Boosting Energy of solar panel using heat pipes

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***Abstract*— *A novel micro heat pipe array was used in solar panel cooling system, both under air-cooled and water cooled mediums, under natural convection. As compared with a ordinary solar panel (without heat pipe arrangement). The result had considerable variation in the efficiency of the energy output, it improved with the help of heat pipe installation. Therefore using a heat pipe gradually improved the efficiency by reducing the heat by cooling the system.*

Keywords*— *Efficiency, Heat pipe, Improved, solar panel.

I. INTRIODUCTION

A heat pipe is a simple device that can quickly transfer heat from one point to another. They are often referred to as the "superconductors" of heat as they possess an extra ordinary heat transfer capacity and rate with almost no heat loss. The idea of heat pipes was first suggested by R.S. Gaugler in 1942. However, it was not until 1962, when G.M. Grover invented it, the remarkable properties were appreciated and serious development began. It consists of a sealed aluminum or copper container whose inner surfaces have a capillary wicking material.

A heat pipe is similar to a thermosyphon. It differs from a thermosyphon by virtue of its ability to transport heat against gravity by an evaporation-condensation cycle with the help of porous capillaries that form the wick. The wick provides the capillary driving force to return the condensate to the evaporator. The quality and type of wick usually determines the performance of the heat pipe, for this is the heart of the product. Different types of wicks are used depending on the application for which the heat pipe is being used.

A heat pipe is a heat transfer device with an extremely high effective thermal conductivity. Heat pipes are evacuated vessels, typically circular in cross sections, which are back-filled with a small quantity of a working fluid. They are totally passive and are used to transfer heat from a heat source to a heat sink with minimal temperature gradients, or to isothermal surfaces.

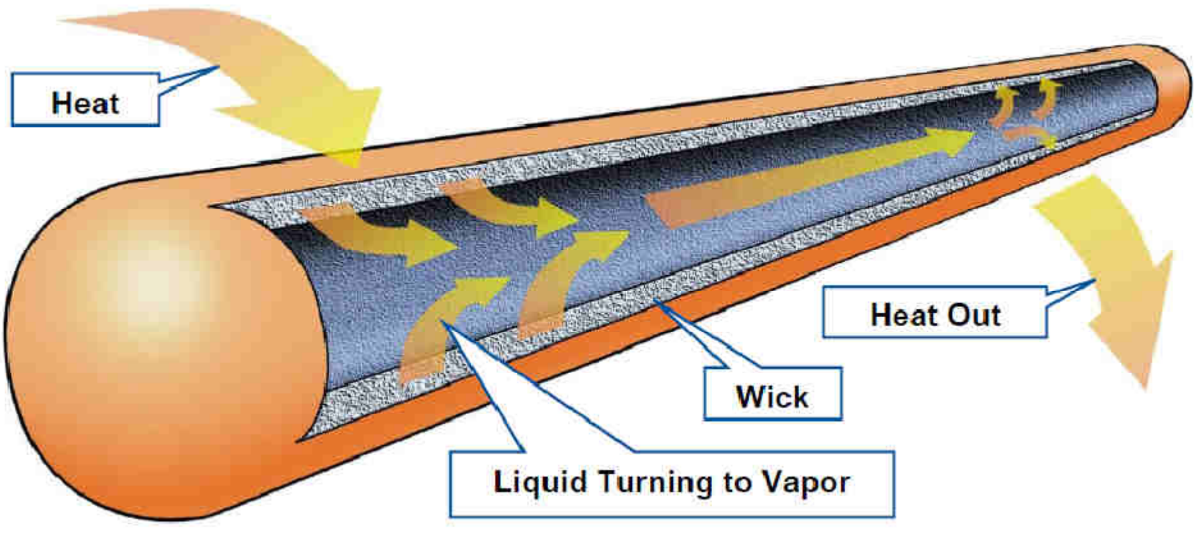

Fig.1: Round heat pipe and its working

In initial years, heat pipes were used in solar panel cooling. Both of air-cooling and water-cooling conditions under nature convection condition were investigated in this paper. Compared with the ordinary solar panel, the maximum difference of the photoelectric conversion efficiency is 2.6%, the temperature reduces maximally by 4.7, the output power increases maximally by 8.4% for the solar panel with heat pipe using air-cooling, when the daily radiation value is 26.3 MJ. Compared with the solar panel with heat pipe using air-cooling, the maximum difference of the photoelectric conversion efficiency is 3%, the temperature reduces maximum by 8, the output power increases maximum by 13.9% for the solar panel with heat pipe using water-cooling, when the daily radiation value is 21.9 MJ.

Concentrating photovoltaic systems (CPV) utilize low cost optical elements such as Fresnel lens or mini-reflecting mirrors to concentrate the solar intensity to 200 to 1000 suns. The concentrated solar energy is delivered to the solar cell at up to 20 to 100 W/cm2. A portion of the energy is converted to electricity, while the portion that is not converted to electricity must be dissipated as waste heat. Solar cell cooling must be an integral part of the CPV design, since lower cell temperatures result in higher conversion efficiencies.

Heat pipes can be used to passively remove the high heat flux waste heat at the CPV cell level, and reject the heat to ambient through natural convection. This paper discusses a cooling design that uses a copper/water heat pipe with aluminum fins to cool a CPV cell by natural convection. With a cell level waste heat flux of 40 W/cm2, the heat pipe heat sink rejected the heat to the environment by natural convection, with a total cell-to-ambient temperature rise of only 40°C.

- **THE PHOTOVOLTAIC CELL**

The conversion of solar radiation into an electron current takes place in the photovoltaic cell, a device consisting of a thin sheet of semiconductor metal, very often made of suitably treated silicon. This treatment is characterized by various chemical processes including so-called "doping".

Adding impurities, that is atoms of boron and phosphorous, to the crystalline structure of the silicon generates an electrical field and produces the charges necessary for the formation of an electrical current. This is created when the cell, whose two faces are connected to a user, is exposed to the light.

The energy which can then be exploited depends on the characteristics of the material the cell is made of: conversion efficiency (the percentage of energy contained in the sunlight incident on the cell which is transformed into electrical energy by the photovoltaic device) for commercial silicon cells generally lies between 13% and 17%, while laboratory cells have produced a reading of 32.5%.

In practice, the typical photovoltaic cell has an overall thickness of between 0.25 and 0.35 mm and is made of mono or multi-crystalline silicon. Generally square, it has a surface measuring somewhere between 100 and 225 m² and, with an irradiation of 1 KW/m² at a temperature of 25°C, produces a current of between 3 and 4 A and a voltage of approximately 0.5V, generating 1.5-2 Wp of power.

- **THE WATT PEAK**

As the power of a photovoltaic cell varies with changes in its temperature and radiation, standard parameters have been defined, producing the so-called watt peak (Wp) relating to the power supplied by the cell at a temperature of 25°C and a radiation of 1000 W/m², in AM1 conditions.

As well as crystalline type silicon, there has recently been a great deal of interest shown by various manufacturers in producing modules based on amorphous silicon. Actually, it is not strictly correct to refer to cells when talking about amorphous silicon, as it is generally deposited in layers on sometimes quite large surfaces.

As far as cost is concerned, traditional amorphous silicon costs less than (mono or multi) crystalline silicon, while the cost of amorphous silicon with two or three junctions should come down if it is to be used on a large scale.

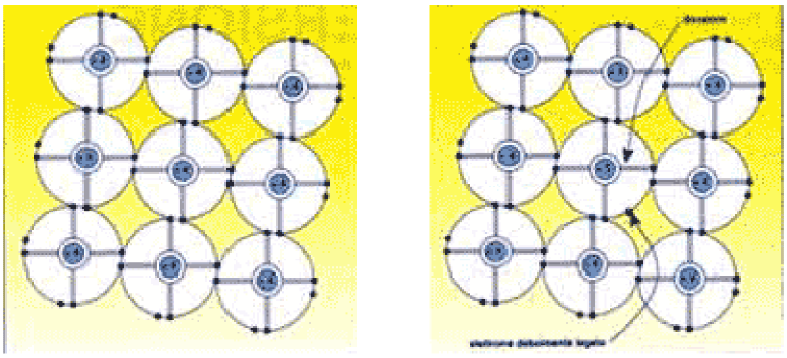

Fig.2: silicon cell

- **THE "PHYSICS" OF THE PHOTOVOLTAIC PROCESS**

The direct conversion of solar energy into electrical energy, achieved with photovoltaic cells, exploits the physical phenomenon of the interaction of light radiation with valence electrons in semiconductor materials. This is known as the photovoltaic effect. Whatever the material used, the mechanism by which the cell transforms sunlight into electrical energy is essentially unvarying. Let's consider, for the sake of simplicity, the case of a conventional photovoltaic cell made of crystalline silicon.

Normally, the silicon atom has 14 electrons, four of which are in the valence band, and can therefore interact with other atoms, whether they are made of silicon or other elements. Two adjacent atoms belonging to a pure silicon crystal have a couple of electrons in common, one belonging to the considered atom, the other belonging to the adjacent one.

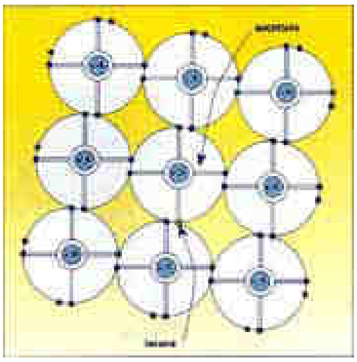

Fig.3: atoms in the silicon cell

Therefore, there is a strong electrostatic bond between an electron and the two atoms which it helps to keep together. However, this bond may be severed by a sufficient amount of energy.

If enough energy is supplied the electron is taken to a higher energy level (conduction band) where it is free to move around, thus contributing to the flow of electricity. When it moves into the conduction band the electron leaves a "hole" behind it, that is a lacuna where an electron is missing. A nearby electron may easily go and fill the hole, thus swapping places with it. To exploit the electricity it is necessary to create a constant movement of electrons (and of holes) or rather a current, by means of an electrical field inside the cell. The field is produced by special physical and chemical treatments, creating a surplus of positively charged atoms in one part of the semiconductor and a surplus of negatively charged atoms in the other. In practice this condition is obtained by adding small quantities of boron atoms (positively charged) and phosphorous atoms (negatively charged) to the silicon lattice, or in other words doping the semiconductor. The electrostatic attraction between the two kinds of atom creates a fixed electrical field which gives the cell a structure known as "the diode structure", in which the transit of the current, consisting of mobile charge carriers, electrons for instance, is obstructed in one direction and facilitated in the opposite direction. The explanation of this phenomenon can be illustrated as follows.

In the layer doped with phosphorous, which has five valence electrons as opposed to the four in silicon, there is, for each atom of phosphorous, an extra unbounded electron, composed of an so-called valence electron that is free to move around.

In the layer doped with phosphorous, which has five valence electrons as opposed to the four in silicon, there is, for each atom of phosphorous, a weakly-bonded negative charge, composed of a so-called valence electron.

- There are many reasons for this low efficiency, which may be grouped into four categories:

  - ***Reflection***: Not all the photons which strike the cell penetrate it, given that some are reflected by the cell's surface and some strike the metal contact grid;
  - *Photons which are too energetic or not energetic enough*: To sever the bond between electron and nucleus a certain amount of energy is required, and not all incident photons have the sufficient energy. On the other hand, photons which have too much energy generate electron-hole pairs, dissipating the surplus energy in the form of heat and splitting the electron from the nucleus.
  - ***Recombination***: not every electron-hole pair generated is collected by the electrical field of junction and sent to the external load, given that on the journey between the point of generation and the junction they may meet opposite charges and therefore recombine.
  - ***Parasite resistance***: the charges generated and collected in the depletion region must be sent to the outside. They are collected by metallic contacts, placed on the front and back of the cell. When fabricated the silicon and aluminum of the contacts are alloyed but there still remains a certain amount of resistance at the interface which provokes a dissipation that reduces the power transferred to the load. In the case of polycrystalline silicon cells, efficiency is reduced even further due to the resistance the electrons meet on the edge between one grain and another and due to the resistance caused by the random direction of single atoms, even more so in the case of amorphous silicon cells.

- **OVERHEATING:**

Overheating problem associated with solar panels can result from temperature fluctuations that occur under severe weather conditions such as lightning, hail or high winds. Severe weather exposure can cause oxidation and corrosion to develop inside panel's metal connections, resulting in warping, loosened screws and electric resistance. These conditions can cause solar panel cell to overheat and eventually burnout. Overheating also has the potential to form electric arcs that can start to melt metal fixtures and burn away the molecule's insulating material.

II. DESIGN CONSIDERATIONS: HEAT PIPES

The three basic components of a heat pipe are:

1. the container
2. the working fluid
3. the wick or capillary structure

Container

The function of the container is to isolate the working fluid from the outside environment. It has to therefore be leak-proof, maintain the pressure differential across its walls, and enable transfer of heat to take place from and into the working fluid.

Selection of the container material depends on many factors. These are as follows:

- Compatibility (both with working fluid and external environment)
- Strength to weight ratio
- Thermal conductivity
- Ease of fabrication, including welding, machine ability and ductility
- Porosity
- Wet ability

Most of the above are self-explanatory. A high strength to weight ratio is more important in spacecraft applications. The material should be non-porous to prevent the diffusion of vapor. A high thermal conductivity ensures minimum temperature drop between the heat source and the wick.

Working Fluid

A first consideration in the identification of a suitable working fluid is the operating vapour temperature range. Within the approximate temperature band, several possible working fluids may exist, and a variety of characteristics must be examined in order to determine the most acceptable of these fluids for the application considered. The prime requirements are:

- compatibility with wick and wall materials
- good thermal stability
- wet ability of wick and wall materials
- vapor pressure not too high or low over the operating temperature range
- high latent heat
- high thermal conductivity
- low liquid and vapor viscosities
- high surface tension
- acceptable freezing or pour point

Wick or Capillary Structure

It is a porous structure made of materials like steel, aluminium, nickel or copper in various ranges of pore sizes. They are fabricated using metal foams, and more particularly felts, the latter being more frequently used. By varying the pressure on the felt during assembly, various pore sizes can be produced. By incorporating removable metal mandrels, an arterial structure can also be molded in the felt.

Fibrous materials, like ceramics, have also been used widely. They generally have smaller pores. The main disadvantage of ceramic fibers is that, they have little stiffness and usually require a continuous support by a metal mesh. Thus while the fiber itself may be chemically compatible with the working fluids, the supporting materials may cause problems. More recently, interest has turned to carbon fibers as a wick material. Carbon fiber filaments have many fine longitudinal grooves on their surface, have high capillary pressures and are chemically stable. A number of heat pipes that have been successfully constructed using carbon fiber wicks seem to show a greater heat transport capability.

The prime purpose of the wick is to generate capillary pressure to transport the working fluid from the condenser to the evaporator. It must also be able to distribute the liquid around the evaporator section to any area where heat is likely to be received by the heat pipe. Often these two functions require wicks of different forms. The selection of the wick for a heat pipe depends on many factors, several of which are closely linked to the properties of the working fluid.

The maximum capillary head generated by a wick increases with decrease in pore size. The wick permeability increases with increasing pore size. Another feature of the wick, which must be optimized, is its thickness. The heat transport capability of the heat pipe is raised by increasing the wick thickness. The overall thermal resistance at the evaporator also depends on the conductivity of the working fluid in the wick. Other necessary properties of the wick are compatibility with the working fluid and wet ability.

III. WORKING OF HEAT PIPE

Heat pipes transfer heat by the evaporation and condensation of a working fluid. As stated above, a heat pipe is a vacuum tight vessel which is evacuated and partially back-filled with a working fluid. As heat is input at the evaporator, fluid is vaporized, creating a pressure gradient in the pipe. This pressure gradient forces the vapor to flow along the pipe to the cooler section where it condenses, giving up its latent heat of vaporization. The working fluid is then returned to the evaporator by capillary forces developed in the porous wick structure or by gravity.

A heat pipe is said to be operating against gravity when the evaporator is located above the condenser. In this orientation, the working fluid must be pumped against gravity back to the evaporator. All heat pipes have wick structures that pump the working fluid back to the evaporator using the capillary pressure developed in the porous wick. The finer the pore radius of a wick structure, the higher against gravity the heat pipe can operate. A thermosyphon is similar to a heat pipe, but has no wick structure and will only operate gravity aided.

Fluids are used in Heat Pipes

Heat pipe working fluids range from Helium and Nitrogen, for cryogenic temperatures. The metals like Sodium and Potassium for high temperature applications. Some of the more common heat pipe fluids used for electronics cooling applications are ammonia, water, acetone, and methanol. Thermacore has experience designing, developing, and manufacturing heat pipes with over 22 different working fluids for a variety of applications from cryogenic (-250°C) to high temperature (>1000°C).

Water heat pipe work below 100ºC

Water at atmospheric pressure boils at 100ºC. Inside a heat pipe, the working fluid (water) is not at atmospheric pressure. The internal pressure of the heat pipe is the saturation pressure of the fluid at the corresponding fluid temperature. As such, the fluid in a heat pipe will boil at any temperature above its freezing point. Therefore, at room temperature (20ºC), a water heat pipe is under partial vacuum, and the heat pipe will boil as soon as heat is input.

The thermal conductivity of a Heat pipe

Heat pipes do not have a set thermal conductivity like solid materials due to the two phase heat transfer. Instead, the effective thermal conductivity improves with length. For example, a 4 inch long heat pipe carrying 100 watts will have close to the same thermal gradient as a 12 inch long pipe carrying the same power. Thus the 12 inch pipe would have a higher effective thermal conductivity. Unlike solid materials, a heat pipe's effective thermal conductivity will also change with the amount of power being transferred and with the evaporator and condenser sizes. For a well-designed heat pipe, effective thermal conductivities can range from 10 to 10,000 times the effective thermal conductivity of copper depending on the length of the heat pipe.

Reliability of Heat Pipe

Since heat pipes have no moving parts, they are extremely reliable. This is the main reason they are used extensively in space applications where maintenance is not available. The main cause of heat pipe failures is gas generation in the heat pipe. This problem is totally eliminated by proper cleaning and assembly procedures.

Water freezes Heat Pipe

Heat pipe working fluids including water maintain the normal freezing point. Properly designed heat pipes, however, will not be damaged by the freezing and thawing of the working fluid. Heat pipes will not operate until the temperature rises above the freezing temperature of the fluid.

Key Features of High Temperature Heat Pipe

1) Extremely high heat transfer in simple container.
2) Allows many heat transfer loops, allowing single point feature.
3) Smaller units allows bulky pressure vessel.
4) Avoids the use of valves, pumps and compressors.
5) Ability to start up the cold and avoid the need for pre-heat.
6) Nearly isothermal temperature transfer and high temp allows very high efficiency operation.

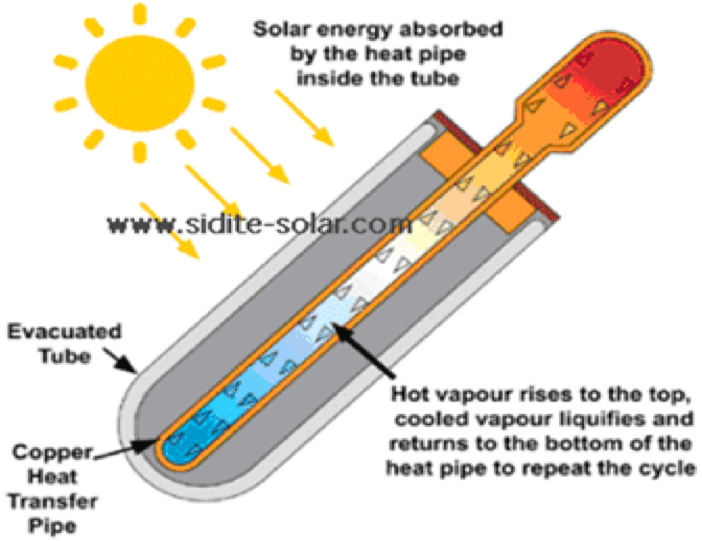

Fig.4: high temperature heat pipes which are directly exposed to sunlight

- **Heat Pipe Selection**

1) Investigate and determine the following operational parameters:

a. Heat load and geometry of the heat source.

b. Possible heat sink location, the distance and orientation relative to the heat source.

c. Temperature profile of heat source, heat sink and ambient

d. Environmental condition (such as existence of corrosive gas)

2) Select the pipe material, wick structure, and working fluid. (consult with an engineer or original heat pipe manufacturer to select the most appropriate heat pipe)

a. Determine the working fluid appropriate for your application

b. Select pipe material compatible to the working fluid

c. Select wick structure for the operating orientation

d. Decide on the protective coating.

3) Determine the length, size, and shape of the heat pipe (consult with engineer)

- **MATERIAL USED TO CONSTRUCT HEAT PIPE**

A particular working fluid can only be functional at certain temperature ranges. Also, the particular working fluid needs a compatible vessel material to prevent corrosion or chemical reaction between the fluid and the vessel. Corrosion will damage the vessel and chemical reaction can produce a non-condensable gas.

For example, the liquid ammonia heat pipe has a temperature range from –70 to +60oC and is compatible with aluminum, nickel and stainless steel.

The liquid ammonia heat pipe has been widely used in space and only aluminum vessels are used due to lightweight. Water heat pipes, with a temperature range from 5 to 230 oC, are most effective for electronics cooling applications and copper vessels are compatible with water. Heat pipes are not functional when the temperature of the pipe is lower than the freezing point of the working fluid. Freezing and thawing is a design issue, which may destroy the sealed joint of a heat pipe when place vertically. Proper engineering and design can overcome this limitation.

Table 1. Typical Operating Characteristics of Heat Pipes

Temperature Range (°C)	Working Fluid	Vessel Material	Measured axial heat flux (kW/cm^2)	Measured surface heat flux (W/ cm^2)
-200 to -80	Liquid Nitrogen	Stainless Steel	0.067 @ -163°C	1.01 @ -163°C
-70 to +60	Liquid Ammonia	Nickel, Aluminum, Stainless Steel	0.295	2.95
-45 to +120	Methanol	Copper, Nickel, Stainless Steel	0.45 @ 100°C[x]	75.5 @ 100°C
+5 to +230	Water	Copper, Nickel	0.67 @ 200°C	146@ 170°C
+190 to +550	Mercury* +0.02% Magnesium +0.001%	Stainless Steel	25.1 @ 360°C*	181 @ 750°C
+400 to +800	Potassium*	Nickel, Stainless Steel	5.6 @ 750°C	181 @ 750°C
+500 to +900	Sodium*	Nickel, Stainless Steel	9.3 @ 850°C	224 @ 760°C
+900 to +1,500	Lithium*	Niobium +1% Zirconium	2.0 @ 1250°C	207 @ 1250°C
1,500 + 2,000	Silver*	Tantalum +5% Tungsten	4.1	413

IV. APPLICATIONS OF HEAT PIPES

Energy Systems

With home heating costs increasing, more attention has been focused on the use of heat pipes to collect solar energy. A relatively simple design incorporates a bank of inclined thermosyphons exposed to the south side of a residence. Solar energy is absorbed and transported into the living space, where it is convected to the interior air or stored in a water tank for later use. During the night, the thermosyphons essentially act as thermal diodes, since the only way heat can be transferred from the interior to the outside is by axial conduction through the pipe walls. A similar design can be used for desalinating sea water using solar energy. In this application, however, a heat pipe would be positioned at the focal point of a trough-shaped parabolic reflector in order to generate the high temperatures and heat fluxes necessary for desalination. A wide range of energy systems including data center cooling, agricultural products cold storage, bakery waste heat recovery and automotive dashboard cooling were discussed. It was argued that zero emission and economical advantages can be achieved by using thermosyphon and capillary pumped loop.

Concentrating photovoltaic (PV) systems use low-cost optical systems such as the Fresnel lens, a mini-reflecting mirror that can concentrate solar intensity from 200 to 1000 suns. The concentrated solar energy delivered from the solar cell is from 20 to 100W/cm². Part of the energy is directly converted to electricity, while the remainder is removed as waste heat. Heat pipe cooling systems were developed to passively remove the high heat flux at the PV cell and reject it to the ambient by natural convection.

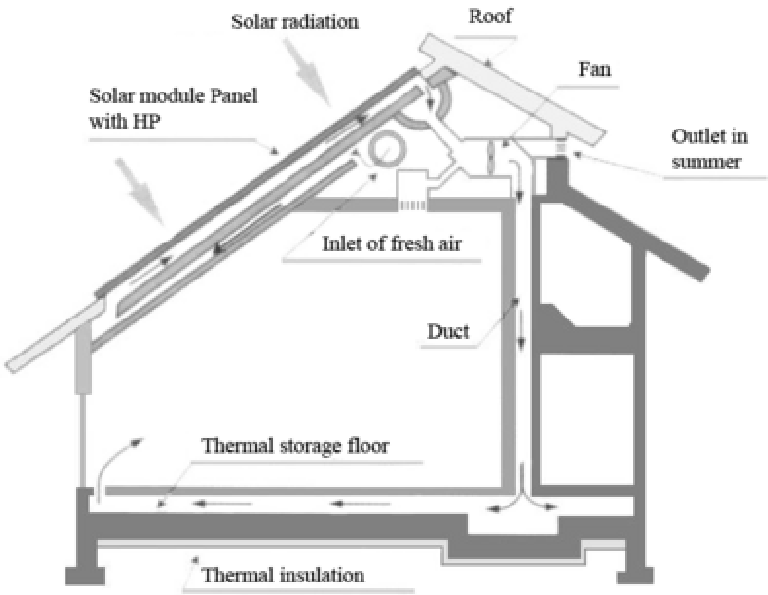

Fig.5: domestic appliances working on solar cells

Electronic and Electrical Equipment Cooling

Miniaturization of electronic components is accompanied by increased demands on heat dissipation systems due to the increased density of the components. For example, the digital computer has evolved from a massive system that filled an entire room to a unit which can be stored in a small briefcase. However, the overheating problems associated with the dense packing of heat-generating integrated circuit chips used in the computer (CPU and GPU Cooling) have escalated dramatically. Since the reliability of these and other types of electronic components is sensitive to their operating temperature, steps have been taken to improve heat dissipation by using heat pipes. Other applications to electronic cooling have included rectifiers, thyristors, transistors, traveling wave collectors, audio and RF amplifiers and high density semiconductor packages.

After the introduction of the Pentium processor in 1993, the processor performance and power consumption trend has significantly increased annually. In the year 2000, the heat flux was approximately 10-15 W/cm2, eventually reaching 120-150 W/cm² in 2010. The average power consumption for laptop/notebook computers is currently between 25-50 W, while desktops and servers consume between 80 and 150 W. Regardless of components, power level, or type of computer/processor, as electronics are packed into smaller volumes, it is important to optimize the thermal management components with higher cooling rates.

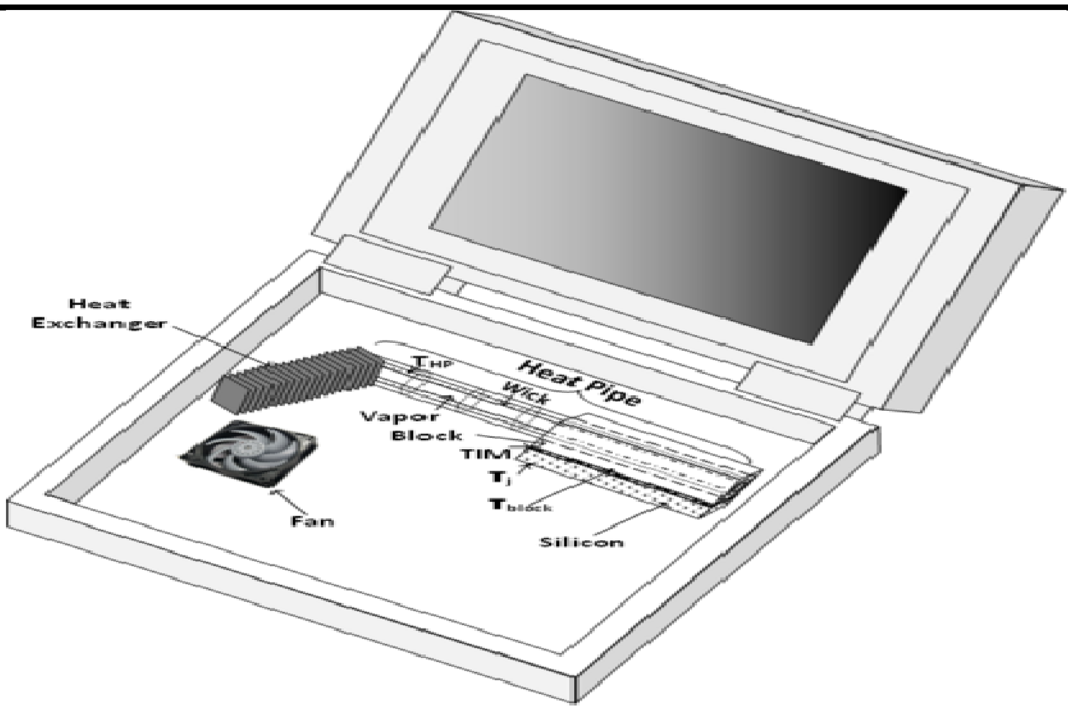

Fig.6: heat pipes used for cooling electrical equipments

Aerospace and Avionics

Heat pipes are very attractive components in the area of spacecraft cooling and temperature stabilization due to their low weight penalty, zero maintenance, and reliability. Structural isothermalization is an important problem with respect to orbiting astronomy experiments due to the possible warpage from solar heating. During orbit, an observatory is fixed on a single point such as a star. Therefore, one side of the spacecraft will be subjected to intense solar radiation, while the other is exposed to deep space. Heat pipes have been used to transport the heat from the side irradiated by the sun to the cold side in order to equalize the temperature of the structure. Heat pipes are also being used to dissipate heat generated by electronic components in satellites. Early experiments of heat pipes for aerospace applications were conducted in sounding rockets which provided six to eight minutes of 0-g conditions.

In 1974, ten separate heat pipe experiments were flown in the International Heat Pipe Experiment. Also in 1974, heat pipe experiments were conducted aboard the Applications Technology Satellite-6 (Kirkpatrick and Brennan, 1976) in which an ammonia heat pipe with a spiral artery wick was used as a thermal diode. With the use of the space shuttle, flight testing of prototype heat pipe designs continued at a much larger scale. In 1983, on the eighth space shuttle flight, a 6-ft. monogroove heat pipe with Freon 21 as the working fluid was flight tested as a heat pipe radiator (Rankin, 1984). The Space Station Heat Pipe Advanced Radiator Element, which consisted of a 50-ft. long high capacity monogroove heat pipe encased in a radiator panel, was flown on the space shuttle in 1989 (Brown et al., 1990), and during a 1991 shuttle flight, two heat pipe radiator panels were separately flight tested (Brown et al., 1991).

Heat pipe thermal buses were proposed which facilitate a connection between heat-generating components and external radiators (Morgownik and Savage, 1987; Amidieu et al., 1987; Peck and Fleischman, 1987). The components may be designed with a clamping device which can be directly attached to the heat pipe thermal bus at various points in the spacecraft. In 1992, two different axially grooved oxygen heat pipes were tested in a Hitchhiker Canister experiment that was flown aboard the Shuttle Discovery (STS-53) by NASA and the Air Force to determine startup behavior and transport capabilities in micro gravity.

Heat Exchangers and Heat Pumps

Increases in the cost of energy have promoted the use of heat pipe technology in industrial applications. Due to their high heat transfer capabilities with no external power requirements, heat pipes are being used in heat exchangers for various applications. In the power industry, heat pipe heat exchangers are used as primary air heaters on new and retrofit boilers. The major advantages of heat pipe heat exchangers compared to conventional heat exchangers are that they are nearly isothermal and can be built with better seals to reduce leakage. Heat pipe air heaters should also be cheaper than conventional tubular heat exchangers, as they are smaller and can be shipped in a small number of modules.

Heat pipe heat exchangers can serve as compact waste heat recovery systems which require no power, a low pressure drop and are easy to install on existing lines. Heat pipe heat exchangers can be categorized into gas-gas, gas-liquid, and liquid-liquid type heat units. Among these three, gas-gas heat pipe heat exchangers have the widest application in industry. A gas-gas heat pipe exchanger consists of a group of externally finned heat pipes which reclaim waste heat. These units eliminate cross-contamination due to the solid wall between the hot and cold gas streams. Also, the heat pipe design is totally reversible (heat can be transferred in either direction). Gas-gas energy recovery units typically fall into three categories: heat recovery in air-conditioning systems (low temperatures), recovery of excess process heat for space heating (moderate temperature), and recovery of waste heat from high temperature exhaust streams for reuse in the process (preheating of combustion air, for example). The units for these applications vary in size and construction depending on the specific application, but many commercial models are now available that implement this heat pipe design. Gas-liquid heat pipe exchangers are less commonly available than gas-gas models due to the fact that the present design of waste heat boilers is very efficient. In the past, exhaust heat from boilers was simply dispersed to the atmosphere.

Gas Turbine Engines and the Automotive Industry

The temperature limitation is one of the most crucial limiting factors related to the efficiency of a gas turbine aircraft engine or power gas turbine. An increased turbine inlet temperature decreases both the specific fuel and air consumption, while increasing efficiency. This desire for a high turbine inlet temperature, however, is often in conflict with materials available to withstand the high temperature. As a result, innovative cooling systems for hot-gas-path components are required. Among the hot-gas-path components, the first-stage rotor blade and nozzle guide vane require the most challenging cooling consideration. In addition to improving energy utilization efficiency, effective cooling could also drastically improve the reliability of high-speed rotating components. It has been observed that the creep life of turbine blades is reduced by half with every 10 to 15°C rise in metal temperature. Therefore, the temperature of the turbine blade must be kept within certain tolerable limits. The primary cooling technology in use today for turbine blades and nozzle guide vanes (NGVs) is the film cooling technology. Since 1995, a number of efforts have been initiated to utilize the concepts of miniature, radial rotating, high-temperature heat pipes, for gas turbine blades and disk cooling. High temperature heat pipe cooling is a promising cooling technology for gas turbine hot components, such as first stage rotor blades, nozzle guide vanes, and rotor disks. This has the potential to significantly reduce the temperature of these hot components, allowing for a much higher gas turbine inlet temperature, while also reducing the consumption of high-pressure compressor air. A Stirling engine heated by sodium heat pipes has been constructed and tested.

This engine operates at highest efficiency when the thermal energy is supplied to it at a very constant temperature and high heat fluxes. Helium is heated to increase its pressure, which is used to drive pistons and a crankshaft for the generation of power from thermal energy. The sodium heat pipes deliver heat from a molten salt heat storage system to the gaseous helium which is used to drive the engine. The coupling of a Stirling cycle engine with sodium heat pipes can also be used in the direct conversion of solar energy.

V. CONCLUSION

As per the practical experiment and records available, it can be said that in today modern and rapidly growing world heat pipes are very necessary for cooling the machines and improve efficiency.

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