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PULSATING HEAT PIPE (PHP)
AS A VERSATILE THERMAL MANAGEMENT TOOL

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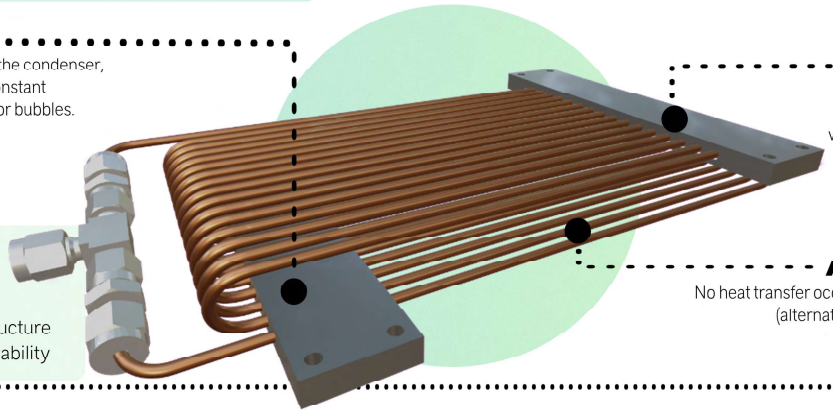
STUDY OBJECTIVE
To gain a deeper understanding of the physical phenomena governing Pulsating Heat Pipes (PHPs) and to optimize their design and development process.

WHAT IS A PHP?
Passive heat transfer device consisting of a meandering capillary structure partially filled with a working fluid[1]. Heat generated in the evaporator section is transferred to the condenser through both conduction in the channel walls and latent and sensible heat transfer with the working fluid.

HOW DOES IT WORK?

CONDENSER
The working fluid releases heat to the condenser, which is usually maintained at a constant temperature. Condensation of vapor bubbles.



EVAPORATOR
Heat input leads to latent and sensible heat transfer between the evaporator and the working fluid, resulting in bubble nucleation and growth.

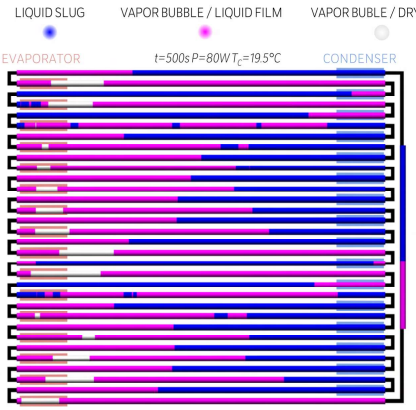
ADIABATIC ZONE
No heat transfer occurs. Intermittent slug-plug flow (alternating liquid slugs and vapor plugs) transports heat along the pipe..

ADVANTAGES
- Passive operation
- Design simplicity
- No internal capillary wick structure
- Ease of integration and adaptability

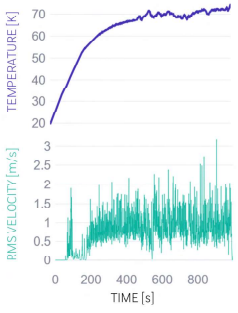
MAIN CHALLENGE
Incomplete understanding of the relationship between internal physical mechanisms (*two-phase flow, heat transfer*) and design parameters (*geometry, fluid properties, boundary conditions*).

NUMERICAL

CASCO v4.0 1D transient simulation software[2] (developed by CEA) is used to predict PHP performance and behavior under various input parameters, such as structural geometry, working fluid, thermal boundary conditions.



Schematic representation of fluid distribution inside the PHP channels within CASCO.



CASCO simulated evaporator temperature and root-mean-square fluid velocity temporal variation.

EXPERIMENTAL

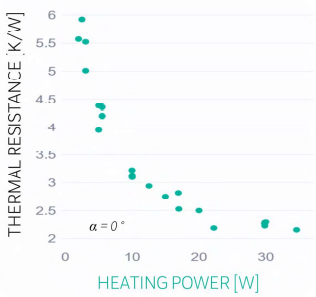
A 16-turn tubular PHP was manufactured using a copper tube with a 1 mm internal diameter and a 0.6 m adiabatic zone length. PHP was tested at varying heating powers and inclination angles.

Experimental parameters

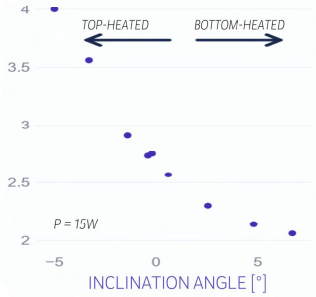
Heating power	Inclination angle	Cooling Temp.	Working fluid
2 – 40 W	**-5 to +6 °C**	**20 °C**	**Acetone**

Key observations

Fluid movement initiated at low heat inputs.



Strong dependenance of the PHP performance on the inclination angle, due to gravity effects.



APPLICATION DOMAINS

EMBEDDED SYSTEMS
Enhancement of heat dissipation for small-scale electronic components (CPUs, GPUs, ...).

HYPERSONIC VEHICLES
Cooling of high-temperature leading edges on hypersonic vehicles and spacecraft during atmospheric re-entry.

BATTERY COOLING
Improvement of temperature regulation and cooling efficiency in battery packs for electric vehicles and other high-performance applications.

HEAT HARVESTING
PHPs can be used to recover thermal energy from waste heat sources, such as solar power, contributing to energy efficiency improvements.

References
[1] Akachi, H. (1993). *U.S. Patent No. 5,219,020.* Washington, DC: U.S. Patent and Trademark Office.
[2] Nikolayev, V. S. *Physical principles and state-of-the-art of modeling of the pulsating heat pipe: A review.* Applied Thermal Engineering, 195, 117111 (2021).

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