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A Retrospect on Thermal Enhancement of Flat Plate Solar Collector with Nanofluid

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Abstract— Solar water heater using flat plate heat pipe solar collector with nanofluid works under three sections i.e, Evaporation, adiabatic expansion and the last but not the least is condensation. Heat pipe used as a heat Exchanger, dissipate the heat using nanofluid (Al_2O_3 –water based) as working fluid. Through flat plate heat Collector working fluid working fluid flows through it and efficiency is calculated at different angles of heat pipe, efficiency can be improve. The performance of the system depends upon the flat plate and the climate conditions because it requires very warm temperature to operate. This analysis signifies that tilt angle of the heat plate increase the heat performance.

Keywords: Al_2O_3, Solar Collector

I. INTRODUCTION

Solar heater is a device which is used for heating the water, for producing the steam for domestic and industrial purposes by utilizing the solar energy. Solar energy is the energy which is coming from sun in the form of solar radiations in infinite amount, when these solar radiations falls on absorbing surface, then they gets converted into the heat, this heat is used for heating the water. This type of thermal collector suffers from heat losses due to radiation and convection. Such losses increase rapidly as the temperature of the working fluid increases.

II. SOLAR WATER HEATING

Solar Water Heating systems are generally very simple using only sunlight to heat water. A working fluid is brought into contact with a dark surface exposed to sunlight which causes the temperature of the fluid to rise. This fluid may b the water being heated directly, also called a direct system, or it may be a heat transfer fluid such as a glycol/water mixture that is passed through some form of heat exchanger called an indirect system. These systems can be classified into two main categories:

III. COMPONENTS

SWH generally consists of a solar radiation collector panel, a storage tank, a pump, a heat exchanger, piping units, and auxiliary heating unit. Some of important components are described in the next sections.

A. Solar Collectors:

The choice of collector is determined by the heating requirements and the environmental conditions in which it is employed. There are mainly three types of solar collectors like flat plate solar collector, evacuated tube solar collector, concentrated solar collector.

B. Storage Tank:

Most commercially available solar water heaters require a well-insulated storage tank. Thermal storage tank is made of high pressure resisted stainless steel covered with the insulated fibre and aluminium foil. Some solar water heaters use pumps to re-circulate warm water from storage tanks through collectors and exposed piping. This is generally to protect the pipes from freezing when outside temperatures drop to freezing or below.

C. Heat Transfer Fluid:

A heat transfer fluid is used to collect the heat from collector and transfer to the storage tank either directly or with the help of heat exchanger. In order to have an efficient SHW configuration, the fluid should have high specific heat capacity, high thermal conductivity, low viscosity, and low thermal expansion coefficient, anti-corrosive property and above all low cost. Among the common heat transfer fluids such as water, glycol, silicon oils and hydrocarbon oils, the water turns out to be the best among the fluids. Water is the cheapest, most readily available and thermally efficient fluid but does freeze and can cause corrosion.

IV. SOLAR WATER HEATER COLLECTOR

A. Flat Plate Collectors:

Flat-plate collectors are used extensively for domestic water heating applications. It is simple in design and has no moving parts so requires little maintenance. It is an insulated, weatherproofed box containing a dark absorber plate under one or more transparent covers. They collect both direct and diffuse radiation. Their simplicity in construction reduces initial cost and maintenance of the system. A more detailed picture of these systems is of interest and is presented in the following section.

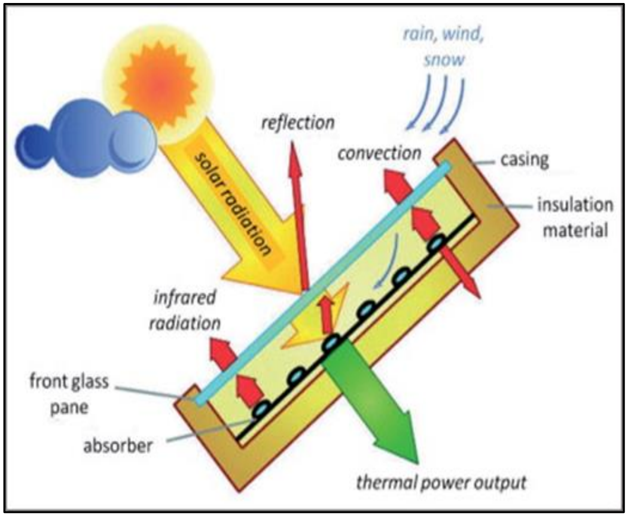

Fig. 1:

Heat pipes are devices of high thermal conductance, which transfer thermal energy by two phase circulation of fluid, and can easily be integrated into most types of solar collector. The basic difference in thermal performance between a heat-pipe solar collector and a conventional one lies in the heat-transfer processes from the absorber tube wall to the energy-transporting fluid. In the case with a heat pipe, the process is evaporation–condensation–convection, while for conventional solar collectors, heat transfer occurs only in the absorber plate. Thus, solar collectors with heat pipes have a lower thermal mass, resulting in a reduction of start-up time. A feature that makes heat pipes an attractive for use in solar collectors is their ability to operate like a thermal-diode, i.e., the flow of the heat is in one direction only. This minimizes heat loss from the transporting fluid, e.g., water, when incident radiation is low. Furthermore, when the maximum design temperature of the collector is reached, additional heat transfer can be prevented.

This would prevent over-heating of the circulating fluid, a common problem in many applications of solar collectors. One of the first studies of heat pipes in solar applications was carried out by Bienert and Wol. In this case, the evaporator end of a heat pipe was inserted in a flat-plate collector, and the condenser protruded into a water manifold attached to the upper end of the collector. The results of this investigation were neither conclusive nor optimistic. Since then, numerous studies have been carried out, including theoretical analysis and calculation, experimental testing, combined investigation involving theoretical analysis and experimental trials , as well as applications in practice . Most of these studies involved the investigation of the thermal performance of various types of heat-pipe solar collectors by analytical, numerical or experimental methods with the aim of establishing suitable structures or system layouts, as well as optimum operating conditions for high efficiency.

Flat-plate heat-pipe solar collectors, have their own set of advantages, including simpler structure, lower cost, easier manufacture and simple operation. The lower efficiency of flat-plate collectors is mainly due to the heat loss via the cover surface due to conduction and convection. Standard flat-plate collectors have typical efficiencies of 50% or less, while evacuated devices have efficiencies of about 50–80%. It would be desirable to develop a new structure for flat plate collectors that would overcome heat loss problems and allow a high efficiency to be achieved, while its capital cost still remains low.

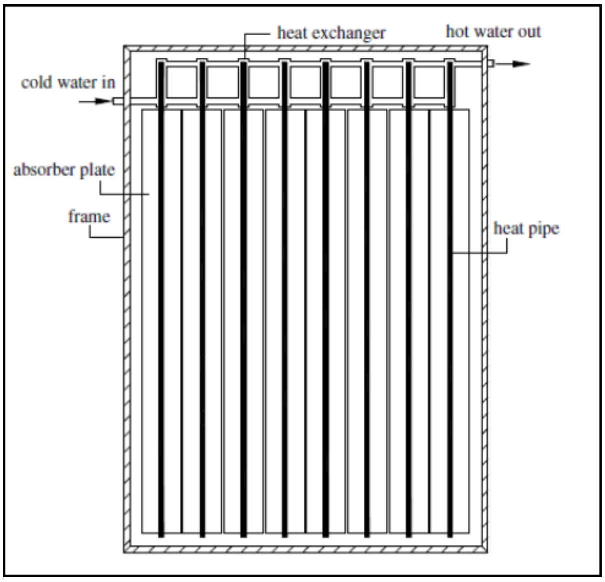

Fig. 2: Flat Plate Heat Pipe Solar Collector

V. HEAT PIPE

Heat pipes have been utilized in heat transfer related applications for many years. Depending on their application area, they can operate over a wide range of temperatures with a high heat removal capability. Heat pipes have been found to be useful in a number of technologies such as electronic cooling, spacecraft thermal control, transportation systems, automotive industry, permafrost stabilization, bio-related applications, solar systems and manufacturing. Heat pipes and their applications in thermal management have been studied for decades. They constitute an efficient, compact tool to dissipate substantial amount of heat.

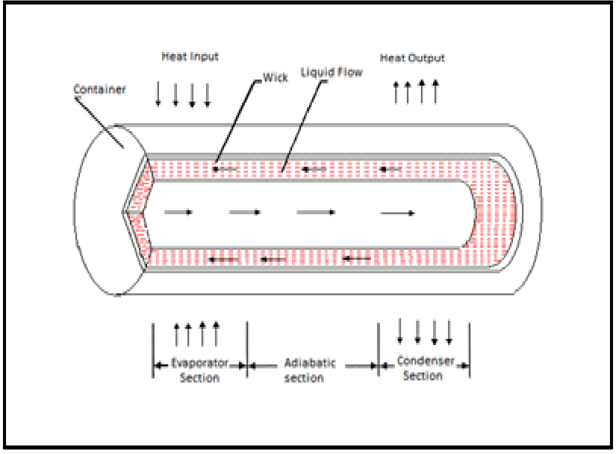

Fig. 3:

A heat pipe is an excellent heat conductor; one end of a heat pipe is the evaporation section, and the other end is the condensation section. When the evaporation section is heated, the liquid in the heat pipe evaporates rapidly. This vapour releases its heat at the condensation section, which has a small vapour pressure difference, and condenses back into liquid. The condensed liquid in the condensation section then flows back to the evaporation section along the inner wall of the heat pipe and undergoes endothermic evaporation in the evaporation section. The heat transfer of a heat pipe uses a working fluid that changes phases in a continuous endothermic and exothermic cycle, giving the heat pipe excellent heat transfer performance. Many researchers have used finned tubes, threaded tubes, sintered tubes, and grooved tubes to increase the contact area between the heat pipe and the internal working fluid, thus improving the heat pipe's thermal performance.

Fig. 4:

Fig. 5:

VI. EFFECT OF WORKING FLUID

Filled ratio is the fraction (by volume) of the heat pipe which is initially filled with the liquid. There is two operational filled ratio limits. At 0% filled ratio ,a heat pipe structure with only bare tubes and no working fluid, is pure conduction mode heat transfer device with a very high undesirable thermal resistance. A 100% fully filled heat pipe is identical in operation to a single phase thermosyphon. The thermosyphon action is maximum for a vertical heat pipe and stops for a horizontal heat pipe and heat transfer takes place purely by axial conduction. When the charge amount was smaller, there was more space to accommodate vapour and make the pressure inside heat pipe become relatively lower. It helped nanofluid undergo vaporization and enhance its heat transfer performance. The heat transfer performance of an OHP was apparently improved after the addition of alumina nanoparticles in the working fluid. Compared with the pure water, the maximal decrease of thermal resistance was 0.14 °C/W (or 32.5%) which occurred at 70% filling ratio and 0.9% mass fraction when the power input was 58.8 W .In PHP, considerably high filled ratio will hinder the pulsation of the bubble and the efficiency of the heat transfer will not be favourable enough. The low filled ratio will get pulsation of the bubble easily, but it is extremely easy to dry out. So the most proper filled ratio is between40% and 60%.The optimum filling ratio of charged fluid in the tested heat pipe was about 0.45 to 0.50 for both pure water and Al2O3-water based the nanofluid, respectively.

The experimental results indicate that the filling ratio and the heat input have the important effects on the heat transfer performance and the optimal performance of the HP was found when the filling ratio ranged between50–75%, at 500inclination angle, while the minimum performance was found when the filling ratio was 25% and 250inclination angle. In general, fill ratios of working fluid greater than 85% of volume of evaporator show better results in terms of increased heat transfer coefficient, decreased thermal resistance and reduced temperature difference across the evaporator and condenser.

VII. SELECTION OF FLUID

A first consideration in the selection of a suitable working fluid is the operating vapour temperature range within the approximate temperature band (50 to1500 C) several possible working fluids may exit .A variety of characteristic must be examined in order to determine the most acceptable of these fluids for the application considered the primary requirements are: compatibility with the heat pipe material (s),thermal stability, wet ability, reasonable vapour pressure, high latent heat and thermal conductivity, low liquid and vapour viscosities and acceptable freezing point.

The increase in heat pipe wall temperature difference was smaller than that for a pure water filled heat pipe under various heat loads when silver nanoparticles dispersed in working fluid. The heat transfer performance of an OHP was apparently improved after the addition of alumina nanoparticles in the working fluid. Compared with the pure water, the maximal decrease of thermal resistance was 0.14°C/W (or 32.5%).Comparing with the water thermosyphons heat pipe, remarkable increases of the heat pipe rate were observed in the case of the thermosyphons heat pipe with different concentration levels of iron oxide nanoparticles .For example the presence of 2% iron oxide nanoparticles in water results in an increase of the heat transfer rate with 19%.The enhancement heat transfer can be approved by changing the fluid transport properties and flow features within nanoparticles suspended. New experimental data on the thermal efficiency enhancement of heat pipe with nanofluids are presented. Effects of % nanoparticles volume concentrations on the heat pipe thermal efficiency are considered. For the heat pipe with0.10% nanoparticles volume concentration, the thermal efficiency is 10.60% higher than that with the based working fluid. The better efficiency of the heat transfer is 100 ppm concentration of silver nanofluid water solution; the worse one is 450 ppm concentration of silver nanofluid water solution.

Although the nanofluid has the higher heat conduction coefficient that dispels more heat theoretically. But the higher concentration will make the higher viscosity. The higher viscosity makes the bubble difficult to produce and the force of friction causes obstruction of the liquid slug with tube wall becomes larger, so obstruction is relatively greater when the bubble is promoted and influences the whole efficiency of the heat transfer. The maximum heat flux apparently increase with the increase of the mass concentration when the mass concentration is less than 1.0 wt. %. Then, they begin to decrease slowly after the mass concentration is over 1.0 wt. %. The mass concentration of 1.0 wt. %corresponds also to the best input power enhancement. The maximum input power of the heat pipe can enhance by 42% after substituting the nanofluid for de ionized water. The presence of nanoparticles in the working fluid leads to a reduction in the speed of the liquid, smaller temperature difference along the heat pipe and the possibility of reduction in size under the same operational conditions. When the concentration of added nanoparticles was 3.0 wt.%, the thermal efficiency turned out to be lower than the concentration of 1.0 wt.%. In addition to the influence of the above mentioned absorbability between nanoparticles and water molecules, adding too many nanoparticles to fluid would make the property of working fluid at evaporator section tend to be in solid phase, and would make the convection performance of nanofluid at evaporator section reduced. This was disadvantage of the thermal efficiency of heat pipe.

VIII. TILT ANGLE

The orientation is important for the operation of a heat pipe. Depending on conditions, a heat pipe can operate in horizontal position or in vertical position. For the horizontal position of a heat pipe, gravity has no effect. But in vertical position gravity can assist or oppose to the operation of the heat pipe. The tilt of a heat pipe is classified into two types; favourable tilt and adverse tilt. Favourable tilt is the tilt position where gravity assists heat pipe operation. In favourable tilt, condenser is positioned above evaporator. By this way, liquid return from condenser to evaporator is assisted by gravity. Therefore, capillary pumping pressure can overcome more pressure losses and this increases the heat transfer capacity of the heat pipe, in terms of capillary limit. Other type is adverse tilt. In this tilt condition, evaporator is positioned above condenser. Therefore, the liquid in the condenser shall overcome gravity force to return to evaporator. This creates extra drag for capillary pumping pressure to overcome. As a result, heat transfer capacity of the heat pipe decreases. Therefore, it is preferable for a heat pipe to operate in favourable tilt position, if possible. An increase of heat transfer rate of 39% is obtained for2% iron oxide nanoparticles when the angle of inclination of heat pipe is 900. The heat pipe efficiency increases with increasing tilt angle because the gravitational force has a significant effect on the flowing of working fluid between evaporator section and condenser section. However, when the heat pipe tilt angle exceeds a value of 60° for de-ionic water and 45° for alcohol, the heat pipe thermal efficiency tends to decrease. The efficiency of heat pipe increases with increasing values of the tilt angle. However, when the heat pipe inclination angle exceeds 30° for de-ionic water and 45° for copper nanofluid and copper nanofluid with aqueous solution of n-Butanol, the heat pipe thermal efficiency tends to decrease.

The design of heat pipe starts with the selection of working fluid. The selection of working fluid considers a number of factors. The working temperature range is the first criteria to be fulfilled by the working fluid. In solar collector, this is a crucial step as it determines the minimum and the maximum temperature for the heat pipe operation. The following are other main criteria for selecting the right working fluid (Dunn (1994)).

IX. SELECTION OF WORKING FLUID

– Compatibility with the wick and the container
– Good thermal stability
– Wettability of wick and wall materials
– Vapor pressure not too high or low over operating temperature
– High latent heat
– High thermal conductivity
– Low liquid and vapor viscosities
– Higher surface tension
– Acceptable freezing or pour point

Since our experiment deals with thermal performance as well as thermal enhancement of flat plate solar collector, we have used conventional fluid water in first set of heat pipe flat plate solar collector. Second flat plate heat pipe solar collector consists of nanofluid whose composition consists of Copper oxide, CuO(0.63% by volume) and Boron Nitride, BN (0.47% by volume) in 0.5lit distilled water.

Alumina (Al2O3) is a ceramic material that exhibit several excellent properties such as very good stability and chemical inertness. But Al2O3 has lower conductivity compared to metallic nanoparticles. Metallic nanoparticles such as copper (Cu), aluminum (Al) possess very high thermal conductivities. But stability and reactivity are two important factors that always impede the use of metallic nanoparticles in the nanofluid applications. The incorporation of small amount of metal particles into an ammonia matrix can significantly improve the thermal properties.

Many different particle materials are used for nanofluid preparation. Al2O3, CuO, TiO2, SiC, TiC, Ag, Au, Cu, and Fe nanoparticles are frequently used in nanofluid research. Carbon nanotubes are also utilized due to their extremely high thermal conductivity in the longitudinal (axial) direction. Base fluids mostly used in the preparation of nanofluids are the common working fluids of heat transfer applications; such as, water, ethylene, glycol and engine oil. In order to improve the stability of nanoparticles inside the base fluid, some additives are added to the mixture in small amounts.

X. PREPARATION OF NANOFLUID:

The preparation of nanofluids begins by direct mixing of the base fluid with the nonmaterial's. In the first step, nonmaterial's are synthesized and obtained as powders, which are then introduced to the base fluid in a second step. Nanoparticles can be produced from several processes which can be categorized into one of five general synthetic methods. These five methods are:

1) Transition metal salt reduction
2) Thermal decomposition and photochemical methods
3) Ligand reduction and displacement from organometallics
4) Metal vapour synthesis.
5) Electrochemical synthesis

Transition-metal nanoclusters are only kinetically stable because the formation of the bulk metal is its thermodynamic minimum. Therefore, nanoclusters that are freely dissolved in solution must be stabilized in a way that prevents the nanoclusters from coalescing, because such agglomeration would eventually lead to the formation of the thermodynamically favoured bulk metal. Bonnemann et al developed a method for the production of very small (< 2 nm) and stable nanoparticles via chemical reduction pathways, which might be suitable for application in nanofluid synthesis. Organo aluminum compounds have been used for the "reductive stabilization" of mono and bi-metallic nanoparticles. Triorgano aluminum compounds were employed as both the reducing agent and colloid stabilizer, which lead to the formation of an organometallic colloidal protecting shell around the particles. This "modification" of the Al-organic protecting shell leaves the particle size stable.

Xuan et al. have used commercially obtained Cu nanoparticles to prepare nanofluids in both water and transformer oil by sonication in the presence of stabilizers. Similarly, Kim et al. prepared nanofluids consisting of commercially obtained CuO nanoparticles in ethylene glycol by sonication without stabilizers. The optimum duration of sonication was found to be 9 hours and the average nanoparticle size was 60 nm.

Some authors suggested that the two-step process works well only for nanofluids containing oxide nanoparticles dispersed in de-ionized water as opposed to those containing heavier metallic nanoparticles. Since nanopowder can be obtained commercially in large quantities, some economic advantage exists in using two-step synthesis methods that rely on the use of such powders.

Lee et al. [1] performed research specifically on nanofluids with oxide particles at Argonne National Laboratory. This experiment examined Al_2O_3 and CuO nanoparticles dispersed in both deionised water and ethylene glycol and their related thermal conductivities as measured by the transient hot-wire method. A strong dependence on particle size and an almost linear increase of conductivity with volume fraction of the particles were found. CuO nanoparticles were found to have a greater heat transfer effect than Al_2O_3 particles, which was suggested to be due to the CuO particles being smaller.

procedure

During the testing procedure, both the solar collectors were held in tilted position facing South and tested in outdoor conditions of Pune, India (latitude 18.52°N and longitude 73.85°E).Experiments were carried out throughout the day from 10:00am to 4:00pm and values of solar intensity(It) as well as different temperatures were recorded at each one hour interval. Different temperatures measured include ambient air temperature (Ta), inlet water temperature (Ti), outlet water temperature for collector with water and nanofluid as working fluid (To,w and To,n resp.).It should be noted that each of these readings were obtained for a fixed mass flow rate.Tests were carried out throughout the day for various tilt angles, namely, 20°, 31.5 and 50° for a given mass flow rate 0.00125 kg/sec.

The rate of thermal energy input(Qin), the rate of thermal energy gain(Qg) and the instantaneous efficiency(η) of each collector were calculated as below:

$$Q_{in} = I_t . A_{coll} \qquad ....\ (1)$$

Where Acoll is the area of collector.

Measuring the collector area on which solar radiations fall we get ,

$$A_{coll} = 0.31 m^2$$

$$Q_g = m\, C_w\, (T_o - T_i) \qquad ....\ (2)$$

Where m is mass flow rate and Cw is specific heat of water

$$\eta_{inst} = Q_g / Q_{in} \qquad ....\ (3)$$

Where ηinst is the instantaneous efficiency

CONCLUSION

An experimental study has been carried out for the thermal performance of heat pipe solar collector by using different working fluids for heat pipes such as: pure water, CuO-BN/water nanofluid. Following conclusions are :

- The thermal performance of wickless heat pipe flat plate solar collector is higher by using CuO-BN /water hybrid nanofluid followed by conventional working fluid pure water.
- The heat transfer rate is found to increase by increasing the tilt angle from 20° to 31.5° for both cases, namely, pure water and CuO-BN/water nanofluid. While, the heat transfer rate decreases by increasing the tilt angle beyond 31.5° to 50°.

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