic devices, cryogenics, and vacuum technology is presented. Three different heat pipes are included: (1) an efficient heat recovery system with a new variable-conductance heat pipe. (2) A universal joint to transmit heat by a cryogenic heat pipe. (3) An aluminum heat pipe with an arterial composite-wick configuration.

B. HEAT PIPE APPLICATIONS

B.1 GENERAL APPLICATIONS

74009 DESIGNING SOPHISTICATED HVAC SYSTEMS FOR OPTIMUM ENERGY USE

Paul C. Greiner (Market Development, Electric Energy Association, New York City, New York). ASHRAE Journal, Vol. 15, February 1973, p. 27-31. Avail: TAC.

Heat reclamation and energy conservation have been special concerns of the electric industry. Here, the author offers a state-of-the-art survey of prevalent systems--from heat pipes to water-cooled luminaires--and their applications in various building systems for accomplishing optimum energy utilization.

74010 THERMOPHYSICAL AND OPTICAL EVALUATION OF HEAT PIPE COOLED LASER MIRRORS

David Raspet (School of Engineering, Air Force Institute of Technology, Wright-Patterson AFB, Ohio). M.S. Thesis, June 1973, 174 pages, refs. Avail: TAC

A concept for cooling laser mirrors with the heat pipe process was evaluated with a 2-inch diameter copper mirror. The mirror was illuminated by a 67 watt/square centimeters incident beam from a 10 kilowatt carbon arc lamp. This beam provides 34.2 watts/squared centimeters to the water heat pipe. Reflecting surface temperature distributions were measured to assess heat pipe operation. Reflecting surface distortions were measured from the change in focal length. Despite a problem with obtaining good wetting of the copper capillary structure of the heat pipe by the water, the heat pipe demonstrated the ability to significantly reduce reflecting surface temperature gradients.

74011 HEAT PIPES, INGENUITY, AND PASSIVE RECOVERY

Benjamin T. Rogers (Consulting Engineer, Embudo, New Mexico). Building Systems Design, Vol. 70, April 1973, p. 23-30. Avail: TAC

The author presents three different designs with passive systems for energy conservation, optimization of structural design, and environmental improvement. The first one is a Charoudi's Percolator which absorbs solar energy with a tracker using no external energy source. The second device is the Maxwell Demon which has an oversized Venetian blind built into one of the roof zones of the house. The blind can be closed or opened depending on the ratio of outside to inside radiation. The last device is a "recool" system which integrates waste water treatment and space conditioning systems to conserve energy, using the heat pipe recovery unit.

74044 HEAT PIPE COPPER VAPOR LASER SEMIANNUAL TECHNICAL REPORT 1 FEBRUARY - 30 SEPTEMBER 1973

Robert J.L. Chimenti (Esso Research and Engineering Co., Linden, New Jersey). Contract N00014-73-C-0317, ARPA Order 1806. 8 October 1973. 8 pages. Avail: TAC

The report describes the development of a heat pipe copper vapor laser with radial discharge excitation and operating temperatures to 2000C.

74045 HIGH EFFICIENCY HEAT EXCHANGERS

C.F. Gottzmann (Union Carbide Corp., Tonawanda, New York), P.S. O'Neill, P.E. Minton. Chemical Engineering Progress, Vol. 69, No. 7, July 1973. p. 69-75. 1 ref. Avail: TAC

Union Carbide's high efficiency heat exchanger tubes (commercially referred to as UC High Flux) feature overall heat transfer coefficients three to eight times higher than conventional equipment in many boiling-condensing and boiling-sensible heat transfer applications. The key component of High Flux tubing is an enhanced nucleate boiling surface with a bonded porous, metallic matrix (I.D. or O.D. of the tube) which achieves about a ten-fold improvement in boiling heat transfer coefficients. Field tests have shown that High Flux tubing can be applied to services involving cryogenic fluids, light hydrocarbons, and aqueous solutions.

74046 REGENERATIVE HEAT ENGINE

Jack E. Noble, Peter Riggle, Stuart G. Emigh, William R. Martini (Inventors, Department of Health, Education, and Welfare, Washington, D.C.). Serial No. 328,075. Filed January 30, 1973. Avail: TAC

A regenerative heat engine designed to produce power for the operation of equipment such as an artificial heart is disclosed. The heat engine includes a temperature control heat pipe located around the periphery of the engine cylinder and a temperature distribution heat pipe located around the periphery of the heat source. A flywheel and bellows seal is included as part of the displacer piston drive, and a flexure support is positioned on the hot end of the displacer piston to allow the piston to move longitudinally while restricting lateral motion.

74047 SNOW AND ICE REMOVAL FROM PAVEMENTS USING STORED EARTH ENERGY

M.F. Pravda, P.L. Marjon (Dynatherm Corporation, Cockeysville, Maryland). Report under the contract to the U.S. Department of Transportation, 1973. Avail: TAC

Dynatherm Corporation under contract to the Department of Transportation, Federal Highway Administration, has studied a snow removal and deicing system utilizing the stored energy in the earth beneath and adjacent to the roadway pavement.

The "heat pipe", a relatively new space age development, was selected to transport the thermal energy from the earth to the pavement. The heat pipe is a closed structure, evacuated of all noncondensible gases, and contains a capillary wick structure and a small amount of vaporizable heat transfer fluid. The capillary wick structure is analogous to a pump in a pumped fluid heat transfer system.

An analytical model describing the various heat transfer mechanisms associated with a pavement snow removal/deicing system employing earth heat was formulated. An experimental program was designed to validate the analytical model. Three 12' x 24' test slabs were constructed--an earth heated slab, an electrically heated slab, and a control slab. Electric power, temperature and weather measuring instrumentation was provided to record the response of the systems under various test conditions.

Tests were conducted during the Winter of 1972-1973. Although the winter was exceptionally mild, some substantive test data were obtained. Melting rates of flake ice were determined under various ambient conditions for the earth heated slab and electrically heated slab. These melting rates were transformed into snow melting rates in inches/hour.

Snow melting rates as high as 1½ inches per hour were measured on the earth heated slab during daylight hours and when the air temperature was in the mid-twenties. Data is currently being evaluated to determine the thermal parameters of the electrical and earth systems.

74048 GAS-HEATED HEAT PIPE VACUUM FURNACE (GASBEHEIZTER WÄRMERÖHREN-VAKUUMOFEN)

M. Stadelmann (Fotos Hutchins Photography, Inc., Belmont, Massachusetts). Schweizerische Technische Zeitschrift, Vol. 71, January 17, 1974. P. 40-43. 5 refs. In German. Avail: TAC

The heat pipe is a very efficient device for the transportation of heat at high temperatures.
One of the applications of the heat pipe is connected with the development of a vacuum furnace which utilizes natural gas for heating. In the new device the heat pipe is used for the transfer of heat from a high-temperature burner to a vacuum chamber. The vacuum furnace provides temperatures up to 1037.5 C at a vacuum of 5 microtorr.

74049 HEAT PIPES - NEW WAYS TO TRANSFER ENERGY
Ed Edelson. Popular Science, June 1974. P. 102-103, 139.
Avail: TAC

The heat pipe technology has a very promising prospect in the heat-recovery business for industry besides aerospace applications, such as the Air-O-Space by Isothermics, Inc. and the Thermal Recovery Units (TRU's) by Q-dot Corporation. In addition to heat recovery, heat pipes are used in furnaces, cooking griddles and rotary heat exchangers. One heat pipe application that should be highly visible in the next 5 years involves use of heat pipes for permafrost protection on the Alaska pipeline.

74050 NEW STIRLING-POWERED ZERO-POLLUTION CAR RUNS ON STORED HEAT
David Scott (Editor). Popular Science, June 1974. p. 66-68, 148. Avail: TAC

This report describes the research and development of Stirling-cycle engine at Philips Research Laboratory in Europe. Heat to run Stirling engine is stored in molten-salt mixture in sealed cylinders and transmitted to the engine through a heat pipe. Engine is "refueled" by reheating molten-salt cyclinders electrically. Later models might use fuel-fired heaters for faster cycling.

74077 NEW WAY TO CAPTURE HEAT FROM YOUR FURNACE WASTES

C. P. Gilmore (Editor). Popular Science, September 1972, p. 96-99. Avail: TAC

Isothermics Inc. is marketing a heat pipe device called the Air-O-Space heater to collect the waste heat escaping from the furnace. Once the heat is collected, it could be applied to the heating system. This unit is recommended for any furnace with a flue temperature above 400° F.

74078 DEVELOPMENT OF A CRYOSURGICAL INSTRUMENT UTILIZING AN OPEN-LOOP HEAT PIPE

A. Basiulis, T. A. Hummel (Hughes Aircraft Co., Torrance, California). AIAA/ASME 1974 Thermophysics and Heat Transfer Conference, Boston, Massachusetts, July 15-17, 1974. AIAA Paper No. 74-750. Avail: TAC

An open-loop heat pipe was successfully designed into a cryosurgical instrument. The instrument is small, self-contained, and weighs 2.0 lbs (including liquid nitrogen charge). The heat pipe utilizes liquid nitrogen as the working fluid and a sintered stainless steel fiber capillary wick. The working tip of the instrument operates at 78°K (-196°C), and the liquid nitrogen charge is maintained for 30 min. The design rationale, fabrication methods, and testing techniques are discussed along with the results of field testing and performance evaluation.

74079 HELIUM THERMOSIPHON AS THERMAL VALVE FOR A MAGNETIC REFRIGERATOR

Hans Quack, P. Grassmann (Swiss Federal Institute of Technology, Zurich, Switzerland). Progress Refrigeration Science Technology, Proceedings International Congress Refrigeration, 13th, 1971. Vol. 1, p. 525-528, published 1973. Avail: TAC

A He-filled thermosiphon was successfully tested as a thermal valve for a magnetic refrigerator working from a bath temperature of 4.12°K. The condenser of the siphon consisted of 2 conical surfaces with an area of 4 cm^2 each. The filling of a He siphon was carried out at liquid He temperatures. The ratio of thermal conductivities in the conducting vs. nonconducting conditions was $> 10^3$.

74080 THE MODELING OF A THERMOSYPHON-TYPE PERMAFROST PROTECTION DEVICE

R.L. Reid, J.S. Tennant (University of Tennessee, Knoxville, Tennessee), and K.W. Childs (Oak Ridge National Laboratory, Oak Ridge, Tennessee). AIAA/ASME 1974 Thermophysics and Heat Transfer Conference, Boston, Massachusetts, July 15-17, 1974. AIAA Paper No. 74-739. Avail: TAC

One promising device for protection of permafrost is the concentric tube thermosyphon. In the winter, the difference in temperature between the annulus and the tube provides a buoyant driving force to move the air down the tube and up the annulus. The resultant heat transfer freezes and subcools the permafrost. The paper describes in detail the flow and heat transfer by solving the boundary-layer equations for velocity and temperature considering conduction and radiation at the boundaries. The predicted thermosyphon performance is compared with experimental data. The results for heat-removal rate are generally within about 10-20%.

(Editor's note: This device is an air convection device and not a heat pipe, but was included as related information).

74081 APPLICATION OF HEAT PIPES TO THE GLASS INDUSTRY

Klaus P. Schubert (Dornier System G.mb.H., West Germany). Chemische Technik, Vol. 3(1), p. 5-8, 1974. In German. Avail: TAC

The uses of air-cooled press stamps has several disadvantages and is limited in capacity. The building-in of heat pipes in the press stamp considerably improves the heat evacuation, and the isothermy of the surface temperature of the stamp. Cs and K heat pipes were calculated and experimentally tested with satisfactory results. The press stamp temperature was easily kept at 450-600°C even with cycles prolonged from 0.8-1.3 sec at an increased number of cycles.

74082 MDC HEAT PIPES TO SAFEGUARD TRANS ALASKA OIL PIPELINE

McDonnell Douglas Corp. (Saint Louis, Missouri). August 1974, 2 pages. Avail: TAC

McDonnell Douglas Corporation's research and development work in heat pipe technology over a period of years has resulted in a $26 million manufacturing contract from the Alyeska Pipeline Service Company. MDC will supply about

100,000 heat pipes for the 798-mile Trans Alaska pipeline. The heat pipes, called Cryo-Ancho soil stabilizers, are intended to prevent thawing of the Permafrost around pipe supports for the elevated portions of the pipeline.

74054 THE MOST EFFICIENT WAY TO TRANSFER HEAT IS BY A PIPE
Cedric Beatson. The Engineer, Vol. 236, p. 40-43, April 12, 1973. Avail: TAC

This paper gives a brief introduction of the heat pipe research and development in Britain. The Jermyn Industries and the Redpoint Associates are the two heat pipe manufacturers on electronics components and assemblies. A self-contained Calocoax furnace using heat pipe is being produced by France and marketed in the United Kingdom. The International Research and Development Corporation (IRD) is developing the rotating wickless heat pipe to improve cooling in electric motors, the variable conductance heat pipe for cooling electronic devices and heat pipes for core pins that augment cooling in the injection moulding and diecasting industries. A computer program for designing heat pipes is also available from IRD.

74095 POWER IN THE DESERT
Electronics and Power. 31 May 1973, p. 204. Avail: TAC

British Honeywell's Systems and Research Center has already designed a proposed 1000 MW solar power station that could be sited in a desert area in the U.S. The station would consist of 500,000 reflectors each capable of collecting an average of 2KW throughout the 24 hour period. Assuming the use of present-day technology only, and with mass production for the reflectors, the heat pipe and associated control mechanisms, the total cost per unit of electricity generated would be twice that for nuclear generation in the U.S.

74121 APPLICATION OF THE HEAT PIPE PRINCIPLE TO AVOID THE ERROR DUE TO THE EMERGENT STEM IN LIQUID-IN-GLASS THERMOMETERS
F.E. Reiss (Inst. fuer Neutronenphysik und Reaktortechnik, Kernforschungszentrum Karlsruhe, West Germany). December 1973, 30 pages, In German, Avail: TAC

The error due to the emergent stem with liquid-in-glass thermometers can be avoided by heating the capillary of the thermometer with a heat pipe to the temperature of the bath. Experimental investigations show that full compensation of the error can be achieved by proper design.

74122 MORE MPG
Engineering, Vol. 214, March 1974, p. 169, Avail: TAC

Applying a heat pipe vaporizer to heat the mixture heading for the inlet manifold of an automobile engine is under research by the National Engineering Laboratory and the Shell's Thornton Research Center, both in England. Using this method of heating the engine feed gives a virtually perfect distribution enabling the engine to run with more than 20 times as much air as fuel instead of the more usual 15 to 1 ratio. Exhaust composition is greatly improved too.

74123 HOW TO GET MORE OF THE HEAT YOU ARE PAYING FOR
Popular Mechanics, October 1974, P. 152-153, Avail: TAC

The Air-O-Space heater is a fully automatic recovery system using heat pipes to reclaim heat from flue gases in a home system. It is produced by the Isothermics, Inc., and can be installed by a do-it-yourselfer in about 15 minutes.

B.2 THERMIONIC AND THERMOELECTRIC CONVERTERS

74012 HEAT PUMPING BY THERMOELECTRIC COOLERS THROUGH A LOW-TEMPERATURE HEAT PIPE
S.C. Kuo (United Aircraft Research Laboratories, East Hartford, Connecticut). In: Progress in Refrigeration Science and Technology, Vol. 1, Westport, Connecticut, AVI Publishing Co., Inc., 1973, p. 203-209; Discussion, p. 209, 7 refs. Avail: TAC

Description of the design and performance characteristics of a refrigerating device consisting of thermoelectric coolers integrated with a low-temperature heat pipe. The device is shown to be particularly well suited for operation in the temperature range of 200 to 300 K, and at a low cooling load of no more than about 5 watts. It has the advantages of simplicity, reliability, low weight, and capability to operate quietly for extended periods of time.

74013 COMPACT THERMOELECTRIC CONVERTER
Westinghouse Electric Corp. (Pittsburgh, Pennsylvania). Quarterly Progress Report, July 1, 1968-September 30, 1968. Phase II-C. Contract AT(29-2)-2638. 12 October 1968. 92 pages. Avail: TAC

A study was initiated to determine an optimum design for a module to be internally fueled using cobalt-60. In addition, alterations to the calculation model TEMOD were made to handle the effects of gamma heating within the lead telluride washers. An experimental test program was defined which would verify the validity of the mathematical model. Additional analytical work was accomplished to correlate predicted axial heat transport rates of heat pipes with experimental data. A study of sodium heat pipe performance data revealed that a sonic vapor velocity can occur in the region between evaporator and condensor sections of the heat pipe to produce a limit to the axial heat transfer rate.

74083 UTILIZATION OF THERMOSIPHON IN THERMOELECTRIC DEVICES

E. A. Kolendo, M. G. Verdiev (Institute of Semiconductors, Academic Science, USSR). Applied Solar Energy (USA), Vol. 9, No. 1-2, p. 7-9, 1973. Translation of Geliotekhnika (USSR), Vol. 9, No. 1, p. 10-12. Avail: TAC

The operational advantages and disadvantages of thermoelectric devices (coolers and generators) are determined by the structure of the heat-exchange systems at the cold and hot junctions of the thermopile. Drawbacks inherent in air cooling systems can be eliminated by combining the radiator with a thermosiphon, a heat-transport system based on an evaporation-condensation-evaporation cycle.

B.3 AEROSPACE ORIENTED APPLICATIONS

74014 DEVELOPMENT OF HEAT PIPE RADIATOR ELEMENTS

U. Hoppe, H. Koch, J. Lorschiedter (Dornier System GmbH, 7990 Friedrichshafen, Federal Republic of Germany). Paper presented at the 1st International Heat Pipe Conference, Stuttgart, West Germany, October 15-17, 1973. Session 10. Avail: TAC.

This report presents the development of heat pipe radiator elements. The following points are particularly discussed: Configuration, Layout, Technology, Testing, and Application in Projects. For the selection of configuration, special importance is attached to the modular design of the radiator. Apart from the thermal layout of the heat pipes, this design comprises a weight optimization. Difficulties involved in titanium processing are analyzed and the finally used method of EB welding is presented. The performance graphs of the radiator are represented for the fluid parameters inlet temperature and mass flow. An outlook demonstrates the application possibility of the developed radiators.

74015 DEVELOPMENT OF VARIOUS HEAT PIPES FOR USE IN SATELLITES

J. Lovschiedter (Dornier-System GmbH, Friedrichshafen, West Germany) and U. Heidtmann (Brown, Boveri et Cie. AG, Mannheim, West Germany). Osterreichische Gesellschaft fur Weltraumforschung und Flugkorpertechnik and Deutsche Gesellschaft fur Luft und Raumfahrt, Gemeinsame Jahrestagung, 6th, Innsbruck, Austria, September 24-28, 1973, DGLR Paper 73-120, 40 pages, 5 refs. In German. Avail: TAC.

Consideration of the use of various types of heat pipes for heat transport in satellites. The principle of operation of a heat pipe is explained, criteria governing the selection of heat pipes are indicated, and the essential special properties of heat pipes are cited. Heat pipe models which have been developed for certain specialized applications are presented, including heat pipes for cooling traveling-wave tubes, heat pipes for steam chamber radiators, heat pipes for distributing loss energy in a voltage converter, and coupling components which use heat pipes for heat transfer. A heat pipe system is described which was used in an experiment in a high-altitude research rocket.

74051 SPACE SHUTTLE HEAT PIPE THERMAL CONTROL SYSTEMS. FINAL REPORT JUNE 1972 - OCTOBER 1973

J. Alario (Grumman Aerospace Corp., Bethpage, New York).
Contract NAS9-12801. NASA-CR-134201, SHM-20. October 1973.
184 pages. Refs. Avail: TAC

Heat pipe (HP) thermal control systems designed for possible space shuttle applications were built and tested under this program. They are: (1) a HP augmented cold rail, (2) a HP/phase change material (PCM) modular heat sink and (3) a HP radiating panel for compartment temperature control. The HP augmented cold rail is similar to a standard two-passage fluid cold rail except that it contains an integral, centrally located HP throughout its length. The central HP core helps to increase the local power density capability by spreading concentrated heat inputs over the entire rail. The HP/PCM modular heat sink system consists of a diode HP connected in series to a standard HP that has a PCM canister attached to its mid-section. It is designed to connect a heat source to a structural heat sink during normal operation, and to automatically decouple from it and sink to the PCM whenever structural temperatures are too high. The HP radiating panel is designed to conductively couple the panel feeder HPs directly to a fluid line that serves as a source of waste heat. It is a simple strap-on type of system that requires no internal or external line modifications to distribute the heat to a large radiating area.

74052 VARIABLE CONDUCTANCE HEAT PIPE/RADIATOR FOR THE LUNAR SURFACE MAGNETOMETER

J.P. Kirkpatrick, B.D. Marcus (Ames Research Center, NASA, Moffett Field, California). Progress in Astronautics and Aeronautics, Vol. 31, 1973, p. 83-102. Avail: TAC

A cold reservoir, variable conductance heat pipe/radiator was developed to supplement the existing cooling system of the Apollo 16 Lunar Surface Magnetometer (LSM). Analysis and tests showed that 2 such devices, on opposite sides of the electronics package, would reduce the diurnal temperature variation by about 40% and thereby would considerably increase the reliability of the welded connections. The usefulness and flexibility of variable conductance heat pipes in solving difficult thermal problems was demonstrated. The LSM design constraints, selection of a variable conductance technique, heat pipe/radiator design features, and thermal performance are discussed.

74084 A NEW GENERATION OF DEVICES FOR THERMAL CONTROL OF SATELLITES--HEAT PIPES (UNE NOUVELLE GENERATION DE DISPOSITIFS DE CONTROLE THERMIQUE DES SATELLITES--LES CALODUCS)

P. Fayet (Centre National d'Etudes Spatiales, Division Etudes et Developpements Techniques, Paris, France). La Recherche Spatiale, Vol. 13, May-June 1974, p. 15-20. In French. Avail: TAC

One of the problems which will occur quite frequently in the future is that of thermal control of highly dissipative equipment. The simplest heat pipe consists of a closed tube, cylindrical, lined on its internal wall with a capillary structure, a grid, metallic fibers, channeling, and containing a condensable vapor. In operation, it receives, at the extremity which makes up the evaporator, a certain quantity of heat. This is transmitted to the fluid, which vaporizes. The vapor displaces itself toward the other extremity, called the condenser, where the heat is dissipated to the outside. The constitutive elements and operation of heat pipes are discussed, as well as the integration of heat pipes in a space radiator for the traveling wave tube of a telecommunications satellite. The actual state of development and space utilization of heat pipes is considered.

74085 DEVELOPMENT OF AN ELECTRICAL FEEDBACK-CONTROLLED VARIABLE--CONDUCTANCE HEAT PIPE FOR SPACE APPLICATION

M. Groll, M. Hage (University of Stuttgart, Stuttgart, West Germany). AIAA/ASME 1974 Thermophysics and Heat Transfer Conference, Boston, Massachusetts, July 15-17, 1974. AIAA Paper No. 74-752. Avail: TAC

A stainless steel modular artery heat pipe with ammonia as the working fluid was developed. An evaporator temperature control of ± 3°K was required for power variations between 20 w and 100 w and a variable setpoint of 35° ± 10°K. Steady-state and transient experiments showed reasonable agreement with theoretical predictions. The temperature control achieved was +0.3°K approximately throughout the setpoint range. The temperature over/undershoots were below 1°K and the related recovery times were 2.5-3.5 min. The auxiliary power for the reservoir heater was 10 w.

74086 CRYOGENIC HEAT PIPE EXPERIMENT: FLIGHT PERFORMANCE ONBOARD AN AEROBEE SOUNDING ROCKET

W. Harwell, J. Quadrini (Grumman Aerospace Corp., Bethpage, New York), and A. Sherman (NASA Goddard Space Flight Center, Greenbelt, Maryland). AIAA/ASME 1974 Thermophysics and Heat Transfer Conference, Boston, Massachusetts, July 15-17, 1974. AIAA Paper No. 74-725. Avail: TAC

More than five minutes of zero-*g* flight data has been obtained for a 36-in.-long, grooved, methane cryogenic heat pipe. Ground testing of this heat pipe indicates a zero-*g* dry-out in the 40-w range at 100°K. The flight data are compared with some of this ground data, as well as theoretical predictions.

74087 THERMOPHYSICS AND SPACECRAFT THERMAL CONTROL

R. G. Hering (Editor, University of Iowa, Iowa City, Iowa). MIT Press (Progress in Astronautics and Aeronautics, Vol. 35), 1974, 560 pages.

The opening papers are concerned with further developing understanding of radiative heat transfer processes and providing advanced techniques to evaluate such energy transfers accurately. Surface radiation properties are discussed, ranging from basic reflectance studies and laboratory property measurements to the recent measurements of coating properties on a spacecraft still in orbit. One chapter deals with conductive heat transfer and the related problem of joint conductance. Heat pipes are the subject of another chapter, and the papers include the range of topics from studies furthering fundamental understanding of heat-pipe operation to flight performance data on heat pipes. Attention is given to thermal control of spacecraft components, thermal control systems, and a summary of temperature control experience with spacecraft which have completed their missions.

74088 COMMUNICATIONS TECHNOLOGY SATELLITE: A VARIABLE CONDUCTANCE HEAT PIPE APPLICATION

P. R. Mock (TRW Systems Group, Redondo Beach, California). AIAA/ASME 1974 Thermophysics and Heat Transfer Conference, Boston, Massachusetts, July 15-17. 1974. AIAA Paper No. 74-749. Avail: TAC

A variable conductance heat-pipe system has been designed to provide thermal control for a Transmitter Experiment Package (TEP) to be flown on the Communications

Technology Satellite (CTS). The Variable Conductance Heat Pipe System (VCHPS) provides for heat rejection during TEP operation and minimizes the heat leak during power down operations. The VCHPS features a unique method of aiding priming of arterial heat pipes. This paper describes the CTS variable conductance heat-pipe system, discusses the system design parameters, and presents the results of the heat-pipe subsystem and system level test programs.

<u>74089</u> CRYOGENIC AND LOW-TEMPERATURE HEAT PIPE/COOLER STUDIES FOR SPACECRAFT APPLICATION

A. Sherman (NASA Goddard Space Flight Center, Greenbelt, Maryland), and P. Brennan (Engineering Consultant, Owing Mills, Maryland). AIAA/ASME 1974 Thermophysics and Heat Transfer Conference, Boston, Massachusetts, July 15-17, 1974. AIAA Paper No. 74-753. Avail: TAC

Cryogenic or low-temperature heat pipe/cooler systems have applications for NASA spacecraft in the cooling of radiometer detector and optical packages. Analysis of cryogenic heat pipe/radiant cooler systems show that within reasonable temperature excursions, heat-pipe fluid property variations have little effect on system performance; therefore, the system can operate over a range of cooling loads. The system size and weight, however, are a strong function of parasitic load, i.e., heat pipe length and diameter. A comparison of data obtained from complete performance maps of applicable nitrogen heat pipes indicates the predictability of heat pipe/cooler system in orbit.

74124 SPACE SHUTTLE HEAT PIPE THERMAL CONTROL SYSTEMS DESIGN AND TEST

J. Alario (Grumman Aerospace Corp., Bethpage, New York). SAE, AIAA, ASME, ASMA, and AICHE, Inter-Society Conference on Environmental Systems, Seattle, Washington, July 29-August 1, 1974, ASME Paper 74-ENAs-38, 13 pages, 7 refs., Avail: TAC

This paper presents the design details and test results for three heat pipe thermal control systems designed for possible shuttle applications. Two of the systems are for electronics cooling and the third for compartment temperature control. The test results support the feasibility of using these selected heat pipe systems to satisfy shuttle thermal control requirements.

74125 DEVELOPMENT OF ELECTRICAL FEEDBACK CONTROLLED HEAT PIPES AND THE ADVANCED THERMAL CONTROL FLIGHT EXPERIMENT.- TECHNICAL SUMMARY REPORT

Walter B. Bienert (Dyna-Therm Corp., Cockeysville, Maryland), Contract NAS2-6227, NASA-CR-114751. May 1974, 151 pages, Refs., Avail: TAC

The development and characteristics of electrical feedback controlled heat pipes (FCHP) are discussed. An analytical model was produced to describe the performance of the FCHP under steady state and transient conditions. An advanced thermal control flight experiment was designed to demonstrate the performance of the thermal control component in a space environment. The thermal control equipment was evaluated on the ATS-F satellite to provide performance data for the components and to act as a thermal control system which can be used to provide temperature stability of spacecraft components in future applications.

74126 HEAT PIPE THERMAL CONDITIONING PANEL

E.W. Saaski (Donald W. Douglas Laboratories, Richland, Washington), J.D. Loose and K.E. McCoy (NASA, Marshall Space Flight Center, Huntsville, Alabama), SAE, AIAA, ASME, ASMA, and AICHE, Inter-Society Conference on Environmental Systems, Seattle, Washington, July 29-August 1, 1974, ASME Paper 74-ENAs-27, 9 pages, Avail: TAC

Thermal control of electronic hardware and experiments on future space vehicles is critical to proper functioning and long life. Thermal conditioning panels (cold plates) are a baseline control technique in current conceptual studies. Heat generating components mounted on the panels are typically cooled by fluid flowing through integral channels within the panel. However, replacing the pumped fluid coolant loop within the panel with heat pipes offers attractive advantages in weight, reliability, and installation. This report describes the development and fabrication of two large 0.76 x 0.76 m heat pipe thermal conditioning panels to verify performance and establish the design concept.

74127 PASSIVE CRYOGENIC COOLING OF ELECTROOPTICS WITH A HEAT PIPE/RADIATOR

B.E. Nelson and G.A. Goldstein (Perkin-Elmer Corp., Danbury, Connecticut), Applied Optics, Vol. 13, September 1974, P. 2109-2111, 16 refs, Avail: TAC

The current status of the heat pipe is discussed with particular emphasis on applications to cryogenic thermal control. The competitive nature of the passive heat pipe/radiator system is demonstrated through a comparative study with other candidate systems for a 1-year mission. The mission involves cooling a spaceborne experiment to 100 K while it dissipates 10W.

74128 EVALUATION OF A LARGE SIZE MODULAR HEAT PIPE/RADIATOR FOR CRYOGENIC THERMAL CONTROL

B.E. Nelson and W. Petrie (Perkin-Elmer Corp., Danbury, Connecticut), SAE, AIAA, ASME, ASMA, and AIChE, Intersociety Conference on Environmental Systems, Seattle, Washington, July 29-August 1, 1974, ASME Paper 74-ENAs-29, 8 pages, 9 refs., Avail: TAC

A strong, current interest exists in cooling spaceborne devices to cryogenic temperatures. Such devices include space communication lasers and infrared detectors for earth resources. A cryogenic heat pipe, isothermalizing a space radiator, provides a very attractive, passive means of thermal control. It must, however, have low thermal resistance to provide design feasibility. The Lobar wicking arrangement proved extremely efficient in previous experiments at 5 W. A series of experiments was, therefore, conducted on a very large cryogenic heat pipe/radiator to determine the wicking limits and performance at higher power levels. The current status of the on-going program is described in this paper. Research goals of a 6 m-long space radiator, rejecting 20 W with a temperature drop of less than 2°K, have been met. Details of the design and experimental phases of the work are discussed.

74129 HEAT PIPE RADIATOR FOR HIGH POWERED TRANSPONDERS

D. Ting and G. Beere (European Space Research Organization, European Space Technology and Research Center, Noordwigk, The Netherlands), Paper presented at the 1st International Heat Pipe Conference, Stuttgart, West Germany, Oct. 15-17, 1973, Session 10.

For the second generation communication satellites, the thermal power dissipation had increased considerably and to a point that ordinary radiators become too large. Therefore, radiators with heat pipes offer very interesting alternative solutions to the spacecraft thermal design.

The authors are investigating analytically and experimentally two types of heat pipe radiators, namely honeycomb radiator with heat pipes buried in the core, and ribbed aluminum plate with heat pipes bounded on the outside surface. Similar radiators without heat pipes were also analyzed and tested to the same boundary conditions so that a direct comparison could be obtained to directly demonstrate the advantage of heat pipe radiators.

In addition, if time permits, vibration tests shall be performed to demonstrate the mechanical integrity of the heat pipe radiators. Immediately following the vibration tests, the radiators will be exposed to thermal vacuum/ solar simulation tests.

74130 DESIGN, FABRICATION, TESTING, AND DELIVERY OF SHUTTLE HEAT PIPE LEADING EDGE TEST MODULES. VOLUME 2: FINAL REPORT

McDonnell Douglas Astronautics Co., St. Louis, Missouri,
Contract NAS8-28656, NASA-CR-13673, MDC-E0775, 20 April 1973,
68 pages, Refs., Avail: TAC

Development in the design of leading edge heat pipes for the space shuttle are reported. The analysis, design, and integration of the heat pipes into the module structure are described along with the recommended tests. Results indicate the design goals were met.

B.4 NUCLEAR SYSTEMS

74016 TEMPERATURE CONTROL OF IRRADIATION EXPERIMENTS WITH GAS-CONTROLLED HEAT PIPES

J. E. Deverall (Los Alamos Scientific Laboratory, New Mexico), H. E. Watson (Naval Research Laboratory, Washington, D. C.). From International Conference on Irradiation Experimentation in Fast Reactors, Jackson Hole, Wyoming, 10 September 1973. 12 pages. Avail: TAC.

One major problem of irradiation experiments is establishing a desired, constant test specimen temperature. It is not possible to instrument most test capsules so that specimen temperatures are not known. Also, isothermal conditions do not exist over the specimen section and the radiation input flux varies with time. The gas-controlled heat pipe has the capability of producing a variable heat-rejection system which can maintain a relatively constant, isothermal temperature with variations of heat input. A heat pipe incorporated into a test capsule can establish and maintain an isothermal specimen temperature with large variations of radiation input flux.

74017 ISOTOPE KILOWATT PROGRAM QUARTERLY PROGRESS REPORT FOR PERIOD ENDING DECEMBER 31, 1972

A. P. Fraas, G. Samuels (Oak Ridge National Laboratory, Tennessee). Contract W-7405-eng-26. May 1973, 25 pages. Avail: TAC.

Work in progress on developing a 1 to 10 kW radioisotope-fueled energy conversion system for terrestrial and undersea use is described. Information is included on: equipment for and results from decomposition testing of Dowtherm which is being evaluated as a working fluid for an organic Rankine cycle conversion system; fabrication and installation of equipment for testing heat pipes; thermal conductivity testing of the ¼-scale aluminum insulation specimen; fabrication and testing of equipment for full-scale fusible insulation evaluation tests; and welding and loading of dummy fuel capsules for acceptance tests.

74053 PROCEEDINGS OF NUCLEAR POWER SYSTEMS CLASSIFIED SESSION, THIRD INTERSOCIETY ENERGY CONVERSION ENGINEERING CONFERENCE (IECEC), NATIONAL BUREAU OF STANDARDS, BOULDER, COLORADO, AUGUST 13-16, 1968

National Bureau of Standards, Boulder, Colorado. 1968. 179 pages. Declassified 27 November 1973. Avail: TAC

Topics discussed include: programmatic evaluation of SNAP-19 intact re-entry heat source development program; SNAP 19 aerospace nuclear safety evaluation; aerothermal analysis and testing of the SNAP-19 intact re-entry heat source; SNAP-27 radioisotopic thermoelectric generators; compact thermoelectric converter program; experimental evaluation of an automatic temperature controlled heat pipe; conceptual design of a radioisotope heat pipe thermionic space power system; fast reactor systems for secondary space power; and a 15 k W(e) modular thermionic thermal reactors (MATTRAC).

74090 DEVELOPMENT CONCEPT FOR A SMALL, SPLIT-CORE, HEAT-PIPE-COOLED NUCLEAR REACTOR
Edward Lantz, Roland Breitwieser, George F. Niederauer (NASA, Lewis Research Center, Cleveland, Ohio). NASA-TM-X-2996, E-7542. April 1974, 35 pages, refs. Avail: TAC

There have been two main deterrents to the development of semiportable nuclear reactors. One is the high development costs; the other is the inability to satisfy with assurance the questions of operational safety. This report shows how a split-core, heat-pipe cooled reactor could conceptually eliminate these deterrents, and examines and summarizes recent work on split-core, heat-pipe reactors. A concept for a small reactor that could be developed at a comparatively low cost is presented. The concept would extend the technology of subcritical radioisotope thermoelectric generators using 238 PuO_2 to the evolution of critical space power reactors using 239 PuO_2.

74131 GENERATION AND RECOVERY OF TRITIUM IN THERMONUCLEAR REACTOR BLANKET USING HEAT PIPES

R.W. Werner (Lawrence Livermore Laboratory, California University, Livermore). Contract W-7405-eng-48, 3 October 1968, 15 pages, Avail: TAC

Controlled thermonuclear reactors using the D-T reaction require a means of regenerating tritium so that cycle continuity is maintained. A unique way is suggested for satisfying the tritium needs. It is proposed that heat pipes using lithium as a working fluid be used as tritium producers in the blanket structure of a reactor. The tritium produced by the reactions ($n + Li^6 \rightarrow T + He^4 +$ 4.6 MeV) and ($n + Li^7 \rightarrow n^1 + T -$ 2.47 MeV) would then be transported within the heat-pipe body to an accessible processing point outside of the blanket. By diffusion or equivalent means, the tritium would be brought outside of the heat-pipe body and then processed for recycling. Heat pipes are explained as heat-transfer devices and as gas handlers and tritium producers. Operation at temperatures not less than 1400°K is required.

B. 5 ELECTRICAL AND ELECTRONIC APPLICATIONS

74018 A NOVEL METHOD OF COOLING SEMICONDUCTOR DEVICES FOR POWER ELECTRONICS

Hermann Birnbreier, Gregor Gammel, Uwe Heidtmann, Mattias Joens, and Peter Pawlowski (Zentrales Forschungslab, Brown, Boveri und cie, A. G., Heidelberg, West Germany). Bonn Bundesmin. fuer Forsch. und Technol. April 1973, 114 pages, refs. In German, with English summary. Avail: TAC

The development of heat pipe coolers for semiconductors in electric power supplies is discussed. The maximum dimensions were calculated for a given heat flux capability. Technologies necessary for the construction of heat pipes were developed, such as the manufacturing of capillary structures as well as the filling and sealing of heat pipes. Various samples of different design were built, and the influence of heat throughput, heat pipe position, and cooling air velocity on the heat resistance and temperature distribution were experimentally determined. The startup behavior of a heat pipe cooler was examined at room temperature and at temperatures below the freezing point of the working fluid. Corrosion tests performed so far have shown that the material combination copper-water is suitable for heat pipe coolers within the desired temperature range and that prospective lifetimes can be reached.

74019 COOLING OF AC MOTOR SHAFT BY CYLINDRICAL ROTATING HEAT PIPE

M. Bubenicek, F. Polasek (Nacional Research Institute for Machine Design, Bechovice, Czechoslovakia), O. Oslejsek (Research Institute Electric Rotating Machines, Brno, Czechoslovakia). In Elektrotechnicky obzor 197[illegible], p. 40-46. In Czech with English translation. Avail: TAC

A cylindrical rotating heat tube was examined in the rotor of an enclosed squirrel cage induction motor. The cooling effect of the tube was confirmed by evaluation of heating tests of the motor. The heat parameters [illegible] in the motor were compared with the [illegible] calculation and of measurements on a model of the tube. The function was also verified in actual tests of the motor. The use of heat tubes for the cooling of [illegible] is promising.

74020 INVESTIGATION OF NOVEL [illegible] TECHNIQUES FOR POWER TRANSISTORS

M. A. Merrigan (Ground Systems Group, Hughes Aircraft Co., Fullerton, California). Final report 15 November 71 - 15 September 73. Report No. FR-73-10-840 ECOM-0021-F-72, September 1973. Contract DAAB07-72-C-0021. 69 pages.
Avail: TAC.

The feasibility of new cooling methods for VHF power transistors capable of providing a reduction in junction temperature of 33%, compared to conventionally packaged devices was investigated. Design objectives for the transistors are 25 watts CW power from a 28-volt supply with a minimum power gain of 6 dB. The electrical characteristics of the devices are to be within 10% of conventional devices, the volume no more than 4 times, and the weight no more than 3 times that of equivalent hermetically sealed devices. Achievement of these objectives was based on the application of heat pipe cooling techniques to the chip surface, within a standard TO-package. The conclusions to be drawn from the program are that the cooling method provides significant improvement in the thermal characteristics of the VHF power transistors without loss of RF performance. No significant deterioration of performance was noted in the extended duration high temperature testing. These goals were achieved without significant change in the transistor case size or weight. The cooling techniques demonstrated on this program are recommended for production development.

74055 COOLING OF RAPID ACTION CIRCUIT BREAKER CONTACTS BY HEAT PIPES

Milan Bubenicek, Frantisek Polasek (National Research Institute for Machine Design, Bechovice near Prague, Czechoslovakia). Paper presented at the 1st International Heat Pipe Confernece, Stuttgart, West Germany, October 15-17, 1973. Avail: TAC

Due to the voltage loss at the place of the contact of the separate elements and in these elements of the contact system of the rapid action circuit breakers there occurs a loss heat which makes the contact warm. With regard to the admissible heating of the copper contact which is 75°C maximum according to the standards the heat must be led away. The results of the experimental verification of the leading of the loss heat away from the existing contact system in the rapid action circuit breaker by means of the heat pipes have shown that in this way the heating of the whole system can be considerably decreased.

74056 COOLING OF AC MOTOR BY HEAT PIPE

Milan Bubenicke, Frantisek Polasek (National Institute for Machine Design, Bechovice near Prague, Czechoslovakia). Paper presented at the 1st International Heat Pipe Conference, Stuttgart, West Germany, October 15-17, 1973. Session I. Avail: TAC

Some theoretical as well as experimental tasks dealing with the cooling of a rotar of a two-pole enclosed asynchronous electric motor of 10 kw output by means of a rotating heat pipe have been conducted by the authors. On the basis of the theoretical analysis of the rotating heat pipe function, the first stage of the tasks consisted of the deduction of the simple but sufficiently accurate calculation relations for the technical stipulation of the thermal as well as flow ratios in the pipe and the optimum volume of the working fluid and of the experiment verification of the machine shaft when designed as the rotating heat pipe. Another stage included the experiment checking of the thermal ratios on the electric motor with the rotating heat pipe. Ascertained heat field was compared with the motor heat field calculated with regard to the previously stipulated thermal resistance of the shaft (heat pipe).

74091 HEAT PIPE COOLED MICROWAVE WINDOW

Gene T. Colwell, Harold L. Bassett, James M. Schuchardt (Georgia Institute of Technology, Atlanta, Georgia). Contract DAH C60-73-C-0068. February 1974, 75 pages. Avail: TAC

The program centered around the examination and selection of suitable dielectric window materials for a heat pipe cooled microwave window and the selection of a working fluid. Two ceramic materials, aluminum oxide and beryllia, were found to be appropriate for window materials in the high average power microwave device. The aluminum oxide material does not possess thermal properties as desirable as the beryllia, but the aluminum oxide is less costly. A number of working fluids were found to have desirable properties, both thermal and microwave, and two of these were very good fluids, Heptane and Carbon Tetrachloride. An experimental heat pipe was constructed and tested as part of this program. The tests indicated that the heat pipe cooled windows could handle up to 2-3 megawatts of RF power at a frequency near 3.0 GHz.

74092 TAKING OUT THE HEAT

G. L. Fitton (Redpoint Association Ltd., England). Electronic Engineering, Vol. 45, No. 550, p. 65, 67-68, December 1973. Avail: TAC

Problems associated with dissipating heat generated by electronic devices and sub-assemblies are discussed. A novel technique now being exploited is described that involves heat pipes which have temperature gradients some hundred times smaller than any known solid conductor.

74093 DEVELOPMENT OF HEAT PIPE COOLED ANODE FOR XENON ARC LAMP

Lloyd A. Nelson (Hughes Aircraft [illegible], California). Final technical report, January [illegible] 1974. Contract DAAK 02-73-C-0113. Report No. FR 74-[illegible], March 1974, 68 pages. Avail: TAC

A heat pipe cooled anode for a 10 KW xenon lamp has been designed, fabricated and tested. The heat pipe was designed to operate at [illegible] and transfer [illegible] from the anode tip to ambient air. The heat pipe cooled anode was designed to be integrated into a 10 KW lamp and gave normal arc characteristics. The heat pipe anode was fabricated, processed and tested. The heat pipe anode operated successfully, demonstrating the feasibility of heat pipe cooling of lamp anodes, although some problems were encountered and the heat pipe did not reach full design power.

74094 DEVELOPMENT OF A SWITCHABLE CRYOGENIC HEAT PIPE FOR INFRARED DETECTOR COOLING

T.H. Sun, R.C. Prager (Hughes Aircraft Co., Torrance, California). AIAA/ASME 1974 Thermophysics and Heat Transfer Conference, Boston, Massachusetts, July 15-17, 1974. AIAA Paper No. 74-751. Avail: TAC

This study was performed to investigate the feasibility of making a cryogenic heat pipe with the capability of thermally coupling an infrared detector to the colder of two heat sinks while thermally isolating the detector from the other. When the two heat sinks cross in temperature, the thermal coupling must switch with a minimum of hysteresis and distrubance of the detector temperature. Prototype heat-pipe models were built of three of the four design approaches investigated, and one was tested for switching capability. During the switching period, the evaporator temperature rose 6°C with a heat load of 2 W.

74132 COOLING OF ELECTRONIC CIRCUITS AND INSTRUMENTS

L.P. Grakovich and S.V. Konev, Heat Transfer - Soviet Research, Vol. 6, No. 3, May-June 1974, P. 123-131, Avail: TAC

The paper examines the operating principles of thermal converters and their practical application for cooling radioelectronic equipment. A description is given of the test equipment and experimental results obtained for different methods of semiconductor-diode cooling. The advantages are shown of evaporative cooling using radiators operating on the heat pipe principle as compared with standard heat removal methods.

74133 AN INTERCELL HEAT PIPE FOR FUEL CELL AND BATTERY COOLING

Dean L. Jacobson (Dept. of Mechanical Engineering, Arizona State University, Tempe, Arizona), Final report, June 72-July 73, Contract F30602-72-C-0418, AFAPL-TR-74-5, December 1973, 44 pages, Avail: TAC

A planar (rectangular cross section) heat pipe was designed to transfer 2000 watts at 115°C plus or minus 12°C. The evaporator area was fixed at 30.48cm by 12.7cm per side so that the design heat flux was 3.45 watts/sq cm. The heat pipe was tested with electrical heaters to simulate waste heat from two adjacent high power density fuel cell or battery modules. The device was constructed from two milled copper plates which were electron beam welded to produce the completed structure. The finished heat pipe thickness was 1.27cm. A single layer of 100 mesh copper screen covered rectangular milled capillary grooves. Triply distilled, deionized water was chosen as the working fluid.

C. HEAT PIPE THEORY

C.1 GENERAL THEORY

74021 FIGURE-OF-MERIT CALCULATION METHODS FOR ORGANIC HEAT PIPE FLUIDS

James F. Morris (NASA, Lewis Research Center, Cleveland, OH).
NASA-TM-X-2945, E-7632. November 1973, 13 pages, refs.
Avail: TAC

With only chemical formulas and operating temperatures specified, selected correlating equations and tables of chemistry-effect functions allow estimates of figures of merit for organic heat-pipe-fluids.

74022 FUNDAMENTALS OF HEAT PIPE THEORY

T. L. Perelman, M. M. Levitan (Akademiia Nauk Belorusskoi SSR, Institut Teplo-i Masoobmena, Minsk, Belorussian SSR).
Inzhenerno-Fizicheskii Zhurnal, Vol. 25, November, 1973, p. 816-826, 6 refs. In Russian. Avail: TAC

The heat and mass transfer processes within and in the body of the pipe are treated jointly. A numerical method for solving the problem by successive iteration of the transfer equations is proposed. A model for calculating transfer processes in a capillary structure consisting of several layers of a serge-type network is developed. The model shows that the experimentally observed substantial changes in vapor temperature may be attributed to partial dessication of the capillary structure. A rigorously formulated expression for heat pipe operation is presented for use in optimization calculations.

74057 OPERATION OF A HEAT PIPE BEYOND THE CAPILLARY LIMIT
James H. Holderness (University of Michigan, Ann Arbor, Michigan). Dissertation, 1973. Microfilm Order No. 74-3645, 225 pages. Avail: TAC

Significant reactivity effects are associated with the capillary failure of a heat pipe used to cool a nuclear reactor. These effects result from the void formed in the heat pipe wick when capillary action cannot supply sufficient condensate to the evaporator of the pipe. A sharp rise in the evaporator temperature accompanies this void. In order to evaluate these effects, the position of the void boundary and the evaporator temperature profile must be determined during the after capillary dryout.

A one-dimension time-dependent model is developed to describe the transient capillary dryout and recovery of a heat pipe. A numerical solution to the coupled energy and momentum equations is obtained for a step increase in power to a level above the capillary limit. From this solution a delay time is found to exist between the power step and the initial void formation. The rate of void formation is a function of both the power level and a characteristics heat pipe response time. Steady state conditions may ultimately be reached in which only a portion of the evaporator is voided. The extent of the steady state void depends on the falling capillary height of a column of liquid in the wick. As the power is decreased following capillary dryout, liquid advances into the dried wick. The position of the void boundary during recovery is a function of the recovery power level and the rising capillary height. Due to capillary hysteresis the recovery power level for complete recovery must be much less than the capillary limit.

A heat pipe is constructed to demonstrate these effects experimentally. Thermocouples embedded in the wick are used to measure the temperature profile and to detect the position of the void boundary. Measured temperatures closely fit the predicted transient temperature profile. Steady state dryout is attained, and the effects of capillary hysteresis are noted during recovery. The rate of void formation is shown to be a function of the characteristic heat pipe response time and the power level. The dependence of the delay time on these two parameters is also demonstrated.

74058 CONTRIBUTION TO THE DETERMINATION OF THE LIQUID METALS HEAT PIPE HEAT PERFORMANCE LIMITS
Fr. Polasek (National Research Institute for Machine Design, Bechovice, Czechoslovakia). Paper presented at the 1st International Heat Pipe Conference, Stuttgart, West Germany, October 15-17, 1973. Session 2. Avail: TAC

A theoretical and experimental determination of the temperature dependence of the capillary and sonic heat performance limits of heat pipes filled with mercury, potassium and sodium, over the temperature range 400 to 800°C, is presented. A capillary wick structure with screen and channels was used. In the case of the heat pipe with a channel capillary structure it was shown that the channel shape and dimensions exert a strong influence on the interaction between the liquid and the vapour and consequently on the achieved heat performance. Under the condition of a low liquid metal vapour pressure experimental results exhibit good agreement with the results calculated with the help of the theoretical model of the sonic heat performance limit.

74067 METHOD FOR SELECTING GEOMETRIC PARAMETERS OF LOW TEMPERATURE HEAT PIPES (METODIKA VYBORA GEOMETRICHESKIKH PARAMETROV NIZKOTEMPERATURNYKH TEPLOVYKH TRUB)
G.F. Smirnov (Odessa Technology Institute of Refrigeration Industry, USSR) and L.N. Mishchenko. Teploenergetika, No. 8, August 1973, p. 82-84. In Russian. Avail: TAC

Problems of heat exchange and hydrodynamics in low-temperature heat pipes with a reticular capillary structure are considered. A formula is obtained for the calculation of the equivalent thermal conductivity of a wetted capillary structure. An engineering method of selection of geometric parameters of low-temperature heat pipes is proposed. It takes into account heat transfer limits due to hydrodynamic locking and to "steaming up" of the capillary structure.

74099 THERMAL CONTROL RANGE ASSOCIATED WITH HEAT PIPE CYCLING

H.B. McKee (McDonnell Douglas Astronautics Co., Huntington Beach, California). In: Heat Transfer and Fluid Mechanics Institute, 24th, Corvallis, Oregon. June 12-14, 1974. Proceedings, Stanford University Press, 1974, p. 57-72, 5 refs. Avail: TAC

The effect of dynamic cycling on variable conductance heat pipes temperature control is examined. Cycling of the heat pipe condenser environment or heat pipe evaporator heat input levels can lead to concentration changes in the gas reservoir with a consequent change in the thermal control range. An analytical model is formulated and results of calculations presented which show the extent of these effects and their implication on gas reservoir charging. Calculations are also compared with experimental data obtained for gas controlled ammonia heat pipes under a simulated space environment. Test data was generated with the heat pipe operating with xenon and with helium control gases.

74135 THEORETICAL STUDY OF HEAT PIPE
H. Kimura (Mitsubishi Electric Corp., Kamakura, Kanafawa, Japan) and Y. Kuriyama (Tokyo University, Tokyo, Japan), In: International Symposium on Space Technology and Science, 10th, Tokyo, Japan, September 3-8, 1973, Proceedings. AGNE Publishing, Inc., 1973, p. 587-593, Avail: TAC

A technique for controlling the effective condensing area of a heat pipe by a noncondensable gas is very useful to keep the heat source temperature within a small range of variation, regardless of a large heat flux variation. In order to determine the design factors of a gas-loaded heat pipe, the temperature distribution in the pipe must be known. Analytical methods were developed to predict the temperature distribution in that region, using a finite-element method. These methods were programmed for solution by digital computer, which, using the input information regarding the fluid and vapor characteristics, the condenser dimensions and the operating condition, gives the distributions of the gas mole-fraction and the temperature.

74136 HEAT PIPE MODEL ACCOUNTING FOR VARIABLE EVAPORATOR AND CONDENSER LENGTHS
C.L. Williams (Westinghouse Electric Corporation, Pittsburgh, Pennsylvania), G.T. Colwell (Georgia Institute of Technology, Atlanta, Georgia). AIAA Journal, Vol. 12, No. 9, September 1974, p. 1261-1267, Avail: TAC

A correlation model is established for the steady-state performance of a horizontal heat pipe operating below the capillary limited heat rate and with internally self adjusting evaporator and condenser lengths. The length along which condensation occurs is found to depend on the axial vapor Reynolds number. The partially saturated evaporator length, and the corresponding length along which evaporation occurs is found to depend on the detail wick geometry and the evaporator meniscus radius. These dependencies are corroborated by experimental data from a cylindrical heat pipe with working fluids of water and methanol. The experimental wick consists of two layers of 100 mesh stainless steel screen separated by a thin liquid region. Comparison of correlation predictions to experimental results of this study and others show agreement to within 15%.

C.2 HEAT TRANSFER

74024 HEAT TRANSFER INTENSITY IN THE CONDENSATION SECTION OF A HEAT PIPE

V. Ja. Sasin, A. Ja. Shelginskii (Moskovskii Energeticheskii Institut, Moscow, U.S.S.R.). Inzhenerno-Fizicheskii Zhurnal Vol. 25, September 1973, p. 436-439. In Russian. Avail: TAC

A dimensionless equation for calculating the heat transfer intensity in the condenser of a heat pipe is derived from a dimensionless analysis of the fundamental convective heat transfer equations. The influence of vapor pressure on the heat transfer intensity in a heat-pipe condenser is determined, and experimental condenser heat-transfer data are generalized.

74060 TWO-DIMENSIONAL ANALYSIS OF HEAT AND MASS TRANSFER IN POROUS MEDIA USING THE STRONGLY IMPLICIT PROCEDURE

Donald M. Curry (NASA, Lyndon B. Johnson Space Center, Houston, Texas). NASA-TN-D-7608, JSC-S-382. March 1974. 36 pages, refs. Avail: TAC

Numerical results of the heat and mass transfer in a porous matrix are presented. The coupled, nonlinear partial differential equations describing this physical phenomenon are solved in finite difference form for two dimensions, using a new iterative technique (the strongly implicit procedure). The influence of the external environment conditions (heating and pressure) is shown to produce two-dimensional flow in the porous matrix. Typical fluid and solid temperature distributions in the porous matrix and internal pressure distributions are presented.

74061 HOT SPOT OF A SODIUM HEAT PIPE LINED WITH MULTI-LAYERED WIRE NETTING, UPON APPROACH TO PRESSURE DROP LIMITS

Koichi Kotani, Yasunori Tanihiro, Isao Sumida (Hitachi At. Energy Research Laboratory, Hitachi Ltd., Kawasaki, Japan). Journal of Nuclear Science Technology, Vol. 11, No. 2, 1974, p. 72-74. In English. Avail: TAC

The step variation of temperature accompanying the transition of the vapor-liquid interface from 1 layer of mesh screen to the next can be evaluated theoretically: (1) in the initial stage of the pressure drop limit, there occurs a step variation of the temperature in a heat pipe covered by a multilayered screen probably caused by the transition of the vapor-liquid interface from 1 layer to the next in the mesh screen; (2) the step variation of temperature amounts to 100° in the case of a 100 mesh screen, which agrees approximately with the model presented; and (3) no significant decrease in the heat-transfer rate was observed immediately preceding burnout of the screen, whereas partial dryout does not appear to affect substantially the heat-transfer characteristics.

74062 PECULIARITIES OF EVAPORATIVE COOLING IN RAREFIED GAS

A.V. Luikov, L.L. Vasiliev, O.G. Rasin (Heat and Mass Transfer Institute, Byelorussian Academy of Sciences, Minsk, USSR). International Journal of Heat and Mass Transfer, Vol. 16, January 1973, p. 3-12. Avail: TAC

The process of evaporative cooling of porous bodies is considered under conditions of rarefaction and simultaneous external and internal heat fluxes.

On the basis of the theortical analysis and experimental study the main relationships are established and optimal conditions are obtained of evaporative cooling. Evaporation mechanism of liquid cooling under vacuum is shown to be controlled by thermophysical and structural properties of the porous body and the recession of the evaporation zone.

74098 FLOODING AND DRY-UP LIMITS OF CIRCUMFERENTIAL HEAT PIPE GROOVES

K.D. Gier, D.K. Edwards (University of California, Los Angeles, California). AIAA/ASME 1974 Thermophysics and Heat Transfer Conference, Boston, Massachusetts, July 15-17, 1974. AIAA Paper No. 74-722. Avail: TAC

Criteria for incipient flooding and dry-up of circumferential heat pipe grooves are developed. A transcendental relationship is found to fix the point of condenser flooding. In the case of evaporator dry-up, an analytical solution is derived to treat the singularity in the groove-flow equations. The analytical solution serves as a starting condition for numerical calculations and indicates the number of watt-inches grooves can handle past the point of meniscus recession. It is shown that evaporators that pass one-g tests will have additional capacity at zero g, but just the opposite is true for condensers.

74102 A UNIT FOR INVESTIGATING BOILING IN VACUUM

A.N. Abramenko. Heat Transfer--Soviet Research. Vo. 6, No. 2, 1974, p. 86-89. Avail: TAC

Some aspects of boiling in capillary-porous bodies are investigated and the effect of certain variables on boiling heat transfer crisis is noted. Analytical expressions are developed for calculating the critical heat flux. A vacuum unit for the study of boiling of various liquids (including cryogenic) in capillary-porous bodies is described.

74103 LAMINAR FILM CONDENSATION ON THE INSIDE OF SLENDER, ROTATING TRUNCATED CONES

P.J. Marto (Department of Mechanical Engineering, Naval Postgraduate School, Monterey, California). ASME Journal of Heat Transfer, May 1973, p. 270-272. Avail: TAC

The heat transfer capability of rotating, non-capillary heat pipes depends primarily upon the condenser performance. This performance is modeled by laminar film condensation on the inside of slender, rotating truncated cones in the region where the half cone angle is close to zero.

74137 COAXIAL HEAT PIPES

L.L. Vasiliev, Inzhenerno Fizicheskii Zhurnal, Vol. 23, No. 6, 1972, p 1030-1036, In Russian, Avail: TAC

Calculation is preformed of the process of heat and mass transfer in wicks of coaxial low temperature tubes with convective heat transfer between a fluid and a tube wall.

74023 ANALYSIS OF A HIGH-HEAT-FLUX WATER HEAT PIPE EVAPORATOR

K.T. Feldman, Jr., and M.E. Berger (Bureau of Engineering Research, University of New Mexico, Albuquerque, New Mexico). Report No. ME-62(73) ONR-012-2, Contract N00014-68-A-0155. September 1973, 396 pages. Avail: TAC

An analysis was made to determine a surface which has potential use in a high-heat-flux, low-temperature-drop water heat pipe evaporator. Two groove geometries were selected for analysis, rectangular and triangular. A mathematical model of the grooves was constructed in order to predict the maximum surface heat flux capability. In addition, a model of the heat transfer within the fluted surface was proposed which postulated that conduction through the wall and liquid to the liquid-vapor interface is the mechanism of heat transfer. A numerical analysis of the heat transfer in the groove was made based on the proposed model to predict evaporator film coefficients. The numerical heat transfer models were two-dimensional which used average meniscus profiles obtained from simpler, three-dimensional models.

74138 ANALYSIS OF A HIGH-HEAT-FLUX WATER HEAT PIPE EVAPORATOR

Michael E. Berger (The University of New Mexico, Albuquerque, New Mexico), Ph.D. Dissertation, 1973, Order No. 74-20308, 397 pages, In Microfilm, Avail: TAC

An analysis was made to determine a surface which has potential use in a high-heat-flux, low-temperature-drop water heat pipe evaporator.

A comprehensive survey of the literature was made to determine those surfaces which had high-heat-flux potential under evaporation. A circumferentially grooved surface was selected as the surface to be analyzed.

Two groove geometries were selected for analysis, rectangular and triangular. A mathematical model of the grooves was constructed in order to predict the maximum surface heat flux capability. In addition, a model of the heat transfer within the fluted surface was proposed which postulated that conduction through the wall and liquid to the liquid-vapor interface is the mechanism of heat transfer. A numerical analysis of the heat transfer in the groove was made based on the proposed model to predict evaporator film coefficients. The numerical heat transfer models were two-dimensional which used average meniscus profiles obtained from simpler, three-dimensional models.

The results of the analyses were compared with experimental data and sufficient agreement was obtained to establish their validity. The computer models showed that the film coefficient of a circumferentially grooved surface nonlinearly increases with increasing surface heat flux and asymptotically approaches a maximum value. In addition, it was determined that the film coefficint of rectnagular grooves is independent of groove depth while that for triangular grooves decreases with increasing depth. Design equations are proposed for predicting the maximum film coefficient for a grooved surface.

It was determined that deep, narrow rectangular grooves with small land widths have the largest heat flux capability for a given temperature difference, however, to attain these heat fluxes without boiling would require impractically large film efficiencies. It was also shown that triangular grooves due to their larger film coefficients, may make a more practical surface for many applications.

74139 THEORETICAL ANALYSIS OF MOLECULAR INTERACTION WITH SURFACE IN HEAT PIPES

T. Matsushita (National Space Development Agency of Japan Minatoku, Tokyo, Japan) and K. Oshima (Tokyo University, Tokyo, Japan), In: International Symposium on Space Technology and Science, 10th, Tokyo, Japan, September 3-8, 1973, Proceedings, AGNE Publishing, Inc., 1973, p. 571-578, Avail: TAC

In order to analyze the characteristics of a heat pipe, the one-dimensional evaporation-condensation flow field between two parallel liquid surfaces with different temperatures is treated in the context of the kinetic theory of gas using the one-dimensional BGK equation, assuming that the vapor gas is one dimensional. The finite element method is applied to this problem. The distributions of the temperature and the number density between the two surfaces and the net mass flux from the hot surface to the cold one are obtained for flows with several temperature ratios and Knudsen numbers.

C.3 FLUID FLOW

74026 STUDY OF THE FLOW CHARACTERISTICS OF TWO-PHASE DISPERSED ANNULAR FLOWS IN HEATED PIPES

B. I. Nigmatulin. PMTF-Zhurnal Prikladnoi Mekhaniki i Tekhnicheskoi Fiziki, July-August 1973, p. 78-88, 15 refs. In Russian. Avail: TAC

Consideration of the characteristics of dispersed annular flows in heated cylindrical pipes at mixture flow rates not too close to critical within the framework of a three-velocity, single-temperature model. A study is made of the conditions of onset of a heat-transfer crisis of the second kind, i.e., a deterioration of heat transfer which leads to a sudden increase in the heating surface temperature and is related to a drying out of the wall liquid film. An analysis is made of the hydraulic resistance, the liquid flow rate in the film, the true bulk vapor content, etc. A two-phase flow in a dispersed annular regime is characterized by the combined motion of the three components of the mixture - vapor, the wall liquid film, and drops. It is assumed that each component of the mixture has its own velocity and that the temperature of the mixture in each cross section of the channel is equal to the saturation temperature at the pressure in a given cross section.

74027 HEAT PIPE STABILITY. 1: A PRELIMINARY INVESTIGATION INTO THERMALLY ASSISTED CAVITATION

NASA Goddard Space Flight Center, Greenbelt, Maryland. NASA-TM-X-70458, X-764-73-224. July 1973, 19 pages, refs. Avail: TAC.

The notion is introduced of thermally assisted cavitation by localized fluctuations in capillary forces. Because cavitation in liquids can be closely approximated by an isothermal process, only momentum and mass balances are used to introduce the notion for liquids under mechanical tension. Brief attention is given to developing a stability theory in terms of the stiffness and compliance coefficients for a working fluid. Interestingly, the particular thermodynamic approach taken can be used to suggest experiments relating working fluid performance to meniscus behavior. A correction to the liquid flow equation is suggested.

74025 ANALYSIS OF THE EFFECTS OF VAPOR PRESSURE DROP ON HEAT PIPE PERFORMANCE

C.L. Tien, A.R. Rohani (Department of Mechanical Engineering, University of Caliornia, Berkeley, California). International Journal of Heat and Mass Transfer, Vol. 17, No. 1, p. 61-67, January 1974. Avail: TAC

An analysis of the effects of vapor pressure variation on the vapor temperature distribution, evaporation and condensation rates, and the overall heat pipe performance is presented. The elliptic mass, momentum and energy conservation equations in conjunction with the thermodynamic equilibrium relation and appropriate boundary conditions are solved numerically for a cylindrical heat pipe with evaporator, adiabatic and condenser sections. The results show that in certain situations vapor pressure variations play a significant role in the heat pipe performance. It is also demonstrated that the approximate solution based on the parabolic boundary-layer equations does not provide an accurate picture of vapor pressure variations at relatively high evaporation and condensation rates.

74059 DETERMINE ABOVE SATURATION PRESSURES IN A CLOSED GAS SYSTEM

Rockwell International Corp., Canoga Park, California. IBM 360, Fortran G, 64 cards. MFS-24472. Avail: TAC

A computer program was written in FORTRAN to calculate vapor pressures as a function of temperature in heat pipes where the fluid is supercritical or above saturation. Since a heat pipe is essentially a pressure vessel from a safety standpoint, it is necessary to establish the pressure-temperature relationships so that the pressure and safety factor in the pipe will be known as well as the maximum temperature to which the pipe can be exposed. In the saturated region, the pressure is only a function of temperature and is readily available from saturation tables. Above saturation, the pressure is a function of the specific volume (amount of charge divided by the free volume) as well as temperature. In this region, limited data is presented in most references, and the pressure-temperature relationships must be computed by an iterative process using compressibility charts. The computer program solves the pressure-temperature relationship by Van Der Waal's equation of state.

74063 TRANSIENT ANALYSIS OF HEAT PIPES WITH APPLICATIONS TO SELECTED EXPERIMENTS AND A CONCEPTUAL REACTOR DESIGN

Charles H. Bowers (The Ohio State University, Ohio) Dissertation, 1973. Microfilm Order No. 74-3124, 269 pages.
Avail: TAC

This dissertation offers a computerized model of two dimensional transient heat pipe vapor flow with a one dimensional wick analysis. This analysis could be used as the basis for a more complete design code to predict the response of the heat pipes to reactor power transients for any proposed design.

The two dimensional vapor flow calculation is based on the Implicit Continuous Fluid Eulerian, ICE, Method developed at Los Alamos Scientific Laboratory and the one dimensional wick analysis is based on experimental correlations obtained from the literature. The result is a code which predicts the response of a heat pipe to various transient power loads. Comparisons with analytical and experimental results are offered and a proposed concept is analyzed highlighting the advantages of the use of such a code in any proposed design.

74096 THEORETICAL AND EXPERIMENTAL INVESTIGATION OF TWO-COMPONENT HEAT PIPES

H.J. Brommer (University of Stuttgart, Stuttgart, West Germany). AIAA/ASME 1974 Thermophysics and Heat Transfer Conference, Boston, Massachusetts, July 15-17, 1974.
AIAA Paper No. 74-720. Avail: TAC

The temperature and and concentration distributions within two-component heat pipes and the rate of separation of components were theoretically investigated. Experiments carried out with water/methanol heat pipes of the six-artery type confirmed the theoretical results that only a partial separation of the components will occur. Performance measurements also demonstrated that water/methanol heat pipes can be operated at high power levels. On the one hand two-component heat pipes have a superior cold start-up behavior compared to respective one-component heat pipes, but their axial temperature drop during nominal operation conditions is considerably higher.

74140 FLUID DYNAMICS AND HEAT TRANSFER OF CAPILLARY-POROUS MEDIA USED IN HEAT PIPES

A.V. Luikov (Heat and Mass Transfer Institute, BSSR Academy of Sciences, Minsk, USSR), Paper presented at the 1st International Heat Pipe Conference, Stuttgart, West Germany, October 15-17, 1973, Session 5.

The paper describes an investigation into the physical mechanism of liquid transport in porous wicking materials of a heat pipe. The governing equation of liquid motion in porous medium is given by the equation describing the flow of liquid at the presence of singular surfaces. The equation differs from that of Navier-Stokes by additional terms of velocity of a singular surface and discontinuity of thermodynamic properties at this surface.

It is shown that during the motion of such a medium an additional force appears which is distinct from the internal friction and external hydrostatic forces. This force results from interaction between a liquid and a porous skeleton of the wick and is responsible for a change in the law of liquid filtration through porous media.

Theoretical calculations are confirmed by the experiments. Moreover, a case is considered of a two-phase fluid (liquid and vapour) motion in a capillary-porous medium. Some new relationships are found which make it possible to enhance heat transfer in a heat pipe. A relation is established between the Nusselt and Brun numbers with respect to heat transfer in a heat pipe.

The trends are outlined of a further analysis of momentum, energy and mass transfer on the basis of nonlinear thermohydrodynamics of the capillary-porous media.

74141 DETERMINATION OF FLOW PARAMETERS IN THE EVAPORATOR SECTION OF A HEAT PIPE DURING NONUNIFORM HEATING (OPREDELENIE PARAMETROV POTOKA V ISPARITELE TEPLOVOI TRUBY PRI NERAVNOMERNOM OBOGREVE)

V.I. Tolubinskii, E.N. Shevchuk, and N.V. Chistopianova (Akademiia Nauk Ukrainskoi SSR, Institut Tekhnicheskoi Teplofriziki, Kiev, Ukrainian SSR), Teplofizika i Teplotekhnika, No. 24, 1973, P. 3-6, In Russian

English abstract is not available.

D. DESIGN, DEVELOPMENT, AND FABRICATION

D.1 GENERAL

74028 USER'S MANUAL FOR THE TRW GASPIPE 2 PROGRAM: A VAPOR-GAS FRONT ANALYSIS PROGRAM FOR HEAT PIPES CONTAINING NON-CONDENSIBLE GAS
D. K. Edwards, G. L. Fleishman, B. D. Marcus (Materials Science Staff, TRW Systems Group, Redondo Beach, California). Contract NAS2-5503. NASA-CR-114672, TRW-13111-6054-RO-00. October 1973, 128 pages, refs. Avail: TAC.

A digital computer program for design and analysis of heat pipes which contain non-condensible gases, either for temperature control or to aid in start-up from the frozen state, is presented. Some of the calculations which are possible with the program are: (1) wall temperature profile along a gas-loaded heat pipe, (2) amount of gas loading necessary to obtain desired evaporator temperature at a desired heat load, (3) heat load versus evaporator temperature for a fixed amount of gas in the pipe, and (4) heat and mass transfer along the pipe, including the vapor-gas front region.

74029 DEVELOPMENT PROGRAM FOR A LIQUID METHANE HEAT PIPE
W. G. Foster, D. O. Murray (Lockheed Research Laboratories, Palo Alto, California). In: Cryogenic Engineering Conference, Boulder, Colorado, August 9-11, 1972, Proceedings. Plenum Press, New York, 1973, p. 96-102, 8 refs. Avail: TAC

Description of a development program on the design of a heat pipe which would transfer 2 W of power over a length of 122 cm, with a total temperature drop of 2 K and a condenser temperature of 110 K. The heat pipe is intended for spacecraft applications, and the design requirements were satisfied by a simple wire-cloth wick, using methane as the working fluid. Thermal tests in a one-g field were conducted, and results agreed closely with the predicted permormance. The radial temperature gradient was found to be smaller than anticipated for a methane heat pipe. No degradation in performance was found after the prototype was subjected to launch environment tests.

74030 STRUCTURAL HEAT PIPE - PATENT APPLICATION
Stanford Ollendorf (NASA Goddard Space Flight Center, Greenbelt, Maryland). Inventor, filed 14 September 1973, 14 pages. NASA-Case-GSC-11619-1, US-Patent-Appl-SN-397476. Avail: TAC.

A combined structural reinforcing element and heat transfer member is described for placement between a structural wall of a container or housing which is to be thermally protected and an outer insulation blanket disposed thereover and spaced apart therefrom. The element consists of a heat pipe, one side of which supports the outer insulation blanket, the opposite side of which is connected to the structural wall. Heat penetrating through the outer insulation blanket directly reaches the heat pipe and is drawn off, thereby reducing thermal gradients in the structural wall. The element, due to its attachment to the structural wall, further functions as a reinforcing member.

74031 HEAT PIPE THERMAL CONDITIONING PANEL DETAILED TECHNICAL REPORT, 28 JUNE 1972 - 12 AUGUST 1973

E. W. Saaski (McDonnell-Douglas Astronautics Co., Richland, Washington). Contract NAS8-28639. NASA-CR-124451, MDC-G4421. September 1973, 50 pages, refs. Avail: TAC.

The technology involved in designing and fabricating a heat pipe thermal conditioning panel to satisfy a broad range of thermal control system requirements on NASA spacecraft is discussed. The design specifications were developed for a 30 by 30 inch heat pipe panel. The fundamental constraint was a maximum of 15° gradient from source to sink at 300 watts input and a flux density of 2 watts per square inch. The results of the performance tests conducted on the panel are analyzed.

74032 HEAT PIPE THERMAL CONDITIONING PANEL EXECUTIVE SUMMARY REPORT, 28 JUNE 1972 - 12 AUGUST 1973

E. W. Saaski (McDonnell-Douglas Astronautics Co., Richland, Washington). Contract NAS8-28639. NASA-CR-124453, MDC-G4422. September 1973, 26 pages, refs. Avail: TAC.

The development, fabrication, and evaluation of heat pipe thermal conditioning panels are discussed. The panels were designed and fabricated to be compatible with several planned NASA space vehicles, in terms of panel size, capacity, temperature gradients, and integration with various heat exchangers and electronic components. It was satisfactorily demonstrated that the heat pipe thermal conditioning panel meets the thermal efficiency and heat transport requirements.

74065 VARIABLE CONDUCTANCE HEAT PIPE TECHNOLOGY
B.D. Marcus, D.K. Edwards, W.T. Anderson (TRW Systems Group, Redondo Beach, California). Contract NAS2-5503. NASA-CR-114686, RR-4. December 1973, 140 pages, refs. Avail: TAC

Research and development programs in variable conductance heat pipe technology were conducted. The treatment has been comprehensive, involving theoretical and/or experimental studies in hydrostatics, hydrodynamics, heat transfer into and out of the pipe, fluid selection, and materials compatibility, in addition to the principal subject of variable conductance control techniques. Efforts were not limited to analytical work and laboratory experimentation, but extended to the development, fabrication and test of spacecraft hardware, culminating in the successful flight of the Ames Heat Pipe Experiment on OAO-C Spacecraft.

74066 A HOMOGENEOUS HEAT PIPE DESIGN CODE
A.M. Nakashima, G.M. Kikin (Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California). Contract NAS7-100. NASA-CR-136831, JPL-TM-33-663. 15 January 1974, 34 pages, refs. Avail: TAC

A computer program was developed to facilitate parametric performance evaluation of heat pipes in lightweight heat rejection systems. A description of the code, user's manual, and sample inputs are provided. The emphasis is placed on the analysis and design of homogeneous wick heat pipes. The analysis of the annualar heat pipe is included as part of the heat pipe radiator subroutine.

74104 VARIABLE CONDUCTANCE HEAT PIPE TECHNOLOGY--FINAL RESEARCH REPORT

W.T. Anderson, D.K. Edwards, J.E. Eninger, B.D. Marcus (TRW Systems Group, Redondo Beach, California). Contract NAS2-5503. NASA-CR-114750, TRW-13111-6060-RU-00. March 1974, 87 pages, refs. Avail: TAC

A research and development program in variable conductance heat pipe technology is reported. The project involved: (1) theoretical and/or experimental studies in hydrostatics, (2) hydrodynamics, (3) heat transfer into and out of the pipe, (4) fluid selection, and (5) materials compatibility. The development, fabrication, and test of the space hardware resulted in a successful flight of the heat pipe experiment of the OAO-3 satellite. A summary of the program is provided and a guide to the location of publications on the project is included.

74105 DEVELOPMENT OF A BLOCKING ORIFICE THERMAL DIODE HEAT PIPE

R.L. Kosson, J.A. Quadrini (Grumman Aerospace Corp., Bethpage, New York), and J.K. Kirkpatrick (NASA Ames Research CEnter, Moffett Field, California). AIAA/ASME 1974 Thermophysics and Heat Transfer Conference, Boston, Massachusetts, July 15-17. 1974. AIAA Paper No. 74-754. Avail: TAC

A new geometry is described for low-temperature diode heat pipes employing excess liquid to block the vapor space of the evaporator and part of the transport section during the reverse mode conditions. An orifice plate is placed in the pipe at the location of the blocking meniscus, with the opening arranged to permit proper liquid distribution in both ground tests and zero-g operation. Parametric analytical results are presented for several fluids (carbon tetrafluoride, methane, ethane). Experimental data are presented for a room-temperature diode verifying feasibility, and a ¼ in. O.D. cryogenic diode with methane working fluid.

74134 THE HEAT PIPE AS THERMAL TRIODE (DAS WARMELITROHR ALS THERMISCHE TRIODE)

P. Grassmann and W. Dorfler (Zurich), Warme and Stoffubertrafung Bd., 2 (1969), S. 144-146, In German, Avail: TAC

It is possible by attachment of a cooling trap to a heat pipe to regulate continually the heat flow by reducing or adding of transported mass. The behaviour of such a thermal triode is calculated here for a model and compared with measurements.

74142 FEASIBILITY STUDY AND DEVELOPMENT OF A CONSTANT TEMPERATURE HEAT PIPE SYSTEM. PHASE 2: EXPERIMENTAL DESIGN - FINAL REPORT

H. Hage (Inst. fuer Kernenergetik, Stuttgart University, West Germany), Contract ESTEC-1703/72-SK, ESRO-CR(P)-430, October 1973, 123 pages. Avail: TAC

Results of preliminary tests carried out with alternative heat pipe designs, the selection of the prototype design, its analysis, manufacture, and extended theoretical and experimental investigations are presented. According to preliminary tests the modular artery heat pipe concept was chosen for the prototype. Measurements showed that the artery heat pipe suffered a performance degradation by a factor of about 3 when noncondensable gas was present in the heat pipe. Therefore the experimental program was modified and power steps between 20 and 100 watts were applied to the heat pipe instead of power steps between 40 and 200 watts. The agreement between theoretical predictions and experimental results was good for the steady state as well as the transient behavior. The mechanical analysis of the system indicated that it should be able to withstand launch conditions.

74143 SIMPLIFIED ANALYTICAL MODEL OF VERTICAL ARTERIAL HEAT PIPES

L.L. Vasiliev and V.G. Kiselyov (Heat and Mass Transfer Institute, Minsk, BSSR, USSR). Paper presented at the 5th International Heat Transfer Conference, September 3-7, 1974, Keidanrenkaikan Building, Tokyo, Japan, Report No. HE2.3, Avail: TAC

In the paper engineering design is given for vertical arterial heat pipes. Such heat transfer devices are of interest since in them liquid is transferred from the condenser to the evaporator through the artery rather than through the film flowing down the wall where suction and distribution of the liquid over the condenser and evaporator walls are performed through triangular grooves. This design provides a higher effective thermal conductivity at high heat fluxes compared to the thermosyphon design. Expressions for a limit heat flux transferred by heat pipes are presented as a function of the groove geometry, groove width and pore dimensions. Heat pipe performances are considered for various ratios of these parameters.

74144 STRUCTURAL HEAT PIPE

Goddard Space Flight Center, Greenbelt, Maryland, NASA
Technical Brief B73-10364, 1 page, Avail: TAC

A more efficient arrangement uses heat pipes as an integral part of the structural support in order to equalize the heat absorbed. The solar heat is absorbed through the structural support member and is fed directly to a heat pipe which transfers the heat around to a cooler spot before it can find its way to the structure.

D.2 WICKS

<u>74033</u> WICK COOLING IS SLOWLY COMING OUT OF LABS AND INTO INDUSTRY

Product Engineering. Vol. 44, January 1973, p. 37-38.
Avail: TAC.

This short message presents some features with capillary passages that help in cooling. The first feature is the Electrohydrodynamic Heat Pipe designed by T. B. Jones. The second feature is Arterial Wicks, which increase the flow capacity of a conventional heat pipe, from the idea of G. D. Johnson and E. W. Saaski. The last one is the phenomenon of Partially-Saturated Wicks developed by C. C. Roberts and K. T. Feldman, Jr.. In addition, the Transpiration Cooling through porous plates done by John Chishom is presented.

74068 VAPORIZATION HEAT TRANSFER IN HEAT PIPE WICK MATERIALS
J.K. Ferrell, E.G. Alexander, W.T. Piver (Department of Chemical Engineering, North Carolina State University, Raleigh, North Carolina). Progress in Astronautics and Aeronautics. Vol. 31, 1973, p. 3-18. Avail: TAC

Vaporization heat-transfer characteristics were measured for several wick materials including 5 samples of felted metal (N_i, Cu, and stainless steel) and 3 samples of sintered Cu metal powder. The experimental apparatus consisted of a heated surface arranged so that the fluid was drawn to the heated surface by capillary forces up to a maximum of 12 inches. Experimental data or dryout, or critical heat flux, agreed with a capillarity-flow resistance model when measured properties of the wick materials were used. Prediction of the heat-transfer coefficent was unsatisfactory, probably due to uncertainties in wick-heated surface contact.

74069 HEAT PIPE
Robert F. Keller (RCA Corp.). U.S. Patent Application No. 104,920, 8 January 1971. German Patent 2,149,883, 23 August 1973. 12 pages. Avail: TAC

A heat pipe is made by providing particles of a 1st metal (Cu,Fe,Ni, and their alloys) coated with a 2nd lower-melting metal (Pb-Zn alloy, In) and heating to a temperature that is higher than the melting point of the 2nd metal to bind the particles to each other and to part of the inside wall. Thus, a cylindrical mandrel was placed coaxially inside a Cu tube. Pb-Zn (60:40 weight ratio) alloy-electroplated spherical, 70-400 mesh. Cu particles were packed into the annular space between the Cu tube and mandrel. The assembly was heated in H to 250-300°C to melt the solder coating, cooled, and the mandrel was removed.

74070 HOW TO CONDUCT HEAT AND HOW NOT TO
Machine Design. Vol. 45, p. 40. June 28, 1973. Avail: TAC

This message describes the electrohydrodynamic heat pipe developed at Colorado State University and the capillary insulator patented by Martin Marietta Corporation.

74097 MENISCI COALESCENCE AS A MECHANISM FOR VENTING NONCONDENSABLE GAS FROM HEAT PIPE ARTERIES
J.E. Eninger (TRW Systems Group, Redondo Beach, California). AIAA/ASME 1974 Thermophysics and Heat Transfer Conference, Boston, Massachusetts, July 15-17, 1974. AIAA Paper No. 74-748. Avail: TAC

Noncondensable gas in an arterial heat pipe, whether a contaminant or intentionally introduced for control, results in arterial bubbles during priming that subsequently grow and deprime the artery when a heat load is applied. A method is presented to vent the gas through capillary-size holes in a foil-walled portion of the artery at the evaporator end. Liquid cannot plug these holes, because the foil is sized so thin that the menisci on either side of a potential liquid plug would coalesce, and the hole would empty. Theoretical and experimental results are presented that relate the hole size to the required foil thinness.

74100 INVESTIGATION OF ARTERIAL GAS OCCLUSIONS. FINAL REPORT, 22 May 1973 to Jan 1974
E.W. Saaski (McDonnell-Douglas Astronautics Co., Richland, Washington). Contract NAS2-7596. NASA-CR-114731, MDC-G4437. March 1974, 89 pages, refs. Avail: TAC

The effect of noncondensable gases on high-performance arterial heat pipes was investigated both analytically and experimentally. Models have been generated which characteize the dissolution of gases in condensate, and the diffusicnal loss of dissolved gases from condensate in arterial flow. These processes, and others, were used to postulate stability criteria for arterial heat pipes under isothermal and non-isothermal condensate flow conditions. A rigorous second-order gas-loaded heat pipe model, incorporating axial conduction and one-dimensional vapor transport, was produced and used for thermal and gas studies. A Freon-22 (CHCIF2) heat pipe was used with helium and xenon to validate modeling. With helium, experimental data compared well with theory. Unusual gas-control effects with xenon were attributed to high solubility.

74101 PROPERTIES OF WIRE-NETTING STRUCTURES AS DISTRIBUTORS OF LIQUID IN THIN-FILM EVAPORATORS (DIE EIGENSCHAFTEN VON DRAHTGEWEBESTRUKTUREN ALS FLUESSIGKEITSVERTEILER IN DUENNSCHICHTVERDAMPFERN)

H. Uhlemann (University of Eindhoven, Netherlands). Philips Research Report, Suppl. No. 1, 1974, 120 pages, 38 refs. In German. Avail: TAC

Wire-wick structures can be used to distribute the liquid in heat pipes and in thin-film evaporators. The properties of the wire-wick structures governing these applications are their geometry as well as their capillary and flow behavior. These features are investigated theoretically and practically, the investigation being restricted to structures of the type of screen gauzes. It is shown that wire-wick structures fashioned as syphons are efficient distributors of liquid in thin-film evaporators.

74106 SELECTION OF OPTIMUM PARAMETERS OF HEAT PIPE WITH WICK IN THE FORM OF A PERFORATED SCREEN WITH ANNULAR GAP

Yu. A. Poskonin, I.I. Mosin, V.K. Shchukin, R.S. Valeev. Soviet Aeronautics, Vol. 16, No. 3, 1973, p. 79-83, 3 refs. Avail: TAC

A technique is developed for the analysis of a heat pipe with a wick in the form of a perforated screen with annular gap operating in a gravity field (in any position in relation to the horizon) or under weightlessness. This technique makes it possible to select optimum geometric dimensions of the heat pipe. An example of the calculation of optimum geometric dimensions of a sodium pipe is presented.

74107 METHOD OF FORMING A WICK FOR A HEAT PIPE--PATENT APPLICATION
Frank G. Arcella, Ernest C. Phillips, Richard P. Sprecace (Inventors to NASA, Westinghouse Elec. Corp.). Contracts NAS7-100, JPL-953074. NASA-Case-NPO-13391-1, US-PATENT-Appl-SN-446567. Filed 27 February 1974, 10 pages. Avail: TAC

A method for forming a tubular wick for heat pipes is presented. The method consists of steps involving forming the wick blank of a predetermined thickness from multiple layers of stainless steel screen mesh. The process makes it possible to reduce the pore size of the wicks by approximately fifty percent.

74108 DETERMINATION OF PROPERTIES OF POROUS MATERIALS FROM THEIR ABSORPTION PUMPING KINETICS
S. V. Konev, Z. N. Kostko. Heat Transfer--Soviet Research, Vol. 6, No. 2, 1974, p. 95-100. Avail: TAC

To determine the properties of porous wicks, which are used in heat pipe design, one must use several facilities of different kind. This paper suggests a technique for calculating the properties of porous materials (porosity, maximum absorption depth, minimum pore radius, pore radius distribution, overall permeability, permeability as a function of moisture content) on the basis of the absorption kinetics of the porous material, determined by electric-capacitance methods of moisture measurement.

74109 WICKING OF LIQUIDS IN SCREENS
Eugene P. Symons (NASA, Lewis Research Center, Cleveland, Ohio). NASA-TN-D-7657, E-7781. May 1974, 33 pages, refs. Avail: TAC

An investigation was conducted to determine the magnitude of the wicking rates of liquids in various screens. Evaluation of the parameters characterizing the wicking process resulted in the development of an expression which defined the wicking velocity in terms of screen and system geometry, liquid properties, and gravitational effects. Experiment data obtained both in normal gravity and in weightlessness demonstrated that the model successfully predicted the functional relation of the liquid properties and the distance from the liquid source to the wicking velocity. Because the pore geometry in the screens was complex, several screen geometric parameters were lumped into a single constant which was determined experimentally for each screen.

74110 INVESTIGATION OF THE EFFECTIVE THERMAL CONDUCTIVITY OF POROUS MATERIALS

S.A. Tanayeva. Heat Transfer--Soviet Research, Vol. 6, No. 2, 1974, p. 112-118. Avail: TAC

The article considers problems of experimental and theoretical investigation of the effective thermal conductivity of porous materials over a wide temperature range. A brief description of the test facility is given and an analysis is presented of the most promising equations for calculating λ eff from data on constituents. Comparison of experimental and theoretical values of λ eff of porous materials shows that the most promising method is that of generalized conductivity.

74145 AN INVESTIGATION OF HEAT PIPE WICK CHARACTERISTICS

Z.N. Kastko, Heat Transfer - Soviet Research, Vol. 6, No. 3, May-June 1974, p. 132-138, Avail: TAC

This study states the need for determining such properties of heat pipe wicks as the porosity, height of capillary pumping and permeability. The results are presented of measuring these employing generally used methods for wicks from glass fiber, fiber glass and brass meshes and the results thus obtained are analyzed.

74146 CHOICE OF OPTIMAL PARAMETERS FOR A HEAT PIPE HAVING A WICK IN THE FORM OF A PERFORATED SCREEN WITH AN ANNULAR GAP (VYBOR OPTIMALNYKH PARAMETROV TEPLOVOI TRUBKI S FITILEM V VIDE PERFORIROVANNOGO EKRANA S KOLTSEVYM Z AZOROM)

In. A. Poskonin, I.I. Mosin, V.K. Shchukin, and R.S. Valeev, Aviatsignnaia Teknika, Vol. 16, No. 3, 1973, p. 97-101, In Russian.

English abstract is not available.

D.3 MATERIALS

74034 EXPERIMENTAL STUDY OF HEAT PIPE CHARACTERISTICS
V.I. Tolubinskiy, E.n. Shevchuk, V.D. Stambrovskiy, E.I. Istomin, M.E. Bezusov, L.V. Solovev. Heat Transfer-Soviet Research, Vol. 5, No. 3, May-June 1973, p. 1-5, 3 refs. Avail: TAC

Development and manufacturing technology of the niobium heat pipes that use sodium as heat transfer medium at very high temperatures is presented. Experimental tests results are reported and discussed.

74147 THE ELIMINATION OR CONTROL OF MATERIAL PROBLEMS IN WATER HEAT PIPES
G.F. Pittinato (McDonnell Douglas Astronautics Co., Huntington Beach, California), Quarterly Progress Report No. 1, 1 January-31 March 74, MDC-G5481; NSF-RA/N-74-037, April 74, 25 pages, Avail: TAC

A definition was made of a water heat pipe associated with a parabolic cylindrical solar collector that will operate in the temperature range of ambient to 300C. A literature survey was conducted on the problem of noncondensable gas generation in water heat pipes. The design of the heat pipes was completed and all of the materials and component parts have been ordered. Eight different alloys were selected for evaluation as candidate materials for water heat pipes.

E. TESTING AND OPERATION

74035 SPECIFIC CHARACTERISTICS OF LOW TEMPERATURE HEAT PIPES

V. V. Barsukov, L. N. Mishchenko, G. F. Smirnov. Inzhenerno-Fizicheskii Zhurnal, Vol. 25, No. 2, 1973, p. 249-253. In Russian. Avail: TAC.

The limiting capacity of low-temperature heat pipes is studied. Equations are derived in integral and dimensionless forms. With Cu pipes with brass and Cu wicks and ethanol working fluid, the capacity decreases from $\sim$70 watt at 90° to 0 watt at -10° to the horizontal. The limiting capacity is accompanied by a sharp increase in the temperature of the wall of the evaporator section.

74036 AN ANALYTICAL AND EXPERIMENTAL INVESTIGATION OF ROTATING, NONCAPILLARY HEAT PIPES

Paul J. Marto (Naval Postgraduate School, Monterey, California). NASA-CR-130373, NPS-59MX72111A. September 1973, 59 pages, refs. Avail: TAC.

An approximate theoretical model is derived for laminar film condensation on the inside of a rotating, truncated cone, and is used to predict the heat transfer performance of rotating noncapillary heat pipes for a wide variety of parametric conditions. Experimental results are presented for water, ethyl alcohol, and freon-113 in a stainless steel heat pipe rotating to speeds of 2800 R.P.M. Results show that these devices can be used effectively to transfer large quantities of heat in rotating systems. Predicted results agree to within plus or minus 20 percent to the experimental data. Dropwise condensation, instead of film condensation, improves heat pipe performance while the presence of noncondensible gases impairs performance.

74037 MECHANISMS OF HEAT TRANSFER IN HEAT PIPES AND THERMOSYPHONS

K. C. Sockalingam, V. E. Schrock (University of California at Berkeley, California). Transactions of American Nuclear Society, Vol. 16, p. 3-4, June 1973. From 19th annual meeting of the American Nuclear Society, Chicago, Illinois. Avail: TAC.

The performances of four heat pipes and one thermosyphon are presented and compared. All the pipes are made of the same stainless-steel tubing. Pipe 1 is constructed with a 20-mil liquid annulus and Pipe 2 has an 8-mil annulus. In pipes 3 and 4 the screens are rolled tightly with 2 to 3 mils liquid annulus. Pipe 3 employs five layers of 200-mesh stainless steel screen wick and Pipe 4 has five layers of 150-mesh screen while Pipe 5 has no wick.

74038 HEAT AND MASS TRANSFER IN HEAT PIPES CONTAINING NONCONDENSING GASES
L.L. Vasiliev, S.V. Konev (Inst. Teplo-Massoobmena, Minsk, U.S.S.R.). Inzhenerno-Fizicheskii Zhurnal, Vol. 25, No. 2, 1973, p. 254-260. In Russian. Avail: TAC

In a heat pipe, a noncondensing gas is pushed by steam towards the cold end of the pipe where the gas plug is formed. The effect of the volume and properties of the gas plug (Ar and air) and of the heat-transfer coefficient on the energy and mass transfer in the pipe was investigated experimentally by using ethanol as a heat-transfer agent. In the condensation zone, thermal resistance of the pipe with the noncondensing gas was considerably higher than that in a pipe without the noncondensing gas. With increasing heat output the temperature sensitivity increased. Reasonable agreement was found between experiment and calculated data. Heat pipes with noncondensing gases can be used as thermoregulators or thermostats.

74064 INVESTIGATION OF GRAVITATIONAL EFFECTS ON THE PERFORMANCE OF A VARIABLE CONDUCTANCE HEAT PIPE
Wayne Ives Humphreys (Naval Postgraduate School, Monterey, California). Master's thesis, December 1973, 68 pages. Avail: TAC

A variable conductance heat pipe with a length to diameter ratio of 96 to 1 was designed and constructed. The performance characteristics of both the conventional and gas loaded variable conductance modes of operation were studied. Particular emphasis was placed upon investigating the gravitational effects in the variable conductance mode. Heat inputs were varied from ten to fifty watts for horizontal and vertical operating positions. Methanol was used as the working fluid with either helium or krypton used as the noncondensable gas. Condenser temperature profiles and liquid crystal pictures, showing the effects of gravity, are presented for the various operating modes.

74071 INVESTIGATION OF THE INFLUENCE OF NONCONDENSING IMPURITIES ON HEAT TRANSFER EFFICIENCY OF EVAPORATING THERMOSIPHON (ISSLEDOVANIE VLIYANIYA NEKONDENSIRUYUSHCHIKHSYA PRIMESEI NA EFFEKTIVNOST'TEPLOPERENOSA ISPARITEL'NOGO TERMOSIFONA)

Z.R. Gorbis (Odessa Technology Institute of the Refrigeration Industry, USSR) and G.A. Savchenkov. Teploenergetika, No. 10, October 1973, p. 70-73. In Russian. Avail: TAC

A model is proposed which describes the processes taking place in the cooled part of an evaporating thermosiphon. An experimental rig is described, consisting of a thermosiphon and the heating, cooling, measurement, preliminary vacuuming, and charging systems. A description is given of the method of investigation and experimental results are analyzed. Satisfactory agreement between the calculated and experimental data permits the formula obtained to be recommended for the methods of calculation of evaporating thermosiphons.

74072 AN EXPERIMENTAL STUDY OF THE TWO-PHASE THERMOSIPHON TUBE

B.S. Larkin (Gas Dynamics Laboratory, Division of Mechanical Engineering, National Research Council of Canada). Paper 70-CSME-6, Transactions of the Engineering Institute of Canada, Vol. 14, No. B-6, August/September 1971. 8 pages. Avail: TAC

The two-phase thermosiphon is basically a simple, cheap, reliable, effective heat transport system which requires no external power supply. The apparatus for testing thermosiphons with water or Freon 11 as working fluids is described. The results of maximum heat flux, tube heat transfer parameter, operating temperature, depth of water or Freon 11, boiling and condensing coefficients, and dryout mechanism are presented.

74073 AN EXPERIMENTAL FIELD STUDY OF THE USE OF TWO-PHASE THERMOSIPHONS FOR THE PRESERVATION OF PERMAFROST

B.S. Larkin, G.H. Johnston (National Research Council, Ottawa, Canada). Paper presented at 1973 Annual Congress of the Engineering Institute of Canada, Montreal, 2 October 1973. 19 pages. Avail: TAC

The design of foundations in permafrost areas is usually based on preservation of the frozen condition of the ground. A possible method of achieving this object is the two-phase thermosiphon. A field evaluation of the effect of simple two-phase thermosiphons was undertaken by the authors between 1967 and 1971 at test sites located in Ottawa, Ontario (no permafrost) and Thompson, Manitoba (marginal permafrost). The results of these tests are presented in this paper.

74074 HEAT PIPE WITH AN ELECTROSTATIC PUMP
F.E. Reiss (Inst. fuer Neutronenphysik und Reaktortechnik, Kermforschungszentrum Karlsruhe, West Germany). Thesis submitted to Karlsruhe University. August 1973, 139 pages. In German. Avail: TAC

The performance of a heat pipe with an electrostatic pump to return the condensed working fluid to the evaporator was investigated. Theoretic predictions of performance agree with experimental data gained from three different heat pipes using nitrobenzene as a working fluid.

74111 EVAPORATIVE HEAT TRANSFER OF LIQUID POTASSIUM IN POROUS MEDIA

Ross Davis (Westvaco, North Charleston, South Carolina), and J. K. Ferrell (North Carolina State University, Raleigh, North Carolina). AIAA/ASME 1974 Thermophysics and Heat Transfer Conference, Boston, Massachusetts, July 15-17, 1974. AIAA Paper No. 74-719. Avail: TAC

An investigation of the vaporization heat transfer of potassium and water in two wicking materials, FM 1308 and Lamipore 7.4, has shown that, for water, the vaporization takes place within the porous medium over the heated surface; for potassium, the heat is conducted across the entire wick and the vaporization occurs at the surface of the wick. The critical heat flux for the potassium heat pipe can be predicted for all values of the heat flux; for the water heat pipe, the critical heat flux can be predicted only for values up to 40,000 BTU/ft^{2}hr.

74112 THERMAL VACUUM TEST OF A FULL-SCALE PROTOTYPE MULTI-HEAT PIPE THERMAL CONTROL ASSEMBLY

W. F. Ekern, M. P. Hollister, V. T. Johnson, H. M. Satterlee, W. A. Stolzenburg (Lockheed Missiles and Space Co., Sunnyvale, California). AIAA/ASME 1974 Thermophysics and Heat Transfer Conference, Boston, Massachusetts, July 15-17, 1974. AIAA Paper No. 74-727. Avail: TAC

Thermal vacuum test results are described that demonstrate the capabilities of a full-scale, active feedback, multiple heat pipe, multiple-controller thermal control assembly to function as an assembly and verify the mutual compatibility of its interrelated components over a typical range of flight conditions. Two equipment-mounting conduction straps are maintained at 35 ± 2°F under varying simulated equipment loads and radiator surface solar loads. Two open-artery ammonia and two closed-artery acetone variable-conductance heat pipes are used. A thermal model of the test assembly has been formulated and used for pretest analyses.

74113 LAMINAR FLOW IN ANNULI AND FLAT-PLATE CHANNELS WITH MASS TRANSFER AT ONE WALL

B. K. Gupta, E. K. Levy (Lehigh University, Bethlehem, Pennsylvania). AIAA/ASME 1974 Thermophysics and Heat Transfer Conference, Boston, Massachusetts, July 15-17, 1974. AIAA Paper No. 74-721. Avail: TAC

An experimental and theoretical study of laminar, incompressible fluid flow in annuli and flat-plate channels with porous walls is described. Experimental data on the axial pressure variations in an annulus with a radius ratio of 0.83 and with uniform injection and suction at the porous inner wall are presented. Similarity solutions are obtained both for the annular geometry and for the plane channel approximation. In addition, entrance region solutions are obtained for a plane channel flow with uniform mass suction at one wall.

74114 ELECTROHYDRODYNAMIC HEAT PIPE EXPERIMENTS
T. B. Jones, M. P. Perry (Colorado State University, Fort Collins, Colorado). Journal of Applied Physics, Vol. 45, May 1974, p. 2129-2132. Avail: TAC

Experiments with two electrohydrodynamic heat pipes are reported. Both devices employ an electromechanical flow structure for axial liquid flow and a capillary wicking structure for (1) collection of condensed liquid at the cooled end and (2) distribution of this liquid at the heated end. One device has circumferential grooving for the capillary structure and the other has feltmetal wicking. The experiments successfully demonstrate the electrohydrodynamic heat pipe concept. Compatibility of the two circumferential wick structures with an axial electromechanical flow structure is also demonstrated. A significant mismatch of the capillary groove and electrohydrodynamic pumping capabilities results in severe hydrodynamic burn-out limiting in the first heat pipe. Both devices have very poor over-all thermal conductances of the order of 1-2 W/deg C, reflecting the generally poor heat-transfer properties of the dielectric working fluids required in electrohydrodynamic heat pipes.

74115 PERFORMANCE TESTS OF GRAVITY-ASSIST HEAT PIPES WITH SCREEN-WICK STRUCTURES
J. E. Kemme, J. E. Deverall, E. S. Keddy, J. R. Phillips, W. A. Ranken (Los Alamos Scientific Lab., Los Alamos, New Mexico). AIAA/ASME 1974 Thermophysics and Heat Transfer Conference, Boston, Massachusetts). July 15-17, 1974. AIAA Paper No. 74-723. Avail: TAC

Performance limits were established at several operating temperatures for sodium heat pipes with screen wicks. After each pipe was tested horizontally, vertical tests were made in a gravity-assist mode with the evaporator down. Limits were higher in the vertical tests, but agreement between measured and calculated limits was not always obtained. Wick imperfections, in the form of large openings, filled with vapor in the gravity-assist mode and produced superheat limitations. Although large wick passages might improve gravity-assist performance, they should be located near the vapor space and arranged to collect condensate and protect it from flowing vapor.

74116 PARAMETRIC PERFORMANCE OF EXTRUDED AXIAL GROOVED HEAT PIPES FROM 80° to 350° K

K. R. Schlitt, J. P. Kirkpatrick (NASA Ames Research Center, Moffett Field, California), and P. J. Brennan (Engineering Consultant, Baltimore, Maryland). AIAA/ASME 1974 Thermophysics and Heat Transfer Conference, Boston, Massachusetts, July 15-17, 1974. AIAA Paper No. 74-724.
Avail: TAC

This paper presents parametric performance data derived from tests with an aluminum axial grooved extruded pipe and the following working fluids: oxygen (80-120°K); methane (100-160°K); ethane (140-220°K); ammonia (200-300°K); acetone (300-350°K). Major emphasis is placed on the cryogenic fluids, since little or no actual performance data exists for them. The effects of operating temperature, fluid inventory, heat flux, and elevation on the transport capability, static height, and on the evaporator and condenser film coefficients are measured and compared to theory.

74148 BOILING AND EVAPORATION FROM HEAT PIPE WICKS WITH WATER AND ACETONE

A. Abhat and R.A. Seban (University of California at Berkeley, Berkeley, California), ASME Journal of Heat Transfer, August 1974, P. 331-337, Avail: TAC

Heat transfer for pool boiling with fluxes in the range of 5×10^2 to 5×10^4 Btu/(ft^2hr) and the associated excess of wall over saturation temperatures are presented, primarily for atmospheric pressure, for vertical tubes in water, ethanol and acetone, bare or wrapped with screen or felt metal. For the wrapped tubes, this performance is given also for evaporation into surrounding saturated vapor with the liquid being supplied by the wick; this is the significant mode in respect to heat pipe applications. For this mode maximum evaporation rates are also indicated and it is shown that this maximum can be rationalized either in terms of a partially full wick with conduction transfer to the evaporation surface or in terms of a full wick with vapor holes originating at nucleation sites on the tube surface.

74149 PRODUCTION OF ALKALINE EARTH METASTABLE STATES BY A DISCHARGE IN A HEAT PIPE

Pierre Camus (Argonne National Laboratory, Argonne, Illinois), Journal of Physics B, Vol. 7, No. 10, 1974, P. 1154-1160, Avail: TAC

An experiment is described in which the 1st excited metastable states nsnp^{3}P^o and nsnd^{3}D of Mg, Ca, Sr and Ba are populated by a continuous discharge running through a metal vapor maintained by a heat pipe. The number of atoms obtained in these excited triplet states is large enough to allow the observation of the series members in a conventional atomic absorption experiment. The Argonne 30 foot Paschen-Runge spectrograph was used to record the spectra with a 0.37 Å mm^{-1} reciprocal dispersion. The wavelength uncertainty of ±0.002 Å gives improved wavelength values for many lines measured previously in emission and gives a energy scheme for the highest terms of the series nsn's^{3}S$_1$, nsn'd^{3}D and nsn'f^{3}F^o that is more accurate than previously reported. The variations of the quantum defect were fitted and the ionization limits, extrapolated from the triplet series, are compared with those obtained from the long principal series ns^2 ^{1}S$_o$-nsn'p^{1}P$_1$^{o}.

F. SUBJECT AND AUTHOR INDEX

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BRENNAN P J
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STAMBROVSKIY V D ISTOMIN E I
BEZUSOV M E SOLOVEV L V
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WICK COOLING IS SLOWLY COMING OUT OF LABS AND
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F.2 SUBJECT INDEX

```
00101 ECHNICAL / HEAT PIPE THERMAL CONDITIONING PANEL DETAILED T   74031   50
00102 SUMMARY R/ HEAT PIPE THERMAL CONDITIONING PANEL EXECUTIVE    74032   50
00104            HEAT PIPE THERMAL CONDITIONING PANEL*             74126   22
00134                       HOW TO CONDUCT HEAT AND HOW NOT TO#    74070   56
00079 HNOLOGY SATELLITE A VARIABLE CONDUCTANCE HEAT PIPE APPLICA   74088   20
00073 OGY#                VARIABLE CONDUCTANCE HEAT PIPE TECHNOL   74065   51
00044 FEEDBACK-CONTROLLED VARIABLE CONDUCTANCE HEAT PIPE FOR SPA   74085   19
00053 HE PERFORMANCE OF A VARIABLE CONDUCTANCE HEAT PIPE# / ON T   74064   53
00061 R FOR THE LUNAR SU/ VARIABLE CONDUCTANCE HEAT PIPE RADIATO   74052   18
00115 ION OF THE EFFECTIVE THERMAL CONDUCTIVITY OF POROUS MATERI   74110   60
00075 OF SLENDER ROTATING TRUNATED CONES# /SATION ON THE INSIDE    74103   42
00137 NERGY CONVERSION ENGINEERING CONFERENCE IECEC NATIONAL BUR   74053   26
00048 Y STUDY AND DEVELOPMENT OF A CONSTANT TEMPERATURE HEAT PIP   74142   53
00018 RAPID ACTION CIRCUIT BREAKER CONTACTS BY HEAT PIPES# / OF    74055   31
00028 LYSIS PROGRAM FOR HEAT PIPES CONTAINING NON-CONDENSIBLE GA   74028   49
00122  MASS TRANSFER IN HEAT PIPES CONTAINING NONCONDENSING GASE   74038   53
00090 TION OF THE LIQUID METALS H/ CONTRIBUTION TO THE DETERMINA   74058   37
00029 TYPE MULTI-HEAT PIPE THERMAL CONTROL ASSEMBLY# /CALE PROTO   74112   66
00013 PES AND THE ADVANCED THERMAL CONTROL FLIGHT EXPERIMENT TEC   74125   22
00025 MENTS WITH GAS-/ TEMPERATURE CONTROL OF IRRADIATION EXPERI   74015   25
00089 IN WATER/ THE ELIMINATION OR CONTROL OF MATERIAL PROBLEMS    74147   61
00031 ATION OF DEVICES FOR THERMAL CONTROL OF SATELLITES HEAT PI   74084   19
00077  HEAT PIPE CYCLING#  THERMAL CONTROL RANGE ASSOCIATED WITH   74099   38
00004 CE SHUTTLE HEAT PIPE THERMAL CONTROL SYSTEMS DESIGN AND TE   74124   22
00003 CE SHUTTLE HEAT PIPE THERMAL CONTROL SYSTEMS FINAL REPORT    74051   18
00050 YSICS AND SPACECRAFT THERMAL CONTROL#             THERMOPH   74087   20
00084 DIATOR FOR CRYOGENIC THERMAL CONTROL# /ODULAR HEAT PIPE RA   74128   23
00124                              CONTROLLED HEAT PIPES#          74119    6
00013 PMENT OF ELECTRICAL FEEDBACK CONTROLLED HEAT PIPES AND THE   74125   22
00137 ON THIRD INTERSOCIETY ENERGY CONVERSION ENGINEERING CONFER   74053   26
00149        COMPACT THERMOELECTRIC CONVERTER#                     74013   15
00082 MP/ DEVELOPMENT OF HEAT PIPE COOLED ANODE FOR XENON ARC LA   74093   32
00095 ICAL EVALUATION OF HEAT PIPE COOLED LASER MIRRORS# /NO OPT   74010    7
00022                    HEAT PIPE COOLED MICROWAVE WINDOW#        74091   32
00057 A SMALL SPLIT-CORE HEAT PIPE COOLED NUCLEAR REACTOR# /FOR    74090   27
00109 ND LOW TEMPERATURE HEAT PIPE COOLER STUDIES FOR SPACECRAFT   74089   21
00066 AT PUMPING BY THERMOELECTRIC COOLERS THROUGH A LOW-TEMPERA   74012   15
00071 PECULIARITIES OF EVAPORATIVE COOLING IN RAREFIED GAS#      . 74062   41
00140 OF LABS AND INTO INDUS/ WICK COOLING IS SLOWLY COMING OUT    74033   55
00017 CYLINDRICAL ROTATING HEAT P/ COOLING OF AC MOTOR SHAFT BY    74019   29
00019 IPE#                         COOLING OF AC MOTOR BY HEAT P   74055   31
00041 S AND INSTRUMENTS#           COOLING OF ELECTRONIC CIRCUIT   74132   34
00083  A HEAT P/ PASSIVE CRYOGENIC COOLING OF ELECTROOPTICS WITH   74127   23
00018 IT BREAKER CONTACTS BY HEAT/ COOLING OF RAPID ACTION CIRCU   74055   31
00014  FOR POWE/ A NOVEL METHOD OF COOLING SEMICONDUCTOR DEVICES   74018   29
00113 T PIPE FOR INFRARED DETECTOR COOLING# /HABLE CRYOGENIC HEA   74094   33
00054 PE FOR FUEL CELL AND BATTERY COOLING# /N INTERCELL HEAT PI   74133   34
00021  TECHNICAL REPORT/ HEAT PIPE COPPER VAPOR LASER SEMIANNUAL   74044    8
00109  HEAT PIPE COOLER STUDIES F/ CRYOGENIC AND LOW TEMPERATURE   74089   21
00083 PTICS WITH A HEAT P/ PASSIVE CRYOGENIC COOLING OF ELECTROO   74127   23
00113  DEVELOPMENT OF A SWITCHABLE CRYOGENIC HEAT PIPE FOR INFRA   74094   33
00049 T FLIGHT PERFORMANCE ONBOAR/ CRYOGENIC HEAT PIPE EXPERIMEN   74086   20
00084 ODULAR HEAT PIPE RADIATOR FOR CRYOGENIC THERMAL CONTROL# /D   74128   23
00138 CAL SCIENCES: THERMODYNAMICS CRYOGENICS AND VACUUM TECHNOL   74120    6
```

```
00040              HIGH EFFICIENCY HEAT EXCHANGERS#              74045   8
00012 PORATOR#  ANALYSIS OF A HIGH HEAT FLUX WATER HEAT PIPE EVA  74138  43
00038 #         NEW WAY TO CAPTURE HEAT FROM YOUR FURNACE WASTES  74077  11
00011 ST EFFICIENT WAY TO TRANSFER HEAT IS BY A PIPE#     THE MO  74054  13
00090  THE LIQUID METALS HEAT PIPE HEAT PERFORMANCE LIMITS# / OF  74058  37
00059 D PIPE#                  THE HEAT PIPE A NEW TUNE ON AN OL  74041   4
00079 LLITE A VARIABLE CONDUCTANCE HEAT PIPE APPLICATION# / SATE  74089  20
00030 TING NONCONDENSABLE GAS FROM HEAT PIPE ARTERIES# / FOR VEN  74097  57
00042                          THE HEAT PIPE AS THERMAL TRIODE#   74134  52
00051 Y LIMIT#      OPERATION OF A HEAT PIPE BEYOND THE CAPILLAR  74057  36
00119        EXPERIMENTAL STUDY OF HEAT PIPE CHARACTERISTICS#     74034  61
00082 NON ARC LAMP/ DEVELOPMENT OF HEAT PIPE COOLED ANODE FOR XE  74093  32
00095 AL AND OPTICAL EVALUATION OF HEAT PIPE COOLED LASER MIRROR  74010   7
00022 NDOW#                        HEAT PIPE COOLED MICROWAVE WI  74091  32
00067 NCEPT FOR A SMALL SPLIT-CORE HEAT PIPE COOLED NUCLEAR REAC  74090  27
00109 RYOGENIC AND LOW TEMPERATURE HEAT PIPE COOLER STUDIES FOR   74089  21
00021 SEMIANNUAL TECHNICAL REPORT/ HEAT PIPE COPPER VAPOR LASER   74044   8
00077 ONTROL RANGE ASSOCIATED WITH HEAT PIPE CYCLING#  THERMAL C  74099  38
00081                A HOMOGENEOUS HEAT PIPE DESIGN CODE#         74066  51
00120  THE EVAPORATOR SECTION OF A HEAT PIPE DURING NONUNIFORM H  74141  48
00012 IS OF A HIGH HEAT FLUX WATER HEAT PIPE EVAPORATOR#  ANALYS  74138  43
00032 IS OF A HIGH-HEAT-FLUX WATER HEAT PIPE EVAPORATOR#  ANALYS  74023  43
00049 ERFORMANCE ONBOAR/ CRYOGENIC HEAT PIPE EXPERIMENT FLIGHT P  74086  20
00055          ELECTROHYDRODYNAMIC HEAT PIPE EXPERIMENTS#         74114  57
00080 CULATION METHODS FOR ORGANIC HEAT PIPE FLUIDS# /-MERIT CAL  74021  35
00054 ATTERY COOLING/ AN INTERCELL HEAT PIPE FOR FUEL CELL AND B  74133  34
00113 NT OF A SWITCHABLE CRYOGENIC HEAT PIPE FOR INFRARED DETECT  74094  33
00044 TROLLED VARIABLE CONDUCTANCE HEAT PIPE FOR SPACE APPLICATI  74085  19
00037 UP LIMITS OF CIRCUMFERENTIAL HEAT PIPE GROOVES# / AND DRY-  74098  42
00092  OF OPTIMAL PARAMETERS FOR A HEAT PIPE HAVING A WICK IN TH  74146  60
00090 INATION OF THE LIQUID METALS HEAT PIPE HEAT PERFORMANCE LI  74058  37
00136 TING AND DELIVERY OF SHUTTLE HEAT PIPE LEADING EDGE TEST M  74130  24
00065 YERED / HOT SPOT OF A SODIUM HEAT PIPE LINED WITH MULTI-LA  74051  41
00128 R VARIABLE EVAPORATOR AND C/ HEAT PIPE MODEL ACCOUNTING FO  74136  39
00007 THOD OF FORMING A WICK FOR A HEAT PIPE PATENT APPLICATION#  74107  59
00117 TS OF VAPOR PRESSURE DROP ON HEAT PIPE PERFORMANCE# /EFFEC  74025  46
00098 THE ERRO/ APPLICATION OF THE HEAT PIPE PRINCIPLE TO AVOID   74121  14
00052               DEVELOPMENT OF HEAT PIPE RADIATOR ELEMENTS#   74014  17
00061 NAR SU/ VARIABLE CONDUCTANCE HEAT PIPE RADIATOR FOR THE LU  74052  18
00118 OWERED TRANSPONDERS#         HEAT PIPE RADIATOR FOR HIGH P  74129  23
00094 TION OF A LARGE SIZE MODULAR HEAT PIPE RADIATOR FOR CRYOGE  74128  23
00083 LING OF ELECTROOPTICS WITH A HEAT PIPE RADIATOR# /ENIC COO  74127  23
00046 PMENT AT THE NUCLEAR ENERGY/ HEAT PIPE RESEARCH AND DEVELO  74118   6
00131 MINARY INVESTIGATION INTO T/ HEAT PIPE STABILITY I A PRELI  74027  45
00005 AT THE UNIVERSITY OF MARYLA/ HEAT PIPE SYMPOSIUM WORKSHOP   74075   5
00048 NT OF A CONSTANT TEMPERATURE HEAT PIPE SYSTEM PHASE 2 EXPE  74142  53
00073         VARIABLE CONDUCTANCE HEAT PIPE TECHNOLOGY#          74065  51
00006 SEARCH/ VARIABLE-CONDUCTANCE HEAT PIPE TECHNOLOGY FINAL RE  74104  52
00146 GRAPHY WITH ABSTRACTS QUART/ HEAT PIPE TECHNOLOGY A BIBLIO  74008   2
00147 GRAPHY WITH ABSTRACTS CUMUL/ HEAT PIPE TECHNOLOGY A BIBLIO  74043   3
00143 GRAPHY WITH ABSTRACTS ANNUA/ HEAT PIPE TECHNOLOGY A BIBLIO  74005   2
00148 GRAPHY WITH ABSTRACTS#       HEAT PIPE TECHNOLOGY A BIBLIO  74076   3
00142 GRAPHY WITH ABSTRACTS CUMUL/ HEAT PIPE TECHNOLOGY A BIBLIO  74004   2
00144 Y UPDATE 1 JANUARY TO 31 MA/ HEAT PIPE TECHNOLOGY QUARTERL  74006   2
```

```
00145 GRAPHY WITH ABSTRACTS QUART/ HEAT PIPE TECHNOLOGY A BIBLIO  74007    2
00088             FUNDAMENTALS OF HEAT PIPE THEORY#                74022   35
00101 G PANEL DETAILED TECHNICAL / HEAT PIPE THERMAL CONDITIONIN  74031   50
00102 G PANEL EXECUTIVE SUMMARY R/ HEAT PIPE THERMAL CONDITIONIN  74032   50
00104 G PANEL#                     HEAT PIPE THERMAL CONDITIONIN  74126   22
00004 TEMS DESIGN A/ SPACE SHUTTLE HEAT PIPE THERMAL CONTROL SYS  74124   22
00003 TEMS FINAL RE/ SPACE SHUTTLE HEAT PIPE THERMAL CONTROL SYS  74051   18
00112                  GAS-HEATED HEAT PIPE VACUUM FURNACE#       74048    9
00056 S#        AN INVESTIGATION OF HEAT PIPE WICK CHARACTERISTIC  74145   60
00033 APORIZATION HEAT TRANSFER IN HEAT PIPE WICK MATERIALS#   V  74068   56
00001 BOILING AND EVAPORATION FROM HEAT PIPE WICKS WITH WATER AN  74148   69
00097 IC PUMP#                     HEAT PIPE WITH AN ELECTROSTAT  74074   65
00091 ION OF OPTIMUM PARAMETERS OF HEAT PIPE WITH WICK IN THE FO  74106   58
00045                              HEAT PIPE WORK IN EUROPE#      74117    6
00087                  STRUCTURAL HEAT PIPE-PATENT APPLICATION#   74030   49
00132                  STRUCTURAL HEAT PIPE#                      74144   54
00026                              HEAT PIPE#                     74040    4
00057                              HEAT PIPE#                     74069   56
00060          THEORETICAL STUDY OF HEAT PIPE#                    74135   39
00019            COOLING OF AC MOTOR BY HEAT PIPE#                74056   31
00035 PROGRAM FOR A LIQUID METHANE HEAT PIPE#      DEVELOPMENT    74029   49
00053 CE OF A VARIABLE CONDUCTANCE HEAT PIPE# / ON THE PERFORMAN  74064   63
00020 E STATES BY A DISCHARGE IN A HEAT PIPE# /E EARTH METASTABL  74149   69
00105 HE CONDENSATION SECTION OF A HEAT PIPE# /ER INTENSITY IN T  74024   40
00017 HAFT BY CYLINDRICAL ROTATING HEAT PIPE# /ING OF AC MOTOR S  74019   29
00066 RS THROUGH A LOW-TEMPERATURE HEAT PIPE# /RMOELECTRIC COOLE  74012   15
00009 UMENT UTILIZING AN OPEN-LOOP HEAT PIPE# /RYOSURGICAL INSTR  74078   11
00064 OCKING ORIFICE THERMAL DIODE HEAT PIPE# /VELOPMENT OF A BL  74105   52
00133 LD PIPE#                     HEAT PIPES A NEW TUNE ON AN O  74003    1
00013 ECTRICAL FEEDBACK CONTROLLED HEAT PIPES AND THE ADVANCED T  74125   22
00100 TRANSPORT CA/ APPLICATION OF HEAT PIPES AND THEIR THERMAL   74001    1
00111 CHANISMS OF HEAT TRANSFER IN HEAT PIPES AND THERMOSYPHONS#  74037   62
00122 E/ HEAT AND MASS TRANSFER IN HEAT PIPES CONTAINING NONCOND  74038   63
00028 S FRONT ANALYSIS PROGRAM FOR HEAT PIPES CONTAINING NON-CON  74028   49
00010  SEARCH OF AN APPLICATION#   HEAT PIPES ELEGANT CONCEPT IN  74039    4
00070 TES#  DEVELOPMENT OF VARIOUS HEAT PIPES FOR USE IN SATELLI  74015   17
00106 CE OF EXTRUDED AXIAL GROOVED HEAT PIPES FROM 80 TO 350 DEG  74116   68
00099 IVE RECOVERY#                HEAT PIPES INGENUITY AND PASS  74011    7
00027 ER ENERGY#                   HEAT PIPES NEW WAYS TO TRANSF  74049   10
00135  ALASKA OIL PIPELINE#    MOC HEAT PIPES TO SAFEGUARD TRANS  74082   12
00107 TRY#          APPLICATION OF HEAT PIPES TO THE GLASS INDUS  74081   12
00015 TO SE/ TRANSIENT ANALYSIS OF HEAT PIPES WITH APPLICATIONS   74063   47
00058 ANCE TESTS OF GRAVITY-ASSIST HEAT PIPES WITH SCREEN-WICK S  74115   57
00123                              HEAT PIPES#                    74042    4
00124                   CONTROLLED HEAT PIPES#                    74119    6
00125                      COAXIAL HEAT PIPES#                    74137   42
00116                              HEAT PIPES#                    74002    1
00008 TERISTICS OF LOW TEMPERATURE HEAT PIPES#   SPECIFIC CHARAC  74035   62
00016 VESTIGATION OF TWO-COMPONENT HEAT PIPES# / EXPERIMENTAL IN  74096   47
00025 ERIMENTS WITH GAS-CONTROLLED HEAT PIPES# / IRRADIATION EXP  74016   25
00018  CIRCUIT BREAKER CONTACTS BY HEAT PIPES# / OF RAPID ACTION  74055   31
00089 F MATERIAL PROBLEMS IN WATER HEAT PIPES# /ION OR CONTROL O  74147   61
00127 UCLEAR REACTOR BLANKET USING HEAT PIPES# /ITIUM IN THERMON  74131   28
00126 L MODEL OF VERTICAL ARTERIAL HEAT PIPES# /LIFIED ANALYTICA  74143   53
```

```
00074 ON OF ROTATING, NONCAPILLARY HEAT PIPES# /NTAL INVESTIGATI   74036    52
00031 HERMAL CONTROL OF SATELLITES HEAT PIPES# /OF DEVICES FOR T   74094    19
00076  INTERACTION WITH SURFACE IN HEAT PIPES# /SIS OF MOLECULAR   74139    44
00072 PILLARY-POROUS MEDIA USED IN HEAT PIPES# /T TRANSFER OF CA   74140    48
00110 ARAMETERS OF LOW TEMPERATURE HEAT PIPES# /TING GEOMETRIC P   74067    37
00066 C COOLERS THROUGH A LOW-TEM/ HEAT PUMPING BY THERMOELECTRI   74012    15
00078 OWER/ INVESTIGATION OF NOVEL HEAT REMOVAL TECHNIQUES FOR P   74020    30
00039  NONCONDENSING IMPURITIES ON HEAT TRANSFER EFFICIENCY OF E   74071    64
00033 CK MATERIALS#   VAPORIZATION HEAT TRANSFER IN HEAT PIPE WI   74068    56
00111 ND THERMOSYPH/ MECHANISMS OF HEAT TRANSFER IN HEAT PIPES A   74037    52
00105 E CONDENSATION SECTION OF A/ HEAT TRANSFER INTENSITY IN TH   74024    40
00072 ROUS MED/ FLUID DYNAMICS AND HEAT TRANSFER OF CAPILLARY-PO   74140    48
00024 SIUM IN POROUS / EVAPORATIVE HEAT TRANSFER OF LIQUID POTAS   74111    66
00139        HOW TO GET MORE OF THE HEAT YOU ARE PAYING FOR#       74123    14
00034              TAKING OUT THE HEAT#                            74092    32
00108 POLLUTION CAR RUNS ON STORED HEAT# /STIRLING-POWERED ZERO-   74050    10
00085 E DISPERSED ANNULAR FLOWS IN HEATED PIPES# /CS OF TWO-PHAS  .74026    45
00120  HEAT PIPE DURING NONUNIFORM HEATING# /ORATOR SECTION OF A   74141    48
00094 L VALVE FOR A MAGNETIC REFR/ HELIUM THERMOSIPHON AS THERMA   74079    11
00040 RS#                          HIGH EFFICIENCY HEAT EXCHANGE   74045     8
00012 E EVAPORATOR#  ANALYSIS OF A HIGH HEAT FLUX WATER HEAT PIP   74138    47
00118        HEAT PIPE RADIATOR FOR HIGH POWERED TRANSPONDERS#     74129    23
00032 E EVAPORATOR#  ANALYSIS OF A HIGH-HEAT-FLUX WATER HEAT PIP   74023    43
00081 CODE#                      A HOMOGENEOUS HEAT PIPE DESIGN    74066    51
00065 E LINED WITH MULTI-LAYERED / HOT SPOT OF A SODIUM HEAT PIP   74061    41
00134       HOW TO CONDUCT HEAT AND HOW NOT TO#                    74070    56
00134 OT TO#                       HOW TO CONDUCT HEAT AND HOW N   74070    56
00139 OU ARE PAYING FOR#           HOW TO GET MORE OF THE HEAT Y   74123    14
00043 GY / DESIGNING SOPHISTICATED HVAC SYSTEMS FOR OPTIMUM ENER   74009     7
00093 ING STORED EARTH E/ SNOW AND ICE REMOVAL FROM PAVEMENTS US   74047     9
00137 RSION ENGINEERING CONFERENCE IECEC NATIONAL BUREAU OF STAN   74053    26
00023 OUS MEDIA USING THE STRONGLY IMPLICIT PROCEDURE# /R IN POR   74060    40
00039 E INFLUENCE OF NONCONDENSING IMPURITIES ON HEAT TRANSFER E   74071    64
                                   'IN ' NOT INDEXED
00107 N OF HEAT PIPES TO THE GLASS INDUSTRY#           APPLICATIO   74081    12
00140  COMING OUT OF LABS AND INTO INDUSTRY# / COOLING IS SLOWLY   74033    55
00039 PURITI/ INVESTIGATION OF THE INFLUENCE OF NONCONDENSING IM   74071    64
00113 ABLE CRYOGENIC HEAT PIPE FOR INFRARED DETECTOR COOLING# /H   74094    33
00099 Y#                HEAT PIPES INGENUITY AND PASSIVE RECOVER   74011     7
                                   'INSIDE ' NOT INDEXED
00046 OPMENT AT THE NUCLEAR ENERGY INSTITUTE UNIVERSITY OF STUTT   74118     6
00009 EVELOPMENT OF A CRYOSURGICAL INSTRUMENT UTILIZING AN OPEN-   74078    11
00041 G OF ELECTRONIC CIRCUITS AND INSTRUMENTS#           COOLIN   74132    34
00105  SECTION OF A/ HEAT TRANSFER INTENSITY IN THE CONDENSATION   74024    40
00076 ETICAL ANALYSIS OF MOLECULAR INTERACTION WITH SURFACE IN H   74139    44
00054 CELL AND BATTERY COOLING/ AN INTERCELL HEAT PIPE FOR FUEL    74133    34
00137 EMS CLASSIFIED SESSION THIRD INTERSOCIETY ENERGY CONVERSIO   74053    26
                                   'INTO ' NOT INDEXED
00002 UM#             A UNIT FOR INVESTIGATING BOILING IN VACU     74102    42
00131 PE STABILITY I A PRELIMINARY,INVESTIGATION INTO THERMALLY    74027    45
00103  OCCLUSIONS FINAL REPORT 22/ INVESTIGATION OF ARTERIAL GAS   74100    57
00053 L EFFECTS ON THE PERFORMANC/ INVESTIGATION OF GRAVITATIONA   74064    53
00055 CK CHARACTERISTICS#       AN INVESTIGATION OF HEAT PIPE WI   74145    60
00078 EMOVAL TECHNIQUES FOR POWER/ INVESTIGATION OF NOVEL HEAT R   74020    30
```

00061	PIPE RADIATOR FOR THE LUNAR	SURFACE MAGNETOMETER# /E HEAT	74052	18
00113	E FOR INFR/ DEVELOPMENT OF A	SWITCHABLE CRYOGENIC HEAT PIP	74094	33
00005	VERSITY OF MARYLA/ HEAT PIPE	SYMPOSIUM WORKSHOP AT THE UNI	74075	5
00048	NSTANT TEMPERATURE HEAT PIPE	SYSTEM PHASE 2 EXPERIMENTAL D	74142	53
00141	ON PRESSURES IN A CLOSED GAS	SYSTEM# /RMINE ABOVE-SATURATI	74059	46
00137	PROCEEDINGS OF NUCLEAR POWER	SYSTEMS CLASSIFIED SESSION TH	74053	26
00004	LE HEAT PIPE THERMAL CONTROL	SYSTEMS DESIGN AND TEST# /UTT	74124	22
00003	LE HEAT PIPE THERMAL CONTROL	SYSTEMS FINAL REPORT JUNE 197	74051	18
00043	DESIGNING SOPHISTICATED HVAC	SYSTEMS FOR OPTIMUM ENERGY US	74009	7
00034		TAKING OUT THE HEAT#	74092	32
00021	OPPER VAPOR LASER SEMIANNUAL	TECHNICAL REPORT 1 FEFUARY TO	74044	8
00101	CONDITIONING PANEL DETAILED	TECHNICAL REPORT 28 JUNE 1972	74031	50
00013	AL CONTROL FLIGHT EXPERIMENT	TECHNICAL SUMMARY REPORT# /RM	74125	22
00078	GATION OF NOVEL HEAT REMOVAL	TECHNIQUES FOR POWER TRANSIST	74020	30
00142	H ABSTRACTS CUMUL/ HEAT PIPE	TECHNOLOGY A BIBLIOGRAPHY WIT	74004	2
00148	H ABSTRACTS# HEAT PIPE	TECHNOLOGY A BIBLIOGRAPHY WIT	74076	3
00145	H ABSTRACTS QUART/ HEAT PIPE	TECHNOLOGY A BIBLIOGRAPHY WIT	74007	2
00146	H ABSTRACTS QUART/ HEAT PIPE	TECHNOLOGY A BIBLIOGRAPHY WIT	74008	2
00147	H ABSTRACTS CUMUL/ HEAT PIPE	TECHNOLOGY A BIBLIOGRAPHY WIT	74043	3
00143	H ABSTRACTS ANNUA/ HEAT PIPE	TECHNOLOGY A BIBLIOGRAPHY WIT	74005	2
00006	RIABLE-CONDUCTANCE HEAT PIPE	TECHNOLOGY FINAL RESEARCH REP	74104	52
00144	JANUARY TO 31 MA/ HEAT PIPE	TECHNOLOGY QUARTERLY UPDATE 1	74006	2
00079	LE CONDUCTAN/ COMMUNICATIONS	TECHNOLOGY SATELLITE A VARIAB	74088	20
00073	RIABLE CONDUCTANCE HEAT PIPE	TECHNOLOGY# VA	74065	51
00138	NAMICS CRYOGENICS AND VACUUM	TECHNOLOGY# /IENCES: THERMODY	74120	6
00025	ATION EXPERIMENTS WITH GAS-/	TEMPERATURE CONTROL OF IRRADI	74018	25
00110	GEOMETRIC PARAMETERS OF LOW	TEMPERATURE HEAT PIPES# /TING	74067	57
00109	STUDIES F/ CRYOGENIC AND LOW	TEMPERATURE HEAT PIPE COOLER	74089	21
00048	ND DEVELOPMENT OF A CONSTANT	TEMPERATURE HEAT PIPE SYSTEM	74142	53
00008	CIFIC CHARACTERISTICS OF LOW	TEMPERATURE HEAT PIPES# SPE	74035	62
00136	UTTLE HEAT PIPE LEADING EDGE	TEST MODULES VOLUME 2 FINAL R	74130	24
00029	E MULTI-HEAT/ THERMAL VACUUM	TEST OF A FULL-SCALE PROTOTYP	74112	56
00004	L CONTROL SYSTEMS DESIGN AND	TEST# /UTTLE HEAT PIPE THERMA	74124	22
00136	LE HEAT / DESIGN FABRICATION	TESTING AND DELIVERY OF SHUTT	74130	24
00058	PIPES WITH SCRE/ PERFORMANCE	TESTS OF GRAVITY-ASSIST HEAT	74115	57
		'THE ' NOT INDEXED		
		'THEIR ' NOT INDEXED		
00076	ULAR INTERACTION WITH SURFA/	THEORETICAL ANALYSIS OF MOLEC	74139	44
00016	INVESTIGATION OF TWO-COMPON/	THEORETICAL AND EXPERIMENTAL	74096	47
00060	E#	THEORETICAL STUDY OF HEAT PIP	74135	39
00088	FUNDAMENTALS OF HEAT PIPE	THEORY#	74022	35
00101	TAILED TECHNICAL / HEAT PIPE	THERMAL CONDITIONING PANEL DE	74031	50
00102	ECUTIVE SUMMARY R/ HEAT PIPE	THERMAL CONDITIONING PANEL EX	74032	50
00104	HEAT PIPE	THERMAL CONDITIONING PANEL#	74126	22
00115	VESTIGATION OF THE EFFECTIVE	THERMAL CONDUCTIVITY OF POROU	74110	60
00029	LE PROTOTYPE MULTI-HEAT PIPE	THERMAL CONTROL ASSEMBLY# /CA	74112	56
00013	HEAT PIPES AND THE ADVANCED	THERMAL CONTROL FLIGHT EXPERI	74125	22
00031	# CERNERATION OF DEVICES FOR	THERMAL CONTROL OF SATELLITES	74034	19
00077	TED WITH HEAT PIPE CYCLING#	THERMAL CONTROL RANGE ASSOCIA	74099	38
00004	N A/ SPACE SHUTTLE HEAT PIPE	THERMAL CONTROL SYSTEMS DESIG	74124	22
00003	RE/ SPACE SHUTTLE HEAT PIPE	THERMAL CONTROL SYSTEMS FINAL	74051	18
00050	THERMOPHYSICS AND SPACECRAFT	THERMAL CONTROL#	74087	20
00094	PIPE RADIATOR FOR CRYOGENIC	THERMAL CONTROL# /MODULAR HEAT	74128	23
00064	OPMENT OF A BLOCKING ORIFICE	THERMAL DIODE HEAT PIPE# /VEL	74105	52

```
00005 PE SYMPOSIUM WORKSHOP AT THE UNIVERSITY OF MARYLAND# /T PI  74075   5
00046 THE NUCLEAR ENERGY INSTITUTE UNIVERSITY OF STUTTGART# /AT   74118   6
00145 PHY WITH ABSTRACTS QUARTERLY UPDATE 1 APRIL TO 30 JUNE 197  74007   2
00144 AT PIPE TECHNOLOGY QUARTERLY UPDATE 1 JANUARY TO 31 MARCH   74006   2
00146 PHY WITH ABSTRACTS QUARTERLY UPDATE 1 JULY TO 30 SEPTEMBER  74008   2
00065 H MULTI-LAYERED WIRE NETTING UPON APPROACH TO PRESSURE DRO  74061  41
00070 NT OF VARIOUS HEAT PIPES FOR USE IN SATELLITES#  DEVELOPME  74015  17
00069 ERIMENTAL FIELD STUDY OF THE USE OF TWO-PHASE THERMOSIPHON  74073  64
00043 C SYSTEMS FOR OPTIMUM ENERGY USE# /GNING SOPHISTICATED HVA  74009   7
00072 ER OF CAPILLARY-POROUS MEDIA USED IN HEAT PIPES# /T TRANSF  74140  48
00028 PIPE 2 PROGRAM A VAPOR-GAS / USER'S MANUAL FOR THE TRW GAS  74028  49
00127 HERMONUCLEAR REACTOR BLANKET USING HEAT PIPES# /ITIUM IN T  74131  28
00093 D ICE REMOVAL FROM PAVEMENTS USING STORED EARTH ENERGY# /N  74047   9
00023 ASS TRANSFER IN POROUS MEDIA USING THE STRONGLY IMPLICIT P  74060  40
00062 N THERMOELECTRIC DEVICES#    UTILIZATION OF THERMOSIPHON I  74083  16
00009 OF A CRYOSURGICAL INSTRUMENT UTILIZING AN OPEN-LOOP HEAT P  74078  11
00112        GAS-HEATED HEAT PIPE VACUUM FURNACE#                  74048   9
00138 HERMODYNAMICS CRYOGENICS AND VACUUM TECHNOLOGY# /IENCES: T  74120   6
00029 ROTOTYPE MULTI-HEAT/ THERMAL VACUUM TEST OF A FULL-SCALE P  74112  66
00002 FOR INVESTIGATING BOILING IN VACUUM#                 A UNIT  74102  42
00094 LIUM THERMOSIPHON AS THERMAL VALVE FOR A MAGNETIC REFRIGER  74079  11
00021 CAL REPORT/ HEAT PIPE COPPER VAPOR LASER SEMIANNUAL TECHNI  74044   8
00117   ANALYSIS OF THE EFFECTS OF VAPOR PRESSURE DROP ON HEAT P  74025  46
00028  THE TRW GASPIPE 2 PROGRAM A VAPOR-GAS FRONT ANALYSIS PROG  74028  49
00033  HEAT PIPE WICK MATERIALS#   VAPORIZATION HEAT TRANSFER IN  74068  56
00044 ECTRICAL FEEDBACK-CONTROLLED VARIABLE CONDUCTANCE HEAT PIP  74085  19
00073 E TECHNOLOGY#                VARIABLE CONDUCTANCE HEAT PIP  74065  51
00053 ECTS ON THE PERFORMANCE OF A VARIABLE CONDUCTANCE HEAT PIP  74064  63
00079 TIONS TECHNOLOGY SATELLITE A VARIABLE CONDUCTANCE HEAT PIP  74088  20
00061 E RADIATOR FOR THE LUNAR SU/ VARIABLE CONDUCTANCE HEAT PIP  74052  18
00128 AT PIPE MODEL ACCOUNTING FOR VARIABLE EVAPORATOR AND CONDE  74136  39
00006 E TECHNOLOGY FINAL RESEARCH/ VARIABLE-CONDUCTANCE HEAT PIP  74104  52
00070  SATELLITES#  DEVELOPMENT OF VARIOUS HEAT PIPES FOR USE IN  74015  17
00030 ALESCENCE AS A MECHANISM FOR VENTING NONCONDENSABLE GAS FR  74097  57
00126 MPLIFIED ANALYTICAL MODEL OF VERTICAL ARTERIAL HEAT PIPES#  74143  53
00147 HY WITH ABSTRACTS CUMULATIVE VOLUME THROUGH 31 DECEMBER 19  74043   3
00136 PE LEADING EDGE TEST MODULES VOLUME 2 FINAL REPORT# /AT PI  74130  24
00142 HY WITH ABSTRACTS CUMULATIVE VOLUME# /HNOLOGY A BIBLIOGRAP  74004   2
00047 LS WITH MASS TRANSFER AT ONE WALL# / AND FLAT PLATE CHANNE  74113  66
00038 PTURE HEAT FROM YOUR FURNACE WASTES#         NEW WAY TO CA  74077  11
00001 ON FROM HEAT PIPE WICKS WITH WATER AND ACETONE# /EVAPORATI  74148  69
00032 ANALYSIS OF A HIGH-HEAT-FLUX WATER HEAT PIPE EVAPORATOR#    74023  43
00012 ANALYSIS OF A HIGH HEAT FLUX WATER HEAT PIPE EVAPORATOR#    74138  43
00089 TROL OF MATERIAL PROBLEMS IN WATER HEAT PIPES# /ION OR CON  74147  61
00038  FURNACE WASTES#         NEW WAY TO CAPTURE HEAT FROM YOUR  74077  11
00011 PIPE#      THE MOST EFFICIENT WAY TO TRANSFER HEAT IS BY A  74054  13
00027                 HEAT PIPES NEW WAYS TO TRANSFER ENERGY#     74049  10
00056 N INVESTIGATION OF HEAT PIPE WICK CHARACTERISTICS#       A  74145  60
00140  OUT OF LABS AND INTO INDUS/ WICK COOLING IS SLOWLY COMING  74033  55
00007 PPLICAT/ METHOD OF FORMING A WICK FOR A HEAT PIPE PATENT A  74107  59
00092 ERS FOR A HEAT PIPE HAVING A WICK IN THE FORM OF A PERFORA  74146  50
00091 PARAMETERS OF HEAT PIPE WITH WICK IN THE FORM OF A PERFORA  74106  58
00033 N HEAT TRANSFER IN HEAT PIPE WICK MATERIALS#   VAPORIZATIO  74068  56
00114 #                            WICKING OF LIQUIDS IN SCREENS  74109  59
```

```
00001 D EVAPORATION FROM HEAT PIPE WICKS WITH WATER AND ACETONE#  74148   69
00022   HEAT PIPE COOLED MICROWAVE WINDOW#                        74091   32
00065 IPE LINED WITH MULTI-LAYERED WIRE NETTING UPON APPROACH TO  74061   41
00121 STRIBUTORS OF/ PROPERTIES OF WIRE-NETTING STRUCTURES AS DI  74101   58
                                 *WITH * NOT INDEXED
00045                      HEAT PIPE WORK IN EUROPE#              74117    6
00005  MARYLA/ HEAT PIPE SYMPOSIUM WORKSHOP AT THE UNIVERSITY OF  74075    5
00082 F HEAT PIPE COOLED ANODE FOR XENON ARC LAMP# /EVELOPMENT O  74093   32
00139  HOW TO GET MORE OF THE HEAT YOU ARE PAYING FOR#            74123   14
00038 NEW WAY TO CAPTURE HEAT FROM YOUR FURNACE WASTES#           74077   11
00108 OPED H/ NEW STIRLING-POWERED ZERO-POLLUTION CAR RUNS ON ST  74050   10
```

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FLUID RESERVOIR
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00038 ROBERTS C C JR
THERMAL TRANSFER APPARATUS PROVIDING TRANSFER CONTROL
U.S. PATENT 3837394
SEPTEMBER 24, 1974

00039 WATERS E D
PERMAFROST STRUCTURAL SUPPORT WITH HEAT PIPE STABILIZATION
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00040 FISCHER W GAMMEL G
HEAT PIPE WITH A SINTERED CAPILLARY STRUCTURE
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OCTOBER 8, 1974

00041 GRAY V H
METHODS AND APPARATUS FOR HEAT TRANSFER IN ROTATING BODIES
U.S. PATENT 3842596
OCTOBER 22, 1974

00042 ENINGER J E FLEISCHMAN G L
EDWARDS D K
HEAT PIPE ARTERIAL PRIMING DEVICE
U.S. PATENT 3844342
OCTOBER 29, 1974

00043 OLLENDORF S
STRUCTURAL HEAT PIPE
U.S. PATENT 3847208
NOVEMBER 12, 1974

00044 WALMET G E CORMAN J C
MCLAUGHLIN M H
HEAT SINK COOLED POWER SEMICONDUCTOR
DEVICE ASSEMBLY HAVING LIQUID METAL INTERFACE
U.S. PATENT 3852803
DECEMBER 3, 1974

00045 CORMAN J C MCLAUGHLIN M H
WALMET G E
DOUBLE-SIDED HEAT PIPE COOLED
POWER SEMICONDUCTOR DEVICE ASSEMBLY
U.S. PATENT 3852804
DECEMBER 3, 1974

00046 BRZOZOWSKI S J
HEAT PIPE COOLED POWER SEMICONDUCTOR DEVICE ASSEMBLY
HAVING INTEGRAL SEMICONDUCTOR DEVICE EVAPORATING SURFACE
UNIT
U.S. PATENT 3852805
DECEMBER 3, 1974

00047 CORMAN J C MCLAUGHLIN M H
WALMET G E
NONWICKED HEAT PIPE COOLED POWER SEMICONDUCTOR DEVICE
ASSEMBLY HAVING ENHANCED EVAPORATED SURFACE HEAT PIPES
U.S. PATENT 3852806
DECEMBER 3, 1974

G.2 SUBJECT INDEX

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                                         'A ' NOT INDEXED
00003 HE INERT GAS TYPE#                  ABSORPTION REFRIGERATION SYSTEM OF
                                         'AND ' NOT INDEXED
00008 ING ONE OR MORE HEAT PIPES/ COOLING APPARATUS FOR FLAT SEMICONDUCTORS U
00041 ING BODIES#             METHODS AND APPARATUS FOR HEAT TRANSFER IN ROTAT
00036                             COOLING APPARATUS FOR INFRARED DETECTORS#
00037                                     APPARATUS FOR MELTING ICE#
00038 #                  THERMAL TRANSFER APPARATUS PROVIDING TRANSFER CONTROL
00010           ROTARY HEAT EXCHANGER AND APPARATUS#
00031 ER SUPPLY#                  COOLING ARRANGEMENT FOR A DIRECT CURRENT P
00034                             COOLING ARRANGEMENT FOR THYRISTOR DISCS#
00033                                     ARRANGEMENT IN HEAT EXCHANGERS#
00028 LLY INSULATED DOUBLE TUBE HEAT PIPE ARRANGEMENT#               ELECTRIC
00042                           HEAT PIPE ARTERIAL PRIMING DEVICE#
00047 E COOLED POWER SEMICONDUCTOR DEVICE ASSEMBLY HAVING ENHANCED EVAPORAT
00046 E COOLED POWER SEMICONDUCTOR DEVICE ASSEMBLY HAVING INTEGRAL SEMICONDUCT
00044 K COOLED POWER SEMICONDUCTOR DEVICE ASSEMBLY HAVING LIQUID METAL INTERF
00027 E COOLED POWER SEMICONDUCTOR DEVICE ASSEMBLY USING COMPRESSION RODS# /I
00026                 SEPARABLE HEAT PIPE ASSEMBLY#
00045 E COOLED POWER SEMICONDUCTOR DEVICE ASSEMBLY#       DOUBLE-SIDED HEAT PI
00021                             DYNAMIC BARRIER FOR HEAT PIPE#
00001 CTOR / ELECTRICALLY INSULATING SEAL BETWEEN A METAL BODY AND A SEMICOND
00017 EAT EXCHANGER FOR TRANSFERRING HEAT BETWEEN GASES#
00041 RATUS FOR HEAT TRANSFER IN ROTATING BODIES#              METHODS AND APP
00001 LLY INSULATING SEAL BETWEEN A METAL BODY AND A SEMICONDUCTOR DEVICE# /C
                                         'BY ' NOT INDEXED
00040           HEAT PIPE WITH A SINTERED CAPILLARY STRUCTURE#
00025 OIR#         HEAT PIPE WITH PLEATED CENTRAL WICK AND EXCESS FLUID RESERV
00009                           METHOD OF CLOSING OFF A HEAT PIPE#
00024  ISOTHERMAL VALVE SEAT FOR INTERNAL COMBUSTION ENGINE#
00027 SEMICONDUCTOR DEVICE ASSEMBLY USING COMPRESSION RODS# /IPE COOLED POWE
00038 ANSFER APPARATUS PROVIDING TRANSFER CONTROL#                   THERMAL T
00014 CAL MACHINE HAVING ROTOR AND STATOR COOLED BY MEANS OF HEAT PIPES# /CTR
00027 SEMBLY USIN/ DOUBLE-SIDED HEAT PIPE COOLED POWER SEMICONDUCTOR DEVICE A
00046 SEMBLY HAVING INTEGRAL S/ HEAT PIPE COOLED POWER SEMICONDUCTOR DEVICE A
00045 SEMBLY#      DOUBLE-SIDED HEAT PIPE COOLED POWER SEMICONDUCTOR DEVICE A
00044 SEMBLY HAVING LIQUID MET/ HEAT SINK COOLED POWER SEMICONDUCTOR DEVICE A
00047 SEMBLY HAVING / NONWICKED HEAT PIPE COOLED POWER SEMICONDUCTOR DEVICE A
00036 TORS#                              COOLING APPARATUS FOR INFRARED DETE
00008 CTORS USING ONE OR MORE HEAT PIPES/ COOLING APPARATUS FOR FLAT SEMICON
00034 SCS#                               COOLING ARRANGEMENT FOR THYRISTOR DI
00031 RENT POWER SUPPLY#                  COOLING ARRANGEMENT FOR A DIRECT CU
00012 OF DEVICES#                         COOLING SYSTEM FOR POWER SEMICONDUCT
00031    COOLING ARRANGEMENT FOR A DIRECT CURRENT POWER SUPPLY#
00036      COOLING APPARATUS FOR INFRARED DETECTORS#
00047 EAT PIPE COOLED POWER SEMICONDUCTOR DEVICE ASSEMBLY HAVING ENHANCED EVA
00044 EAT SINK COOLED POWER SEMICONDUCTOR DEVICE ASSEMBLY HAVING LIQUID METAL
00046 EAT PIPE COOLED POWER SEMICONDUCTOR DEVICE ASSEMBLY HAVING INTEGRAL SEMI
00027 EAT PIPE COOLED POWER SEMICONDUCTOR DEVICE ASSEMBLY USING COMPRESSION R
00045 EAT PIPE COOLED POWER SEMICONDUCTOR DEVICE ASSEMBLY#      DOUBLE-SIDED
00046 EMBLY HAVING INTEGRAL SEMICONDUCTOR DEVICE EVAPORATING SURFACE UNIT# /S
00042          HEAT PIPE ARTERIAL PRIMING DEVICE#
00039                       HEAT TRANSFER DEVICE#
00007                       HEAT TRANSFER DEVICE#
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00040 STRUCTURE#                          HEAT PIPE WITH A SINTERED CAPILLARY
00025 AND EXCESS FLUID RESERVOIR#         HEAT PIPE WITH PLEATED CENTRAL WICK
00043                          STRUCTURAL HEAT PIPE#
00021                 DYNAMIC BARRIER FOR HEAT PIPE#
00015                  METHOD OF MAKING A HEAT PIPE#
00009             METHOD OF CLOSING OFF A HEAT PIPE#
00018 S#                                  HEAT PIPES WITH EXTREMELY SMALL POR
00016         HEAT EXCHANGER USING U-TUBE HEAT PIPES#
00004                                     HEAT PIPES#
00014 ROTOR AND STATOR COOLED BY MEANS OF HEAT PIPES# /CTRICAL MACHINE HAVING
00047  HAVING ENHANCED EVAPORATED SURFACE HEAT PIPES# /NDUCTOR DEVICE ASSEMBL
00008 AT SEMICONDUCTORS USING ONE OR MORE HEAT PIPES# /OOLING APPARATUS FOR FL
00044  DEVICE ASSEMBLY HAVING LIQUID MET/ HEAT SINK COOLED POWER SEMICONDUCTO
00011                               SOLAR HEAT SOURCE AND RECEIVER SYSTEM#
00030                                     HEAT TRANSFER DEVICE#
00007                                     HEAT TRANSFER DEVICE#
00019                                     HEAT TRANSFER DEVICE#
00041           METHODS AND APPARATUS FOR HEAT TRANSFER IN ROTATING BODIES#
00013                 RADIOISOTOPE FUELED HEAT TRANSFER SYSTEM#
00020                                     HEAT TRANSFERRING DEVICE#
00023                                     HEAT TRANSPORTING DEVICE#
00022                                     HEATRONIC VALVES#
00037               APPARATUS FOR MELTING ICE#
                                         'IN ' NOT INDEXED
00003 ORPTION REFRIGERATION SYSTEM OF THE INERT GAS TYPE#                     AD
00036               COOLING APPARATUS FOR INFRARED DETECTORS#
00028 NGEMENT#               ELECTRICALLY INSULATED DOUBLE TUBE HEAT PIPE ARR
00001  AND A SEMICONDUCTOR / ELECTRICALLY INSULATING SEAL BETWEEN A METAL BOD
00046 EMICONDUCTOR DEVICE ASSEMBLY HAVING INTEGRAL SEMICONDUCTOR DEVICE EVAPO
00044 DEVICE ASSEMBLY HAVING LIQUID METAL INTERFACE# /LED POWER SEMICONDUCTOR
00032                           HEAT PIPE INTERFACES#
00024           ISOTHERMAL VALVE SEAT FOR INTERNAL COMBUSTION ENGINE#
00029  PERMAFROST STRUCTURAL SUPPORT WITH INTERNAL HEAT PIPE MEANS#
00024 OMBUSTION ENGINE#                   ISOTHERMAL VALVE SEAT FOR INTERNAL
00035 NUFACTURE#                          LAMINATED HEAT PIPE AND METHOD OF M
00044 EMICONDUCTOR DEVICE ASSEMBLY HAVING LIQUID METAL INTERFACE# /LED POWER
00014 ED BY MEANS OF/ ROTATING ELECTRICAL MACHINE HAVING ROTOR AND STATOR CO
00015                           METHOD OF MAKING A HEAT PIPE#
00035   LAMINATED HEAT PIPE AND METHOD OF MANUFACTURE#
00014 E HAVING ROTOR AND STATOR COOLED BY MEANS OF HEAT PIPES# /CTRICAL MACHI
00029 RAL SUPPORT WITH INTERNAL HEAT PIPE MEANS#                PERMAFROST STRUCT
00037                       APPARATUS FOR MELTING ICE#
00001 CTRICALLY INSULATING SEAL BETWEEN A METAL BODY AND A SEMICONDUCTOR DEVI
00044 UCTOR DEVICE ASSEMBLY HAVING LIQUID METAL INTERFACE# /LED POWER SEMICON
00009                                     METHOD OF CLOSING OFF A HEAT PIPE#
00015                                     METHOD OF MAKING A HEAT PIPE#
00035             LAMINATED HEAT PIPE AND METHOD OF MANUFACTURE#
00041 FER IN ROTATING BODIES#             METHODS AND APPARATUS FOR HEAT TRANS
00008 OR FLAT SEMICONDUCTORS USING ONE OR MORE HEAT PIPES# /OOLING APPARATUS F
00047 ICONDUCTOR DEVICE ASSEMBLY HAVING / NONWICKED HEAT PIPE COOLED POWER SE
                                         'OF ' NOT INDEXED
00009                   METHOD OF CLOSING OFF A HEAT PIPE#
00008 RATUS FOR FLAT SEMICONDUCTORS USING ONE OR MORE HEAT PIPES# /OOLING APP
                                         'OR ' NOT INDEXED
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00039 EAT PIPE STABILIZATION#             PERMAFROST STRUCTURAL SUPPORT WITH H
00029 NTERNAL HEAT PIPE MEANS#            PERMAFROST STRUCTURAL SUPPORT WITH I
00035                      LAMINATED HEAT PIPE AND METHOD OF MANUFACTURE#
00028 TRICALLY INSULATED DOUBLE TUBE HEAT PIPE ARRANGEMENT#               ELEC
00042                                HEAT PIPE ARTERIAL PRIMING DEVICE#
00026                      SEPARABLE HEAT PIPE ASSEMBLY#
00027 CE ASSEMBLY USIN/ DOUBLE-SIDED HEAT PIPE COOLED POWER SEMICONDUCTOR DEVI
00045 CE ASSEMBLY#      DOUBLE-SIDED HEAT PIPE COOLED POWER SEMICONDUCTOR DEVI
00046 CE ASSEMBLY HAVING INTEGRAL S/ HEAT PIPE COOLED POWER SEMICONDUCTOR DEVI
00047 CE ASSEMBLY HAVING / NONWICKED HEAT PIPE COOLED POWER SEMICONDUCTOR DEVI
00032                                HEAT PIPE INTERFACES#
00029 RUCTURAL SUPPORT WITH INTERNAL HEAT PIPE MEANS#            PERMAFROST ST
00039 AFROST STRUCTURAL SUPPORT WITH HEAT PIPE STABILIZATION#             PERM
00006 AFROST STRUCTURAL SUPPORT WITH HEAT PIPE STABILIZATION#             PERM
00040 TURE#                          HEAT PIPE WITH A SINTERED CAPILLARY STRUC
00025 XCESS FLUID RESERVOIR#         HEAT PIPE WITH PLEATED CENTRAL WICK AND E
00043                     STRUCTURAL HEAT PIPE#
00009        METHOD OF CLOSING OFF A HEAT PIPE#
00021            DYNAMIC BARRIER FOR HEAT PIPE#
00015             METHOD OF MAKING A HEAT PIPE#
00018                                HEAT PIPES WITH EXTREMELY SMALL PORES#
00016    HEAT EXCHANGER USING U-TUBE HEAT PIPES#
00004                                HEAT PIPES#
00014  AND STATOR COOLED BY MEANS OF HEAT PIPES# /CTRICAL MACHINE HAVING ROTOR
00047 NG ENHANCED EVAPORATED SURFACE HEAT PIPES# /NDUCTOR DEVICE ASSEMBLY HAVI
00008 MICONDUCTORS USING ONE OR MORE HEAT PIPES# /OOLING APPARATUS FOR FLAT SE
00025 D RESERVOIR#         HEAT PIPE WITH PLEATED CENTRAL WICK AND EXCESS FLUI
00018     HEAT PIPES WITH EXTREMELY SMALL PORES#
00027 USIN/ DOUBLE-SIDED HEAT PIPE COOLED POWER SEMICONDUCTOR DEVICE ASSEMBLY
00047 HAVING / NONWICKED HEAT PIPE COOLED POWER SEMICONDUCTOR DEVICE ASSEMBLY
00044 HAVING LIQUID MET/ HEAT SINK COOLED POWER SEMICONDUCTOR DEVICE ASSEMBLY
00045       DOUBLE-SIDED HEAT PIPE COOLED POWER SEMICONDUCTOR DEVICE ASSEMBLY#
00046 HAVING INTEGRAL S/ HEAT PIPE COOLED POWER SEMICONDUCTOR DEVICE ASSEMBLY
00012                  COOLING SYSTEM FOR POWER SEMICONDUCTOR DEVICES#
00031 NG ARRANGEMENT FOR A DIRECT CURRENT POWER SUPPLY#                  COOLI
00042                  HEAT PIPE ARTERIAL PRIMING DEVICE#
00038          THERMAL TRANSFER APPARATUS PROVIDING TRANSFER CONTROL#
00013 STEM#                               RADIOISOTOPE FUELED HEAT TRANSFER SY
00011              SOLAR HEAT SOURCE AND RECEIVER SYSTEM#
00003 S TYPE#                  ABSORPTION REFRIGERATION SYSTEM OF THE INERT GA
00025 EATED CENTRAL WICK AND EXCESS FLUID RESERVOIR#         HEAT PIPE WITH PL
00027 R DEVICE ASSEMBLY USING COMPRESSION RODS# /IPE COOLED POWER SEMICONDUCTO
00010                                     ROTARY HEAT EXCHANGER AND APPARATUS#
00041  AND APPARATUS FOR HEAT TRANSFER IN ROTATING BODIES#             METHODS
00014 OTOR AND STATOR COOLED BY MEANS OF/ ROTATING ELECTRICAL MACHINE HAVING R
00014  ROTATING ELECTRICAL MACHINE HAVING ROTOR AND STATOR COOLED BY MEANS OF
00001 CONDUCTOR / ELECTRICALLY INSULATING SEAL BETWEEN A METAL BODY AND A SEMI
00024                    ISOTHERMAL VALVE SEAT FOR INTERNAL COMBUSTION ENGINE#
00001 ING SEAL BETWEEN A METAL BODY AND A SEMICONDUCTOR DEVICE# /CALLY INSULAT
00012            COOLING SYSTEM FOR POWER SEMICONDUCTOR DEVICES#
00046  INTEGRAL S/ HEAT PIPE COOLED POWER SEMICONDUCTOR DEVICE ASSEMBLY HAVING
00045 DOUBLE-SIDED HEAT PIPE COOLED POWER SEMICONDUCTOR DEVICE ASSEMBLY#
00046 TOR DEVICE ASSEMBLY HAVING INTEGRAL SEMICONDUCTOR DEVICE EVAPORATING SUR
00044  LIQUID MET/ HEAT SINK COOLED POWER SEMICONDUCTOR DEVICE ASSEMBLY HAVING
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00027 DOUBLE-SIDED HEAT PIPE COOLED POWER SEMICONDUCTOR DEVICE ASSEMBLY USING
00047  / NONWICKED HEAT PIPE COOLED POWER SEMICONDUCTOR DEVICE ASSEMBLY HAVIN
00008 T PIPES/ COOLING APPARATUS FOR FLAT SEMICONDUCTORS USING ONE OR MORE HEA
00026                                     SEPARABLE HEAT PIPE ASSEMBLY#
00027 DUCTOR DEVICE ASSEMBLY USIN/ DOUBLE-SIDED HEAT PIPE COOLED POWER SEMICO
00045 DUCTOR DEVICE ASSEMBLY#      DOUBLE-SIDED HEAT PIPE COOLED POWER SEMICO
00044 CE ASSEMBLY HAVING LIQUID MET/ HEAT SINK COOLED POWER SEMICONDUCTOR DEVI
00040                    HEAT PIPE WITH A SINTERED CAPILLARY STRUCTURE#
00019           HEAT PIPES WITH EXTREMELY SMALL PORES#
00011 M#                                  SOLAR HEAT SOURCE AND RECEIVER SYST
00011                          SOLAR HEAT SOURCE AND RECEIVER SYSTEM#
00002                         TEMPERATURE STABILIZATION SYSTEM#
00006 T STRUCTURAL SUPPORT WITH HEAT PIPE STABILIZATION#             PERMAFROS
00039 T STRUCTURAL SUPPORT WITH HEAT PIPE STABILIZATION#             PERMAFRO
00014 ELECTRICAL MACHINE HAVING ROTOR AND STATOR COOLED BY MEANS OF HEAT PIPES
00043                                     STRUCTURAL HEAT PIPE#
00039 ABILIZATION#             PERMAFROST STRUCTURAL SUPPORT WITH HEAT PIPE ST
00029 T PIPE MEANS#            PERMAFROST STRUCTURAL SUPPORT WITH INTERNAL HEA
00006 ABILIZATION#             PERMAFROST STRUCTURAL SUPPORT WITH HEAT PIPE ST
00040 HEAT PIPE WITH A SINTERED CAPILLARY STRUCTURE#
00031 ANGEMENT FOR A DIRECT CURRENT POWER SUPPLY#                  COOLING AR
00039 #             PERMAFROST STRUCTURAL SUPPORT WITH HEAT PIPE STABILIZATIO
00006 #             PERMAFROST STRUCTURAL SUPPORT WITH HEAT PIPE STABILIZATIO
00029 S#            PERMAFROST STRUCTURAL SUPPORT WITH INTERNAL HEAT PIPE MEA
00047 ASSEMBLY HAVING ENHANCED EVAPORATED SURFACE HEAT PIPES# /NDUCTOR DEVICE
00046 AL SEMICONDUCTOR DEVICE EVAPORATING SURFACE UNIT# /SSEMBLY HAVING INTEGR
00012 ES#                         COOLING SYSTEM FOR POWER SEMICONDUCTOR DEVIC
00003            ABSORPTION REFRIGERATION SYSTEM OF THE INERT GAS TYPE#
00002           TEMPERATURE STABILIZATION SYSTEM#
00005                       HEAT EXCHANGE SYSTEM#
00013   RADIOISOTOPE FUELED HEAT TRANSFER SYSTEM#
00011      SOLAR HEAT SOURCE AND RECEIVER SYSTEM#
00002                                     TEMPERATURE STABILIZATION SYSTEM#
                                         'THE ' NOT INDEXED
00038  TRANSFER CONTROL#                  THERMAL TRANSFER APPARATUS PROVIDIN
00034             COOLING ARRANGEMENT FOR THYRISTOR DISCS#
00038 R CONTROL#                  THERMAL TRANSFER APPARATUS PROVIDING TRANS
00038 HERMAL TRANSFER APPARATUS PROVIDING TRANSFER CONTROL#
00030                                HEAT TRANSFER DEVICE#
00007                                HEAT TRANSFER DEVICE#
00019                                HEAT TRANSFER DEVICE#
00041      METHODS AND APPARATUS FOR HEAT TRANSFER IN ROTATING BODIES#
00013            RADIOISOTOPE FUELED HEAT TRANSFER SYSTEM#
00020                                HEAT TRANSFERRING DEVICE#
00017                  HEAT EXCHANGER FOR TRANSFERRING HEAT BETWEEN GASES#
00023                                HEAT TRANSPORTING DEVICE#
00028       ELECTRICALLY INSULATED DOUBLE TUBE HEAT PIPE ARRANGEMENT#
00016             HEAT EXCHANGER USING U-TUBE HEAT PIPES#
00003 FRIGERATION SYSTEM OF THE INERT GAS TYPE#                  ABSORPTION RE
                                         'U ' NOT INDEXED
00046 UNDUCTOR DEVICE EVAPORATING SURFACE UNIT# /SSEMBLY HAVING INTEGRAL SEMIC
00027 POWER SEMICONDUCTOR DEVICE ASSEMBLY USING COMPRESSION RODS# /IPE COOLED
00008 G APPARATUS FOR FLAT SEMICONDUCTORS USING ONE OR MORE HEAT PIPES# /OOLIN
00016                      HEAT EXCHANGER USING U-TUBE HEAT PIPES#
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00024 NGINE*                      ISOTHERMAL VALVE SEAT FOR INTERNAL COMBUSTION E
00022                               HEATRONIC VALVES*
00025       HEAT PIPE WITH PLEATED CENTRAL WICK AND EXCESS FLUID RESERVOIR*
                                          'WITH ' NOT INDEXED
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G.3 AUTHOR INDEX

1240

00026	ANDERSON J H
00019	ASSELMAN G A A
00009	ASSELMAN G A A
00005	BARKMAN H G
00031	BEASLEY J C
00003	BLOMBERG P E
00036	BRUNO R P
00046	BRZOZOWSKI S J
00002	BUSSE C
00044	CORMAN J C
00045	CORMAN J C
00030	CORMAN J C
00027	CORMAN J C
00047	CORMAN J C
00014	CORMAN J C
00020	CORVILLE P
00019	DIRNE A P
00021	DUNN P D
00014	EDGAR R F
00042	EDWARDS D K
00004	EGGERS P E
00042	ENINGER J E
00040	FISCHER W
00042	FLEISCHMAN G L
00003	FRIES P
00040	GAMMEL G
00034	GAMMEL G
00028	GAMMEL G
00041	GRAY V H
00021	HAMERDINGER R W
00023	HEIDTMANN U
00034	HEIDTMANN U
00017	HELLER L
00033	JOHANSSON A H
00028	JONS M
00007	KALKBRENNER R W
00001	KELLER R F
00001	KESSLER S W JR
00020	LAURENCIER A
00037	LEA J F JR
00007	LOW G M
00035	MADSEN P
00012	MAREK A
00014	MCLAUGHLIN M H
00027	MCLAUGHLIN M H
00045	MCLAUGHLIN M H
00044	MCLAUGHLIN M H
00047	MCLAUGHLIN M H
00022	MOORE R D
00008	MORITZ K
00034	MULLER E
00036	NAUGLER A W
00043	OLLENDORF S
00010	PAUL R S

00028	PAWLOWSKI P H
00015	PECK W P
00011	PETERSEN C B
00032	POGSON J T
00011	RAMSEY J W
00024	RHINE S
00038	ROBERTS C C JR
00002	SCHLITT K
00011	SCHMIDT R N
00024	SHOWALTER M R
00013	SPARBER F J
00016	STEWART W G
00017	SZABO Z
00017	SZUCS L
00014	TOMPKINS P F
00018	VINZ P
00027	WALMET G E
00030	WALMET G E
00044	WALMET G E
00045	WALMET G E
00047	WALMET G E
00029	WATERS E D
00026	WATERS E D
00025	WATERS E D
00039	WATERS E D
00006	WATERS E D
00010	WEILER D W
00023	WEINHARDT E
00013	WHITING G H
00023	WIT C L DE

G.4 PATENT NUMBER INDEX

HEAT PIPE RELATED PATENT 1974 ANNUAL

00018	GERM PATENT 2351452#
00001	U.S. PATENT 3769668#
00002	U.S. PATENT 3782449#
00003	U.S. PATENT 3786653#
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00007	U.S. PATENT 3789920#
00008	U.S. PATENT 3792318#
00009	U.S. PATENT 3797086#
00010	U.S. PATENT 3797552#
00011	U.S. PATENT 3799144#
00012	U.S. PATENT 3800190#
00013	U.S. PATENT 3801446#
00014	U.S. PATENT 3801843#
00015	U.S. PATENT 3803688#
00016	U.S. PATENT 3807493#
00017	U.S. PATENT 3809154#
00019	U.S. PATENT 3811496#
00021	U.S. PATENT 3812905#
00020	U.S. PATENT 3812908#
00022	U.S. PATENT 3818980#
00023	U.S. PATENT 3820596#
00024	U.S. PATENT 3822680#
00025	U.S. PATENT 3822743#
00026	U.S. PATENT 3823769#
00027	U.S. PATENT 3826957#
00028	YS. PATENT 3827480#
00029	U.S. PATENT 3828845#
00030	U.S. PATENT 3828849#
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00032	U.S. PATENT 3831664#
00033	U.S. PATENT 3834171#
00034	U.S. PATENT 3834454#
00035	U.S. PATENT 3834457#
00036	U.S. PATENT 3836779#
00037	U.S. PATENT 3837311#
00038	U.S. PATENT 3837394#
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00040	U.S. PATENT 3840069#
00041	U.S. PATENT 3842596#
00042	U.S. PATENT 3844342#
00043	U.S. PATENT 3847208#
00044	U.S. PATENT 3852803#
00045	U.S. PATENT 3852804#
00046	U.S. PATENT 3852805#
00047	U.S. PATENT 3852806#