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

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

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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 particular, 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
Technology Application Center
University of New Mexico
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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A. GENERAL INFORMATION, REVIEWS, SURVEYS
APPLICATION OF HEATPIPES AND THEIR THERMAL TRANSPORT CAPABILITY

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.

HEAT PIPES

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.

HEAT PIPE - A NEW TUNE ON AN OLD PIPE

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.
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.
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.

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.
HEAT PIPES. ELEGANT CONCEPT IN SEARCH OF AN APPLICATION
p. 38-39, 41. Avail: TAC

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

HEAT PIPE
P.D. Dunn (University of Reading, England) and D.A. Reay.
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.

THE HEAT PIPE - A NEW TUNE ON AN OLD PIPE
Ron Kemp (Jermyn Manufacturing, Seven Oaks, Kent, England).
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.

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.
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, manufacturing methods, low temperature operation, gravity-assist heat pipes for high temperature applications, solar and space applications. The second day dealt 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

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)

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

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

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

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

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

74045 HIGH EFFICIENCY HEAT EXCHANGERS
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
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

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)
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

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

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 cylinders electrically. Later models might use fuel-fired heaters for faster cycling.
74077 NEW WAY TO CAPTURE HEAT FROM YOUR FURNACE WASTES

 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

 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

 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 cm² 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 >10³.
74080 THE MODELING OF A THERMOSYPHON-TYPE PERMAFROST PROTECTION DEVICE

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

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 Corporation's research and development work in heat pipe technology over a period of years has resulted in a $3.6 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.


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 EROSION DUE TO THE EMERGENT STEM IN LIQUID-IN-GLASS THERMOMETERS


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


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 fuel 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 THERMEOLECTRIC CONVERTERS

74012 HEAT PUMPING BY THERMEOLECTRIC COOLERS THROUGH A LOW-TEMPERATURE HEAT PIPE

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 THERMEOLECTRIC CONVERTER

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 condenser sections of the heat pipe to produce a limit to the axial heat transfer rate.
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

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). Österreichische Gesellschaft für Weltraumforschung und Flugkorpertechnik and Deutsche Gesellschaft für 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.
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.

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)

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


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


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.

THERMOPHYSICS AND SPACECRAFT THERMAL CONTROL


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.

COMMUNICATIONS TECHNOLOGY SATELLITE: A VARIABLE CONDUCTANCE HEAT PIPE APPLICATION


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.

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

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
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
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
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 feasi-
bility. The Lobar wicking arrangement proved extremely effi-
cient 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, Noordwijk,
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
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.
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.).
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
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 1/2-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.
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).
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 PuO₂ to the evolution of critical space power reactors using 239 PuO₂.
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 $(n + \text{Li}^6 \rightarrow \text{T} + \text{He}^4 + 4.6 \text{MeV})$ and $(n + \text{Li}^7 \rightarrow \text{n}^1 + \text{T} - 2.47 \text{MeV})$ 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 $1400^\circ\text{K}$ is required.
B. 5 ELECTRICAL AND ELECTRONIC APPLICATIONS

74018 A NOVEL METHOD OF COOLING SEMICONDUCTOR DEVICES FOR POWER ELECTRONICS

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

A cylindrical rotating heat pipe was examined in the rotor of an enclosed cylindrical cage induction motor. The cooling effect of the tube was confirmed by evaluation of heating tests of the motor. The heat generated was only one third of that in the motor without the heat pipe due to a combination of reduction of distribution and of measurements on a model of the tube. The function was also verified in actual tests of the motor. The use of heat pipes for the cooling of induction motor is promising,
The feasibility of novel 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 HEATPIPES
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
Some theoretical as well as experimental tasks dealing with the cooling of a rotor 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).
HEAT PIPE COOLED MICROWAVE WINDOW

Gene T. Colwell, Harold L. Bassett, James M. Schuchardt
(Georgia Institute of Technology, Atlanta, Georgia).
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.

TAKING OUT THE HEAT

G. L. Fitton (Redpoint Association Ltd., England).

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.

DEVELOPMENT OF HEAT PIPE COOLED ANODE FOR XENON ARC LAMP

Lloyd A. Nelsen (Nuclear Physics Laboratory, University of California).

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 200 C and situated 4.5 in. from the anode tip to ambient air. The heat pipe cooled anode was designed to be integrated into a 10 KW lamp and give...
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


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 disturbance 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.
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.

A planar (rectangular cross section) heat pipe was designed to transfer 2000 watts at ±12°C. The evaporator area was fixed at 30.48 cm by 12.7 cm 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 1.27 cm. 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).
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

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.
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-dimensional 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 characteristic 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.
CONTRIBUTION TO THE DETERMINATION OF THE LIQUID METALS HEAT PIPE HEAT PERFORMANCE LIMITS

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.

METHOD FOR SELECTING GEOMETRIC PARAMETERS OF LOW TEMPERATURE HEAT PIPES (METODIKA VYBORA GEOMETRICHESKIH 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.
THERMAL CONTROL RANGE ASSOCIATED WITH HEAT PIPE CYCLING


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

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

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
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
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.
HOT SPOT OF A SODIUM HEAT PIPE LINED WITH MULTILAYERED WIRE NETTING, UPON APPROACH TO PRESSURE DROP LIMITS

Koichi Kotani, Yasunori Tanihiro, Isao Sumida (Hitachi At. Energy Research Laboratory, Hitachi Ltd., Kawasaki, Japan).

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.

PECULIARITIES OF EVAPORATIVE COOLING IN RAREFIED GAS


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 theoretical 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
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
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
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 performed 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.
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.
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 coefficient of rectangular 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


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
In Russian. Avail: TAG
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
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.
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.

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


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


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.
FLUID DYNAMICS AND HEAT TRANSFER OF CAPILLARY-POURS MEDIA USED IN HEATPIPES

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.

DETERMINATION OF FLOW PARAMETERS IN THE EVAPORATOR SECTION OF A HEAT PIPE DURING NONUNIFORM HEATING
V.I. Toluminskii, E.N. Shevchuk, and N.V. Chistopianova (Akademila 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


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


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 performance. 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


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

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

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.
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.

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 annular heat pipe is included as part of the heat pipe radiator subroutine.
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.

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 ½ in. O.D. cryogenic diode with methane working fluid.

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.
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.

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.
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

WICK COOLING IS SLOWLY COMING OUT OF LABS AND INTO INDUSTRY

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.
VAPORIZATION HEAT TRANSFER IN HEAT PIPE WICK MATERIALS

Vaporization heat-transfer characteristics were measured for several wick materials including 5 samples of felted metal (Ni, 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 on 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 coefficient was unsatisfactory, probably due to uncertainties in wick-heated surface contact.

HEAT PIPE

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.

HOW TO CONDUCT HEAT AND HOW NOT TO

This message describes the electrohydrodynamic heat pipe developed at Colorado State University and the capillary insulator patented by Martin Marietta Corporation.
74097 MENISCI COALESCE AS A MECHANISM FOR VENTING NONCONDENSABLE GAS FROM HEAT PIPE ARTERIES

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

The effect of noncondensable gases on high-performance arterial heat pipes was investigated both analytically and experimentally. Models have been generated which characterize the dissolution of gases in condensate, and the diffusional 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.
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.

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

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**


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**


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

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 testing 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

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 TEPOLOVOI TRUBKI S FITILEM V VIDE PERFORIROVANNOGO EKRANA S KOLTSEVYM Z AZOROM)

English abstract is not available.
D.3 MATERIALS

74034 EXPERIMENTAL STUDY OF HEAT PIPE CHARACTERISTICS

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-
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 ~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).  
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 condi-
tions. Experimental results are presented for water, ethyl al-
cohol, 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, in-
stead of film condensation, improves heat pipe performance  
while the presence of noncondensible gases impairs performance.

74037  MECHANISMS OF HEAT TRANSFER IN HEAT PIPES AND THERMO-
SYPHONS  
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 stain-
less steel screen wick and Pipe 4 has five layers of 150-mesh  
screen while Pipe 5 has no wick.
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.

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.
INVESTIGATION OF THE INFLUENCE OF NONCONDENSING IMPURITIES ON HEAT TRANSFER EFFICIENCY OF EVAPORATING THERMOSIPHON


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.

AN EXPERIMENTAL STUDY OF THE TWO-PHASE THERMOSIPHON TUBE


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.

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


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

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

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/ft² hr.

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

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
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

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

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

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.
BOILING AND EVAPORATION FROM HEAT-PIPE WICKS WITH WATER AND ACETONE


Heat transfer for pool boiling with fluxes in the range of 5 x 10^2 to 5 x 10^4 Btu/(ft^2/hr) 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.

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


An experiment is described in which the 1st excited metastable states nsnp^3p^0 and nsnd^3D 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^3S_1, nsn'd^3D and nsn'f^3F^0 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 1S_0-nsn'p^1P^0.
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ANNUAL SUPPLEMENT 1973, TAC-HP-73-11, 236 PAGES,
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00028 GAMMEL G PAWLOWSKI P H
HEIDTMANN U JONS M
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00029 WATERS E D
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00030 COPMAN J C WALTMEIT G E
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00031 WEASLEY J D
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00032 POGSON J T
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00033 JOHANSSON A H
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00037 LEA J F JP
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00042 FRIEDERICH J E FRIEDRICH H J
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00045 CORMAN J C MCLAUGHLIN M H WALLET G E
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00046 BRZUSZOWSKI S J
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00047 CORMAN J C MCLAUGHLIN M H WALLET G E
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3. METHODS AND APPARATUS FOR HEAT TRANSFER IN ROTATING GASES (*)

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00020 HEAT TRANSFERRING DEVICE#
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- Heat pipes with pleated central wall
- Structural heat pipes
- Dynamic barrier for heat pipes
- Method of making a heat pipe
- Method of closing off a heat pipe
- Heat pipes with extremely small bees
- Heat exchanger using U-tube heat pipes
- Heat pipes
- Rotor and stator cooled by means of heat pipes / electrical machine having solar heat source and receiver system
- Heat transfer device
- Heat transfer device
- Heat transfer device
- Methods and apparatus for heat transfer in rotating bodies
- Radiisotope fueled heat transfer system
- Heat transporting device
- Heatronic valves
- Apparatus for melting ice
- Cooling apparatus of the inert gas type
- Cooling apparatus for infrared detectors
- Electrically insulated double wall heat pipe apparatus
- Electrical insulating seal between a metal body and a semiconductor device assembly having liquid metal interface / LED power semiconductor
- Device assembly having liquid metal interface / LED power semiconductor
- Isothermal valve seat for internal combustion engine
- Permafrost structural support with internal heat pipe means
- Perfusion engine
- Laminated heat pipe and method of manufacture
- Semiconductor device assembly having liquid metal interface / LED power semiconductor
- Method of making a heat pipe
- Method of closing off a heat pipe
- Permafrost structural support with internal heat pipe means
- Apparatus for melting ice
- Electrically insulating seal between a metal body and a semiconductor device assembly having liquid metal interface / LED power semiconductor
- Method of closing off a heat pipe
- Laminated heat pipe and method of manufacture
- Methods and apparatus for heat transfer
- Methods and apparatus for heat transfer
- Heat pipes / cooling apparatus
- Apparatus for flat semiconductors using one or more heat pipes / cooling apparatus
- Method of closing off a heat pipe
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- Not indexed
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00039 HEAT PIPE STABILIZATION* PERMAFROST STRUCTURAL SUPPORT WITH:
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00042 HEAT PIPE ARTERIAL PRIMING DEVICE* COOL! HEAT PIPES* PERMAFROST STRUCTURAL SUPPORT WITH:
00039 THERMAL TRANSFER APPARATUS PROVIDING TRANSFER CONTROL* COOL! HEAT PIPE ARTERIAL PRIMING DEVICE* PERMAFROST STRUCTURAL SUPPORT WITH:
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00001 CONDUCTOR / ELECTRICALLY INSULATING SEAL BETWEEN A METAL BODY AND A SEMICONDUCTOR DEVICE* ELECTRICALLY INSULATING SEAL BETWEEN A METAL BODY AND A SEMICONDUCTOR DEVICE* PERMAFROST STRUCTURAL SUPPORT WITH:
00004 ISO-THERMAL VALVE SEAL FOR INTERNAL COMBUSTION ENGINE* ISO-THERMAL VALVE SEAL FOR INTERNAL COMBUSTION ENGINE* PERMAFROST STRUCTURAL SUPPORT WITH:
00001 ISO-THERMAL VALVE SEAL FOR INTERNAL COMBUSTION ENGINE* ISO-THERMAL VALVE SEAL FOR INTERNAL COMBUSTION ENGINE* PERMAFROST STRUCTURAL SUPPORT WITH:
00012 ING SEAL BETWEEN A METAL BODY AND A SEMICONDUCTOR DEVICE* ELECTRICALLY INSULATING SEAL BETWEEN A METAL BODY AND A SEMICONDUCTOR DEVICE* PERMAFROST STRUCTURAL SUPPORT WITH:
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00022
00025 HEAT PIPE WITH PLEATED CENTRAL WICK AND EXCESS FLUID RESERVOIR®
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