Pulsating heat pipe and its potential application

POTPLOS

Performance Optimization of
Two-phase Passive Loop System

Dipartimento di Ingegneria e Architettura

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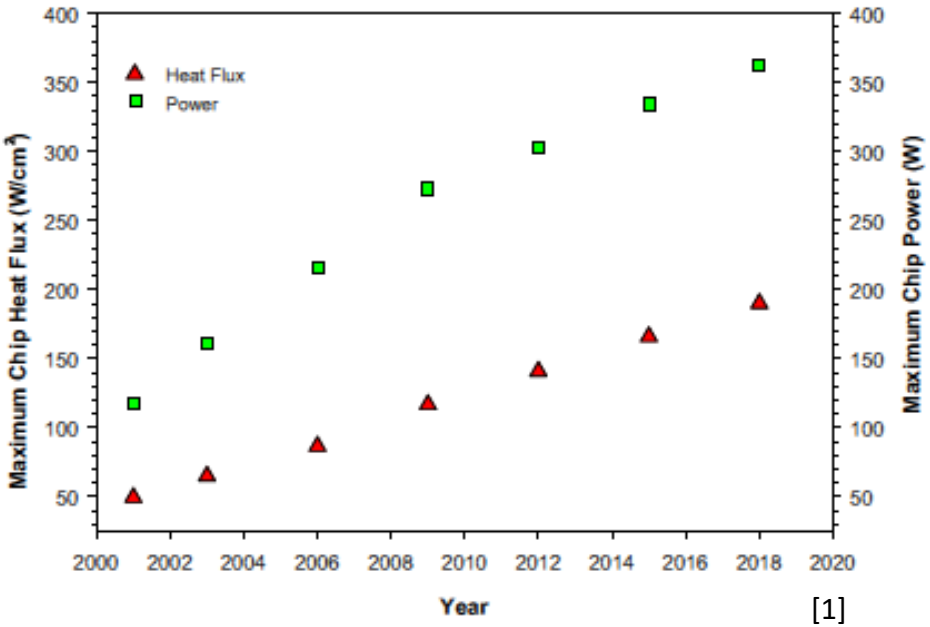
Outline

- Thermal management problem
- Heat transfer device
- Pulsating heat pipe (PHP)
- 10 examples of potential PHP applications

Thermal management issue

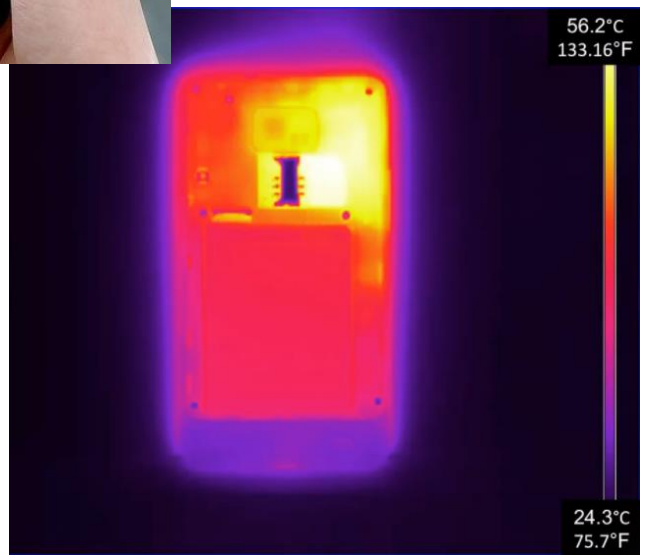
Increasing heat flux and power of microprocessor chips



[1]

High temperature in electrical devices reduces their performance and reliability

Image by JESHOOTS-com/Pixabay



[2]

Top Priority : Innovative heat transport devices

- high thermal performance
- Compact
- low-cost

Role of Heat transfer device

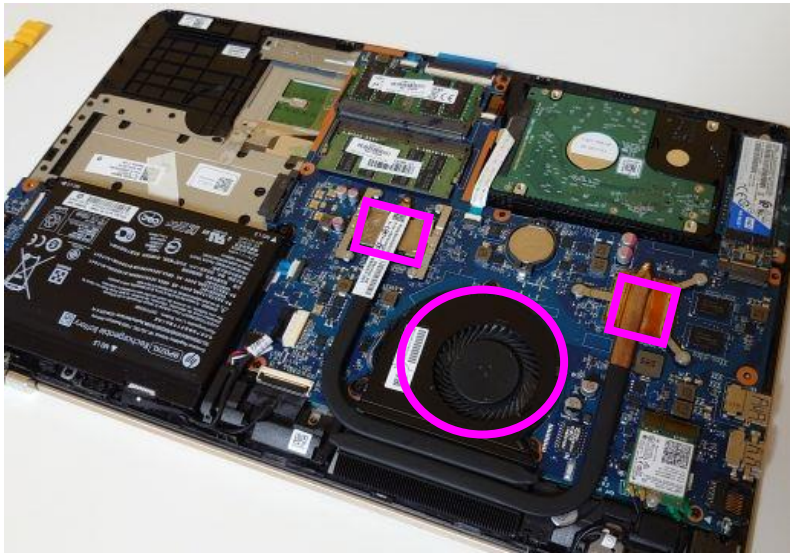
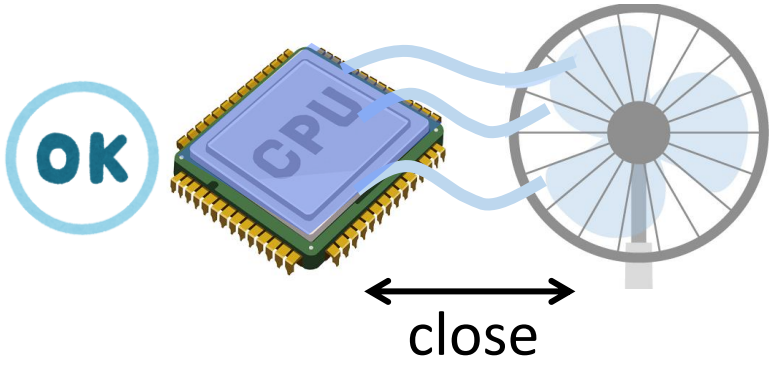
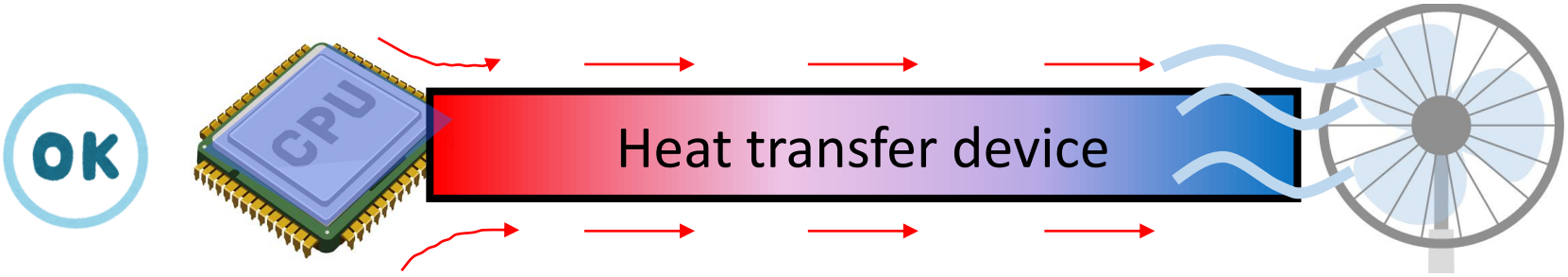


Image by photo AC #4113586



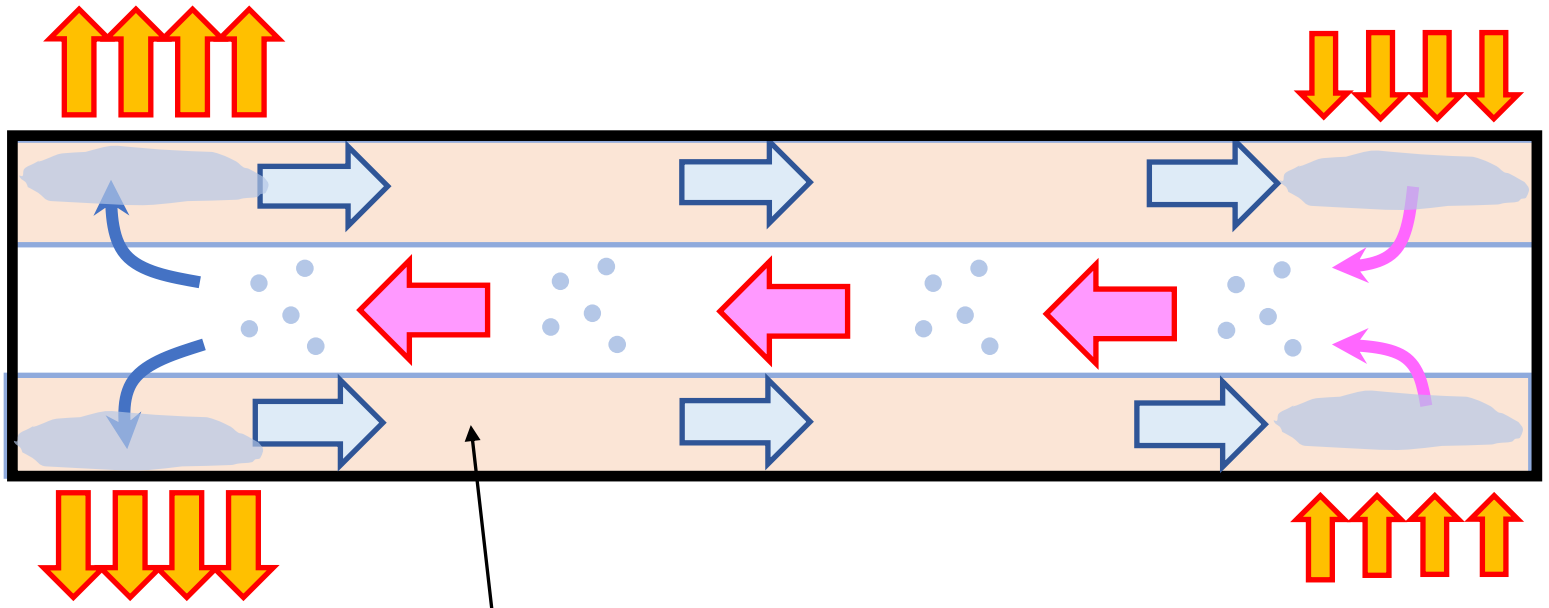


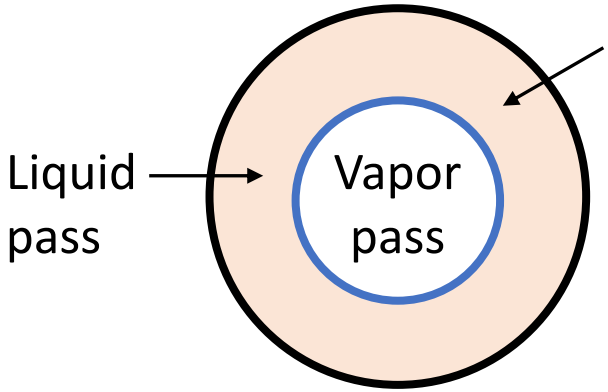
Heat pipe

Two-phase (vapor and liquid) heat transfer device

Condensation

Evaporation





Wick structure pumping up liquid by **capillary force**

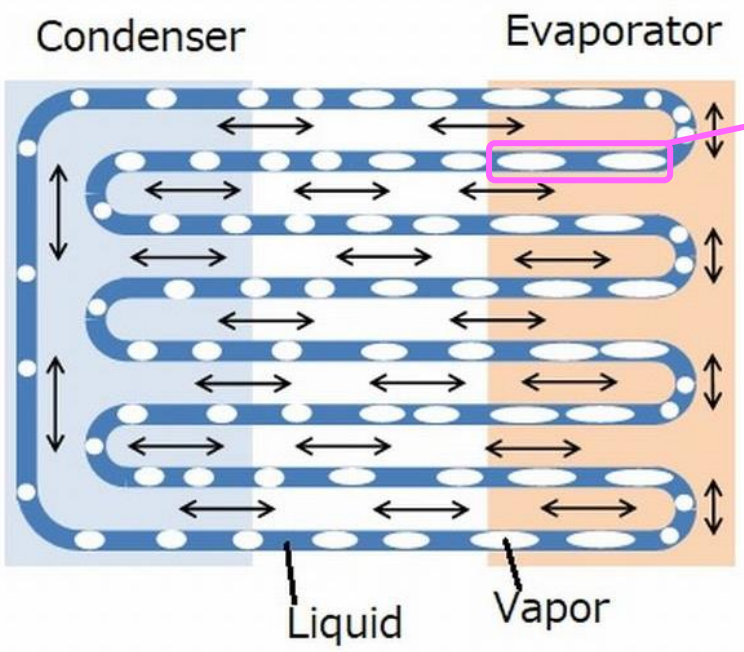
Groove-type

[3]

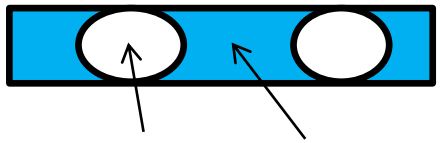
Powder-type

[4]

Pulsating heat pipe (PHP)



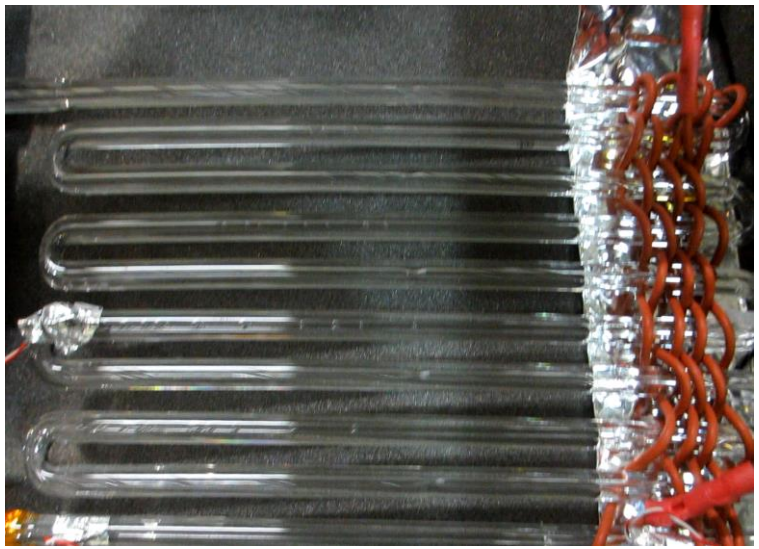
Small diameter tube/channel



vapor plug
(vapor bubble)

liquid slug

Self-excited oscillation of vapor and liquid



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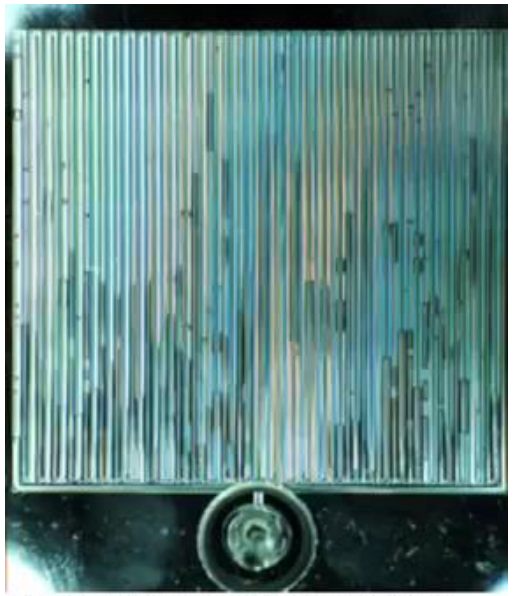
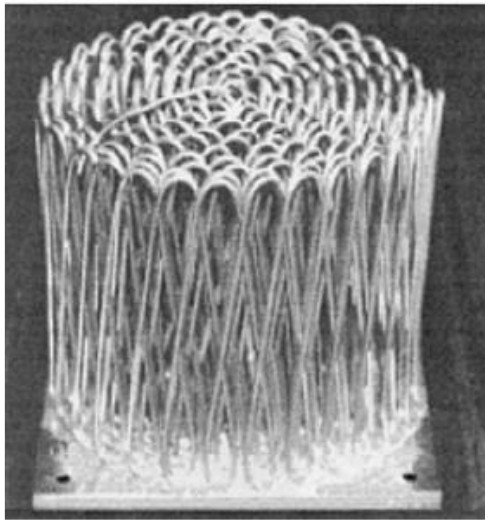


[6]

Advantages of PHP

- ✓ High effective thermal conductivity
- ✓ Large contact area
- ✓ Simple wickless-structure
- ✓ Compact and Light weight
- ✓ Flexibility
- ✓ Low cost - commercially available tube

[7]



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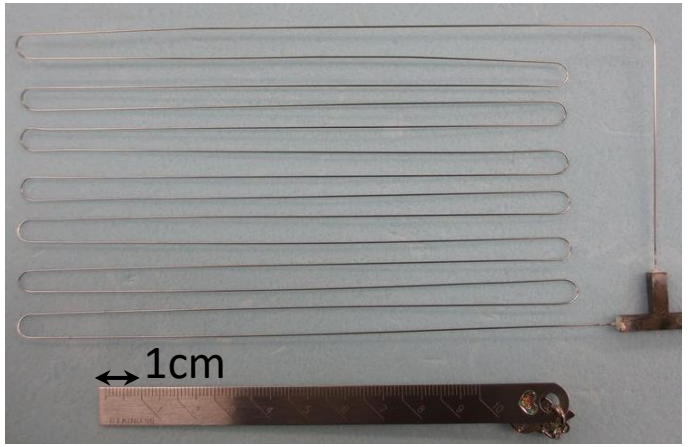
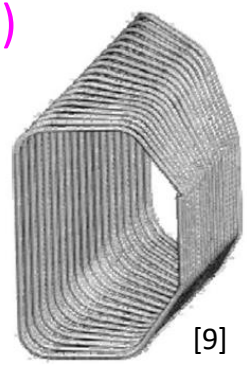


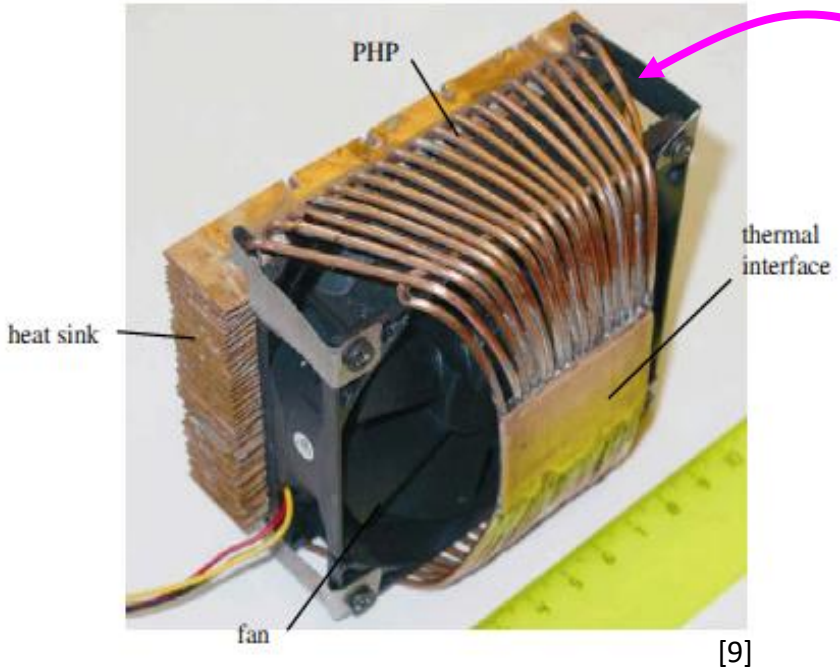
Potential application #1 - electronics

- Most potential application
- PHP are probably required to operate not only in bottom heat mode (with gravity assist) but also in horizontal mode (without gravity assist) and top heat mode (against gravity)



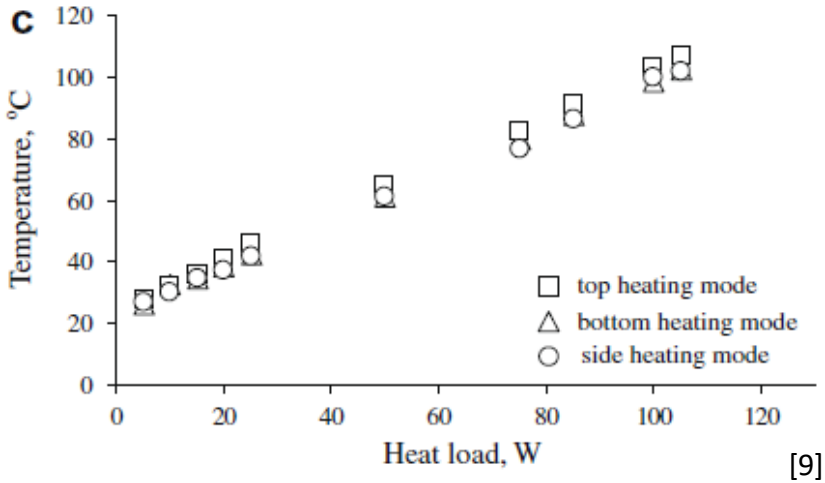
3D shape PHP

[9]



[9]

PHP operates even in top heat mode

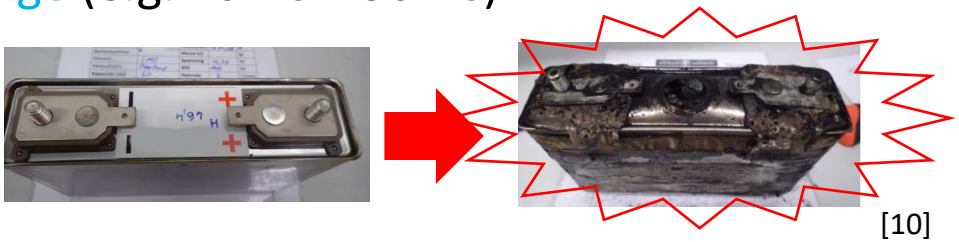


[9]

Heating section temperature
(working fluid: R142b)

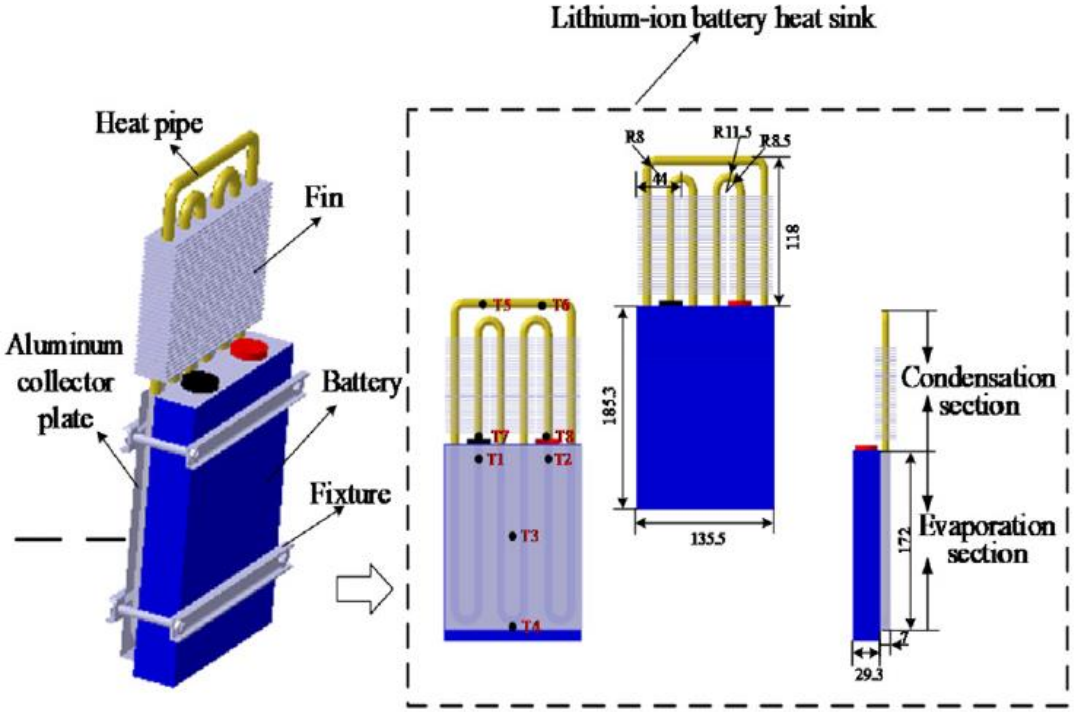
Potential application #2 - batteries

In general, Li-ion battery has:
- narrow allowable temperature range (e.g. 10 °C ~ 50 °C)
- critical risk of thermal runway



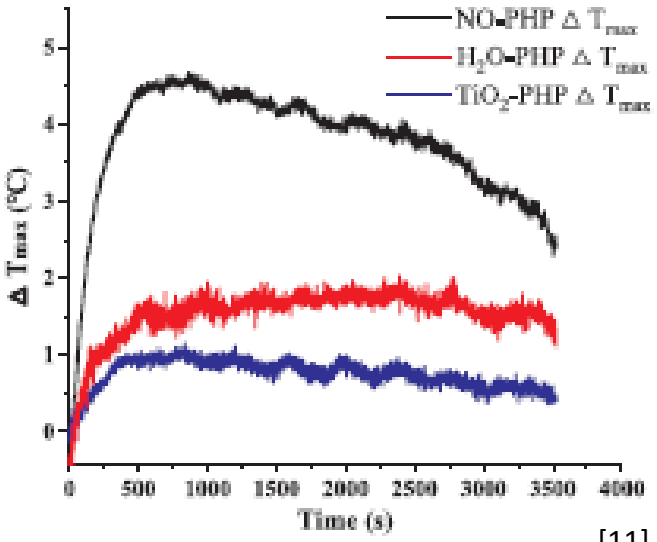
[10]

Thin PHP configuration can be suitable for battery thermal management



[11]

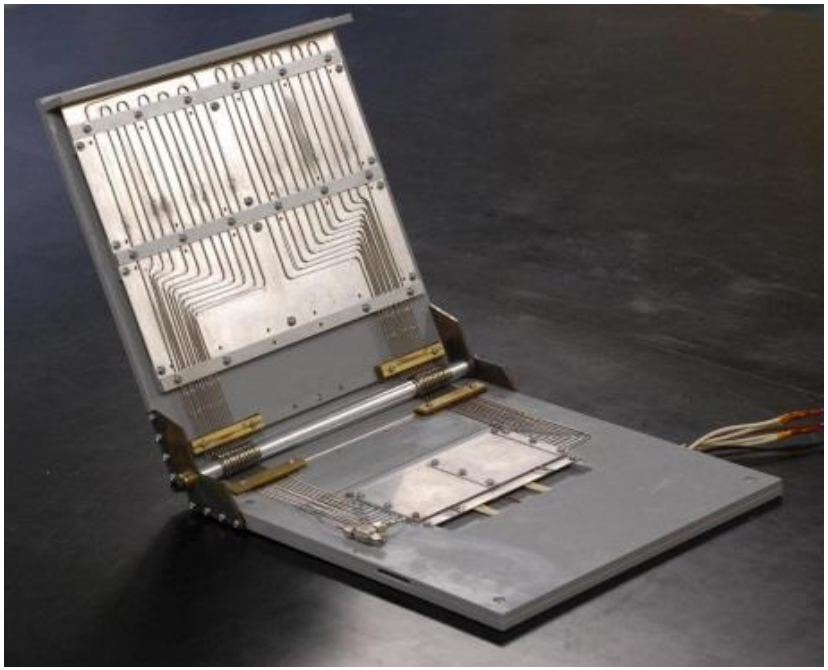
Maximum temperature gradient during continuous discharge process



[11]

Potential application #3 - mobile PC

Thermal test model



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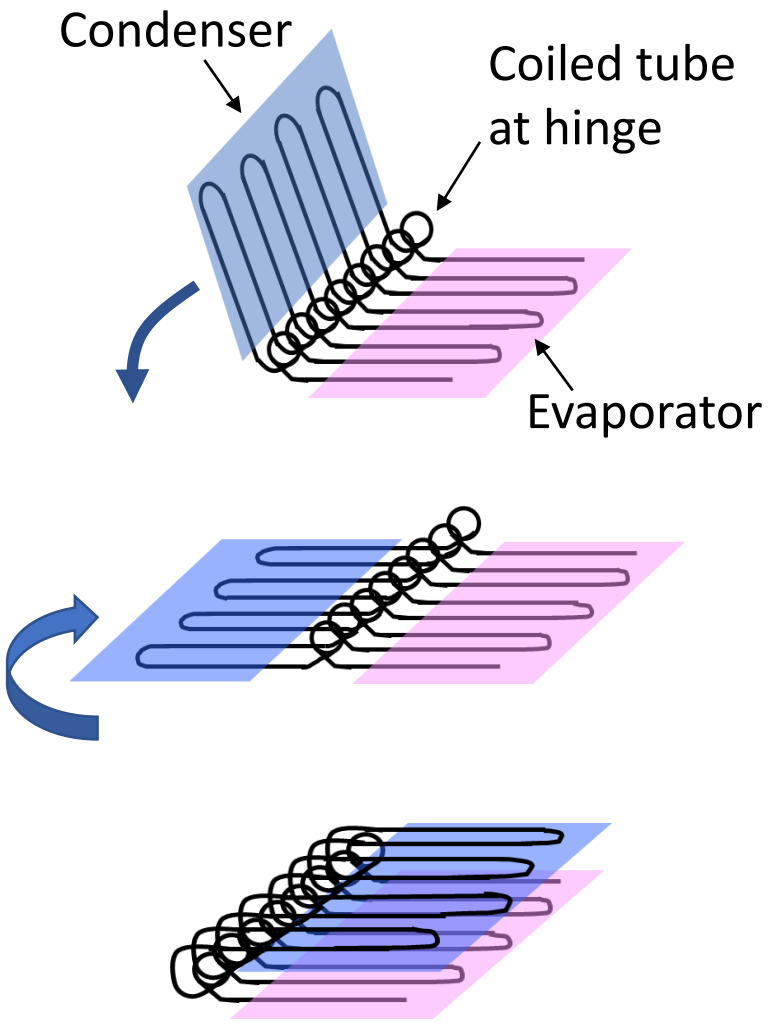
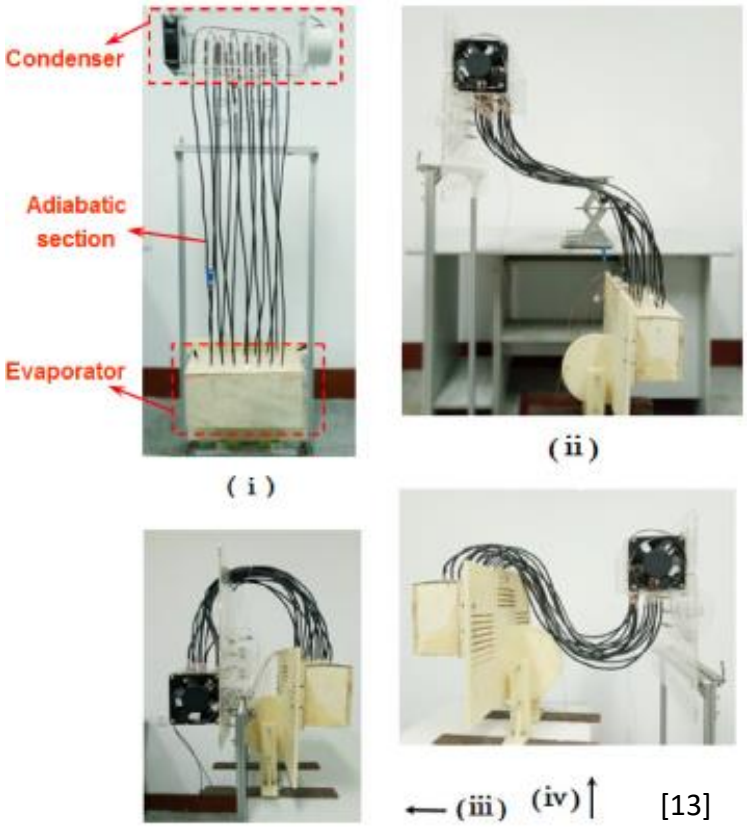


Open and close repeatedly

Potential application #4 - flexible strap

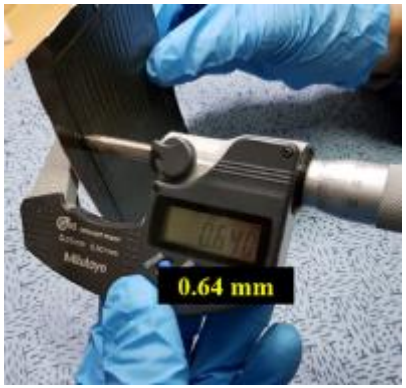
Polymeric materials or thin tubes provide flexibility to PHP

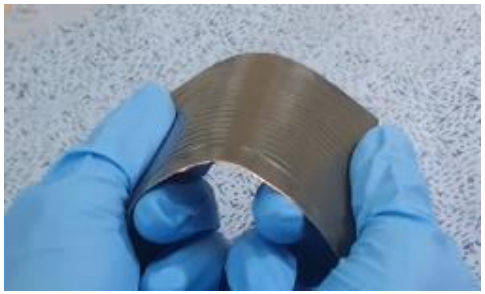
Fluororubber tubular PHP with micro-grooved copper tubes in evaporator and condenser



[13]

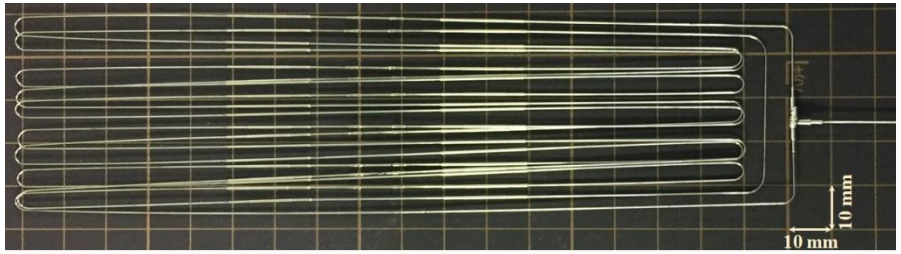
Polycarbonate-based flat PHP (wrapped in flexible-copper-clad-laminates)





[14]

Metallic tubular PHP with outer diameter of 0.4 mm or less

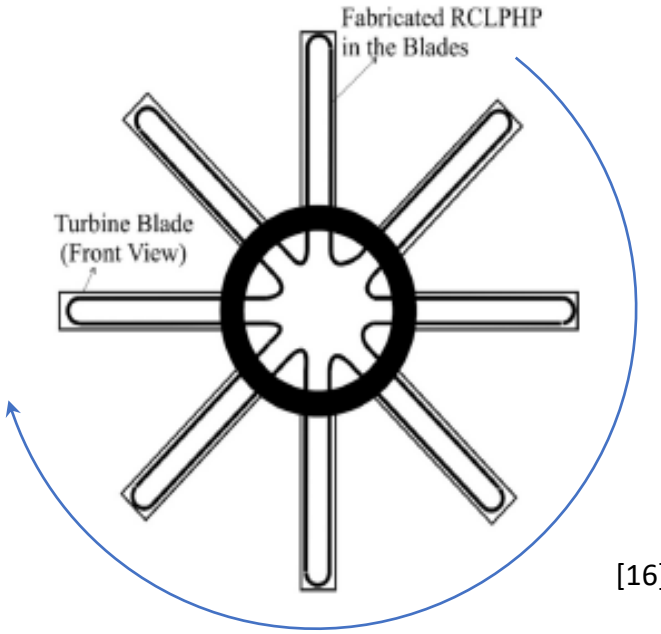


[15]

Potential application #5 - turbine blades

- Rotating devices such as turbine blades, griding wheel, etc.
- Centrifugal force can assist fluid flow in PHP: past study reported that PHP performance improved

PHP integrated in turbine blades



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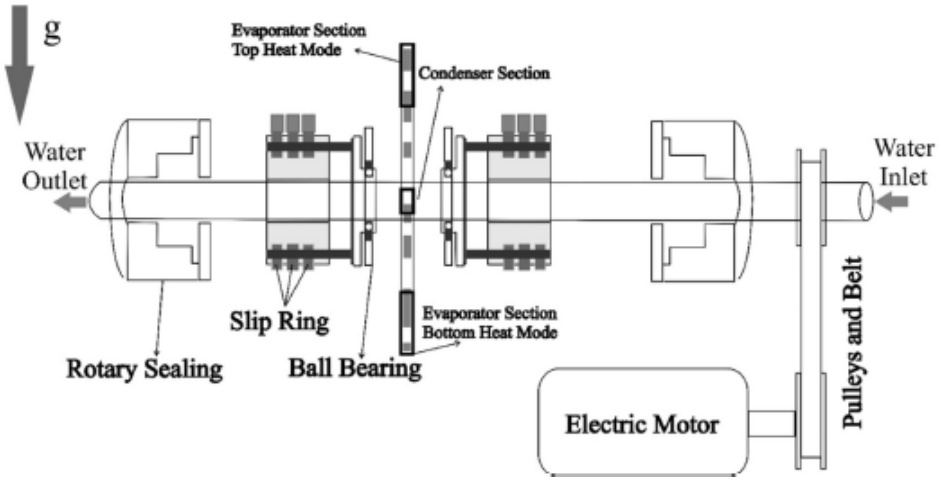


[16]

Potential application #6 - waste heat recovery unit (heat exchanger)

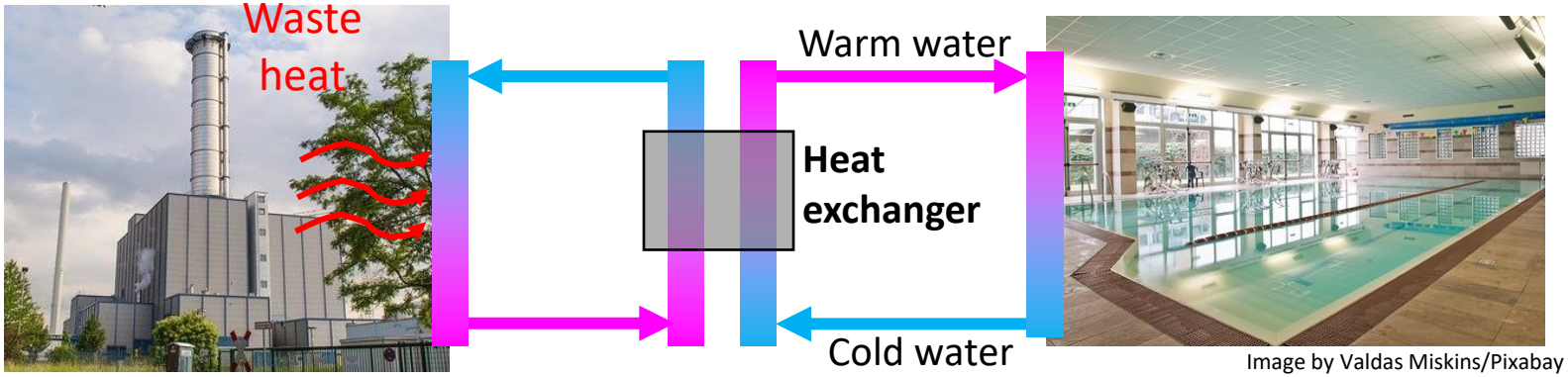
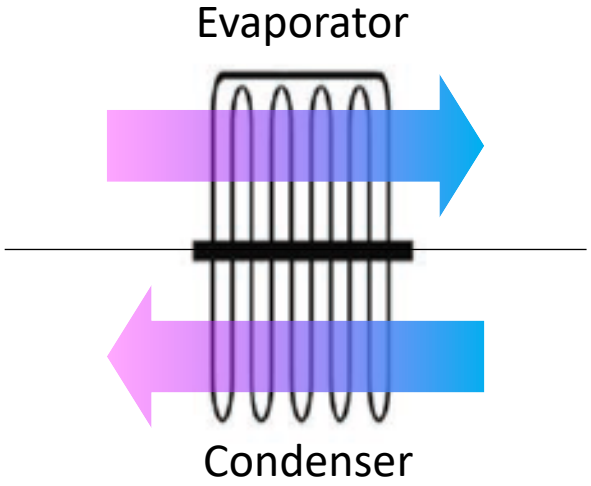
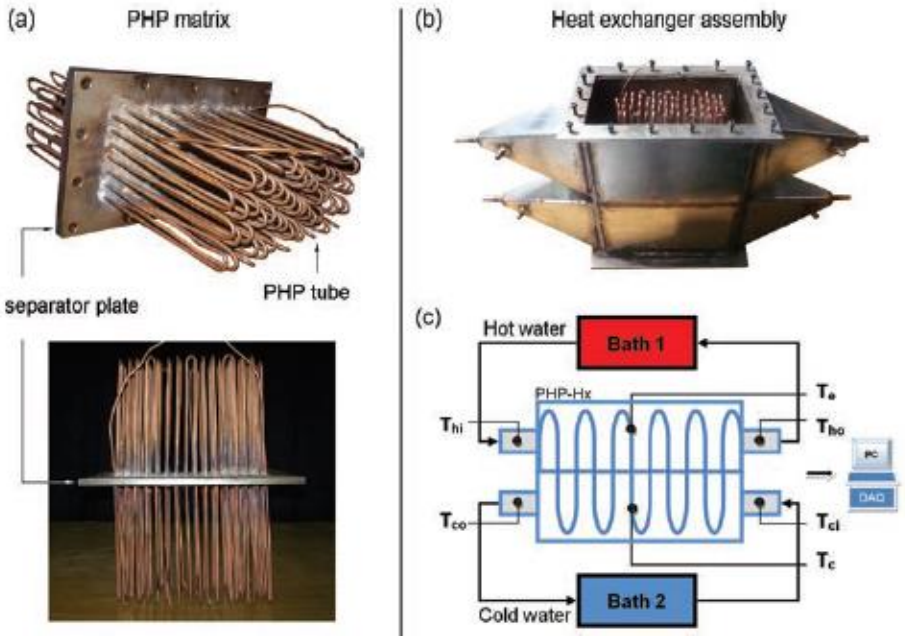


Image by maurizio18/Pixabay

Image by Valdas Miskins/Pixabay





[17]

Potential application #7 - solar water heating

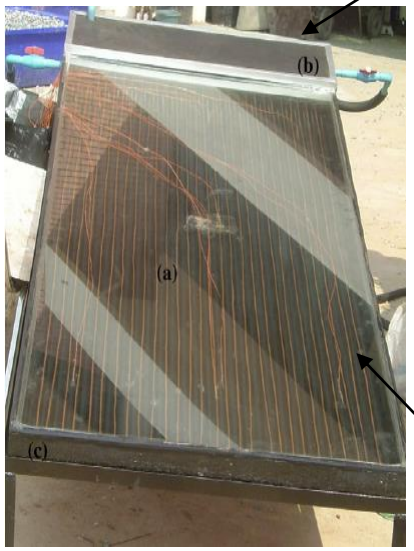
Solar collector

Image by Vijayanarasimha/Pixabay

Hot water

Image by tookapic/Pixabay

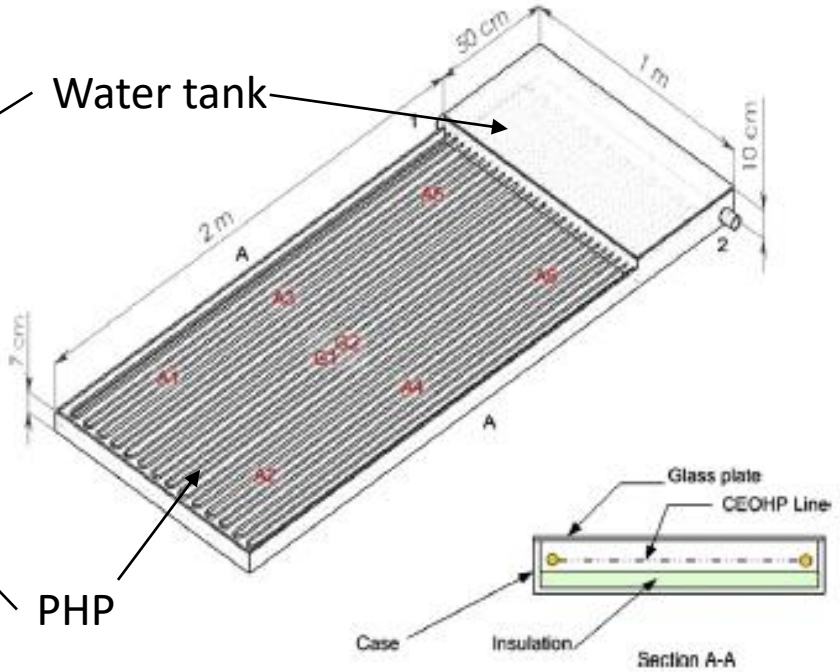
- PHP, with large heat transfer area is suitable for solar collector
- Demonstration results show a cumulative collect efficiency of 62 %



[18]

Water tank

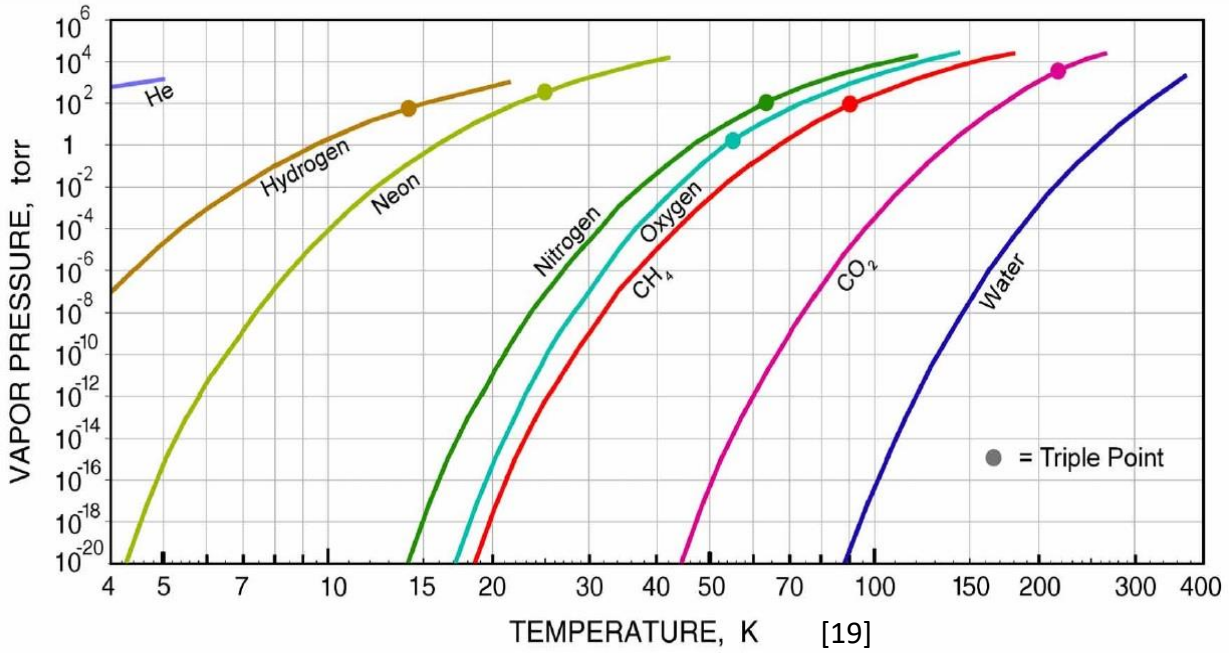
PHP



[18]

Potential application #8 - cryogenic device

Suitable working fluid for cryogenic PHP

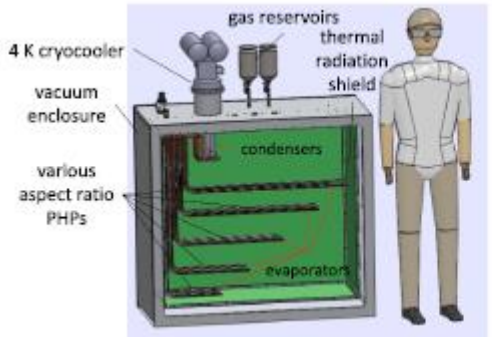


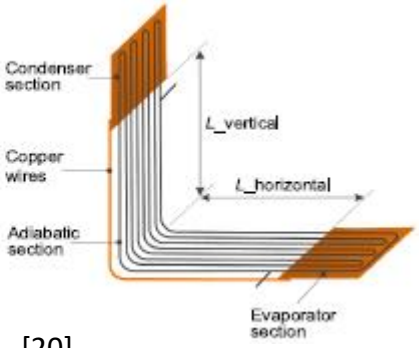
[19]

Application example: superconducting magnet system

MRI (magnetic resonance imaging)

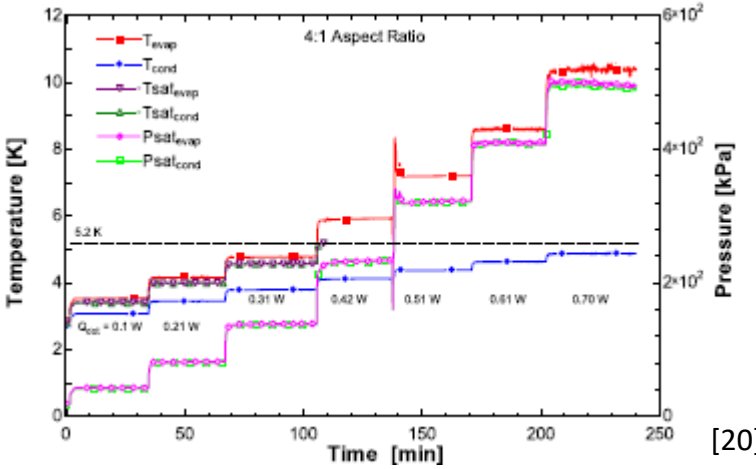
Photo by Michal Jarmoluk/Pixabay





[20]

Test result of Helium PHP



[20]

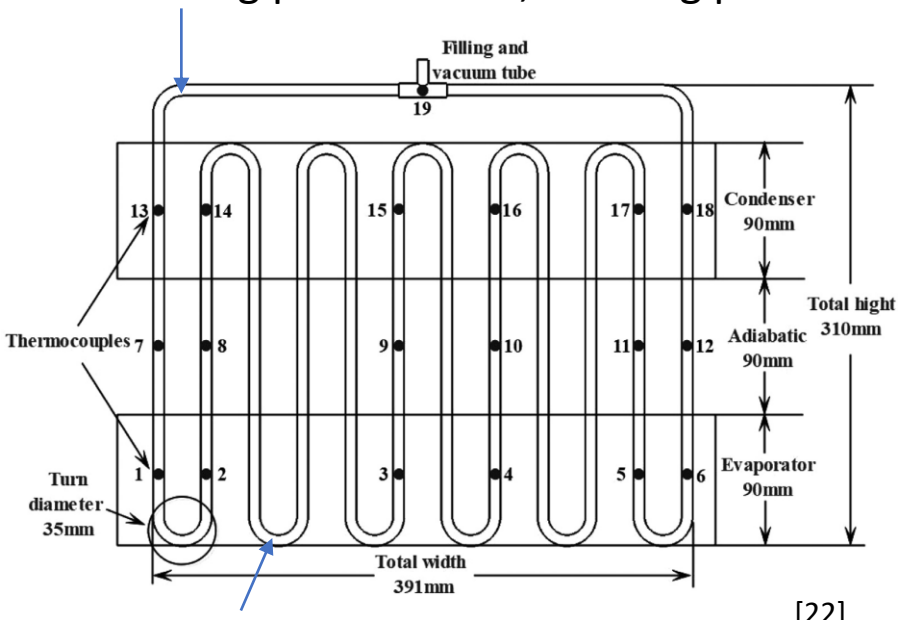
Potential application #9 - high temp. device

Liquid sodium-potassium alloy

[21]

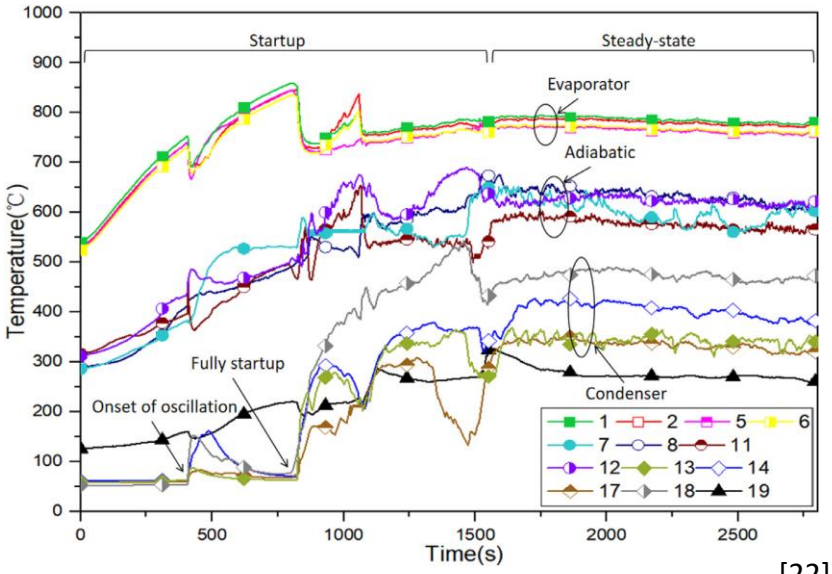
Using liquid metal as a working fluid, we can get high temperature PHP with operating temperature of over 500 °C

Working fluid: sodium-potassium alloy (potassium 78%)
boiling point 785 °C, melting point -12.65 °C



[22]

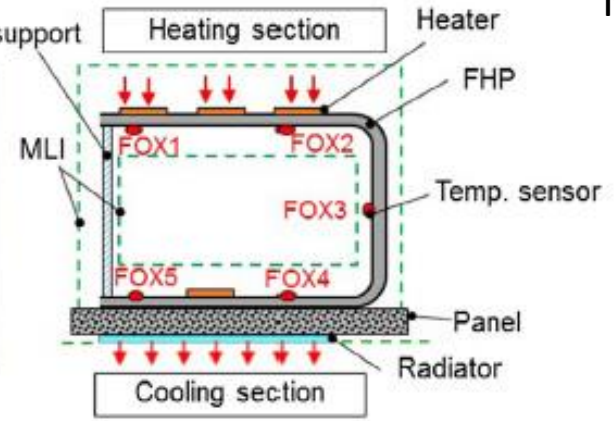
310S stainless-steel tube



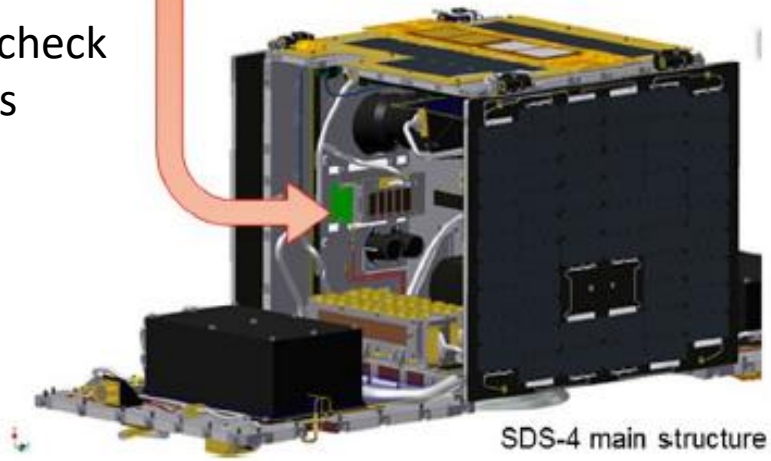
[22]

Potential application #10 - spacecraft

- Lightweight PHP is suitable for spacecraft
- Successfully demonstrated in orbit for four years

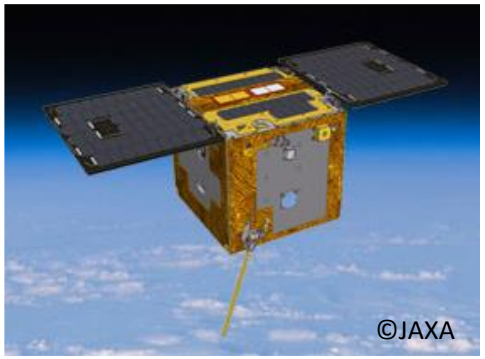


5-turn PHP with check valves



[23]

Mounted on small satellites “SDS-4”



Launched in 2012

Summary

- Thermal management has been critical issue of electronics due to increasing power and heat flux
- Heat transfer device is effective to transfer heat from the heat source to cooling device
- Pulsating heat pipe (PHP) is a promising two-phase passive heat transfer device with many advantages
- Ten examples of the potential PHP applications was introduced

References

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