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Proceedings of the 14th International Heat Pipe Conference

-2007-

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14th International Heat Pipe Conference (14th IHPC), Florianópolis, Brazil, April 22-27, 2007.

HEAT PIPE – A BRIEF HISTORY AND A FUTURE APPLICATION VIEW

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ABSTRACT

Considering heat pipe history and evolution, a brief frame of functionality and existing applications is laid out. Matching energy consumption profiles and some data on opportunities for improvement in energy use, a possible forecast for heat pipe industrial applications is traced, proposing new concepts in projects for greater efficiency and sustainability

KEY WORDS: Heat pipe, thermosyphon, energy efficiency, energy conservation

14th International Heat Pipe Conference (14th IHPC), Florianópolis, Brazil, April 22-27, 2007.

CONVECTIVE HEAT TRANSFER PERFORMANCE OF NANOFLUIDS

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ABSTRACT

Nanofluids are colloidal suspensions, which are created by merging solid nanoparticles into a base liquid. When the particle volume fraction is limited to a few percent, these fluids keep a quasi homogeneous Newtonian behavior, but show an increase in thermal conductivity. Another interesting aspect of nanofluids is a possible significant increase in the critical heat flux, which would be favourable for heat transfer working fluid application. For most nanofluids, especially water-based nanofluids, the enhancement in thermal conductivity is moderate, i. e. about 3 % for each percent of particle volume fraction. In some cases of organic based nanofluids, literature reports on a dramatic increase in thermal conductivity of about 30 % for a one percent particle volume fraction nanofluid. This large enhancement is not well understood and not easy reproduceable. The paper will give a short summary about the experimental evidence on enhanced thermal conductivity of nanofluids, based on a literature review and on own measurements.
An increase in thermal conductivity of a fluid is expected to result in an increase of the convective heat transfer capability of this fluid. Unfortunately the viscosity of a nanofluid also rises as compared to the base fluid. There are diverging results reported in literature about more or less enhancement of the convective heat transfer with nanofluids. The paper will analyse in detail the results on convective heat transfer with nanofluids reported in literature and compare these results with own measurements at our Institute.
Two different setups have been used for our own measurements, one with a 8 mm inner diameter copper pipe and one with a 0.8 mm steel capillary tube. The copper pipe is heated via condensing steam while the capillary tube has an indirect electric heat supply.
A second focus of the paper will give attention to the pool boiling results with nanofluids. The critical heat flux for nanofluids will also be analysed. The results are employed in an evaluation for the applicability of nanofluids for heat pipe applications.

KEY WORDS: Nanofluid, thermal conductivity, convective heat transfer, boiling

HEAT PIPE IN FUTURE MOBILE PLATFORMS

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ABSTRACT

Heat pipes have become ubiquitous in notebook computer system cooling and will likely remain so for the foreseeable future. From a research perspective, most work in heat pipes in the past have focused on increasing the carrying capacity of the heat pipe or reducing the "adiabatic" resistance of the heat pipe. Although these are important considerations, future heat pipes for mobile systems will likely have different requirements as compared to the past. In this paper, we describe possible trends in the areas of heat pipes and potential areas of future technical development. One potential need of future heat pipes is the ability to handle tighter bends and the ability to be flattened to thinner cross-sections. This would enable heat pipes to reduce the overall volume dedicated to the thermal solution thereby enabling thinner form factor notebooks and/or leaving more room for other notebook components. Another potential future need of heat pipes is the desire to have a single heat pipes have multiple heat absorbing locations and heat rejection locations with a relatively high carrying capacity and low thermal resistance. This becomes particularly important when the heat pipe is used to cool multiple integrated circuits or if the heat pipe connects to multiple heat exchangers. In this paper, we discuss these future heat pipe needs and describe relevant figures of merit in order to evaluate the effectiveness of any proposed heat pipe improvements.

KEY WORDS*:* Laptop, thermal resistance, heat pipes, future mobile thermal trends

EXPERIMENTAL EVALUATION OF THE FLOW AND HEAT TRANSFER IN A CLOSED LOOP THERMOSYPHON

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ABSTRACT

A closed loop thermosyphon is an energy transfer device that employs thermally induced density gradients to induce circulation of the working fluid thereby obviating the need for any mechanical moving parts such as pumps and pump controls. This increases the reliability and safety of the cooling system and reduces installation, operation and maintenance costs. These characteristics make it a particularly attractive option for the cavity cooling system of the Pebble Bed Modular Reactor (PBMR). Loop thermosyphons are however known to become unstable under certain initial and operating conditions. It is therefore necessary to conduct an experimental and theoretical study of the start-up and transient behaviour of such a system. A small scale test loop was built representing a section of a concept cooling system. A number of representative yet typical experimental temperature and flow rate curves for a range of initial and boundary conditions were generated, plotted and are given as a function of time. These curve showed that oscillatory temperature and flow occurred that was dependent on the differing design and operating conditions. A number of theoretical modelling and actual cooling system design problem areas were identified. These problem areas need to be addressed if more accuracy is required to capture the erratic and ostensibly chaotic heat transfer behaviour of the loop. They would also need to be addressed if a theoretical heat transfer model is to be experimentally validated.

KEY WORDS: Closed loop two-phase thermosyphon, Two-phase flow, Experimental evaluation, transient analysis, natural circulation loop

EXPERIMENTAL STUDY OF MERCURY AND NAPHTHALENE THERMOSYPHONS

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ABSTRACT

The technology involving heat pipes and thermosyphons can be applied to several areas, as for example, for heat exchangers, thermal control of space vehicles, refrigeration systems for electronic components and in ovens for the food industry. The appropriate choices of both the working fluid and the pipe material are important considerations for the design of the heat transfer equipment that use the heat pipe and thermosyphon technology. Different working fluids can be employed, such as water, liquefied gases, organic liquids, liquid metals, etc. The present work has as the main objective to investigate the use of naphthalene and mercury as working fluid for high temperature thermosyphons for industrial applications. The experimental apparatus are formed by a vertical themosyphon in an electric furnace. The furnace is connected to a voltage controller and then a control of the heat flux is possible. The thermosyphons were made of stainless steel tube with 1.0 m of length and 25.4 mm of external diameter. Then, the experimental study can supply the temperature distribution on wall surface and the possible rate heat flux that it is designed to transfer. The tests demonstrated that Brazil has developed technology to design equipments which employ naphthalene and mercury, which have great potential as working fluid for high operation temperature industrial equipment.

KEY WORDS: thermosyphons, naphthalene, mercury.

14th International Heat Pipe Conference (14th IHPC), Florianópolis, Brazil, April 22-27, 2007.

HEAT TRANSFER CHARACTERISTICS IN A TWO-PHASE CRANK-SHAPE CLOSED THERMOSYPHON –THE EFFECT OF OFFSET LENGTH–

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ABSTRACT

This paper describes heat transfer characteristics in a two-phase crank-shape closed thermosyphon. Usually, the thermosyphon is composed of an evaporator, an adiabatic section and a condenser arranged on a straight tube. However, a bent geometry of the thermosyphon is sometimes needed to use because of the limited space for the straight thermosyphon to be installed. Therefore, in the present study, a crank-shape thermosyphon is studied on the heat transfer coefficients and critical heat fluxes. The evaporator and condenser are positioned vertically and the adiabatic section horizontally. The inside diameter of the thermosyphon is 16 mm and each length of the evaporator and condenser is 500 mm. As the working fluids, water, ethanol, 20 mass % and 40 mass % ethylene glycol aqueous solutions, and hydrofluoroether 7100 and 7200 are used in this series of experimental investigation. The distance between the centers of the vertical evaporator and condenser, i.e., the offset length is varied from 220 mm to 620 mm. Also, the filling ratios of the working fluids are varied to be 0.3, 0.4, 0.5 and 0.6, and the operating temperatures 40, 50, 60, 70 and 80 °C. The heat transfer coefficients and critical heat fluxes of water, ethanol, ethylene glycol aqueous solutions and hydrofluoroethers for the offset length of 320 mm have been already presented in the Proceedings of 6 IHPS (2000) and Trans. of the JSRAE (2004). Therefore, in the present report, the effect of offset length on the heat transfer coefficients and critical heat fluxes is presented using water. In the cranked thermosyphon, it is revealed that the heat transfer coefficients are almost the same values as those for straight tubes but the critical heat fluxes decrease with an increase in the offset length.

KEY WORDS: Heat transfer coefficient, Critical heat flux, Boiling, Condensation, Crank-shape thermosyphon, Offset length

14th International Heat Pipe Conference (14th IHPC), Florianópolis, Brazil, April 22-27, 2007.

HEAT TRANSFER PERFORMANCE IN A LOOPED PARALLEL THERMOSYPHON

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ABSTRACT

To improve insufficient heat transfer performance of a conventional thermosyphon (STT) such as low maximum heat transfer rate and nonuniform wall temperature in an evaporator section a new type of thermosyphon, referred to a looped parallel thermosyphon (LPT), has been developed in order to make use of flow fluctuation occurred by vapor bubble formation. It consists of two STTs connected by two U tubes at the top and bottom ends. This study is to experimentally examine how the LPT improve the performance. Experiments are conducted in both STT and LPT for water and ethanol working fluids at the same experimental conditions of the charge ratios of 0.5 and 0.9 and coolant temperatures of 25, 38, and 50 °C. Major findings are as follows: The wall temperature profiles in the evaporator section are much more uniform in the LPT than those in the STT. This characteristic is significant for the water working fluid. The heat transfer coefficients in the evaporator and condenser sections in the LPT are similar to those in the STT. The maximum heat transfer rates obtained in the LPT are by 3 to 6 times larger than those in the STT and this enhancement is the major advantage of the LPT.

KEY WORDS: Thermosyphon, Looped, Wall temperature profile, Maximum heat flux, Heat transfer

TECHNO-ECONOMIC OPTIMIZATION OF THERMOSYPHON HEAT EXCHANGERS DESIGN USING MATHEMATICAL PROGRAMMING

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ABSTRACT

An Optimal Synthesis program for designing Heat Pipe Heat Exchangers (HPHE) is developed in this work. The program is the union of a simulation model, mainly based on heat transfer and fluid flow empirical correlations for thermosyphons, and an optimization procedure based on Evolutionary Algorithms. The simulation model was implemented on an Excel® spreadsheet, with aid of Visual Basic for Applications® programming. The chosen optimization method procedure was a Genetic Algorithm. Several shapes and arrangements of two-phase thermosyphons can be considered to attend one single thermal load. The objective of this work is to prescribe the cheaper design configuration among all chosen possibilities. Using the proposed optimization program, a case study is performed regarding the design of a heat recovery heat exchanger for a small gas turbine. The purpose of the equipment is to recover heat from the turbine flue gases for thermally driving an air conditioning absorption chiller. The use of an evolutionary optimization technique allows the program to deal with discrete variables, such as a given set of tube diameters that are commercially available. Using a small number of design variables, a comparison between exhaustive simulation and the optimization program is done. The proposed technique has found the optimum solution with a very few computational effort, in comparison with exhaustive techniques. The optimization program showed itself a useful design tool.

KEY WORDS: Evolutionary algorithms, thermal design, mathematical programming

14th International Heat Pipe Conference (14th IHPC), Florianópolis, Brazil, April 22-27, 2007.

THEORETICAL SIMULATION OF THE FLOW AND HEAT TRANSFER IN A CLOSED LOOP THERMOSYPHON

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ABSTRACT

A natural circulation closed loop thermosyphon can transfer heat over relatively large distances without any moving parts such as pumps and active controls. Such loops are thus considered suitable for nuclear reactor cooling applications where safety and high reliability are of paramount importance. A theoretical basis on which to predict the flow and heat transfer performance of such a loop is presented and the theoretical equations and major assumptions made in deriving these equations are given. Theoretical simulations are conducted for single phase and single and two-phase operating modes and a sensitivity analysis of the various variables is undertaken. It is seen that the theoretical results capture the single and two-phase flow operating modes well for a loop that includes an expansion tank. It is concluded that the theoretical model may be used to study transient and dynamic non-linear effects for single and two-phase modes of operation. To more accurately predict the heat transfer rate of the loop however, loop specific experimentally determined heat transfer coefficients still need to be determined and incorporated into the theoretical model.

KEY WORDS: Closed loop two-phase thermosyphon, Natural circulation loop, Two-phase flow, Theoretical modeling, Transient analysis

14th International Heat Pipe Conference (14th IHPC), Florianópolis, Brazil, April 22-27, 2007.

TWO-PHASE CLOSED THERMOSYPHON WITH NANOFLUIDS

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ABSTRACT

Nanofluids, stabilized suspensions of nanoparticles typically < 100 nm in conventional fluids, are evolving as potential enhanced heat transfer fluids due to their better thermal conductivity, increase in single phase heat transfer coefficient and significant increase in critical boiling heat flux. In the present paper, we investigate the overall thermal resistance of a closed two-phase thermosyphon using pure water and various water based nanofluids (of Al_2O_3, CuO and Laponite clay) as working fluids. We observed that all these nanofluids show inferior thermal performance than pure water. Furthermore, it is observed that the wettability of all nanofluids on copper substrate, having the same average roughness as that of the thermosyphon container pipe, is better than that of pure water. The behavior of nanofluids is explained in the light of pool boiling dynamics and the interplay of nucleating cavities with wettability of the nanofluids.

KEY WORDS: Nanofluids, Pool boiling, Two-phase Closed Thermosyphon, Wettability.

14th International Heat Pipe Conference (14th IHPC), Florianópolis, Brazil, April 22-27, 2007.

TWO PHASE LOOPS WITH CIRCULATING FACTOR OF THE VAPOR AND LIQUID FLOWS

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ABSTRACT

Heat transport systems on the basis of the Two Phase Loops (TPL) technology offers capabilities to play an important role for cooling and instrument thermal control on some space and earth applications. The TPL are classified as a rule with capillary pumps (loop heat pipes and capillary pumped loops) and without capillary pumps (loop thermosyphon and oscillating heat pipes). However, it is little known heat transport systems on basis of TPL are able to transform heat and kinetic energy of vapor flow in motive power for working fluid circulation. For example, these TPL are interesting for the heat transport in gravity direction without capillary pumps. This paper presents some configurations of TPL with injection rate **U** ($U = \dot{m}_l / \dot{m}_v > 1$), where ($\dot{m}_l$) liquid and ($\dot{m}_v$) vapor mass flows and examines the experimental data for cooling systems which is investigated for heat transport in gravity direction and using the injector condenser (TPL with injector-condenser) or vapor bubbly flow (TPL with vapor-lift pump). The experiment was supplemented by extensive hardware development, analytical modeling development and ground test verification.

KEY WORDS: Heat transport systems, two phase loops (TPL), loop heat pipes, loop thermosyphon, injection rate, injector-condenser, vapor-lift pump

DEVELOPMENT OF A LIGHT-WEIGHT COPPER / WATER HEAT PIPE

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ABSTRACT

The most common heat pipe type in today's space applications is the axially grooved aluminum profile with ammonia as heat carrier. System and technology studies define the need for higher temperature heat pipes with an operating temperature of 80 to 200°C and embedded into honeycomb panels for application in thermal radiators. In this temperature range the space-qualified material combination ammonia / aluminum cannot be applied because of the limited upper operation temperature of ammonia of about 80°C. The heat pipe, developed in this study, is based on a water / copper material combination. A galvanic process is used to fabricate a thin-walled corrugated copper profile, which is then inserted into a flanged aluminum profile. During the program several prototype heat pipes were performance tested and compared to analytical results. The results show an excellent heat transport performance of about 500 Wm at 120°C (against 200 Wm as specified) and a good correlation between test and analytical results. The paper detail the development, manufacture and test campaign of this lightweight copper / water heat pipe. The work has been performed within an ESA contract awarded to the OHB / IKE team.

KEY WORDS*:* Copper/Water, Heat Pipe, Galvanic, Corrugated

14th International Heat Pipe Conference (14th IHPC), Florianópolis, Brazil, April 22-27, 2007.

EBoWIT
EHP CHARACTERIZATION DEVICE FOR CAPILLARY EVAPORATOR DEVELOPMENT

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ABSTRACT

In order to develop the next-generation of evaporator a specific apparatus called EBoWIT - Evaporator Body / Wick Interface Testing - has been designed by Euro Heat Pipes. EBoWIT allows an easy testing of samples (porous & wall) that are representative of the vaporization zone inside capillary evaporator's. The present paper describes the setup and provides vaporization heat transfer data for ammonia, methanol and water, T_{sat} ranging from 30 to 86°C, heat fluxes up to 56 W/cm² and ΔP up to 8 kPa.

KEY WORDS: Loop Heat Pipes, Capillary Pumped Loop, Porous Media, Wicks, Heat Transfer, Heat flux, Electronic cooling.

14th International Heat Pipe Conference (14th IHPC), Florianópolis, Brazil, April 22-27, 2007.

EXPERIMENTAL STUDY OF THE PHASE CHANGE MATERIAL HEAT PIPE

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ABSTRACT

At the phase change temperature, phase change material (PCM) absorbs or dissipates latent heat while the temperature does not change. For this characteristic, it is used in the thermal control of spacecraft. Considering the advantages of the heat pipe (HP) and the PCM, it is a good idea to apply the HP together with the PCM to transfer heat and restrain temperature fluctuation. This paper shows a new-designed PCM ($C_{12}H_{26}$) heat pipe, which would be used in a spacecraft. Through the experiment, the basic characteristic and the thermal coupling between the HP and the PCM have been investigated. The experimental results show that the PCMHP can transfer heat effectively and it can absorb or dissipate heat at phase change temperature stably. The ammonia heat pipe couples the PCM well, the temperature difference between the ammonia heat pipe and the PCM is small.

KEY WORDS: heat pipe (HP), phase change material (PCM), phase change material heat pipe (PCMHP), thermal coupling

14th International Heat Pipe Conference (14th IHPC), Florianópolis, Brazil, April 22-27, 2007.

FLAT HEAT PIPES WITH SELF-REWETTING FLUIDS

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ABSTRACT

Dilute aqueous solutions of high carbon alcohols (number of carbon atoms ≥ 4), the so-called “self-rewetting fluids”, show an increase in the surface tension with increasing temperature. Such a particular surface tension behavior, coupling with a preferential evaporation of alcohol-rich component, results in a strong surface tension gradient in the course of liquid/vapor phase change. The Marangoni effect caused by the surface tension gradient induces a rigorous liquid flow toward higher temperature region. This spontaneous liquid flow is expected to improve the thermal performance of wicked heat pipes. The present authors experimentally demonstrated an appreciable increase in the dryout limit of wicked heat pipes with self-rewetting fluids as a working fluid comparing with ordinary water heat pipes. The authors recently initiated a thorough experimental study on flat heat pipes with self-rewetting fluids. The first preliminary tests have been conducted for a series of heat pipes of 1.5 mm in thickness and 8 mm in width and 150mm in length, which contained water and several different self-rewetting fluids. The experimental results demonstrated an outstanding thermal performance of self-rewetting fluids in flat heat pipes.

KEY WORDS: Flat heat pipes, working fluids, alcoholic aqueous solutions, surface tension, Marangoni effect

14th International Heat Pipe Conference (14th IHPC), Florianópolis, Brazil, April 22-27, 2007.

HEAT FLUX DENSITY CHARACTERISATION IN HEAT PIPES USING CAPILLARY POROUS MEDIA

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ABSTRACT

Nowadays electronics requires more and more strong cooling techniques with cheap and robust systems. Phase change heat transfer devices are particularly adapted to this task because of their efficiency and ability to transfer heat fluxes. Functioning without using moving parts makes them all the more reliable. The use of such systems is widespread, but the continuous growth of heat dissipation due to electronics miniaturisation gives concern.
Indeed, phase change heat exchangers are very sensitive to applied heat flux density, which can easily produce local dry-out and lead to a very fast increase of temperature and failure of the device. This study is concerned with this kind of problems in a capillary porous media used within a heat pipe. The purpose is to investigate heat transfer phenomena during dissipation in different porous media applying great heat flux density to them.

KEY WORDS: Heat pipes, phase change, porous wick, heat density

14th International Heat Pipe Conference (14th IHPC), Florianópolis, Brazil, April 22-27, 2007.

HEAT PIPE GROOVE DRY OUT FRONT POSITION IDENTIFICATION USING INVERSE METHODS ANALYSIS

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ABSTRACT

A numerical study based on inverse methods has been performed to identify dry out front positions in each groove of an axially grooved cylindrical heat pipe using experimentally measured wall temperatures. A nodal direct model has been developed taking into account heat conduction in evaporator heat pipe enclosure and evaporation at groove liquid meniscus. As simulation tests show good results, the inversion procedure has been considered reliable and efficient. The heat pipe wall thermal behavior can consequently be interpreted by dry out zone localization using inverse methods analysis. At working limit, the evaporator zone is approximately out of liquid phase especially in heat pipe upper side, closer to heating source.

KEY WORDS: Axially grooved heat pipe, dry out front, evaporator zone, conduction model, inverse methods.

14th International Heat Pipe Conference (14th IHPC), Florianópolis, Brazil, April 22-27, 2007.

HEAT TRANSFER IN GROOVED HEAT PIPES: VISUALISATION AND EXPERIMENTAL ANALYSE OF FLUID BEHAVIOUR

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ABSTRACT

High performance heat pipe modelling needs an increased knowledge of flow behaviour inside grooves. Thus, even if this flow is usually laminar, a free surface governed by capillarity leads to many difficulties to calculate the mean friction factor of the groove. In this study, an experimental bench has been developed in order to visualize the liquid-vapour interface channels of five different axially grooved heat pipes. This experimentation, associated with image processing programs, allows the measurement of height of liquid and meniscus radius and so the determination of the friction factor.

KEY WORDS: groove, meniscus, pressure drop, visualisation, heat pipe

14th International Heat Pipe Conference (14th IHPC), Florianópolis, Brazil, April 22-27, 2007.

PERFORMANCE OF HEAT PIPE EVAPORATORS FOR SPACE APPLICATIONS WITH COMBINED RE-ENTRANT GROOVES AND MICROGROOVES

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ABSTRACT

An advanced capillary structure with combined re-entrant grooves and microgrooves for heat pipe evaporators was investigated in micro gravity conditions during the FOTON-M2 mission of the European Space Agency (ESA). The advanced capillary structure was used in a flat heat pipe featuring two evaporator sections with a different number of microgrooves. Based on temperature measurements the performance of each evaporator section is quantitatively evaluated in terms of a heat transfer coefficient. Additionally, the liquid distribution in the grooves was observed with an IR and a CCD camera. The recorded images show a complete wetting of the grooves in all experiments. The performance of the heat pipe in space is similar to the performance on ground in the horizontal position. For both evaporators the heat transfer coefficients show a dependency on the vapour temperature and particularly on the evaporative heat flux. The results clearly demonstrate the superior performance of the evaporator with the larger number of microgrooves owing to the extension of the 3-phase contact line and, hence, the intensification of thin film evaporation.

KEY WORDS: advanced capillary structure, thin film evaporation, space experiment

STEADY SIMULATION OF CYLINDRICAL HEAT PIPES IN HIGH CONDITIONS OF ROTATION

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ABSTRACT

Rotating cylindrical heat pipes have some important applications, as electric engines cooling, turbine thermal control, and other kinds of equipment. It can also be applied to satellites with spin movement. The effect of rotation in its operation becomes important when the angular velocity is too large, compared to the heat transfer and fluid flow scales. In this case, recirculation appear, growing and scattering the vapor phase, and the fluid involved in such recirculation cannot take part in the heat exchange process, which reduces the efficiency of the heat pipe. In some cases, the combination of high rotation and heat flux can obstruct the phase change from one section to another. In this work, a steady rotating cylindrical heat pipe is simulated through the finite volume method. For the vapor flow and for the liquid flow in the wick structure, that is modeled as a porous media. The Navier-Stokes equations are adopted. The energy and momentum equations are coupled through the flux at the liquid-vapor interface that defines the suction and velocities of injection for the liquid and vapor flow. The result is compared with some experimental data, using the experimental temperature profile to analyze the heat pipe behavior in high speed rotation.

KEY WORDS: Rotating heat pipes, Finite volume, Phase change in porous media

14th International Heat Pipe Conference (14th IHPC), Florianópolis, Brazil, April 22-27, 2007.

TWO PHASE HEAT TRANSFER ENHANCEMENT IN MICRO CHANNELS AND HEAT PIPE EVAPORATORS WITH NANO POROUS STRUCTURES

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ABSTRACT

Experimental investigation of heat transfer in annular channel between a copper horizontal tube with porous coating and transparent glass tube applied as an evaporator of mini loop heat pipe or thermosyphon was performed to analysis its cooling efficiency. The data obtained on a flooded and partially flooded tube in confined space (annular channel 0.1 to 2 mm thick) testify the phenomena of micro heat pipe inside a porous structure. A micro scale heat transfer effect took place inside the porous body and a mini-scale effect was realized in annular mini channel. Visual analysis and experimental results show, that such combination is favorable for the enhancement of the evaporation and two-phase convection heat transfer for propane as a working fluid. The availability of annular mini channel significantly promotes to intense heat transfer (up to 2.5 - 3 times as high) at heat fluxes < 50 kW/m^2, as compared with the same sample disposed in the liquid pool. Experimental investigation of a transparent flat mini evaporator heated by laser beam testifies the influence of nano particles immersed in water on the heat transfer intensification to compare with clean fluid heat transfer.

KEY WORDS: mini heat pipes, porous structure, nano-particles, transparent evaporator, laser beam

WICK MANUFACTURING AND CHARACTERIZATION

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ABSTRACT

Capillary pumping systems have been used in a variety of applications. These systems show a strong dependence with the porous structures used to assemble the capillary evaporators. Studies aiming the solution of problems related to working stability have been carried out. Pore critical diameter, porosity and thermal conductivity are properties that determine the working limits of the capillary evaporator. The objectives of this work are to study the porous samples manufacturing process, as well as, to characterize the porous structures. Nickel, stainless steel, mullite and alumina were employed as raw materials. The sintering parameters were modified to adjust the porous structure properties. Several techniques were employed to determine those properties. These techniques include image analysis, mercury intrusion porosimetry and Archimedes method for the determination of the porosity. The best manufacturing path and sintering parameters are presented in this work. Nickel porous structures with critical pore diameter less than 3.2μm and porosity of about 50% were obtained. In the same way, pore samples of stainless steel and ceramic material were manufactured with critical diameter lower than 3.3μm and 2.5μm and porosity of about 40% and 50%, respectively. The manufactured ceramic porous samples have shown most adequate properties to be used in capillary pumping systems.

KEY WORDS Porous Wicks, Capillary Evaporator, Wick Characterization.

14th International Heat Pipe Conference (14th IHPC), Florianópolis, Brazil, April 22-27, 2007.

COMPARISON OF THE COOLING PERFORMANCE BETWEEN HEAT PIPES AND ALUMINIUM CONDUCTORS FOR ELECTRONIC EQUIPMENT ENCLOSURES

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ABSTRACT

The use of heat pipes and aluminium conductors for the cooling of electronic equipment was investigated using experimental and theoretical methods. The heat pipes were found to have a conductivity of around 7200 W/mK, while the aluminium conductors had a thermal conductivity of around 200 W/mK. The steady-state temperature of a constant heat dissipating thermal source cooled by a heat pipe was achieved in around 1-5 minutes, while the thermal source cooled by an aluminium conductor took between 30 minutes and 1 hour to achieve steady state temperatures. Heat pipes were found to be better than conductor plates to transfer the heat from the heat source. The finned heat sink was found to also be an important cooling consideration as its surface area and air flow rate has to be large enough so as not to negate the superior heat transfer capability of heat pipes. The use of heat pipes are recommended if the distance between the thermal source and thermal sink is relatively large or if there are multiple thermal sources along the heat pipe heat transfer path.

KEY WORDS: Heat pipe, electronic enclosure cooling

14th International Heat Pipe Conference (14th IHPC), Florianópolis, Brazil, April 22-27, 2007.

DEVELOPMENT AND RESULTS OF TESTING COOLERS ON THE BASIS OF COPPER-WATER LHPS FOR DESKTOP PCS.

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ABSTRACT

The paper is devoted to the development of passive and active cooling systems for the central processors (CPU) of desktop personal computers (PC) on the basis of copper-water loop heat pipes (LHPs). Passive systems, in which heat was transferred to an external radiator and then removed by free air convection, had a thermal resistance of about 0.5-0.6°C/W in the range of heat loads from 80 to 100W. Besides bench tests with heat load up to 160W, the systems were also tested as parts of PCs with a maximum dissipated power of CPUs up to 70W. Active systems were made in the form of compact coolers, which contained fans creating forced convection. At heat loads of 70-130W the thermal resistance of such coolers was in the range from 0.19-0.22°C/W. The maximum heat-transfer capacity of active coolers achieved in the tests was 250W.

KEY WORDS: Loop Heat Pipe, Cooler, CPU, Thermal Resistance.

14th International Heat Pipe Conference (14th IHPC), Florianópolis, Brazil, April 22-27, 2007.

EXPERIMENTAL STUDY OF TWO-PHASE HEAT SPREADERS FOR PEMFC COOLING APPLICATIONS

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ABSTRACT

This paper is devoted to an experimental study to investigate the thermal behaviour of two-phase heat spreaders (TPHS) developed in order to ensure the cooling of fuel cells (PEMFC). The aim of this study is to reduce the volume of actual cooling systems and to homogenize the temperature in the core of PEMFC. Four different TPHS have been tested in three French laboratories in order to compare the thermal performances of different capillary structures: longitudinal micro-grooves, crossed micro-grooves and porous sintered particle media. In this paper, the thermal performances of these four TPHS are compared for three different working fluids in vertical favourable position. Additionally, some specific results concerning the TPHS with longitudinal grooves are analysed.

KEY WORDS: Two-phase heat spreader, PEMFC, fuel cell

14th International Heat Pipe Conference (14th IHPC), Florianópolis, Brazil, April 22-27, 2007.

MANUFACTURING AND MODELING OF FLAT MINIATURE HEAT PIPES IN MULTILAYER PRINTED CIRCUIT BOARD TECHNOLOGY

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ABSTRACT

A novel, integrated approach in thermal management of electronic products, based on two-phase cooling, is presented. A flat miniature heat pipe, integrated inside the laminated structure of a printed circuit board (PCB) has been developed, based on mainstream PCB multilayer technology. Hot spots on the PCB, caused by heat dissipating components, can be cooled with relatively small temperature gradients across the board. A model, based on control volume elements, is presented to analyze the behavior of the embedded heat pipes for transient applications. The advantage of this approach, compared to e.g. finite element models, is that the model can be expanded with additional components (e.g. multiple evaporators) very easily. Actual PCBs with several hot spots cooled by flat miniature heat pipes and their parameter effects can be analyzed very quickly, without the necessity of complex and time-consuming finite element analyses. Experimental verification has shown successful heat pipe operation and experimental results compare well with model predictions. The results show an equivalent thermal conductivity 7 times better compared to solid copper. Low thermal resistance values establish this concept as a promising thermal management solution for future electronic products.

KEY WORDS: Heat Pipe, Electronics, Multilayer PCB, Thermal Management, Control Volume Modeling

MINIATURE LOOP HEAT PIPES WITH DIFFERENT EVAPORATOR CONFIGURATIONS FOR COOLING COMPACT ELECTRONICS

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ABSTRACT

In this paper, results from the investigation of two different designs of miniature Loop Heat Pipe (mLHP) for thermal control of compact electronic devices like notebooks have been discussed. Two prototypes of mLHP, one with a disk shaped evaporator of 30 mm in diameter and 10 mm thick, and the other with a rectangular shaped evaporator of 45x35 mm^2 planar area and 5 mm thick, were designed to handle heat fluxes of up to 50 W/cm^2. In the disk shaped evaporator, the compensation chamber was incorporated in the overall thickness of the evaporator whereas for the rectangular shaped evaporator, a new design approach was used in which the compensation chamber was positioned on the sides of the wick structure. This new approach helps to decrease the thickness of the evaporator by 50% and thus helps to adapt and integrate mLHPs inside compact electronic enclosures. All the tests were conducted in horizontal orientation. Both mLHP models showed reliable start up behaviour at different heat loads and were able to achieve steady state without any symptom of wick dry out. Total thermal resistance of these mLHPs lies in the range of 1-5 $^{\circ}C/W$. A comparison of the thermal performance of both prototypes is presented focusing on the advantages and disadvantages of the two design approaches. As an outcome of the current investigation, mLHPs can be classified as potential candidates for the thermal control of the compact electronic devices with restricted space and high heat flux chipsets.

KEY WORDS: mLHP, flat evaporator, novel design, thermal control, heat transfer

14th International Heat Pipe Conference (14th IHPC), Florianópolis, Brazil, April 22-27, 2007.

PERFORMANCE OF HIGH FREQUENCY PERIODIC TWO-PHASE THERMOSYPHONS FOR ELECTRONIC COOLING APPLICATIONS

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ABSTRACT

This paper deals with a particular miniature two-phase loop named Periodic Two-Phase Thermosyphon (PTPT), whose operation is periodic. A Periodic two-phase thermosyphon allows remote condensation and broad flexibility in the mutual displacement of the evaporator with respect to the condenser. In addition, a PTPT allows the overall dimensions of the evaporator to be drastically reduced, and allows it to be placed close to the electronic equipment; it is suitable for high density packaging thermal control applications.
In this paper the authors have experimentally compared the performance of two mini-PTPT prototypes which operate at high frequency (0.016 Hz) with those obtained by 4 high performance commercial devices which are designed to be implemented on the surface of a Pentium© IV processor.
The PTPT device shows a specific thermal resistance of 5.1 K cm^2/W, about twice those measured with commercial devices, but similar to other capillary thermal loops (LHP). These devices show that their performance is not influenced by the tilt angle of the heating surface. The dynamic response of these devices is influenced by the operational frequency. In the case of compact high frequency operating PTPT, the dynamic response is quicker than with other capillary loops such as LHP and CPL, and similar to that of heat pipe cooling devices, which do not allow remote condensation. The PTPT device can really be a low cost solution for compact thermal control application.

KEY WORDS: Two-phase loops, electronic cooling, periodic operations, thermosyphon

14th International Heat Pipe Conference (14th IHPC), Florianópolis, Brazil, April 22-27, 2007.

CIRCUMFERENTIALLY MICROGROOVED CAPILLARY EVAPORATORS: GROUND AND MICROGRAVITY EXPERIMENTAL RESULTAS

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ABSTRACT

Circumferentially microgrooved capillary evaporators have been tested and proposed as an alternative solution to be used in spacecraft thermal control systems. The capillary evaporator is provide with internally machined circumferentially microgrooves in a ¾" diameter aluminum tubes with an average opening of about 33 μm. An internal profile is used to separate the liquid from the vapor channel. The capillary pumping pressure has been measured around 1.5 kPa. Several tests were carried out since 1994 using different working fluids. Freon was first used in the ground tests carried out at IKE (Institut für Kernenergetik und Energiesysteme) in Germany, showing heat fluxes up to 12 kW/m², as the capillary limit. Acetone, ammonia and deionized water were also used as working fluids in the following ground tests carried out at UFSC (Federal University of Santa Catarina). For acetone, heat fluxes up to 7.87 kW/m² were measured as the capillary limit. Deionized water was successfully used in the first microgravity testing, carried out on the ISS (International Space Station) in 2006. In this paper, the results concerning the startup and thermal behavior of the capillary evaporator at the steady state operation are presented. In general, the capillary evaporator showed good performance and reprime capacity even in presence of non condensable gases (NCG) along the liquid channel. The results showed reliability for ground and satellite thermal control applications.

KEY WORDS: Two-phase heat transfer, Microgroove wick, CPL, LHP, Ground and microgravity experiments.

14th International Heat Pipe Conference (14th IHPC), Florianópolis, Brazil, April 22-27, 2007.

LONG TERM LIFE TEST & IN ORBIT TEST OF MINIATURIZED LOOP HEAT PIPE

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ABSTRACT

Mini-Loop Heat Pipes (mini-LHP) have been developed by ASTRIUM since 1996. They are dedicated to cool dissipative equipments and powerful electronics. The design of the mini-LHP is based on a flat stainless steel evaporator. The evaporator dimensions are 30 x 30 x 19 mm, its mass is about 40 g. This mini-LHP works with the working fluid Ammonia, in the power range: 0.5W to 50 W. In 2004, a long-term life test of 6 mini-LHPs was initiated. The six mini-LHPs were instrumented and a continuous recording of the mini-LHP temperatures was done. Moreover in parallel, in the frame of this qualification campaign, a flight opportunity on board the Russian FOTON M2 spacecraft was provided by CNES and ESA. This spacecraft, launched by the Soyouz Rocket, is dedicated to scientific & technology micro-gravity research. The flight duration was 15 days and all experiments were recovered after landing. During the flight, the mini-LHP was tested in a wide power range for heat transport capacity assessment and also in temperature control mode. After a presentation of the mini-LHP design and test set-up, the performance of the mini-LHP during two years of continuous operation and during the flight are shown. A synthesis of mini-LHP qualification status is provided and the way forward described.

KEY WORDS: Miniaturized, capillary fluid loop, thermal, dissipation, space, electronic

14th International Heat Pipe Conference (14th IHPC), Florianópolis, Brazil, April 22-27, 2007.

MICROGRAVITY EXPERIMENTS ON SQUARE-TYPE TWO-COMPONENT HEAT PIPES UTILIZING THE PARABOLIC FLIGHT OF AN AIRPLANE

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ABSTRACT

The results of microgravity experiments using two-component heat pipes are presented in this paper. The aim of this study was to determine the potential of a heat pipe utilizing the Marangoni effect that can be used without wicks even in a microgravity condition. Microgravity experiments using the parabolic flight of an airplane were carried out for 16mm×16mm×300mm square-type heat pipes made of Pyrex glass that contained a two-component mixture, i.e., water-ethanol, for the working fluid. The effects of heat quantity, temperature of the coolant and initial concentration of working liquid on temperature distribution in the heat pipes were clarified. Temperature variation in the heat pipes accompanying change in gravity level was shown to depend on the distribution of the working liquid. The results of image processing on the observed condensate features showed that the liquid content in the cooling section increased abruptly due to intermittent boiling that occurred as soon as it entered a microgravity state but decreased after that at an almost constant rate except for the case of a relatively high concentration of initial mixture. Comparison of liquid flow rates calculated from image data and those estimated from previous theory confirmed that the flow-back of working liquid induced by the Marangoni effect possibly occurred by the predicted mechanism. It was also shown that the liquid support mechanism at the edges of the square-type heat pipe could prevent the formation of liquid plugs and made the Marangoni effect more effectively utilizable for wickless heat pipes.

KEY WORDS: Microgravity experiment, heat pipe, two-component mixture, Marangoni effect

14th International Heat Pipe Conference (14th IHPC), Florianópolis, Brazil, April 22-27, 2007.

NUMERICAL AND EXPERIMENTAL INVESTIGATIONS OF A GROOVED HEAT PIPE IN MICROGRAVITY-LIKE CONDITIONS

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ABSTRACT

In collaboration with Euro Heat Pipes (EHP), we continuously improve a one dimensional thermohydraulic model able to predict the heat transport capacity of grooved heat pipes for microgravity and gravity assisted applications. The code is used through a Java user-friendly interface easing the heat pipe design of the space industries dealing with this technology. After a short description of the code and its interface, this paper proposes a comparison between numerical results and experimental measurements obtained on a re-entrant grooved heat pipe in microgravity-like conditions. To reproduce the 0-g environment, a smart setup, based on the rotation of the heat pipe, was built up. By investigating the evolution of the maximum power versus the heat pipe load, we found both good qualitative and quantitative agreement between the code and the experiment. Different analyses are proposed to illustrate the results, such as the cumulated friction loss increase along the pipe axis or the liquid level profile inside of the grooves.

KEY WORDS : Capillary meniscus, heat pipe, friction losses, groove

WIRE MINI HEAT PIPE UNDER MICROGRAVITY CONDITIONS

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ABSTRACT

The mini heat pipe considered in this work consists of the union of cylindrical cooper wires between two thin copper plates. The edges formed between the wire and the plate provides the capillary pressure. This device was tested under microgravity conditions, with the objective of determining the lack of gravity effect on the heat transfer capacity of the device, by comparison with its performance under gravity. Two wire mini heat pipes were tested under microgravity conditions aboard the International Space Station (ISS) by the Brazilian Cosmonaut Marcos Pontes during the 13th Expedition of the Soyuz rocket to the ISS. The Mission was part of the Brazilian Space Agency Microgravity Program, in the frame of a partnership with Energia/Roscosmos Russian Agency. The flight took place on March 30th in a Soyuz rocket in Baykonur Cosmodrome – Kazakhstan. A compact data acquisition system was developed to measure and save the temperature distribution along the mini heat pipe. The heat was released to the evaporator by means of an electric heater attached to the wire mini heat pipe surface and was removed from the condenser by fin surfaces, through which air is blown by fans. Results indicated a good agreement between the microgravity and gravity results, showing the efficiency of the device in the thermal management of equipment under microgravity conditions.

KEY WORDS Mini heat pipe, microgravity

14th International Heat Pipe Conference (14th IHPC), Florianópolis, Brazil, April 22-27, 2007.

ADVANCED COOLING CHIP BY HEAT PIPES AND VAPOR CHAMBER FOR PERSONAL COMPUTERS

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ABSTRACT

After the introduction of Pentium™ processor in 1993, the trend of the processor performance and power consumption have been increased significantly each year. Heat dissipation has been increased but in contrast the size of die on the processor has been reduced or remained the same size due to nano-size circuit technology and thus the heat flux is critically high. The heat flux was about 10-15 W/cm^2 in the year 2000 and had reached 100 W/cm^2 in 2006. The purpose of this paper is to provide an overview of practical various cooling solutions, including the use of heat pipes and vapor chambers for cooling high power processors in a confined space of PCs. Included in this paper are designs, data and discussions of various fan sink air cooling designs showing how the design changes to push the limit of the air cooling capability. As one of significant issue, the authors would suggest that the heat spreading technology from Silicon becomes a key function using two phase heat transfer. Finally the authors would suggest what and which way we are going to develop for next generation of high power cooling chips.

KEY WORDS: Heat pipe, Vapor chamber, Computer cooling, Fan heat sink.

14th International Heat Pipe Conference (14th IHPC), Florianópolis, Brazil, April 22-27, 2007.

TESTING AND SIMULATION OF VAPOUR CHAMBER USED IN ELECTRONICS COOLING

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ABSTRACT

Continuous development of compact and more powerful electronic components has created new challenges in finding innovative and effective cooling solutions. The present study will focus on the development of a mini-vapour chamber (VC), also know as a flat plate heat pipe, capable of fitting into small spaces and handling large heat loads. Experimental measurements on the mini-vapour chamber and CFD simulations on its application are presented in this paper.

The vapour chamber (VC), with square sides of 45 x 45mm and thickness of 3mm, was tested using a heater block of 10 x 10mm to simulate the heat source for the evaporator and a cooling plate to remove heat from the condenser surface. The performance of the vapour chamber was investigated by determining the thermal resistance over a heat input range of 10 to 100W with the condenser held at constant temperature. Test results for two vapour chambers with sintered and mesh type wicks were presented, and then compared to results obtained from tests on identical solid copper samples of 1 and 3mm base thickness. The experimental results show that the vapour chamber with sintered wick material performed markedly better than solid copper at high heat fluxes, with vapour chamber orientation having minimal effect. On the other hand, the vapour chamber with a mesh wick showed no improvement over the 3mm solid copper base and its performance even degraded at high heat fluxes and when operated against gravity. Furthermore, a CFD analysis was also undertaken to investigate the performance of the vapour chamber when fully integrated into with the packaged electronics enclosure.

The test-rig set up, experimental results and CFD analysis will be presented in detail.

KEY WORDS: Vapour chambers, flat plate heat pipes, thermal management, high heat flux, computational fluid dynamics, electronics cooling.

14th International Heat Pipe Conference (14th IHPC), Florianópolis, Brazil, April 22-27, 2007.

TRANSIENT THERMAL CHARACTERISTICS OF A VAPOR CHAMBER

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ABSTRACT

This paper describes numerical analyses on transient thermal characteristics of a vapor chamber. The vapor chamber is essentially a flat-plate type heat pipe and works as a heat spreader to spread heat flux from a small heat source to a large heat sink. The vapor chamber is developed as a novel thermal solution for cooling high-heat-flux small heat sources, such as central processing units (CPUs) in personal computers, servers and workstations. Three-dimensional heat transfer inside the vapor chamber and the heat sink base-plate is computed. The mathematical model of the vapor chamber consists of three regions of a solid wall, a liquid-wick and a vapor, and wick columns as well as wick sheets are placed inside the vapor chamber. Based on the authors' previous findings, only heat conduction is considered in the liquid-wick region and a lumped analysis is applied in the vapor region. The governing equations for each region are solved numerically by employing a control volume method. The numerical results of the start-up heat transfer characteristics and the responses for sudden change in heat flux are presented and compared with the authors' experimental results. As the close agreement is obtained between them, the validity of the present numerical analyses is confirmed.

KEY WORDS: Heat Transport, Unsteady State, Vapor Chamber, Heat Spreader, PC Cooling

14th International Heat Pipe Conference (14th IHPC), Florianópolis, Brazil, April 22-27, 2007.

USE OF VAPOR CHAMBER ON ELECTRONIC DEVICES TO ELIMINATE HOT SPOTS UNDER FIN HEAT SINKS

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ABSTRACT

The growing challenge in the area of electronic components demands development of mechanisms to eliminate hot spots from these components. These hot spots are generated by high heat fluxes originating from the large amount of trails and high processing of microprocessors. As these surfaces are usually small in some applications, even materials which are good thermal drivers, such as aluminum and copper, are not capable of dissipating the heat generated by the processor. Consequently, the component is damaged by high temperature levels. The technological development of computational equipments has allowed an increase in the processing speed and a reduction in sizes of equipments, which made them faster and portable. These specific equipments generate large amount of heat in small areas. The present work analyses the increase of the heat sink efficiency by using a vapor chamber with a wick structure. A finned heat sink with a vapor chamber with dimensions of 120 x 109 x 70 mm was built and tested with filling ratios ranging from 10 to 40% of the vapor chamber volume and heat power input from 25 to 200 W. According to experiments, the filling ratio of 30% leads to the smallest thermal resistance of a vapor chamber equal to 0.21ºC/W at 200 W. For comparison purposes, a conventional heat sink was also tested, which resulted in 0.24ºC/W under the same conditions, i.e. a decrease in the total thermal resistance of the heat sink was equal to 12.5%.

KEY WORDS: vapor chamber, heat sink, heat flux, heat spreader

14th International Heat Pipe Conference (14th IHPC), Florianópolis, Brazil, April 22-27, 2007.

AN EXPERIMENTAL INVESTIGATION OF A CO_2 PULSATING HEAT PIPE

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ABSTRACT

Since their invention in the early-nineties, pulsating heat pipes (PHPs) have been typically suited for micro electronics cooling. However, behavior and efficacy of these devices under low temperature (less than room temperature) is a new and promising challenge. This paper attempts to present preliminary experimental results of pulsating heat pipes operating with an evaporator average temperature ranging from -20°C to 5°C and having carbon dioxide (CO_2) as the working fluid. The results show the effects of input heat flux, inclination angle and volumetric filling ratio on the PHP thermal performance. The present results enables one to conclude that CO_2 can be used as a working fluid to efficiently transfer heat at low temperature.

KEY WORDS : pulsating heat pipes, carbon dioxide, heat exchangers.

14th International Heat Pipe Conference (14th IHPC), Florianópolis, Brazil, April 22-27, 2007.

EFFECT OF GEOMETRICAL SIZES ON MAXIMUM HEAT FLUX OF A VERTICAL CLOSED-LOOP PULSATING HEAT PIPE

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ABSTRACT

The objective of this paper is to study the effect of the geometrical sizes, consisting of evaporator section lengths, numbers of meandering turns and internal diameters, on maximum heat flux of a vertical closed-loop pulsating heat pipe. Moreover, these results can be compared with the results from a past study of a closed-end pulsating heat pipe at the same state. The closed-loop pulsating heat pipe was made by a long copper capillary tube. The geometrical sizes, which were the variable parameters of this study, were: evaporator section length of 50, 100 and 150 mm, number of 5, 10 and 15 turns, internal diameter of 0.66, 1.06 and 2.03 mm. Thus, there were totally 27 sets and each set was tested with 3 types of working fluid, viz. R123, Ethanol and Water. The adiabatic temperature was controlled at 50^{o}C. A low-voltage high-current power transformer was used as the heat source and heat transfer rate was obtained by using calorific method at the condenser section. It is found from the study that, higher maximum heat flux was obtained at lower evaporator section length, higher number of meandering turns and the higher internal diameter. In addition, It is found that, the effect of evaporator section lengths and internal diameters on maximum heat flux in this research fairly agrees with the past results of a closed-end pulsating heat pipe.

KEY WORDS: closed-loop pulsating heat pipe, maximum heat flux

14th International Heat Pipe Conference (14th IHPC), Florianópolis, Brazil, April 22-27, 2007.

EMBEDDED PULSATING HEAT PIPE RADIATORS

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ABSTRACT

With the aim of exploring potential applications of pulsating heat pipe (PHP) technology for space as well as terrestrial sectors, experimental study of embedded structures in an aluminum substrate subjected to conjugate heat transfer conditions, i.e. natural convection and radiation, has been carried out under different thermo-mechanical boundary conditions. To compliment the experimental study, system level 3D computational simulation of the complete experimental set-up has also been undertaken using commercial software. The effective thermal conductivity of the embedded structures has been estimated to be ~2500 W/mK by comparing experimental spatial temperature distribution on the plate with corresponding simulations. The study reveals that embedded PHP structures can be beneficial only under certain conditions. The effectiveness of such structures asymptotically levels off as its thermal conductivity increases beyond a particular limit. In addition, the degree of isothermalization of the radiator plate strongly depends on its thermal properties.

KEY WORDS: pulsating heat pipe, conjugate heat transfer, space radiators

14th International Heat Pipe Conference (14th IHPC), Florianópolis, Brazil, April 22-27, 2007.

EXPERIMENTAL INVESTIGATION OF PULSATING HEAT PIPES

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ABSTRACT

The pulsating heat pipe (PHP) constitutes a technological innovation in the field of two-phase heat transfer. Actually, this original device is attractive because of its very simple geometry (a smooth capillary meandering tube). Firstly, vacuum is created in this tube. Then, it is partially filled with a working fluid, in a saturation state, which leads to a particular distribution of vapour plugs and liquid slugs. This repartition allows transferring substantial heat quantities between the heated zone and the cooled one because of an oscillatory displacement, of plugs and slugs, caused by pressure variation within the PHP. However, there is no theoretical model, at the present time, which permits to precisely describe the complex physics of this system. An experimental set-up, dedicated to explore the influence of different parameters (heat flux, inclination angle…) on the operation and the performance of an open loop pulsating heat pipe, has been developed and several tests have been conducted. The first results and conclusions stemming from this experimental study are presented in this paper.

KEY WORDS: pulsating heat pipe, two-phase heat transfer, oscillations, capillary tube

14th International Heat Pipe Conference (14th IHPC), Florianópolis, Brazil, April 22-27, 2007.

EXPERIMENTAL INVESTIGATION OF UNLOOPED PULSATING HEAT PIPE (PHP) PERFORMANCE

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ABSTRACT

Pulsating heat pipes (PHP) have recently emerged as possible cooling devices for high heat flux electronics to replace conventional cooling methods. A PHP dissipates the heat through the oscillatory movement of a working liquid within and the sensible heat dominates the heat exchange mechanism over the latent heat. In this study, an optimum PHP design for best efficiency is investigated. The PHPs were constructed of multiport extruded aluminum tubing with square or triangular channel cross sections. A heat source with a 13 cm^2 surface area and a maximum power input of 200W was used. Several parameters were varied for this purpose: types of working fluid (ethanol and acetone), the fluid fill ratio (20 to 80%), the heat pipe orientation (horizontal and vertical), and the PHP dimensions (160 mm and 200 mm lengths) and inner structures (35-port and 26-port). Addition of diamond nanoparticles to the working fluid was also tested to enhance the thermal performance. It was found that the optimum fluid fill ratio depends on the PHP structure, with 50% and 20% being the best values for the 36-port and 26-port PHPs, respectively. Also, the 36-port design was able to dissipate a higher power input of 80W, versus 60W for the 26-port case, and keep the heat source temperature under 110^oC. In the vertical orientation the PHP delivered better performance compared to the horizontal case. As a working fluid, acetone outperformed ethanol only at low power inputs. The addition of nanoparticles slightly improved the PHP performance.

KEY WORDS*:* Pulsating heat pipe, filling ratio, thermal resistance, nanofluid, nanoparticles

14th International Heat Pipe Conference (14th IHPC), Florianópolis, Brazil, April 22-27, 2007.

EXPERIMENTAL STUDY ON MINI PULSATING HEAT PIPE WITH SQUARE AND REGULAR TRIANGLE CAPILLARIES

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ABSTRACT

How the structure and size of mini angular capillaries affect the PHP performance is focused. The pulsating heat pipes with small scale capillaries of square and regular triangle cross-sections are designed and experimented. The results demonstrate that gravity also influences the performance of mini angular capillary PHP. The bottom heating mode is also better obviously than those of the top heating mode. For the same dynamic diameter, the thermal resistance of the regular triangle capillary PHP is smaller than those of the square capillary. For the same capillary structure, the thermal resistance of 1.5 mm hydraulic diameter PHP is smaller than those of 1.0 mm. The thermal resistance will decrease gradually, and then increase suddenly with further increase in power after a certain value. For capillary structure and size influences, the mechanisms are tentatively explained. The experimental results can be referenced to design the mini angular capillary PHP.

KEY WORDS：Pulsating heat pipe, mini angular capillaries, square and regular triangle, thermal resistance

FABRICATION OF MINI TYPE PULSATING HEAT PIPE

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ABSTRACT

This paper reports on preliminary experimental results of using polydimethylsiloxane (PDMS) to manufacture mini pulsating heat pipes. An Aluminum mold was utilized using a mold turning process to finish the pulsating heat pipe using PDMS materials that includes the vacuum management for filling and packaging. We tried to design a standard process to manufacture the prototype and to complete the test platform structure. The semicircle groove diameter and the depth of the channel are 2mm and the final experimental device size is 56mm×50mm×10mm in this research. When the working fluid is methanol, according to the heating power versus thermal resistance, increasing the heating power, then the PHP is making and moving. When the heating power reaches 8 watts and the PHP makes and moves in an obvious way. So we can get the lowest thermal resistance. But as the heating power increases continuously, because the condenser is unable to offer a satisfactory condensation result, the working fluid in the evaporator will gradually become less and dry-out, the thermal resistance of the condenser and the evaporator will become higher.

KEY WORDS: PDMS, Pulsating Heat Pipes, Turn Over the Mold, Filled Ratio

14th International Heat Pipe Conference (14th IHPC), Florianópolis, Brazil, April 22-27, 2007.

INVESTIGATION ON OHP OPERATIONAL CRITERIA AND CRITERIA TO USE THE OHP AS HEAT SWITCH

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ABSTRACT

The paper describes Oscillating Heat Pipe (OHP) research at NLR, the Netherlands. The OHP research at NLR has been focussed on the development of an OHP for high-g applications and recently on OHP heat switch applications. Due to the nature of the envisaged applications NLR research focused on OHP-operation in extreme environments, resulting in experiments able to verify the OHP critical diameter criterion. Specific high-g experiments are suitable to verify the criterion due to the gravity dependence of the Bond-number. The results show a discrepancy for ethanol and a reasonable agreement with the criterion for acetone. It can be concluded that the applicability of the Bond-number as OHP operational criterion is questionable. For operation other criteria should be used. Main difficulty is to capture the force of the evaporation inducing the oscillating process in the OHP. Two possible dimensionless numbers are proposed. Both numbers are strongly temperature dependent and increase with temperature. For normal OHP operation, strong temperature dependence would be detrimental for reliable performance predictions and reliable operation. However in case an OHP is used as heat switch strong temperature dependence is essential to create two temperature zones, one zone of OHP operation and one non-operation zone. A selection of optional heat switch working fluids is made and a heat switch breadboard is manufactured and successfully tested. It can be concluded that OHP heat switching behaviour is possible.

KEY WORDS: Oscillating Heat Pipe, Dimensionless number, Radiator

14th International Heat Pipe Conference (14th IHPC), Florianópolis, Brazil, April 22-27, 2007.

OSCILLATING TWO-PHASE FLOW IN A CAPILLARY TUBE: EXPERIMENTS AND MODELING

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ABSTRACT

In order to analyse phenomena governing Pulsating Heat Pipes (PHP), an investigation of oscillating two-phase flows in a capillary tube was performed. A review of steady-state models of PHP shows some lacks in the numerical results: the distribution of liquid slugs and vapour plugs is in contradiction with experimental visualisations, and pressure drops resulting from the meniscus deformation are not taken into account. A test bench has been built in order to assess the relative importance of various phenomena. An oscillating two-phase flow of pentane is created and visualized thanks to a high speed camera. Experimental results show a strong dissymmetry of the liquid slugs. An empirical correlation is proposed between the liquid-vapour interface velocity and the meniscus curvature radius on the tube wall. A numerical model has been developed to simulate this kind of flow. The phase change phenomena are neglected and the flow is considered as adiabatic. The model results were compared to the results of other models of the literature and to experimental results. In both cases, a good agreement was found. The importance of the pressure drop resulting from menisci deformations and of the friction pressure losses was quantified thanks to the experimental correlation. This pressure drop cannot be neglected, particularly at low interface velocities. Moreover, for particular excitation frequencies, resonance phenomena were highlighted, as well as their consequences on the flow characteristics.

KEY WORDS: Pulsating Heat Pipe, capillary, two-phase flow, dynamic contact angles

14th International Heat Pipe Conference (14th IHPC), Florianópolis, Brazil, April 22-27, 2007.

A THEORETICAL INVESTIGATION OF THE TRANSIENT BEHAVIOR OF LHP

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ABSTRACT

Despite their apparent design simplicity and operational robustness, there are still many unexplained behaviors in LHP start-up and transient operation. As an example, it has been sometimes observed for various designs [1-2] that, consequently to transient changes such as start-up or variations in power load and/or sink temperature, the LHP sometimes never reaches a true steady-state but instead displays an oscillatory behavior. In order to avoid and control such versatile regimes, the transients of the LHP have to be intensively studied. This paper focuses on the system response time during a power cycling test by means of a numerical thermo hydraulic model previously validated with some literature extensive test data [5]. Two approaches have been used to investigate the transients of the LHP. The model is first used to obtain as far as possible the analytical expressions of the intrinsic system time constants. This leads to the explicit dependence of these times according to the various parameters linked to geometry and heat and mass transfers in the different components of the loop (condenser, evaporator, reservoir, transport lines, ...). In a second hand, the investigation is completed by the analysis of simulation results using tools like eigenvalues analysis which lead to damping times and oscillation periods taking into account couplings between physical phenomena. These are then compared with intrinsic time constants in order to understand which phenomena are involved in a dominant way in the LHP response time. These results notably highlight the role of the energy transport in the condenser and liquid line for different heat loads and should be useful in the LHP design considering transients behavior.

KEY WORDS: Transient behavior, Intrinsic time constant, System response time, Eigenvalue.

14th International Heat Pipe Conference (14th IHPC), Florianópolis, Brazil, April 22-27, 2007.

DEVELOPMENT AND RESULTS OF TESTING MINIATURE LHPs WITH CYLINDRICAL EVAPORATORS

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ABSTRACT

Miniature Loop Heat Pipes (MLHPs) are an attractive object for development and investigation as quite a promising means for cooling powerful electronics operating in the temperature range from 50 to 100 ˚C. The paper generalizes and presents the results of development and tests of 15 different variants of ammonia MLHPs with cylindrical evaporators 5 and 6mm in diameter, which have an active zone length of 20mm and are equipped with titanium and nickel wicks. As a result of successive efforts aimed at increasing the MLHPs efficiency, it was possible to achieve values of the heat transfer coefficient close to 162 0000 W/m^2 ˚C at a value of heat flux of about 100×10^4 W/m^2. A maximum heat flux value of about 135×10^4 W/m^2 was achieved at a value of the heat-transfer coefficient equal approximately to 75 000 W/m^2 ˚C.

KEY WORDS: Loop Heat Pipe (LHP), evaporator, condenser, heat flux, thermal resistance, heat-transfer coefficient.

14th International Heat Pipe Conference (14th IHPC), Florianópolis, Brazil, April 22-27, 2007.

EFFECT OF FLUID THERMOPHYSICAL PROPERTIES ON LOOP HEAT PIPE OPERATION

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ABSTRACT

As numerous Loop Heat Pipes (LHPs) were designed for spacecraft thermal control, most of the LHP experimental studies have been performed using ammonia as the working fluid. With the new interest of using LHP for terrestrial and aeronautic applications, such as electronic cooling, several candidate working fluids may be convenient. Some authors have observed a significant effect of the working fluid on the LHP performance by comparing LHP test results for various fluids. However, these studies do not attempt to specify the role of each fluid property on the LHP performance. In this paper, a LHP steady-state model is developed to study the influence of the working fluid choice on LHP performance. This model is based on the momentum and energy conservation equations and thermodynamic relationships. It has been validated using Boo & Chung (2004) experimental results, for a small-scale stainless steel LHP with a polypropylene wick, filled with methanol, ethanol and acetone. The parametric sensitivity analysis shows the preponderant effect of the latent heat of vaporization and liquid specific heat on the LHP operating temperature T_R, particularly in variable conductance mode. The liquid thermal conductivity has a minor effect on T_R. The thermal resistance from the evaporator wall to the liquid-vapour interface is also an important parameter affecting the LHP behaviour.

KEY WORDS: Loop Heat Pipe, numerical model, working fluid, thermophysical properties

EXPERIMENTAL INVESTIGATIONS AND THEORETICAL MODELING OF A MINIATURE LOOP HEAT PIPE

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ABSTRACT

Miniaturization of loop heat pipes is at the cutting edge of an extensive research and development to provide cooling solutions to the high heat load/flux problems of advanced electronics packaging. We present the test results on a miniature loop heat pipe (mLHP) at various sink temperatures and mLHP orientations. Temperature oscillations and transient start-up behavior of the mLHP have been studied. The thermal resistance of the mLHP is 0.2K/W for a heat load of 72W. The orientation has little effect on the thermal resistance whereas it decreases significantly with an increase in sink temperature. A one-dimensional steady-state analytical model for horizontal mLHP orientation is developed. The predicted results show acceptable agreement with experiments.

KEYWORDS: Electronics Cooling, Miniature Loop Heat Pipe, Start-up Behavior, Performance Prediction

14th International Heat Pipe Conference (14th IHPC), Florianópolis, Brazil, April 22-27, 2007.

GRAVITATIONAL EFFECTS ON LOOP HEAT PIPE PERFORMANCE

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ABSTRACT

A Loop Heat Pipe (LHP) capillary pump contains two wick structures. One is the primary (1st) wick, which is responsible for the fluid circulation in the loop. The other called *secondary* (2nd) wick feeds liquid from the compensation chamber (CC) to the 1st wick in case of a deficit of the returning liquid. Unlike the 1st wick, the 2nd wick does not have much design margin regarding transport capacity. In ground testing, liquid level in the CC is usually higher than the 2nd wick. Hence the gravity head may help feeding the liquid in the CC to the 1st wick. In other words, the 2nd wick transport capability cannot be verified if the pump/CC assembly is tested in a "flat" (horizontal) configuration. This concern prompted the U.S. Naval Research Laboratory to initiate a test program to investigate the LHP performance when the loop was tilted or rotated in a way that the CC liquid level was reduced. This paper will discuss the effects of gravity on the 2nd wick performance.

KEY WORDS: Loop Heat Pipe, Capillary Heat Transport, Thermal Control Systems, Two-Phase Heat Transfer

INVESTIGATION ON EFFECTS OF AUXILIARY MEASURES FOR STARTUP OF LOOP HEAT PIPE

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ABSTRACT

Experiments have been conducted to investigate the feasibility of the two active measures, namely local heating on the evaporator and cooling the compensation chamber with the thermoelectric cooler. A new passive auxiliary measure, which utilizes the latent heat of phase change material to maintain the compensation chamber temperature at the melting point to help estimate the required superheat, has been presented for the first time. The effects of the three auxiliary measures on startups and the steady-state operation have been investigated. Test results indicate that the three auxiliary measures are helpful to establish the required liquid superheat and reduce the evaporator temperature overshoot as well as lessen the startup time. Local heating on the evaporator near the evaporator outlet will not affect the steady-state operation, whereas local heating on the evaporator near the compensation chamber will lead to either sustaining operating temperature rises or higher operating temperatures. The continued operation of the thermoelectric cooler will decrease the operating temperatures at low heat loads and the typical "V" operating temperature curve will be changed to a nearly linear one. At too low heat loads, the phase change material can only delay the evaporator temperature rise and gain time for the LHP to wait for the coming of a higher heat load, which is more favorable for startups.

KEY WORDS: Loop heat pipe, Auxilliary

14th International Heat Pipe Conference (14th IHPC), Florianópolis, Brazil, April 22-27, 2007.

NUMERICAL INVESTIGATION OF THERMAL COUPLING BETWEEN THE TRANSPORT LINES OF AN LHP

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ABSTRACT

Loop Heat Pipes (LHPs) are being increasingly used as the main thermal control systems in several applications. Accurate temperature control is a crucial requirement in many of these applications, in particular for spacecraft thermal control. To achieve this requirement, several temperature control devices (TCD) have been proposed. The present study focuses on vapor-liquid heat exchanger, made by coupling the transport lines of an LHP, as a passive TCD. To study the thermal coupling between the transport lines, a new LHP configuration has been created using the mathematical model developed within EcosimPro. A brief description of the mathematical model is given, paying special attention to the aspects related with the heat exchanged externally by the components. The model results are presented and discussed in detail.

KEY WORDS: Loop Heat Pipe, temperature control, vapor-liquid heat exchanger.

14th International Heat Pipe Conference (14th IHPC), Florianópolis, Brazil, April 22-27, 2007.

NUMERICAL SIMULATION OF A PROPYLENE LHP: STATIONARY AND START-UP CONDITIONS

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ABSTRACT

The start-up and the stationary conditions of an innovative propylene Loop Heat Pipe for the Alpha Magnetic Spectrometer (the so-called 'AMS-02' Project for the International Space Station) are simulated. A global loop model has been designed by using a well-known lumped parameter code (SINDA/FLUINT). Some recent developments of this code are used to model non-equilibrium states between the two-phases in the compensation chamber (CC) and the separated flow in the lines. Parametric analyses are run to test the influence of some important heat transfer processes on the start-up.

KEY WORDS: Loop Heat Pipe, Start-up, Lumped Parameter Simulation

14th International Heat Pipe Conference (14th IHPC), Florianópolis, Brazil, April 22-27, 2007.

PERFORMANCE OF A LOOP THERMOSYPHON USING METHANOL AND WATER AS WORKING FLUID

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ABSTRACT

Experimental investigations were performed on a loop thermosyphon, consisting of a condensation section and an evaporation section. The evaporator chamber used in this study has an inside diameter of 25 mm and a height of 25 mm. Three evaporators, without wick structure and with 1 mm and 4 mm thickness wick structures were examined in the test. The experiments were conducted under the condition of 20 °C, 30 °C, 40 °C and 50 °C cooling water, for heating powers from 20 to 150W, working fluid methanol fill ratios of 5 %, 10 %, 20 %, 30 %, 40 % and 50 %. When the system reached the steady state, the temperature was recorded in order to evaluate the performance of the thermosyphon. Effect of cooling water temperatures, effect of fluid fill ratio and effect of evaporator type were studied.

KEY WORDS: Loop Thermosyphon, Enhanced Boiling, Copper Sinter

14th International Heat Pipe Conference (14th IHPC), Florianópolis, Brazil, April 22-27, 2007.

PORE-NETWORK MODELS AS A TOOL FOR THE ANALYSIS OF HEAT AND MASS TRANSFER WITH PHASE CHANGE IN THE CAPILLARY STRUCTURE OF LOOP HEAT PIPE

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ABSTRACT

The heat and mass transfer with liquid-vapour phase change in a two-dimensional section of the capillary structure of a loop heat pipe (LHP) is studied using a mixed pore-network model. The model combines the computation of temperature and pressure fields in both vapour and liquid regions with local pore invasion rules depending of the capillary pressure thresholds associated with each local constriction between two pores. The metallic body through which heat is transferred to the porous wick is also taken into account in the simulations. Two regimes are identified and studied. For moderate heat loads, the wick is fully saturated by the liquid and vaporisation takes place at the vapour groove/wick boundary. Above a critical heat flux, a vapour zone develops within the wick and vaporisation mainly occurs within the wick. The model is used to study the evaporator local conductance.

KEY WORDS: Loop heat pipes, capillary evaporators, porous wick, pore-network model

14th International Heat Pipe Conference (14th IHPC), Florianópolis, Brazil, April 22-27, 2007.

THERMAL PERFORMANCE OF A MINIATURE LOOP HEAT PIPE WITH MULTIPLE EVAPORATORS AND MULTIPLE CONDENSERS

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ABSTRACT

This paper describes experimental results of comprehensive ground testing of a miniature loop heat pipe (MLHP) with two evaporators and two condensers designed for future small systems applications requiring low mass, low power and compactness. Each evaporator has an outer diameter of 9 mm, and has its own integral compensation chamber (CC). Multiple evaporators provide flexibility for placement of instruments that need to be maintained at the same temperature, and facilitate heat load sharing among instruments, resulting in a reduced auxiliary heater power requirement. A flow regulator is used to regulate heat dissipations among all condensers, and provide flexibility for placement of radiators on the spacecraft. A thermoelectric converter (TEC) is attached to each CC for operating temperature control and enhancement of start-up success. Tests performed included start-up, power cycle, sink temperature cycle, high power and low power operation, heat load sharing, and operating temperature control. The MLHP demonstrated excellent performance in all tests.

KEY WORDS: Loop Heat Pipe, Two-Phase Heat Transfer, Spacecraft Thermal Control

14th International Heat Pipe Conference (14th IHPC), Florianópolis, Brazil, April 22-27, 2007.

VAPOR PRESSURE LIMITS IN CAPILLARY PUMPED LOOPS

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ABSTRACT

The viscous, or vapor pressure, limit has been long established in conventional heat pipe analysis, however, the fact that similar conditions can exist in capillary pumped loops and loop heat pipes has been given little attention in the literature, primarily since these systems are traditionally based on high-pressure fluids such as ammonia. Future needs for thermal technology in consumer electronics provide incentive to use low-pressure, low-toxicity fluids such as water or alcohols. Potential development of liquid-metal CPLs or LHPs would be also greatly impacted by the vapor pressure limit. This work describes the fundamental limitations of low vapor pressure on capillary pumped loops and presents theoretical performance maps for several loops using methanol as a working fluid.

KEY WORDS: CPL, Vapor Pressure, Methanol

14th International Heat Pipe Conference (14th IHPC), Florianópolis, Brazil, April 22-27, 2007.

A NEW COOLING TECHNOLOGY FOR THE COOLING OF HTS MAGNETS

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ABSTRACT

For decades, the cooling method of conventional superconducting magnets has been "pool-boiling" in liquid cryogens. The commercial availability of HTS superconductors with an operating temperature in the 20 K region however calls for a new cooling strategy due to cost and availability of the new coolants involved. In this paper an alternative to the traditional bath-cooling of magnets with liquid helium is presented by employing a network of dedicated cooling tube structures capable of satisfying the different operating conditions of the magnet as well as the conductor stability requirements. The proposed closed-loop cooling tube concept based on the thermosiphon principle without loss of coolants and minimizing the coolant inventory while at the same time requiring no operator intervention has been tested. The design and the test results are discussed.*

KEY WORDS: HTS magnets, cryogenic cooling, thermo-siphon, heat pipes, cooling loops, cryocooler

14th International Heat Pipe Conference (14th IHPC), Florianópolis, Brazil, April 22-27, 2007.

COMBINED THERMOSYPHON AND THERMOELECTRIC MODULES FOR POWER GENERATION FROM SALINITY GRADIENT SOLAR PONDS

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ABSTRACT

Salinity-gradient solar ponds can collect and store solar heat at temperatures up to 80 ^{o}C. They can thus be a renewable source of heat for generation of electricity using thermoelectric modules capable of operating at temperature differences in the range 30 ^{o}C to 50 ^{o}C. The temperature difference between the lower convective zone and the upper convective zone is applied across the hot and cold surfaces of the thermoelectric modules. A system in which heat from the lower zone is transferred to the hot surface of the thermoelectric modules using gravity-assisted heat pipes as thermosyphons has been investigated experimentally. The modules are located so that their cold surfaces are in contact with the upper convective zone of the solar pond. The pipe surfaces are insulated in the region they pass through the gradient layer of the solar pond. Results for power output of the proposed combination of thermosyphon and thermoelectric cells operating over temperature differences existing in solar ponds are reported. The prospects for using solar pond – thermoelectric power generation for remote area power supply system are discussed. A potential advantage of such a system is its ability to continue to provide useful power output at night time or on cloudy days because of the thermal storage capability of the solar pond. The proposed combined thermosyphon and thermoelectric system was installed in a small experimental solar pond at RMIT campus in Bundoora and electric power was generated utilizing the temperature difference between the top and the bottom of the pond. Research results in the present work indicate that there is a significant potential for electric power generation from small solar ponds through a simple and passive device incorporating thermosyphons and thermoelectric cells.

KEY WORDS: thermosyphon, thermoelectric, solar pond, power generation

14th International Heat Pipe Conference (14th IHPC), Florianópolis, Brazil, April 22-27, 2007.

DESIGN OF A HEATER FOR NATURAL GAS STATIONS ASSISTED BY TWO-PHASE LOOP THERMOSYPHON

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ABSTRACT

The thermal model, used in the preliminary design of a gas station heater, is presented. The aim of this research is to develop equipment that should be a new option to heat the natural gas at city-gates stations. The two-phase close loop thermosyphon technology is employed for indirect heating, with water as working fluid and the material selected is carbon steel. At present, water-bath heater is widespread used for gas industry to heat the natural gas. Its large size, the need for water reposition, its low thermal efficiency, are the main operational problems of the traditional equipment. To design better equipment is the main challenge of the present work. Furthermore, the recent success obtained by the use of two-phase thermosyphons in many different types of equipment for industry encourages this research. The heater design procedure is showed. This new concept resulted in small equipment. On the other side, it is not possible to use one simple on-off burner, which is used in the water-bath heater, the conventional equipment. One transient analysis is made to define how many levels the burner must present to work properly.

KEY WORDS: **natural gas heater; gas pipeline station; loop thermosyphon; thermal design.**

14th International Heat Pipe Conference (14th IHPC), Florianópolis, Brazil, April 22-27, 2007.

EVALUATION OF PERFORMANCES OF TWO LOOP HEAT PIPES WITH DIFFERENT EXTERNAL CONDITIONS OVER RADIATORS FOR APPLICATION IN TELECOMMUNICATION SATELLITE

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ABSTRACT

The results of the numerical simulation of transient performance of a thermal control system (TCS) composed of two loop heat pipes (LHPs) are presented. The previously developed mathematical model was validated on the base of experimental results obtained for the small-size LHP laboratory prototypes. Then the LHP model was scaled up to match the heat loads and radiator size to a telecommunication satellite mission. Two separate LHPs are loaded from a unique structural panel carrying heat dissipating equipment; the LHP condensers are placed on two separate radiator panels, experiencing different external fluxes. Various operation scenarios are simulated, including gradual and switch-on-type start-up from cold and hot initial temperatures, change of heat loads, passage of eclipse. A scenario of the evaporator drying up following the ammonia freezing in the condenser under low heat load is simulated. The heat transfer limits of LHPs filled with acetone or propylene are also evaluated.

KEY WORDS: Loop heat pipe, thermal control, telecommunication satellite, mathematical model

14th International Heat Pipe Conference (14th IHPC), Florianópolis, Brazil, April 22-27, 2007.

EXPERIMENTAL INVESTIGATION OF A COMPOUND PARABOLIC CONCENTRATOR COLLECTOR WITH HEAT PIPE

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ABSTRACT

A novel kind of compound parabolic concentrator (CPC) collector with heat pipe, which consisted of a CPC reflector and a tubular receiver, was developed. The reflector of the CPC with a half-acceptance angle of 8°was designed for a tubular receiver of OD 58mm. The concentration ratio was 3.25. The tubular receiver was consisted of an all glass Dewar tube, a 'W' shape aluminum fin and a heat pipe of OD 8mm. Water was used as heat transfer fluid. Experimental testing of the collector was carried out. The performance of the CPC collector with heat pipe was investigated. The collector efficiency can reach to 61%.

KEYWORDS: CPC, heat pipe, solar receiver, collector efficiency

EXPERIMENTAL STUDY OF A NOVEL THERMOELECTRIC/HEAT-PIPE ASSEMBLY FOR PROBE COOLING OF THE SURFACE ANALYSING MACHINE

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ABSTRACT

Development of electronics requires reducing the size of electronic components and increasing their density in a fixed-size package. This will result in increased power density and reduced space within the package, and will cause difficulties in dissipating heat off the system and remaining its thermal stability. In this application, a long heat pipe (525mm) of 8mm diameter, in conjunction with a thermoelectric (TEC) element, was used to resolve the problem. The TEC cooled the probe of the surface analysis machine and thus keep the probe at a low temperature level to ensure its measurement accuracy. Tests showed that the first group of TEC/heat pipe assemblies have dramatic temperature oscillations which was likely caused by non-optimal water fill of the heat pipes. To work out the solutions, we investigated two types of wick structures (mesh and sintered) and obtain the appropriate water fill amounts for each that can ensure stable operation of the surface analysis machine. InfraRed thermography was used to investigate heat transfer from the TECs to heat pipes and condenser fins, which was represented by the temperature distribution profile over the whole area of the assembly. InfraRed picture of workable and failed units are also compared and some conclusions drawn up consequently.

KEY WORDS: Heat pipe, thermal management, electronics cooling, infrared measurements, TEC

14th International Heat Pipe Conference (14th IHPC), Florianópolis, Brazil, April 22-27, 2007.

GEAR BOX OIL COOLING FOR CONVEYOR SYSTEM BY USING HEAT PIPE

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ABSTRACT

The purpose of this research is to design, construct and test a heat pipe heat exchanger for cooling in gear box oil of conveyer system. Data of oil temperature in gear box of The Mae Moh Mine, which has oil temperature in gear box maximum 80 C , ambient temperature limit 40 C were recorded and used as a basic for the mathematical simulation. The condition of the experiments is to control oil temperature in gear box at working temperature about 60 C. In our simulation system, a heat pipe heat exchanger in natural convection mode has been numerically applied in gear box oil cooling for conveyer system with active components. All effects of concerned parameters, e.g. geometrical sizes, working temperature, were included in our simulation program. The optimum condition was achieved by the thermo-economic basis in which the analysis of net saving, i.e. the net profit of the cost of investment, the accumulated operating cost and the gained-back energy price, was included. After the optimum condition was obtained, a prototype of heat pipe heat exchanger has been designed, constructed and tested to verify the experimental results with the simulated ones. The results from comparison were fairly well fitted.

KEY WORDS: gear box , oil cooling , conveyor, heat pipe

14th International Heat Pipe Conference (14th IHPC), Florianópolis, Brazil, April 22-27, 2007.

LOOP HEAT PIPE FOR COOLING OF HIGH POWER IGBT MODULE

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ABSTRACT

This paper presents the development of a loop heat pipe (LHP) technology that has been undergone in Porous Media Laboratory, Minsk, Belarus and Laboratoire d'Etudes Thermiques, Futuroscope, France for its applications in cooling systems of high power semiconductor elements for space and ground applications. The design of LHP with a nominal capacity up to 900 W for steady-state condition and up to 1150 W for periodic mode of operation at maximum temperature level below 100°C and a heat transfer distance of 1.5 m was performed for cooling of high-power electronic module. An experimental program has been developed to execute the performance tests of LHP to check its operationability over time. An investigation of the effect of different parameters on the performance of LHP, such as evaporator and condenser temperature and LHP orientation in gravity field, are treated. As a result of this first test series, it has been found that the orientation of LHP in space in the nominal range of heat loads does not drastically affect LHP functioning, while the temperature of condenser plays an important role, especially in the range of heat load near critical.

KEY WORDS: Loop heat pipe, wick structure, evaporation, heat transfer

14th International Heat Pipe Conference (14th IHPC), Florianópolis, Brazil, April 22-27, 2007.

MULTI-PHASE HEAT SWITCH

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ABSTRACT

A new type of heat switch for application in the satellite thermal control is proposed. It is a heat pipe like device that uses the freezing of the working fluid to provide the switch-off feature. For temperatures above the triple point of the working fluid, the multiphase heat switch (MPHS) operates as a flat heat pipe, based on an evaporation-condensation cycle. For low temperatures the fluid freezes and its circulation is interrupted. When the temperature increases, the fluid melts and circulation is established again. A mathematical model, based on the lumped parameter method, is developed to simulate its operation. An example of application of MPHS is simulated and its performance is discussed.

KEY WORDS: heat switch, satellite thermal control, numerical model

14th International Heat Pipe Conference (14th IHPC), Florianópolis, Brazil, April 22-27, 2007.

NUMERICAL SIMULATION AND EXPERIMENTAL STUDY OF HEAT PIPE BIOMASS GASIFIER

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ABSTRACT

A novel heat pipe biomass gasifier was developed. Based on mass balance, energy balance and chemical equilibrium, an equilibrium model of biomass gasification of the heat pipe biomass gasifier was proposed to simulate the process of biomass steam gasification. Simulation values compared reasonably well with experimental data. The results show that the gasification temperature is the key factor on the components and the heating value of the product gas. Heat pipe is used to provide the reaction heat of biomass steam gasification, to control the bed temperature around the optimum gasification temperature, and to improve the utilization ratio of biomass.

KEY WORDS*:* biomass gasification, heat pipe, gasifier, heating value

14th International Heat Pipe Conference (14th IHPC), Florianópolis, Brazil, April 22-27, 2007.

PERFORMANCE SIMULATION OF AN AIR-TO-AIR HEAT EXCHANGER WITH HIGH-TEMPERATURE HEAT PIPES

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ABSTRACT

Theoretical simulation process is presented for the optimum operation of a heat pipe heat exchanger with liquid metal heat pipes for high-temperature air-to-air heat transfer. The heat exchanger was expected to have 300-kW heat transfer capacity of which the cross-sectional dimension was 1.4 m(H) by 1.13 m(W) with several heat pipe rows in staggered configuration. The heat pipe element was made of stainless steel and sodium of which the diameter and length were 25.4 mm and 1 m, respectively. With hot gas inlet temperature of 800˚C, cold-side air temperatures, ratio of air-to-gas velocities, and the number of rows were considered as variables to determine the performance of the heat exchanger. A constraint was considered on the inlet air temperature to ensure the normal operation of the liquid metal heat pipe. Heat recovery rate and effectiveness of the heat exchanger were calculated for various configuration and operating conditions. The simulation results coincided with experimental data within 5% error when the heat pipes operated normally, but within 19% error when the minimum temperature was lower than that can ensure normal operation of liquid metal heat pipes.

KEY WORDS: high-temperature, heat pipe heat exchanger, liquid metal heat pipe, simulation, ffectiveness, recovery heat rate, inlet temperature ratio, inlet velocity ratio

QUALIFICATION PROCEDURES OF LOOP HEAT PIPES FOR SPACE APPLICATIONS

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ABSTRACT

This paper presents the qualification procedure of loop heat pipes (LHPs) for space applications that has been developed by this institute. The qualification procedure is focused not on the device itself but on the procedures used to fabricate it, which are related to materials evaluation and certification, manufacturing, assembling, cleaning, charging, life tests, etc. Since the procedures used to qualify the LHPs are important to certify such a device for future space applications, all steps must be properly certified and repeated in order to accomplish any goals related to this thermal control device. Afterwards, any LHP can be built as a certified device destined to perform the thermal control in space conditions. Its final acceptance would only depend on the requirements for the specific project that has been designed for. The results obtained so far have certified all procedures since the manufacturing until the verification of a LHP to support launching and the thermal cycling that might face in space. Life tests have indicated a continuous operation for more than 8 years, operating with acetone as the working fluid. However, the main focus of the life tests is to certify LHPs to operate for at least 10 years, which should meet the requirements for future projects of geo-stationary satellites are ongoing in this institute. The same techniques have been applied to build multiple evaporators and miniature LHPs with reliable results. Upon qualifying the technology for LHPs, their application in space missions can be accepted.

KEY WORDS: Loop heat pipe, thermal control, design, qualification.

14th International Heat Pipe Conference (14th IHPC), Florianópolis, Brazil, April 22-27, 2007.

STUDY ON THE PERFORMANCE LIMIT OF ROLL HEAT PIPE (RHP)

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ABSTRACT

The purpose of this work is the study on the performance limit of Roll Heat Pipe (RHP) which can be regarded as a uniform heating device. Experimental work as well as theoretical study is done to investigate the performance limit of RHP due to capillary limit. The maximum heat input applied to RHP can not exceed more than 140 Watt because of condenser cooling limit. Therefore, dryout point of RHP is determined by reducing the amount of liquid fill charge. A theoretical model based on pressure balance relation is proposed to predict the capillary limit of RHP at different rotational speed of RHP and different fill charge. At the condenser section of RHP, heat is dissipated to atmosphere by free convection which is not so efficient. Therefore, condenser cooling limit is considered as another performance limit of RHP and is studied in this work. In RHP, heat is transferred in radial direction and formation of bubbles on the surface of evaporator is possible which causes boiling limit of RHP. In order to be able to apply more heat input to RHP without the temperature exceeding the allowable value, condenser limit of RHP should be increased. In this work, heat transfer coefficient of condenser of RHP is increased by attaching a container full of cold water on the condenser of RHP. The results of this work show that at certain amount of fill charge, increasing the number of liquid return path from condenser to evaporator, improves the performance of RHP.

KEY WORDS: Roll Heat Pipe, Performance limit

14th International Heat Pipe Conference (14th IHPC), Florianópolis, Brazil, April 22-27, 2007.

THERMAL CONTROL TECHNOLOGIES FOR THE NEW AGE OF SPACE EXPLORATION

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ABSTRACT

Under a recent Presidential Directive, the United States National Aeronautics and Space Administration is reemphasizing Exploration as a major theme. This focus will increasingly bring robotic and human-crewed spacecraft out from Low Earth Orbit and to many locations that pose very challenging thermal environments. Both innovative uses of existing thermal control technology and new technology will be needed to meet the emerging requirements. This paper discusses the technical challenges, emerging system designs, and new technologies with emphasis on heat pipes and two-phase thermal loops. Three upcoming missions; the Lunar Reconnaissance Orbiter, the Mars Science Laboratory, and the New Millennium Space Technology 8 spacecraft, are used as examples.

KEY WORDS: Heat pipes, two-phase loops, spacecraft

13th International Heat Pipe Conference (13th IHPC), Shanghai, China, September 21-25, 2004

SCALING ISSUES RELATED TO LOOP HEAT PIPES

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ABSTRACT

Decreasing the size of the loop heat pipe for application in miniature systems is one of the current objectives in the field of heat pipe research, thus highlighting the need for scaling of loop heat pipe components. Scaling issues are related to numerous parameters that affect the phase conditions in the evaporator and compensation chamber of the loop heat pipe. Important geometric factors include the LHP elements length-diameter ratio, wick thickness, effective pore radius and permeability relations. Using the resulting dimensionless groups, scaling issues related to size reduction of loop heat pipe components were evaluated.

KEY WORDS: loop heat pipes, scaling, miniature LHP