Heat Pipes

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Heat pipes are very effective heat transfer devices employed to transmit large quantities of heat through a small cross-sectional area over a considerable distance with no additional power input to the system. They are also capable of controlling and transporting large quantities of heat at various temperature levels. They were first conceptualised in 1836 by Jacob Perkins and was called the Perkins tube. The initial design was a closed tube containing a small quantity of water operating in a two-phase cycle. Heat transfer was achieved by phase changes of the water enclosed in the pipe. Most Perkins tubes were wickless gravity-assisted heat pipes, also known as thermosyphons.

A heat pipe consists essentially of a cylindrical metal container with a quantity of working fluid sealed inside the cylinder as shown in Figure 1. Under normal conditions, the fluid exists in liquid form. The inside of the pipe is also lined with a capillary wicking material. The length of the pipe is segmented into three parts, viz., the evaporator, adiabatic and condenser sections. Heat applied on the surface of the pipe in the evaporator section by an external heat source causes the working fluid inside to boil and vaporise, picking up the latent heat of vaporisation. The vapour travels inside the sealed container to the cooler condenser section of the pipe where it condenses.

Here, the vapour gives up the latent heat of condensation. The condensate is then transported back to the evaporator section by capillary action. Heat is thus continuously transferred from the evaporator section to the condenser section of the heat pipe. This process will continue as long as there is sufficient capillary pressure to drive the condensate back to the evaporator.

The idealised thermodynamic cycle of the heat pipe may be visualised as shown in Figure 2(a) and by the T-s diagram of Figure 2(b). The fluid enters the evaporator as compressed liquid at temperature T1 and leaves at temperature T2 (saturated vapour) or T2' (superheated vapour).

The vapour then flows through the vapour channel from the evaporator section to the condenser section due to the vapour pressure differential in the evaporator and condenser sections (2 – 3 or 2 – 2' – 3). The vapour enters the condenser section as saturated vapour or mixture. The condensate enters the condenser section as saturated liquid at the temperature T4. Finally, the liquid leaves the adiabatic section to enter the evaporator as compressed liquid at T1. The cycle then repeats itself. Heat pipes have an effective thermal conductivity many thousands of times that of a solid copper pipe because of the nature of heat transfer, by evaporation and condensation, instead of by pure conduction along the pipe.

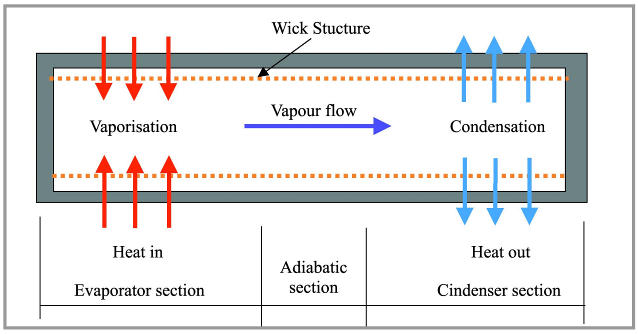

Figure 1: Typical heat pipe construction and operation

A thermosyphon is a heat pipe constructed without a wick. It relies on gravity to return the condensate. Hence, thermosyphons are only able to operate with the evaporator section below the condenser section as shown in Figure 3. They are capable of operating in an inclined position as long as the condensed liquid from the condenser section can travel back down to the evaporator section. The thermal performance of heat pipes and thermosyphons are dependent on the operating temperature difference between the evaporator and condenser sections, type of fill liquid, fill ratio, geometrical dimensions of the pipe, orientation and type of wick material incorporated.

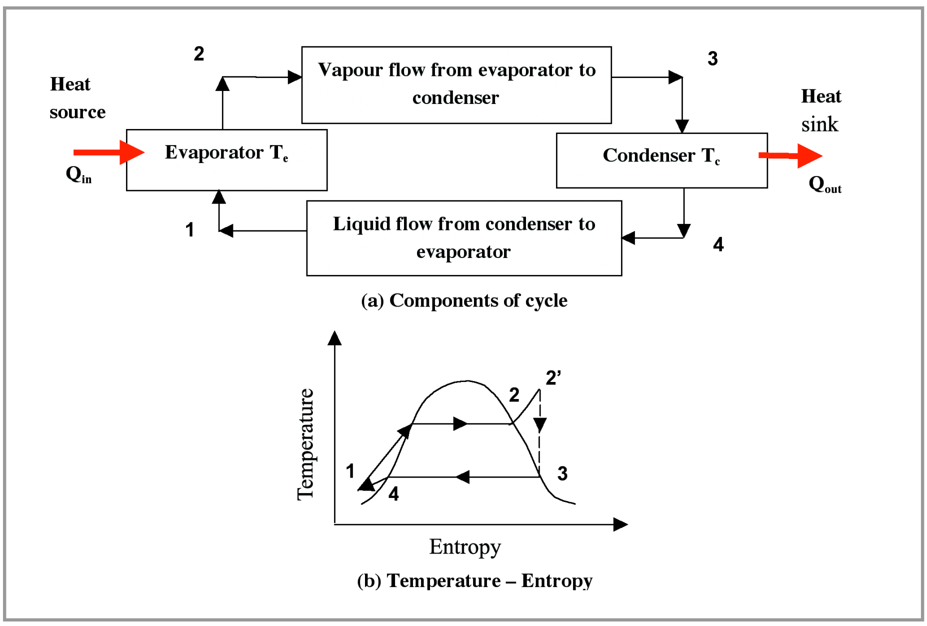

Figure 2: Thermodynamic cycle of a typical heat pipe

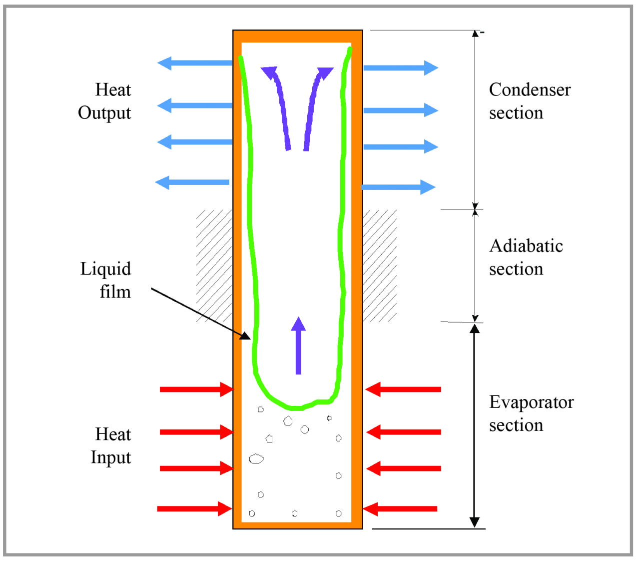

Figure 3: Cross sectional view of a thermosyphon

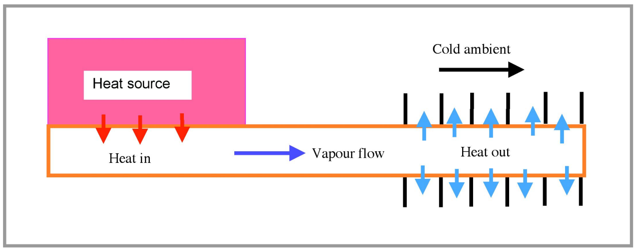

Figure 4: Typical heat pipe for semi conductor cooling

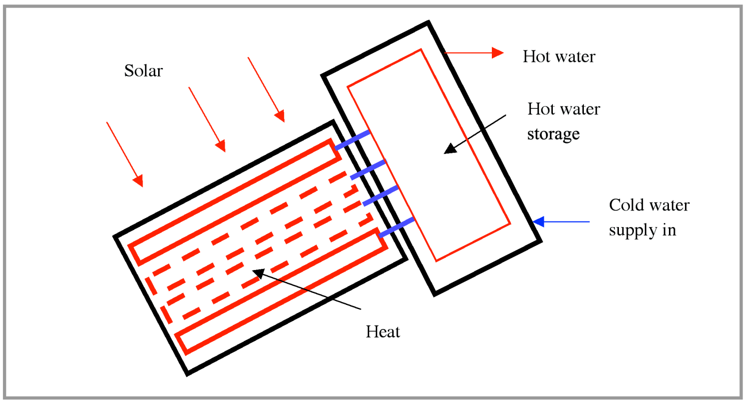

Figure 5: Schematic layout of a heat pipe solar water heater

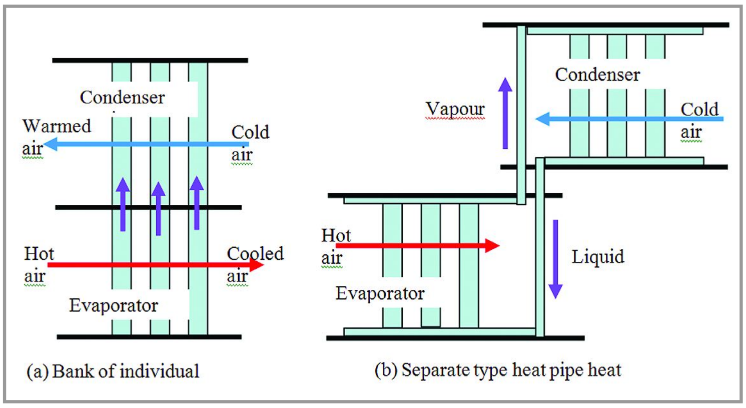

Figure 6: Schematic layout of a heat pipe heat exchanger

Modern heat pipe technology has been developing since the mid 1960s, mainly for spacecraft control and the cooling of semiconductors. Heat pipes are now commercially available in a wide range of sizes and applications ranging from micro heat pipes for extra-terrestrial applications to down-to-earth and much larger sized industrial heat exchangers for heat recovery and humidity control. They are also manufactured in a multitude of shapes. Unusual application geometries can be easily accommodated by the heat pipe's versatility to be shaped as a heat transport device. If some range of motion is required, heat pipes can even be made of flexible material.

Heat pipes are employed in a wide range of applications. They are very attractive components in the area of spacecraft cooling and temperature stabilisation due to their low weight penalty, zero maintenance and reliability. The rapid development of telecommunication equipment, particularly with the increased miniaturisation of microelectronic components, has led to increased demands for greater heat dissipation systems due to the increased density of the components. Conventional CPU cooling employs extruded aluminium heats. High performance micro heat pipes, especially flat heat pipes, are increasingly being used for cooling printed circuit boards or for heat levelling to produce an isothermal plane. Examples of the heat pipe spreader to achieve efficient cooling of micro processor units in personal computers, servers and workstations are shown in Figure 4.

The conventional tube-in-strip type of flat plate solar collectors suffers from corrosion and fouling in the collector tubes. Heat pipes could be used as solar collectors in order to overcome this problem. As shown in Figure 5, an array of individual thermosyphons is held together in a row inside a solar collector box. The top of the thermosyphons protrude inside the hot water storage tank. Solar energy incident on the evaporator section vaporises the fill liquid in the thermosyphons. The vapour travels up the tubes and condenses in the top condenser section releasing its heat and thus heating up the water in the storage tank. Instead of connecting individual thermosyphons, a single serpentine tube thermosyphon collector could be designed. Heat pipe solar water heaters produce higher temperatures than conventional flat plate solar heaters and are more efficient especially in low ambient temperature conditions.

In the industrial sector, heat pipe heat exchangers (HPHEs) are highly efficient heat exchangers employed in heat recovery systems. Each module of the counterflow air-to-air heat pipe heat recovery unit shown schematically in Figure 6(a) consists of an array of individual thermosyphons connected by headers at the top and bottom of each module in a parallel fashion. In an actual installation, there may be numerous modules connected in a series arrangement. The condenser section is located higher than the evaporator section to enable the condensed liquid to return to the evaporator. When hot air is blown past the evaporator section, the liquid boils and vapour is condensed at the condenser section. The bottom air stream is cooled and the upper air stream is heated in the process.

The separate type HPHE shown in Figure 6(b) is essentially similar to the modular array of thermosyphons. Here, the condenser and evaporator sections are connected via headers which effectively separate the two sections. This type of HPHE is used when constraints are placed on the air flow ducting system. HPHEs could be employed as economisers in boilers to recover waste heat from hot exhaust flue gas to preheat boiler feedwater. They could also be employed as precoolers in air conditioning systems especially in a hot and humid tropical country like Malaysia where incoming fresh air at high ambient temperatures could be pre-cooled by the cold exhaust air stream.

Heat pump dehumidifiers are known to be energy efficient for the drying of agricultural crops. In the conventional heat pump refrigeration cycle schematic shown in Figure 7, the evaporator coil condenses the water vapour out of the air stream to produce dry air while the condenser coil heats up the dry air to raise its temperature before discharging it into the drying chamber. The loop heat pipe (LHP) heat exchanger located before and after the evaporator coil of the conventional refrigeration machine assists in the efficiency of the process. The evaporator section of the LHP acts as a pre-cooler while the condenser section acts as a pre-heater.

In the HVAC field, loop HPHEs could be employed to increase the dehumidification capacity of conventional air conditioners. As illustrated schematically in Figure 8, the evaporator section of the LHP precools the incoming warm and moist fresh air while the condenser section reheats the air to a comfortable level. The LHP thus acts as a run-around-coil.

Another important application of heat pipes is in the field of die casting and injection moulding for the removal of heat during the process of cooling down the moulds in the solidification process. Most commercial dies are water cooled. Thermal shock causing damage to the dies could be avoided with heat pipes. Furthermore, heat pipes could also reach inaccessible parts of the die. One of the newest applications with potential for growth is the use of heat pipes related to human physiology for the control of body temperature.

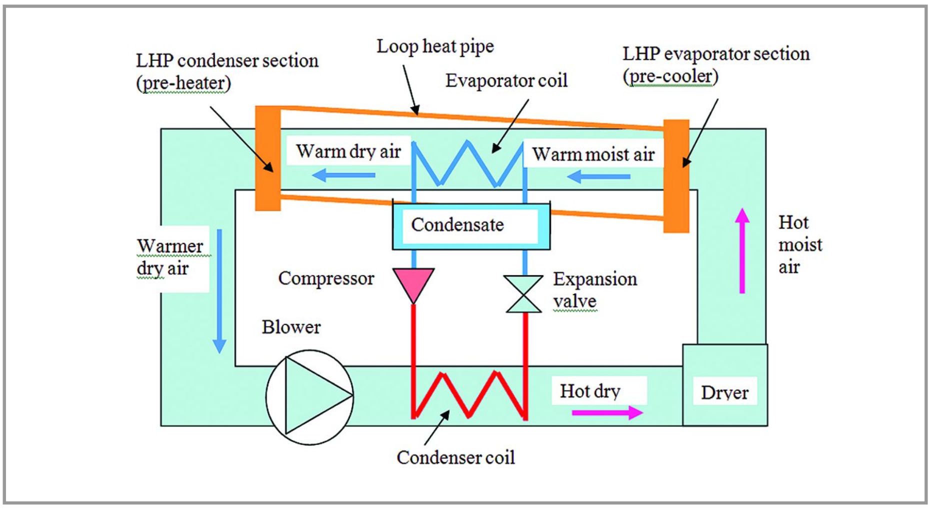

Figure 7: Schematic diagram of heat pump dehumidifier with heat pipe

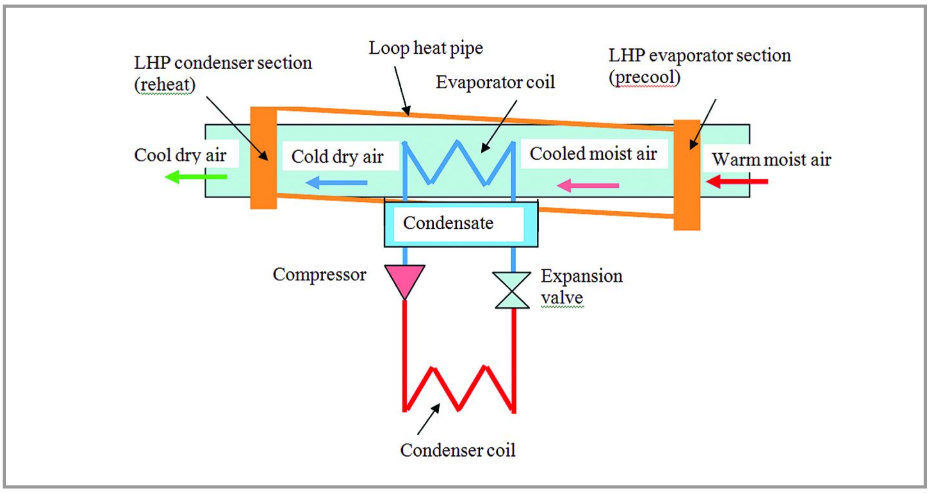

Figure 8: Schematic diagram of dehumidification with heat pipe

Heat pipes embedded in gloves could transfer body heat from the forearm to the fingers to prevent frostbite. There are many other applications for heat pipes that have been developed or in the developmental stages.

Research on thermosyphons in Monash Malaysia focused on the theoretical modelling of thermosyphons. Current research is focusing on HPHEs and the use of heat pipes in dehumidification.

The 9th International Heat Pipe Symposium would be organised and held at the Monash University Sunway Campus in Kuala Lumpur from 17-20 November 2008. The symposium is held once every two years and alternates with the International Heat Pipe Conference. This coming symposium, which is fully supported by the IEM Mechanical Engineering Technical Division and IMechE Malaysia Chapter, will bring together engineers, scientists and industries working in the field of heat and mass transfer especially HPHEs, heat recovery systems and semi conductor cooling. This international symposium will provide a forum for the exchange of the latest scientific R&D information as well as technologies developed for the commercial enhancement of heat pipes. Internationally well-known researchers from various universities and entrepreneurs will present keynote papers. During the symposium, participants would also have the opportunity to discuss and view some of the state-of-the-art commercial products which would be on display in the exhibition hall. It is hoped that engineers, scientists, technologists, academics, industrialists, policymakers, entrepreneurs as well as members of the general public who are interested to know more about new and innovative heat pipes for cooling and industrial heat exchange technologies would attend. For further information, please log onto the website www.monash.edu.my/events/9IHPS. ■