CONTENTS

20th IHPC & 14th IHPS

7 – 10 September 2021,

Gelendzhik,

Russia

Joint 20th International Heat Pipe Conference &
14th International Heat Pipe Symposium

WELCOME MESSAGE

Dear guests, dear colleagues and friends,

Joint 20th International Heat Pipe Conference and 14th International Heat Pipe Symposium (Joint 20th IHPC & 14th IHPS) are being held in Russia, in a wonderful place on the Black Sea coast, Gelendzhik!

The International Heat Pipe Conference has a long history as well as great scientific and cultural traditions. In the recent years, the International Heat Pipe Conference has been held jointly with the International Heat Pipe Symposiums. The Joint 20th IHPC & 14th IHPS will cover both theoretical and practical aspects in the fields of heat pipes and thermosiphons, and broader topics of the heat transfer and thermodynamic processes occurring in the different types of thermal control systems. The Joint 20th IHPC & 14th IHPS is a prestigious platform for the professional communication between the specialists and scientists and business representatives of the leading companies in the thermal control field.

Despite such difficult time, when a pandemic is separating countries and people, we have found a way to bring together heat pipe specialists using a hybrid conference format. The team of the Local Organizing Committee made every effort to create optimal conditions for participants both who came to the conference in person and online. All this allows us to save traditions and continue the development of cooperation in the field of heat pipes.

WELCOME TO JOINT 20th IHPC & 14th IHPS!

Chairman of the Local Organizing Committee
MPEI Rector, Professor Nikolay D. Rogalev

History of the International Heat Pipe Conference (IHPC)

	LOCATION	YEAR
1st IHPC	Stuttgart, Germany	1973
2nd IHPC	Bologna, Italy	1976
3rd IHPC	Palo Alto, USA	1978
4th IHPC	London, UK	1981
5th IHPC	Tsukuba, Japan	1984
6th IHPC	Grenoble, France	1987
7th IHPC	Minsk, Belarus	1990
8th IHPC	Beijing, China	1992
9th IHPC	Albuquerque, USA	1995
10th IHPC	Stuttgart, Germany	1997
11th IHPC	Tokyo, Japan	1999
12th IHPC	Moscow, Russia	2002
13th IHPC	Shangai, China	2004
14th IHPC	Florianopolis, Brazil	2007
15th IHPC	Clemson, USA	2010
16th IHPC	Lyon, France	2012
17th IHPC	Kanpur, India	2013

History of the International Heat Pipe Symposium (IHPS)

	LOCATION	YEAR
1st IHPS	Tokyo, Japan	1985
2nd IHPS	Osaka, Japan	1987
3rd IHPS	Tsukuba, Japan	1988
4th IHPS	Tsukuba, Japan	1994
5th IHPS	Melbourne, Australia	1996
6th IHPS	Chiangmai, Thailand	2000
7th IHPS	Jeju, Korea	2003
8th IHPS	Kumamoto, Japan	2006
9th IHPS	Kuala Lumpur, Malaysia	2008
10th IHPS	Taipei, Taiwan	2011
11th IHPS	Beijing, China	2013

Joint 18th IHPC& 12th IHPS	Jeju, Korea	2016
Joint 19th IHPC& 13th IHPS	Pisa, Italy	2018

Joint 20th International Heat Pipe Conference &
14th International Heat Pipe Symposium

INTERNATIONAL COMMITTEE

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Prof. J. Bonjour, Lyon, France.

Past-Chairman

Prof. Yu. Maydanik, Ekaterinburg, Russia.

Honorary Chairman

Prof. M. Groll, Stuttgart, Germany.

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Prof. J. H. Boo, Seoul, Korea;
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Prof. S. Khandekar, Kanpur, India;
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Prof. M. Marengo, Brighton, UK;
Prof. J. M. Ochterbeck, Clemson, USA;
Prof. K. S. Ong, Kuala Lumpur, Malaysia;
Prof. W. Qu, Beijing, China;
Mr. W. Supper, Noordwijk, The Netherlands;
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Prof. H. Nagano, Nagoya, Japan.

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Chairman

Prof. Rogalev N.D., National Research University «MPEI».

Co-chairs

Dr. Savchenkova N.M., NRU «MPEI»;
Dr. Goncharov K.A., Tais Ltd.

Honorary members

Prof. L. L. Vasiliev, Minsk, Belarus;
Prof. V. V. Yagov, Moscow, Russia;
Acad. A. I. Leontiev, Moscow, Russia.

Members

Prof. Maydanik Yu.F., Ural Branch of the Russian Academy of Sciences;
Prof. Kabov O.A., Institute of Thermophysics of the SB RAS;
Mr. Khmelnitsky A.K., ORPE Technologiya named after A. G. Romashin;
Prof. Dragunov V.K., NRU «MPEI»;
Prof. Zamolodchikov V.N., NRU «MPEI»;
Prof. Garyaev A.B., NRU «MPEI»;
Prof. Shelginsky A.Ya., NRU «MPEI»;
Dr. Prudnikova Yu.I., NRU «MPEI»;
Dr. Tarasov A.E., NRU «MPEI»;
Dr. Zhigulina E.V., NRU «MPEI»;
Prof. Kuzma-Kichta Y. A., NRU «MPEI»;
Prof., D.Sc. Kiseev V.M.,Ural Federal University;
Prof. Dvirny V.V., JSC «ISS Reshetnev Company»;
Dr. Panin Yu.V., Lavochkin Association;
Mrs. Novichkova S.A., Lavochkin Association

GENERAL INFORMATION

Conference Venue

METROPOL Grand Hotel Gelendzhik.

Russia, 353461, Gelendzhik, Revolutsionnaya Str., 53.

Lectures / Presentations / Sessions / Exhibition will be held in the Congress Hall of the hotel.

Registration

Conference registration will start from September 6, 15:00 Moscow time. (M. t.)

The opening ceremony will be scheduled on September 7, 08:40 M. t.

All participants are invited to collect the conference kit and certificate at the reception desk or by post.

Registration fee includes:

→ Admission to all sessions
→ Access to the exhibition
→ Welcome reception, lunches, coffee breaks, banquet and conference tour
→ Conference kit: program book, pen, notebook, pin, badge
→ Online broadcast

Name badges

All attendees are expected to wear the name badge at all times throughout the conference. This badge is a conference ticket to all events that should be safely preserved and presented to the staff, on request.

Internet Access

Free Wi-Fi Internet access is available throughout the conference venue with no time limit. Wi-Fi access is available for participants in all the areas of the venue; ask for the access details at the hotel reception. The online broadcast will be in live mode.

Welcome Reception

Welcome reception will be held at the Astoria restaurant located at the address Gelendzhik, Revolutsionnaya str., 54. The event will be held on September 6, starting at 17:00 M. t. All are welcome.

Lunches & Coffee Breaks & Conference Banquet

All lunches will be held in the main restaurant of the hotel - the Riviera Restaurant. Coffee Breaks will be held in the Renaissance Lobby and the Conference banquet will be held in the Versailles Conference Hall, located at the conference venue.

All attendees are cordially invited to the events.

About the Conference Venue

METROPOL Grand Hotel Gelendzhik is a resort and congress hotel featuring world class service on the Black Sea coast.

Located in Cape Tolstyi with a great view over Gelendzhik bay and the Black Sea, this prestige first class Hotel provides the ideal venue for the perfect holiday and business meetings.

Hotel is surrounded by gardens with ancient pine trees and has its own private beach with crystal clear water.

Electric Supply

Electricity in Russia comes out of the wall socket at 220 volts alternating at 50 cycles per second. Participants wishing to use electrical appliances such as laptops, battery

charges, hair dryers and others will need to be aware of the applicable socket and voltage conversion, if required.

Insurance

The conference organizers cannot accept responsibility for any health/medical related issues, accidents and damages thereof that might occur to participants. It is expected that all delegates are properly insured (medical, personal accident, luggage, third-party damages etc.).

Useful Telephone Numbers

In any emergency situation, call **112.** This is a single number for mobile phones of all operators. A call from a mobile phone is free and possible, even if the number is blocked for non-payment and a SIM card is not inserted into the phone.

TOPICS

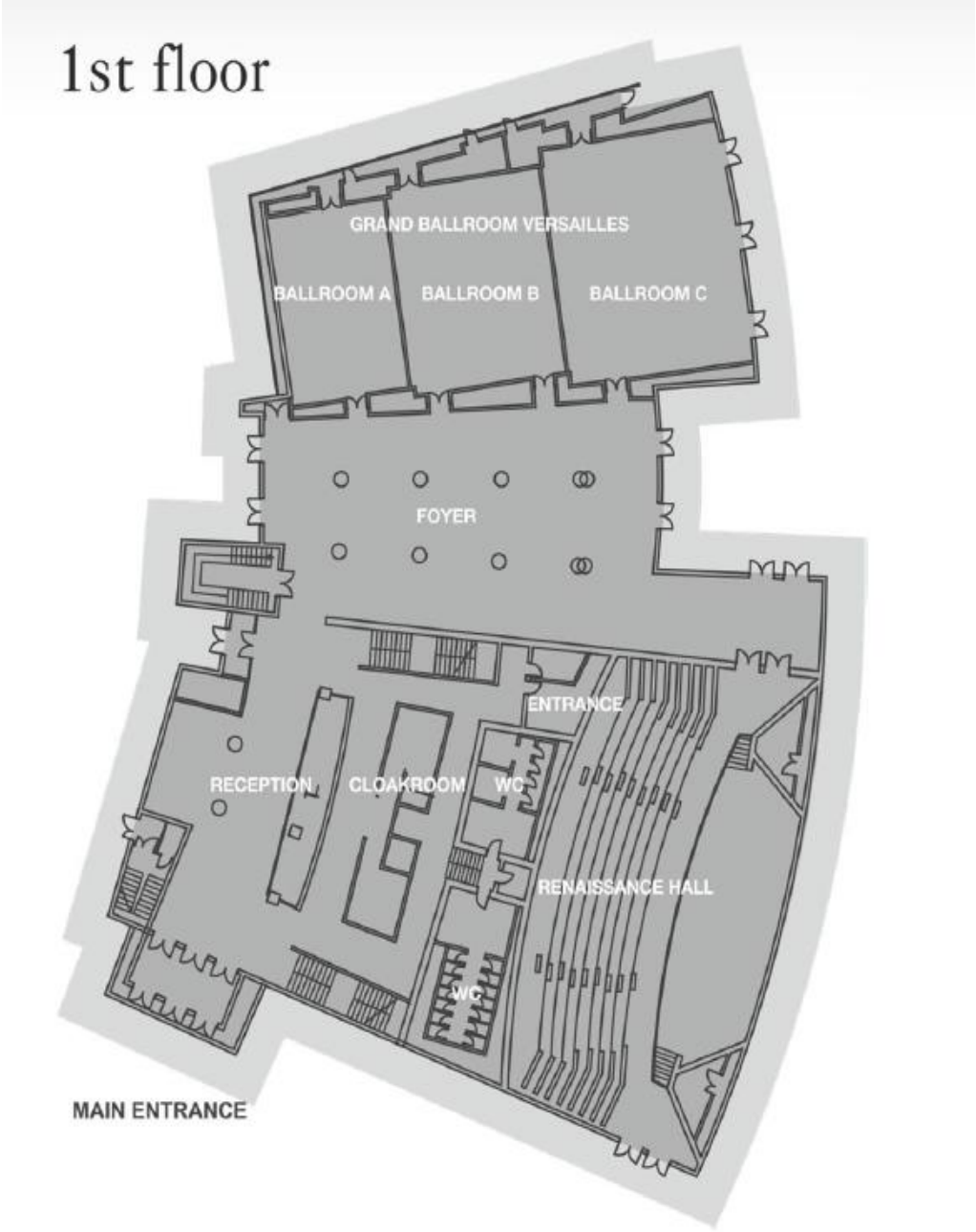
Sec №	Section description
1	Fundamental studies on thermal-fluid phenomena associated with heat pipes and closed two-phase thermosyphons
2	Theoretical and experimental studies on capillary pumped loops (CPL), loop heat pipes (LHP)
3	Theoretical and experimental studies on thermosyphons, oscillating (or pulsating) heat pipes (OHP/PHP), mini/micro-heat pipes, etc.
4	Heat Pipe and Thermosyphon Applications & Special Devices
5	Aerospace applications of heat pipes, including spacecraft thermal control, space power systems, aircraft thermal control, avionics cooling, etc.
6	Manufacturing processes and material processing associated with heat pipes and thermosyphons, including new developments of wicks, working fluids, materials, modeling of corrosion and life tests.
7	State-of-the-art heat pipe development and applications, novel ideas of heat pipe development.

EXHIBITION

Exhibition will be available in the Ballroom A.

Day 1-3, 7th – 9th September from 10:40 till 18:00

VENUE MAP



Renaissance hall	- main conference room	(M)
Ballroom A	- exhibition room	(A)
Ballroom B	- posters room	(B)
Ballroom C	- second conference room	(C)
Foyer	- coffee break	(F)
Main restaurant	- lunch room	(R)

PROGRAM AT A GLANCE

<table>
<tr><th></th><th>Sept 6 (Mon)</th><th>Sept 7 (Tue)</th><th>Sept 8 (Wed)</th><th>Sept 9 (Thu)</th><th>Sept 10 (Fr)</th></tr>
<tr><td>07.30 - 08.20</td><td rowspan="14"></td><td rowspan="3">Registration
F</td><td colspan="3" rowspan="3">Chairpersons and Speakers Meeting
R</td></tr>
<tr><td>08:00 - 08:20</td></tr>
<tr><td>08:20 – 08:40</td></tr>
<tr><td>08:40-09:00</td><td rowspan="3">Opening ceremony
M</td><td rowspan="4">2
M</td><td rowspan="3">1
M</td><td rowspan="4">3
M</td></tr>
<tr><td>09:00-09:20</td></tr>
<tr><td>09:20-09:40</td></tr>
<tr><td>09:40-10:00</td><td rowspan="3">1
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M</td></tr>
<tr><td>10:00-10:20</td></tr>
<tr><td>10:20-10:40</td></tr>
<tr><td>10:40-11:00</td><td colspan="4">Coffee break F</td></tr>
<tr><td>11:00-11:20</td><td>Keynote Lecture 1 – Dr. Kabov Oleg M</td><td>Keynote Lecture 2 – Dr. Singh Randeep M</td><td>Keynote Lecture 3 – Dr. Miao Jianyin M</td><td rowspan="2">Posters
B</td></tr>
<tr><td>11:20-11:40</td><td rowspan="5">2
M</td><td rowspan="5">3
M</td><td rowspan="2">2
M</td></tr>
<tr><td>11:40-12:00</td><td rowspan="4">Closing ceremony
M</td></tr>
<tr><td>12:00-12:20</td><td rowspan="3">6-7
M</td></tr>
<tr><td>12:20-12:40</td></tr>
<tr><td>12:40-13:00</td></tr>
<tr><td>13:00-14.00</td><td colspan="4">Lunch R</td></tr>
<tr><td>14:00-14:20</td><td rowspan="6">2
M</td><td rowspan="11">Conference tour</td><td rowspan="6">4
M</td><td rowspan="11"></td></tr>
<tr><td>14:20-14:40</td></tr>
<tr><td>14:40-15:00</td></tr>
<tr><td>15:00-15:20</td><td rowspan="4">Registration
F</td></tr>
<tr><td>15:20-15:40</td></tr>
<tr><td>15:40-16:00</td></tr>
<tr><td>16:00-16:20</td><td>Coffee break F</td><td>Coffee break F</td></tr>
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M</td><td>4 M</td></tr>
<tr><td>16:40-17:00</td><td rowspan="5">3
M</td></tr>
<tr><td>17:00-17:20</td><td rowspan="9">Welcome
Reception
Astoria</td></tr>
<tr><td>17:20-17:40</td></tr>
<tr><td>17:40-18:00</td></tr>
<tr><td>18:00-18:20</td></tr>
<tr><td>18:20-18:40</td><td rowspan="3">Posters
B</td></tr>
<tr><td>18:40-19:00</td><td>Free time</td></tr>
<tr><td>19:00-19:20</td><td rowspan="3">Conference Banquet
C</td></tr>
<tr><td>19:20-19:40</td><td rowspan="2">Free time</td></tr>
<tr><td>19:40-20:00</td><td>Free time</td></tr>
<tr><td>20:00-21:00</td><td></td></tr>
</table>

CONFERENCE PROGRAM

WELCOME DAY, Monday, September 6, 2021		
15:00 - 17:00	*Registration Open - Foyer*	
17:00 - 21:00	*Welcome Reception – Restaurant Astoria*	
DAY 1, Tuesday, September 7, 2021		
7:30 - 8:40	*Registration - Foyer*	
8:40 - 9:40	*Opening Ceremony-Renaissance Hall*	
DAY 1, Section 1		
09:40 - 10:00	8 - Novel loop thermosyphon with porous coating on the cylindrical (flat) horizontal evaporator	Leonard L. Vasiliev, Zhuravlyov A. S., Kuzmich M. A., Kulikouski V. K., Khartonik A. A., Sadchenko D. I.
10:00 - 10:20	16 - Experimental study and analysis on thermosyphon of initial boiling and geysering by single working fluid and two-fluid mixture	Qu Wei, Zhihu Xue
10:20 - 10:40	222 - A model of stable functioning of the single branch pulsating heat pipe	Vadim S. Nikolayev and Fabrice N. Fourcade
10:40 - 11:00	***Coffee break***	
11:00 - 11:40	***Keynote Lecture 1*** *Evaporation, boiling and dry spots dynamic in thin liquid films under intense heating*	***Dr. Kabov Oleg***
DAY 1, Section 2		
11:40 - 12:00	29 - Research on Ground and Space Flight Tests of a New Type of Ceramic Wick Flat Capillary Pump	Yang T., Gao T., Zhao S.L., Zhang M.J., Liu Z., Yan Y.X., Zhao Y.

12:20 - 12:40	104 - Performance enhancement of a loop-type thermosyphon for cooling of a high heat flux power transistor module	Boo Joon Hong, Bae, J. H. Cho, Y. T., Choi, Y. D., Han, C. W
12:40 - 13:00	106 - Effect of vapor escape passage shape on the thermal performance of a loop heat pipe having a flat evaporator	Boo Joon Hong, Im, K. T., Choi, Y. D., Cho, Y. T.
13:00 - 14.00	***Lunch***	
14:00 - 14:20	20 - Operating characteristics and analytical model of loop heat pipes with R245fa, R1234yf and R1234ze(E) as working fluid for electronics cooling	Suzheng Zheng, Nanxi Li, Chenyang Zhao, Bo Shao, Rongjian Xie
14:20 - 14:40	172 - Numerical investigation on a combined loop heat pipe and graphite sheets cooling system for automotive applications	Marco Marengo, Bernagozzi M., Georgoulas A., Miché N, Rouaud C.
14:40 - 15:00	120 - Study of a loop heat pipe operation using neutron radiography	Maydanik Yury, Pastukhov V.G, Kichanov S.E.
15:00 - 15:20	212 - Effect of different gravity inclination on operating characteristic of a stainless-stell-ammonia loop heat pipe with the long heat transport distance	Ma ZhengYuan, ZhiChun Liu, Lei Li, ZiKang Zhang, Wei Liu
15:20 - 15:40	119 - Loop heat pipes in electronics cooling systems	Maydanik Yury, Ivanov A.V.
15:40 - 16:00	211 - Experimental investigation of a loop heat pipe with long heat transfer distance at different charge ratios	Zhang Zikang, Wei Liu, ZhiChun Liu, RunZe Zhao
16:00 - 16:20	***Coffee break***	
DAY 1, Section 5		
16:20 - 16:40	27 - Application of Truss Heat Pipe in GF-13 Satellite Camera and its on-Orbit Performance	SHEN Chunmei, LUO Shikui, CUI Jin, YANG Ming, YANG Tao

16:40 - 17:00	132 - Development of T-shaped flat heat pipes for cooling electronic equipment	Nesterov Denis, Derevyanko V. A., Suntsov S.B.
17:00 - 17:20	224 - Experimental study of NH3 evaporator embedded into a structural panel made by additive manufacturing	Martin Raynaud, Montredon F., Chouteau E., Chayka D.,
17:20 - 17:40	236 - Theoretical and experimental studies of the dynamic parameters of variable conductance heat pipes intended for use in spacecraft thermal control systems	Panin Yuriy, Goncharov K., Kuznetsov I., Savchenkova N.
17:40 - 18:00	202 - Experience on CBERS 04A Satellite Thermal Control Heat Pipes	Valeri Vlassov, Henghui M., Costa R.L., Santos N., Bertoldo Junior J.
18:00 - 18:20	84 - Preliminary design of a self-deployable Pulsating Heat Pipe by means of a Shape Memory Alloy actuator	Perna R., Mameli M., Bucchi F., Frendo F., Filippeschi S.
DAY 1, Posters, Ballroom B		
18:20 - 19:40	*Posters*	
DAY 2, Wednesday, September 8, 2021		
DAY 2, Section 2		
08:40 - 09:00	200 - A simple vapour chamber model based on spreading relations	Velardo J., Koirala R., Akbarzadeh A., Singh R., Date A.
09:00 - 09:20	234 - Operating characteristics of a water-pressure controlled loop heat pipe	Joung Wukchul,Park C.
09:20 - 09:40	121 - Investigation of a loop heat pipe at a high heat load concentration	Chernysheva Maria, Vershinin S. V., Maydanik Y.F.

09:40 - 10:00	137 - Features of the Loop heat pipes start up at various gravity positions and heat input	Panin Yuriy, Korzhov K. N., Balyukin M.A., Holyakov A.E., Bondarenko V. A., Kupershtein V.
10:00 - 10:20	28 - Experimental study of a loop heat pipe with vapor-driven jet injector	Liu Lei, Xiaoping Yang, Bo Yuan, Jie Liu, Jinjia Wei
10:20 - 10:40	80 - Effect of Wick Oxidation on the Thermal Performance of a Copper-Acetone Loop Heat Pipe	Khandekar Sameer, Prem Kumar, Mayur Gachake
10:40 - 11:00	***Coffee break***	
11:00 - 11:40	***Keynote Lecture 2*** *Electric Vehicle Cooling with Heat Pipes: Challenges and Scope* *Dr. Singh Randeep*	Randeep SINGH
DAY 2, Section 3		
11:40 - 12:00	51 - Experimental study on heat transfer performance of potassium heat pipe	Zhixing Tian, Chenglong Wang, Wenxi Tian, Suizheng Qiu and G H Su
12:00 - 12:20	23 - Effects of operating temperature on the heat transfer performance of a liquid metal high-temperature oscillating heat pipe	Mengke Wu, Yanmin Feng, Xin Yang, Qinan Liu, Yadong Li, Zhe Wang, Yantao Li, Daan Cui, Hongbin Ma, Yulong Ji
12:20 - 12:40	65 - Effect of non-condensable gas on the flat plate pulsating heat pipe under various gravity conditions	Slobodeniuk Maksym, Bertossi R., Ayel V., Romestant C., Bertin Y
12:40 - 13:00	82 - Effect of magnetic manipulation of Taylor flow of ferrofluids on two-phase heat transfer	Khandekar Sameer, Ram Krishna Shah
13:00 - 14.00	***Lunch***	
14:00 - 19:00	***Conference tour***	

DAY 3, Thursday, September 9, 2021		
DAY 3, Section 1		
08:40 - 09:00	96 - Visualization of fluid flow in a heat pipe with a centered wick structure	Koito Y., Yamamoto K., Chen C., Kakizoe R.
09:00 - 09:20	127 - Investigation of nanofluid boiling in thermosyphons	Kiseev V.M., Sazhin O.V.
09:20 - 09:40	186 - Thermosyphon-heat exchanger for cooling high-power electronic elements	Rabetsky M.I., Grakovich L.P., Vasiliev L.L.
DAY 3, Section 2		
09:40 - 10:00	227 - Local heat transfer in a micro heat pipe	Iwata N., Bozzoli F., Pagliarini L., Cattani L., Vocale P., Malavasi M., Ranieri S.
10:00 - 10:20	176 - Modeling of vapor generation in a loop heat pipe evaporator	Buz Vasily, Goncharov Konstantin
10:20 - 10:40	153 - Analysis of Loop Heat Pipes control methods	Goncharov K.A.
10:40 - 11:00	***Coffee break***	
11:00 - 11:40	***Keynote Lecture 3*** *Development and Space Application of Loop Heat Pipes in China*	Jianyin Miao
DAY 3, Section 2		
11:40 - 12:00	152 - Investigation of the impact of mechanical loads on LHP	Savrushkin V.A., Goncharov K. A., Antonov V.A.
12:00 - 12:20	204 - Experimental study of a miniature loop heat pipe for electronics application	Domiciano Kelvin Guessi, Krambeck L., Mera J. P. F., Mantelli M. B. H.

DAY 3, Section 6-7		
12:20 - 12:40	63 - Experimental investigation of the performance of an adsorption based anti-freeze system for loop heat pipes	Vyas SRINIVASAN, Frédéric LEFÈVRE, Sameer KHANDEKAR and Jocelyn BONJOUR
12:40 - 13:00	165 - Thermal performance of a flexible polypropylene pulsating heat pipe at different bending angles	Bertola Volfango, Alqahtani, A. A., Edwardson, S., Marengo, M.
13:00 - 14.00	***Lunch***	
DAY 3, Section 4		
14:00 - 14:20	231 - Field and numerical study of groundwater flow effect for enhancement of heat transfer in ground source heat pipes	Chishimba Johnson, , Nagano K., Sakata Y., Mochizuki M.
14:20 - 14:40	225 - Thermal Management of High-power LED using a Copper Wick Loop Heat Pipe	Sahu Gopinath, Prem Kumar, Mayur Gachake, Sameer Khandekar
14:40 - 15:00	244 - The Specifics of Design and Prediction of Thermohydraulic Characteristics of Thermosiphons for Energy	Egorov Mikhail, Balunov B. F., Lychakov V. D., Shcheglov A. A., Matyash A. S., Borisov A. O., Il'in V. A.
15:00 - 15:20	4 - Packaging and testing of a multi – Loop Heat Pipes solution, working with a non-flammable and dielectric fluid, to cool double sided SiC MOSFET power modules for aircraft systems	Dupont Vincent, Nicolle T., Kapaun F., Lasserre P., Piaud B., Ludovic Y.
15:20 - 15:40	13 - Experimental analysis of 3D hybrid heat pipes for electronics cooling	J V C Batista, J C P Almeida, J P F Mera and M B H Mantelli

15:40 - 16:00	162 - Study of Gas to Liquid Heat Pipe Heat Exchanger	Pratik Prakash Gupta and Shung-Wen Kang
16:00 - 16:20	***Coffee break***	
16:20 - 16:40	57 - Experiment study on cooling performance of heat pipe cold plate and heat pipe module for electronic equipment	Jinwang Li, Bowen Xu, Changji Wang
DAY 3, Section 3		
16:40 - 17:00	7 - Development of flexible flat heat pipe	Delendik Kirill, Kim J., Kim J. W., Voitik O. L., Kolyago N. V., Penyazkov O. G.
17:00 - 17:20	87 - Heat Transfer Delay Method for the average fluid velocity evaluation in a multi-turn pulsating heat pipe	Bozzoli Fabio, Pagliarini L., Cattani L., Mameli M., Filippeschi S
17:20 - 17:40	151 - Heat pipes with axial grooves at high heat flux density in the evaporator. Modeling and analysis	Savchenkova Natalia, Buz V.N., Kuznetsov I.O., Goncharov K.A.
17:40 - 18:00	169 - Sodium heat pipes for a novel high-temperature thermal energy storage system	Pawel Nycz, Claudio G, Eames P. R.
18:00 - 18:20	158 - Heat transfer in shear driven locally heated liquid film with microstructures	Cheverda V V, Kabov O.A.
18:20 - 18:40	246 - Bulging of cylindrical heat pipes, caused by water freezing	D Torresin, O Sologubenko, A Petrov and B Agostini
18:40 - 19:00	85 - Experimental validation of a Pulsating Heat Pipe transient model during the start-up in microgravity environment	Mauro Abela, Mauro Mameli, Vadim Nikolayev, Sauro Filippeschi
18:40 - 19:00	***Free time***	
19:20 - 21:00	***Conference Banquet***	

DAY 4, Friday, September 10, 2021		
DAY 4, Section 3		
08:40 - 09:00	94 - Measurement of two-dimensional Temperature Distribution and point Pressure inside Pulsating Heat Pipe Using Temperature-sensitive Paint	Ishii Keiko, Omata R., Otaka Y., Fumoto K.
09:00 - 09:20	223 - Temperature homogenization of a 3D metallic structure with a printed integrated PHP	Levêque Marie, Lips S., Agazzi A., Sartre V., Lefèvre F.
09:20 - 09:40	69 - Flat-plate Pulsating Heat Pipe tested with surfactant: experimental investigation and use of transient reactivation phases for the fluid-wall heat transfers analysis	Ayel V., Slobodeniuk M., Sabathé M., Graziani C., Bertossi R., Romestant C., Bertin Y.
09:40 - 10:00	70 - Liquid film dynamics during meniscus oscillation	Zhang Xiaolong, Vadim S. Nikolayev
10:00 - 10:20	5 - Development of ultra-thin vapor chamber	Kolyago Natalia Vladimirovna, Delendik K. I., Voitik O. L., Penyazkov O. G.
10:20 - 10:40	177 - Cryogenic Flat Plate Oscillating Heat Pipe	Wilson Corey, Boswell, J.
10:40 - 11:00	***Coffee break***	
Ballroom B, Posters		
11:00 - 12:00	*Posters*	
Closing ceremony		
12:00 - 13:00	*Closing ceremony*	
13:00 - 14.00	*Lunch*	

KEYNOTES

DAY #1: Tuesday, September 7, 2021

Renaissance hall: – Keynote Lecture #1

Dr. Kabov Oleg

Kutateladze Institute of Thermophysics SB RAS, 630090 Novosibirsk, Russia
E-mail: kabov@itp.nsc.ru

Evaporation, boiling and dry spots dynamic in thin liquid films under intense heating

Kabov O.A.[1], Kochkin D.Y.[1, 3], Tkachenko E.M.[1], Belosludtsev V.V.[1,2], Zaitsev D.V.[1], Shebelev A.V.[1,4], Minakov A.V.[1,4]

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Abstract. Various passive and semi-passive devises provide a very efficient indirect cooling of microelectronics like chips, LEDs, lasers, radars, converters, inverters and others. An extremely high efficiency of upper mentioned devises is closely connected with thin film evaporation. It was found that the process of film rupture involves film thinning down to a stable residual film that can exist several seconds depending on the type of the fluid. This residual film thickness was measured for water and is equal 7-10 μm. Existence of such thin film provides an additional heat transfer enhancement. The maximum intensity of heat removal from the heater is achieved in the mode, when the film flow continuity was broken due to microscale bubbles arise in the film. The dynamics of formation of typical dry spots 100 microns in size and with the lifetime of about 1 ms have been studied. Experiments have resulted in the values of heat transfer coefficient up to 250 kW/m^{2}K.

Keywords: Film deformation and rupture; Heat transfer coefficient; Three phase contact line

DAY #2: Wednesday, September 8, 2021

Renaissance hall: – Keynote Lecture #2

Dr. Randeep Singh

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Electric Vehicle Cooling with Heat Pipes: Challenges and Scope

Abstract: Electrification of vehicles intensifies their cooling demands due to increase in electronics/electrical systems, and requirements to maintain temperatures, for these systems, below their maximum threshold. In this paper, passive cooling approaches, based on heat pipes, have been considered for thermal management of different systems in electric vehicles. Heat pipes have potential to provide range of benefits in automotive; to name few, full passive cooling for headlamps and displays, handling hot spots in high flux (> 25 W/cm^2) chipsets in autonomous driving and high-performance computing, providing better thermal uniformity (< 5 °C) and leak safe cooling system for high voltage battery packs. Nonetheless, there are structural, integration and economical challenges which need to be addressed to improve applicability of two-phase systems in automotive domain. This presentation will provide technical insight and scope for two phase system in vehicle cooling. Based on experience in different application domains, it can be concluded that heat pipes have potential to improve overall reliability, performance and safety of cooling systems in electric vehicles.

Keywords: electric vehicle two-phase cooling, headlamp, autonomous-driving, Li-ion battery

DAY #3: Thursday, September 9, 2021

Renaissance hall: – Keynote Lecture #3

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Development and Space Application of Loop Heat Pipes in China

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Abstract. This paper presents the development and space application of Loop heat pipes (LHPs) in China. LHP technology has been developed for spacecraft thermal control in China since 1990s. After a SS-Ammonia LHP manufactured by China Academy of Space Technology started up and operated successfully on orbit for the first time in 2002, LHPs have been widely used and tested in dozens of Chinese satellites. The LHPs has solved lots of thermal control problems for spacecraft. The typical applications are introduced in this paper. They can work as a thermal-switch heat transfer system, an effective cryogenic heat transfer system and a reliable passive thermal control network without vibration for space telescope. They also can extend the heat dissipation ability of the cube satellite without additional radiator.

Oral sections

DAY 1, Section 1 Tuesday, September 7, 2021

[No. 8] Novel loop thermosyphon with porous coating on the cylindrical (flat) horizontal evaporator

L L Vasiliev[1], A S Zhuravlyov, M A Kuzmich, V K Kulikouski, A A Khartonik and D I Sadchenko

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Abstract. A reliable high-performance loop thermosyphon device was designed. Three samples of LTPE were tested using different evaporators, condensers and working fluids (R245fa and water). The scope of this study is an evaluation of the evaporation and condensation heat transfer inside of a novel loop thermosyphon with horizontal porous evaporator and horizontal condenser (LTPE). There is a thin capillary structure on the inner casing wall of the evaporator. It serves for efficient liquid distribution overall the porous surface and for intensive heat exchange due to liquid evaporation. Two different designs of condenser were developed: liquid-cooled condenser and condenser for air cooling. Working fluids are R245fa and water. Two evaporators (cylindrical and flat) were tested using small and high heat loads. The thermal resistance of the evaporator, condenser, total thermal resistance of thermosyphon, critical heat flux (CHF) maximum and the temperature drop along the thermosyphon were determined. An LTPE guarantees a short start-up time, decreases the evaporator wall temperature, has a small temperature hysteresis during the increase/decrease of the heat load and suppresses the temperature pulsations inside the evaporator. Loop thermosyphons with porous coating of annular evaporator are suggested as convenient device for cooling electronic devices.

[No. 16] Experimental study and analysis on thermosyphon of initial boiling and geysering by single working fluid and two-fluid mixture

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Abstract. Thermosyphon is a kind of common and important heat pipe. The experimental thermosyphon is made of glass, for distilled water, ethanol and their mixture of volume ratio 50%-50% respectively. The performance of the initial boiling and geysering are visualized, heat fluxes versus wall temperature are gotten, they are the boundary to better operation. The physical and mathematical models were studied and derived for the boiling. The analytic solutions of overheated wall temperature, the density of vapour and liquid mixture in the evaporator, the mixture pressure are also obtained. The results show that the wall microrelief of the inner tube, the working fluid are the major factors to affect the initial boiling, geysering and boiling. The calculation and the experimental results are compared, they have greater agreements. The analytical equations could predict the thermosyphon performance.

[No. 222] **A model of stable functioning of the single branch pulsating heat pipe**

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Abstract. A simplified model nonlinear describing the stable functioning of the single branch PHP is proposed. It is based on the earlier proposed film evaporation-condensation approach and assumes harmonic oscillations of the meniscus displacement and vapor pressure. The model predicts the frequency as a function of the oscillation amplitude and the relationship between the amplitudes of meniscus displacement and pressure. Results of the model are compared to available in the literature experimental data of different groups; they show a good agreement. The added mass caused by the oscillating ow in the liquid plug is discussed.

DAY 1, Section 2 Tuesday, September 7, 2021

[No. 29] **Research on Ground and Space Flight Tests of a New Type of Ceramic Wick Flat Capillary Pump**

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Abstract. A new type of flat capillary pump is designed, which is significantly different from traditional flat capillary pumps in material selection and internal structure configuration. In terms of material selection, the main capillary wick is sintered with low thermal conductivity silicon nitride material, and its thermal conductivity is only 2.7W/m.K, which significantly reduces the heat leakage from the evaporator to the compensation chamber. At the same time, its pore size and porosity reach 0.5μm and 70%, which can provide greater capillary force. The secondary capillary wick is made of stainless-steel material sintered with a pore size of 50um and a porosity of 60%. It has good permeability and can effectively collect liquid and transport it to the main capillary wick, which significantly improves the microgravity and anti-gravity environment adaptability of the flat plate loop heat pipe (FLHP). In terms of structural configuration, the outer contour size of the flat capillary pump is 82.0mm×53.0mm×16.0mm. The silicon nitride main capillary wick is designed into a cylindrical body, a total of 8 pieces, which are in interference fit with the inner wall of the evaporator shell. It solves the mutual sealing problem between the steam channels and the compensation chamber. The secondary capillary wick is located between the main capillary wick and the compensation chamber, and is closely attached to the main capillary wick through a screw connection. The experiments test the start-up characteristics and heat transfer performance of the flat capillary pump in the horizontal (compensation chamber is located directly above the evaporator), vertical, and inverted direction (the compensation chamber is located directly below the evaporator). In the three postures, FLHP can start quickly under the load of 5W and 20W, and the heat transfer limit and heat flux limit can exceed 400.0W and 26.3W/cm^2. In a horizontal position, the equilibrium temperature of the the FLHP is relatively lowest, and the minimum thermal resistance is 0.02℃/W. In addition, the flat capillary pump was launched with a geostationary satellite in March 2021, and passed the 50W load start-up and stable operation test in orbit.

[No. 104] **Performance enhancement of a loop-type thermosyphon for cooling of a high heat flux power transistor module**

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Abstract. A series of experiments was conducted to enhance the thermal performance of a loop-type thermosyphon for cooling of a power transistor module under the average evaporator heat flux up to 17.6 W/cm^2. The flat evaporator was made of copper and configured vertically with a heating area of 190 mm (W) × 114 mm (H). The working fluid was water and the inner diameters of the vapor and liquid lines were 16.0 mm and 12.4 mm, respectively, which were made of copper and polyethylene tubes, respectively. The condenser was a fin-tube heat exchanger cooled by forced air convection. The condenser was horizontally separated by 1.3 m from the evaporator and positioned 0.6 m higher. The inner surface of the evaporator was covered by screen mesh to uniformly distribute the liquid capillary effect and thus to enhance heat transfer. The thermal performance varied greatly with the working fluid fill charge. For a fill charge ratio of 60%, the loop thermosyphon, with cooling air at room temperature and 90-W fan power, transported a maximum heat load of 3.8 kW maintaining the evaporator temperature below 100°C with a system thermal resistance of 0.022 K/W.

[No. 106] **Effect of vapor escape passage shape on the thermal performance of a loop heat pipe having a flat evaporator**

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Abstract. The effect of vapor escape passage shape in the flat evaporator of a loop heat pipe (LHP) on the thermal performance was experimentally investigated. Rectangular grooves were machined in a sintered nickel powder wick to provide vapor escape passage. Six different groove geometries were alternately used in an LHP to compare the resultant performance. The groove width varied among 1.0, 1.5 and 2.1 mm, and its height varied between 1.0 and 2.0 mm, while maintaining the same contact area between the wick and the evaporator. The LHP was made of stainless steel and the working fluid was methanol. Outer diameters of the vapor and liquid lines were 6.35 mm and 3.18 mm, respectively, and the distance between the evaporator and the condenser was 0.3 m. At horizontal configuration, the LHP achieved stable start-up at 24 W and demonstrated performance up to 349 W (evaporator heat flux 22 W/cm^2). Performance tests were conducted for adverse tilts up to 90°, with the evaporator wall temperature below 130°C. The results showed that the groove with smaller width and the higher height had favourable effect on the thermal performance of the LHP, as it resulted in the lower evaporator wall temperature and thermal resistance.

[No. 20] **Operating characteristics of loop heat pipes with R245fa, R1234yf and R1234ze(E) as working fluid for electronics cooling**

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Abstract. In order to propose a more efficient and environmentally-friendly solution for electronic cooling, an experimental investigation on a loop heat pipe (LHP) with a flat-disk evaporator, 39 mm in diameter and 2 mm in thickness, which contains a zirconia ceramic wick with benefits of small density, high strength, corrosion resistance, high capillary force and low thermal conductivity was carried out. R245fa, R1234ze (E), and R1234yf were used as working fluid, heat transfer and hydrodynamic characteristics were analysed in the LHP respectively. Tests were conducted at horizontal configuration under water-cooling at temperature of 20℃, and the temperature of heat source no more than 80℃ is taken as the upper limit during the experiment. Among the three working fluids, the LHP with R245fa showed the best performance in the temperature range of 20℃~80℃, which can start stably at 5W, with the maximum heat transfer capacity of 60W and heat flux of 15W/cm^2, and the total pressure drops were largest when R245fa was applied in the LHP, which is attribute to the relatively low density of vapor and high viscosity of liquid. The pressure drops in the wick contributed approximately 90% of total pressure drops for all of the testing refrigerants. And the experimental results are in good agreement with the FOM (figure of merit) theory.

[No. 172] **Numerical investigation on a combined loop heat pipe and graphite sheets cooling system for automotive applications**

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Abstract. An innovative Battery Thermal Management System for a 3-cell Electric Vehicle module is proposed, involving Loop Heat Pipes and graphite sheets, with the particular aim of fast charging and reacting to automotive requirements. The design feasibility is verified through a Lumped Parameter Model, which has been validated comparing the data from an experimental demonstrator which included a copper/copper flat plate Loop Heat Pipe running ethanol. Results show that this solution is able to maintain the maximum temperature below 32°C after a 10 min fast charge cycle. System performance with a standard working fluid such as ethanol are compared with the system performance using a novel fluid, Novec™ 649, which has desirable features for the automotive industry, such as non-flammability, non-flammability, below-zero freezing point and outstanding environmental properties (GWP = 1, ODP = 0). Nevertheless, comparison between the results with the two fluids reported no significant difference in thermal performance showing no contraindication in the use of the novel working fluid. Moreover, the model was used to estimate the effect of the Loop Heat Pipe building material, resulting in no sensible difference between the utilization of copper and aluminum, de facto justifying the choice of this material for future applications.

[No. 120] **Study of a loop heat pipe operation using neutron radiography**

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Abstract. Neutron radiography was used to visually investigate the operation of two compact loop heat pipes (LHPs) of a similar configuration, made of stainless steel and equipped with a titanium wick. One of them was filled with ammonia, and the second with methanol. The experimental setup made it possible to obtain a visual picture of the distribution and movement of a working fluid simultaneously in all the structural components of the LHPs. Unique data was obtained on the operation of the devices at three different orientations in the range of heat loads from 10 to 110 W, which allow to understand in more detail the peculiarities of their operation. Visual observations were supplemented by the results of thermal tests, which were presented in the form of heat load dependences of the temperature at the heating (thermal contact) surface of a heat source.

Keywords: Two-phase heat transfer device, Loop heat pipe, Visualization, Neutron radiography.

[No. 212] **Effect of different gravity inclination on operating characteristic of a stainless-steel-ammonia loop heat pipe with the long heat transport distance**

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Abstract. Loop heat pipe (LHP) is a passive heat transfer device applied on aerospace and electronic device cooling. A stainless-steel-ammonia loop heat pipe with a flat disk evaporator and the long heat transport distance was designed and produced in this paper, the heat transport distance was 1.6m and the biporous wick was made from sintered nickle powders. Three different gravity inclinations, 0° (LHP I), +5° (LHP II), -5° (LHP III), were employed to investigate the effect of different gravity inclination on operating characteristic of LHP with the allowable evaporator temperature below 65°C and the heat sink temperature of 0°C. For the LHPs' start-up characteristic with heat load of 10 W, the LHP I and LHP II can start-up smoothly, but the LHP III temperature of the heat source appears a "spike" phenomenon and stabilizes to 8°C. The heat load ranging of LHP I is 10~110 W (heat flux of 0.6-6.63 W/cm^2). comparing with LHP I, the critical heat load of LHP II is 150 W (heat flux of 913.25 W/cm^2) and the critical heat load of LHP III is 220 W (heat flux of 13.25 W/cm^2). The minimum LHP thermal resistances for LHP I, II, III are 0.446 °C/W, 0.228 °C/W and 0.163 °C/W, respectively.

[No. 119] **Loop heat pipes in electronics cooling systems**

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Abstract. Loop Heat Pipes (LHPs) are passive two-phase heat transfer devices that can be effectively used in electronics cooling systems, including computer and LED technology. The main properties that determine the effectiveness of these devices, especially with remote heat sinks, include high heat transfer capacity and low thermal resistance at any position, excellent configurability and adaptability to various conditions of placement and operation. This paper contains a discussion of the factors determining the limitations, possibilities and conditions for the use of LHPs in various cooling system of electronics. Examples of experimental and real application of these devices in such systems are presented.

Keywords: Two-phase heat transfer devices; Loop heat pipes; Electronics cooling; Computers; LEDs.

[No. 211] **Experimental investigation of a loop heat pipe with long heat transfer distance at different charge ratios**

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Abstract. In this study, a loop heat pipe with a flat disk evaporator and a biporous wick was constructed and investigated. The heat transfer distance was 3.07 m and the heat surface temperature was constrained below 70±2 °C. Ammonia was used as the working media. The effect of different charge ratios and heat sink temperatures on operating performance was studied. Tests illustrated that the loop could operate effectively at the tilt angle of 4.6 ° without any temperature oscillation or unfavorable overshoot. The maximum heat load reached 330 W (heat flux of 19.9 W/cm^2). During the start-up process, a slight dryout situation in wick and the vapor formation in compensation chamber were occurred, leading to a secondary increase in evaporator temperature before stabilization. Meanwhile, the vapor-liquid distribution inside the compensation chamber affected the temperature trend greatly during the continuous heat load tests. The minimum LHP thermal resistance was 0.161 °C/W. Higher heat sink temperature and lower charge ratio led to a reduction in LHP thermal resistance, thus promoting the loop operating performance.

[No. 27] Application of Truss Heat Pipe in GF-13 Satellite Camera and its on-Orbit Performance

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Abstract: GF-13 satellite camera is a large aperture and high-resolution optical camera. High-resolution and high-quality imaging requires high precision temperature control for the primary and secondary mirrors, which are located at the light inlet of the camera. To realize the high precision temperature control of the two mirrors, the front lens barrel temperature, which is the temperature environment of the two mirrors, has to be uniform and stable. But the thermal control resources of the GF-13 camera are limited, because of its large size and so many internal heat sources with large power consumption and long working time. Thus, it is necessary to realize the lightweight and energy-saving temperature equalization of the three-dimensional large-scale front lens barrel, which is a challenge because of the large aperture. To solve the problem effectively, a truss heat pipe cylindrical frame composed of four sets of semicircular truss heat pipes, which are composed of multiple heat pipe shells with inner capillary wicks connected to each other by special joints with additional inner capillary wicks, is used as the support truss of the camera front lens barrel. And heat consumed by the two focal plane cryocoolers transmits to the front lens barrel efficiently and evenly through the coupling heat transfer between the truss heat pipe and the loop heat pipe. On orbit data show that, whether under the cryocoolers off mode or operation mode, the maximum difference between all of the temperature measuring points on the truss heat pie frame is within 10.7℃, always providing the necessary uniform and stable temperature environment. Furthermore, this design can not only eliminate the traditional radiator of the two focal plane cryocoolers and the additional active temperature control heating circuits which are needed for the traditional radiator, but can also reduce the active temperature control power consumption of the front lens barrel under camera imaging mode case.

Keywords: Truss heat pipe; Thermal design; Thermal Management; Large aperture and high-resolution space optical camera; Space remote sensor

[No. 132] **Development of T-shaped flat heat pipes for cooling electronic equipment**

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Abstract. The results of the development of T-shaped flat heat pipes made of copper and titanium are presented. The novel T-shaped design provides efficient heat transfer between perpendicular surfaces. The copper flat heat pipes filled with water provide efficient heat transfer of more than 75 W at the temperature of 67 °C and are currently used in standard equipment to remove heat from electronic components. The titanium T-shaped flat heat pipes have a similar design. Acetonitrile was tested and applied for the titanium heat pipes as a working fluid. Acetonitrile provides the heat pipe operation at sub-zero temperatures and has significantly lower pressure of saturated vapor compared to other conventional working fluids (acetone, methanol). The titanium heat pipes with acetonitrile provide heat transfer for heat loads of 2-3 times lower than copper heat pipes with water, but the weight of the titanium heat pipes is much less, which is important for space applications.

[No. 224] **Experimental study of NH3 evaporator embedded into a structural panel made by additive manufacturing**

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Abstract. For space application, there is an ongoing search of mass decrease. The thermal control of a satellite with a two phases mechanically pumped loop presently uses evaporators and condensers that are mounted onto honeycomb panels. The heat exchangers only have a thermal function while the panel has only a structural function. The Additive Manufacturing (AM) process offer freedom in the design of 3D objects that is very well suited for space applications due to the combination of low series (number of parts between 1 and 100) and weight saving objectives. This work focuses on the experimental study of an ammonia evaporator embedded into a structural aluminum panel. The panel was built in a single print by additive manufacturing. The size is 530 mm x 230 mm x 30 mm for a total mass of 1.25 kg. Two straight evaporators are integrated in the panel. The thermal performance for various heat dissipations, various saturation temperatures, various inlet sub cooling and mass flow rates are presented. These results are compared to the one obtained by numerical simulation in order to adjust the thermal model and validate the correlation used to determine the convective boiling heat transfer coefficient.

[No. 236] **Theoretical and experimental studies of the dynamic parameters of variable conductance heat pipes intended for use in spacecraft thermal control systems**

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Abstract. Variable conductance heat pipes (VCHP) are used in thermal control systems when there is a need to maintain the temperature of an object by passive means in a narrow temperature range when the heat load changes. Predicting the parameters of the VCHP is a difficult task, since the position of the vapor-gas front in the condensation section depends on many factors and can significantly affect the characteristics of the HP. Application of currently existing two-dimensional models of heat and mass transfer makes it possible to determine the static parameters of the VCHP with high accuracy. However, in practical modeling of systems with VCHP, it is necessary to take into account the parameters which change over time, and this leads to the necessity of creation of complex dynamic models. Therefore, the most correct way to determine the parameters of heat pipes designed basing on the VCHP application is a computational and experimental study.

[No. 202] **Experience on CBERS 04A Satellite Thermal Control Heat Pipes**

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Abstract. The paper reveals the experience and presents main results obtained through the testing and performance evaluation of the heat pipes applied in the CBERS04A satellite. Electronic equipment temperature requirements define the lay-out and distribution of the axially-grooved ammonia charged heat pipes over structural honeycomb panels. Thermal Mathematical Model of the CBERS04A developed with Thermal Desktop SINDA software includes heat pipe sub-models which are included in the global model by an effective simple way. The model was used for the satellite thermal project and for the evaluation of redundant heat pipes application in case if a primary heat pipe fails. Testing program includes unit acceptance test, performance test after embedding the heat pipes into sandwich panels and then after satellite structure integration. A specific ammonia-leakage test was performed for entire satellite Service Module which has been stored for several years. The paper also presents comparative results of the heat pipe performance during satellite thermal balance test and in-flight phase of nominal satellite orbital operation.

[No. 84] **Preliminary design of a self-deployable Pulsating Heat Pipe by means of a Shape Memory Alloy actuator**

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Abstract. The preliminary design of thermally driven self-deployable pulsating heat pipe with Shape Memory Alloy (SMA) actuator is presented. The use of SMA wire allows the passive folding of the heat transfer device: the hot side of the heat exchanger acts as hot source for the SMA deformation. The system consists of a torsion-spring shaped Pulsating Heat Pipe tube portion (Al6063, 1.8 and 2.6 mm inner and outer diameter) and a SMA wire (0.5 mm diameter, closed and open configuration length 165 mm and 172 mm respectively). When the SMA wire is heated up by the hot source, it shortens inducing a moment on the PHP torsion spring that allows the PHP panel to rotate 90 deg.

Keywords: Deployable system, Pulsating Heat Pipe, Shape Memory Alloy actuator.

[No. 200] **A simple vapor chamber model based on spreading relations**

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Abstract. Vapour chambers are two-phase heat transfer devices that are commonly used as heat spreaders in electronic devices where they aim to reduce thermal resistance of the module. Finding the thermal resistance of the vapour chamber is not simple and generally requires experimental measurement. This can cause many issues for thermal designers in the initial design phase. This paper describes a new model for predicting the thermal resistance of vapour chambers that can be used early in the design process. This model is based on analytical thermal spreading relations that can be implemented easily with spreadsheet software and is thus low cost and fast. The development of this model is discussed before simple validation is carried out with good agreement using an existing vapour chamber. A case study comparing solid metal heat spreaders to the vapour chamber is also performed. This reveals some insights into the use of vapour chambers as heat spreaders and also highlights the versatility of the model introduced in this work.

[No. 234] **Operating characteristics of a water-pressure controlled loop heat pipe**

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Abstract. In this work, a pressure-controlled loop heat pipe (PCLHP) utilizing water as a working fluid was constructed, and its operating characteristics were investigated in the context of the operating temperature controllability under gas pressure control on its compensation chamber (i.e., the pneumatic temperature control technique). The PCLHP was equipped with an isothermal region in the vapor transport line, which was essentially an annular vapor flow passage, and the temperature of the isothermal region, which was very close to the saturated vapor temperature in the evaporator, was actively controlled by changing pressure inside the compensation chamber using He as a control gas and an external gas pressure controller. In this work, the effect of heat load on the stable range of the pneumatic temperature control of the isothermal region of the PCLHP was investigated to enhance understanding and applicability of the proposed method. From the test results, it was found that the range of the stable pneumatic temperature control was extended with increasing heat load due to the increased mass flow rate of the working fluid, which resulted in the augmented pressure difference between the evaporator and the compensation chamber.

[No. 121] **Investigation of a loop heat pipe at a high heat load concentration**

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Abstract. The problem of cooling small-sized objects with an extremely high heat release density is considered. For this purpose, a copper-water loop heat pipe (LHP) with a flat-oval evaporator measuring 7 × 42 × 80 mm and an active zone 32 × 40 mm was made. Experimental studies of the LHP with three heat sources with different dimensions of heating surfaces of 0.25 cm^2, 0.9 cm^2 and 9.0 cm^2 were carried out. To intensify heat-exchange processes in the evaporator, use was made of copper heat spreaders with a thermal contact surface area of 30 × 30 mm and different thicknesses of 1-, 2- and 3-mm. Experimental results have shown that heat spreaders can reduce the temperature of a heat source. The greatest decrease in temperature was observed at a heat source with a heating surface of 0.25 cm^2. Numerical simulation of the temperature field of the evaporator with spreaders of different thicknesses was performed, which showed that the temperature reduction is achieved by a more efficient distribution of heat flows in the active zone of the evaporator.

Keywords: Loop heat pipe; Evaporator; Cooling of microelectronic components; High heat flux

[No. 137] **Features of Loop heat piped start-up at various gravity positions and heat input**

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Abstract. Among all types of heat pipes, loop heat pipes stand out for their ability to generate a significant capillary pressure and can rightfully be called as anti-gravity heat pipes. At the same time, the loop heat pipe has a number of specific features. In particular, for the reliable start-up of the loop heat pipe, certain conditions shall be provided. Development of loop heat pipe for the landing module of the interplanetary station "Exomars" was carried out taking into account the above-mentioned features of the loop heat pipe operation and is presented in this paper.

[No. 28] **Experimental study of a loop heat pipe with vapor-driven jet injector**

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Abstract. Loop heat pipe (LHP) is an efficient and passive heat transfer device. However, heat leakage may lead to several problems such as temperature oscillation and even startup failure, which hinders the practical application. To weaken the negative effects of heat leakage and improve the performance, a loop heat pipe with vapor-driven jet injector (LHPI) is proposed. Comprehensive experimental research was conducted to evaluate the heat transfer performance of the LHPI and visualization study was carried out to reveal its operation mechanism. The results indicate that a directional motion of liquid is formed in the compensation chamber owing to the injecting effect of the injector, which takes away the heat leakage and keeps the compensation chamber at relatively low temperature. The LHPI can operate at the heat load range of 50–550 W. The maximum heat flux is 48.6 W/cm^2, with the corresponding total thermal resistance of 0.27 ℃/W. While maintaining the heating wall temperature within 85 ℃, the maximum heat flux reaches 22.1 W/cm^2, corresponding to a thermal resistance of 0.33 ℃/W. The heat transfer performance of LHPI is greatly improved compared with most of the conventional LHPs.

[No. 80] **Effect of Wick Oxidation on the Thermal Performance of a Copper-Acetone Loop Heat Pipe**

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Abstract. Loop Heat Pipe (LHP) is a passive phase-change heat transfer device. Among other factors, its performance largely depends on the heat leak from the evaporator to the compensation chamber (CC). For copper wick LHP, a high heat leak creates a problem in successful LHP start-up and can adversely affect its operation. The present study focuses on reducing the heat leak through manipulation of the copper wick properties. The effect of wick oxidation on thermal performance is investigated. A cylindrical copper-acetone LHP is tested in favorable orientation for two cases with (1) pure copper wick and (2) oxidized copper wick in its evaporator. The charging ratio is kept constant at 50%. LHP can transfer a heat load of 90 W (h_{Evp} = ~ 900 W/m^{2}K) and 180 W (h_{Evp} = ~ 2500 W/m^{2}K) at the evaporator temperature below 100ºC for the pure copper and oxidized wick, respectively. The significant improvement in LHP thermal performance is attributed to a decrease in heat leak because of the low thermal conductivity of the oxidized porous wick.

[No. 51] Experimental study on heat transfer performance of potassium heat pipe

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Abstract. Heat pipe cooled reactor (HPR) is considered as an excellent candidate for space power systems. As a core cooling method, the operational characteristics of high-temperature heat pipes need to be researched. In this paper, the heat transfer performance of potassium heat pipes (Φ30mm×800mm) is studied experimentally. The thermal behaviour of heat pipe is tested under various conditions, including heating power (0.2-4kW), air/water cooling method, inclination angle (0°-90°), and filling ratio (20% and 100% of void in wick). And the characteristics of heat transfer limits are analysed, consisting of dryout, entrainment, and sonic limit. The results show heating power is beneficial to heat transfer within the capillary limit. However, overheating occurs when heating power exceeds the capillary limit. The inclination angle has a strong effect on the thermal efficiency of heat pipe for the competition between gravity and entrainment, and the angle of 30° corresponds to the best thermal performance. Sonic limit and entrainment limit are estimated with a relative error of 38.7% and 17.9%. Dryout is divided into local dryout (< 200 °C/m) and integral dryout (> 200 °C/m). It is concluded that the high filling ratio (100%) and the small inclination angle (30°) are helpful to realize the optimal thermal performance. This work makes it possible to validate the operation of a high-temperature heat pipe and provides a reference for the design and application of HPR.

[No. 23] Effects of operating temperature on the heat transfer performance of a liquid metal high-temperature oscillating heat pipe

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Abstract. The liquid metal high-temperature oscillating heat pipe (LMHOHP) is a kind of high efficiency heat transfer device, which can function in high-temperature environments above 500 ℃. In this paper, the effects of operating temperature on the start-up and heat transfer performance of a LMHOHP were investigated experimentally. The sodium-potassium alloy (potassium 78 %) was used as the working fluid and the 310S stainless steel tube with an inner diameter of 6 mm as the shell tube, the filling ratio was 50 %. The start-up characteristics and heat transfer performance of the LMHOHP at four operating temperatures of 150 ℃, 200 ℃, 300 ℃ and 400 ℃ were tested with the input power of 2000 W to 4000 W, respectively. Experimental results show that (1) The LMHOHP can start-up and function at all the tested operating temperatures, the maximum temperatures of the evaporator and condenser can exceed 1000 ℃ and 700 ℃, respectively. (2) The thermal resistance of the LMHOHP decreases with operating temperature increases, the thermal resistance at the operating temperature of 400 ℃ decreases by up to 34.6 %, 26.2 % and 16.7 % compared with that at the operating temperature of 150 ℃, 200 ℃ and 300 ℃, respectively. (3) When the input power exceeds 3000 W, the flow patterns of LMHOHP can be changed from the oscillating motion to the

unidirectional circulating flow. (4) The heat transfer performance of LMHOHP increases with the increase of input power, at the operating temperature of 400 ℃ and the input power of 4026 W, the LMHOHP presents a minimum thermal resistance of 0.067 ℃/W. The results prove that the LMHOHP can function at different operating temperatures and has well heat transfer performance.

[No. 65] **Effect of non-condensable gases on the flat plate pulsating heat pipe under various gravity conditions**

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Abstract. Influence of non-condensable gases on the thermal performances of the closed looped flat plate pulsating heat pipe has been investigated. Studied pulsating heat pipe represents 3 mm thickness copper substrate with milled 3 mm width and 2.5 mm depth rectangular channels bent into a planar serpentine with eight U-turns curves (sixteen parallel channels, respectively) at the evaporator zone and filled with deionized water (volumetric filling ratio of 50%), and air as non-condensable gas with ratio of 0.01 wt%. Experimental measurements of temperatures and pressure during 71st ESA parabolic flight campaign have been performed for range of 50-200 W applied heating power. On one hand, injection of non-condensable gases leads to overall rise of operating temperature and pressure, in comparison with pure water. On the other hand, temperature difference between normal and microgravity conditions are quite higher for pure water (up to 10 K for NCG and up to 20 K for water). Besides, non-condensable gases presence induced significant temperature and pressure fluctuations during both microgravity and normal gravity phases.

[No. 82] **Effect of magnetic manipulation of Taylor flow of ferrofluids on two-phase heat transfer**

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Abstract. We have investigated the thermal transport characteristics of the magnetically manipulated Taylor bubble flow (TBF) of ferrofluid. In an earlier investigation, we had shown that the TBFs of gas and ferrofluids could effectively be magnetically manipulated to vary the size of Taylor bubbles and unit-cells without changing the respective flow rates of the two phases (DOI: 10.1016/j.colsurfa.2020.124589). An identical manipulation technique is applied to change the size of Taylor bubbles and unit-cells generated through a T-junction mini-channel by the application of a magnetic field in the present study. Smaller sized Taylor bubbles and unit-cells are generated without changing the flow rates of the two phases, and their thermal transport characteristics are examined. It is observed that heat transfer improves significantly by the smaller bubble/slug unit-cells compared to bigger bubble/slugs generated without the assistance of the magnetic field at the given flow rates. The motion of smaller bubbles produces frequent disturbance to the interfacial and boundary layer regions of the flow and more recirculation zones are formed in the resulting two-phase flow, which improves both local and overall transport.

[No. 96] **Visualization of fluid flow in a heat pipe with a centered wick structure**

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Abstract. Visualization experiments were conducted on the thermal-fluid-flow characteristics within a centered-wick heat pipe. The centered wick structure has been used in recent years to develop an ultra-thin heat pipe for smartphone cooling. A semi-transparent heat pipe with the centered wick structure was fabricated, and water was enclosed as a working fluid. In experiment, an evaporator section of the heat pipe was heated by a heater while a condenser section was water-cooled using a cooling jacket. The thermal-fluid-flow phenomena within the heat pipe were captured by a video camera, and the temperatures of the heat pipe were measured by thermocouples. Different from a conventional cylindrical heat pipe, the liquid droplets and slugs were found in the vapor flow channels of the centered-wick heat pipe. This caused to reduce the amount of working fluid in the wick structure, and thus increase the thermal resistance at the evaporator section of the heat pipe. An additional working fluid is essential for the centered-wick heat pipe.

[No. 127] **Investigation of Nanofluid Boiling in Thermosyphons**

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Abstract. This research focuses on two-phase thermal control systems, namely thermosyphons filled with nanofluids, and their use as cooling devices. The behavior of the fluid in the thermosyphons (TS) and the mechanisms explaining the possible impact of nanoparticles on the thermal properties of the working fluid, as well as the processes in the TS, are addressed. Nanoparticle distribution in the nanofluid, methods of preparing nanofluids and the nanofluid degradation processes (aging) are studied. The results are obtained from a set of experiments on thermosyphon characteristics depending on the thermophysical properties of the working fluid, filling volume, geometry and nanoparticle mass concentrations. The impact of nanofluids on the heat-transfer process occurring inside the thermosyphon is also studied. The heat transfer coefficients (HTC) and critical heat fluxes (CHF) in thermosyphons with front heat load were mainly studied. The results indicate the strong influence of nanoparticles on the thermal properties of the thermosyphons, with up to a 20-25% increase in the heat transfer coefficient and critical heat flux. It is shown that this effect is due to the aggregation of nanoparticles and the formation of a micro/nano relief on the vaporization surface. The nanofluids are shown to be effective means for enhancing heat transfer in two-phase thermal management systems.

[No. 186] **Thermosyphon-heat exchanger for cooling high-power electronic elements**

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Abstract. The work is devoted to the study of the parameters of a two-phase thermosyphon with an extended condenser surface. The main purpose the thermosyphon was designed for is to cool high-power electronic and electrical devices, the heat emission in which can reach 1 kW or higher. The thermosyphon is made of copper, the heat carrier in it is water. In the course of experiments, the parameters of evaporators with various types of capillary structures, liquid -and air-cooled condensers were investigated. It is shown that coating of capillary grooves with a thin layer of sintered powder makes it possible to more than halve the thermal resistance of the thermosyphon evaporator. The total thermal resistance of the device does not exceed 0.1 K/W when the condenser is air cooled.

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[No. 227] **Local heat transfer in a micro heat pipe**

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Abstract. The thermal behaviour of Pulsating Heat Pipes (PHPs), which is inherently time-dependent, could also significantly change from local position to local position. Hence, the evaluation of local heat flux distributions could lead to a better understanding of the fundamental governing mechanisms of PHPs, which are, so far, only partially understood. In fact, most of the studies regarding the working principles of PHPs have focused on analysing the heat transfer rate averaged over the evaporator and condenser areas, or on evaluating the overall thermal resistance of the system. A 7-turn micro-PHP with an inner diameter of 0.32 mm is charged with HFC-134a at filling ratio of 46% and tested in bottom heated mode. The external wall temperature distribution of the condenser is measured by a high-speed and high-resolution infrared camera. The local heat fluxes exchanged between the fluid and the PHP wall are estimated in the whole condenser by solving the inverse heat conduction problem with the temperature maps as input data. The local heat transfer behaviour is furthermore investigated in terms of characteristic frequencies of the oscillatory flow by means of the wavelet method, coupled with an original statistical approach. At low heat input the variations over time and along space of axial coordinate in the heat flux is significant and each tube shows multiple peaks with similar energy in the power spectrum. On the other hand, the variation weakens under the high heat input conditions and the dominant fluid oscillation frequency is found more clearly around 1 Hz.

[No. 176] **Modeling of vapor generation in a loop heat pipe evaporator**

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Abstract. A non-stationary mathematical model of vaporization in the capillary-porous media of a loop heat pipe evaporator is proposed. The model contains equations for the thermal conductivity of the porous media skeleton, the energy of the coolant flow, and the filtration of liquid and vapor. It may be used for porous media with any pore distribution law over radii. The model is implemented in a one-dimensional version, when vapor is removed from the entire surface of the evaporator. Examples of calculation results are presented, and the main mechanisms of heat transfer identified during the calculation analysis are described. It is shown that in the case of a capillary-porous media with an inverted meniscus, pulsations of the working fluid occur near the heat supply section, accompanied by periodic drying and irrigation of the porous media until the section is completely filled with liquid. The analysis of the influence of porous media thermal conductivity on heat and mass transfer processes is presented. The features of processes with heat flows close to the maximum are determined.

[No. 153] **Analysis of Loop Heat Pipes control methods**

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Abstract. Different methods of Loop Heat Pipe (LHP) reliable and precise temperature control are considered in this paper. Designs of LHP secondary wick and compensation chamber were developed for providing LHP stable and reliable control. Created analytical model makes it possible to simulate heat and mass transfer processes taking place in LHP in dynamics, taking into account heat capacities of LHP components. Special algorithms developed for LHP active control make it possible to avoid pulsations and thermal resonance. Created passive methods of LHP regulation provide control of vapor and liquid flows in the loop without pulsations occurrence and without stop of a working fluid circulation. Developed LHP control methods are successfully applied in different satellites.

Keywords: Loop heat pipes; heat and mass transfer; modelling; maximum heat power; working fluid

[No. 152] **Investigation of the impact of mechanical loads on LHP**

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Abstract. It is known that loop heat pipes (LHPs) are currently widely used in the spacecraft thermal control systems. The LHPs are highly efficient heat transfer devices that are capable of transferring relatively high specific heat fluxes compared to axial low temperature heat pipes. Another distinguishing feature of LHPs is their ability to work against the gravity vector.

Both of these features make the LHP a promising heat sink for gravity applications. Such devices could be successfully used, for example, in river or sea transport, on railways and in air transportation. However, in this case, LHPs shall pass additional qualifications to prove their ground performance under mechanical loads.

This paper will discuss the impact of mechanical loads on the LHP performance.

Keywords: Loop heat pipes; Thermal control system, Evaporator, Condenser,

[No. 204] **Experimental study of a miniature loop heat pipe for electronics applications**

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Abstract. Sintering and diffusion bonding processes were used to manufacture a miniature flat loop heat pipe (mLHP) with 1.6 mm of thickness. Due to the particular geometrical characteristics, the mLHP is a candidate for electronics cooling applications, such as portable projectors, tablets, and smartphones. A workbench was developed to simulate the operating condition of a chip processor with 1 cm², capable of evaluating the mLHP thermal performance. The heat transfer device was experimentally investigated using ethanol as the working fluid with a filling ratio of 30%, which corresponds to a volume of 0.24 ml. The miniature loop heat pipe was tested in the horizontal position (non-assisted by gravity force) with the condenser under natural air convection. The experimental analysis showed that the mLHP operates effectively, starting to work at low heat flux (2 W/cm²) with an evaporator temperature of 47 ºC. The device revealed a minimum thermal resistance of 0.24 °C/W at 8 W/cm². The experimental results proved that the mLHP operates in an almost isothermal condition with an evaporator temperature below 100 ºC, which is suitable for electronics cooling applications.

[No. 165] **Thermal performance of a flexible polypropylene pulsating heat pipe at different bending angles**

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Abstract. The thermal performance of flexible polypropylene pulsating heat pipes (PHPs) is characterized for different spatial orientations, different reciprocal positions of the evaporator and the condenser (configurations), and different bending angles (conformations). The dependence of PHPs performance on their geometric orientation, configuration and conformation is poorly understood to date, however it is essential to develop polymeric PHPs characterized by high mechanical flexibility, which will have significant impact on thermal management of smartphones, portable electronics, and deployable systems such as cube satellites. Prototype PHPs were fabricated bonding together three polypropylene sheets by selective transmission laser welding, after cutting out a serpentine channel in the central sheet. The thermal performance of the devices was characterized by supplying an ascending/descending stepped thermal power ramp to the evaporator, and measuring the corresponding equivalent thermal resistance between the evaporator and the condenser.

[No. 63] **Experimental investigation of the performance of an adsorption based anti-freeze system for loop heat pipes**

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Abstract. Water is usually considered as an excellent working fluid for Loop Heat Pipes (LHP) due to its inherent advantages such as availability, high thermal performance, non-toxicity, etc. However, the usage of water is impossible if the LHP is to be stored at rest at subfreezing conditions. This is due to the anomalous volume expansion of water as it freezes, which can affect the structural integrity of the LHP. The present communication aims at demonstrating experimentally the usefulness of a solution to mitigate the challenge of using water, by integrating an adsorption-based anti-freeze tank with a LHP. RD-type silica gel stored in this external tank is used to adsorb water from the LHP during its shutdown. Once the LHP is free from water after shutdown, it can safely be subjected to subfreezing temperatures. The water from the tank is desorbed back into the LHP when its operation is required. The operational performance and characteristics of such an adsorption-based anti-freeze system is reported. The performance of the LHP is unaffected by the adsorption/desorption process. Further, the adsorption/desorption processes does not require any external pumping action, which makes the integration of the LHP with the tank easier.

[No. 231] Field and simulation study of groundwater flow effect for enhancement of heat transfer in ground source heat pipes

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Abstract. The field and simulation study of heat transfer rates of ground-source heat pipes in shallow geothermal temperatures of an alluvial fan of Toyohira River, Sapporo, is conducted in this work. The study observed the effects of groundwater flow on heat pipes by testing them in two sites: Site 1 in the fan-toe for negligible groundwater flows and Site 2 in the apex for fast discharge rates from the river. The analysis of the enhancement effect of advection on heat pipes in various conditions of groundwater flow velocities was also conducted through a simulation model. The single heat pipe experiment results showed that the heat extraction rates ranged between 0.23 and 0.79 kW in Site 1 and between 0.44 and 0.75 kW in Site 2. Site 2 result at −5 ºC was lower than Site 1 result, this heat transfer deterioration in result of Site 2 was assumed to have been caused by fluid entrainment at the condenser. For double heat pipes, the heat extraction rates were not changed in Site 1 but were about 146 % higher in Site 2 than Site 1 due to the advection effect. The simulation results revealed that an increase in groundwater flow velocity increases the heat extraction rates of the ground-source heat pipes.

[No. 225] Thermal Management of High-power LED Module using a Copper Wick Loop Heat Pipe

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Abstract. Electronic devices are facing severe thermal challenges because of the significant rise in heat flux due to high-density packaging and smaller chip sizes. Contemporary high-power LED modules dissipate nearly 70% of electrical power in the form of heat power, which needs to be dissipated for better reliability and efficient operation. In this context, a copper wick LHP is designed for the thermal management of a 100 W high-power LED. Before starting the real-time cooling of high-power LED using cylindrical copper-pentane LHP, its performance is characterized for different heat loads (40 W – 126 W) and various sink temperatures (5°C – 45°C). The thermal performance parameters of the LHP, like overall thermal resistance, evaporative heat transfer coefficients (HTC), maximum evaporator temperature at different heat loads, are obtained experimentally. The maximum evaporator temperature of the LHP is maintained under 90°C at a maximum heat load of 126 W at a sink temperature of 5°C. Steady-state simulation of the equivalent 3D model of LED cooling set-up is performed to predict the thermal field distribution over the LED module for various electrical power and to support the results obtained from the experiments. The real-time thermal management of high-power LED is tested to check the efficacy of LHP as a potential cooling solution. The results obtained from these experimental and numerical studies support using the present loop heat pipe for cooling of the high-power LEDs for a stable operation in real-time applications.

[No. 244] **Circulation in a Thermosiphon Slightly Inclinedy**

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Abstract. A pronounced stratification of the temperature (density) of the fluid over the cross section of the heating zone occurs in a thermosyphon that is slightly inclined to the horizontal and has a high degree of water filling, which leads to the onset of natural circulation of the medium along the length of the thermosiphon. In this case, there is an upward flow of water or a steam–water mixture in the upper part of the thermosiphon and a downward flow in the lower part. In experiments with a full-scale thermosiphon, the natural circulation in question increased the axial heat transfer through nonboiling water along all thermosiphon zones by three to seven times as compared to the heat transfer in a vertical thermosiphon. The estimated mass flow rate of natural circulation along the heating zone ranged from 25 to 105 kg/ (m^2 s). The heat-transfer coefficient and friction factor are estimated at the boundary of countercurrent water flows induced by natural circulation. The conditions of poorer cooling of the thermosiphon heating zone due to steam separation at its upper generatrix are examined. A decrease in the mass filling of the thermosiphon, i.e., an increase in the average void fraction of the medium in it, successively leads to the onset of bubbling steam condensation within the transport section and then in the cooling zone, with a decrease in the length of the upper section of nonboiling water. A transition to film condensation of steam occurs at the limit along the entire length of the cooling zone with a countercurrent steam flow and a near-wall film of its condensate above the level of the steam–water mixture in the thermosiphon.

[No. 4] **Using Loop Heat Pipe solutions, and a dielectric fluid, to cool SiC MOSFET power modules for aircraft systems**

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Abstract. In the scope of a technical exploration for an aircraft application four LHPs working with R-1233zd(E) have been designed and adapted to cool the four sides of the two specific double-sided power modules (DSPM). Four air exchangers equipped with fans reject the heat to the air. The present paper discusses the iterative thermal design methodology used to optimize the evaporator wall thickness to the location of the SiC chips on the substrate and the experimental performances of a demonstrator able to transfer up to 170W per MOSFET with an estimated heat flux of 675W/cm² at chip level.

Keywords: Loop Heat Pipe; Dielectric; high heat flux, MOSFET; power electronic; R-1233zd(E).

[No. 13] **Experimental analysis of 3D hybrid heat pipes for electronics cooling**

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Abstract. As the power density of electronic devices increases, overheating appears as an undesirable side-effect. In this context, heat pipes are an alternative for efficiently removing heat and stabilizing the electronic component's temperature. Moreover, in electronics industry applications, geometric flexibility is a requirement due to tight spaces available in most electronics products. In this regard, four 3D hybrid heat pipes were manufactured by diffusion bonding a set of copper frames and wires. An experimental setup was fabricated to test these devices. Distilled water, ethanol, and HFE7100 were used as working fluids, for several working fluid filling volumes. Water and ethanol shown to be a suitable working fluid for these devices. On the other hand, comparing to the empty devices, the heat pipes filled with HFE7100 showed poor thermal resistance improvements, being able to work in only one test configuration. Concluding, the present research shows the viability of using 3D hybrid heat pipes for electronics cooling even with complex geometry constraints.

[No. 162] **Study of Gas to Liquid Heat Pipe Heat Exchanger**

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Abstract. This study is focused on the study and development of a gas to liquid heat pipe heat exchanger (HPHE) based on numerical and experimental analysis. Stainless steel heat pipes are installed inside the heat exchanger in 3 equilateral triangles staggered into a hexagonal configuration to simulate the waste heat recovery from hot exhaust gas to a water flow. The first main agenda of this study is focused on 3D designing and numerical analysis, which were used to create and calculate the effect of similar input condition on the overall system. The system is tested for overall heat transfer by obtaining the temperature change in both fluids. The heat transfer and overall average temperature were used to calculate the effectiveness of the system. In the second part of this study the test of waste heat recovery through the setup created with cooling fluid as water. The study was conducted with different input velocity and temperature of waste hot air controlled simultaneously by the input fan and air heater, while the cooling water is kept at a steady state of 30˚C and 0.940kg/s at input. The hot air velocity is controlled by fan with different mass flow rate of 0.114kg/min, 0.192kg/min and 0.270kg/min, moreover the temperature of air was changed from 150˚C to 250˚C with a step of 25˚C. The increase in temperature and the velocity of air is directly proportional to the amount of heat transferred from the air to the cooling water, also the effectiveness was found to be inversely proportional to both the varying input parameters. The numerical study shows a maximum increase of 12% on the heat transfer, meanwhile the output temperature of hot and cold fluids shows maximum increase of 7K and 3K respectively. The numerical system with such tolerance can be evaluated further to predict the behavior of changes in design and parameters.

[No. 57] **Experiment study on cooling performance of heat pipe cold plate and heat pipe module for electronic equipment**

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Abstract. The cooling performance of heat pipe cold plate and heat pipe module with different heat flux was studied by comparative experiments in this paper. The result shows that using heat pipe cold plate to replace common cold plate can make the average temperature of the heat sources drop 1.0℃, 4.2℃ and 12.5℃, and the maximum temperature difference of different heat sources in the same module reduce 1.4℃, 1.4℃ and 1.7℃ when the heat flexes are 16.7W/cm^2, 29.6W/cm^2 and 46.3W/cm^2, respectively. While using heat pipe module to replace common module can make the average temperature of the heat sources drop 8.2℃, 19.6℃ and 32.4℃, and the maximum temperature difference of different heat sources in the same module reduce 4.1℃, 9.6℃ and 14.6℃ when the heat flex is the same as above, respectively. When the heat flex is higher, the effect of using heat pipe cold plate or heat pipe module is more obvious. When the heat flex is the same, using heat pipe module is better than using heat pipe cold plate. The cooling performance of heat pipe embedded module is good and the method can be used to solve the ultra-high heat flux chip thermal control problem in the future.

DAY 3, Section 3 **Thursday, September 9, 2021**

[No. 7] **Development of flexible flat heat pipe**

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Abstract. This work is concerned with developing and investigating of novel ultra-thin flexible flat heat pipe. Wicks with high porosity and permeability were developed, ensuing heat pipe operate stably and reliably in high heat flux condition. Choices of wick structures leaded to trade-offs between high permeability and high capillary capability (value of capillary parameter $K/(r_{eff}\cdot\varepsilon)$=3.84 μm). 100 mm × 100 mm × 0.4 mm flexible flat heat pipe was developed and tested. Thermal resistance was measured to be 1.8 K/W rendering effective thermal conductivity of 667 W/(m·K). Maximum heat transfer capacity was 20.5 W. Challenges affecting the development of flexible heat pipe are outlined, and recommendations for future research are presented.

[No. 87] **Heat Transfer Delay Method for the average fluid velocity evaluation in a multi-turn pulsating heat pipe**

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Abstract. A multi-turn closed loop pulsating heat pipe is tested in vertical bottom heated mode with the aim of providing quantitative information regarding its flow dynamics through a novel post-processing technique on the local wall-to-fluid heat flux, evaluated within the adiabatic section. The studied device is made of an annealed aluminium tube (inner/outer diameter: 3/5 mm), folded in 14 turns and partially filled with methanol (volumetric filling ratio: 0.5). The aluminium channels are coated with a high-emissivity opaque paint, thus allowing thermographic measurements on the outer wall by means of a high-speed and high-resolution medium wave infrared camera. The acquired time-space temperature maps are used as input data for the inverse heat conduction problem resolution approach in the wall to estimate the local convective heat flux locally exchanged at the fluid to internal wall interface. The resulting wall-to-fluid heat fluxes are therefore post-processed by applying the heat transfer delay method to evaluate the fluid average velocity at varying working conditions during the circulatory flow.

Keywords: Pulsating Heat Pipes; Local Thermal Analysis; Inverse Heat Conduction Problem; Heat Transfer Delay Method.

[No. 151] **Heat pipes with axial grooves at high heat flux density in the evaporator. Modeling and analysis**

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Abstract. Mathematical models of heat-hydraulic processes occurring in heat pipes with axial grooves have been developed. The Groove 2.0 computer program was created on their basis. It is used to calculate the characteristics of heat pipes with different profiles. The results of calculations and tests were compared. Calculations and experiments have confirmed the performance of axial heat pipes at a heat flux density of up to 6 W/cm^2 in the evaporator.

[No. 169] **Sodium heat pipes for a novel high-temperature thermal energy storage system.**

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Abstract. High-temperature Sodium Heat Pipes (HP) are proposed for integration of a Thermal Energy Storage (TES) system with a Stirling Engine (SE) to produce electricity and heat domestic hot water (DHW). This system has the potential to balance the load on the electrical distribution system. A key challenge is system integration at high temperatures while achieving both high efficiency and low cost. In this study, an experimental test platform was developed to assess the thermal performance of low-cost wickless Sodium heat pipes for evaporation temperatures of up to 700ºC.

[No. 158] **Heat transfer in shear driven locally heated liquid film with microstructures**

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Abstract. In this paper authors are studding the effect of microgrooves on heat transfer in shear driven liquid film. Due to the capillary effect, it is possible to observe enhancement of heat transfer for surface with microgrooves.

[No. 246] **Bulging of cylindrical heat pipes caused by water freezing**

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Abstract. We present the experimental results on mechanical damages caused by water freezing in water copper heat pipes. The results confirm the theoretical expectations, that the main cause of damage is the excess water present at the bottom of the heat pipe. The minimum amount of excess fluid necessary for freezing-caused damage has being identified. Transient temperature features during freezing and thawing have been proven to correlate with the amount of pipe bulging. A simple finite element model reproduced the main transient features observed in the tests.

[No. 85] **Experimental validation of a Pulsating Heat Pipe transient model during the start-up in micro-gravity environment**

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Abstract. A large diameter Pulsating Heat Pipe (PHP) is a device operating as a thermosyphon on ground and as a PHP under microgravity conditions. Such a prototype with a transparent (sapphire) tube section in the adiabatic region has been tested during the 67th ESA parabolic fight campaign. Infrared visualizations of the fluid in the sapphire section along with measurements of all the relevant quantities, which characterize the device state (pressures, temperatures), are acquired during the tests and exploited for the validation of CASCO code of PHP simulation. After accurate implementation of the PHP geometry and material properties, transient simulations have been carried out. A comparison with the experiment is possible only for the cases where the PHP can be initially assumed at equilibrium. The transients for tube wall temperatures, liquid plug velocities, lengths and temperatures show a good agreement with the experiments during the start-up phase in microgravity conditions reducing the gap towards the development of a fully validated PHP design tool.

[No. 94] Measurement of two-dimensional Temperature Distribution and point Pressure inside Pulsating Heat Pipe Using Temperature-sensitive Paint

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Abstract. The mechanism of Pulsating Heat Pipe (PHP) is not clear because of its complex thermal fluid property. This study executed the simultaneous measurement of temperature distribution and point pressure inside the optical PHP. Temperature-sensitive Paint (TSP) was painted on the optical window to measure the temperature distribution. The TSP was excited by UV LED light and the luminescence image was captured by High Speed Camera. The standard deviation of the measurement was 0.486°C. The temperature and pressure inside the PHP fluctuated in opposite phases in the cooling section and fluctuated in the same phase in the heating section and the adiabatic section. In addition to this, the movement of the fluid was captured by using stripe shaped TSP and working fluid mixed with fluorescent dye, and the simultaneous measurement of the temperature field and fluid movement was executed.

[No. 223] Temperature homogenization of a 3D metallic structure with a printed integrated PHP

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Abstract. A Pulsating Heat Pipe (PHP) is integrated within a 3D solid structure in order to replace an existing water-cooling system. Additive manufacturing is used to build a 3D PHP shape within the system using maraging steel as the printed material. In this preliminary study, the PHP thermal conductance and its temperature homogenization capacity are experimentally quantified using water as the working fluid. An analytical model is developed to estimate the time response of the system and to analyze the influence of the main parameters. Furthermore, the direct integration of a PHP within an existing system raise the question of its chemical compatibility with the working fluid, which is analyzed using a specific test bench.

Keywords: Pulsating Heat Pipe, 3D geometry, Temperature homogenization, Chemical compatibility, Additive manufacturing

[No. 69] **Flat-plate Pulsating Heat Pipe tested with surfactant: experimental investigation and use of transient reactivation phases for the fluid-wall heat transfers analysis**

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Abstract. In this study, a copper closed loop Flat Plate Pulsating Heat Pipe (FPPHP) is experimentally tested in horizontal orientation, using pure water with 0.5% Tween® 20 and 0.5% Tween® 40 surfactant aqueous solutions. The surfactant solution does not improve, but even deteriorates the performances of the FPPHP tested in horizontal inclination, unlike the results reported in the literature for capillary tubular PHP tested in vertical bottom heated mode. Nevertheless, a numerical comparison with the experimental curves of sudden transitional phases of the fluid flow reactivation after dry-out phases allows to estimate the order of magnitude of the heat transfer coefficient (HTC) between fluid and wall: it appears that there is a real gap between evaporation and adiabatic zones, with a HTC at least between 10 times higher in the evaporator zone comparing to the adiabatic zone. This leads to the faster temperature drop in the evaporator zone with temperatures becoming lower than in the adiabatic zone, while steel being heated. Such behavior brings new data that help understanding the fundamental operation of pulsating heat pipes.

[No. 70] **Liquid film dynamics during meniscus oscillation**

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Abstract. To describe the functioning of pulsating heat pipe, one needs to understand the dynamics of evaporation of thin liquid films deposited by the oscillating meniscus inside a heated capillary. Following the theory of Taylor bubbles, the dynamic profle of the liquid-vapor interface is calculated within a 2D numerical approach using the lubrication approximation. First, the steady vicinity of the contact line is analyzed under evaporation for the partial wetting case to find a relation between the microscopic and apparent contact angles. Next, the film evolution driven by the oscillating meniscus with a pinned contact line is discussed under adiabatic conditions. Finally, the evaporation of oscillating film is considered. It is shown that the film oscillation with a pinned contact line is impossible when the capillary superheating exceeds a threshold; the contact line receding needs to be taken into consideration.

[No. 5] **Development of ultra-thin vapor chamber**

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Abstract. The paper presents results of the development and investigation of vapor chamber series (width is 25 mm, length is 100 mm) ranging in thickness from 0.5 mm to 0.2 mm with heat transfer capacity from 19.8 W to 3.2 W and thermal resistance from 0.19 to 1.56 K/W.

[No. 177] **Cryogenic Flat Plate Oscillating Heat Pipe**

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Abstract. An experimental investigation was conducted on an aluminum flat plate oscillating heat pipe (OHP). The OHP was tested with argon and methane working fluids across a range of heat loads and fill fractions. The 35.6 cm aluminum flat plate OHP had a 3.8 cm long heat source at one end and a 3.8 cm long heat sink on the other end. The OHP was instrumented to measure the heat load, heat rejection and temperatures. The experiment was designed to validate the cryogenic OHP for space environments and their operational envelope. The experimentally operational envelop of the OHP was also compared to predicted operational limits for model validation and to enable prediction of other cryogenic working fluids.

Keywords: Oscillating Heat Pipe, Pulsating Heat Pipe, Cryogenic, Limits of Operation

POSTER SECTION INSTRUCTION

At the beginning of the poster session, each paper will be located in the Ballroom B, and it will be available for all time of holding Conference.

Poster session will take two days of the Conference:

Day 1: 7th September 2021 (18:20 to 19:40)

Day 4: 10th September 2021 (11:00 to 12:00)

Each poster must have an identification number which was assigned during the registration of the paper. The poster template is located on the Conference website.

POSTER SECTIONS

Ballroom B

[No. 25] **Experimental study of silicon-based flat-plate loop heat pipe under water and ethanol filling**

Yanfeng Xu[1,2], Xiaoxiao Gu[1,2], Lihong Xue[1,2], Kun Jiang[1,2], Chunsheng Guo*[1,2]

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Abstract: Integration and miniaturization have always been the development trend of electronic products. The heat dissipation problem is the bottleneck that limits the performance of electronic chips especially in the 5G era. This research combines semiconductor microchannel processing technology and loop heat pipe technology, a silicon-based ultra-thin loop heat pipe (s-UTLHP) is designed with a thickness of only 1.45mm. The s-UTLHP was filled with deionized water and 95% ethanol, respectively, and a visual heat transfer experiment was performed used high-speed camera. Experiments show that the pipes-UTLHP filled with the two working fluids can run stably for a long time, which proves that the s-UTLHP of this design can effectively dissipate heat. The heat flow density of the s-UTLHP filled with deionized water can reach 42W/cm^2, and the heat flow density of the ethanol working fluid can be reach 49W/cm^2. The heat pipe filled with the ethanol working fluid starts more smoothly and quickly, and the gas-liquid interface of the ethanol working fluid is clearer, and the advancement of the gas-liquid interface is more stable. The heat transfer performance of deionized water is better than that of ethanol working fluid, and the performance after stable operation is also more stable.

[No. 34] **Experimental research on the performance of cylindrical loop heat pipe using g-C3N4 and NaCl as pore-forming agents**

Wenjing Ning[1,2], Chunsheng Guo[1,2*], Peidong Yang[1,2]and Zhuosheng Han[1,2]

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Abstract. The loop heat pipe (LHP) is a passive cooling device used in aerospace and electronic devices. As the core component of the LHP, the porous wick directly affects comprehensive performances of the LHP. The comprehensive performances of the biporous wick exhibit obvious advantages compared with the monoporous wick. Among them, fibrous and sheet pore formers have become a new research direction. In this study, g-C_3N_4, a kind of sheet-like pore former is prepared by sintering urea as raw material. The effects of g-C_3N_4 and NaCl as pore-forming agents on the performance parameters of the porous wick and the overall operation performance of the LHP are studied under different proportions of pore-forming agents (10%wt, 20%wt, 30%wt).The experimental results show that when the ratios of pore-forming agents are the same, the suction quality and speed of the porous wicks with g-C_3N_4 as the pore-forming agent are higher than thouse of the porous wicks with NaCl as the pore-forming agent.Compared with the porous wick of the same size, the mass of the porous wick with g-C_3N_4 can be reduced by 50.48%, which is beneficial

to reduce the overall mass of the LHP. The operating range of the LHP is tested to be 10~260W under the condition that the heat sink is -10℃ while the maximum temperature of the evaporator wall does not exceed 85℃. The minimum resistance value of evaporator is 0.055℃/W and the minimum resistance value of LHP is 0.133℃/W.
***Key words*:** Loop heat pipe; Porous wick; Pore-forming agent; performance parameters; Heat transfer performances

[No. 55] **Experimental research on the performance of cylindrical loop heat pipe using g-C3N4 and NaCl as pore-forming agents**

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Abstract. The loop heat pipe (LHP) is a passive cooling device used in aerospace and electronic devices. As the core component of the LHP, the porous wick directly affects comprehensive performances of the LHP. The comprehensive performances of the biporous wick exhibit obvious advantages compared with the monoporous wick. Among them, fibrous and sheet pore formers have become a new research direction. In this study, g-C_3N_4, a kind of sheet-like pore former is prepared by sintering urea as raw material. The effects of g-C_3N_4 and NaCl as pore-forming agents on the performance parameters of the porous wick and the overall operation performance of the LHP are studied under different proportions of pore-forming agents (10%wt, 20%wt, 30%wt).The experimental results show that when the ratios of pore-forming agents are the same, the suction quality and speed of the porous wicks with g-C_3N_4 as the pore-forming agent are higher than thouse of the porous wicks with NaCl as the pore-forming agent.Compared with the porous wick of the same size, the mass of the porous wick with g-C_3N_4 can be reduced by 50.48%, which is beneficial to reduce the overall mass of the LHP. The operating range of the LHP is tested to be 10~260W under the condition that the heat sink is -10℃ while the maximum temperature of the evaporator wall does not exceed 85℃. The minimum resistance value of evaporator is 0.055℃/W and the minimum resistance value of LHP is 0.133℃/W.

Key words: Loop heat pipe; Porous wick; Pore-forming agent; performance parameters; Heat transfer performances

[No. 64] **Experimental study of operating regimes in a vapor chamber with integrated hollow fins**

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Abstract. A thermosyphon vapor chamber was manufactured and tested. The evaporator is made of copper and has a circular geometry (185 mm outer diameter). The condenser consists of an array of hollow fins made of 300 µm thick polymer layer and having an inner diameter ranging from 5.3 to 10.7 mm. It is cooled by forced convection. Experiments were carried out to characterize operating regimes depending on the working fluid, fins diameter, fluid fill charge and heat flux. HFE-7100, n-pentane and water were tested. Visualizations were made, as well as temperature and pressure measurements over time. For HFE and pentane, a stable oscillating regime was observed for all operating conditions, with film condensation and nucleate boiling. For water, dropwise condensation occurs and

many hydrodynamic phenomena were observed depending on the operating conditions (geyser effect, liquid plugs, flooding of tubes), leading to intermittent behaviors. Operating regime maps are proposed. The influence of the regimes on the thermal performance of the vapor chamber is small as long as the fins' inner diameter is large enough to prevent the occurrence of stable liquid plugs occupying the whole height of the tubes. The determination of the critical diameter is thus of great importance for the performance optimization, considering condensation heat transfer as well as external convection.

[No. 71] **Radial Pulsating Heat Pipe**

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Abstract. Pulsating heat pipes (PHP) are increasingly used for the thermal management of hot spots. Thereby, local evaporation effects occur that are still not fully understood due to complex interactions of flow patterns and heat transfer. For hot spot applications, it is necessary to modify the channel design of PHPs. This study quantifies the thermal performance and the flow behavior of PHPs with a centrally located hot spot heater. To achieve this target, we present a new Flower PHP design that consists of radial channels and a chamber in the center. The fluid leaves the chamber through a 1.5 mm × 1 mm channel and is divided into two smaller channels with a cross section of 0.75 mm × 1 mm. The return channels lead the fluid back into the chamber. By splitting the channels, an unidirectional pulsating flow occurs, which increases the heat transfer. Based on this background the current paper presents an experimental study to quantify the thermal performance of the new Flower-PHP design. Using acetone as a working fluid and varying the filling ratio, the thermal resistance and the flow pattern are evaluated.

[No. 90] **Experimental demonstration of an oscillating heat pipe fabricated by metal additive manufacturing**

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Abstract. An oscillating heat pipe (OHP) is an attractive thermal control device, which has high heat transport capability and enables heat transfer from narrow space. The Japan Aerospace Exploration Agency (JAXA) has developed an OHP with check valves (CVOHP) for space applications. The CVOHP successfully operated on-orbit, and now we are at the stage of working toward practical use of the CVOHP. In this study, we focused on metal additive manufacturing as a fabricating method of the CVOHP, aiming at developing a CVOHP with thinner plate thickness, higher thermal performance, and ease of shaping complex structures. This paper describes the first step demonstration experiment of a CVOHP fabricated by metal additive manufacturing using AlSi10Mg powders by selective laser melting (SLM) in a powder bed. The flow channel including straight lines, turn sections and check valves were fabricated without any clogging. The thermal performance test results indicated that the additively manufactured CVOHP could operate as a two-phase heat transfer device. However, the operation of the CVOHP was confirmed

only under limited conditions. Further investigation is necessary to improve the thermal performance of the additively manufactured CVOHP.

[No. 100] **Evaluation of effective thermal conductivity of a vapor chamber-type heat spreader**

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Abstract. Recent progress in modern electronic devices has led a maximum heat flux approaching a level of a few hundred W/cm2, which often causes malfunctions or premature failures of those devices, necessitating a heat-flux-transforming heat spreader. In this circumstance, as no diffusion-based heat spreaders can handle this high level of heat flux, a heat spreader utilizing phase-change heat transfer and convection of a working fluid in a passive way (i.e. vapor chamber) is gaining ever-increasing interests in the related technical fields. In this work, a vapor chamber-type heat spreader having dimensions of 102 mm × 102 mm × 5 mm (width × length × thickness) was fabricated, and effective thermal conductivity of the devised heat spreader was evaluated based on the defining equation of the thermal conductivity and on precisely measured temperature differences over the surface of the heat spreader. In particular, the effective thermal conductivity of the heat spreader was nondimensionalized with respect to the effective thermal conductivity of a copper plate having the same dimensions to reduce the number of measurands. Uncertainty of the evaluated thermal conductivity ratio was fully assessed to make the determined value of the thermal conductivity reliable.

[No. 102] **Development of an aluminum flat heat pipe with a separable connecting wall structure for application to multiple hot spots**

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Abstract. Eliminating hot spots in electronic packages with a heat flux of up to 192 W/cm2 is essential for extending the performance and life of semiconductor chips and package modules. Especially when the package structure changes from 2D and 2.5D to 3D, finding a solution to dissipate heat from hot spots is limited. Currently, heat dissipation is primarily achieved using a through-silicon via or package bonding materials with high thermal conductivity. For heat pipe technology to be applied to an electronic package structure below a module-level size, not only the heat pipe size and thickness must be very thin, but also the shape change of the heat pipe applicable to various package structures needs to be possible. In view of such aspects, this study developed an aluminum thin flat heat pipe that can be separated by channels for applying to multiple hot spots and has sizes of 0.7 mm in thickness, 20 mm in width, and 114 mm in total length. The influence of the position of the composite wick (cw) capillary structure in the channel of the aluminum flat heat pipe (AFHP) under the inclination angle range of ±5° was evaluated. The limiting power in the case of one cw located at the channel center was larger than that with two cws located on the channel sides. The structure in which the cw was located at the center was confirmed to be excellent even in the comparative evaluation

in the state that the thickness of the AFHP was reduced to 0.7 mm. After the carbon wire bundle and Cu braid constituting cw were separated, their capillary force performance was compared. The carbon wire bundle and Cu braid presented an increase of approximately 1.8 times in temperature difference between evaporator and condenser compared with cw. The heat transfer rate decreased by approximately 22% in the carbon wire bundle and by 41% in the Cu braid compared with that in cw. In three separated channels, the thermal load of one channel changed, while the temperature of the channel to which thermal load was applied reached 110 °C. The temperature of the adjacent channel increased by approximately 16.6 °C, and that of the distant channel increased by approximately 9.6 °C. This result in which the channels were not greatly synchronized confirmed that the evaporator of the separated channels of the AFHP was attached to a plurality of hot spots and that one condenser could act as a heat dissipation block.

[No. 105] **Experimental study of stainless steel-acetone loop heat pipe with a flat evaporator at adverse inclination**

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Abstract. Experimental investigation was conducted for thermal performance of a loop heat pipe especially at adverse inclination. The loop heat pipe was made of stainless steel and the working fluid was acetone. The evaporator had a flat rectangular shape with exterior dimensions of 48 (W) x 48 (L) x 15 (H) mm^3. Sintered nickel wick having a porosity of 55 % was inserted as a capillary structure. Outer diameters of the vapor and liquid lines were 6.35 mm and 3.18 mm, respectively, and the distance between the evaporator and the condenser was 0.6 m. The working fluid charge was varied from 50 % to 60 % based on the total internal volume of the LHP. At horizontal configuration, the LHP achieved stable start-up at 30 W and demonstrated performance up to 300 W (heat flux 20 W/cm^2). At a maximum adverse tilt angle of 90° (height difference 0.6 m), LHP successfully operated up to 260 W with the evaporator wall temperature below 110℃. Thermal resistance changed less than 0.07 K/W against full variation of adverse tilt. Furthermore, cold start-up test was made at 80° adverse tilt for 180 W thermal load.

[No. 109] **Heat pipe with a bypass line**

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Abstract. Dryout prevention is an important index of heat pipe performance. The balance between the capillary pressure supplied by the wick structure of a heat pipe and the flow resistance of the liquid returning to the evaporator determines the maximum heat transfer rate under which a steady state can be maintained. The maximum heat transfer rate is referred to as the capillary limit. If the heat pipe operates at a certain thermal load exceeding the capillary limit, then the onset of dryout in the wick structure occurs at the starting point of the evaporator and expands throughout the entire heat pipe over time. In this study, a bypass line for accelerating working fluid was first devised in order to improve the dryout prevention performance during heat pipe operation. The bypass line is designed so that a part of

the working fluid can be bypassed without passing through the capillary structure by connecting the evaporator and the condenser. The liquid bypass line has the effect of increasing the maximum heat transfer rate of the heat pipe because it can increase the thermal load that can cause dryout by reducing the flow resistance of the working fluid on the phase change interface. Acetone was used as the working fluid. The effect of the bypass line on the heat transfer performance of the heat pipe was experimentally investigated. The maximum heat transfer rates of the heat pipe with and without the liquid bypass line were analyzed and compared at tilt angles of 0° to 20°. The results show that the maximum heat transfer rate was increased by approximately 35.5% using a horizontal arrangement.

Keywords: heat pipe, liquid bypass line, maximum heat transfer rate, start-up, thermal performance, temperature overshoot, thermal load.

[No. 110] **Study on the effects of flow characteristics on heat transfer mechanisms of pulsating heat pipes**

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Abstract. The heat transfer mechanisms of a pulsating heat pipe (PHP) are experimentally investigated to clarify the reason for the relationship between flow characteristics and thermal performance of a PHP. For this, a micro PHP with 5-turns and the hydraulic diameter of 0.8 mm is fabricated. Ethanol is used as the working fluid. Experiments are performed at various input powers in a vertical orientation. The oscillation amplitude is measured as the representative of flow characteristics using high-speed photography. The distributions of temperature and heat flux at the fluid-wall interface are measured using infrared thermometry. The heat transfer mechanisms of the PHP are quantitatively investigated through synchronization of flow and thermal images. As the input power increases, the oscillation amplitude increases 2.4 times and the contribution of the latent heat to the overall heat increases by 49%. This indicates the contribution of latent heat increases with the oscillation amplitude, resulting in a decrease of the thermal resistance of the PHP.

[No. 118] **Experimental Study of Loop Heat Pipes with Several Distributed Heat Sources**

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Abstract. The paper presents the results of experimental investigations of three loop heat pipes (LHPs) intended for simultaneous cooling of several distributed heat sources dissipating different capacities. The LHPs had one capillary evaporator joined to the main heat source and one condenser joined to the heat sink. Less powerful additional heat sources were located on the vapor and liquid lines. The working fluids were Freon-152a, ammonia and water. The LHP efficiency was estimated by the relation of the maximum heat load of the additional heat sources to the heat load of the main heat source. It has been shown that the maximum heat load of the additional heat sources on the liquid line is 36 W (60%) for the LHP with Freon-152a, 75 W (31%) with ammonia and 69 W (17%) with water. For the heat sources on the vapor line these values are equal to 15 W (15%), 16 W (5%) and 10 W (2%), respectively. It is

shown that the efficiency to cool additional sources is directly proportional to the relation between the heat capacity of a working fluid and the heat of evaporation.

[No. 123] **The design improvement of a heat exchanger with heat pipes based on the CFD modeling results**

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Abstract. The article deals with a comparative analysis of a heat exchanger with heat pipes of two designs for heat recovery from ventilation emissions. A brief description of the utilization devices used in ventilation systems for heat recovery of outgoing air is presented. The characteristic of the use of a heat exchanger with heat pipes in premises ventilation systems is given. The waste heat recovery analysis was carried out using the *ANSYS Fluent* software package. The simulation results are compared with the results of a direct physical experiment performed on a laboratory test bench.
***Key words*:** heat exchanger, heat pipe, thermal condition, condensation, evaporation, numerical simulation.

[No. 136] **High Thermal Conductive Carbon Fiber Radiators with Controlled Loop Heat Pipes**

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Abstract. Main results of development of high thermal conductive carbon-fiber radiators with LHPs are presented in this paper. LHPs are intended for controlled cooling of storage batteries and operating systems of the SC. Test results of radiator prototype with face sheets made of thermal conductive carbon-fiber reinforced plastic are considered in this paper. Scope of the radiator qualification tests including autonomous and full-scale tests is presented in the paper.

Keywords: loop heat pipe, thermal control system.

[No. 144] **Thermosiphon with combined evaporator and condenser cover**

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Abstract. The paper presents a technology for the formation of a hydrophilic coating in a thermosyphon evaporator. A method is proposed for hydrophobizing the condenser and improving the transport properties of the evaporator. The contact angle and the height of the liquid rise for the obtained coatings were measured. The dependences of thermal resistance and temperature head on the transferred heat flux for models of heat stabilizers made of steel and aluminum are obtained.

[No. 146] **Prospects for the use of additive technologies in the production of heat pipes**

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Abstract. This paper discusses key issues related to the prospects of using 3D printing in the production of heat pipes. As a result of the analysis of the key characteristics of traditional production methods, a number of problems are identified and the need for assessing the feasibility of using new technologies in the field of heat pipe production is identified. It has been found that 3D printing has several advantages over traditional production methods. The results of a comparative analysis of existing 3D printing technologies are presented: electron beam melting (EBM) and selective laser melting (SLM). The advantages and disadvantages of these technologies are identified. The study allowed us to determine the prospects for the use of 3D printing in the design of heat pipes.

Keywords: 3D Printing; SLM; EBM; Heat Pipes; Additive Manufacturing; Thermal Management; Thermal Resistance.

[No. 149] **Features of Loop Heat Pipes application on small spacecraft**

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Abstract. The application of Loop Heat Pipes (LHP) in small spacecraft is advisable and necessary due to their unique capabilities for transferring heat through small-diameter lines, comparable to the diameter of electrical wires, and the ability to regulate temperature and heat fluxes over a wide range. In this paper, we consider the features of LHP application in small spacecraft (SC). The world's first successful application of LHP took place precisely in the thermal control system of a small spacecraft.
Keywords: Loop Heat Pipe; Modeling of two-phase unit (LHP); TEMC modeling software.

[No. 150] **Meniscus liquid curvature influence in capillary grooves on heat transfer coefficient**

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Abstract. Due to evaporation process occurring in evaporating section of heat pipe the 80% of general heat goes through evaporating thin-film region of liquid meniscus. The research of influence of meniscus curvature to heat transfer coefficient proved that the most effective heat transfer region of evaporation section in capillary axial heat pipes is on contact line at a liquid/solid interface. A present work is focused on studying of evaporation process occurring in rectangular grooves of axial heat pipes. Several experiments were undertaken using a microscope. A model of heat pipe evaporator was created to conduct the experiment. Numerical calculations were obtained using experimental data.

Keywords: meniscus; groove; heat transfer coefficient

[No. 154] **Development of thermosyphon heat exchangers for heat recovery during gas compression**

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Abstract. In many technological systems, the heat of gas compression is removed to the environment. In this paper, it is proposed to use the heat of compressed air for heating the feed water at the input the heat recovery boiler by installing a thermosyphon heat exchanger. A schematic diagram of air cooling using a thermosyphon heat exchanger and an algorithm for its development are presented. Full-scale tests were carried out in the nitric acid production process system, which showed that the transferred heat flow was 1,330 kW, and the feed water was heated to 86 °C. Thermosyphon heat exchangers of this type are very perspective for utilization of gas flows heat.

Keywords: Thermosyphon; Heat exchanger; Heat recovery; Air cooling; Algorithm for developing

[No. 155] **Reliability analysis of axial groove heat pipes**

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Abstract. This paper is devoted to the study of reliability dual core axial groove heat pipes (AGHP) in the thermal control systems for space application (TCS). First of all, this concerns the reliability of heat pipes, as well as the expansion of their functionality and circuit solutions. The use of two AGHP made of a single core profile and installed close to each other provides greater reliability and manufacturability in comparison with one AGHP made of a dual core profile. However, this design option is more expensive. The paper presents design options for single core and dual core heat pipes.

[No. 156] **Investigation of the effect of microgravity on the thermal and operational characteristics of heat pipes based on the results of the space experiment**

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Review. Some results of the completed space experiment "Phasoperkhod" "Development and research of parameters of small-mass heat pipes for cooling systems, thermal stabilization of devices, equipment and spacecraft structure", which consisted in obtaining systematic information about the parameters of axial heat pipes in microgravity and the impact of space factors using a specialized flight experimental installation equipped with sensors and high-precision converting equipment, are presented.

Keywords: Axial heat pipe; Heat Transfer element; Thermal processes; Space experiment

[No. 157] **Operating experience of loop heat pipes for thermal regulation of spacecraft with long life cycle**

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Abstract. Results of application of autonomous thermocontrol means, based on loop heat pipes, mounted aboard spacecraft with long life cycle, developed in RSC «Energia» were reviewed. On example of sixteen years space flight aboard geostationary spacecraft «Yamal-200» and ten years space flight aboard module «Rassvet» of ISS stability of working of loop heat pipes and nonelectric tools of its regulating was presented under condition of different rate of variation outside heat fluxes affected on spacecraft. Data are given on the use reserve means of regulation of loop heat pipes. Some features of on-ground tests loop heat pipes after their integration into spacecraft were considered. Result efficiency of application loop heat pipes in spacecraft for various purposes was analyzed.

[No. 183] **Experimental study of thermal performance of a 3D-printed thermosyphon with flat evaporator**

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Abstract. We report our experimental study of the performance of a 3D-printed closed two-phase thermosyphon. Using laser powder-bed fusion (L-PBF) technique, the thermosyphon has been additively manufactured with stainless steel (316L), which has excellent resistance and compatibility with chemicals and coolants. The specific feature of the thermosyphon and the novelty of the study is that the device is printed as a single unit, including an extruded helical heat exchanger into the condenser body and integrated pillar arrays in the evaporation section. The evaporation, adiabatic, and condensation section lengths are 20 mm, 30 mm, and 50 mm, respectively. The micropillars size is 2.5 mm. We considered the effects of the filling ratio of acetone as a working fluid and heat flux on the thermal performance of the thermosyphon. The filling ratios used are 0%, 1.7%, 4.9%, 6.3%, 10.4%, 17.1%, 27.9%, 40.5%, 50.4%, 64.2%, 76.6%, and 84.1%. We found that the minimum total thermal resistance is 0.48 °C/W which is achieved at the minimal value of the filling ratio of 1.7 % and thermal power of 13.7 W. The filling ratio of 4.9% shows the best stable thermal performance of the thermosyphon.

[No. 185] **Experimental researches of start-up and blocking of loop heat pipes in the thermal control system of a spacecraft**

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Abstract. Thermal control systems are designed to maintain the operating temperature range of the spacecraft's onboard equipment. One of the most promising thermal control methods is based on loop heat pipes. The article showcases the results of thermal vacuum tests of the thermal mock-up of the thermal control system under various thermal influences. In addition, the article describes how the power of the electric heater installed on the compensation cavity of a loop heat pipe influences the shut-off of the loop heat pipes. And finally, the article analyses how the start-up and shut-off of loop heat pipes occurs at different power fed to the compensation cavity of loop heat pipes and at different temperatures of the evaporator of loop heat pipes.

[No. 187] **Numerical and Experimental Studies of the Thermosiphon Effect in Scaled-Down Models and Nuclear Plants with Liquid Sodium**

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Abstract. In operation of BN-600 and BN-800, the Russian sodium-cooled fast reactors (SFRs), it was discovered that the pipelines and the equipment were heated up in the shutdown loop where the pumps were stopped and the heat was removed only by the heat losses through the heat insulation. The result of the studies showed that the heat up was caused by intensive free convection of sodium (a thermosiphon effect). This paper discusses operating experience in a Russian SFRs and evaluates the scale of the thermosiphon effect in the 0.8 m inside diameter pipelines. Provided are the results of special tests on scaled-down pipeline models — two closed cavities filled with liquid sodium (Prandtl number is near 0.008). The length-to-diameter ratio for the cavities is 5 and 20; the Rayleigh number (calculated by the cavity diameter) is 5×10^6 and 300, respectively. The tests are performed with heat supplied and removed at the ends of the cavity at different inclination angles. A CFD analysis is performed with using CONV-3D, a quasi-DNS code. As a result of the analysis, a flow pattern and flow characteristics are obtained. The obtained results are compared with the known thermosiphon data.

[No. 192] **The effect of operating parameters on the heat transfer in the heat pipe**

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Abstract. Heat pipes are a good solution for temperature stabilisation, for example, of microelectronics, because these kinds of systems are without any moving parts. The experimental research of the operating parameter influence on the heat transfer in a cylindrical heat pipe have been conducted. The effect of the working fluid properties and the porous layer thickness on the heat flux and temperature difference in the heat pipe has been investigated. The temperature field of the heat pipe has been investigated using the IR-camera and K-type thermocouples. The data obtained by IR-camera and K-type thermocouple have been compared. It is demonstrated the power transferred from the evaporator to the condenser is linear function of the temperature difference between them.

Keywords: heat pipes, porous media, infrared thermography, heat transfer

[No. 196] **Long-term operation experience of nickel-hydrogen storage batteries with LHP on the SC "Yamal-200"**

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Abstract. The use of heat pipes (HP) in the thermal control system (TCS) of a nickel-hydrogen battery (NAB) as part of a spacecraft (SC) improves the mass characteristics of the NAB together with the TCS and brings flexibility to the configuration of the spacecraft. The organization of heat removal from the NAB directly with the help of HP is provided in the Yamal-200, BelKA, KazSat-2 spacecraft and in the NAB 17NV-95. Variants of the organization of the TCS with the use of HP are considered on the example of various spacecraft. The choice of the optimal design of the NAB and TCS depending on the thermal conditions is demonstrated. The stability and reliability of ensuring the thermal regime of the NAB during its long-term operation as part of the spacecraft is shown.

[No. 207] **Heat transfer characteristics in radial rotating heat pipes under high-speed rotation and different filling ratios**

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Abstract. Turbine disks, as key safety parts of aero-engines, have maximum weight and stress, which bears extreme centrifugal and thermal stresses at a large temperature gradient. Heat pipes have the advantages of simple structure, high thermal conductivity, and operational stability. Therefore, the combination of radial rotating heat pipe and turbine disk, which aims to reduce stress, control weight, and optimize temperature, has potential applications. This study deals with the numerical simulation of high-speed rotating heat pipes to predict their heat transfer performance and internal two-phase flow. The multiphase numerical simulation model of phase change and rotational centrifugal force is established using a user-defined function. The heat transfer performance and flow motion of thermosyphon and radial rotating heat pipes are compared with the changes in centrifugal acceleration from 100 g to 10000 g, liquid filling ratio from 25% to 125%, and heat flux from 38 W to 315 W. Results show that the effective thermal conductivity of rotating heat pipes slightly decreases with the increasing rotating speed, because the high centrifugal acceleration boiling phenomenon in the evaporator section of the heat pipes is inhibited, but the equivalent thermal resistance of rotating heat pipes increases to no more than 10%. In addition, compared with thermosyphon the rotating heat pipe with higher filling ratio (>50%) is required and higher heat transfer limit may exist. To summarize, radial rotating heat pipes can still work steadily at high-speed rotation, satisfying the operation requirements of aero-engines.

[No. 209] **Theoretical heat transfer analysis of a horizontal two-phase loop thermosiphon receiver**

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Abstract. A horizontal two-phase loop thermosiphon (HLTS) receiver suitable for solar parabolic trough collectors operating at 473.15-673.15 K was developed. The heat transfer performance was theoretically investigated in this work. The heat transfer capacity, which is compromised by the boiling limit, cooling limit, and flow limit, was analyzed. In addition, a steady-state heat transfer model based on the energy, momentum, and mass balance equations was established to evaluate the intermediate temperature heat transfer properties of the receiver. The results show that the optimal filling ratio of the HLTS should be in the range of 30%-43% when operating at the intermediate temperature range. The heat transfer capacity of the receiver is higher than 9.4 kW, which could meet the requirement of the parabolic trough collector (PTC). The research provides theoretical support for the application of the HLTS-based receiver in the field of the PTC.

[No. 228] **Comparison between closed-end oscillating heat pipe and closed-loop oscillating heat pipe by numerical calculation**

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Abstract. This study investigated the Closed-end Oscillating Heat Pipe (CLOHP) and Closed-End Oscillating Heat Pipe (CEOHP) using numerical calculations. Although various studies have been conducted on CLOHP and CEOHP, there are still many unclear points regarding the difference in performance. We used a one-dimensional mathematical model of CLOHP and CEOHP to simulate the flow, and compared the heat transfer performance, internal flow, and pressure distribution, focusing on the low heat input. The results showed that the heat transport performance of the CEOHP was higher than that of the CLOHP at low heat input. This is largely due to the pressure propagation and vibration amplitude distribution in the CEOHP tube.

[No. 230] **Development of miniature loop heat pipe for thermal management of high-heat-flux devices**

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Abstract. This paper describes the development of a miniature loop heat pipe (mLHP) for cooling high-heat-flux devices such as discrete semiconductors. Based on the numerical design, we fabricated the mLHP that comprises an evaporator integrated with the compensation chamber (15 mm × 16 mm × t3 mm), plate-type condenser (12.5 mm × 12 mm × t2 mm), and 100-mm transport lines (O.D. 1.6 mm). We used Shirasu porous glass (SPG) as the wick and ethanol as the working fluid. The heat transport performance was tested under a few kinds of heat-dissipation conditions at the condenser using a copper plate, a small cooling fan, or an aluminum cold plate (35 mm × 20 mm × t3 mm). In particular, the mLHP heat transport performance was 15 W (60 W/cm2) for the aluminum cold plate condition (refrigerant: water, flow rate: 1 ml/min, inlet temperature: 25℃). The heat source and evaporator temperature, as well as the thermal resistance at 15 W, were measured as 249.8℃, 142.2℃, and 0.72℃/W, respectively. According to the numerical calculations, the heat transfer coefficient of evaporation in the evaporator was approximately 24,000 W/m2/K.

[No. 232] **Thermo-fluid behavior in a micro-grooved evaporator of LHP based on microscale infrared / visible observations**

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Abstract. In this paper, a thermo-fluid behavior in an capillary evaporator of a loop heat pipe (LHP) is studied experimentally. In our group, it was clarified that the micro-grooves on the inner wall of the evaporator improved wettability and thereby improved the heat transfer performance. In order to investigate this further, the effect of the micro-grooves on a thermo-fluid behavior was investigated while changing the widths of the vapor grooves of the porous wicks. The experimental setup simulated the inside of the LHP evaporator, and consisted of a heating plate, a porous wick, and a liquid reservoir, and observed with a microscopic infrared and a visible camera. The porous wicks are made of a stainless steel whose pore radius is 4.5 μm. Three kinds of porous wicks with different vapor grooves widths were used. The vapor grooves widths are 1.0 mm, 0.5 mm, 0.2 mm. For the heating plate, the normal plate and micro-grooved plate are used. As results, the heat transfer coefficient and the maximum heat flux were improved by the micro-grooves. Furthermore, both of them increase more greatly as the vapor grooves width increases.

[No. 233] **Thermal performance of micro pulsating heat pipes engraved on a thin copper plate**

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Abstract. The thermal performance of micro pulsating heat pipes (MPHP) has been investigated experimentally. The MPHP was engraved on a 1 mm thick copper plate of 25x100 mm. The upper cover was made with Plexiglas plate so that the flow motions were visualized with a high-speed video camera. The working fluid was FC-72, degassed. The experimental condition was a temperature-boundary, i.e., the heating part was maintained at 75ºC and the cooling part at 23ºC in general using water jackets and constant temperature circulation baths. The experimental parameters were channel size (0.8x0.8 mm, 0.6x0.6 mm), number of turns (7,9), and dual patterns of channel size (1.0-0.5 mm) primarily for investigating optimum design for horizontal installation of MPHP. In single diameter MPHP, the better thermal performance was found in the 0.8x0.8 mm than 0.6x0.6 mm. The former showed circulating pattern and the later showed oscillating patter. But it failed to operate when laid horizontally. A dual-diameter MPHP was found to work in horizontal installation and the heat transfer rate was comparably good as that of vertical installation. The optimum value of the ratio of the larger channel size to the smaller channer size was found to be 2.0 in the present experimental conditions.

[No. 237] **Joint application of thermal storages and heat pipes for cooling spacecraft electronics**

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Abstract. The report is focused onways of cooling powerful electronic devices operating during intermittent communications sessions followed by long pauses aboard spacecraft. It is beneficial and cost-effective to use alternative renewable energy sources of passive type to cool them. These energy sources are distinguished by high endothermic effects, arising from phase transitions of working substances, accompanied by a slight change in an occupied volume. This makes it possible to construct thermal energy storage (TES) systems both autonomous and integrated into complicated complexes, in which the dissipated energy is transported outside of the electronic devices towards the spacecraft heat sinks using heat pipes. The report highlights the experience gained while designing that type of two-phase systems. Analytical methods for calculating the required parameters when the thermal storages and heat pipes are used together are presented. The problems of transient heat conduction with phase changes for the systems of contacting bodies with uneven contact surfaces between them have being solved. The technological and engineering solutions necessary for manufacturing the space electronics for different types of spacecraft are revealed. The results of testing the electronics, which employ composite dielectric shape-stable materials, not requiring pressurization of the occupied volume, are highlighted. A method, that enables multidimensional conjugated phenomena to be presented as a result of the realization of one-dimensional physical processes on the example of computer simulation of the thermal conditions for the radio equipment with heat-loaded electronic components is proposed.

[No. 238] **A study of the thermophysical characteristics of short linear heat pipes**

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Abstract. The results of studies by solving the inverse thermal conductivity problem the heat capacity of the evaporator of short linear heat pipes (HP's) with a Laval nozzle-liked vapour channel and intended for cooling spacecraft and satellites with strict take-off mass regulation are presented. Mathematical formulation of the inverse problem for the HP's thermal conductivity in one-dimensional coordinate system is accompanied by the results of studies using the monotonic heating method in a vacuum adiabatic calorimeter the HP's surface temperatures over the entire temperature load range on the evaporator, and thermal resistance in stationary states. By using the experimental results of thermal resistance R_{HP} obtained at high thermal loads and the working fluid boiling beginning in the evaporator, HP's surface temperature experimental data around the HP's evaporator allow us to determine the heat capacity C_{ev} of the evaporator by solving the inverse thermal conductivity problem (ITCP).

[No. 239] **Technology for manufacturing elements of thermal control coating for spacecraft**

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Abstract. Various types of thermal control coatings (TCC) are used in the systems for ensuring the thermal regime of spacecraft. One such TCC is the K-208Sr coating of the «solar reflector» class. In this publication, a brief analysis of the production technology of the thermal control coating and its characteristics is made. It also describes the main stages of the technology that are carried out by the «Center of Optical Glass» limited liability company in the manufacture of elements of thermal control coating for spacecraft.

[No. 241] **Development of a radiator based on heat pipes and thermal-conducting carbon fiber for space applications**

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Abstract. An essential part of the spacecraft is a radiation heat exchanger (RHE), which provides heat removal from the cooled equipment or power plant (Fig. 1) [1]. In structural term, it is a device consisting of heat pipes and a radiating surface attached to them, which can be thin-walled plates made of aluminum, beryllium or copper, depending on the temperature. The choice of these materials is determined by their good thermal conductivity, which minimizes the amount of heat pipes that supply it with heat. The current trend of increasing the power of spacecraft, both in terms of increasing the amount of electronic equipment and increasing the number of their power plants, causes the necessity of reducing the specific mass of RHE. Reducing the mass of RHE can go in two directions. The first is a decrease in the mass of heat and their amount, which is associated with an increase in their heat transfer capacity. The second direction is the search for heat-conducting materials for a radiating surface with a lower density than that of the materials mentioned above.

Keywords: Radiator on heat pipes, Thermal-conducting carbon fiber, Radiating surface, Radiation heat exchanger.