Luikov Heat and Mass Transfer Institute

National Academy of Sciences of Belarus

Two-phase passive thermal devices as a cooling system of power electronic, data-centres, electrical transport, solar receivers.

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Abstract

Two phase thermal **passive** systems do not have moving parts and are compact, reliable, and cost-effective. Fluid motion in these passive devices could be driven by capillary force, gravity, osmotic pressure, and/or concentration gradient. The fundamental mechanisms and limitations of transport phenomena for passive systems are highlighted, followed by their applications in heat pipes, thermosyphons, vapor chambers, electronic devices, solar cooling, thermal energy storage, and electric transport. The capabilities of the passive systems are limited based on the balance between the driving force and transport resistance. Based on the fundamental understanding of fluid flow and phase change in passive systems, this study proposes associated transport phenomena and quantitative criteria to determine the maximum heat transfer rate, the transport distance, and minimum pore size of wick structures (when relevant) in these passive devices.

Boiling and condensation are the key heat-transfer modes with high heat transfer coefficients and widespread applications in various industries and processes. The classical case for boiling is nucleate pool boiling, which started to be investigated at the beginning of the 20th century. Despite a long-term history of research into boiling heat transfer, we still have two groups of scientists who believe that the thermophysical properties of the boiling surface and its microstructure impact the heat transfer coefficient, and another group denies this impact. Therefore, more details and thorough experiments should be performed to extend our knowledge of various parameters impacting basic boiling characteristics.

Flow boiling is an even more intense heat-transfer process and is widely used in various heat-transfer devices and equipment, including thermal and nuclear power plants. This type of boiling is more complicated than nuclear pool boiling and contains more characteristics/parameters, which have to be calculated. Condensation is another high-intensity heat-transfer process which is widely used in the Rankine power cycle and other industrial processes. Therefore, it is important to follow up with the latest advances in boiling and condensation.

Part 1

Contracts:

Short Historical overeviews of the Porous media laboratory Luikov HMTI NAN, Belarus with HUAWEI, CHINA 2014 – 2022 (some examples)

1. Contracts between **HUAWEI** and Porous media Lab., Luikov Insitute, HMTI NAN Belarus , 2014 – 2018.

1. № HTS-HMTI- 01, YB2014090048. 30.09.2014
"To research and develop the technology to enhance the hot spot natural convection cooling capacity"

2. № HTS-HMTI- 02. YBN2017060028. 31.12.2016 - 21.10.2017
"Server LHP cooling system design"

3. № PPA3071BLR18110500413638903796 73 от 05.11.2018
"Development, fabrication and research of compressible vapor chamber (CVC)"

4. № YBN 2017060028 , 11.2017 – 2018,
"Anti-Gravity Heat Pipe"

2.Contracts between BELHUAWEI (SOW) and Porous media Lab., Luikov Insitute, HMTI NAN Belarus , 2018 – 2022.

1. SOW №1, 2019-2020
“Development, Fabrication and testing of the loop thermosyphon (LTS) with specified technical characteristics”.

2. SOW №2, 2019-2021
“To improve the thermal performance of the existing Vapor Chamber (hereinafter VC)”.

3. SOW №3, 2019-2020
“Compressible Vapor Chamber (CVC)”.

4. SOW №4, 2020-2021
“Development the aluminum thermosyphon (LTS)”

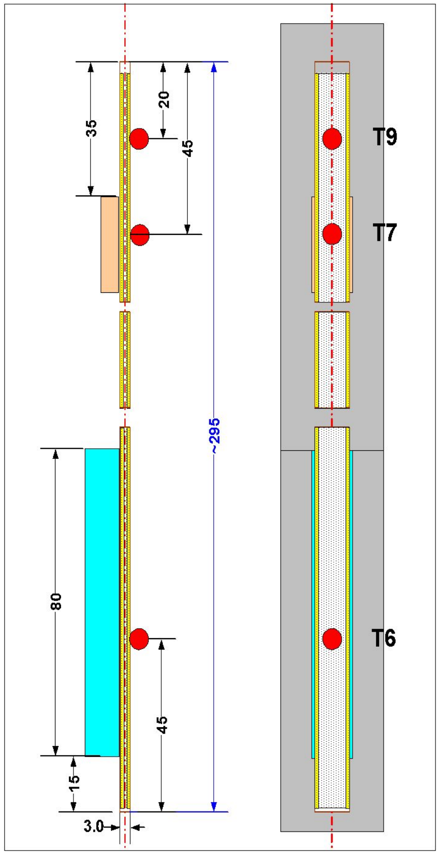
5. SOW №6, 2021-2022 (finalizing)
“Development, fabrication and testing of the aluminum evaporator, satisfying the specified technical characteristics”.

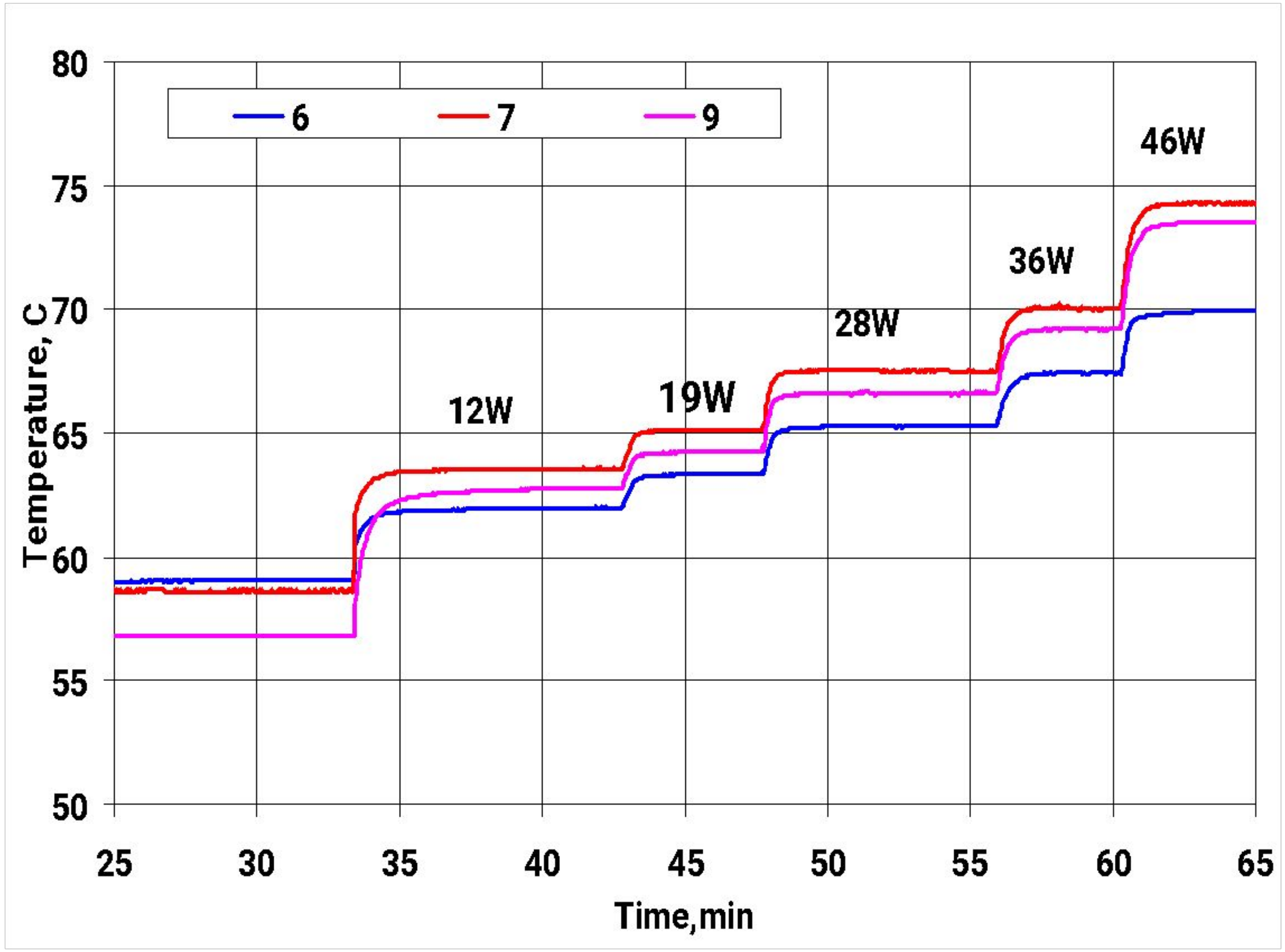
6. SOW №12, 2022 -2023 (in progress)
“To develop a high power evaporator with a porous structure that meets the parameters of this SOW”.

1. № YBN 2017060028 , 11.2017 – 2018,
“Anti-Gravity Heat Pipe”

- **Developed and tested antigravity copper flat heat pipe (heat source above the heat sink) has the open type heterogeneous porous structure (sintered powder) which includes particles of different size and form, pore sizes decrease along a direction from the condenser to the evaporator.**
- **The designed antigravity flat heat pipe has a low mass and low cost production. The experimental results represent a certain advances over state-of-the-art cooling devices in terms of performance, robustness and simplicity. At a heat load of 35 W, the surface temperature of the heat pipe is near 70°C for water as the working fluid.**

Anti-gravity flat heat pipe - 300 mm long, 12 mm width and 3 mm thick





Temperature/time dependence of the heat pipe evaporator and condenser at various heat loads: 6-condenser, 7 – evaporator, 9 – top of the evaporator

2. **Vapor chambers with water as a working fluid**

1. “Development, fabrication and research of compressible vapor chamber (CVC)”, 2018.

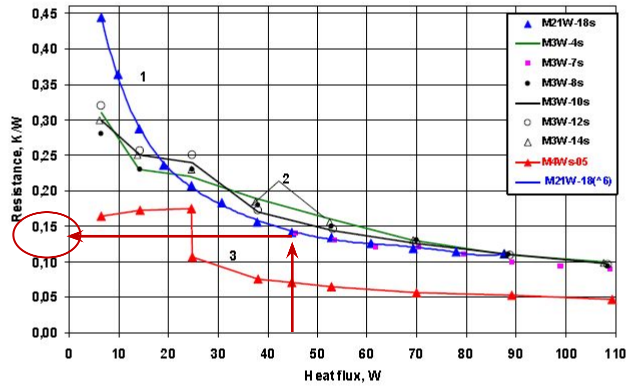
2. “To improve the thermal performance of the existing Vapor Chamber (hereinafter VC)” 2019-2021.

The Compressible Vapor Chamber (CVC) and Capillary Week Structure

1.Compressible vapor chamber (CVC)

1st stage delivery

CVC sample

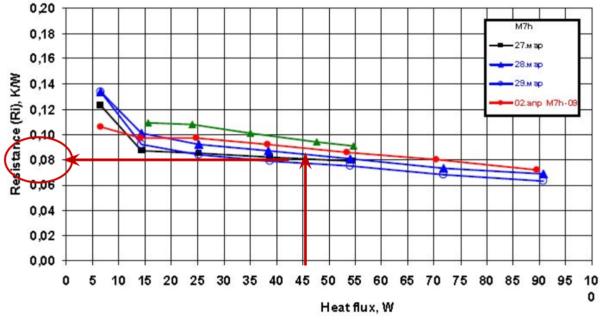


CVC sample of the 1st stage tested data

CVC sample main performances
Total thickness □ ***5.8mm***
Working fluid pure □ ***degassed water***
Evaporator outer diameter □ ***23mm***
Thermal resistance □ ***0.12K/W (45W)***
Liquid cooling temperature □ 6***0ºC***

2nd stage delivery

CVC evaporator design

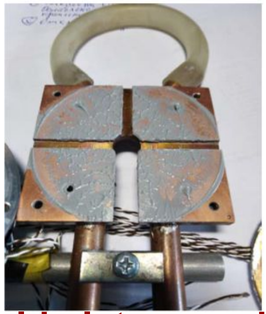


CVC sample of the 2nd stage tested data

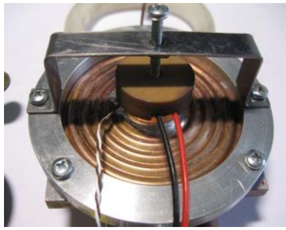
CVC design#1
Rth=0.072K/W – 0.084K/W @60oC, 45W

March 27th, 2019 – April 2nd, 2019

Experimental setup overview



Cold plate overview



Heater with holder overview

Rth < 0.1K/W target was successfully achieved. The main improvement is evaporator wick design: HTC was increased from 25,000W/m^{2}K □ to 75,000W/m^{2}K

Conclusions

- 1. In the process of performing the work, three CVC constructions have been developed, manufactured and tested to transport the required heat fluxes in a vertical orientation. CVC 1 has a porous coating on the surface of the evaporator and a mesh coating on the surface of the membrane for transporting liquid. CVC 2 also has a porous coating on the surface of the evaporator, and a porous path for transporting liquid from the bottom of the CVC to the surface of the evaporator. CVC 3 is equipped with an additional metal ring in the area of the condenser to increase the gap between the capacitor and the membrane. The working liquid in the CVCs is distilled water. 2. In the process of experiments, the optimal sizes of the CVC evaporator were determined. The diameter of the evaporator is 34 mm, the thickness of the porous coating is 0.7 mm. Copper powder with particles of a dendritic form and dimensions of 63–100 μm was used for the porous coating of the evaporator. 3. All three selected types of CVC ensure that the parameters required in the technical specification are met: the transmitted heat flux is not less than 45 W, thermal resistance is 0.1 K/W, and the thickness of the device is not more than 5 mm. Transported heat flux exceeds the required. 4. CVCs have extended connections of individual elements. In this regard, there is a high probability of the existence of micro-leaks that cannot be parameters. 5. In some cases, in the manufacture of CVCs using high-temperature processes (welding, brazing), its elements may be deformed.determined by traditional methods. Since the internal volume of the CVC is very small, and low pressure must be maintained in it, even a small amount of air leakage can significantly degrade its

2. Statement of Work No. 2 (SOW-2)

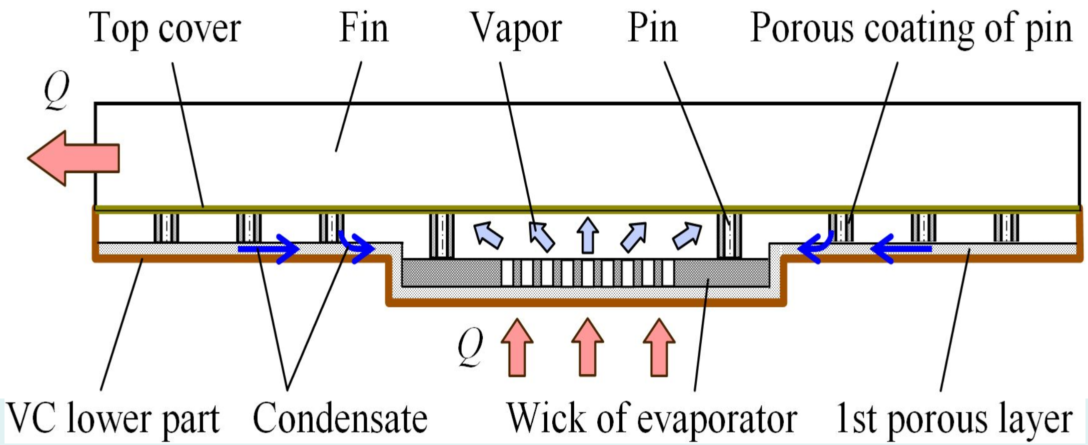
Improvement made the thermal performance of the existing vapor chamber (VC) (50% MORE EFFICIENT)

- **Project Target --- (Twenty two VC's were delivered)**
- Temperature difference of the evaporator is reduced by 50% + (from 14.3 to 8 K) with heat flux 104 W/cm^2.
- Increased heat flux of the vapor chamber by 50%+ (from 104 to 135 W/cm ^{2}) with same temperature difference(14.3 K).

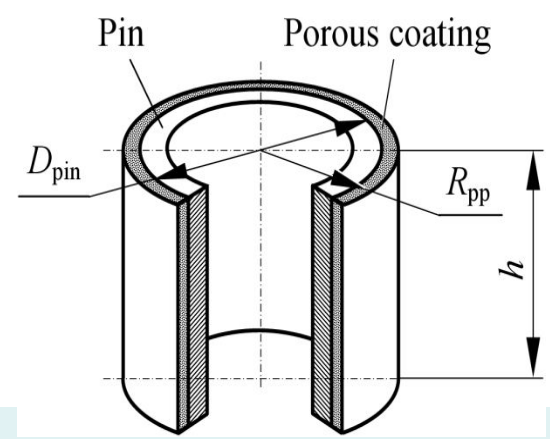
Vapor chamber with heterogeneous copper porous wick

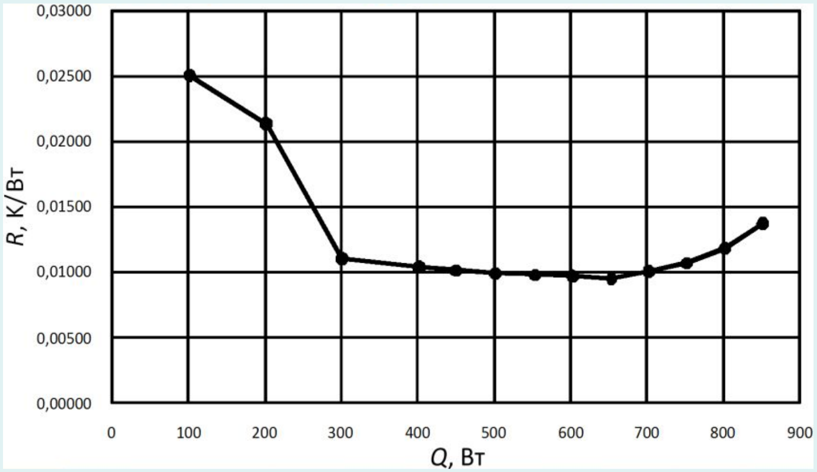
SOW-2

Vapor chamber



Pin with porous coating



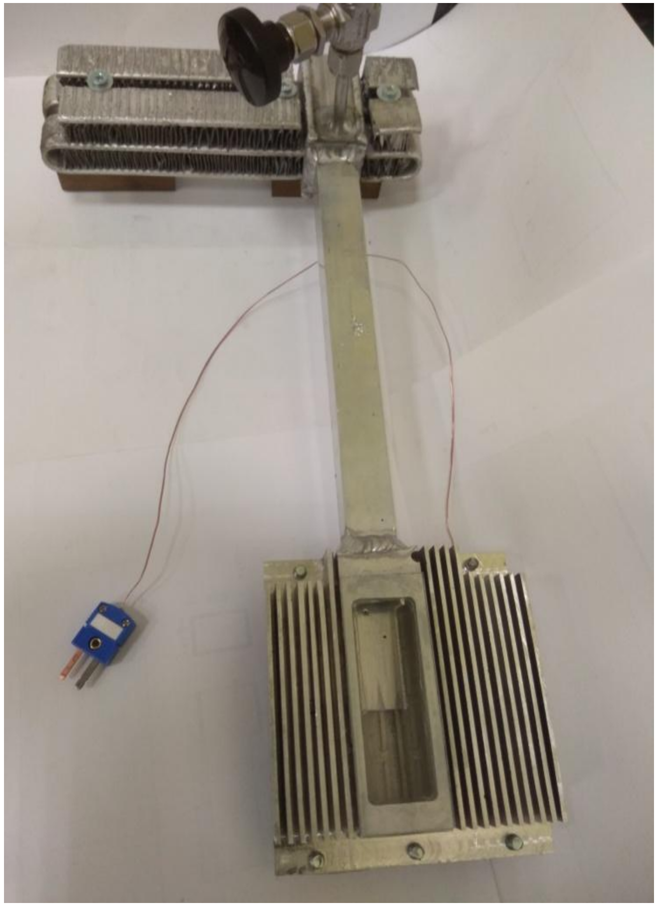


VC thermal resistance depending of the heat load

Characteristics of the innovated VC:

- VC heat load was 500 W with heat flux 104 W/cm^2.
- Working temperature (temperature of the vapor inside the chamber) of the VC was not higher than 70°C.
- Temperature difference of the evaporator was 14.3 degree when the working temperature was 70 °C.
- VC was cooled by fins and airflow in longitudinal direction.

1. BELHUAWEI SOW №1, 2019-2020
“Development, Fabrication and testing of the alumina loop thermosyphon (LTS) with specified technical characteristics



- *The design of an aluminum annular thermosiphon (LTS) for cooling high-power electronic devices has been developed, made and studied.*

- *R245fa is used as a working fluid.*

- *Heat flow of 420 W with a total thermal resistance R of no more than 0.12 K/W from the heat source to the ambient air is transferred*

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SOW №1, 2019-2020
"Development, Fabrication and testing of the alumina loop thermosyphon (LTS) with specified technical characteristics

- *Thermal resistance of LTS is near R = 0.02 K/W with a heat transfer coefficient h = 110,000 W/m^{2}K. The thermal resistance of such a heat exchanger between the heat sink and the cooling air is 0.076 - 0.08 K/W. A high vapor pressure (up to 7 bar) is available in the LTS cavity when R245fa is used as a working fluid.*
- *The maximum heat flow transferred by the LTS (acetone as a working fluid) exceeded 500 W with a heat flux density of more than 100 W / m2.*
- *The thermal resistance of the tested samples of the LTS evaporators was within 0.1 - 0.05 K / W. The best heat transfer rates were obtained for samples of evaporators with mini grooves and a minicoating of porous AL2O3 with a thickness of 50-200 microns. The heat exchangers --- condensers available for manufacture had a thermal resistance of 0.06 - 0.1 K / W.*

Members of Porous media Lab.HMTI.AS.NANB

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