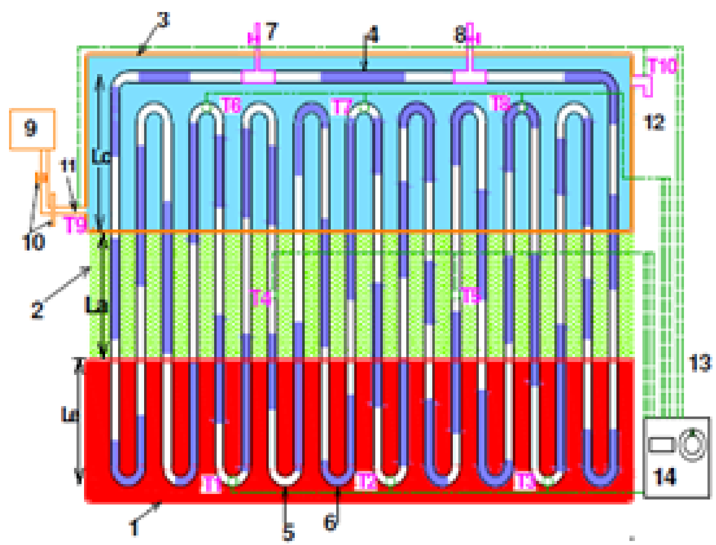
Industry Developments:

Pulsating Heat Pipes

Heat pipes are passive heat transport devices that work via phase change (evaporation and condensation) to transfer heat from the evaporator site to a condenser location where heat is dissipated. Traditional heat pipes feature an internal wick structure for returning condensate back to their evaporator section. Pulsating heat pipes (PHPs), on the other hand, use thermo-hydrodynamic characteristics that involve several different processes. But, like all effective heat pipes, they can provide continuous, passive heat transport in many electronics applications.

There are two broad categories of PHPs: closed loop and open loop. On closed loop PHPs the tube ends connect to each other to form a continuous loop. With an open loop PHP, the ends are not self-connected. It is basically one long tube, bent in multiple turns with both its ends sealed after being filled with a working fluid. [1]

A pulsating heat pipe, sometimes called an oscillating heat pipe, converts heat from the heat-generating area into liquid-slugs. The tubing is only partially filled with its working fluid. This results in a natural, uncontrolled, asymmetric liquid-vapor, plug-bubble distribution in its tube sections, due to the dominance of surface tension forces. If the capillary diameters are not too large, the fluid distributes itself into an arrangement of liquid slugs separated by vapor bubbles (or plugs). The looped, serpentine structure is heated at one end (evaporator), while cooled at the opposite end (condenser). [1]



Part No.	Description
1	Evaporator
2	Adiabatic Section
3	Condenser
4	Cooper tube
5	Vapor plug
6	Liquid slug
7	Filling valve (T-joint)
8	To Vacuum pump (T-joint)
9	Cooling water tank
10	Control valve and Flow meter
11	Cooling water Inlet
12	Cooling Water Outlet
13	Thermocouple connections
14	Temperature Recorder

Figure 1. Schematic Diagram of a Closed Loop Pulsating Heat Pipe with Stages Labeled and Defined [2]

Non-Equilibrium Chaotic Process

During operation, heat is transferred by the pulsating action of the liquid-slugs and vapor bubbles. Because each tube section between the evaporator and the condenser has a different volumetric distribution of the working fluid, the pressure drop associated with each sub-section is different. This causes pressure imbalances leading to thermally driven two-phase flow instabilities eventually responsible for the thermofluidic transport. In a closed loop PHP, bubble generation processes at one end create a sustained 'non-equilibrium' state as the internal pressure tries to equalize within the closed system. Thus, a self-sustaining thermally driven oscillating flow is obtained. There is no steady state in PHP operation. Instead, pressure waves and fluid pulsations are generated in each of the individual tube sections. [1]

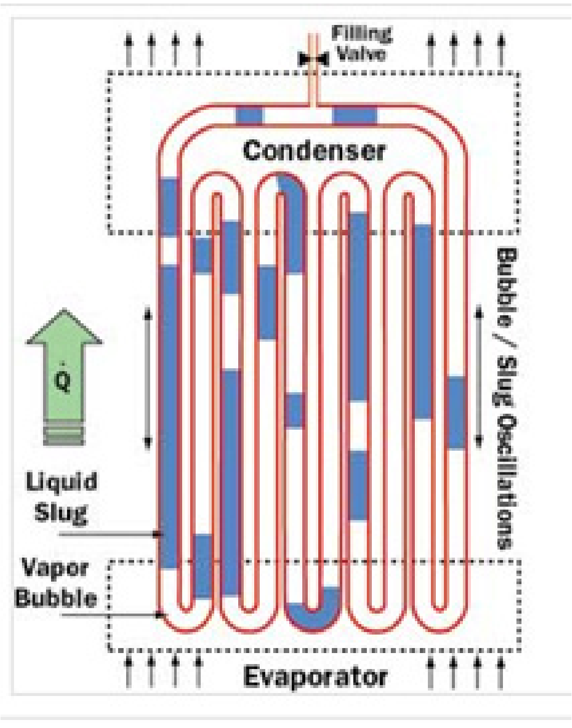


Figure 2. Closed Loop Pulsating Heat Pipe Showing Liquid-Slugs and Vapor Bubbles [4]

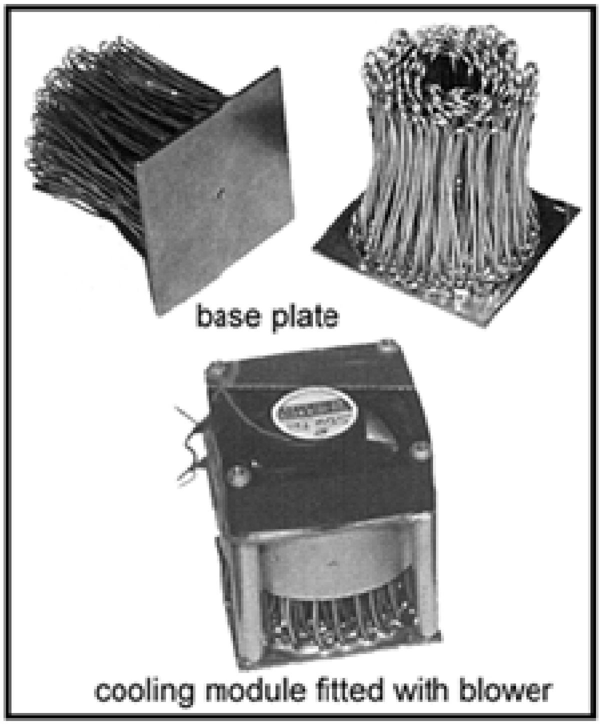


Figure 3. A Prototype Cooling Module Constructed with Pulsating Heat Pipes, Base Plate and Fan [1]

As with most heat pipes, no external power source is needed to either initiate or sustain the fluid motion or the transfer of heat. Pulsating heat pipes are made from long capillary tubes shaped with several turns at the top and bottom. The evaporator and condenser sections are located at opposite sides of these loops. A unique feature of PHPs is that they have no wick structures, as are inside conventional heat pipes, to return the condensate to the heating section. As with most heat pipes, no external power source is needed to either initiate or sustain the fluid motion or the transfer of heat. Pulsating heat pipes are made from long capillary tubes shaped with several turns at the top and bottom. The evaporator and condenser sections are located at opposite sides of these loops. A unique feature of PHPs is that they have no wick structures, as are inside conventional heat pipes, to return the condensate to the heating section.

Studies and Developments

Nagvase and Pachghare [2] compiled several parameters affecting closed loop PHP performance, summarizing from studies performed in recent years. They sectioned these into design/geometrical and operating parameters, along with the properties of the working fluids.

Among the design and geometric parameters are the diameter and material of the tube. The diameter of the pipe plays a vital role in the design of the heat pipe. A large, hydraulic diameter results in a lower wall thermal resistance and increases the effective thermal conductivity. The internal diameter must be small enough so that surface tension forces dominate and stable liquid-slugs are formed.

Number of Loop Turns

Khandekar et al [1] observed that the number of turns, or loops, in a PHP, increases the level of perturbations inside the device. If the number of turns is less than a critical value, then there is a possibility of a stop-over condition – this is a dry out state where all the evaporator U-sections have a vapor bubble and the rest of the PHP has liquid. Other studies, by Zhang and Faghri [5], found that an increase in the number of turns has no effect on the amplitude and circular frequency of oscillation when there are five or fewer turns.

Tilt Angle

The orientation of a PHP is another consideration. A study by Mameli et al [6] showed that the performance of a PHP is affected by its inclination with respect to gravity. This was particularly true of their test PHP which featured only a few loops. Per their report, every orientation has its own stable operating range in terms of heat input level. There was considerable degradation of thermal performance as their device orientation was changed from bottom heat mode to horizontal operation, at which point their device would no longer operate.

Working Fluids with Nano Fillers

Comparing the thermal properties of common PHP working fluids, Verma et al [3] observed that most heat transfer fluids exhibit extremely poor thermal conductivity. The exceptions are liquid metals which cannot be used at many of the critical temperature ranges. Thus, efforts to increase heat transfer by creating turbulence and increasing surface area are still subject to the thermal conductivity of the working fluid.

Much research has gone into the use of nanofluids in PHPs. Nanofluids are liquids filled with various nanoparticles, and it has been shown that the thermal conductivity of nanofluids increases significantly with a rise in temperature. Nano materials that have been tested include diamond, and such particles as CuNi, CuO, Ag and Al_2O_3. Among the findings of the different studies was that the relatively large surface area of nanoparticles increases the heat conduction between the base fluid and the particles. [5] In addition, the smaller the nanoparticles, the higher the thermal conductivity of the nanofluid. But there is a trade-off here, as the smaller particles can agglomerate, settle, or coalesce to the capillary walls over time. [3]

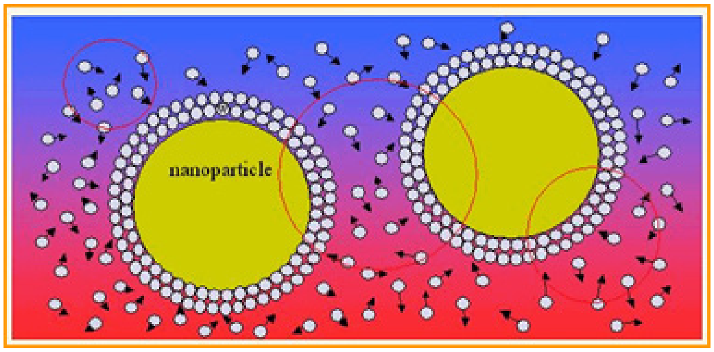


Figure 4. The Motion Between Nanoparticles and the Base Fluid in a PHP Can Enhance Thermal Conductivity by Approximately 250% [7]

A team of researchers at Indira Gandhi Centre for Atomic Research Centre, Kalpakkam [8] developed a new class of magnetically polarizable nanofluids where the thermal conductivity enhancement up to 300% of base fluids is demonstrated.

References:

1. Khandekar, S., Groll, M., Charoensawaan, P., Rittidech, S. and Terdtoon, P., "Closed and Open Loop Pulsating Heat Pipes, 13th International Heat Pipe Conference", September 2004.

2. Nagvase, S. and Pachghare, P., "Parameters Affecting the Functioning of Closed Loop Pulsating Heat Pipe: A Review", Research Journal of Engineering Sciences, January 2013.

3. Verma, B., Yadav, V. and Srivastava, K., "Nano Fluid – An Alternative Fluid in Pulsating Heat Pipe/Oscillating Heat Pipe", IOSR Journal of Electronics and Communication Engineering, Sep-Oct 2012.

4. Khandekar, S., "An Introduction to Pulsating Heat Pipes", Electronics Cooling, May 2003.

5. Zhang, Y. and Faghri, A., "Oscillatory Flow in Pulsating Heat Pipes with Arbitrary Numbers of Turns", Journal of Thermophysics and Heat Transfer, July-September 2003.

6. Mameli, M., Marengo, M. and Khandekar, S., "Local Heat Transfer Measurement and Thermo-Fluid Characterization of a Pulsating Heat Pipe", Intl. Journal of Thermal Sciences, 2014.

7. http://minsfet.utk.edu/Research/heat_transport.htm

8. http://en.wikipedia.org/wiki/Nanofluid